A Documentation of the Mintz-Arakawa Two-Level Atmospheric General Circulation Model

W. L. Gates, E. S. Batten, A. B. Kahle and A. B. Nelson

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Rand
SANTA MONICA, CA 90406
PREFACE

This documentation describes the two-level Mintz-Arakawa atmospheric general circulation model developed by Professors Mintz and Arakawa of the Department of Meteorology, University of California, Los Angeles. This is the first of a series of numerical models of the global circulation being used at Rand in a research program on the dynamics of climate. Through the selective alteration of the model's initial and boundary conditions, and of the model's physical and numerical treatment of atmospheric processes, it is planned that the sensitivity and response of the world's climates to either deliberate or inadvertent modification be explored. It is the purpose of the present documentation to facilitate those modifications of the model that may be required to simulate such climatic effects. This model, which was developed at UCLA with the support of the National Science Foundation, is undergoing continuing development, particularly with respect to the parameterization of convective heating and radiative transfer. The numerical solutions shown in this report are for illustrative purposes only and should not be used to judge the model's ability to simulate climate. Although every effort has been made to ensure the accuracy of the model description used here, the responsibility for any errors or misrepresentations rests solely with the authors.

The Rand research program on climate dynamics is sponsored by the Advanced Research Projects Agency, and is directed to the systematic exploration of the structure and stability of the earth's climate. Meteorological studies suggest that technologically feasible operations might trigger substantial changes in the climate over broad regions of the globe. Depending on their character, location, and scale, these changes might be both deleterious and irreversible. If such perturbations were to occur, the results might be seriously detrimental to the welfare of this country. So that we may react rationally and effectively to any such occurrences, it is essential that we: (1) evaluate all consequences of a variety of possible
occurrences that might modify the climate, (2) detect trends in the
global circulation that presage changes in the climate, either natural
or artificial, and (3) determine, if possible, means to counter
potentially deleterious climatic changes. Our possession of this
knowledge would make incautious experimentation unnecessary. The
present Report is a technical contribution to this larger study of the
effects on climate of environmental perturbations.
SUMMARY

In this documentation the physical bases of the Mintz–Arakawa two-level atmospheric model are summarized, and the numerical procedures and computer program for its execution are presented in detail. The physics of the model is summarized, with particular attention given to the treatment of the moisture and heat sources, including the parameterization of convective processes, cloudiness, and radiation. The numerical approximations and finite-difference equations used in the model's numerical simulations are also given. Throughout the documentation the emphasis is on the specific details of the model in its present form, rather than on the derivation or justification of its present design.

To facilitate the use of this model, a complete listing of the code as written in FORTRAN language is given, together with a description of all constants and parameters used. A complete dictionary of FORTRAN variables, a dictionary of principal physical features, and a complete list of symbols are presented. To illustrate the model's performance, samples of its solutions for selected variables at a specific time are also given.
ACKNOWLEDGMENTS

The authors would like to acknowledge the permission given by Professors Yale Mintz and Akio Arakawa of the University of California, Los Angeles, to use their atmospheric general circulation model, and for their numerous comments and suggestions made during their review of a draft version of this Report. They would like also to thank Dr. A. Katayama, of the Meteorological Research Institute, Tokyo, for a number of suggestions that have clarified the program description, and Professor R. T. Williams of the Naval Postgraduate School for his assistance during the early stages of the preparation of the model's code description. An expression of thanks is also due our colleagues in the Rand/ARPA Climate Dynamics Program for their encouragement. Finally, we would like to acknowledge the capable and patient typing of the manuscript by Phyllis Davidson.
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I. INTRODUCTION

One of the more widely known numerical models of the global atmospheric general circulation is that developed by Professors Mintz and Arakawa at the Department of Meteorology, UCLA. First formulated in the early 1960s, this model has undergone a series of modifications and improvements, and has been used in a number of simulations of the global climate and in tests of atmospheric predictability. Although it addresses the primary dynamical and thermal variables at only two tropospheric levels, the model is relatively sophisticated in its treatment of the physics of large-scale atmospheric motion, and the method of numerical solution is relatively complex.

It is the purpose of this Report to describe the model from a user's viewpoint, in order to facilitate its actual use in a program of climatic simulation. Although some description of the model's basic equations is necessary, it is not our present purpose to present their derivation nor to discuss the justification of the model's many physical parameterizations and numerical procedures. Instead, we have attempted to set forth several aspects of the model: its physical basis, its numerical formulation and solution, its computer code, and its typical results. These aspects are related to one another by the provision of a dictionary of selected terms and a list of physical and FORTRAN symbols. The description of the model's physics, given in Chapter II, is intended to present the basic differential equations and physical constants; the corresponding difference equations and other numerical approximations used in the program are presented in Chapter III. This is followed by a summary of the program's operating characteristics in Chapter IV, together with some typical results for selected variables, and by Chapter V, which presents a physics dictionary giving a brief summary of the treatment of certain variables and effects. As a supplement to the preceding chapters, a comprehensive list of symbols is given in Chapter VI. Finally, the model's integration and output map-routine codes as written in FORTRAN are presented in extenso in Chapter VII, followed by a FORTRAN dictionary in Chapter VIII, whose purpose is to permit ready interpretation of
specific portions of the program. It is hoped that this documentation will answer the question, "Just how are the circulation simulations made?"

A previous description of the model (in one of its earlier versions) was given by Mintz (1965, 1968), and has been supplemented by Arakawa (1970). Further details of the treatment of convection and radiation were given by Arakawa, Katayama, and Mintz (1969). An extended description of the basic model and the computational procedures used was prepared by Langlois and Kwok (1969). This latter publication has been of particular use in the preparation of the present documentation, although the present version of the model differs slightly from the version described by them. In one form or another the Mintz-Arakawa two-level model was applied to the estimation of atmospheric predictability by Charney (1966) and Jastrow and Halem (1970), and was applied to the simulation of the circulation of the Martian atmosphere by Leovy and Mintz (1969). The present version of the model is being used in a program of experimentation on the dynamics of climate at Rand, and will form the basis of future model changes and extensions.
II. MODEL DESCRIPTION — PHYSICS

In this chapter the physical and dynamical basis of the Mintz-Arakawa two-level general circulation model is presented, together with a summary of the basic differential equations and boundary conditions. Particular attention has been given to the preparation of a summary of the various physical approximations in the model's treatment of radiation, moisture, and convection.

A. NOTATION AND VERTICAL LAYERING

In the first instance the present model is for the troposphere only, and divides the atmosphere beneath an assumed isobaric tropopause into two layers, as sketched in Fig. 2.1. At the center of each layer are the reference levels (1 and 3) at which the basic variables of the model are carried. At the interface between the layers (level 2), as well as at the tropopause and earth's surface, certain additional variables and conditions are specified. For convenience, the atmosphere is divided in the vertical according to mass (or pressure), and the dimensionless vertical coordinate, \( \sigma \), is introduced

\[
\sigma \equiv \frac{p - p_T}{p_s - p_T}
\]  

(2.1)

where \( p \) is the pressure, \( p_T \) the (constant) tropopause pressure, and \( p_s \) the (variable) pressure at the earth's surface. The levels 1, 2, and 3 are defined as those for \( \sigma = 1/4, 1/2, \) and \( 3/4 \), respectively, with the tropopause corresponding to \( \sigma = 0 \) and the surface always given by \( \sigma = 1 \). Thus, if the surface pressure is approximately 1000 mb and the tropopause is assumed to be at 200 mb, the levels 1 and 3 correspond approximately to the 400-mb and 800-mb levels, respectively.

Although a comprehensive list of symbols appears later in this report (see Chapter VI), it is convenient to introduce the more common variables at this point. Anticipating the use of spherical coordinates, the independent variables are:
Fig. 2.1 -- Schematic representation of the model's vertical structure.
\( \phi \) = latitude, positive northward from the equator
\( \lambda \) = longitude, positive eastward from Greenwich
\( \sigma \) = dimensionless vertical coordinate, \( 0 \leq \sigma \leq 1 \), increasing downward
\( t \) = time

The primary dependent (prognostic) variables are:
\[ \vec{V} = (u,v) \], horizontal vector velocity
\( T \) = temperature
\( \pi = p_s - p_T \), surface pressure parameter
\( q \) = mixing ratio

The other dependent (diagnostic) variables are:
\( \phi \) = geopotential
\( \alpha \) = specific volume
\( p \) = pressure
\( \dot{\sigma} = \frac{d\sigma}{dt} \), sigma vertical-velocity measure

The forcing terms are:
\( \vec{F} \) = horizontal vector frictional force per unit mass
\( \dot{H} \) = diabatic heating rate per unit mass
\( \dot{Q} \) = rate of moisture addition per unit mass

The basic physical constants are:
\( f = 2\Omega \sin \phi \), Coriolis parameter
\( \Omega \) = earth's rotation rate
\( a \) = earth's radius
\( \hat{k} \) = vertical unit vector
\( c_p \) = specific heat (for dry air) at constant pressure
\( R \) = specific gas constant (for dry air)
\( g \) = acceleration of gravity
B. DIFFERENTIAL EQUATIONS

The vector equation of horizontal motion (in \( \sigma \) coordinates) may be written

\[
\frac{\partial}{\partial t} (\pi \hat{V}) + (\nabla \cdot \pi \hat{V}) \hat{V} + \frac{\partial}{\partial \sigma} (\pi \hat{\phi}) + f \hat{k} \times \pi \hat{V} + \pi \nabla \phi + \sigma \pi \alpha \nabla \pi = \pi \hat{F} \tag{2.2}
\]

where

\[
\nabla \cdot \vec{\alpha} = \frac{1}{a \cos \varphi} \left[ \frac{\partial A_\lambda}{\partial \lambda} + \frac{\partial}{\partial \varphi} (A_\varphi \cos \varphi) \right] \tag{2.3}
\]

for a vector \( \vec{\alpha} = (A_\lambda, A_\varphi) \).

The thermodynamic energy equation (in \( \sigma \) coordinates) is written

\[
\frac{\partial}{\partial t} \left( \pi_c T \right) + \nabla \cdot \left( \pi_c T \hat{V} \right) + \frac{\partial}{\partial \sigma} \left( \pi_c T \hat{\phi} \right) - \pi \alpha \left( \sigma \frac{\partial \pi}{\partial t} + \sigma \hat{V} \cdot \nabla \pi + \pi \hat{\phi} \right) = \pi \hat{H} \tag{2.4}
\]

The mass continuity equation is

\[
\frac{\partial \pi}{\partial t} + \nabla \cdot (\pi \hat{V}) + \frac{\partial}{\partial \sigma} (\pi \hat{\phi}) = 0 \tag{2.5}
\]

The moisture continuity equation is

\[
\frac{\partial}{\partial t} (\pi q) + \nabla \cdot (\pi q \hat{V}) + \frac{\partial}{\partial \sigma} (\pi q \hat{\phi}) = \pi \hat{Q} \tag{2.6}
\]

The equations (2.2) and (2.4) to (2.6) are the prognostic equations for the dependent variables \( \hat{V}, T, \pi, \) and \( q \). The specification of the frictional force (\( \hat{F} \)), the heating rate (\( \hat{H} \)), and the moisture-addition
rate \( \dot{Q} \), on the right-hand sides of these equations is considered in subsequent sections. Supplementing these equations are the diagnostic equation of state,

\[
\alpha = \frac{RT}{p}
\]

and the hydrostatic equation,

\[
\frac{2\phi}{\sigma} + \pi \alpha = 0
\]

These complete the dynamical system in \( \sigma \) coordinates, with \( \sigma \) itself given by \( \sigma = (p - p_T)/\pi \), where \( p_T \) is a constant (tropopause) pressure.

**C. BOUNDARY CONDITIONS**

Accompanying the dynamical system, Eqs. (2.2) to (2.8), are physical boundary conditions at only the earth's surface and the tropopause, as there are no lateral boundaries in the \( \sigma \) system for the global atmosphere. At the earth's surface we require zero (air) mass flux normal to the earth's surface and either a zero heat flux or a specified surface temperature, depending upon the surface character. Thus, we write at the earth's surface:

\[
\begin{align*}
\dot{\sigma} &= 0 \\
\phi &= \phi_4(\lambda, \phi) & \text{at } \sigma = 1 \text{ over land} \\
F_H &= 0 & \text{at } \sigma = 1 \text{ over ocean}
\end{align*}
\]

(2.8a)

\[
\begin{align*}
\dot{\sigma} &= 0 \\
\phi &= 0 & \text{at } \sigma = 1 \text{ over ocean}
\end{align*}
\]

(2.8b)
Here $\hat{\phi}_4(\lambda, \varphi)$ denotes the fixed distribution of the geopotential of the earth's land (or ice) surface, $F_H$ is the vertical heat flux at the surface, and $T_s(\lambda, \varphi)$ the fixed distribution of the sea-surface temperature.

At the assumed isobaric tropopause $p = p_T$ we require the free-surface condition $dp/dt = 0$, or

$$\dot{\sigma} = 0, \quad \text{at } \sigma = 0$$  \hspace{1cm} (2.8c)

Although they are not strictly boundary conditions, we may regard the specification of the surface drag coefficient which contributes to the horizontal frictional force, $\vec{F}$, in Eq. (2.2) as fixing the vertical momentum transfer at the surface, and similarly regard the specification of the surface evaporation (minus the surface precipitation and runoff) as determining the moisture available for the source $\dot{Q}$ in Eq. (2.6). The determination of these transfers in terms of the model is described below. We might also regard the solar radiation at the top of the atmospheric model at $\sigma = 0$ as a boundary condition. Here this flux is assumed to be given by the solar constant, modified as described below by the eccentricity of the earth's orbit and by the zenith angle of the sun.

D. VERTICALLY DIFFERENCED EQUATIONS

1. Vector Form

As an introduction to the presentation of the complete difference equations (including the horizontal and time finite-difference forms), the model's dynamical equations are here first stated in terms of the variables at specific model levels (which statement constitutes the vertical differencing in $\sigma$ coordinates), and then given in terms of the horizontal (rectangular) map coordinates actually used in the computations. The dependent variables are computed at the several levels as shown below:
Table 2.1

DISPOSITION OF THE DEPENDENT VARIABLES

<table>
<thead>
<tr>
<th>Level</th>
<th>( c )</th>
<th>( \dot{c} )</th>
<th>( \ddot{c} )</th>
<th>( p )</th>
<th>( T )</th>
<th>( \dot{v} )</th>
<th>( q )</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 .....</td>
<td>0</td>
<td>0</td>
<td>...</td>
<td>( p_T )</td>
<td>...</td>
<td>...</td>
<td>...</td>
</tr>
<tr>
<td>1 ----</td>
<td>( \frac{1}{2} )</td>
<td>...</td>
<td>( \dot{c}_1 )</td>
<td>( p_1 )</td>
<td>( T_1 )</td>
<td>( \dot{v}_1 )</td>
<td>0</td>
</tr>
<tr>
<td>2 .....</td>
<td>( \frac{1}{4} )</td>
<td>( \dot{c}_2 )</td>
<td>...</td>
<td>( p_2 )</td>
<td>...</td>
<td>...</td>
<td>...</td>
</tr>
<tr>
<td>3 ----</td>
<td>( \frac{3}{4} )</td>
<td>...</td>
<td>( \dot{c}_3 )</td>
<td>( p_3 )</td>
<td>( T_3 )</td>
<td>( \dot{v}_3 )</td>
<td>( q_3 )</td>
</tr>
<tr>
<td>4 .....</td>
<td>1</td>
<td>0</td>
<td>...</td>
<td>( p_T + \tau )</td>
<td>...</td>
<td>...</td>
<td>...</td>
</tr>
<tr>
<td>(surface)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

We note that the mixing ratio, \( \zeta \), is carried only at level 3, and that the surface pressure is computed by means of \( \tau \). At the midlevel 2, only the \( \dot{c} \) vertical velocity \( \dot{c}_2 \) is independently computed, although it is sometimes useful to regard the wind and temperature at level 2 in terms of values interpolated between levels 1 and 3.

The equation of horizontal motion, Eq. (2.2), is now written for levels 1 and 3 (with corresponding subscripts) as

\[
\frac{\partial}{\partial t} (\pi \dot{V}_1) + (\nabla \cdot \pi \dot{V}_1) \dot{V}_1 + \pi \dot{c}_2 (\dot{V}_1 + \dot{V}_3) + \pi \dot{f} \pi \times \dot{V}_1 \\
+ \pi \dot{v}_c + \sigma_1 \pi \dot{\tau} \pi \tau = \pi \dot{T}_1
\]  
(2.9)
\[ \frac{\partial}{\partial t} \left( \pi \mathbf{v}_3 \right) + \left( \nabla \cdot \pi \mathbf{v}_3 \right) \mathbf{v}_3 - \pi \delta_2 \left( \mathbf{v}_1 + \mathbf{v}_3 \right) + \pi \mathbf{f}' \times \mathbf{v}_3 \]

\[ + \pi \nabla \phi_3 + \sigma_3 \pi \alpha_3 \nabla \pi = \pi \mathbf{F}_3 \]  

(2.10)

where vertical finite differences between \( \sigma = 0 \) and \( \sigma = 1/2 \) and between \( \sigma = 1/2 \) and \( \sigma = 1 \) have been taken, and the conditions \( \dot{\sigma} = 0 \) at \( \sigma = 0,1 \) and \( \dot{\mathbf{v}}_2 = 1/2(\dot{\mathbf{v}}_1 + \dot{\mathbf{v}}_3) \) used.

The thermal energy equation (2.4) may be similarly written for levels 1 and 3 as

\[ \frac{\partial}{\partial t} \left( \pi T_1 \right) + \nabla \cdot \left( \pi T_1 \mathbf{v}_1 \right) + \left( \frac{p_1}{p_o} \right)^\kappa \pi \delta_2 \left( \theta_1 + \theta_3 \right) \]

\[ - \frac{\pi \alpha_1 \sigma_1}{c_p} \left( \frac{\partial}{\partial t} + \dot{\mathbf{v}}_1 \cdot \nabla \pi \right) = \frac{\pi \dot{H}_1}{c_p} \]  

(2.11)

\[ \frac{\partial}{\partial t} \left( \pi T_3 \right) + \nabla \cdot \left( \pi T_3 \mathbf{v}_3 \right) - \left( \frac{p_3}{p_o} \right)^\kappa \pi \delta_2 \left( \theta_1 + \theta_3 \right) \]

\[ - \frac{\pi \alpha_3 \sigma_3}{c_p} \left( \frac{\partial}{\partial t} + \dot{\mathbf{v}}_3 \cdot \nabla \pi \right) = \frac{\pi \dot{H}_3}{c_p} \]  

(2.12)

where the condition \( \theta_2 = 1/2(\theta_1 + \theta_3) \) has been used with the potential temperature, \( \theta \), given by

\[ \theta = T(p_o/p)^\kappa \]

with \( p_o = 1000 \) mb, a reference pressure, and \( \kappa = R/c_p = 0.286 \).

Manipulation of the mass continuity equation (2.5) applied at levels 1 and 3 with the conditions \( \dot{\sigma} = 0 \) at \( \sigma = 0,1 \) leads to the relations

\[ \frac{\partial \pi}{\partial t} = -\frac{1}{2} \nabla \cdot \left[ \pi \left( \mathbf{v}_1 + \mathbf{v}_3 \right) \right] \]  

(2.13)
\[ \delta_2 = -\frac{1}{4\pi} \nabla \cdot \left[ \pi (\mathbf{V}_1 - \mathbf{V}_3) \right] \]  

(2.14)

for the prediction of the surface pressure and the computation of the mid tropospheric vertical motion field.

The moisture continuity equation (2.6) is applied only at the (lower) level 3, giving

\[ \frac{\partial}{\partial t} (\pi q_3) + \nabla \cdot \left[ \pi q_3 \left( \frac{5}{4} \mathbf{V}_3 - \frac{1}{4} \mathbf{V}_1 \right) \right] = 2g(E - C) \]  

(2.15)

where the conditions \( \delta = 0 \) at \( \sigma = 1 \) and \( q = 0 \) at \( \sigma = 1/2 \) have been used, and the wind at level 3 (\( \sigma = 3/4 \)) is replaced by a wind at \( \sigma = 7/8 \) found by linear extrapolation from \( \mathbf{V}_1 \) and \( \mathbf{V}_3 \). The moisture source term, \( 2g(E - C) \), represents the net rate of vapor addition as a result of the evaporation rate, \( E \), and condensation rate, \( C \), into the air column of unit cross section between \( \sigma = 1 \) and \( \sigma = 1/2 \).

The hydrostatic equation (2.8) is integrated from the surface to the levels 1 and 3, yielding the relations

\[ \phi_1 = \phi_4 + \frac{1}{2} c_p \theta_2 \left[ \left( \frac{p_3}{p_0} \right)^\kappa - \left( \frac{p_1}{p_0} \right)^\kappa \right] + \frac{\pi}{2} (\sigma_3 a_3 + \sigma_1 a_1) \]  

(2.16)

\[ \phi_3 = \phi_4 - \frac{1}{2} c_p \theta_2 \left[ \left( \frac{p_3}{p_0} \right)^\kappa - \left( \frac{p_1}{p_0} \right)^\kappa \right] + \frac{\pi}{2} (\sigma_3 a_3 + \sigma_1 a_1) \]  

(2.17)

where \( \phi_4 \) is the (fixed) geopotential of the earth's surface, and where \( \theta \) has been assumed linear in \( p^\kappa \) space from \( \sigma_1 = 1/4 \) to the ground \( \sigma = 1 \).

2. Rectangular (Map) Coordinates

As a final transformation prior to the consideration of the difference equations used in the computations, it is convenient to present the vertically differenced equations (2.9) to (2.17) in terms of
the rectangular (or map) coordinates \( x \) and \( y \). The grid-scale distances \( m \) and \( n \), defined as

\[
m = a\Delta \lambda \cos \varphi
\]

\[
n = a\Delta \varphi
\]

represent the longitudinal and latitudinal distances between grid points separated by \( \Delta \lambda \) and \( \Delta \varphi \), respectively. The dimensionless map coordinates \( x \) and \( y \) may then be defined as

\[
x = m^{-1}a\lambda \cos \varphi
\]

\[
y = n^{-1}a\varphi
\]

so that a rectangular grid-point array is generated with unit distance between points. The reciprocals \( m^{-1} \) and \( n^{-1} \) are the conventional map-scale or magnification factors.

We also introduce the new area-weighted variables

\[
\Pi = mn\tau
\]

\[
\mathcal{S} = 2mn\pi \epsilon_2
\]

\[
F = mnf - u \frac{dm}{dy}
\]

and the weighted mass fluxes

\[
u^* = n \pi u
\]

\[
v^* = mn v
\]

at both levels 1 and 3.
Upon multiplication by \(\frac{\partial}{\partial t}\), the equations of motion, Eqs. (2.9) and (2.10), may thus be written:

\[
\begin{align*}
\frac{\partial}{\partial t} (\nabla u_1) + \frac{\partial}{\partial x} (u_1^* u_1) + \frac{\partial}{\partial y} (v_1^* u_1) + \frac{\partial}{\partial z} (u_1 + u_2) = \sum \left( \frac{u_1 + u_2}{2} \right) \\
+ n \left( -\frac{\partial \zeta_1}{\partial x} + \sigma_1 \nabla a_1 \right) - F_1 v_1 = \frac{\Pi F_1^X}{2} 
\end{align*}
\] (2.27)

\[
\begin{align*}
\frac{\partial}{\partial t} (\nabla v_1) + \frac{\partial}{\partial x} (u_1^* v_1) + \frac{\partial}{\partial y} (v_1^* v_1) + \frac{\partial}{\partial z} (v_1 + v_2) = \sum \left( \frac{v_1 + v_2}{2} \right) \\
+ m \left( -\frac{\partial \zeta_1}{\partial y} + \sigma_1 \nabla a_1 \right) + F_1 u_1 = \frac{\Pi F_1^Y}{2} 
\end{align*}
\] (2.28)

\[
\begin{align*}
\frac{\partial}{\partial t} (\nabla u_3) + \frac{\partial}{\partial x} (u_3^* u_3) + \frac{\partial}{\partial y} (v_3^* u_3) - \frac{\partial}{\partial z} (u_1 + u_2) = \sum \left( \frac{u_1 + u_2}{2} \right) \\
+ n \left( -\frac{\partial \zeta_3}{\partial x} + \sigma_3 \nabla a_3 \right) - F_3 v_3 = \frac{\Pi F_3^X}{2} 
\end{align*}
\] (2.29)

\[
\begin{align*}
\frac{\partial}{\partial t} (\nabla v_3) + \frac{\partial}{\partial x} (u_3^* v_3) + \frac{\partial}{\partial y} (v_3^* v_3) - \frac{\partial}{\partial z} (v_1 + v_2) = \sum \left( \frac{v_1 + v_2}{2} \right) \\
+ m \left( -\frac{\partial \zeta_3}{\partial y} + \sigma_3 \nabla a_3 \right) + F_3 u_3 = \frac{\Pi F_3^Y}{2} 
\end{align*}
\] (2.30)

where the frictional force \(\mathbf{F} = (F^X, F^Y)\) at levels 1 or 3.

The thermodynamic equations (2.11) and (2.12) may be similarly written as

\[
\begin{align*}
\frac{\partial}{\partial t} (\nabla T_1) + \frac{\partial}{\partial x} (u_1^* T_1) + \frac{\partial}{\partial y} (v_1^* T_1) + \left( \frac{p_1}{p_0} \right) \left( \frac{\theta_1 + \theta_3}{2} \right) = \sum \left( \frac{\theta_1 + \theta_3}{2} \right) \\
- \frac{\sigma_1 \nabla}{c_p} \left( -\frac{\partial H_1}{\partial x} + u_1 \frac{\partial \pi}{\partial x} + v_1 \frac{\partial \pi}{\partial y} \right) = \frac{\Pi H_1}{c_p} 
\end{align*}
\] (2.31)
\[
\frac{\partial}{\partial t} (\Pi T_3) + \frac{\partial}{\partial x} \left( u_3^* T_3 \right) + \frac{\partial}{\partial y} \left( v_3^* T_3 \right) - \left( \frac{p_3}{p_o} \right)^K \left( \frac{\theta_1 + \theta_3}{2} \right) \frac{\partial}{\partial t} \frac{\Pi H_3}{c_p} - \sigma^{\alpha_3} \left( \frac{\partial \Pi}{\partial t} + u_3^* \frac{\partial}{\partial x} + v_3^* \frac{\partial}{\partial y} \right) = \frac{\Pi H_3}{c_p} \frac{\partial}{\partial t}
\]
(2.32)

The mass and moisture continuity equations (2.13) to (2.15) may also now be written as

\[
\frac{\partial \Pi}{\partial t} = -\frac{1}{2} \left[ \frac{\partial}{\partial x} \left( u_1^* + u_3^* \right) + \frac{\partial}{\partial y} \left( v_1^* + v_3^* \right) \right]
\]
(2.33)

\[
\frac{\partial}{\partial t} \left( \Pi q_3 \right) + \frac{\partial}{\partial x} \left[ q_3 \left( \frac{5}{4} u_3^* - \frac{1}{4} u_1^* \right) \right]
+ \frac{\partial}{\partial y} \left[ q_3 \left( \frac{5}{4} v_3^* - \frac{1}{4} v_1^* \right) \right] = \frac{2 \Pi g}{\pi} \left( E - C \right)
\]
(2.35)

Equations (2.27) to (2.35), together with (2.16) and (2.17), constitute the final dynamical statement of the model in vertically differenced form. The introduction of time and horizontal spatial finite differences is considered in the following sections.

E. FRICTION TERMS

The frictional terms \( \mathcal{F}_1 \) and \( \mathcal{F}_3 \) in the equations of horizontal motion (2.9) and (2.10) are given by relations of the form

\[
\mathcal{F}_1 = -\mu \left( \frac{\partial \mathcal{V}}{\partial z} \right)_2 \frac{2g}{\pi} = -\mu \left( \frac{\mathcal{V}_1 - \mathcal{V}_3}{z_1 - z_3} \right) \frac{2g}{\pi}
\]
(2.36)

\[
\mathcal{F}_3 = -\mathcal{F}_1 - C_D c_s \left( \left| \mathcal{V}_s \right| + G \right) \frac{2g}{\pi}
\]
(2.37)
where \( \mu \) is an empirical coefficient for the vertical shear stress, and the factor \( 2g/\pi \) represents the mass per unit area in each of the two model layers. Here \( z_1 - z_3 \) is the height difference between the levels 1 and 3, \( C_D \) is the surface drag coefficient, \( \rho_4 \) the surface air density, \( \vec{V}_s \) a measure of the surface wind (= 0.7 \( \vec{V}_4 \), with \( \vec{V}_4 \) an extrapolated wind at level 4), and \( G \) an empirical correction for gustiness.

The frictional force \( \vec{F}_1 \) thus represents the internal downward transfer of momentum between the levels due to the vertical shear of the horizontal wind, whereas the force \( \vec{F}_3 \) also includes the effects of surface skin friction.

**F. MOISTURE, CONVECTION, AND CLOUDS**

The purpose of this section is to describe the physics of the hydrologic cycle used in the model and to develop the expressions used to evaluate the moisture-source term, \( 2 \frac{H}{\pi} (E - C) \), on the right-hand side of the moisture-balance equation for the atmosphere [Eq. (2.35)]. The moisture source for the atmosphere is evaporation from the surface, \( E \), and the moisture sink is precipitation, \( C \). All the moisture condensed in the model atmosphere is assumed to fall to the surface as precipitation. Thus the moisture sink for the atmosphere, \( C \), is specified by large-scale, convective, and surface condensation. The variables specifying the amount of moisture in the atmosphere and in the ground are \( q_3 \), the lower-level mixing ratio, and \( GW \), the ground-wetness parameter. While \( q_3 \) is determined in part by horizontal advection and is thus modified every time step, \( GW, E, C \), and that part of the change of \( q_3 \) due to \( E \) and \( C \) are computed every fifth time step (see Chapter III, Section A).

Clearly, the amount of evaporation, condensation, and convection depend on the thermal state of the atmosphere, which is in turn a function of the exchange of heat taking place during these processes. Instead of obtaining a simultaneous solution for the moisture and thermal states of the atmosphere, the model evaluates the evaporation and the components of the condensation in a sequence. At each step
of the sequence the thermal state of the atmosphere is modified, and
the new values of temperature are used in the next step.

In the following subsections each process is discussed in the
sequence in which it is evaluated in the FORTRAN program. First, the
temperature lapse rate between $\sigma = 3/4$ and $\sigma = 1/4$ is adjusted to the
dry-adiabatic lapse rate if it is found to be dry-adiabatically un-
stable; this convective adjustment is discussed in Subsection F.1.
Second, if the air is supersaturated at $\sigma = 3/4$, large-scale condensa-
sion occurs and the temperature and mixing ratios at $\sigma = 3/4$ are
adjusted (see Subsection F.2). Third, the temperature lapse rates be-
tween levels and the humidity are tested to determine the existence
of moist convective instability. If there is instability, convective condensation occurs and the temperatures and mixing ratios are ad-
justed according to the three types of convection permitted:

(a) Middle-level convection, which occurs if the layer between
$\sigma = 3/4$ and $\sigma = 1/4$ is unstable (for moist convection).
(b) Penetrating convection, which occurs if the layer from $\sigma = 3/4$
to $\sigma = 1/4$ is stable but the layer from the surface to
$\sigma = 3/4$ is unstable and, in the mean, unstable from the sur-
face to $\sigma = 1/4$.
(c) Low-level convection, which occurs if the atmosphere is un-
stable only between the surface and $\sigma = 3/4$.

To determine the existence of convection types (b) and (c), one needs
the temperature and mixing ratios at the top of the surface boundary
layer. All three forms of convective condensation and the physics of
the boundary layer are discussed in Subsection F.3. Fourth, the quan-
tities needed to evaluate the evaporation from the surface are dis-
cussed in Subsection F.4, and the moisture balance at the surface and
in the atmosphere is discussed in Subsection F.5.

The final two subsections are devoted to parameters which are re-
lated to the moisture content of the atmosphere and are used in the
radiation balance calculation in Section G. In Subsection F.6, the
cloud types and cloud amounts produced by the various forms of condens-
sation are discussed, and in Subsection F.7, equations for the effec-
tive water-vapor content of the atmosphere are derived.
1. Convective Adjustment

If, as a result of the changes due to advection, the atmosphere is found to be dry-adiabatically unstable ($\theta_1 \leq \theta_3$) at the beginning of the heating and moisture-balance calculations, then a "convective adjustment" is made. This consists of setting both $\theta_1$ and $\theta_3$ equal to an average $\bar{\theta}$, which is calculated from

$$\bar{\theta} = \overline{T} \left[ \frac{1}{2} \left( p_o^\kappa + p_o^\nu \right) \right]^{-1}$$

assuming that

$$\overline{T} = \frac{1}{2} (T_1 + T_3)$$

Thus, the convective adjustment consists of setting

$$\frac{\theta_1}{p_o^\kappa} = \frac{\theta_3}{p_o^\nu} = \frac{\theta_2}{p_o^\nu} = \frac{T_1 + T_3}{p_1 + p_3^\nu}$$

(2.38)

from which the temperatures are accordingly recalculated as

$$T_1 = \frac{\theta_1}{p_o^\kappa} p_3^\kappa$$

(2.39)

$$T_3 = \frac{\theta_3}{p_o^\nu} p_3^\nu$$

After this convective adjustment, the model proceeds as usual to the moisture and convection calculations.

2. Large-Scale Condensation

Large-scale condensation occurs if the lower-level grid cell is supersaturated at the beginning of the moisture-balance calculation.
The saturation mixing ratio is given by

\[ q_s(T) = \frac{\frac{M_w}{M_d} e_s(T)}{p - e_s(T)} \] (2.40)

where \( M_w \) and \( M_d \) are the mean molecular weights of water vapor and dry air, respectively (\( M_w / M_d = 0.622 \)), and where the saturation vapor pressure is given by the equation

\[ e_s(T) = e_o \exp(A_e - B_e/T) \] (2.41)

with \( e_o = 1 \text{ mb}, A_e = 21.656 \), and \( B_e = 5418 \text{ deg K.} \)

If it is then determined that \( q_3 > q_s(T_3) \) as a result of the computed solution of the moisture continuity equation (2.35), large-scale condensation is allowed to occur. This condensation will remove moisture from the atmosphere and will also warm the atmosphere by releasing latent heat, with the warming in turn modifying the saturation mixing ratio \( q_s(T_3) \). The condensation proceeds until \( q_3 = q_s(T) \) at the new (warmed) temperature. If the original temperature and mixing ratio at level 3 are written as \( T_o \) and \( q_o \), the new temperature \( T \) satisfies

\[ c_p(T - T_o) = L[q_o - q_s(T)] \] (2.42)

In view of the dependence of \( q_s \) on \( T \), as given by Eqs. (2.40) and (2.41), we seek the approximate value of \( l \) when

\[ F(T) = T - T_o + \left( \frac{L}{c_p} \right)[q_s(T) - q_o] = 0 \] (2.43)

Using the Newton-Raphson method, the first-order approximation of \( T \) becomes

\[ T \approx T_o - \frac{F(T_o)}{F'(T_o)} \] (2.44)
where

\[ F(T_o) = -\frac{L}{c_p} [q_o - q_s(T_o)] \]  \hspace{1cm} (2.45)

and

\[ F'(T_o) = \frac{dF}{dT}(T_o) = 1 + \frac{L}{c_p} q_s(T_o) \frac{B e}{T_o^2} \left[ 1 + \frac{M_d}{M_w} q_s(T_o) \right] \]  \hspace{1cm} (2.46)

Substituting Eqs. (2.45) and (2.46) into (2.44) and neglecting \((M_d/M_w)q_s(T_o)\) in comparison with 1, the change in temperature at level 3 as a result of large-scale condensation becomes

\[ (\Delta T_3)_{LS} = T - T_o = \frac{\frac{L}{c_p} [q_o - q_s(T_o)]}{1 + \frac{L}{c_p} q_s(T_o) \frac{B e}{T_o^2}} \]  \hspace{1cm} (2.47)

The change in moisture content due to this large-scale condensation is found from

\[ (\Delta q_3)_{LS} = \frac{c_p}{L} (T_3)_{LS} \]  \hspace{1cm} (2.48)

and the new \(q_3\) is given by

\[ q_3 = q_3 - (\Delta q_3)_{LS} \]  \hspace{1cm} (2.49)

Since the amount of precipitation is assumed to be equal to the condensation, the large-scale precipitation rate becomes

\[ P_{LS} = (\pi/2g\rho)(\Delta q_3)_{LS} \]  \hspace{1cm} (2.50)
where \((\pi/2g)/\omega\) is a conversion factor used to obtain the precipitation rate from the condensation rate (see Chapter IV, Large-Scale Precipitation Rate: Map 9). Finally, the large-scale condensation produces type-2 clouds (see Subsection F.6).

3. **Convective Condensation**

To determine the possibility of convection, suitable stability criteria must first be defined. The equivalent potential temperature, defined as

\[
\theta_e = \theta_d \exp \left( \frac{Lq}{c_p T} \right) \quad (2.51)
\]

where

\[
\theta_d = T \left( \frac{p_0}{p - e} \right)^{\kappa} \quad (2.52)
\]

is conservative in both unsaturated-adiabatic and saturated-adiabatic processes. A more convenient parameter for our purposes is given by the approximation

\[
\frac{c_p T}{\theta_e} \frac{\partial \theta_d}{\partial h} = dh \quad (2.53)
\]

Here

\[
h = \frac{c_p T}{\theta_e} + g z + Lq \quad (2.54)
\]

shall be referred to as the static energy; it is the sum of the enthalpy, the potential energy, and the latent energy of a parcel of air. The static energy is very nearly conservative in both unsaturated and saturated adiabatic processes, and thus can be used in the analysis of convective phenomena. For example, following the argument
of Arakawa et al. (1969), if we assume that the air in the clouds at level 1 is saturated, then the static energy in the cloud at level 1 becomes

\[ h_c = \frac{c_p}{p} T_{cl} + g z_1 + L q_s (T_{cl}) \]  \hspace{1cm} (2.55)

where \( q_s (T_{cl}) \) is the saturation mixing ratio at the cloud temperature \( T_{cl} \). For convenience we define the quantity

\[ h_1^* = \frac{c_p}{p} T_1 + g z_1 + L q_s (T_1) \]  \hspace{1cm} (2.56)

where \( T_1 \) is the temperature of the air surrounding the clouds at level 1. Eliminating \( g z_1 \) from Eqs. \( (2.55) \) and \( (2.56) \), the temperature difference between the clouds and the surrounding air at level 1 becomes

\[ T_{cl} - T_1 = \frac{1}{1 + \gamma_1} \frac{h_c - h_1^*}{c_p} \]  \hspace{1cm} (2.57)

where

\[ \gamma_1 = \frac{L}{c_p} \left( \frac{\partial q_s}{\partial T} \right)_1 \approx \frac{L}{c_p} \frac{q_s (T_{cl}) - q_s (T_1)}{T_{cl} - T_1} \]  \hspace{1cm} (2.58)

Thus it can be seen from Eq. \( (2.57) \) that when \( h_c > h_1^* \) the temperature in the clouds at level 1 is warmer than that in the surroundings, and any convection that has been initiated will tend to continue.

We now seek to determine the value of \( h_c \) in terms of the Mintz-Arkawa two-level model's parameters. To do this we assume that all the entrainment takes place at level 3, and thus the vertical mass flux \( (M) \) through the cloud above level 3 becomes

\[ M = M_b \eta \]  \hspace{1cm} (2.59)
where $M_b$ is the vertical mass flux through the bottom of the cloud and $\eta$ is the entrainment factor. When there is entrainment, $\eta > 1$, and the static energy in the cloud is a mixture of the static energy entering the base of the cloud, $h_b$, and that of the surrounding air, $h_3$. Thus we have

$$h_c = h_3 + \frac{1}{\eta} (h_b - h_3)$$ (2.60)

What is assumed for the amount of entrainment will therefore determine the value of $h_c$ in Eq. (2.57) and thus the existence of stability in the model.

In the following subsections, the value of $\eta$ for each type of convection will be discussed and the stability criteria derived. The criteria will then be used to determine the temperature and moisture changes resulting from the convection.

a. Middle-Level Convection. In middle-level convection we assume that the entrainment at level 3 is much larger than the mass flux through the bottom of the cloud. Mathematically, it can be represented by setting $\frac{1}{\eta} = 0$ while leaving $\eta M_b$ finite. Thus from Eq. (2.60) we have $h_c = h_3$, and from Eq. (2.57) the condition for middle-level convection becomes $h_3 > h^*_3$. The parameters $h_3$ and $h^*_3$, rewritten in terms of the potential temperatures and mixing ratios at levels 1 and 3, are

$$\frac{h^*_3}{\theta_3} = \frac{\theta_3}{\theta_3} \left( \frac{p_3}{p_0} \right)^\kappa + \left( \frac{\theta_1 - \theta_3}{\theta_0} \right) \left( \frac{p_0}{p_0} \right)^\kappa + \frac{L}{c_p} q_s (T_1)$$ (2.61)

$$\frac{h_3}{\theta_3} = \frac{\theta_3}{\theta_3} \left( \frac{p_3}{p_0} \right)^\kappa + \frac{L}{c_p} q_3$$ (2.62)
where

$$\theta_3 \left( \frac{p_3}{p_0} \right)^\kappa \approx T_3 + \frac{g}{c_p} z_3$$  \hspace{1cm} (2.63)$$

and

$$\theta_1 - \theta_3 \left( \frac{p_2}{p_0} \right)^\kappa = \left( T_1 + \frac{g}{c_p} z_1 \right) - \left( T_3 + \frac{g}{c_p} z_3 \right)$$  \hspace{1cm} (2.64)$$

To determine the temperature change at levels 1 and 3 due to this convection, we introduce the concept of "dry" static energy, S, where

$$S = \frac{c_p}{g} T + gz$$  \hspace{1cm} (2.65)$$

Considering convection only, the continuity equation for S at level 1 is

$$\frac{\partial \rho S_1}{\partial t} = - \frac{\partial (\frac{\rho M \rho}{g} S_1)}{\partial z}$$  \hspace{1cm} (2.66)$$

which may be approximated by

$$\frac{\Delta \rho}{g} \frac{\partial S_1}{\partial t} = \rho M b (S_{c1} - S_2)$$  \hspace{1cm} (2.67)$$

Neglecting the time change of the geopotential and using Eq. (2.57) we may write Eq. (2.67) as

$$\frac{\partial T_1}{\partial t} = \frac{g}{c_p \Delta \rho} \rho M b \left[ \frac{1}{1 + \gamma_1} (h_3 - h_1^*) + (S_1 - S_2) \right]$$  \hspace{1cm} (2.68)$$
With similar approximations, the temperature change at level 3 is given by

$$\frac{\partial T_3}{\partial t} = \frac{\mathcal{G}}{\Delta \rho} \frac{n M_b}{c_p} (S_2 - S_3) \quad (2.69)$$

Equations for the mixing ratios at levels 1 and 3 can be derived in a similar fashion. However, in the model all the moisture is assumed to be carried at level 3, and thus the change of $q_3$ due to convection becomes

$$\frac{\partial q_3}{\partial t} = \frac{\mathcal{G}}{\Delta \rho} n M_b [q_s(T_1) - q_3]$$

$$= \frac{\mathcal{G}}{\Delta \rho} n M_b [q_s(T_1) - q_3 + \frac{\gamma_1}{1 + \gamma_1} \frac{1}{L} (h_3 - h_1^*)] \quad (2.70)$$

Here, Eq. (2.57) has been used to eliminate $q_s(T_{c1})$.

To eliminate the unknown mass flux in Eqs. (2.68) to (2.70), we relate $n M_b$ to the relaxation time, $\tau_r$, of free cumulus convection. As a result of convection, the instability of the layer diminishes and $h_3 - h_1^*$. The time rate of change of $(h_3 - h_1^*)$ is given by

$$\frac{3}{\partial t} (h_3 - h_1^*) = \frac{3}{\partial t} (S_3 - S_1) + L \frac{\partial q_3}{\partial t} - L \frac{\partial q_s(T_1)}{\partial T_1} \frac{\partial T_1}{\partial t}$$

$$= - \frac{\mathcal{G}}{\Delta \rho} n M_b \frac{2 + \gamma_1}{1 + \gamma_1} [(h_3 - h_1^*) + \frac{1}{2} (1 + \gamma_1)(S_1 - S_3)] \quad (2.71)$$

If the instability diminishes exponentially with $e$-folding time $\tau_r$, then

$$n M_b = \frac{1}{\tau_r} \mathcal{G} \frac{1 + \gamma_1}{2 + \gamma_1} \left[ \frac{h_3 - h_1^*}{h_3 - h_1^* + \frac{1}{2} (1 + \gamma_1)(S_1 - S_3)} \right] \quad (2.72)$$
When Eq. (2.72) is combined with (2.68) and (2.69), the change in temperature at levels 1 and 3 [over the time interval (5Δt) between heating calculations] due to the release of latent heat is given by

\[
\frac{\Delta T_1}{CM} = \frac{h_3 - h_1^*}{c_p(2 + \gamma_1)} \frac{5\Delta t}{\tau_r} \tag{2.73}
\]

\[
\frac{\Delta T_3}{CM} = \frac{(\Delta T_1)_{LR/2}}{(h_3 - h_1^*)/c_p + (1 + \gamma_1)LR/2} \tag{2.74}
\]

where \(\gamma_1 = (L/c_p) 5418\text{deg} \quad q_8 (T_1)T_1^{-2}\) and \(LR = (\theta_1 - \theta_3)(p_2/p_0)^K\) is a "nominal lapse rate." In this model, the relaxation time, \(\tau_r\), is taken to be 1 hour. From Eqs. (2.70) and (2.73) the change in moisture at level 3 is given by

\[
\frac{\Delta q_3}{CM} = \frac{L}{c_p} \left[ \frac{(\Delta T_1)}{CM} + \frac{(\Delta T_3)}{CM} \right] \tag{2.75}
\]

As in Eq. (2.50), the precipitation rate due to middle-level convection is given by

\[
P_{CM} = (\pi/2g\rho_{w})(\Delta q_3)_{CM} \tag{2.76}
\]

Type-1 clouds may be produced by this middle-level convection (see Subsection F.6), and the associated convective precipitation rate is illustrated in Map 13, Chapter IV.

b. Boundary-Layer Temperature and Moisture. If middle-level convection does not occur, either "penetrating convection" or "low-level convection" may. Since both of these convection types originate at the air/ground interface, it is convenient to discuss first the computation of the moisture, \(q_4\), and air temperature, \(T_4^*\), at the surface along with other air/ground interaction parameters. A thin
boundary layer is assumed at the air/ground interface, with the subscript "4" referring to values at the top of the boundary layer and the subscript "g" referring to values at the bottom of the layer, just above the ground or water surface.

We assume that the flux of static energy [see Eq. (2.54)] from the surface into the bottom of the boundary layer is equal to the flux out the top. We neglect horizontal convergence in this thin boundary layer and also assume negligible geopotential difference between its top and bottom. Thus the flux of static energy from the surface may be approximated by

\[ \Gamma_h = \rho_4 C_D W(h_g - h_4) \]  

(2.77)

where

\[ W = |\mathbf{\hat{V}}_s|^{\pi} + G \]  

(2.78)

is a surface-wind parameter corrected for gustiness and \( C_D \) is the drag coefficient. Implied in Eq. (2.77) are the assumptions that the eddy-diffusion coefficient for the static energy can be approximated by that for momentum, and that a constant transfer coefficient may be used in the boundary layer. Equating (2.77) to the flux through the top of the boundary layer, we obtain

\[ \rho_4 C_D W(h_g - h_4) = \rho_A v \frac{h_4 - h_3}{z_3} \]  

(2.79)

where \( A_v \) is the vertical eddy-diffusion coefficient. Solving Eq. (2.79) for \( h_4 \) we obtain

\[ h_4 = (\text{EDR}) h_3 + (1 - \text{EDR}) h_g \]  

(2.80)
where \( h_3 \) is given by Eq. (2.62), \( h_g \) is given by

\[
\frac{h_g}{c_p} = T_g + \frac{L}{c_p} q_g
\]  

(2.81)

and

\[
EDR = \frac{A_v/z_3}{A_v/z_3 + C_D \bar{w}}
\]  

(2.82)

In the present version of the model it is assumed that \( A_v = 1|\bar{v}_s|^\pi \text{ m}^2 \text{ sec}^{-1} \), where the surface wind \( \bar{v}_s \) is in m sec\(^{-1}\).

In order to obtain the surface moisture, \( q_4 \), and temperature, \( T_4 \), we now write the parameter \( h_4 \) from Eq. (2.54) as

\[
\frac{h_4}{c_p} = T_4 + \frac{L}{c_p} q_4
\]  

(2.83)

By defining the values of \( q_g \) and \( q_4 \), one may solve Eqs. (2.80) and (2.83) for \( T_4 \) in terms of the surface parameters \( T_g \) and \( GW \) and the static energy at level 3. In general, the ground temperature, \( T_g \), and the ground wetness, \( GW \) (0 \( \leq \) GW \( \leq \) 1), are available from the previous time step, along with the level-3 temperature and moisture. From these data, the relative humidities at levels 3 and 4 may be determined from

\[
RH_3 = \frac{q_3}{q_s(T_3)}
\]  

(2.84)

and

\[
RH_4 = \frac{(2GW)(RH_3)}{GW + RH_3}
\]  

(2.85)
where RH₄ is the harmonic mean of RH₃, the relative humidity at level 3, and the ground wetness, GW. The ground-level mixing ratio is assumed to be directly proportional to the ground wetness. Hence

\[ q_g = GW \ q_s(T_g) \]  \hspace{1cm} (2.86)

where \( q_s(T_g) \) is calculated from \( T_g \) in the usual fashion [see Eq. (2.40)],

\[ q_s(T_g) = \frac{0.622 \ e_s(T_g)}{p_4 - e_s(T_g)} \]  \hspace{1cm} (2.87)

and the ground-level saturation vapor pressure is given by

\[ e_s(T_g) = \min[e_o \ \exp(A_e - B / T_g), \ p_4/16.62] \]  \hspace{1cm} (2.88)

The mixing ratio at level 4 can now be obtained from Eq. (2.85) and an extrapolation of \( q_s(T_g) \) to level 4. Thus

\[ q_4 = RH_4 \left[ q_s(T_g) + \Delta z \frac{dq_s(T_g)}{dT} \frac{dT}{dz} \right] \]

\[ = RH_4 \left[ q_s(T_g) + \frac{c_p}{L} \ \gamma_g(T_4 - T_g) \right] \]  \hspace{1cm} (2.89)

where \( \gamma_g \) is evaluated from

\[ \gamma_g = \frac{L}{c_p} \frac{dq_s(T_g)}{dT} = \frac{L}{c_p} \ 5418 \text{deg} \ \frac{q_s(T_g)}{T_g^2} \]  \hspace{1cm} (2.90)

Using Eqs. (2.83), (2.89), and (2.80), the temperature at level 4 becomes finally
\[
T_4 = \begin{cases} 
\frac{\bar{h}_4}{c_p} - \frac{RH_4}{1 + RH_4 \gamma_g} & \text{if } T_4 \left( \frac{p_o}{p_4} \right)^\kappa \leq \theta_3 \\
\theta_3 \left( \frac{p_4}{p_o} \right)^\kappa & \text{otherwise}
\end{cases}
\] (2.91)

where \(\bar{h}_4\) is the value of the static energy at level 4 as given by Eq. (2.80). The condition on \(T_4\) given by Eq. (2.91) is invoked to prevent a super-adiabatic lapse rate between levels 4 and 3. From the quantities \(T_4\) and \(q_4\) given by Eqs. (2.89) and (2.91) the convection parameter \(h_4^*\) defined by Eq. (2.83) may then be evaluated, although the quantities \(T_4\) and \(q_4\) will be redefined later if penetrating or low-level convection occurs [see Eqs. (2.96) and (2.97) below].

c. Penetrating and Low-Level Convection. In the model, both penetrating convection and low-level convection are mutually exclusive with middle-level convection. Thus, the first criterion to be met is that the layer between level 3 and level 1 be stable, i.e., that \(h_3 < h_1^*\). A second criterion, similar to Eq. (2.57) for middle-level convection, is obtained from instability conditions for the layer between levels 4 and 3. Thus we first write

\[
T_{c3} - T_3 = \frac{1}{1 + \gamma_3} \left( \frac{h_c - h_3^*}{c_p} \right)
\] (2.92)

where \(T_{c3}\) is the temperature of the rising air in the clouds at level 3,

\[
\gamma_3 = \frac{L}{c_p} \frac{dq_s(T_3)}{dT} = \frac{L}{c_p} 5418 \text{deg} \frac{q_s(T_3)}{T_3^2}
\] (2.93)

and

\[
\frac{h_3^*}{c_p} = \theta_3 \left( \frac{p_s}{p_o} \right)^\kappa + \frac{L}{c_p} q_s(T_3).
\] (2.94)
For penetrating and low-level convection we assume that there is no entrainment at level 3 \((n = 1)\), and from Eq. (2.60) we then find \(h_c = h_b\). Further, we take the static energy at the base of the cloud, \(h_b\), to be equal to its value at the top of the boundary layer, \(h_4\). Therefore the second criterion for penetrating and low-level convection becomes \(h_4 > h_3^*\), along with the primary criterion \(h_3 < h_1^*\). When these two conditions are met, we may then discriminate between penetrating and low-level convection. From Eq. (2.57) with \(h_c = h_4\) we see that if \(h_4 \geq h_1^*\), convection can penetrate into the stable layer above level 3 and reach all the way to level 1. This is therefore the distinguishing condition for penetrating convection. If, on the other hand, \(h_4 < h_1^*\), the convection stops at level 3. This is therefore the condition for low-level convection.

In the case of low-level convection, it is assumed that \(h_4\) is modified to \(h_3^*\), because of the process of transporting static energy out of the boundary layer. This is equivalent to assuming that static energy in the cloud becomes \(h_3^*\). Low-level convection may produce type-3 clouds (see Subsection F.6), and condensation and precipitation are not allowed to occur; all the moisture transported as clouds is assumed to evaporate again within the same layer with no release of latent heat. The effect of this type of convection is thus felt only in the vertical transport of sensible heat and in surface evaporation, where it alters the surface moisture and temperature.

Indicating by primes the values prior to modification by low-level convection, we may write

\[
h_4' = h_4' - (h_4' - h_3^*)
\]

Substituting the definitions of \(h_4\) and \(h_4'\) into Eq. (2.95) and using Eq. (2.89) for the old and new mixing ratios at level 4, the surface temperature and mixing ratios are given, after convection, as

\[
T_4 = T_4' - \frac{(h_4' - h_3^*)/c_p}{1 + RH_4 \gamma g}
\]
\[ q_4 = \frac{1}{L} \left( \frac{h_4' - T_4}{c_p} \right) \]  

(2.97)

The temperature and mixing-ratio adjustments at level 4 given by Eqs. (2.96) and (2.97) also occur in the case of penetrating convection. To find the change in the temperature and mixing ratios at levels 3 and 1 in this case we continue to assume modification of \( h_4' \) to \( h_3^* \), and follow the same procedure used in middle-level convection. Thus, as in Eqs. (2.68) and (2.69) and using \( h_3^* \) as the static energy in the cloud, we obtain

\[ \frac{\partial T_1}{\partial t} = \frac{g}{c_p \Delta p} M_b \frac{1}{1 + \gamma_1} (h_3^* - h_1^*) + \frac{S_1 - S_2}{c_p} \]  

(2.98)

and

\[ \frac{\partial T_3}{\partial t} = \frac{g}{c_p \Delta p} M_b \frac{S_2 - S_4}{c_p} \]  

(2.99)

To determine the value of the mass flux, \( M_b \), we assume, as in the case of middle-level convection, that the penetrating convection decays with a relaxation time \( \tau_r \). Here \( M_b \) is determined by the time required to remove the instability in the layer from level 4 to level 3, i.e., the time required for \( h_4' \) to approach \( h_3^* \). With this assumption, the mass flux becomes

\[ M_b = \frac{\Delta p}{\tau_r g} \frac{h_4' - h_3^*}{EDR \left( \frac{h_3^* - h_1^*}{1 + \gamma_1} + S_1 - S_2 \right) + (1 + \gamma_3) (S_2 - S_4)} \]  

(2.100)

Using Eqs. (2.98), (2.99), and (2.100), the temperature changes at the levels 1 and 3 due to penetrating convection over the time interval \( 5\Delta t \) are given by
\[
\begin{align*}
(\Delta T_1)_{CP} &= \frac{h_4 - h_3^*}{c_p \tau_1} \frac{5\Delta t}{\tau_r} \\
(\Delta T_3)_{CP} &= \frac{h_4 - h_3^*}{c_p \tau_2} \frac{5\Delta t}{\tau_r}
\end{align*}
\]

where

\[
\tau_1 = \frac{h_3^* - h_1^*}{(1 + \gamma_1) c_p} + \frac{LR}{2}
\]

\[
\tau_2 = \left(\frac{LR}{2}\right) + \theta_3 \left(\frac{p_4}{p_0}\right)^k - T_4
\]

\[
\tau = \begin{cases} 
\text{EDR } \tau_1 + (1 + \gamma_3) \tau_2, & \text{if } \tau \geq 0.001 \\
0.001, & \text{otherwise}
\end{cases}
\]

and \(\tau_r\) is the convection relaxation time as before. As with the middle-level convection, all the moisture condensed (and hence precipitated) is assumed to originate in the lower layer, so that the level-3 moisture change due to penetrating convection is given by

\[
(\Delta q_3)_{CP} = \frac{c_p}{L} \left[ (\Delta T_1)_{CP} + (\Delta T_3)_{CP} \right]
\]

Type-1 clouds may be produced by this convection (see Subsection F.6), and the precipitation rate due to penetrating convection is given by

\[
P_{CP} = (\pi/2gw)(\Delta q_3)_{CP}
\]
This contributes to the total convective precipitation rate illustrated in Map 13, Chapter IV.

4. Evaporation

The evaporation rate per unit area from the surface is approximated by an equation similar to (2.77) for the flux of static energy from the surface. Thus

\[ E = \rho_4 c_D W(q_g - q_4) \]  

(2.108)

where \( \rho_4 = \varphi_s (RT_4)^{-1} \) with \( R \) the gas constant, \( \varphi_s \), the surface (level-4) pressure, and \( T_4 \) and \( q_4 \) are given by Eqs. (2.96) and (2.97) if penetrating or low-level convection exists, and otherwise by Eqs. (2.91) and (2.89). The ground-level value of the mixing ratio is given by

\[ q_g = GW_{qse} (T_{gr}) \]  

(2.109)

where \( q_{se} (T_{gr}) \) is the effective saturation mixing ratio at the bottom of the boundary layer after a correction to include the effects of the radiation balance at the surface on the ground-level temperature (see Subsection G.3). Thus

\[ q_{se} = q_s (T_g) + \frac{dq_s (T_g)}{dT} (T_{gr} - T_g) \]  

(2.110)

where \( T_{gr} \) is the new value of \( T_g \) calculated to include the radiation.

The evaporation thus calculated can be either positive or negative, and is available as a separate output from the program (see Map 14, Chapter IV). The moisture at level 3 will be changed in direct proportion to this evaporation. Thus, over the time interval \( 5 \Delta t \), the contribution by evaporation to the total moisture balance at level 3 (see following subsection) is given by

\[ \langle \Delta q_3 \rangle = \frac{2E \cdot E}{\pi} \cdot 5 \Delta t \]  

(2.111)
5. Moisture Balance and Ground Water

Moisture balance is maintained both in the form of moisture at level 3 and as the ground water on the land. The ocean, ice, and snow are considered both as infinite sources (for evaporation) and infinite sinks (for precipitation, negative evaporation, and runoff). Although the upper-level moisture is calculated as a function of lower-level moisture for radiation purposes, the total amount at the upper level is otherwise considered to be negligible, as is any transport between the upper and lower layers of the model.

The level-3 moisture balance is calculated from

\[
(q_3)^{\text{new}} = (q_3)^{\text{old}} + (\Delta q_3)^{\text{TOTAL}}
\]

(2.112)

where \((\Delta q_3)^{\text{TOTAL}}\) is the sum of the level-3 moisture changes due to middle-level convection, CM, or penetrating convection, CP, large-scale condensation, LS, and evaporation, E. Thus the expression for the moisture-source term of Eq. (2.35) becomes

\[
2\text{mmg}(E - C) = \frac{\Pi}{5\Delta t} (\Delta q_3)^{\text{TOTAL}}
\]

\[
= \frac{\Pi}{5\Delta t} \left[ (\Delta q_3)_E - (\Delta q_3)_LS - (\Delta q_3)_CM - (\Delta q_3)_CP \right]
\]

(2.113)

The ground water is carried as the variable GW, which varies between 0 for dry ground and 1 for saturated ground. For ocean, ice, or snow, GW is always considered to be 1. This quantity is used in the determination of ground temperature and evaporation, and is recalculated (for land) after the level-3 moisture balance has been determined. If \((\Delta q_3)^{\text{TOTAL}}\) is negative (a decrease in level-3 moisture), enough precipitation occurs for runoff to be calculated. If the ground is not saturated (GW < 1) then the runoff is taken as 0.5 GW; if the ground is saturated, the runoff is taken as unity. The new ground wetness is then given by
\[ (GW)_{\text{new}} = (GW)_{\text{old}} + (1 - \text{runoff})(\Delta q_3)_{\text{TOTAL}} \frac{1}{GWM} \frac{\pi}{2g} \] (2.114)

where GWM is the maximum mass of water per unit area which the ground can absorb (here assumed to be 30 g/cm²), and the factor \( \pi/2g \) is the air mass in a vertical column of unit area in the lower model layer. If \( (\Delta q_3)_{\text{TOTAL}} \) is not negative, because evaporation is greater than precipitation, the runoff is zero and Eq. (2.114) represents the net decrease of moisture at the ground. If \( (GW)_{\text{new}} < 0 \) then \( (GW)_{\text{new}} \) is set to zero, and if \( (GW)_{\text{new}} > 1 \) it is set to 1.

6. Clouds

The type of clouds present in the model depends upon which condensation and/or convection processes have occurred. The amount of cloud cover depends upon the relative humidity at level 3, RH₃, for convective clouds, whereas a complete overcast is assumed for clouds caused by large-scale condensation. Figure 2.2 shows the assumed physical dimensions of the various cloud types. Although the clouds are only parameterized entities as far as the moisture is concerned, they must have physical dimensions for the radiation calculations. In the present version of the program, type-1 clouds cannot coexist with other types in any given grid cell; types 2 and 3 may coexist.

Type-1 clouds may be described as towering cumulus, having their bases at level 3 and their tops at level 1. They exist if either middle-level or penetrating convection occurs. The amount of cloud cover (given as the fraction of the sky covered with clouds) is defined by \( CL = -1.3 + 2.6 \times RH₃ \). If \( CL \leq 0 \) the sky is defined to be clear. This convection therefore does not create clouds unless the relative humidity at level 3 is greater than 50 percent. If \( CL > 1 \) it is reset to 1, implying a completely cloudy sky.

Type-2 clouds may be described as a heavy overcast with base at level 3 and top at level 2. They exist if large-scale condensation takes place (as described in Subsection F.2 above), and if type-1 clouds do not exist (since strong convection would destroy these clouds).
Fig. 2.2 -- Schematic representation of convective cloud types. Type-1 cloud represents either penetrating or middle-level convection and is assumed to extend from level $\sigma_3$ to $\sigma_1$, type-2 cloud represents large-scale condensation and is assumed to extend from level $\sigma_3$ to $\sigma_2$, and type-3 cloud represents low-level cumulus convection and is assumed to be confined to level $\sigma_3$ itself.
When type-2 clouds are present they always form a completely overcast sky -- i.e., CL = 1 or 0.

Type-3 clouds may be described as shallow cumulus with bases and tops both at level 3. They exist if there is low-level convection but no penetrating convection. The cloud amount is again defined as CL = -1.3 + 2.6 RH, with CL reset to 1 if CL > 1 and with CL ≤ 0 meaning a clear sky. This cloud type could possibly coexist with type 2, but if so it would not affect the radiation, since cloud type 2 is a complete overcast in the same region.

7. Effective Water-Vapor Content

To determine the effect of the moisture on radiation we must estimate the entire vertical profile of \( q \) from the single value \( q_3 \). The \( q_3 \) value used here is a revised one, including the effects of large-scale condensation, but not including changes due to convective condensation or evaporation. If \( q_3 < 10^{-5} \) it is set equal to \( 10^{-5} \). Above 120 mb the vapor pressure is assumed to be constant with height, with the value 0.3316 dynes/cm\(^2\) corresponding to the frost-point temperature 190 deg K, as suggested by Murgatroyd (1960). Thus

\[
q = 0.622 \left( \frac{0.3316}{p_{cgs}} \right) = \frac{0.206255}{p_{cgs}}, \quad p < 120 \text{ mb} \tag{2.115}
\]

where \( p_{cgs} \) is pressure in cgs units (dynes/cm\(^2\)). Below 120 mb it is assumed that

\[
q_3 = \left( \frac{p}{p_3} \right)^{K(p_3,q_3)}, \quad p \geq 120 \text{ mb} \tag{2.116}
\]

where \( K \) is evaluated by matching \( q \) from Eqs. (2.115) and (2.116) at the 120-mb level

\[
K(p_3,q_3) = \frac{\ln q_3 / 1.7188 \times 10^{-6}}{\ln (p_3/120 \text{ mb})} \tag{2.117}
\]
The effective water-vapor amount per unit area in a vertical column below a given level, \( n \), with a pressure-broadening correction term included, is defined to be

\[
 u^*_n = \int_{z_4}^{z_n} \rho \left( \frac{p}{p_0} \right)_q \, dz = \frac{1}{g} \int_{p_n}^{p_4} \left( \frac{p}{p_0} \right)_q \, dp \quad (2.118)
\]

Combined with the values of \( q \) defined above, this becomes, for level \( n \),

\[
 u^*_n = \frac{q_3 (p_3)^2}{g p_0 (2 + K)} \left[ \left( \frac{p_4}{p_3} \right)^{2+K} - \left( \frac{p_n}{p_3} \right)^{2+K} \right] \quad (2.119)
\]

and for the entire atmospheric column, including the stratosphere, the effective water-vapor content becomes

\[
 u^*_\infty = \frac{q_3 (p_3)^2}{g p_0 (2 + K)} \left[ \left( \frac{p_4}{p_3} \right)^{2+K} - \left( \frac{p(120 \text{ mb})}{p_3} \right)^{2+K} \right] + 2.526 \times 10^{-5} \quad (2.120)
\]

where the additive term is the effective vapor amount above 120 mb, and where \( q_3 \) is set equal to \( 10^{-5} \) if it is less than \( 10^{-5} \). The effective vapor content of clouds is described in the following section.

G. RADIATION AND HEAT BALANCE

In this section the heat budget of the earth/atmosphere system is discussed and the expressions which are used to evaluate the diabatic-heating terms in the thermodynamic equations, (2.31) and (2.32), are developed, together with those expressions used to determine the surface temperature over land and over ice-covered oceans.

In addition to being partly determined by the release of latent heat during convection (see Subsection F.3), the net heating rate at level 1 (\( \sigma = 1/4 \)) is also determined by the amount of solar radiation absorbed by, and the long-wave radiation emitted from, the layer \( \sigma = 0 \).
to \( \sigma = 1/2 \). The heating rate at level 3 (\( \sigma = 3/4 \)) is determined by
the flux of sensible heat from the surface and the release of latent
heat in large-scale condensation (Subsection F.2), in addition to the
absorbed and emitted radiation and the convective latent heating in
the layer \( \sigma = 1/2 \) to \( \sigma = 1 \). The treatment of the short-wave (solar)
radiation and the long-wave (terrestrial) radiation used in the model
follows the discussion of Arakawa, Katayama, and Mintz (1969). The
so-called short-wave radiation includes all the solar radiation, re-
gardless of wavelength, and the parameterization for the attenuation
of this radiation by Rayleigh scattering, for its reflection from the
earth's surface and from clouds, and for its absorption in the atmo-
sphere and in clouds is given in Subsection G.1. The treatment of the
flux of long-wave radiation, which includes all that which is emitted by
the atmosphere, clouds, and the earth's surface, is given in Subsection
G.2.

The ground temperature, \( T_{gr} \), needed to evaluate the evaporation,
the sensible heat flux from the surface, and the net long-wave surface
radiation is determined from the heat balance at the earth's surface
in Subsection G.3, and in Subsection G.4 a discussion of the heat bal-
ance in the atmosphere and the expressions for the temperature change
due to diabatic heating are given.

1. Short-Wave Radiation

The incoming solar radiation is immediately divided into two parts,
that of wavelength \( \lambda < 0.9 \mu \), which is assumed to be subject to Rayleigh
scattering only, and that of wavelength \( \lambda \geq 0.9 \mu \), which, in a clear at-
mosphere, is assumed to be subject to absorption only. The actual wave-
length does not again enter into the model's treatment of radiation.
The two parts of the radiation are designated \( S_o^S \) (part subject to scat-
tering) and \( S_o^A \) (part subject to atmospheric absorption), and are approx-
nimated as

\[
S_o^S = 0.651 S_o \cos \zeta
\]  
(2.121)

\[
S_o^A = 0.349 S_o \cos \zeta
\]  
(2.122)
where $S_0$ is the solar constant (adjusted for the earth/sun distance), and $\zeta$ is the zenith angle of the sun. The rationale for this partitioning is described by Joseph (1966). A summary of the disposition of these components of the short-wave radiation for both clear and cloudy skies is given in Figs. 2.3 and 2.4, and is described in detail in the following paragraphs.

a. **Albedo.** The albedo of the clear atmosphere for the portion of the radiation assumed subject to (Rayleigh) scattering is given by

$$\alpha_o = \min \{1, 0.085 - 0.247 \log_{10}[(p_s/p_o) \cos \zeta]\}$$

(2.123)

as deduced by Katayama using the estimate of Joseph (1966).\(^{+}\) For an overcast atmosphere, the albedo for the scattered part of the radiation is composed of the contributions of Rayleigh scattering (by atmospheric molecules) and of Mie scattering (by cloud drops). The simplest useful formulation adopted by Katayama is

$$\alpha_{ac} = 1 - (1 - \alpha_o)(1 - \alpha_{c_1})$$

(2.124)

where $\alpha_{c_i}$ is the cloud albedo (for both $S_0^A$ and $S_0^S$), which is assumed to be given by

$$\alpha_{c_1} = 0.7 \quad \text{for cloud type } 1$$

$$\alpha_{c_2} = 0.6 \quad \text{for cloud type } 2$$

(2.125)

$$\alpha_{c_3} = 0.6 \quad \text{for cloud type } 3$$

The various cloud types are discussed in Subsection F.6 below.

\(^{+}\)In the program, the expression $p_s/p_o$ in Eq. (2.128) was inadvertently coded as $(p_s - p_T)(p_o - p_T)^{-1}$; see instruction 10450 in COMP 3 in the listing of Chapter VII. This error, which is not thought to be serious, was brought to our attention by A. Katayama.
Fig. 2.3 — Short-wave radiation in a clear atmosphere. The solid arrows indicate the path of radiative flux, while the dashed lines indicate a region of the atmosphere in which interaction occurs or in which a diffuse path is followed. The absorbed radiation $A_1 = S_T^A - S_2^A$ and $A_3 = S_2^A - S_4^A$, according to (2.136). The program (FORTRAN) symbols are given in parentheses following certain of the physical symbols.
Fig. 2.4 -- Short-wave radiation in an overcast atmosphere, illustrated for cloud type 1. The absorbed radiation \( A_1 = S^A_T - S^A_{21} - S^A_{1c} \) according to (2.141), and
\( A_3 = S^A_{21} - S^A_{4} \) according to (2.136). See also Fig. 2.3.
The ground albedo $a_g$ (again for both $S^A_o$ and $S^S_o$) is taken as

$$a_g = 0.07 \quad \text{for ocean}$$

$$a_g = 0.14 \quad \text{for land}$$

$$= 0.45[1 + (\text{CLAT} - 10)^2/[(\text{CLAT} - 30)^2 + (\text{CLAT} - 10)^2]] \quad (2.126)^*$$

for south-polar ice and snow

$$= 0.40[1 + (\text{CLAT} - 5)^2/[(\text{CLAT} - 45)^2 + (\text{CLAT} - 5)^2]]$$

for north-polar ice and snow

These values for land, ice, and snow were developed by Katayama (1969) as approximations to the data of Posey and Clapp (1964). In the expressions for polar ice and snow, CLAT is the number of degrees poleward from the assumed northern or southern snowline (as appropriate) given by the functions SN0WN and SN0WS. The expression for north-polar ice and snow applies also for ice at latitudes between the two snow lines, with CLAT = 0.

b. The Radiation Subject to Scattering ($S^S_o$). The part of the solar radiation which is assumed to be scattered does not interact with the atmosphere, except to be partly scattered back to space. Thus the only part with which we are concerned is that amount which reaches, and is absorbed by, the earth's surface. This is given by the expressions

$$S^S_o' = S_o^S(1 - a_g)(1 - a_o)/(1 - a_o a_g)$$

for clear sky

$$S^S_o'' = S_o^S(1 - a_g)(1 - a_{ac})/(1 - a_{ac} a_g) \quad (2.127)$$

for overcast sky

Multiple reflections between sky and ground or between cloud base and

*These expressions are coded incorrectly in the program; see instructions 23720 and 23760, Chapter VII.
ground are accounted for by the terms in the denominators (see Joseph, 1966). For partly cloudy conditions (neither clear nor overcast) the scattered radiation absorbed at the earth's surface is

\[ S_g^s = CL S_g^s'' + (1 - CL) S_g^s' \]  
(2.128)

where CL is the fractional cloudiness of the sky (see Subsection F.6). The absorption of this radiation by the ground affects the ground temperature, and subsequently affects the long-wave emission from the ground and the ground-level heat balance (see Figs. 2.3 and 2.4).

c. The Radiation Subject to Absorption \( \left( s_o^A \right) \). The solar radiation subject to absorption is distributed as heat to the various layers in the atmosphere and to the earth's surface. The absorption is assumed to depend only upon the effective water-vapor content \( (u^*) \) in a layer -- a quantity calculated from the model as previously outlined (see Subsection F.7). The absorptivity of a layer is given by the empirical formula

\[ A(u^*, \zeta) = 0.271(u^* \sec \zeta)^{0.303} \]  
(2.129)

Here the (dimensionless) coefficient 0.271 has been found by increasing the (dimensional) coefficient 0.172 ly min\(^{-1}\) of the Mügge-Möller absorption formula by 10 percent, as suggested by Manabe and Möller (1961), and then dividing by the total radiative flux subject to absorption, which is given by 0.349S\(_o\) = 0.698 ly min\(^{-1}\) according to Eq. (2.122).

For clear sky the flux of \( S_o^A \) transmitted to a level \( n \) is given by

\[ S_n^A' = S_o^A[1 - A(u^* - u_n^*, \zeta)] \]  
(2.130)

and the flux absorbed in a layer between an upper level, \( i \), and a lower level, \( j \), is given by

\[ \frac{A_{i+1}^j}{2} = S_i^A' - S_j^A' \]  
(2.131)
For a cloudy sky the absorption in a cloud is calculated by assuming an equivalent water-vapor content which will absorb the same amount of radiation as would the cloud itself. These amounts are assumed in the present version of the model to be

\[
u_{c1}^* = 65.3 \text{ g/cm}^2 \quad \text{for cloud type 1}
\]

\[
u_{c2}^* = 65.3 \text{ g/cm}^2 \quad \text{for cloud type 2}
\]

\[
u_{c3}^* = 7.6 \text{ g/cm}^2 \quad \text{for cloud type 3}
\]

The incoming beam becomes diffuse in the cloud, and its path is assumed to be 1.66 times the vertical thickness of the cloud. Below the cloud the beam is still diffuse, and the factor 1.66 for path length is retained. Therefore we have the following expressions for the downward flux at various levels

\[
S_i^{A''} = S_o^A \left[ 1 - A(u_\infty^* - u_i^*, \zeta) \right] \quad \text{(2.133)}
\]

above the cloud at level \(i\)

\[
S_m^{A''} = S_o^A (1 - \alpha_c) \left\{ 1 - A \left[ (u_\infty^* - u_{CT}^*) \sec \zeta + 1.66 \left( \frac{\Delta p_m}{\Delta p_c} \right) u_c^* \right] \right\} \quad \text{(2.134)}
\]

inside a cloud at level \(m\)

\[
S_j^{A''} = S_o^A (1 - \alpha_c) \left\{ 1 - A \left[ (u_\infty^* - u_{CT}^*) \sec \zeta + 1.66(u_c^* + u_{CB}^* - u_j^*) \right] \right\} \quad \text{(2.135)}
\]

below a cloud at level \(j\)

\[\text{\dagger}\text{The fraction } \Delta p_m/\Delta p_c, \text{ which is equal to } 1/2 \text{ when } m = 2 \text{ and type-1 clouds are present, has been inadvertently omitted from the model's present FORTRAN program.}\]
where subscripts CT and CB refer to the cloud top and cloud bottom, respectively, \( \Delta p_c \) is total pressure thickness of the cloud, and \( \Delta p_m \) is the pressure thickness of the cloud above level \( m \). The factor \( (1 - \alpha_c) \) accounts for reflection from the cloud top.

The flux absorbed in a layer in a cloudy sky will, in general, be \( \frac{A_{i+1}}{2} = S_i^{A''} - S_j^{A''} \), in a fashion similar to Eq. (2.131) for clear sky.

If there is a cloud top anywhere within a layer, however, the flux absorbed by that layer will not be just the flux difference at the levels above and below the layer, since there will be a flux reflected from the cloud top and therefore lost. Thus, for the layer between levels \( i \) and \( j \), the absorbed radiation is given by

\[
\frac{A_{i+1}}{2} = S_i^{A''} - S_j^{A''} - S_i^{A''} \frac{\alpha_c}{CT}
\]  

(2.136)

where the last term is the flux reflected from the cloud top. When the sky is partly cloudy, the total flux at level \( i \) is given by a weighted average of the clear and overcast fluxes:

\[
S_i^{A'} = CL \cdot S_i^{A''} + (1 - CL)S_i^{A'}
\]  

(2.137)

That part of the flux subject to absorption which is actually absorbed by the ground is given by

\[
(1 - \alpha_g)S_4^{A'} = S^{A'}_g
\]  

(2.138)

for clear sky, and by

\[
\frac{(1 - \alpha_g)S_4^{A''}}{1 - \alpha_c \alpha_g} = S^{A''}_g
\]  

(2.139)
for completely cloudy (overcast) sky, where the factor \(1/(1 - a_g)\) again accounts for multiple reflections between the ground and cloud base. For partly cloudy skies, the radiation absorbed by the ground is the sum

\[
S^A_g = CL S^{A''}_g + (1 - CL) S^{A'}_g
\]

(2.140)

The total solar radiation absorbed by the ground will be the sum of that part of the solar radiation subject to (atmospheric) absorption that is absorbed instead by the ground and that part subject to scattering (atmospheric) that is absorbed by the ground. Thus, from Eqs. (2.128) and (2.140), we have

\[
S_g = S^A_g + S^S_g
\]

(2.141)

2. Long-Wave Radiation

The calculation of the long-wave radiation, like that of the shortwave radiation, is based on an empirical transmission function depending primarily upon the amount of water vapor. The net upward long-wave radiation at a level \(i\) can be expressed as the sum of three terms

\[
R_i = R_A + R_B + C_i
\]

(2.142)

where \(R_A\) is the radiative flux downward from the atmosphere above the level \(i\), and \(R_B\) is the flux from below. The term \(C_i\) was intended to be a correction term accounting for a possible large temperature difference between the level-4 air temperature, \(T_4\), and the ground surface temperature, \(T_g\). However, in the early stages of evolution of the Mintz-Arakawa program the two temperatures were assumed to be equal, and both were designated in the program with the same symbol. At the time the program was modified to calculate the two separately, a programming error was made whereby the terms were not changed consistently. In several statements the ground temperature, \(T_g\), is used
in place of the air temperature $T_A$, and in the ground temperature correction term, $C_i$, the values of ground temperatures before and after the heating cycle ($T_g, T_{gr}$) are used in place of $T_A$ and $T_{gr}$.

In this Report we have described what the program actually does, rather than what was intended. Those equations in which $T_g$ was used in place of $T_A$ are indicated throughout Subsections G.2 and G.3 by the symbol $\pm$. In future work, the program will be corrected and the effects of this error will be investigated.

The term $C_i$ in Eq. (2.142) is thus now apparently a "correction" involving the change in the ground temperature during the heating time interval. This term depends upon all the various heat-exchange mechanisms in the program, including the other terms involving long-wave radiation. Therefore $R_A + R_B$ is calculated first and the $C_i$ term is left until later (see Subsection G.3). A schematic overview of the long-wave radiation balance is given in Fig. 2.5.

The fluxes at level $i$ are given by the expressions

$$R_A = \sigma T_{1}^4 \bar{\tau}_A$$

$$R_B = (\sigma T_{g}^4 - \sigma T_{1}^4) \bar{\tau}_B$$

(2.143)

(2.144)

where $\sigma$ is here the Stefan-Boltzman constant, and the empirical transmission functions are given by

$$\bar{\tau}_A = \tau(u_m^* - u_d^*)$$

(2.145)

$$\bar{\tau}_B = \frac{1 + \tau(u_d^*)}{2}$$

(2.146)

with

$$\tau(u^*) = \frac{1}{(1 + 1.75u^{0.416})}$$

(2.147)
Fig. 2.5 -- Long-wave radiation in a clear atmosphere. See also Fig. 2.3.
as found by Katayama for the Callendar water–vapor transmission function. Here $u^*$ is the effective vapor content defined in Subsection F.7. For a clear sky, if we define $R'_1 \equiv R_A + R_B$, we have at the three levels $\sigma = 0 \ (i = 0)$, $\sigma = 1/2 \ (i = 2)$, and $\sigma = 1 \ (i = 4)$, where radiation is determined by:

$$R'_0 = \sigma T_0^4 (u_\infty^* - u_0^*) + (\sigma T_g^4 - \sigma T_0^4) \frac{1 + \tau(u_0^*)}{2} \quad (2.148)$$

$$R'_2 = \sigma T_2^4 (u_\infty^* - u_2^*) + (\sigma T_g^4 - \sigma T_2^4) \frac{1 + \tau(u_2^*)}{2} \quad (2.149)$$

$$R'_4 = \sigma T_g^4 \tau(u_\infty^*) \quad (2.150)$$

Here the primes indicate a clear sky. To account for the absorption by CO$_2$, which is not included in the above expressions, the model incorporates a number of empirical modifications [due to Katayama (1969)] of the long-wave fluxes. We thus redefine the clear-sky fluxes given above as

$$R'_0 = 0.820R'_0 \quad (2.151)$$

$$R'_2 = 0.736R'_2 \quad (2.152)$$

$$R'_4 = \sigma T_g^4 \left[ 0.6 \sqrt{\tau(u_\infty^*)} - 0.1 \right] \quad (2.153)$$

which are the clear-sky expressions used in the program. The expression for $R'_4$ is similar to Brunt's formula.

Clouds are treated as opaque black bodies, and the cloud cover may consist of any of the model's three cloud types. Including empirical corrections, one uses the following expressions for the radiation in
completely overcast skies. For cloud type 1 (top at level 1, bottom at level 3)

\[
R''_0 = 0.820 \left[ \sigma T^4_0 \tau (u^*_w - u^*_0) + (\sigma T^4_1 - \sigma T^4_0) \frac{1 + \tau(u^*_0 - u^*_1)}{2} \right]
\]

(2.154)

\[
R''_2 = 0
\]

(2.155)

\[
R''_4 = 0.85(\sigma T^4_g - \sigma T^4_3) \left[ 1 + 3\tau(u^*_3) \right]/4
\]

(2.156)

where the double primes indicate an overcast sky and \( R''_1 = R_A + R_B \). For cloud type 2 (top of cloud at level 2, bottom at level 3),

\[
R''_0 = 0.820 \left[ \sigma T^4_0 \tau (u^*_w - u^*_0) + (\sigma T^4_2 - \sigma T^4_0) \frac{1 + \tau(u^*_0 - u^*_2)}{2} \right]
\]

(2.157)

\[
R''_2 = [0.736\sigma T^4_2 \tau (u^*_w - u^*_2)]/2\]

(2.158)

\( R''_4 \) = same as for cloud 1 [Eq. (2.156)]

For cloud type 3 (top and bottom at level 3):

\[
R''_0 = 0.820 \left[ \sigma T^4_0 \tau (u^*_w - u^*_0) + (\sigma T^4_3 - \sigma T^4_0) \frac{1 + \tau(u^*_0 - u^*_3)}{2} \right]
\]

(2.159)

\[
R''_2 = 0.736 \left[ \sigma T^4_2 \tau (u^*_w - u^*_2) + (\sigma T^4_3 - \sigma T^4_2) \frac{1 + \tau(u^*_0 - u^*_3)}{2} \right]
\]

(2.160)

\( R''_4 \) = same as for cloud type 1 [Eq. (2.156)]

\[\text{This } R''_2 \text{ is divided by 2 because the cloud top is assumed to be an irregular surface lying half-above, half-below level 2.}\]
If we now define \( \tilde{R}'_1 \) as the net upward long-wave radiation for partly cloudy skies prior to the ground-temperature correction, \( R'_1 \) and \( R''_1 \) combine to give

\[
\tilde{R}'_1 = (1 - CL)R'_1 + (CL)R''_1
\]  \hspace{1cm} (2.161)

where CL is the fractional cloudiness (see Subsection F.6).

Finally, after the ground temperature has been determined using \( \tilde{R}'_1 \) and the calculated short-wave radiation (among other quantities, as described in Subsection G.3 below), the long-wave radiation is calculated in its complete form \( R'_1 \) by applying the correction (C) given at level 4 by

\[
C_4 = 4\sigma T^3_g (T_{gr} - T_g)
\]  \hspace{1cm} (2.162+)

where \( 4\sigma T^3_g T_{gr} - T_g \) is an approximation to \( \sigma (T^4_{gr} - T^4_g) \). The complete long-wave flux at level 4 is thus given, according to Eq. (2.96), by

\[
R'_4 = \tilde{R}'_4 + C_4 = (1 - CL)R'_4 + (CL)R''_4 + 4\sigma T^3_g (T_{gr} - T_g)
\]  \hspace{1cm} (2.163+)

At levels 2 and 0 the complete long-wave flux is similarly given by

\[
R'_2 = \tilde{R}'_2 + C_2 = \tilde{R}'_2 + 0.8(1 - CL)C_4 \tau (u^*_2)
\]  \hspace{1cm} (2.164)

\[
R'_0 = \tilde{R}'_0 + C_0 = \tilde{R}'_0 + 0.8(1 - CL)C_4 \tau (u^*_0)
\]  \hspace{1cm} (2.165)

where \( \tilde{R} \) is given by Eq. (2.161) and \( C_4 \) by (2.162), and where the coefficient 0.8 is the correction factor for \( CO_2 \) absorption. These are the long-wave radiation fluxes calculated in the program as the net transfers at the levels 4, 2, and 0, and are used in the preparation of the
long-wave radiative budgets for the layers 0 to 2 and 2 to 4 as well as for the surface (level-4) radiation budget in the output programs (see Chapter IV). The various components of these long-wave fluxes are summarized in Fig. 2.6.

3. Heat Balance at the Ground

The ground temperature, $T_{gr}'$, as corrected for surface radiation and as used to find the evaporation, is itself obtained from the heat balance at the ground. The treatment of the heating of the ground depends first of all upon the character of the ground or underlying surface.

If the surface is ice-free ocean, it is considered to be an infinite heat reservoir whose surface temperature, $T_g$, is a specified function of position and does not change during the heating time interval ($5\Delta t$). The new ground temperature, $T_{gr}'$, is set equal to the old $T_g$.

Where the surface is bare land, snow-covered land, or ice-covered land, the ground is considered to be a perfect insulator with zero heat capacity. For these types of ground, the total flux of heat across the air/ground interface must be zero, according to

$$R_4 + \Gamma + H_E - S_g = 0 \quad (2.166)$$

where $R_4$ is the long-wave radiation emitted from the surface, $\Gamma$ is the sensible heat flux from the surface, $H_E$ is the flux of latent heat due to evaporation from the surface, and $S_g$ is the solar radiation absorbed by the ground.

For ice-covered ocean, the surface heat balance is modified to include conduction of heat through the ice, $\tilde{B}$, in which case Eq. (2.166) is changed to read

$$R_4 + \Gamma + H_E - S_g = \tilde{B} = B(T_o - T_{gr}) \quad (2.167+)$$
Fig. 2.6 -- Long-wave radiation in an overcast atmosphere (cloud types 1, 2, or 3). See also Fig. 2.3.
where $T_0$ equals the freezing point of seawater (273.1 deg K). Equation (2.167) is applicable to the land, snow- and ice-covered land surfaces too, if we define $B = 0$ for these locations; for sea ice the conduction coefficient $B$ is equal to 1.44 ly day$^{-1}$ deg$^{-1}$, found from an assumed thermal conductivity of 0.005 ly cm sec$^{-1}$ deg$^{-1}$ and an ice thickness of 300 cm. Note that, except for the solar radiation, these heating terms depend upon the as-yet-undetermined new value of the ground temperature, $T_{gr}$, as well as upon the old value, $T_g$, upon the temperature of the air, $T_A$, or upon the freezing point of sea water, $T_0$.

The heating terms are given by

$$R_4 = \tilde{R}_4 + \sigma(T_{gr}^4 - T_g^4)$$

(2.168)

where $\tilde{R}$ is the long-wave radiation without the ground-temperature correction as given by Eq. (2.161) and $\sigma(T_{gr}^4 - T_g^4)$ is the "correction" term. (See, however, Subsection G.2.) The sensible (turbulent) heat flux, $\Gamma$, is given by

$$\Gamma = C_T(T_{gr} - T_A)$$

(2.169)

where

$$C_T = \rho_4 c p c_w$$

(2.170)

where $W$ is the surface wind speed, as corrected for gustiness in Eq. (2.78). The latent heat flux is given by

$$H_E = LE = C_T L_c \left\{ GW \left[ q_s(T_g) + \frac{dq_s(T)}{dT} (T_{gr} - T_g) \right] - \dot{q}_4 \right\}$$

(2.171)
where Eqs. (2.108) and (2.109) have been used to evaluate the evaporation.

Substituting Eqs. (2.168), (2.169), and (2.171) for \( R_4, \Gamma, \)
and \( H_{E} \) into the heat-balance equation, (2.167), and approximating
\( \sigma(T_g^4 - T_{gr}^4) \) by \( 4\sigma T_g^3(T_g - T_{gr}) \), we can solve for the unknown ground tem-
perature \( T_{gr} \). Thus, we have

\[
T_{gr} = \frac{C_T \left( T_4 + \frac{L_s}{c_p} \left( q_4 + GW \left[ \frac{d_q s(T_g)}{dT} T_g - q_s(T_g) \right] \right) \right)}{C_T \left[ 1 + \frac{L_s}{c_p} \frac{d_q s(T_g)}{dT} GW \right] + 4\sigma T_g^3 + B}
\]

(2.172)+

Having found \( T_{gr} \), we can complete the calculation of the individual radiation and heating terms \( R_4 \) (and \( R_2, R_0 \) as in Subsection G.2), \( \Gamma \) and
\( H_{E} \) from Eqs. (2.167) to (2.171), and the surface evaporation, \( E \), from Eq.
(2.108). The equations are applicable to an ocean surface as well as to land, ice, and snow: for oceans, \( T_{gr} = T_g \), some of the terms will be
zero, and there will be no correction terms for the long-wave radiation;
for ice and snow, if the calculated value of \( T_{gr} \) is greater than \( T_0 \)
(= 273.1 deg K) it is set equal to \( T_0 \).

4. Heat Budget of the Atmosphere

The heat balance is maintained at the ground through the calcu-
lated ground temperature (see previous section), and at the levels 3
and 1 by means of the diabatic heating terms on the right-hand sides
of Eqs. (2.31) and (2.32). After the temperature changes due to con-
vective adjustment (see Subsection F.1), no further change is made
until the end of all the radiation- and moisture-balance calculations.
Then the change in temperature over the interval \( 5\Delta t \) at levels 3 and
1 is given by

\[
H_3 = 5\Delta t \tilde{H}_3
\]

\[
= (A_3 + R_4 - R_2 + \Gamma)(2g/\pi c_p)5\Delta t + (\Delta T_3)_{CM} + (\Delta T_3)_{CP} + (\Delta T_3)_{LS}
\]

(2.173)
\[ H_1 = 5\Delta t \hat{H}_1 \]
\[ = (A_1 + R_2 - R_0)(2g/\pi c_p)5\Delta t + (\Delta T_1)_{CM} + (\Delta T_1)_{CP} \]  

(2.174)

Here \( A_1 \) and \( A_3 \) are the net absorption of solar radiation at the levels 1 and 3 (see Subsection G.1), \( R_4 - R_2 \) and \( R_2 - R_0 \) are the long-wave radiation absorbed in the layers 4-2 and 2-0 (see Subsections G.2 and G.3), and \( \Gamma \) is the sensible heat flux (see Subsection G.3). The \( (\Delta T) \) terms are the latent heat released during large-scale condensation (LS) [Eq. (2.47)], middle-level convection (CM) [Eqs. (2.73) and (2.74)], and penetrating convection (CP) [Eqs. (2.101) and (2.102)] (see Subsections F.2 and F.3). The factor \( 5\Delta t \) is the time interval between heating calculations, and together with the factor \( 2g/\pi c_p \) converts the heating rate to the layers' temperature change.

There is some smoothing of the heating as given by Eqs. (2.173) and (2.174) in both the vertical and horizontal directions before the temperatures \( T_1 \) and \( T_3 \) are redefined at the end of the time interval. The average heating, \( \bar{H} = 1/2(H_1 + H_3) \), is first weighted according to the area of the grid cell surrounding the \( \tau \) point, and is then subjected to a 9-point areal smoothing with the central heating value weighted by \( 1/4 \), the four values to the north, south, east, and west each weighted by \( 1/8 \), and the four values to the northeast, northwest, southeast, and southwest each weighted by \( 1/16 \). If we denote the result of this smoothing operation on \( \bar{H} \) by \( \bar{H}^A \), the final temperatures, after correction for diabatic heating at levels 1 and 3, are determined from

\[ T_1 = T'_1 + \frac{H_1}{2} - \frac{H_3}{2} + \bar{H}^A \]  

(2.175)

\[ T_3 = T'_3 + \frac{H_3}{2} - \frac{H_1}{2} + \bar{H}^A \]  

(2.176)

where \( T'_1 \) and \( T'_3 \) are the temperatures at levels 1 and 3 before the correction for diabatic heating.
III. MODEL DESCRIPTION -- NUMERICS

Equations (2.27) to (2.33) and Eq. (2.35) form a set of eight prognostic equations for the eight dependent variables \( u_1, v_1, u_3, v_3, T_1, T_3, \pi, \) and \( q_3 \). The time-extrapolation method and the horizontal finite-difference schemes used to solve these equations were developed by Professor Arakawa at UCLA and are discussed in the following sections. For convenience, Eqs. (2.27) to (2.33) and Eq. (2.35) have been restated in Tables 3.1 to 3.4 and Table 3.6, where the subsections describing the numerical treatment of each term are indicated, along with the location in the FORTRAN program where each term is evaluated. The diagnostic equation for the vertical velocity [Eq. (2.34)] is given a similar treatment in Table 3.5. In the present chapter, particular attention has been given to the preparation of a systematic statement of the precise finite-difference approximations actually used in the programmed numerical solution of the model. The smoothing procedures, provisions for global mass conservation, and the various parameters and constants used in the model are also summarized here.

A. TIME FINITE DIFFERENCES

1. The General Scheme of Time Extrapolation

From the equations in Tables 3.1 to 3.4 and Table 3.6, we can obtain expressions for the tendencies of the dependent variables \( \psi = u_1, v_1, \) at the point \( ij \) in the general form

\[
\left[ \frac{\partial \psi}{\partial t} \right]_{ij} = D\psi + S\psi
\]  

(3.1)

while the pressure-tendency equation is written in the form

\[
\left[ \frac{\partial \pi}{\partial t} \right]_{ij} = D\pi
\]  

(3.2)
Table 3.1

DESCRIPTION OF THE ZONAL \( u \) MOMENTUM EQUATIONS

<table>
<thead>
<tr>
<th>u Momentum Tendency</th>
<th>Horizontal Advection of u Momentum</th>
<th>Vertical Advection of u Momentum</th>
<th>Coriolis Force</th>
<th>Pressure-Gradient Force</th>
<th>Friction Term</th>
</tr>
</thead>
<tbody>
<tr>
<td>Eq. (2.27): ( \frac{\partial}{\partial t} (\Pi u_1) = \frac{\partial}{\partial x} (u_1 u_1^<em>) - \frac{\partial}{\partial y} (v_1 u_1^</em>) - \frac{\partial}{\partial x} u_2 + \frac{\partial}{\partial y} v_1 F - n \left[ \frac{\partial \phi_1}{\partial x} + \sigma_1 \phi_1 \frac{\partial \pi}{\partial x} \right] + \Pi F_1^x )</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Eq. (2.29): ( \frac{\partial}{\partial t} (\Pi u_3) = \frac{\partial}{\partial x} (u_3 u_3^<em>) - \frac{\partial}{\partial y} (v_3 u_3^</em>) + \frac{\partial}{\partial x} u_2 + \frac{\partial}{\partial y} v_3 F - n \left[ \frac{\partial \phi_3}{\partial x} + \sigma_3 \phi_3 \frac{\partial \pi}{\partial x} \right] + \Pi F_3^x )</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Program Reference</th>
<th>STEP (1850-2280)</th>
<th>COMP 1 (3750-4120)</th>
<th>COMP 1 (4690-4830)</th>
<th>COMP 2 (5010-5200)</th>
<th>COMP 2 (5450-5690)</th>
<th>COMP 2 (5710-6050)</th>
<th>COMP 3 (11500-11620)</th>
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</table>

<table>
<thead>
<tr>
<th>Text Reference</th>
<th>III.A (1-4)</th>
<th>III.C.3</th>
<th>III.C.4</th>
<th>III.C.5</th>
<th>III.C.6</th>
<th>III.C.10</th>
</tr>
</thead>
</table>


Table 3.2
DESCRIPTION OF THE MERIDIONAL (v) MOMENTUM EQUATIONS

<table>
<thead>
<tr>
<th>v Momentum Tendency</th>
<th>Horizontal Advection of v Momentum</th>
<th>Vertical Advection of v Momentum</th>
<th>Coriolis Force</th>
<th>Pressure-Gradient Force</th>
<th>Friction Term</th>
</tr>
</thead>
<tbody>
<tr>
<td>Eq. (2.28): ( \frac{\partial}{\partial t} (\Pi v_1) = )</td>
<td>- ( \frac{\partial}{\partial x} (u_1^* v_1) - \frac{\partial}{\partial y} (v_1^* v_1) )</td>
<td>- ( S^* v_2 )</td>
<td>- ( \pi u_1 F )</td>
<td>- ( m \left[ \pi \frac{\partial \psi_1}{\partial y} + \sigma_1 \frac{\partial \pi}{\partial y} \right] )</td>
<td>+ ( \Pi F^y_1 )</td>
</tr>
<tr>
<td>Eq. (2.30): ( \frac{\partial}{\partial t} (\Pi v_3) = )</td>
<td>- ( \frac{\partial}{\partial x} (u_3^* v_3) - \frac{\partial}{\partial y} (v_3^* v_3) )</td>
<td>+ ( S^* v_2 )</td>
<td>- ( \pi u_3 F )</td>
<td>- ( m \left[ \pi \frac{\partial \psi_3}{\partial y} + \sigma_3 \frac{\partial \pi}{\partial y} \right] )</td>
<td>+ ( \Pi F^y_3 )</td>
</tr>
</tbody>
</table>

<table>
<thead>
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<th>Text Reference</th>
<th>III.A.(1-4)</th>
<th>III.C.3</th>
<th>III.C.4</th>
<th>III.C.5</th>
<th>III.C.6</th>
<th>III.C.10</th>
</tr>
</thead>
</table>
### Table 3.3

**DESCRIPTION OF THE THERMODYNAMIC ENERGY EQUATION**

<table>
<thead>
<tr>
<th>Equation</th>
<th>Temperature Tendency</th>
<th>Horizontal Advection of Temperature</th>
<th>Energy Conversion Terms</th>
<th>Diabatic Heating Term</th>
</tr>
</thead>
<tbody>
<tr>
<td>Eq. (2.31): ( \frac{\partial}{\partial t} (\Pi T) = )</td>
<td>( - \frac{\partial}{\partial x} (u^<em>_1 T_1) - \frac{\partial}{\partial y} (v^</em>_1 T_1) )</td>
<td>(-\left(\frac{p_1}{p_0}\right)^k \theta_2 )</td>
<td>( \frac{\alpha_1}{c_p} \theta \frac{\partial}{\partial t} + \frac{\alpha_1}{c_p} \left[ \frac{\partial}{\partial x} \left( u^<em>_1 \frac{\partial}{\partial x} + v^</em>_1 \frac{\partial}{\partial y} \right) \right] )</td>
<td>( \frac{\hat{h}_1}{c_p} )</td>
</tr>
<tr>
<td>Eq. (2.32): ( \frac{\partial}{\partial t} (\Pi T) = )</td>
<td>( - \frac{\partial}{\partial x} (u^<em>_3 T_3) - \frac{\partial}{\partial y} (v^</em>_3 T_3) )</td>
<td>( \left(\frac{p_3}{p_0}\right)^k \theta_2 )</td>
<td>( \frac{\alpha_3}{c_p} \theta \frac{\partial}{\partial t} + \frac{\alpha_3}{c_p} \left[ \frac{\partial}{\partial x} \left( u^<em>_3 \frac{\partial}{\partial x} + v^</em>_3 \frac{\partial}{\partial y} \right) \right] )</td>
<td>( \frac{\hat{h}_3}{c_p} )</td>
</tr>
</tbody>
</table>

| Program Reference | STEP (1850-2280) | COMP 1 (3250-3730) | COMP 1 (4560-4670) | COMP 2 (6070-6370) | COMP 3 (11280-11480) |

| Text Reference | III.A.(1-4) | III.C.7 | III.C.8 | III.C.12 |
Table 3.4

DESCRIPTION OF THE PRESSURE-TENDENCY EQUATION

<table>
<thead>
<tr>
<th></th>
<th>Pressure Tendency</th>
<th>Mass Convergence at the Upper Level</th>
<th>Mass Convergence at the Lower Level</th>
</tr>
</thead>
<tbody>
<tr>
<td>Eq. (2.33):</td>
<td>$\frac{\partial \Pi}{\partial t} =$</td>
<td>$-\frac{1}{2} \left( \frac{\partial}{\partial x} u^* + \frac{\partial}{\partial y} v^* \right)$</td>
<td>$-\frac{1}{2} \left( \frac{\partial}{\partial x} u^<em>_3 + \frac{\partial}{\partial y} v^</em>_3 \right)$</td>
</tr>
</tbody>
</table>

**Program Reference**

<table>
<thead>
<tr>
<th></th>
<th>STEP (1850-2280)</th>
<th>COMP 1 (4130-4540)</th>
</tr>
</thead>
</table>

**Text Reference**

<table>
<thead>
<tr>
<th></th>
<th>III.A.(1-4)</th>
<th>III.C.2</th>
</tr>
</thead>
</table>
Table 3.5  
DESCRIPTION OF THE VERTICAL VELOCITY EQUATION

<table>
<thead>
<tr>
<th>Vertical Velocity</th>
<th>Mass Convergence at Upper Level</th>
<th>Mass Convergence at Lower Level</th>
</tr>
</thead>
<tbody>
<tr>
<td>Eq. (2.34): [ \dot{S} = + \frac{1}{2} \left( \frac{\partial}{\partial x} u_3^* + \frac{\partial}{\partial y} v_3^* \right) - \frac{1}{2} \left( \frac{\partial}{\partial x} u_1^* + \frac{\partial}{\partial y} v_1^* \right) ]</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Program Reference</td>
<td>COMP 1 (4530)</td>
<td>COMP 1 (4130-4540)</td>
</tr>
<tr>
<td>Text Reference</td>
<td>III.C.2</td>
<td>III.C.2</td>
</tr>
</tbody>
</table>
Table 3.6
DESCRIPTION OF THE MOISTURE-BALANCE EQUATION

<table>
<thead>
<tr>
<th>Moisture Tendency</th>
<th>Horizontal Advection of Moisture</th>
<th>Moisture-Source Term</th>
</tr>
</thead>
<tbody>
<tr>
<td>Eq. (2.35): ( \frac{3}{3t} (\Pi q_3) = )</td>
<td>(- \frac{3}{3x} \left[ q_3 \left( \frac{5}{4} u_3^* - \frac{1}{4} u_1^* \right) \right] - \frac{3}{3y} \left[ q_3 \left( \frac{5}{4} v_3^* - \frac{1}{4} v_1^* \right) \right] + 2 \nu g (E - C) )</td>
<td>( \frac{1}{C_f} )</td>
</tr>
</tbody>
</table>

Program
Reference
STEP (1850-2280)
COMP 1 (3250-3730)
COMP 3 (11280-11480)

Text
Reference
III.A.(1-4)
III.C.9
III.C.11
The expression $S_\psi$ represents the friction terms in the momentum equations, the diabatic heating term in the energy equation, or the moisture source term in the moisture equation. These terms will be referred to collectively as the "source terms." All the other terms are included in the expression $D_\psi$. Both $D_\psi$ and $S_\psi$ are complicated finite-difference expressions involving the independent variables and the dependent variables at $ij$ and neighboring points.

In the time-extrapolation method used in this model, the source terms are evaluated every fifth time step. The remaining terms ($D_\psi$) are evaluated each time step by means of a sequence of uncentered and centered horizontal differences. Thus, the time extrapolation proceeds in a repeated sequence of five individual time steps of $\Delta t$ each. The first four time steps consist of two substages each, and the fifth time step consists of three substages. The first substage, which is identical in all five time steps, provides a preliminary estimate of the dependent variables for time $\tau + n$ by evaluating $D_\psi$ using values of the dependent variables at time $\tau + (n - 1)$. The second substage obtains a final estimate of the dependent variables using the preliminary estimates to evaluate $D_\psi$ with the horizontal-difference scheme appropriate to the position in the five-step sequence. The special third substage in the fifth time step consists of evaluating the source terms using values of the dependent variables obtained from the second substage. An outline of this procedure is shown in Fig. 3.1, and each substage of the time step is described below.

2. Preliminary Estimate of the Dependent Variables (All Time Steps)

The preliminary estimate (identified in the FORTRAN code by the flag MRCH=1) is obtained using a forward time step and evaluating $D_\psi$ by a centered horizontal difference. However, the horizontal and vertical advection terms and the Coriolis force term of $D_\psi$ are advanced only a half time step, while the remaining terms are advanced a full time step ($\Delta t$). Thus, from Eq. (3.1) for the momentum, energy, and moisture equations we have, upon omitting the source terms,
Fig. 3.1 -- Sequence of time steps and substages in the time-integration procedure.
\[
(\hat{\Pi}^\psi)_{ij}^{\gamma+1} = (\Pi^\psi)_{ij}^{\gamma} + \frac{\Delta t}{2} A^\psi (\pi^{\gamma}, u^{\gamma}, \ldots)_{ij}
+ \Delta t R^\psi (\pi^{\gamma}, u^{\gamma}, \ldots)_{ij}
\]

(3.3)

where \( A^\psi \) represents the advection terms in \( D^\psi \), \( R^\psi = D^\psi - A^\psi \) represents the remaining terms of \( D^\psi \), the superscript \( \gamma \) refers to values at time \( \gamma \), and the caret is used to indicate the preliminary estimate of a quantity. Similarly, the pressure-tendency equation (3.2) becomes

\[
(\hat{\Pi})_{ij}^{\gamma+1} = (\Pi)_{ij}^{\gamma} + \Delta t D^\pi (\pi^{\gamma}, u^{\gamma}, \ldots)_{ij}
\]

(3.4)

The first estimate of the dependent variables \( \psi \) is therefore given by Eqs. (3.3) and (3.4) as

\[
\hat{\psi}_{ij}^{\gamma+1} = \frac{(\hat{\Pi}^\psi)_{ij}^{\gamma+1}}{(\hat{\Pi})_{ij}^{\gamma+1}}
\]

(3.5)

which serves to remove the \( \Pi \) weighting of the variables. As noted previously, this procedure is used as a preliminary estimate in each time step of the numerical integration.

3. Final Estimate of the Dependent Variables (Time Steps 1 to 4)

Using the preliminary estimates given above, the final estimates of the dependent variables at the nth time step of the sequence \( n = 1, 2, 3, 4 \) become

\[
(\Pi^\psi)_{ij}^{\gamma+n} = (\Pi^\psi)_{ij}^{\gamma+(n-1)} + \Delta t D^\psi (\hat{\pi}, \hat{u}, \ldots)_{ij}
\]

(3.6)

\[
\Pi_{ij}^{\gamma+n} = \Pi_{ij}^{\gamma+(n-1)} + \Delta t D^\pi (\hat{\pi}, \hat{u}, \ldots)_{ij}
\]

(3.7)

from which we calculate
\( \psi_{i,j}^{t+n} = \frac{(n\psi)_{i,j}^{t+n}}{n_{i,j}^{t+n}} \) \hfill (3.8)

When \( n = 1 \) an up-right uncentered horizontal space difference is used (identified by the flag MRCH=3); when \( n = 2 \), a down-left uncentered horizontal space difference is used (identified by the flag MRCH=4), and when \( n = 3 \) or \( 4 \), a centered horizontal space difference is used (identified by the flag MRCH=2). The case for \( n = 5 \) is considered below.

4. **Final Estimate of the Dependent Variables (Time Step 5)**

The first two substages of the fifth time step (\( n = 5 \)) are performed as described above by Eqs. (3.6) to (3.8). If we represent the variables at the end of the second substage of the fifth time step by a tilde, (~), the final estimates become

\[
(\psi)^{t+5}_{i,j} = (\tilde{\psi})^{t+5}_{i,j} + 5\Delta t \frac{S_{\psi}^{t+5} (\tilde{u}^{t+5}, \ldots)_{i,j}}{\pi^{t+5}_{i,j}} \hfill (3.9)
\]

The final estimate at every fifth time step thus introduces the source terms (as evaluated in subroutines COMP 3 and COMP 4), and weights them for the full \( 5\Delta t \) time interval. Because the continuity (or pressure-tendency) equation (3.2) is source free, the value of \( \pi^{t+5}_{i,j} \) is given directly by the final estimate [Eq. (3.7)] for \( n = 5 \).

Upon the completion of this time step, the sequence of five steps begins again. The flow of this time-integration procedure is controlled by subroutine STEP (steps 1850 to 2280). The horizontal finite-difference expressions used in the determination of the terms \( S_{\psi}, D_{\psi}, \) and \( R_{\psi} \) are given below.
B. HORIZONTAL FINITE DIFFERENCES

1. The Horizontal Finite-Difference Grid

The earth's surface is represented in the numerical calculations by a rectangular grid of points extending from pole to pole, an arbitrary point of which is designated \(ij\) and identified by \((J,I)\) in the code. The 180th meridian is represented by the set of points \((1,j)\), the longitude 175W by the points \((2,j)\), etc., the South Pole by \((1,1)\), and the North Pole by \((1,J)\); the equator is not a member of this grid, but corresponds to the value \(j = 23\frac{1}{2}\). This set of primary grid points can be regarded as the centers of the network of rectangular cells outlined by dashed lines in Fig. (3.2). The velocity variables \(u\) and \(v\) are carried at the corners of the cells (designated by + in the figure), the west/east mass flux \(u^*\) at the midpoints of the vertical sides (designated >), and the south/north mass flux \(v^*\) at the midpoint of the horizontal sides (designated \(\wedge\)). All other quantities are carried at the midpoint of the cells (designated \(\circ\)). The values of \(u\) and \(v\) at the lower right-hand corner of the cell \((i,j)\) are denoted by \(u_{ij}\) and \(v_{ij}\), the value of \(u^*\) on the right-hand side of the cell by \(u^*_{ij}\), and the value of \(v^*\) on the lower side of the cell by \(v^*_{ij}\). In the remainder of the text, the points \(\circ\), +, >, and \(\wedge\) will be referred to as "\(\pi\) points," "\(u,v\) points," "\(u^*\) points," and "\(v^*\) points," respectively. It may be noted that the poles are "\(\pi\) points," while the points at the equator are "\(u,v\) points."

The grid-point separation factors \(m\) and \(n\) represent the geographical distance between grid points, and are defined by Eqs. (2.18) and (2.19). The factors \(m,n\) and the area \((mn)\) of the cells surrounding the \(\pi\) points are computed in subroutine MAGFAC (steps 14360 to 14850), where the following quantities are defined:

---

For purposes of computational efficiency, the notation \((J,I)\), listing the \(y\)-index \(J\) first, is used in the FORTRAN code in lieu of the more conventional \((I,J)\) notation. When reproducing specific FORTRAN statements this \((J,I)\) notation, where \(J = 1, 2, \ldots, JM\) and \(I = 1, 2, \ldots, IM\), will be used. Elsewhere, the notation \((i,j)\), where \(i = 1, 2, \ldots, I\) and \(j = 1, 2, \ldots, J\), will be used.
Fig. 3.2 -- The horizontal finite-difference grid with zonal index \( i \) and meridional index \( j \). Here the open circles (o) represent grid points of the primary or \( \pi \) grid at which \( \pi \), \( T \), \( q \), and \( \phi \) are carried, while the plus (+) signs represent points at which \( u \) and \( v \) are carried (the \( u,v \) grid). The carets (\(^\wedge\) and \(>\)) denote points of supplementary grids at which the northward and eastward mass fluxes \( v^* \) and \( u^* \) are determined.
LAT(j) = \varphi_j = \Delta \varphi (j - \frac{J + 1}{2}) \quad 1 \leq j \leq J \quad (3.10)

DXP(j) = a\Delta \lambda \cos \varphi_j \quad 1 \leq j \leq J \quad (3.11)

DXU(j) = a\Delta \lambda \frac{1}{2} (\cos \varphi_j + \cos \varphi_{j-1}) \quad (3.12)

= \frac{1}{2} [DXP(J) + DXP(J-1)] \quad 1 \leq j \leq J

DYU(j) = a(\varphi_j - \varphi_{j-1}) \quad j \geq 2 \quad (3.13)

DYU(1) = DYU(2)

DYP(j) = a\frac{1}{2} (\varphi_{j+1} - \varphi_{j-1}) \quad (3.14)

= \frac{1}{2} [DYU(j+1) + DYU(j)] \quad 2 \leq j \leq J

DYP(1) = DYU(2)

DYP(J) = DYU(J)

DXYP(j) = DYP(j) \frac{[DXU(j+1) + DXU(j)]}{2} \quad 2 \leq j \leq J \quad (3.15)

DXYP(1) = \frac{1}{2} DXU(2) \frac{DYP(1)}{2}

DXYP(J) = \frac{1}{2} DXU(J) \frac{DYP(J)}{2}

These quantities are illustrated in Figs. 3.3 to 3.5. From Fig. 3.2 we see that \pi and \upsilon^* are carried at the same latitudes, whereas u, v, v^* are carried at intermediate latitudes. Thus, the factors m,n centered at \pi or \upsilon^* points are given by DXP and DYP, whereas those centered at u, v, or v^* points are given by DXU and DYU. In this scheme the pressure (\pi) is thus given at the poles but not at the equator, whereas the velocity (u,v) is given at the equator but not at the poles.
Fig. 3.3 -- The map metric $n$, the meridional distance between grid points. At latitude $\varphi_j$, $n = DYP$ is the north/south distance between points of the $u,v$ grid (and between points of the $v^*$ grid), while $n = DYU$ gives the corresponding distance between points of the $\pi$ grid (and between points of the $u^*$ grid).

Fig. 3.4 -- The map metric $m$, the zonal distance between grid points. At latitude $\varphi_j$, $m = DXP$ is the east/west distance between points of the $\pi$ grid (and between points of the $u^*$ grid), while $m = DXU$ gives the corresponding distance between points of the $u,v$ grid (and between points of the $v^*$ grid).
Fig. 3.5 -- The area \( mn = DXYP \) surrounding a point of the \( \pi \) grid (a). At the north and south poles \((j=J\) and \(j=1)\) this area is identified as the shaded regions shown in (b) and (c), respectively.
2. Finite-Difference Notation

The [J,I] indexing used in the FORTRAN code is identical for each of the four grid networks described above. That is, \( \pi_{JI} \), \( u_{JI} \), and \( v_{JI} \), \( u^*_{JI} \), and \( v^*_{JI} \) all have the same index, \((J,I)\), but each of these is carried and computed at different points in the horizontal finite-difference grid. It is convenient, therefore, to define \( \pi^- \), \( u^*^- \), \( u^- \), and \( v^- \) centered notations to be used in formulating the finite-difference expressions. These notations are illustrated in Figs. 3.6 to 3.9. Here the index used for the finite-difference expressions is given below each point, and the [J,I] index used in the FORTRAN code is given above each point. These figures facilitate the transformation of the finite-difference expressions given below into the equivalent FORTRAN statements found in the program itself (see Chapter VII).

It is also convenient to introduce a notation for the grid-point separation factors (the horizontal distances between grid points on the surface of the earth). For each of the \( \pi^- \), \( u^- \), \( u^* \), and \( v^- \) centered notations (see Figs. 3.6 to 3.9), \( m_{-1} \), \( m_0 \), and \( m_1 \) will denote the distance from -20 to 00, from -10 to 10, and from 00 to 02, respectively. Similarly, \( n_{-1} \), \( n_0 \), and \( n_1 \) will denote the distance from 00-2 to 00, from 00-1 to 01, and from 00 to 02, respectively. The numerical values of \( m_0 \), \( n_0 \), etc. are given in Eqs. (3.11) to (3.15). For example, when \( \pi^- \) or \( u^* \) centered notation is used, \( m_0 \) and \( m_{+1} \) are given by \( \text{DXP}(j) \), \( n_0 \) by \( \text{DYP}(j) \), \( n_{-1} \) by \( \text{DYU}(j) \), and \( n_1 \) by \( \text{DYU}(j+1) \), whereas when \( u^- \) or \( v^- \) centered notation is used, \( m_0 \) and \( m_{+1} \) are given by \( \text{DXY}(j) \), \( n_0 \) by \( \text{DYU}(j) \), \( n_{-1} \) by \( \text{DYP}(j-1) \), and \( n_1 \) by \( \text{DYP}(j) \).

In the following subsections, variables at the two vertical levels will be indicated by the subscript \( \ell \), with \( \ell = 1 \) denoting the (upper) level \( \sigma_1 \) and \( \ell = 3 \) denoting the (lower) level \( \sigma_3 \). In the FORTRAN code the index \( L \) is used to indicate the levels, with \( L = 1 \) denoting the level \( \sigma_1 \) and \( L = 2 \) denoting the level \( \sigma_3 \).

3. Preparation for Time Extrapolation

At the beginning of each time step the dependent variables are transformed into a set of pressure-area-weighted variables. This trans-
Fig. 3.6 -- The schematic finite-difference grid in \( \pi \)-centered notation. The symbols above each point are the FORTRAN J, I index, and those below each point are the finite-difference subscript notation relative to the origin 00 or relative to the poles (p). The open circles (o) are points of the \( \pi \) grid, the plus signs (+) are points of the u, v grid, and the carets (\( \wedge \) and \( \triangleright \)) are points of the v* and u* grids, respectively.
Fig. 3.7 -- The schematic finite-difference grid in u,v-centered notation. See Fig. 3.6 for symbol identification.
Fig. 3.8 -- The schematic finite-difference grid in \( u^* \)-centered notation. See Fig. 3.6 for symbol identification.
Fig. 3.9 -- The schematic finite-difference grid in \( v^* \)-centered notation.

See Fig. 3.6 for symbol identification.
formation is performed at the beginning of subroutine COMP 1 (steps 2500 to 2680). For the quantities carried at \( T \) points (\( \pi, \Pi, T_3, \) and \( q_3 \)) the transformation is straightforward, and is given by

\[
\Pi_{00} = (mn)_{00} \pi_{00} \tag{3.16}
\]

\[
(\Pi T)_0,00 = (mn)_{00} \pi_{00} T_0,00 \tag{3.17}
\]

\[
(\Pi q)_3,00 = (mn)_{00} \pi_{00} q_3,00 \tag{3.18}
\]

where \((mn)_{00}\) is the \( \pi \)-centered area \( DXYP(J) \) (see Fig. 3.5).

For the transformation of the velocity components we similarly write (in \( u,v \)-centered notation)

\[
(\Pi u)_0,00 = \Pi_{00}^u u_0,00 \tag{3.19}
\]

\[
(\Pi v)_0,00 = \Pi_{00}^v v_0,00
\]

where the \( u,v \)-centered area-weighted \( \Pi \) is defined in \( u,v \)-centered notation as

\[
\Pi_{00}^u = \frac{1}{4} \left[ (mn)_{-11} \pi_{-11} + (mn)_{11} \pi_{11} + (mn)_{-1-1} \pi_{-1-1} + (mn)_{1-1} \pi_{1-1} \right] \\
\text{for } 2 < j < J - 1 \tag{3.20}
\]

with the polar expressions

\[
\Pi_{0,p+1}^u = \frac{1}{4} \left[ (mn)_{-1,p+2} \pi_{-1,p+2} + (mn)_{1,p+2} \pi_{1,p+2} \right] + (mn)_{1, \pi_{1,1}} \tag{3.21}
\]

\[
\Pi_{0,p-1}^u = \frac{1}{4} \left[ (mn)_{-1,p-2} \pi_{-1,p-2} + (mn)_{1,p-2} \pi_{1,p-2} \right] + (mn)_{1, \pi_{1,J}} \tag{3.22}
\]
where \( p \) denotes the South or North Pole, and where

\[
\overline{v}_{i,1} = \frac{1}{I} \sum_{i=1}^{I} v_{i,1}
\]

(3.23)

and

\[
\overline{v}_{i,J} = \frac{1}{I} \sum_{i=1}^{I} v_{i,J}
\]

(3.24)

The quantities given by Eqs. (3.20) to (3.24) are illustrated in Fig. 3.10. Note that since the poles are mapped into \( I \) grid points, Eqs. (3.23) and (3.24) provide unique values of \( \pi \) for all \( I \) grid points of the South and North Poles. The other dependent variables carried at the poles (\( T_1, T_3 \), and \( q_3 \)) and quantities computed at the poles, such as the mass convergence discussed in the next section, are similarly averaged. The polar adjustment of \( \pi, T_1, T_3, \) and \( q_3 \) is performed in subroutine COMP 2 (steps 6410 to 6560).

C. SOLUTION OF THE DIFFERENCE EQUATIONS

1. The Mass Flux

The west/east and south/north mass fluxes are defined by Eqs. (2.25) and (2.26). These quantities require three finite-difference approximations corresponding to the three space-difference schemes (the up-right, down-left, and centered) used during the cycle of the time integration. Furthermore, \( u^* \) is given a longitudinal smoothing to avoid computational instability resulting from the decrease in the longitudinal spacing as the poles are approached. The mass-flux parameters are computed in subroutine COMP 1 (steps 2710 to 2950) and the longitudinal smoothing of \( u^* \) is performed in subroutine AVRX(K).

In the \( v^* \)-centered notation (see Fig. 3.9), the south/north mass flux \( v^* \) at the level \( k \) becomes
Fig. 3.10 -- Illustration of the area-pressure weighting function \( P^U \) centered at \( u,v \) points. At non-polar points, \( P^U \) is the sum of the four shaded areas shown in (a), each weighted by its adjacent value of \( \pi \); at polar points, \( P^U \) is given by the sum of the three shaded areas shown in (b) weighted by the indicated values of \( \pi \).
\[ v^*_{\ell,00} = \begin{cases} 
\frac{m_0}{2} \left( \frac{v_{\ell,10} + v_{\ell,-10}}{2} \right) \left( \frac{\pi_{01} + \pi_{0-1}}{2} \right) & \text{when } \text{MRCH} = 1 \text{ or } 2 \\
\frac{m_0 v_{\ell,10}}{2} \left( \frac{\pi_{01} + \pi_{0-1}}{2} \right) & \text{when } \text{MRCH} = 3 \\
\frac{m_0 v_{\ell,-10}}{2} \left( \frac{\pi_{01} + \pi_{0-1}}{2} \right) & \text{when } \text{MRCH} = 4 
\end{cases} \] (3.25)

The west/east mass flux \( u^* \) is computed in three stages. First, \((nu)_{\ell,00}\) at the level \( \ell \) is computed according to

\[ (nu)_{\ell,00} = \begin{cases} 
\frac{n_1 u_{\ell,01} + n_{-1} u_{\ell,0-1}}{2} & \text{when } \text{MRCH} = 1 \text{ or } 2 \\
n_1 u_{\ell,01} & \text{when } \text{MRCH} = 3 \\
n_{-1} u_{\ell,0-1} & \text{when } \text{MRCH} = 4 
\end{cases} \] (3.26)

where \( u^* \)-centered notation has been used (see Fig. 3.8). Second, the values of \((nu)_{\ell,00}\) are smoothed in subroutine AVRX(K) using a three-point zonal smoothing routine that may be represented by

\[ (\overline{nu})_{\ell,00} = \lambda_0 (nu)_{\ell,-10} + (1 - 2\lambda_0) (nu)_{\ell,00} + \lambda_0 (nu)_{\ell,10} \] (3.27)

where \( \lambda_0 \) is the weighting factor of the smoothing routine. This smoothing procedure is described further in Section D below. After this calculation, the west/east mass flux \( u^* \) at the level \( \ell \) is finally computed from

\[ u^*_{\ell,00} = (\overline{nu})_{\ell,00} \frac{(\pi_{-10} + \pi_{10})}{2} \] (3.28)

where the superscript \( N_0 \) denotes the smoothed result after application of the subroutine AVRX(K) \( N_0 \) times (see Section D).
At this point it should be noted that \( u^* \) at the poles \( (u^*_{1,1} \text{ and } u^*_{1,J}) \) has no meaning. However, to determine the advection of momentum in the polar caps, an equivalent \( u^* \) at the poles is defined. The routine used to compute this equivalent polar \( u^* \) is described in Subsection C.3 below.

2. Continuity Equation

The prognostic equation (2.33) for the pressure tendency and the diagnostic equation (2.34) for the vertical-velocity term may be rewritten in terms of the mass convergence at levels 1 and 3. Thus,

\[
\frac{\partial \Pi}{\partial t} = -\frac{1}{2} \left( \frac{\partial u^*_{1}}{\partial x} + \frac{\partial v^*_{1}}{\partial y} \right) - \frac{1}{2} \left( \frac{\partial u^*_{3}}{\partial x} + \frac{\partial v^*_{3}}{\partial y} \right)
\]

(3.29)

\[
\dot{s} = -\frac{1}{2} \left( \frac{\partial u^*_{1}}{\partial x} + \frac{\partial v^*_{1}}{\partial y} \right) + \frac{1}{2} \left( \frac{\partial u^*_{3}}{\partial x} + \frac{\partial v^*_{3}}{\partial y} \right)
\]

(3.30)

In the \( \tau \)-centered notation (see Fig. 3.6), the mass convergence at all grid points, except the poles, is given by

\[
\left( \frac{\partial u^*_{\tau \ell}}{\partial x} + \frac{\partial v^*_{\tau \ell}}{\partial y} \right)_{\ell,00} = \text{CONV}_{\tau \ell,00}
\]

\[
= (u^*_{\tau \ell,10} - u^*_{\tau \ell,-10}) + (v^*_{\tau \ell,01} - v^*_{\tau \ell,0-1})
\]

\[
2 \leq \ell \leq J - 1
\]

(3.31)

Only the south/north mass flux \( (v^* \) contributes to the total mass convergence within the polar cap. The total mass convergence at the South and North Poles is therefore given by

\[
\text{CONV}_{\tau \ell,1} = \sum_{i=1}^{I} v^*_{\tau \ell,i,p+1}
\]

(3.32)
\[ \text{CONV}_{L,J} = - \sum_{i=1}^{I} v_{L,i,p-1}^* \]  

while the mass convergence attributed to each of the I sectors of the polar caps is given by

\[ \text{CONV}_{L,i,1} = \frac{1}{I} \sum_{i=1}^{I} v_{L,i,p+1}^* \]  

\[ \text{CONV}_{L,i,J} = \frac{1}{I} \sum_{i=1}^{I} v_{L,i,p-1}^* \]  

Thus, Eqs. (3.29) and (3.30) may be written in the computational forms

\[ \left( \frac{3\Pi}{3t} \right)_{00} = - \frac{1}{2} (\text{CONV}_{1,00} + \text{CONV}_{3,00}) \]  

\[ \dot{S}_{00} = \frac{1}{2} (\text{CONV}_{3,00} - \text{CONV}_{1,00}) \]  

for an arbitrary point outside the polar cap,

\[ \left( \frac{3\Pi}{3t} \right)_{1,1} = - \frac{1}{2} (\text{CONV}_{1,1,1} + \text{CONV}_{3,1,1}) \]  

\[ \dot{S}_{1,1} = \frac{1}{2} (\text{CONV}_{3,1,1} - \text{CONV}_{1,1,1}) \]  

at the South Pole, and

\[ \left( \frac{3\Pi}{3t} \right)_{1,J} = - \frac{1}{2} (\text{CONV}_{1,1,J} + \text{CONV}_{3,1,J}) \]  

\[ \dot{S}_{1,J} = \frac{1}{2} (\text{CONV}_{3,1,J} - \text{CONV}_{1,1,J}) \]  

at the North Pole.
3. Horizontal Advection of Momentum

The horizontal advection of momentum at the u,v-grid point i,j
and at the level $\ell$ is approximated in the equations of motion (2.27) to (2.30) by

$$\left[ \frac{\partial}{\partial x} (u^* u) + \frac{\partial}{\partial y} (v^* u) \right]_{i,j,\ell} \approx \oint_{\Gamma} u^* \cdot \hat{N} d\Gamma \quad (3.42)$$

and

$$\left[ \frac{\partial}{\partial x} (u^* v) + \frac{\partial}{\partial y} (v^* v) \right]_{i,j,\ell} \approx \oint_{\Gamma} v^* \cdot \hat{N} d\Gamma \quad (3.43)$$

where $\hat{U}^*$ is a vector in the x,y plane with $u^*$ and $v^*$ as its x and y
components, and $\hat{N}$ is the outward unit vector normal to the contour $\Gamma$
of the rectangular grid defined by the four $\pi$ points surrounding the
u-grid point i,j (see Fig. 3.11).

To evaluate the integrals in Eqs. (3.42) and (3.43) the contour $\Gamma$
is divided into eight segments. Along each of the eight segments,
$u^* \cdot \hat{N}$ is defined (using u,v-centered notation) as

$$U_{10} = \frac{2}{3} \cdot \frac{1}{4} \left[ u_{01}^* + u_{21}^* + u_{2-1}^* + u_{0-1}^* \right], \quad \text{along ab}$$

$$\tilde{U}_{11} = \frac{1}{6} \cdot \frac{1}{2} \left[ u_{01}^* + u_{21}^* \right] + \frac{1}{6} \cdot \frac{1}{2} \left[ v_{10}^* + v_{12}^* \right], \quad \text{along bc}$$

$$V_{01} = \frac{2}{3} \cdot \frac{1}{4} \left[ v_{10}^* + v_{12}^* + v_{-12}^* + v_{-10}^* \right], \quad \text{along cd}$$

$$\tilde{V}_{-11} = \frac{1}{6} \cdot \frac{1}{2} \left[ v_{-10}^* + v_{-12}^* \right] - \frac{1}{6} \cdot \frac{1}{2} \left[ u_{01}^* + u_{-21}^* \right], \quad \text{along de} \quad (3.44)$$

$$-U_{-10} = -\frac{2}{3} \cdot \frac{1}{4} \left[ u_{01}^* + u_{-21}^* + u_{-2-1}^* + u_{0-1}^* \right], \quad \text{along ef}$$

$$-\tilde{U}_{-11} = -\frac{1}{6} \cdot \frac{1}{2} \left[ u_{0-1}^* + u_{-2-1}^* \right] - \frac{1}{6} \cdot \frac{1}{2} \left[ v_{-10}^* + v_{-1-2}^* \right], \quad \text{along fg}$$

$$-V_{0-1} = -\frac{2}{3} \cdot \frac{1}{4} \left[ v_{10}^* + v_{1-2}^* + v_{-1-2}^* + v_{-10}^* \right], \quad \text{along gh}$$

$$-\tilde{V}_{1-1} = -\frac{1}{6} \cdot \frac{1}{2} \left[ v_{10}^* + v_{1-2}^* \right] + \frac{1}{6} \cdot \frac{1}{2} \left[ u_{0-1}^* + u_{2-1}^* \right], \quad \text{along ha}$$
Fig. 3.11 -- Schematic representation of the fluxes $U, V$ and $\tilde{U}, \tilde{V}$ on the grid cell surrounding a point of the $u, v$ grid (identified by 00 in $u, v$ notation; see Fig. 3.7).
With these definitions, Eqs. (3.42) and (3.43) become

\[
\left[ \frac{\partial}{\partial x} (u^* u) + \frac{\partial}{\partial y} (v^* u) \right]_{00} = \frac{1}{2} \left[ U_{10} (u_{00} + u_{20}) - U_{-10} (u_{-20} + u_{00}) \right. \\
+ V_{01} (u_{00} + u_{02}) - V_{0-1} (u_{0-2} + u_{00}) + \tilde{u}_{11} (u_{00} + u_{20}) \\
- \tilde{u}_{-1-1} (u_{-2-2} + u_{00}) + \tilde{v}_{-11} (u_{00} + u_{-22}) \\
- \tilde{v}_{1-1} (u_{2-2} + u_{00}) \right] \quad (3.45)
\]

\[
\left[ \frac{\partial}{\partial x} (u^* v) + \frac{\partial}{\partial y} (v^* v) \right]_{00} = \frac{1}{2} \left[ U_{10} (v_{00} + v_{20}) - U_{-10} (v_{-20} + v_{00}) \right. \\
+ V_{01} (v_{00} + v_{02}) - V_{0-1} (v_{0-2} + v_{00}) + \tilde{u}_{11} (v_{00} + v_{20}) \\
- \tilde{u}_{-1-1} (v_{-2-2} + v_{00}) + \tilde{v}_{-11} (v_{00} + v_{-22}) - \tilde{v}_{1-1} (v_{2-2} + v_{00}) \right] \quad (3.46)
\]

at all points outside the polar cap. In Eqs. (3.44) to (3.46) the subscript \( \ell \) has been dropped, and it should be understood that these expressions for the horizontal advection are valid for \( \ell = 1 \) and 3.

The momentum advection within the polar cap requires special treatment. In Fig. 3.11 it can be seen that when the unit square represents a north polar sector, the fluxes \( \tilde{v}_{-11}, V_{01}, \) and \( \tilde{u}_{11} \) represent advection across the pole. Physically, advection can occur across the pole only from a single sector to that sector separated by 180 deg of longitude. Thus, transpolar advection is not calculated and \( \tilde{v}_{-11}, V_{01} \) and \( \tilde{u}_{11} \) are not defined. However, the fluxes \( U_{-10} \) and \( U_{10} \) represent advection between adjacent sectors within the polar cap, but the definitions for these fluxes [Eq. (3.44)] break down since \( u^* \) is not defined at the poles. To circumvent this, a polar \( u^* \) is determined in subroutine COMP 1 (steps 2790 to 3230) so that the near-polar \( U \) are given by

\[
U_{\pm 1,p-1} = \frac{1}{6} \left( u^*_{0,J} + u^*_{\pm 2,J} + u^*_{0,p-2} + u^*_{\pm 2,p-2} \right) \quad (3.47)
\]
and the continuity equation

\[
\frac{\partial}{\partial t} \left( \Pi_{0,p-1}^u \right) + U_{1,p-1} - U_{-1,p-1} - V_{0,p-2} - \tilde{U}_{-1,p-2} - \tilde{V}_{1,p-2} - \tilde{S}_{0,p-1}^u = 0
\] (3.48)

is satisfied for each of the north polar sectors. Here \( u,v \)-centered notation has been used, and the definition of \( \tilde{S}_{0,p-1}^u \) is given in the next subsection.

It is shown by Langlois and Kwok (1969) that under the above conditions \( v^* \) at a polar grid point \( i,J \) is given by

\[
u_{i,J}^* = 3 \left( \psi_i - \frac{1}{I} \sum_{i=1}^{I} \psi_i \right)
\] (3.49)

where \( \psi_i \) is given by

\[
\psi_1 = 0, \psi_2 = v_{3/2}'^*, \psi_3 = v_{3/2}'^* + v_{5/2}'^*, \ldots, \psi_i = \sum_{k=1}^{i-1} v_{k+1/2}'^;
\] (3.50)

\[
i = 2, 3, \ldots, I
\]

and

\[
v_{i+1/2}'^* = v_{i+1/2,p-1}^* - \frac{1}{I} \sum_{i=0}^{I-1} v_{i+1/2,p-1}^*
\] (3.51)

In Eqs. (3.50) and (3.51) the fractional values of the index \( i \) are used to denote the \( v^* \)-grid points to the right of the \( u,v \)-grid point \( (i,p-1) \). Similar expressions can be derived for the South Pole.

If we use Eqs. (3.49) to (3.51) to determine the values of \( u_{0,J}^* \) and \( u_{\pm 2,J}^* \) in Eq. (3.47), the polar horizontal advection of momentum in \( u,v \)-centered notation becomes
\[
\begin{align*}
\left[ \frac{\partial}{\partial x} (u^* u) + \frac{\partial}{\partial y} (v^* u) \right]_{0,p+1} &= \frac{1}{2} \left[ U_{1,p+1}(u_0,p+1 + u_{2,p+1}) \\
- U_{-1,p+1}(u_{-2,p+1} + u_{0,p+1}) + V_{0,p+2}(u_{0,p+1} + u_{0,p+3}) \\
+ \tilde{U}_{1,p+2}(u_0,p+1 + u_{2,p+3}) + \tilde{V}_{1,p+2}(u_0,p+1 + u_{-2,p+3}) \right] (3.52)
\end{align*}
\]

and

\[
\begin{align*}
\left[ \frac{\partial}{\partial x} (u^* v) + \frac{\partial}{\partial y} (v^* v) \right]_{0,p+1} &= \frac{1}{2} \left[ U_{1,p+1}(v_0,p+1 + v_{2,p+1}) \\
- U_{-1,p+1}(v_{-2,p+1} + v_{0,p+1}) + V_{0,p+2}(v_{0,p+1} + v_{0,p+3}) \\
+ \tilde{U}_{1,p+2}(v_0,p+1 + v_{2,p+3}) + \tilde{V}_{1,p+2}(v_0,p+1 + v_{-2,p+3}) \right] (3.53)
\end{align*}
\]

at the South Pole, and

\[
\begin{align*}
\left[ \frac{\partial}{\partial x} (u^* u) + \frac{\partial}{\partial y} (v^* u) \right]_{0,p-1} &= \frac{1}{2} \left[ U_{1,p-1}(u_0,p-1 + u_{2,p-1}) \\
- U_{-1,p-1}(u_{-2,p-1} + u_{0,p-1}) - V_{0,p-2}(u_{0,p-3} + u_{0,p-1}) \\
+ \tilde{U}_{1,p-2}(u_{-2,p-3} + u_{0,p-1}) - \tilde{V}_{1,p-2}(u_{2,p-3} + u_{0,p-1}) \right] (3.54)
\end{align*}
\]

and

\[
\begin{align*}
\left[ \frac{\partial}{\partial x} (u^* v) + \frac{\partial}{\partial y} (v^* v) \right]_{0,p-1} &= \frac{1}{2} \left[ U_{1,p-1}(v_0,p-1 + v_{2,p-1}) \\
- U_{-1,p-1}(v_{-2,p-1} + v_{0,p-1}) - V_{0,p-2}(v_{0,p-3} + v_{0,p-1}) \\
+ \tilde{U}_{1,p-2}(v_{-2,p-3} + v_{0,p-1}) - \tilde{V}_{1,p-2}(v_{2,p-3} + v_{0,p-1}) \right] (3.55)
\end{align*}
\]

at the North Pole.
4. Vertical Advection of Momentum

In Subsection C.2 the vertical velocity parameter \( \hat{\mathbf{S}} \) is defined at \( \pi \)-grid points [Eqs. (3.37), (3.39), and (3.41)]. However, for use in the momentum equations, a \( \hat{\mathbf{S}}^u \) analogous to \( \hat{\mathbf{F}}^u \) [Eqs. (3.20) to (3.24)] must be defined at u,v-grid points. Thus, at u,v points outside the polar cap the vertical advection term in u,v-centered notation is given by

\[
\frac{(u_{1,0} + u_{3,0})}{2} \hat{\mathbf{S}}^u_{0,0} = u_{2,0} \frac{1}{4}(\hat{\mathbf{S}}_{-1,1} + \hat{\mathbf{S}}_{1,1} + \hat{\mathbf{S}}_{1,-1} + \hat{\mathbf{S}}_{-1,-1}) \tag{3.56}
\]

and at the poles by

\[
\frac{(u_{1,0,p+1} + u_{3,0,p+1})}{2} \hat{\mathbf{S}}^u_{0,p+1} = u_{2,0,p+1} \left[ \frac{1}{4}(\hat{\mathbf{S}}_{-1,p+2} + \hat{\mathbf{S}}_{1,p+2}) + \overline{\hat{\mathbf{S}}}_{1,1} \right] \tag{3.57}
\]

and

\[
\frac{(u_{1,0,p-1} + u_{3,0,p-1})}{2} \hat{\mathbf{S}}^u_{0,p-1} = u_{2,0,p-1} \left[ \frac{1}{4}(\hat{\mathbf{S}}_{-1,p-2} + \hat{\mathbf{S}}_{1,p-2}) + \overline{\hat{\mathbf{S}}}_{1,J} \right] \tag{3.58}
\]

where

\[
\overline{\hat{\mathbf{S}}}_{1,1} = \frac{1}{I} \sum_{i=1}^{I} \hat{\mathbf{S}}_{1,1}
\]

and

\[
\overline{\hat{\mathbf{S}}}_{1,J} = \frac{1}{I} \sum_{i=1}^{I} \hat{\mathbf{S}}_{1,J}
\]
5. Coriolis Force

To evaluate the Coriolis force term in the momentum equations, the parameter $F$ [Eq. (2.24)] and the Coriolis parameter $f = 2\Omega \sin \varphi$ are the first obtained at the $\pi$-grid points. The Coriolis parameter is computed in subroutine MAGFAC (steps 14710 to 14750). In terms of $\pi$-centered notation it is defined as

$$f_{00} = \Omega \frac{a}{2(mn)_{00}} \left[ \left( \cos \varphi_{-2} + \cos \varphi_{0} \right)_{m-1} \right.$$\nonumber
$$- \left( \cos \varphi_{0} + \cos \varphi_{2} \right)_{m+1} \right] \quad (3.61)$$

Equation (3.61) can be reduced to

$$f_{00} = -2\Omega \frac{\cos \varphi_{2} - \cos \varphi_{-2}}{\varphi_{2} - \varphi_{-2}}$$

which is a finite-difference analog of

$$f = 2\Omega \sin \varphi = -2\Omega \frac{\partial (\cos \varphi)}{\partial \varphi}$$

At the poles $f$ is given by

$$f_{J} = \Omega \frac{a}{(mn)_{J}} \left[ (\cos \varphi_{J} + \cos \varphi_{J-1})m_{J} \right] \quad (3.62)$$

and

$$f_{1} = -f_{J} \quad (3.63)$$
With the Coriolis parameter defined by Eqs. (3.61) to (3.63), the finite-difference form of Eq. (2.24) in \( \pi \)-centered notation becomes

\[
F_{00} = (mn)_{00} F_{00} - \frac{1}{4} (u_{-11} + u_{11} + u_{1-1} + u_{-1-1})(m_1 - m_{-1}) \tag{3.64}
\]

Finally, the Coriolis term at a \( u,v \)-grid point is represented in terms of \( F \) at the four surrounding \( \pi \) points by

\[
(u\pi F)_{x,00} = \frac{1}{2} \left[ \frac{(\pi_{11} + \pi_{1-1})}{2} \frac{(F_{11} + F_{1-1})}{2} + \frac{(\pi_{-11} + \pi_{-1-1})}{2} \frac{(F_{-11} + F_{-1-1})}{2} \right] u_{x,00} \tag{3.65}
\]

\[
(v\pi F)_{x,00} = \frac{1}{2} \left[ \frac{(\pi_{11} + \pi_{1-1})}{2} \frac{(F_{11} + F_{1-1})}{2} + \frac{(\pi_{-11} + \pi_{-1-1})}{2} \frac{(F_{-11} + F_{-1-1})}{2} \right] v_{x,00} \tag{3.66}
\]

where \( u,v \)-centered notation has been used.

6. Pressure-Gradient Force

The pressure-gradient force terms require a treatment analogous to that for the mass flux discussed in Subsection C.1. That is, they require three finite-difference approximations corresponding to the three space-difference schemes used during the cycle of the time integration, and the pressure-gradient terms of the \( u \)-momentum equation are smoothed using subroutine AVRX(K), as discussed in Subsection C.1.

In \( u,v \)-centered notation, the pressure-gradient force in the \( u \)-momentum equation [Eqs. (2.27) and (2.29)] is given by
\[ n_0 \left( \pi \frac{\partial \phi_l}{\partial x} + \sigma_{kl} \pi \alpha_{kl} \frac{\partial \pi}{\partial x} \right) \] 

\[ = \frac{n_0}{4} \left( (\pi_{-11} + \pi_{11}) (\phi_{k,11} - \phi_{k,-11}) + [(\sigma_{k} \pi \alpha_{k})_{-11} + (\sigma_{k} \pi \alpha_{k})_{11}](\pi_{11} - \pi_{-11}) \right) \] 

\[ + \frac{n_0}{4} \left( (\pi_{-1-1} + \pi_{1-1}) (\phi_{k,1-1} - \phi_{k,-1-1}) + [(\sigma_{k} \pi \alpha_{k})_{-1-1} + (\sigma_{k} \pi \alpha_{k})_{1-1}](\pi_{1-1} - \pi_{-1-1}) \right) \] 

when MRCH = 1 or 2

\[ = \frac{n_0}{2} \left( (\pi_{-11} + \pi_{11}) (\phi_{k,11} - \phi_{k,-11}) + [(\sigma_{k} \pi \alpha_{k})_{-11} + (\sigma_{k} \pi \alpha_{k})_{11}](\pi_{11} - \pi_{-11}) \right) \] 

when MRCH = 3

\[ = \frac{n_0}{2} \left( (\pi_{-1-1} + \pi_{1-1}) (\phi_{k,1-1} - \phi_{k,-1-1}) + [(\sigma_{k} \pi \alpha_{k})_{-1-1} + (\sigma_{k} \pi \alpha_{k})_{1-1}](\pi_{1-1} - \pi_{-1-1}) \right) \] 

when MRCH = 4

\[ (3.67) \]

where \( \left( \right)_{N_0} \) indicates the smoothing procedure in subroutine AVRX(K) and \( \phi_l \) is the geopotential at the levels \( l = 1 \) and 3 defined by Eqs. (2.16) and (2.17). The geopotential is evaluated at \( \pi \) points in subroutine COMP 2 (steps 5260 to 5430).

For the v-momentum equations [Eqs. (2.28) and (2.30)] the pressure-gradient force is given by
\[
\begin{align*}
\pi_0 \left( \pi \frac{\partial \phi}{\partial y} + \sigma \pi \phi \frac{\partial \pi}{\partial y} \right)_{1,00} \\
= \pi_0 \left\{ \frac{1}{2} \left[ \frac{\pi_{-11} + \pi_{-1-1}}{2} \left( \phi_{1,11} - \phi_{1,-1-1} \right) + \frac{\pi_{11} + \pi_{1-1}}{2} \left( \phi_{1,11} - \phi_{1,-1-1} \right) \right]
\right. \\
+ \frac{1}{2} \left[ \frac{(\sigma \pi \phi_{1,11} - 11) + (\sigma \pi \phi_{1,-1-1})}{2} \right] \left( \pi_{-11} - \pi_{-1-1} \right) \\
\left. + \frac{(\sigma \pi \phi_{1,11} + (\sigma \pi \phi_{1,-1-1})}{2} \right) \left( \pi_{11} - \pi_{1-1} \right) \right\}
\right\}
\end{align*}
\]

when \( \text{MRCH} = 1 \) or \( 2 \)

\[
= \pi_0 \left[ \frac{\pi_{11} + \pi_{1-1}}{2} \left( \phi_{1,11} - \phi_{1,-1-1} \right) + \frac{(\sigma \pi \phi_{1,11} + (\sigma \pi \phi_{1,-1-1})}{2} \right) \left( \pi_{11} - \pi_{1-1} \right) \]
\]

when \( \text{MRCH} = 3 \)

\[
= \pi_0 \left[ \frac{\pi_{11} + \pi_{1-1}}{2} \left( \phi_{1,11} - \phi_{1,-1-1} \right) + \frac{(\sigma \pi \phi_{1,11} + (\sigma \pi \phi_{1,-1-1})}{2} \right) \left( \pi_{-11} - \pi_{-1-1} \right) \]
\]

when \( \text{MRCH} = 4 \)

(3.68)

7. Horizontal Advection of Temperature

The horizontal advection of temperature at the level \( \ell \) and for an arbitrary \( \pi \) point at the latitudes from \( \varphi_0 \) to \( \varphi_{j-2} \) is given in \( \pi \)-centered notation as

\[
\left[ \frac{\partial}{\partial x} (u^* T) + \frac{\partial}{\partial y} (v^* T) \right]_{1,00} = (u^* T)_{1,10} - (u^* T)_{1,-10}
\]

\[
+ (v^* T)_{1,01} - (v^* T)_{1,0-1}
\]

(3.69)
where

\[(u^* T)_{x, \pm 10} = u^*_{x, \pm 10} \frac{1}{2} (T_{x, 00} + T_{x, \pm 20}) \]  \hspace{1cm} (3.70)

and

\[(v^* T)_{x, 0 \pm 1} = v^*_{x, 0 \pm 1} \frac{1}{2} (T_{x, 00} + T_{x, 0 \pm 2}) \]  \hspace{1cm} (3.71)

At the poles only the south/north mass flux contributes to the advection of temperature. Thus, for the South Pole, Eq. (3.69) reduces to

\[\frac{\partial}{\partial x} (u^* T) + \frac{\partial}{\partial y} (v^* T) = (v^* T)_{x, 0, p+1} \]  \hspace{1cm} (3.72)

where

\[(v^* T)_{x, 0, p+1} = v^*_{x, 0, p+1} \begin{cases} T_{x, 0, 1} & \text{if } v^*_{x, 0, p+1} \geq 0 \\ T_{x, 0, p+2} & \text{if } v^*_{x, 0, p+1} < 0 \end{cases} \]  \hspace{1cm} (3.73)

while at the North Pole it reduces to

\[\frac{\partial}{\partial x} (u^* T) + \frac{\partial}{\partial y} (v^* T) = (v^* T)_{x, 0, p-1} \]  \hspace{1cm} (3.74)

where

\[(v^* T)_{x, 0, p-1} = v^*_{x, 0, p-1} \begin{cases} T_{x, 0, J} & \text{if } v^*_{x, 0, p-1} \leq 0 \\ T_{x, 0, p-2} & \text{if } v^*_{x, 0, p-1} > 0 \end{cases} \]  \hspace{1cm} (3.75)
At the latitudes $\varphi_2$ and $\varphi_{J-1}$ [the points $(i, p+2)$ in $\pi$-centered notation] the west/east advection term $\frac{\partial}{\partial x} u^* T$ is given a special treatment. The form of the total advection term, analogous to Eq. (3.69), is given at these latitudes by

$$\left[ \frac{\partial}{\partial x} (u^* T) + \frac{\partial}{\partial y} (v^* T) \right]_{l,0,p+2} = (u^* T)_{l,1,p+2} - (u^* T)_{l,-1,p+2}$$

$$\pm (v^* T)_{l,0,p+3} + (v^* T)_{l,0,p+1} \quad (3.76)$$

with $(v^* T)_{l,0,p+1}$ given by Eqs. (3.73) and (3.75), and with

$$\quad (v^* T)_{l,0,p+3} = v^*_{l,0,p+3} \frac{1}{2} (T_{l,0,p+2} + T_{l,0,p+4}) \quad (3.77)$$

$$\quad (u^* T)_{l,1,p+2} = u^*_{l,1,p+2} \begin{cases} T_{l,2,p+2} & \text{if } u^*_{l,1,p+2} < 0 \\ T_{l,0,p+2} & \text{if } u^*_{l,1,p+2} \geq 0 \end{cases} \quad (3.78)$$

$$\quad (u^* T)_{l,-1,p+2} = u^*_{l,-1,p+2} \begin{cases} T_{l,-2,p+2} & \text{if } u^*_{l,-1,p+2} \geq 0 \\ T_{l,0,p+2} & \text{if } u^*_{l,-1,p+2} < 0 \end{cases} \quad (3.79)$$

8. Energy-Conversion Terms

The first two energy-conversion terms in the thermodynamic energy equations (see Table 3.3) do not require horizontal finite-difference expressions. They are evaluated at $\pi$ points in subroutine COMP 1 (steps 4560 to 4660) from the equations

$$\left[ \left( \frac{p_\pi}{p_0} \right)^{\kappa} \frac{\theta_1 + \theta_3}{2} S \right]_{l,0,0} = p^\kappa_{l,0,0} \frac{1}{2} \left( \frac{T_{1,0,0}}{p_1^{\kappa}} + \frac{T_{3,0,0}}{p_3^{\kappa}} \right) S_{0,0} \quad (3.80)$$
\[
\left( \frac{\sigma \Delta \Pi}{c_p} \frac{\partial \Pi}{\partial t} \right)_{\ell,00} = \sigma \varpi_{00} \left( \frac{\Pi}{\partial t} \right)_{\ell,00} \left( \frac{\Pi}{\partial t} \right)_{00} 
\]

(3.81)

where \( \delta \) and \( \partial \Pi / \partial t \) are evaluated at \( \pi \) points using Eqs. (3.36) to (3.41), and the pressure at level \( \ell \) is given by

\[
p_{\ell} = p_T + \sigma_{\ell} \pi
\]

(3.82)

In Eq. (3.80) the definition

\[
\theta_{\ell} = T_{\ell} \left( \frac{P_0}{P_{\ell}} \right)^{\kappa}
\]

has been used to eliminate the potential temperature, and in Eq. (3.81) the equation of state in the form

\[
\sigma_{\ell} = c_p \kappa \left( \frac{T_{\ell}}{P_{\ell}} \right)
\]

has been used to eliminate the specific volume.

The remaining energy-conversion terms at the level \( \ell \) are evaluated from the expression

\[
\left[ \frac{\sigma \alpha}{c_p} \left( u^* \frac{\partial \Pi}{\partial x} + v^* \frac{\partial \Pi}{\partial y} \right) \right]_{\ell,00} = \frac{1}{c_p} \frac{1}{2} \left[ (\sigma u^* \frac{\partial \Pi}{\partial x})_{\ell,-10} + (\sigma v^* \frac{\partial \Pi}{\partial y})_{\ell,10} + (\sigma v^* \frac{\partial \Pi}{\partial y})_{\ell,0-1} \right] + (\sigma v^* \frac{\partial \Pi}{\partial y})_{\ell,01}
\]

(3.83)

where \( \pi \)-centered notation has been used, and where
\[
\left(\sigma u^* \frac{\partial \pi}{\partial x}\right)_{\ell, \pm 10} = (\pm \pi_{\pm 20} \mp \pi_{00})\left[(\sigma \alpha \pi)_{\ell, \pm 20} + (\sigma \alpha \pi)_{\ell, 00}\right]/2
\]

\[
N_0 \left\{ \begin{array}{l}
\frac{n_1 u_{\ell, \pm 11} + n_{-1} u_{\ell, \pm 1-1}}{2} \quad \text{if } MRCH = 1 \text{ or } 2 \\
(n_1 u_{\ell, 11})^{N_0} \quad \text{if } MRCH = 3 \\
(n_{-1} u_{\ell, \pm 1-1})^{N_0} \quad \text{if } MRCH = 4
\end{array} \right.
\]

\[
\left(\sigma v^* \frac{\partial \pi}{\partial y}\right)_{\ell, 0\pm 1} = (\pm \pi_{0\pm 2} \mp \pi_{00})\left[(\sigma \alpha \pi)_{\ell, 0\pm 2} + (\sigma \alpha \pi)_{\ell, 00}\right]/2
\]

\[
N_0 \left\{ \begin{array}{l}
\frac{m_1 v_{\ell, l+1} + m_{-1} v_{\ell, -l-1}}{2} \quad \text{if } MRCH = 1 \text{ or } 2 \\
m_{-1} v_{\ell, l+1} \quad \text{if } MRCH = 3 \\
m_{-1} v_{\ell, -l-1} \quad \text{if } MRCH = 4
\end{array} \right.
\]

In Eq. (3.84), \(N_0\) denotes the zonal smoothing routine in subroutine AVRNX(K) (see Chapter III, Subsection C.1).

9. Horizontal Advection of Moisture

As discussed in Chapter II, moisture is carried only at the level \(\ell = 3\). Furthermore, the moisture is considered to be advected by the average wind in the layer between \(\ell = 3\) and the surface. By linear extrapolation to the surface of the winds at levels \(\ell = 1\) and \(\ell = 3\), the average pressure-area-weighted wind in this layer is given by the equations
\[
\frac{u_3^* + u_4^*}{2} = \frac{5}{4} u_3^* - \frac{1}{4} u_1^*
\]
\[
\frac{v_3^* + v_4^*}{2} = \frac{5}{4} v_3^* - \frac{1}{4} v_1^*
\]
(3.86)

Using Eqs. (3.86) for the advecting wind, the expressions for the west/east and south/north moisture advection at \( \pi \) points outside the poles are given in \( \pi \)-centered notation by

\[
\left\{ \frac{2}{\partial x} \left[ q_3 \left( \frac{5}{4} u_3^* - \frac{1}{4} u_1^* \right) \right] \right\}_{3,00} = \frac{5}{4} \left[ (q_3 u_3^*)_{3,10} - (q_3 u_3^*)_{3,-10} \right] - \frac{1}{4} \left[ (q_3 u_1^*)_{3,10} - (q_3 u_1^*)_{3,-10} \right]
\]
(3.87)

and

\[
\left\{ \frac{2}{\partial y} \left[ q_3 \left( \frac{5}{4} v_3^* - \frac{1}{4} v_1^* \right) \right] \right\}_{3,00} = \frac{5}{4} \left[ (q_3 v_3^*)_{3,01} - (q_3 v_3^*)_{3,0-1} \right] - \frac{1}{4} \left[ (q_3 v_1^*)_{3,01} - (q_3 v_1^*)_{3,0-1} \right]
\]
(3.88)

Physically the moisture parameter \( q \) is a non-negative quantity. Therefore, the fluxes \( (q_3 u_3^*)_{3,01} \), etc. on the right-hand sides of Eqs. (3.87) and (3.88) must be defined in such a way that when a grid cell becomes "dry," advection to neighboring cells will be prevented. With this restriction, the moisture fluxes in \( \pi \)-centered notation are given by
\[
\begin{align*}
\left\{ \begin{array}{l}
q_3^{*,3,10} \\
q_3^{*,3,10}
\end{array} \right\} &= \left\{ \begin{array}{l}
q_3^{*,3,10} \\
v_{3,10}^{*}
\end{array} \right\} \\
\times & 2 \quad \frac{q_{3,00} q_{3,20}}{q_{3,00} + q_{3,20}} \\
& \begin{cases}
0 & \text{if } (q_{3,00} + q_{3,20}) < 10^{-10} \\
\frac{q_{3,00} q_{3,20}}{q_{3,00} + q_{3,20}} & \begin{cases}
q_{3,00} < q_{3,20} \quad \text{and} \quad \begin{array}{l}
u_{3,10}^{*,*} > 0 \\
u_{3,10} > 0
\end{array} \\
q_{3,00} > q_{3,20} \quad \text{and} \quad \begin{array}{l}
u_{3,10} < 0 \\
u_{3,10}^{*,*} < 0
\end{array}
\end{cases}
\end{cases}
\end{align*}
\] (3.89)

\[
\begin{align*}
\left\{ \begin{array}{l}
q_3^{*,3,-10} \\
q_3^{*,3,-10}
\end{array} \right\} &= \left\{ \begin{array}{l}
q_3^{*,3,-10} \\
v_{3,-10}^{*}
\end{array} \right\} \\
\times & 2 \quad \frac{q_{3,00} q_{3,-20}}{q_{3,00} + q_{3,-20}} \\
& \begin{cases}
0 & \text{if } (q_{3,00} + q_{3,-20}) < 10^{-10} \\
\frac{q_{3,00} q_{3,-20}}{q_{3,00} + q_{3,-20}} & \begin{cases}
q_{3,-20} < q_{3,00} \quad \text{and} \quad \begin{array}{l}
u_{3,-10}^{*,*} > 0 \\
u_{3,-10} > 0
\end{array} \\
q_{3,-20} > q_{3,00} \quad \text{and} \quad \begin{array}{l}
u_{3,-10} < 0 \\
u_{3,-10}^{*,*} < 0
\end{array}
\end{cases}
\end{cases}
\end{align*}
\] (3.90)

\[
\begin{align*}
\left\{ \begin{array}{l}
q_3^{*,3,01} \\
q_3^{*,3,01}
\end{array} \right\} &= \left\{ \begin{array}{l}
q_3^{*,3,01} \\
v_{3,01}^{*}
\end{array} \right\} \\
\times & 2 \quad \frac{q_{3,00} q_{3,02}}{q_{3,00} + q_{3,02}} \\
& \begin{cases}
0 & \text{if } (q_{3,00} + q_{3,02}) < 10^{-10} \\
\frac{q_{3,00} q_{3,02}}{q_{3,00} + q_{3,02}} & \begin{cases}
q_{3,00} < q_{3,02} \quad \text{and} \quad \begin{array}{l}
u_{3,01}^{*,*} > 0 \\
u_{3,01} > 0
\end{array} \\
q_{3,00} > q_{3,02} \quad \text{and} \quad \begin{array}{l}
u_{3,01} < 0 \\
u_{3,01}^{*,*} < 0
\end{array}
\end{cases}
\end{cases}
\end{align*}
\] (3.91)

\[
\begin{align*}
\left\{ \begin{array}{l}
q_3^{*,3,0-1} \\
q_3^{*,3,0-1}
\end{array} \right\} &= \left\{ \begin{array}{l}
q_3^{*,3,0-1} \\
v_{3,0-1}^{*}
\end{array} \right\} \\
\times & 2 \quad \frac{q_{3,00} q_{3,0-2}}{q_{3,00} + q_{3,0-2}} \\
& \begin{cases}
0 & \text{if } (q_{3,00} + q_{3,0-2}) < 10^{-10} \\
\frac{q_{3,00} q_{3,0-2}}{q_{3,00} + q_{3,0-2}} & \begin{cases}
q_{3,0-2} < q_{3,00} \quad \text{and} \quad \begin{array}{l}
u_{3,0-1}^{*,*} > 0 \\
u_{3,0-1} > 0
\end{array} \\
q_{3,0-2} > q_{3,00} \quad \text{and} \quad \begin{array}{l}
u_{3,0-1} < 0 \\
u_{3,0-1}^{*,*} < 0
\end{array}
\end{cases}
\end{cases}
\end{align*}
\] (3.92)
In the polar caps only the south/north advection terms given by Eq. (3.88) contribute to the advection of moisture. In \( \pi \)-centered polar notation, Eq. (3.88) at the South Pole becomes

\[
\left. \left( \frac{\partial}{\partial y} \left[ q_3 \left( \frac{5}{4} v_3^* - \frac{1}{4} v_1^* \right) \right] \right) \right|_{3,0i} = \frac{5}{4} \left( q_3 v_3^* \right)_{3,0,p+1} - \frac{1}{4} \left( q_3 v_3^* \right)_{3,0,p+1} \tag{3.93}
\]

and at the North Pole

\[
\left. \left( \frac{\partial}{\partial y} \left[ q_3 \left( \frac{5}{4} v_3^* - \frac{1}{4} v_1^* \right) \right] \right) \right|_{3,0J} = -\frac{5}{4} \left( q_3 v_3^* \right)_{3,0,p-1} + \frac{1}{4} \left( q_3 v_1^* \right)_{3,0,p-1} \tag{3.94}
\]

where the fluxes on the right-hand side of Eq. (3.93) are given by Eq. (3.91) and those on the right-hand side of Eq. (3.94) are given by Eq. (3.92).

10. Horizontally Differenced Friction Terms

The friction terms \( F_{1,x}^y \) and \( F_{3,x}^y \) appearing in the equations of motion (2.27) to (2.30) are given in horizontally differenced form in \( u,v \) notation by

\[
F_{1,00}^x = -g\tilde{\beta}(u_{1,00} - u_{3,00})(\pi_{00})^{-2} \tag{3.95}
\]

\[
F_{1,00}^y = -g\tilde{\beta}(v_{1,00} - v_{3,00})(\pi_{00})^{-2} \tag{3.96}
\]

\[
F_{3,00}^x = g\tilde{\beta}(u_{1,00} - u_{3,00})(\pi_{00})^{-2} \tag{3.97}
\]

\[
\begin{align*}
&- \frac{2g}{\nu} \left[ \frac{\pi_{00} + P_T}{RT^u_{4,00}} \right] \left( \left. \frac{\partial v}{\partial x} \right|_{00} + G \right) \left( 0.7u_{4,00} \right) \tag{3.97}
\end{align*}
\]
\[ P_{3,00}^Y = g \beta (v_{1,00} - v_{3,00})(\pi_{00})^{-2} \]

\[ - \frac{2g}{\pi_{00}} C_D \frac{(\pi_{00} + P_T)}{R T_{4,00}} \left( |\hat{V}_s|_{00}^\pi + G \right) (0.7)v_{4,00} \]  

(3.98)

These forms rest upon the approximation of the height difference \((z_1 - z_3)\) in Eq. (2.36) by \(\Delta z(\pi/\pi_S)\), where \(\Delta z(= 5400 \text{ m})\) and \(\pi_S(= 800 \text{ mb})\) are standard values of \((z_1 - z_3)\) and \(\pi\), respectively. The coefficient \(\beta\) thus becomes \(\beta = 2\pi_S \nu(\Delta z)^{-1}\), and is taken as 0.13 mb\(^{-1}\) sec m\(^{-1}\), corresponding to \(\nu = 0.44 \text{ mb sec}\).

In Eqs. (3.97) and (3.98) the surface wind speed \(|\hat{V}_s|_{00}\) is given (in \(u,v\) notation) by

\[ |\hat{V}_s|_{00}^\pi = \frac{1}{2} \left( |\hat{V}_s|_{00}^2 + |\hat{V}_s|_{-20}^2 + |\hat{V}_s|_{02}^2 + |\hat{V}_s|_{-22}^2 \right)^{1/2} \]  

(3.99)

where \(\hat{V}_s = 0.7|\hat{V}_4|\) and where \(\hat{V}_4 = \frac{3}{2} \hat{V}_3 - \frac{1}{2} \hat{V}_1 = (u_4,v_4)\) is the wind extrapolated to level 4. Here the subscripts refer to the \(u,v\) grid (see Fig. 3.7). The gustiness term is given by the constant \(G = 2.0 \text{ m sec}^{-1}\). The surface drag coefficient is given by the relations

\[
C_D = \begin{cases} 
\min \left[ \left( 1.0 + 0.07 |\hat{V}_s|_{00}^\pi \right) 10^{-3}, \ 0.0025 \right], & \text{if ocean} \\
0.002 + 0.006(z_4/5000 \text{ m}), & \text{otherwise} 
\end{cases}
\]  

(3.100)

where \(z_4\) is the elevation of the surface of the ground. Hence \(C_D\) varies between 0.001 and 0.0025 over the ocean, while over either bare land or ice, \(C_D\) is independent of the wind speed and varies between 0.002 over lowlands and sea ice to about 0.007 over the higher mountains. This increase of the drag coefficient with \(z_4\) is an attempt to simulate the increased roughness or ruggedness of the terrain in higher elevations, as suggested by the work of Cressman (1960).
As elsewhere in this section, the subscript 00 (in \(u,v\)-centered notation) denotes an arbitrary point of the \(u,v\) grid, and the superscript \(u\) denotes the average of the four surrounding points of the \(\pi\) (or primary) grid. Hence

\[
P_0^u = \frac{1}{4} \left( P_{11} + P_{11} + P_{1-1} + P_{1-1} \right)
\]  \hspace{1cm} (3.101)

recalling that the \(\pi\) grid is displaced upward and to the left of the \(u,v\) grid (see Fig. 3.2). The factor \((P_{00}^u + p_T)(RT_{4,00}^u)^{-1}\) in Eqs. (3.97) and (3.98) is thus the surface air density \(\rho_4\). This averaging serves to "center" the pressure and temperature on the local velocity point. Note, however, that \(\mathbf{\vec{v}}_{00}^\pi\) also involves a 4-point averaging; although this is unnecessary for a point of the \(u,v\) grid, it is consistent with the calculation of the surface evaporation and sensible heat flux at points of the \(\pi\) grid (where averaging over velocity points is necessary).

In the program the frictional terms (3.95) to (3.98) are computed every fifth time step as part of the COMP 3 subroutine (instructions 9700 to 9920), and directly give the frictionally induced speed change in m sec\(^{-1}\) for the \(5\Delta t = 30\) min interval. The factor \(\Pi\) in Eqs. (2.27) to (2.30) is effectively divided out in the finite-difference computations.

11. Moisture-Source Terms

The source term \(2mng(E - C)\) in the moisture equation (2.35) may be written in differenced form as

\[
2mng(E - C) = 2(mn)_{00}g(E - C)_{00} = \Pi_{00} \frac{\Delta \Pi}{5\Delta t} \left[ (\Delta q_3)_E - (\Delta q_3)_L - (\Delta q_3)_C - (\Delta q_3)_G \right]_{00}
\]  \hspace{1cm} (3.102)

where the subscript 00 denotes (in \(\pi\)-centered notation) an arbitrary point of the \(\pi\) grid (see Fig. 3.6). This source computation is carried out for level 3 every five time steps in subroutine COMP 3, instructions
11300 to 11310. Here the level-3 moisture change (in $5\Delta t$) due to evaporation is given by

$$\frac{\Delta q_3}{E,00} = \frac{28}{\pi} E_{00}^{0.5} \Delta t$$

(3.103)

according to Eq. (2.111), where $E_{00}$ is the local evaporation rate itself. The level-3 moisture change due to large-scale condensation is given by

$$\frac{\Delta q_3}{LS,00} = \frac{c^2}{L} (\Delta T_3)_{LS,00}$$

(3.104)

where $(\Delta T_3)_{LS,00}$ is the local temperature change (over $5\Delta t$) at level 3 due to the large-scale latent-heat release, as given by Eq. (2.47).

The level-3 moisture change due to middle-level convection is given by

$$\frac{\Delta q_3}{CM,00} = \frac{c^2}{L} \left[ (\Delta T_1)_{CM,00} + (\Delta T_3)_{CM,00} \right]$$

(3.105)

where $(\Delta T_1)_{CM,00}$ and $(\Delta T_3)_{CM,00}$ are the temperature changes (over $5\Delta t$) at levels 1 and 3 due to the latent-heat release in middle-level convective condensation, as given by Eqs. (2.73) and (2.74), respectively.

Finally, the moisture change at level 3 due to penetrating convection is given by

$$\frac{\Delta q_3}{CP,00} = \frac{c^2}{L} \left[ (\Delta T_1)_{CP,00} + (\Delta T_3)_{CP,00} \right]$$

(3.106)

where $(\Delta T_1)_{CP,00}$ and $(\Delta T_3)_{CP,00}$ are the temperature changes (over $5\Delta t$) at levels 1 and 3 due to the release of latent heat in penetrating convective condensation, as given by Eqs. (2.101) and (2.102), respectively.
The three moisture-change terms, Eqs. (3.104) to (3.106), collectively constitute the total moisture sink due to condensation, which we may then write as

\[
\left[ (\Delta q_3)_{LS} + (\Delta q_3)_{CM} + (\Delta q_3)_{CP} \right]_{00} = \frac{2g}{\pi_0} c_{00} 5 \Delta t \tag{3.107}
\]

in analogy with (3.103) for the evaporation. Since all condensed water vapor is assumed to fall out as precipitation, we may also rewrite Eq. (3.107) in the form

\[
c_{00} = (P_{LS} + P_{CM} + P_{CP})_{00} \tag{3.108}
\]

where \( P_{LS}, P_{CM}, \) and \( P_{CP} \) are the precipitation rates resulting from large-scale condensation, middle-level convection, and penetrating convection, as given by Eqs. (2.50), (2.76), and (2.107), respectively.

12. Diabatic Heating Terms

The heating terms \( \Pi \dot{H}_1/c_p \) and \( \Pi \dot{H}_3/c_p \) in Eqs. (2.31) and (2.32) may be written in differenced form as

\[
\Pi_{00} \dot{H}_{1,00}/c_p \tag{3.109}
\]

\[
\Pi_{00} \dot{H}_{3,00}/c_p \tag{3.110}
\]

where the subscript 00 (in \( \pi \)-centered notation) denotes an arbitrary point of the \( \pi \) grid. These terms are computed every fifth time step in the subroutine COMP 3. Here the diabatic heating rates at levels 1 and 3 are given by
\[ (c_p)^{-1} H_{1,00} = (A_1 + R_2 - R_0) \left( \frac{2g}{n_{00} c_p} \right) + \left[ \frac{\Delta T_1}{C_M} \right]_{00} / 5\Delta t \] (3.111)

\[ (c_p)^{-1} H_{3,00} = (A_3 + R_4 - R_2) \left( \frac{2g}{n_{00} c_p} \right) + \left[ \frac{\Delta T_3}{C_M} \right]_{00} + \left( \frac{\Delta T_3}{C_P} \right)_{00} / 5\Delta t \] (3.112)

According to Eqs. (2.173) and (2.174), where \( A_1 \) and \( A_3 \) are the net short-wave radiation absorbed at levels 1 and 3, and \( R_2 - R_0 \) and \( R_4 - R_2 \) are the net long-wave radiation absorbed at the two levels. These terms in Eqs. (3.111) and (3.112) therefore constitute the radiative portions of the diabatic heating. The lower-level heating also contains a contribution from the vertical sensible heat flux from the surface \( \Gamma_{00} \). The terms in \( \Delta T_1 \) and \( \Delta T_3 \) are the temperature changes due to convective effects, with the subscript CM denoting midlevel convection and CP denoting penetrating or deep convection. Together with the term in the level-3 temperature change due to large-scale condensation, LS, these terms constitute the portions of the diabatic heating due to the release of the latent heat of condensation, as considered in Eqs. (3.104) to (3.106). The total diabatic heating is illustrated in Map 8, Chapter IV.

D. SMOOTHING

Aside from the smoothing built into the time finite-difference approximations themselves, relatively little explicit smoothing is performed in the present version of the program. The subroutine AVRX(K), which performs a three-point zonal averaging, is employed in the main subroutines COMP 1 and COMP 2 principally for the mass-flux variables \( u_1^* \) and \( u_3^* \), as described in Subsection C.1 above. The only other use of AVRX(K) is with the zonal-pressure force terms \( \left( \frac{3\phi_1}{\partial \chi} + \sigma_1 \frac{\partial \pi}{\partial \chi} \right) \) and \( \left( \frac{3\phi_3}{\partial \chi} + \sigma_3 \frac{\partial \pi}{\partial \chi} \right) \) in the momentum equations, as described in
Subsection C.6 above. The effect of the use of subroutine AVRX(K) is to introduce a multiple-point zonal difference for higher latitudes to help avoid computational instability; the variables such as $u^*_1$ are not themselves smoothed.

This selective zonal averaging subroutine is called every time step, with the number of smoothing passes made at each step (as well as the smoothing weighting factor) increasing with latitude. Denoting ( ) the smoothed value of a variable ( ), the zonal smoothing subroutine AVRX(K) may be described by

$$
(\bar{ })_{00} = \lambda_0(\bar{ })_{-10} + (1 - 2\lambda_0)(\bar{ })_{00} + \lambda_0(\bar{ })_{10}
$$

where the subscripts denote identity points in the (i,j) grid array, and where the weighting or smoothing factor $\lambda_0$ is given by

$$
\lambda_0 = \begin{cases} 
0, & \text{for } N_0 < 1 \\
\frac{1}{8}\left(n_e/m_0 - 1\right)/N_0, & \text{for } N_0 \geq 1
\end{cases}
$$

Here $n_e$ is the latitudinal separation of grid points at the equator, $m_0$ is the longitudinal separation of $n$ points at the latitude of the smoothing, and $N_0$ is the integer part of ($n_e/m_0$). The smoothing is applied $N_0$ times at each latitude, as shown in Table 3.7. Note that the number of applications of the smoothing operator increases from zero between the equator and $\pm 34$ deg latitude to 11 near the poles. The strength of the smoothing as given by $\lambda_0$ is also seen to vary with latitude.

An explicit smoothing occurs in the subroutine COMP 3, where the heating rates $\dot{H}_1$ and $\dot{H}_2$ for the two model layers [as in Eqs. (2.31) and (2.32)] are first averaged together, area weighted, and then subjected to a 9-point horizontal averaging prior to their final incorporation into the temperature-change computation at each level. This smoothing is described as part of the subroutine COMP 3 (see Chapter II, Subsection G.4).
Table 3.7

SMOOTHING PARAMETERS USED IN SUBROUTINE AVRnx(K)

Here $\lambda_0$ is the three-point smoothing weighting factor [as in Eq. (3.27)] and $N_0$ is the number of times the smoothing is repeated at each latitude.

<table>
<thead>
<tr>
<th>$\varphi$, deg (LAT)</th>
<th>$N_0$, (NM)</th>
<th>$\lambda_0$, (ALPHA)</th>
</tr>
</thead>
<tbody>
<tr>
<td>-34 to +34</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>±38</td>
<td>1</td>
<td>$1.90 \times 10^{-3}$</td>
</tr>
<tr>
<td>±42</td>
<td>1</td>
<td>$9.56 \times 10^{-3}$</td>
</tr>
<tr>
<td>±46</td>
<td>1</td>
<td>$1.90 \times 10^{-2}$</td>
</tr>
<tr>
<td>±50</td>
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<td>1</td>
<td>$6.37 \times 10^{-2}$</td>
</tr>
<tr>
<td>±62</td>
<td>1</td>
<td>$8.80 \times 10^{-2}$</td>
</tr>
<tr>
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<td>1</td>
<td>$1.21 \times 10^{-1}$</td>
</tr>
<tr>
<td>±70</td>
<td>2</td>
<td>$8.37 \times 10^{-2}$</td>
</tr>
<tr>
<td>±74</td>
<td>2</td>
<td>$1.19 \times 10^{-1}$</td>
</tr>
<tr>
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<td>$1.19 \times 10^{-1}$</td>
</tr>
<tr>
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<td>5</td>
<td>$1.19 \times 10^{-1}$</td>
</tr>
<tr>
<td>±86</td>
<td>11</td>
<td>$1.19 \times 10^{-1}$</td>
</tr>
</tbody>
</table>
The remaining smoothing operations are performed on the lapse rate in the subroutine COMP 4, which is called every 5 time steps. Here the temperature at levels 1 and 3 is smoothed according to

\[ T_1 = \frac{1}{2} (T_3 + T_1) - \pi [TD + \frac{1}{48} (\overline{TD} - TD)] \]  
(3.113)

\[ T_3 = \frac{1}{2} (T_3 + T_1) + \pi [TD + \frac{1}{48} (\overline{TD} - TD)] \]  
(3.114)

where the temperature difference (or lapse rate) TD is given by

\[ TD = \frac{1}{\pi} \left( \frac{T_3 - T_1}{2} \right) \]  
(3.115)

and \( \overline{TD} \) denotes the 9-point horizontal average about a point 00 of the \( \pi \) grid, given in \( \pi \)-centered notation by

\[ \overline{TD}_{00} = \frac{1}{16} (TD_{-2} + 2TD_{02} + TD_{22} + 2TD_{-20} + 4TD_{00} + 2TD_{20} + TD_{-2-2} + 2TD_{0-2} + TD_{2-2}) \]  
(3.116)

Since the first terms of Eqs. (3.113) and (3.114) are a form of vertical averaging, this subroutine may be regarded as a three-dimensional smoothing operation, wherein the temperature at levels 1 and 3 is altered in proportion to the departure of the local lapse rate from the 9-point averaged lapse rate. If TD = \( \overline{TD} \), for example, \( T_1 \) and \( T_3 \) remain unaltered by this smoothing. Viewed in another fashion, from Eqs. (3.113) and (3.114) we have

\[ \frac{T_3 - T_1}{2\pi} = TD_{\text{smoothed}} = TD + \frac{1}{48} (\overline{TD} - TD) \]  
(3.117)

and the averaging may be regarded as a local smoothing of the lapse rate.
Another part of the subroutine COMP 4 (instructions 12270 to 12680) provides for the smoothing of the local velocity change through the simulation of a horizontal diffusion of momentum. This portion is omitted in the present version of the code through the assignment of a zero lateral-diffusion coefficient.

E. GLOBAL MASS CONSERVATION

Although the continuity equation (2.33) is solved at each (mass) point of the grid at each time step (see Chapter III, Subsection C.2), a small loss of mass over the globe still occurs because of the truncation caused by the retention of at most 7 decimal digits in the single-precision calculation (which does not round) of the surface pressure on the IBM 360/91 computer. Over the globe this amounts to approximately a 0.0028 percent \(2.8 \times 10^{-5}\) loss of mass per day of simulated time. To correct for this effect, the subroutine GMP is used once every 24 hours; in GMP the local value of the surface pressure parameter, \(\tau\), is increased (at every point) by the amount 984 mb - \(\overline{p}_s\), where \(\overline{p}_s\) is the global average surface pressure determined each day (as the sum of the global average of the current \(\tau\) distribution and the constant tropopause pressure \(p_T = 200\) mb). Here the constant 984 mb is used to represent the observed global average surface pressure, and is read into the program as the loaded constant PSF. In the present version of the program this correction at each \(\tau\)-grid point thus amounts to approximately 0.028 mb per day.

F. CONSTANTS AND PARAMETERS

1. Numerical Data List

Although a number of the constants and parameters used in the model integration are given elsewhere [see particularly the chapters on model performance (IV), the list of symbols (VI), and the FORTRAN dictionary (VIII)], it is useful to collect them here for easy reference.

\(^\dagger\)Presumably this loss would be reduced by the use of double-precision arithmetic.
Those symbols with an asterisk (*) are defined within the subroutines COMP 3 or INPUT, with the others loaded via data cards (see Chapter IV, Section A).

<table>
<thead>
<tr>
<th>Constant</th>
<th>Symbol</th>
<th>Value and Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>ratio of latent heat of condensation to specific heat at constant pressure, ( \frac{L}{c_p} )</td>
<td>CLH*</td>
<td>580/0.24 deg</td>
</tr>
<tr>
<td>length of day</td>
<td>DAY</td>
<td>86,400 sec</td>
</tr>
<tr>
<td>days per year</td>
<td>DAYPYR*</td>
<td>365 days</td>
</tr>
<tr>
<td>maximum solar declination</td>
<td>DECMAX*</td>
<td>( 23.5\pi/180 ) radians</td>
</tr>
<tr>
<td>north/south grid-point spacing</td>
<td>DLAT</td>
<td>4 deg</td>
</tr>
<tr>
<td>east/west grid-point spacing</td>
<td>DLØN*</td>
<td>( 2\pi/10 ) radians (= 5 deg)</td>
</tr>
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<td>time step, ( \Delta t )</td>
<td>DT*</td>
<td>360 sec</td>
</tr>
<tr>
<td>time step, ( \Delta t )</td>
<td>DTM</td>
<td>6 min</td>
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<tr>
<td>standard value of vertical eddy mixing coefficient</td>
<td>ED</td>
<td>( 10 \text{ m}^2 \text{ sec}^{-1} )</td>
</tr>
<tr>
<td>gravity, ( g )</td>
<td>GRAV</td>
<td>9.81 m sec(^{-2})</td>
</tr>
<tr>
<td>vertical shear-stress coefficient (( \times 10^{-5} ))</td>
<td>FNX</td>
<td>0.2 sec(^{-1})</td>
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<td>grid points in meridional direction</td>
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<td>46</td>
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<tr>
<td>grid points in zonal direction</td>
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<td>72</td>
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<td>thermodynamic ratio, ( \kappa )</td>
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<td>0.286</td>
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<td>frequency of source-term calculation</td>
<td>NC3</td>
<td>5 (every 30 min)</td>
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<td>average surface pressure</td>
<td>PSF</td>
<td>984 mb</td>
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<td>standard sea-level pressure</td>
<td>PSL</td>
<td>1000 mb</td>
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<tr>
<td>tropopause pressure, ( p_T )</td>
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<td>200 mb</td>
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-113-

<table>
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<th>Symbol</th>
<th>Value and Units</th>
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<td>$6.3750 \times 10^6$ m</td>
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<td>dry-air gas constant, R</td>
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<td>$287.0 \text{ m}^2 \text{ deg}^{-1} \text{ sec}^{-2}$</td>
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<td>solar rotation period</td>
<td>RØTPER*</td>
<td>24 hr</td>
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<td>upper model level, $c_1$</td>
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<td>0.25</td>
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<tr>
<td>lower model level, $c_3$</td>
<td>SIG(2)*</td>
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<tr>
<td>solar constant (normalized)</td>
<td>SØ*</td>
<td>$2880 \text{ ly day}^{-1}$ ($= 2 \text{ ly min}^{-1}$)</td>
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<tr>
<td>freezing temperature</td>
<td>TICE*</td>
<td>273.1 deg K</td>
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2. Geographical Finite-Difference Grid

The specific geographical position of the points of the 46 by 72 grid is shown in Fig. 3.12. Here the grid points of the primary or $\pi$ grid are given over the oceans every 4 deg latitude and 5 deg longitude, together with the outlines of the continents and islands resolved by the interlocking points of the $u,v$ grid. The left-hand and right-hand columns of grid points are at 180 deg longitude; the top and bottom rows are at the North and South Poles, respectively, with the latitude identification on the right of the figure. The finite-difference indices $i$ and $j$ are shown on the bottom and left side of the figure, respectively. This map is on the same scale as that used to show the land elevations and sea-surface temperatures in Figs. 3.13 and 3.14, and is the same as that used for the selected variables produced by the map-generation program in the figures of Chapter IV.

3. Surface Topography (Elevation, Sea-Surface Temperature, Ice, and Snow Cover)

During the course of a numerical simulation, the land surface elevation and the ocean surface temperature are held fixed, and thus serve as physical surface boundary conditions. Although these data may conceivably be changed from one simulation to another, their normal distributions are shown in Figs. 3.13 and 3.14 in the form of the programmed Map 5 output (see Map Routine Listing, Chapter VII), and
Fig. 3.12 -- The geographical grid and land-mass outlines. The points shown over water surfaces are those of the primary or \( \pi \) grid every 4° latitude and 5° longitude (90S, ..., 6S, 2S, 2N, 6N, ..., 90N; 180W, 175W, ...). The continental and major island outlines are formed by zonal and meridional lines connecting points of the \( u,v \) grid (88S, ..., 4S, 0, 4N, ..., 88N; 177.5W, 172.5W, ...). The latitude is shown on the right, and the longitude of both the left-hand and right-hand columns is 180°W. The grid indexes \( i \) and \( j \) (for the \( \pi \) grid) are shown on the bottom and left, respectively. This map is on the same scale as those of Figs. 3.13, 3.14, and 4.1 to 4.31.
Fig. 3.13 -- The distribution of surface elevation, with isolines every $10^3$ ft and the 3000-ft contour dashed. The overprinted symbol I denotes ice-covered land. The grid-point elevation data themselves are given in Table 3.8.
Fig. 3.14 -- The distribution of sea-surface temperature, with isolines every 2 deg C and the 20°C isotherm dashed. The overprinted symbol I denotes ice-covered ocean. The grid-point temperature data themselves are given in Table 3.10.
the corresponding global grid-point values are given every 5 deg longitude and 4 deg latitude (at the points of the \( \pi \) grid) in the tabulation following the maps.

The land elevations shown in Fig. 3.13 are based upon the values at points of the 4 deg latitude, 5 deg longitude grid (see data tabulation), which were themselves obtained from the subjective interpolation of topographic maps. These data resemble (but are not identical to) the data given by Berkofsky and Bertoni (1955), and are tabulated in Table 3.8. In Fig. 3.13 the overprinted symbol I designates those grid points at which the land is ice covered; in the data tabulation, the elevation of these points is given separately in Table 3.9, where 0 denotes the locations of sea ice. In the present version of the model, the ice-covered points are not permitted to change their surface cover during the course of the simulation.

The ocean surface temperatures shown in Fig. 3.14 are based upon the values at points of the 4 deg latitude, 5 deg longitude grid (see data tabulation) which were obtained from the average annual sea-surface temperature data given by Dietrich (1963). These data resemble (but are not identical to) the mean of the average February and August distributions given by Sverdrup (1943), and are tabulated in Table 3.10. In Fig. 3.14 the overprinted symbol I here designates those \( \pi \)-grid points at which sea ice is prescribed (and held intact throughout the simulation); in the data tabulation these sea-ice points may be identified by the assigned constant temperature 0 deg C (see Table 3.9). Because the ocean's surface temperature is not allowed to change, even though there are evaporation, radiative transfer, and sensible-heat fluxes at the surface, the ocean has effectively been assumed to be of infinite thermal capacity. The surface temperatures of the sea ice, land ice, snow-covered land, and bare land, on the other hand, are allowed to change, and are separately computed (see COMP 3 in the Program Listing, Chapter VII).

All land grid points north of a seasonally varying northern snow-line (SN\( \text{\textit{O}} \text{\textit{W}} \text{\textit{N}} \)) are considered to be snow covered. Snow does not cover either ice-covered land or sea ice. The northern snowline has a 15-deg sinusoidal seasonal variation around 60 deg north latitude given by
SNOWN = 60 deg - 15 deg cos \left[ \frac{2\pi}{365} (\text{day} - 24.6) \right]

where "day" is the number of the day of the year, with day 0 corresponding to 1 January. A constant southern snowline (SNOWS) is defined at 60 deg south latitude. Although the value of this southern snowline is required by the program for the surface-albedo calculation (see Chapter III, Section H), it actually has no function in defining snow cover, since all land south of 60 deg is permanently ice covered (see Fig. 3.13).
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Table 3.8

LAND ELEVATION (100 FT)

180W175W170W165W160W155W150W145W140W135W130W125W120W115W110W105W100W 95W
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LAND ELEVATION (100 FT)

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Note: The table continues with elevation values for different points along the ice.
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| 88N | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   |
| 82N | 0   | 23  | 27  | 20  | 13  | 0   | 22  | 31  | 35  | 38  | 34  | 33  | 31  |
| 78N | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   |
| 74N | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   |
| 70N | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   |
| 66N | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   |
| 62N | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   |
| 58N | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   |
| 54N | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   |
| 50N | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   |
| 46N | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   |
| 42N | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   |
| 38N | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   |
| 34N | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   |
| 30N | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   |
| 26N | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   |
| 22N | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   |
| 18N | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   |
| 14N | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   |
| 10N | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   |
| 6N  | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   |
| 2N  | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   |
| 8S  | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   |
| 4S  | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   |
| 10S | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   |
| 14S | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   |
| 18S | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   |
| 22S | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   |
| 26S | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   |
| 30S | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   |
| 34S | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   |
| 38S | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   |
| 42S | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   |
| 46S | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   |
| 50S | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   |
| 54S | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   |
| 58S | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   |
| 62S | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   |
| 66S | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   |
| 70S | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   |
| 74S | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   |
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| 82S | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   |
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<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
</tr>
</tbody>
</table>
IV. MODEL PERFORMANCE

A. OPERATING CHARACTERISTICS

1. Integration Program

The Mintz-Arakawa two-level model is written in IBM FORTRAN IV (see program listing, Chapter VII). The core size, central processing unit (CPU) time, and the input/output (I/O) requirements are based on experience with the FORTRAN IV compiler on an IBM 360/91 at UCLA for a 46-by-72 array. The model uses about 400,000 bytes of core memory, and each simulated day requires about 25 minutes of CPU time and about 1000 I/O requests. All calculations are performed with single-precision arithmetic.

The program in its present form is expected to start from nonzero initial data, and the history-restart tape is used to provide the initial values for continuing the calculations. The time to restart is specified by the parameters TAUID and TAUH (see the control-card sequence below). The tape is read until the last record is reached or until TAU from tape (expressed in hours) is less than or equal to TAUH + 24*TAUID. If the last record on the tape (identified by -TAU) is reached before the specified time to restart, the last set of data will be used. This allows automatic continuation of the calculation from the last time data were stored on the tape.

The input parameters TRST and TERM control the disposition of the old and new sets of data. If TRST = 0, the newly computed data will be written on the old history-restart tape as if no interruption had occurred; otherwise, the new data are written at the beginning of a different tape. If TRST ≠ 0, the parameter TERM determines whether the old history-restart tape is to be terminated after the restart data are read from it. If TERM = 0, the old tape is not terminated. The data-set reference number of the tape to be written is always 11. If TRST ≠ 0, the initial data is read from data-set reference number 10.

Various control parameters and constants in the program are read from cards, although several of the parameters that are read in the
model's present version no longer influence the program. The topography deck following card number fourteen (MARK) is read only if a change is desired in sea-surface temperature, land elevation, or the assigned distribution of ice. All numerical values follow the standard FORTRAN convention except KAPA, which is a real number. Only the constants NCYCLE, NC3, JM, IM, MARK, LDAY, LYM, and the sequence numbers in the topography deck are in integer format. The control-card sequence and layout are as follows:

<table>
<thead>
<tr>
<th>Card Number</th>
<th>Name</th>
<th>Card Columns</th>
<th>Units</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>ID</td>
<td>1-4</td>
<td>--</td>
<td>Four-character identifier</td>
</tr>
<tr>
<td>1</td>
<td>XLABL</td>
<td>5-40</td>
<td>--</td>
<td>Thirty-six-character identifier</td>
</tr>
<tr>
<td>2</td>
<td>TAUID</td>
<td>1-10</td>
<td>day</td>
<td>Day to start ( \text{start time = TAUH + 24 \cdot TAUID} )</td>
</tr>
<tr>
<td>2</td>
<td>TAUH</td>
<td>11-20</td>
<td>hour</td>
<td>Hour to start</td>
</tr>
<tr>
<td>2</td>
<td>TRST</td>
<td>21-30</td>
<td>--</td>
<td>Output-tape control parameter ( \text{see re-start procedure} )</td>
</tr>
<tr>
<td>2</td>
<td>TERM</td>
<td>31-40</td>
<td>--</td>
<td>Output-tape control parameter</td>
</tr>
<tr>
<td>3</td>
<td>TAUO</td>
<td>1-10</td>
<td>--</td>
<td>Not used</td>
</tr>
<tr>
<td>3</td>
<td>TAUD</td>
<td>11-20</td>
<td>hour</td>
<td>Frequency to recompute solar declination</td>
</tr>
<tr>
<td>3</td>
<td>TAUH</td>
<td>21-30</td>
<td>hour</td>
<td>Frequency to write history-restart tape</td>
</tr>
<tr>
<td>3</td>
<td>TAUE</td>
<td>31-40</td>
<td>day</td>
<td>Time to stop computation</td>
</tr>
<tr>
<td>3</td>
<td>TAUC</td>
<td>41-50</td>
<td>--</td>
<td>Not used</td>
</tr>
<tr>
<td>4</td>
<td>DTM</td>
<td>1-10</td>
<td>min</td>
<td>Time step</td>
</tr>
<tr>
<td>4</td>
<td>NCYCLE</td>
<td>11-15</td>
<td>Is(^{(1)})</td>
<td>Time extrapolation control parameter</td>
</tr>
<tr>
<td>4</td>
<td>NC3</td>
<td>16-20</td>
<td>Is(^{(1)})</td>
<td>Frequency to call COMP 4 and COMP 3</td>
</tr>
<tr>
<td>5</td>
<td>JM</td>
<td>1-5</td>
<td>--</td>
<td>Number of N-S grid points (in ( \pi ) grid)</td>
</tr>
<tr>
<td>5</td>
<td>IM</td>
<td>6-10</td>
<td>--</td>
<td>Number of E-W grid points (in ( \pi ) grid)</td>
</tr>
<tr>
<td>5</td>
<td>DLM</td>
<td>11-20</td>
<td>deg</td>
<td>Distance between N-S grid points</td>
</tr>
<tr>
<td>6</td>
<td>AX</td>
<td>1-10</td>
<td>--</td>
<td>Diffusion coefficient (not used)</td>
</tr>
</tbody>
</table>

\(^{(1)}\) The IS unit is one integration time step.
<table>
<thead>
<tr>
<th>Card Number</th>
<th>Name</th>
<th>Card Columns</th>
<th>Units</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>7</td>
<td>FMX</td>
<td>1-10</td>
<td>(10^{-5} \text{ sec}^{-1})</td>
<td>Shear-stress coefficient</td>
</tr>
<tr>
<td>7</td>
<td>ED</td>
<td>11-20</td>
<td>m</td>
<td>Constant used in air/ground</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>interaction</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>TCNV</td>
<td>21-30</td>
<td>sec</td>
<td>Relaxation time for cumulus</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>convection</td>
</tr>
<tr>
<td>8</td>
<td>RAD</td>
<td>1-10</td>
<td>km</td>
<td>Earth radius, (a)</td>
</tr>
<tr>
<td>8</td>
<td>GRAV</td>
<td>11-20</td>
<td>m (\text{ sec}^{-2})</td>
<td>Gravitational acceleration, (g)</td>
</tr>
<tr>
<td>8</td>
<td>DAY</td>
<td>21-30</td>
<td>hour</td>
<td>Length of day</td>
</tr>
<tr>
<td>9</td>
<td>RGAS</td>
<td>1-10</td>
<td>(m^{2} \text{ deg}^{-1} \text{ sec}^{-2})</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Gas constant, (R)</td>
</tr>
<tr>
<td>9</td>
<td>KAPA</td>
<td>11-20</td>
<td>--</td>
<td>Thermodynamic coefficient, (\kappa)</td>
</tr>
<tr>
<td>10</td>
<td>PSL</td>
<td>1-10</td>
<td>mb</td>
<td>Sea-level pressure</td>
</tr>
<tr>
<td>10</td>
<td>PTRP</td>
<td>11-20</td>
<td>mb</td>
<td>Tropospheric pressure, (p_{T})</td>
</tr>
<tr>
<td>11</td>
<td>PSF</td>
<td>1-10</td>
<td>mb</td>
<td>Surface pressure, (p_{S})</td>
</tr>
<tr>
<td>12</td>
<td>DLIC</td>
<td>1-10</td>
<td>--</td>
<td>Not used</td>
</tr>
<tr>
<td>13</td>
<td>KSET</td>
<td>1-10</td>
<td>--</td>
<td>Not used</td>
</tr>
<tr>
<td>14</td>
<td>MARK</td>
<td>1-3</td>
<td>--</td>
<td>Flag indicating presence of</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>topography deck (sea-surface</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>temperature and land elevation)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>and number of sets of cards to be</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>read. In 46-by-72 grid version,</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>MARK = 72.</td>
</tr>
</tbody>
</table>

15-376  Topography Deck -- see description below.

377   CLKSW  1-4  --  If the characters \(\text{OFF}\) are punched in columns 1 to 3 with column 4 blank, the solar declination will remain fixed.

377   RSETSW 11-14  --  If the characters \(\text{RESE}\) are punched in columns 1 to 4, the day and year counters (SDEDY and SDEYR) will be set to LDAY and LYR.

377   LDAY  21-23  day  Day of year if time is reset

377   LYR   31-34  year Year if time is reset

The topography deck is read only if \(\text{MARK} \neq 0\). The deck contains \(2 + 5 \cdot \text{MARK}\) cards and is read in subroutine INIT 2. The topography deck card layout is as follows:
The principal output of the model is written on magnetic tape, and a history-restart tape is written at specified intervals. Eighteen logical records are written with a frequency of TAUH: TAU and C, P, U, V, T, Q3, T¥PG, PT, GW, TS, GT, SN, TT, Q3T, SD, H, TD, -TAU and C. These arrays contain all constants and current variables, and in addition, several arrays of packed data generated in subroutine COMP 3. [Note
that TS is equivalent to UT(1,1,2) and SN is equivalent to VT(1,1,2) in the data from subroutine COMP 3. ¹ In the present version of the model these records are written on tape every 6 hours (= TAUH). The last logical record (-TAU,C) is identified as the last record written on the tape, and will be written over the next time the tape is written; hence, only seventeen records are saved every TAUH. A test is made before writing the tape to determine if it is properly positioned. About sixty sets of seventeen logical records can be saved on a 2400-ft reel of tape. The automatically printed output consists of the input parameters, the time at each integration step, and the amount of pressure added at each grid point every twenty-four hours of simulated time in the subroutine CMP.

2. Map-Generation Program

The map-generation program for use with the model uses about 520,000 bytes of core, and averages about 0.2 seconds of CPU time and about 5 I/O requests for each map generated. This program reads the data produced by the model and processes them to form arrays of data in map form. The source of the basic data may be tape or disk.

The tape input format is the same as the tape output from the model: TAU and C, P, U, V, T, Q3, TØPØG, PT, GW, TS, GT, SN, TT, Q3T, SD, H, TD. The first logical record on a disk is always TØPØG, which does not change during a run. The subsequent logical records for each time step that was saved are TAU and C, P, U, V, T, Q3, PT, GW, TS, GT, SN, TT, Q3T, SD.

The card input to the map-generation program consists of an interval and data-source control card, followed by as many as ninety-nine map selection cards. The end of the map selection card deck is indicated by a blank card. The interval and data-source control card contains TØ (the time, in days, to start generating the map arrays), TEND (the time, in days, to stop generating the map arrays), and TAPIN (the data-source indicator). The card layout is as follows:

¹Some arrays may be referred to by different names. For example, Q(J,I,K) contains π, U1, U3, V1, V3, T1, T3, and Q3 for K = 1 through 8. See the common and equivalence block in Chapter VII for more detail.
The desired maps will be generated for $T\Phi$, TEND, and for each intermediate time available from the data source. If the characters TAPE are punched in columns 21 to 24 (TAPIN), the data source is a tape; otherwise the source is assumed to be a disk.

The map selection cards contain MAPN$\Phi$ (the map number) and SURF (the $\sigma$ surface, $< 2.0$, or the pressure level, in millibars, at which the map is to be calculated). The card layout is as follows:

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Card Columns</th>
</tr>
</thead>
<tbody>
<tr>
<td>MAPN$\Phi$</td>
<td>1-2</td>
</tr>
<tr>
<td>SURF</td>
<td>3-12</td>
</tr>
</tbody>
</table>

Some values of SURF are not valid for certain maps, and in some cases the following convention has been used:

- **topography maps**: SURF $< 2.0$ for ocean temperature
- SURF $\geq 2.0$ for surface elevation

- **cloudiness maps**: SURF $\leq 0.5$ for high cloudiness
- SURF $= 1.0$ for low cloudiness
- $0.5 <$ SURF $\neq 1.0$ for middle cloudiness
- SURF $> 1.0$ for cloudiness (maximum)

The processed data representing each requested map array are written on tape along with various other data, and the tape may be used for further processing and map displays. The map array is dimensioned (JM, IM), where JM is the total number of north/south grid points and IM is the total number of east/west grid points. One logical
record is written for each map, and contains the following data:

<table>
<thead>
<tr>
<th>Name and Dimension</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>TAU (1)</td>
<td>Time in hours</td>
</tr>
<tr>
<td>ID (1)</td>
<td>Four-character identification from the model</td>
</tr>
<tr>
<td>MAPNØ (1)</td>
<td>Map number</td>
</tr>
<tr>
<td>NAME (13)</td>
<td>Map title</td>
</tr>
<tr>
<td>SURF (1)</td>
<td>Sigma surface or pressure level for which the map is generated</td>
</tr>
<tr>
<td>STAGI (1)</td>
<td>Logical variables indicating whether the maps are staggered (offset) in the I and J directions</td>
</tr>
<tr>
<td>STAGJ (1)</td>
<td>Logical variables indicating whether the maps are staggered (offset) in the I and J directions</td>
</tr>
<tr>
<td>SINT (1)</td>
<td>Not used in the present version</td>
</tr>
<tr>
<td>WØRK2 (JM,IM)</td>
<td>Map array</td>
</tr>
<tr>
<td>ZM (JM)</td>
<td>Zonal mean</td>
</tr>
<tr>
<td>ZM2 (JM)</td>
<td>Zonal mean, excluding points on land or ice</td>
</tr>
<tr>
<td>ZMM (1)</td>
<td>Global mean</td>
</tr>
</tbody>
</table>

The printed output consists of the input parameters, along with the map time, number, surface or level, and map title of each record as written on the tape.

B. SAMPLE MODEL OUTPUT

1. Maps of Selected Variables

To illustrate the general nature and structure of the solutions of the circulation model, a series of programmed map outputs for selected variables has been developed (see Map Routine Listing in Chapter VII). Presented here are samples of this output for the primary dependent variables \( p_s, u_1, u_3, v_1, v_3, T_1, T_3, \) and \( q_3 \) (as represented by the relative humidity), and for the geopotential heights. A selection of variables related to the heat and water balance in the model layers and at the surface is also given. These data are for day 400 (28 January, hour 0 GMT) of a basic or control simulation of
northern-hemisphere winter, with the program as listed in Chapter VII and with the fixed sea-surface temperature and ice distributions as shown in Chapter III.

For each of the maps shown below, a brief identification and description of the mapped quantity is given on the facing page, while the values of the minimum and dashed isolines and of the isoline interval are given at the upper right of each map's label. The symbols H and L designate locations of local maxima and minima, respectively, that are not resolved by the selected isoline interval. A rectangular map representation of the spherical grid has been used for convenience, with the points of the $\pi$ grid and continental outlines shown as in Fig. 3.12. For each map the designation $S/P$ denotes the $\sigma$ level of the map, with $S/P = 1$ for those maps without a level designation as well as for the surface. The velocity, temperature, and geopotential heights may be generated for any $0 \leq \sigma \leq 1$ by extrapolation and interpolation from the solutions at $\sigma = 1/4$ and $\sigma = 3/4$, and may also be displayed for any pressure surface $p_T \leq p \leq p_s$ (see Map Routine Listing, Chapter VII). The complete list of available maps is given in Chapter VII just before the map code listings.

Those maps listed in Table 4.1 are given in $\sigma$ coordinates, with the exception of the geopotential height in Map 6, which is given for both $\sigma$ and $p$ surfaces.
### Table 4.1

**LIST OF MAPS OF SELECTED VARIABLES**

<table>
<thead>
<tr>
<th>Map</th>
<th>Title</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Smoothed sea-level pressure ($\sigma = 1$)</td>
</tr>
<tr>
<td>2</td>
<td>Zonal (west/east) wind component ($\sigma = 1/4, 3/4$)</td>
</tr>
<tr>
<td>3</td>
<td>Meridional (south/north) wind component ($\sigma = 1/4, 3/4$)</td>
</tr>
<tr>
<td>4</td>
<td>Temperature ($\sigma = 1/4, 3/4$)</td>
</tr>
<tr>
<td>6</td>
<td>Geopotential height ($\sigma = 1/4, 3/4$; $p = 400, 800$ mb)</td>
</tr>
<tr>
<td>8</td>
<td>Total diabatic heating ($\sigma = 1/4, 3/4$)</td>
</tr>
<tr>
<td>9</td>
<td>Large-scale precipitation rate</td>
</tr>
<tr>
<td>10</td>
<td>Sigma vertical velocity ($\sigma = 1/2$)</td>
</tr>
<tr>
<td>11</td>
<td>Relative humidity ($\sigma = 3/4$)</td>
</tr>
<tr>
<td>12</td>
<td>Precipitable water</td>
</tr>
<tr>
<td>13</td>
<td>Convective precipitation rate</td>
</tr>
<tr>
<td>14</td>
<td>Evaporation rate ($\sigma = 1$)</td>
</tr>
<tr>
<td>15</td>
<td>Sensible heat flux ($\sigma = 1$)</td>
</tr>
<tr>
<td>16</td>
<td>Lowest-level convection ($\sigma = 1$)</td>
</tr>
<tr>
<td>19</td>
<td>Long-wave heating in layers ($\sigma = 0$ to $1/2$, $\sigma = 1/2$ to 1)</td>
</tr>
<tr>
<td>20</td>
<td>Short-wave absorption (heating) in layers ($\sigma = 0$ to $1/2$, $\sigma = 1/2$ to 1)</td>
</tr>
<tr>
<td>22</td>
<td>Surface short-wave absorption ($\sigma = 1$)</td>
</tr>
<tr>
<td>23</td>
<td>Surface air temperature ($\sigma = 1$)</td>
</tr>
<tr>
<td>24</td>
<td>Ground temperature ($\sigma = 1$)</td>
</tr>
<tr>
<td>25</td>
<td>Ground wetness ($\sigma = 1$)</td>
</tr>
<tr>
<td>26</td>
<td>Cloudiness (high, middle, low)</td>
</tr>
<tr>
<td>28</td>
<td>Total convective heating in layers ($\sigma = 0$ to $1/2$, $\sigma = 1/2$ to 1)</td>
</tr>
<tr>
<td>29</td>
<td>Latent heating ($\sigma = 1/2$ to 1)</td>
</tr>
<tr>
<td>30</td>
<td>Surface long-wave cooling ($\sigma = 1$)</td>
</tr>
<tr>
<td>31</td>
<td>Surface heat balance ($\sigma = 1$)</td>
</tr>
</tbody>
</table>
Fig. 4.1. Smoothed Sea-Level Pressure (Map 1)

(mb - 1000 mb)

This map is calculated from the expression

\[ p_s \exp \left( \frac{\phi_4}{RT} \right) - 1000 \text{ mb} \]

where \( p_s \) is the surface pressure, \( \phi_4 \) is the geopotential at the ground, \( R \) is the dry-air gas constant, and \( \bar{T} \) is the average temperature between level 4 and sea level, given by

\[ \bar{T} = T_4 + \frac{1}{2} \frac{\gamma \phi_4}{g} \]

Here \( T_4 = \frac{3}{2} T_3 - \frac{1}{2} T_1 \) is the air temperature extrapolated to the surface, \( g \) is acceleration of gravity, and \( \gamma \) is an assumed constant lapse rate in the hypothetical layer between the earth's surface and sea level, taken here as \( \gamma = 0.6 \text{ deg C/100 m} \). The resulting sea-level pressures are then averaged over the local 9 points at which pressure is computed. At nonpolar points this smoothing operator is

\[ ( \cdot )_{00}, \text{smoothed} = \frac{1}{16} \left[ ( \cdot )_{-22} + 2( \cdot )_{02} \right. \]

\[ + ( \cdot )_{22} + 2( \cdot )_{-20} + 4( \cdot )_{00} + 2( \cdot )_{20} \]

\[ + ( \cdot )_{-2-2} + 2( \cdot )_{0-2} + ( \cdot )_{2-2} \]

where the subscripts (in \( \pi \)-centered notation) refer to adjacent points of the \( \pi \) grid (see Fig. 3.6).
Fig. 4.1 -- Smoothed sea-level pressure. The dashed line is 1000 mb and the isoline interval is 5 mb.
Fig. 4.2. Zonal (West/East) Wind Component (Map 2) (m sec$^{-1}$)

This map is calculated from the expression

$$u = 2 \left[ u_3 \left( \sigma - \frac{1}{4} \right) + u_1 \left( \frac{3}{4} - \sigma \right) \right]$$

with $0 \leq \sigma \leq 1$ an arbitrary $\sigma$ surface. For $\sigma = 1/4$ and $\sigma = 3/4$ this reduces to the primary variables $u_1$ and $u_3$, respectively, and for other $\sigma$ represents a linear extrapolation and interpolation of $u$ in $\sigma$ (or $p$) space. The zonal wind component may also be generated for an arbitrary pressure surface $p$, in which case $\sigma$ in the above expression is replaced by $(p - p_T)/p^u$, where $p^u$ is the average of $p$ at the four $\pi$ points surrounding each $u,v$ point. The symbols $E$ and $W$ designate locations of local maxima of positive (eastward) and negative (westward) zonal wind speed, respectively, which are not resolved by the selected isoline interval.

Level shown in map at right: $\sigma = 1/4$. 
Fig. 4.2 -- Zonal (u) wind speed at $\sigma = 1/4$. The dashed line is 0 and the isoline interval is $5 \text{ m sec}^{-1}$. 
Fig. 4.3. Zonal (West/East) Wind Component (Map 2) (m sec\(^{-1}\))

This map is calculated from the expression

\[
u = 2 \left[ u_3 \left( \sigma - \frac{1}{4} \right) + u_1 \left( \frac{3}{4} - \sigma \right) \right]
\]

with 0 ≤ \(\sigma\) ≤ 1 an arbitrary \(\sigma\) surface. For \(\sigma = 1/4\) and \(\sigma = 3/4\), this reduces to the primary variables \(u_1\) and \(u_3\), respectively, and for other \(\sigma\) represents a linear extrapolation and interpolation of \(u\) in \(\sigma\) (or \(p\)) space. The zonal wind component may also be generated for an arbitrary pressure surface \(p\), in which case \(\sigma\) in the above expression is replaced by \((p - p_T)/(\text{\(\pi\)}^u)\), where \(\text{\(\pi\)}^u\) is the average of \(\pi\) at the four \(\pi\) points surrounding each \(u,v\) point. The symbols E and W designate locations of local maxima of positive (eastward) and negative (westward) zonal wind speed, respectively, which are not resolved by the selected isoline interval.

Level shown in map at right: \(\sigma = 3/4\).
Fig. 4.3 -- Zonal (u) wind speed at $a = 3/4$. The dashed line is 0 and the isoline interval is 5 m sec$^{-1}$. 
Fig. 4.4. Meridional (South/North) Wind Component (Map 3)

(m sec\(^{-1}\))

The map is calculated from the expression

\[ v = 2 \left[ v_3 \left( \sigma - \frac{1}{4} \right) + v_1 \left( \frac{3}{4} - \sigma \right) \right] \]

with \(0 \leq \sigma \leq 1\) an arbitrary \(\sigma\) surface. For \(\sigma = 1/4\) and \(\sigma = 3/4\), this reduces to the primary variables \(v_1\) and \(v_3\), respectively, and for other \(\sigma\) represents a linear extrapolation and interpolation of \(v\) in \(\sigma\) (or \(p\)) space. The meridional wind component may also be generated for an arbitrary pressure surface \(p\), in which case \(\sigma\) in the above expression is replaced by \((p - p_i)/(\bar{\pi}^u)\), where \(\bar{\pi}^u\) is the average of \(\pi\) at the four \(\pi\) points surrounding each \(u,v\) point. The symbols \(N\) and \(S\) designate locations of local maxima of positive (northward) and negative (southward) meridional wind speed, respectively, which are not resolved by the selected isoline interval.

Level shown in map at right: \(\sigma = 1/4\).
Fig. 4.4 -- Meridional (v) wind speed at $\sigma = 1/4$. The dashed line is 0 and the isoline interval is 5 m sec$^{-1}$. 
Fig. 4.5. Meridional (South/North) Wind Component (Map 3)

\[ m \text{ sec}^{-1} \]

This map is calculated from the expression

\[ v = 2 \left[ v_3 \left( \sigma - \frac{1}{4} \right) + v_1 \left( \frac{3}{4} - \sigma \right) \right] \]

with \( 0 \leq \sigma \leq 1 \) an arbitrary \( \sigma \) surface. For \( \sigma = 1/4 \) and \( \sigma = 3/4 \), this reduces to the primary variables \( v_1 \) and \( v_3 \), respectively, and for other \( \sigma \) represents a linear extrapolation and interpolation of \( v \) in \( \sigma \) (or \( p \)) space. The meridional wind component may also be generated for an arbitrary pressure surface \( p \), in which case \( \sigma \) in the above expression is replaced by \( (p - p_N)/(p^u) \), where \( p^u \) is the average of \( p \) at the four \( p \) points surrounding each \( u,v \) point. The symbols \( N \) and \( S \) designate locations of local maxima of positive (northward) and negative (southward) meridional wind speed, respectively, which are not resolved by the selected isoline interval.

Level shown in map at right: \( \sigma = 3/4 \).
Fig. 4.5 -- Meridional (v) wind speed at $\sigma = 3/4$. The dashed line is 0 and the isoline interval is 5 m sec$^{-1}$.
Fig. 4.6. Temperature (Map 4)

deg C

This map is calculated from the expression

\[ T = \frac{(\sigma \pi + p_T)^\kappa}{p_3^\kappa - p_1^\kappa} \left\{ \frac{T_1^\kappa}{p_1^\kappa} \left[ (\sigma \pi + p_T)^\kappa - (\sigma \pi + p_T)^\kappa \right] \right\} - 273.1 \text{ deg} \]

with \( 0 \leq \sigma \leq 1 \) an arbitrary \( \sigma \) surface. This represents the linear interpolation and extrapolation of the potential temperature \( \theta = T(p_o/p)^\kappa \) in \( p^\kappa \) space. For \( \sigma = 1/4 \) and \( \sigma = 3/4 \), this reduces to the primary variables \( T_1 \) and \( T_3 \), respectively. Here \( p_T \) is the tropopause pressure (= 200 mb) and \( \kappa = 0.286 \). The temperature may also be obtained at an arbitrary pressure surface \( p_T \leq p \leq p_s = \pi + p_T \) by replacing \( (\sigma \pi + p_T) \) in the above expression by \( p \).

Level shown in map at right: \( \sigma = 1/4 \).
Fig. 4.6 -- Temperature at $\sigma = 1/4$. The dashed line is $-20^\circ \text{C}$ and the isoline interval is 5 deg C.
Fig. 4.7. Temperature (Map 4) (deg C)

This map is calculated from the expression

\[ T = \frac{(\sigma \pi + p_T)^\kappa}{p_3^\kappa - p_1^\kappa} \left\{ \begin{array}{c} \frac{T_1}{p_1^\kappa} [p_3^\kappa - (\sigma \pi + p_T)^\kappa] \\ + \frac{T_3}{p_3^\kappa} [(\sigma \pi + p_T)^\kappa - p_1^\kappa] \end{array} \right\} - 273.1 \text{ deg} \]

with \( 0 \leq \sigma \leq 1 \) an arbitrary \( \sigma \) surface. This represents the linear interpolation and extrapolation of the potential temperature \( \theta = T(p_0/p)^\kappa \) in \( p^\kappa \) space. For \( \sigma = 1/4 \) and \( \sigma = 3/4 \), this reduces to the primary variables \( T_1 \) and \( T_3 \), respectively. Here \( p_T \) is the tropopause pressure (= 200 mb), and \( \kappa = 0.286 \). The temperature may also be obtained at an arbitrary pressure surface \( p_T \leq p \leq p_s = \pi + p_T \) by replacing \( (\sigma \pi + p_T) \) in the above expression by \( p \).

Level shown in map at right: \( \sigma = 3/4 \).
Fig. 4.7 -- Temperature at $\sigma = 3/4$. The dashed line is 0°C and the isoline interval is 5 deg C.
Fig. 4.8. Geopotential Height of $\sigma$ Surface (Map 6)

(100 m)

This map is calculated from the expression

$$z = \frac{\phi + \phi_4}{10^2 g}$$

where $\phi_4$ is the geopotential of the earth's surface, $g$ is the acceleration of gravity, and where the geopotential $\phi$ of an arbitrary $\sigma$ surface is given by

$$\phi = \frac{R}{2} \left\{ T_1 \left[ \frac{p_1 - p_T}{p_1} + \frac{p_3 - p_1 + 2 \rho_1^2}{p_1^2} \frac{2\kappa}{p_3 - p_1} \frac{4(\sigma \pi + p_T)\rho_1}{p_3 - p_1} - 2(\sigma \pi + p_T)^2 \right] } + T_3 \left[ \frac{p_3 - p_T}{p_3} + \frac{2\kappa}{p_3} \frac{2\rho_1^2}{p_3} \frac{4(\sigma \pi + p_T)\rho_1}{p_3} - 2(\sigma \pi + p_T)^2 \right] \right\}$$

Here $p_T$ is the tropopause pressure (= 200 mb), $\kappa = 0.286$, and $R$ is the dry-air gas constant. For $\sigma = 1/4$ and $\sigma = 3/4$, this reduces to $\phi_1$ and $\phi_3$, respectively, while for other $\sigma$ it represents a linear interpolation and extrapolation of the potential temperature in $p^\kappa$ space. The geopotential height of an arbitrary pressure surface $p_T \leq p \leq \pi + p_T$ may also be obtained by replacing $(\sigma \pi + p_T)$ in the above expression by $p$ (see Figs. 4.8a and 4.9a).

Level shown in map at right: $\sigma = 1/4$. 
Fig. 4.8 -- Geopotential height at $\sigma = 1/4$. The dashed line is 7000 m and the isoline interval is 100 m.
Fig. 4.8a. Geopotential Height of Pressure Surface (Map 6)

(100 m)

This map is calculated from the expression

\[ z = \frac{\phi + \phi_4}{10^2 g} \]

where \( \phi_4 \) is the geopotential of the earth's surface, \( g \) is the acceleration of gravity, and where the geopotential \( \phi \) of an arbitrary \( p \) surface is given by

\[
\phi = \frac{R}{2} \left[ T_1 \left( \frac{p_1 - p_T}{p_1} + \frac{2\kappa p_3 - p_1}{2p_1 p_3} + \frac{2\kappa p_3 p_1 - 4p_1^\kappa p_3^\kappa + 2p_2^\kappa}{2\kappa p_1^\kappa (p_3^\kappa - p_1^\kappa)} \right) \right]
\]

\[ + T_3 \left( \frac{p_3 - p_T}{p_3} + \frac{2\kappa p_3 - p_1}{2p_1 p_3} + \frac{2\kappa p_3 p_1 - 4p_1^\kappa p_3^\kappa - 2p_2^\kappa}{2\kappa p_3^\kappa (p_3^\kappa - p_1^\kappa)} \right) \]

Here \( p_T \) is the tropopause pressure (= 200 mb), \( \kappa = 0.286 \), and \( R \) is the dry-air gas constant. For \( p = p_1 \) and \( p = p_3 \), this reduces to the height of the 400-mb and 800-mb surfaces, respectively, while for other \( p \) it represents a linear interpolation and extrapolation of the potential temperature in \( p^\kappa \) space. The geopotential height of an arbitrary \( \sigma \) surface \( 0 \leq \sigma \leq 1 \) may also be obtained by replacing \( p \) in the above expression by \( (\sigma\pi + p_T) \) (see Figs. 4.8 and 4.9).

Level shown in map at right: \( p = 400 \) mb.
Fig. 4.8a -- Geopotential height at $p = 400$ mb. The dashed line is $7000$ m and the isoline interval is $100$ m.
Fig. 9. Geopotential Height of σ Surface (Map 6)

(100 m)

This map is calculated from the expression

\[ z = \frac{\phi + \phi_4}{10^2 g} \]

where \( \phi_4 \) is the geopotential of the earth's surface, \( g \) is the acceleration of gravity, and where the geopotential \( \phi \) of an arbitrary \( \sigma \) surface is given by

\[
\phi = \frac{R}{2} \left\{ T_1 \left[ \frac{p_1 - p_T}{p_1} + \frac{2\kappa}{p_3 - p_1} + \frac{2\kappa}{p_1 p_3} - 2p_1^\kappa p_3^\kappa - 4(\sigma \pi + p_T)^\kappa p_3^\kappa + 2(\sigma \pi + p_T)^{2\kappa}}{2\kappa p_1^\kappa (p_3^\kappa - p_1^\kappa)} \right] \right. \\
\left. + T_3 \left[ \frac{p_3 - p_T}{p_3} + \frac{2\kappa}{p_3 - p_1} + \frac{2\kappa}{p_1 p_3} + 4(\sigma \pi + p_T)^\kappa p_1^\kappa - 2(\sigma \pi + p_T)^{2\kappa}}{2\kappa p_3^\kappa (p_3^\kappa - p_1^\kappa)} \right] \right\}
\]

Here \( p_T \) is the tropopause pressure \((= 200 \text{ mb})\), \( \kappa = 0.286 \), and \( R \) is the dry-air gas constant. For \( \sigma = 1/4 \) and \( \sigma = 3/4 \), this reduces to \( \phi_1 \) and \( \phi_3 \), respectively, while for other \( \sigma \) it represents a linear interpolation and extrapolation of the potential temperature in \( p^\kappa \) space.

The geopotential height of an arbitrary pressure surface \( p_T \leq p \leq \pi + p_T \) may also be obtained by replacing \( (\sigma \pi + p_T) \) in the above expression by \( p \) (see Figs. 4.8a and 4.9a).

Level shown in map at right: \( \sigma = 3/4 \).
Fig. 4.9 -- Geopotential height at $a = 3/4$. The dashed line is 2500 m and the isoline interval is 250 m.
Fig. 4.9a. Geopotential Height of Pressure Surface (Map 6)

(100 m)

This map is calculated from the expression

\[ z = \frac{\phi + \phi_4}{10^2 g} \]

where \( \phi_4 \) is the geopotential of the earth's surface, \( g \) is the acceleration of gravity, and where the geopotential \( \phi \) of an arbitrary \( p \) surface is given by

\[ \phi = \frac{R}{2} \left[ T_1 \left( \frac{p_1 - p_T}{p_1} + \frac{2^\kappa}{p_3 - p_1} + \frac{2^\kappa}{p_1 p_3} - \frac{4^\kappa p_1 p_3}{2^\kappa p_1 (p_3 - p_1)} \right) \right] \\
+ T_2 \left[ \frac{p_3 - p_T}{p_3} + \frac{2^\kappa}{p_3 - p_1} + \frac{2^\kappa}{2 p_1 p_3} - \frac{4^\kappa p_1 p_3}{2^\kappa p_1 (p_3 - p_1)} \right] \]

Here \( p_T \) is the tropopause pressure (= 200 mb), \( \kappa = 0.286 \), and \( R \) is the dry-air gas constant. For \( p = p_1 \) and \( p = p_3 \), this reduces to the height of the 400-mb and 800-mb surfaces, respectively, while for other \( p \) it represents a linear interpolation and extrapolation of the potential temperature in \( p^\kappa \) space. The geopotential height of an arbitrary \( \sigma \) surface \( 0 \leq \sigma \leq 1 \) may also be obtained by replacing \( p \) in the above expression by \( (\sigma \pi + p_T) \) (see Figs. 4.8 and 4.9).

Level shown in map at right: \( p = 800 \) mb.
Fig. 4.9a -- Geopotential height at p = 800 mb. The dashed line is 2300 m and the isoline interval is 100 m.
Fig. 4.10. Total Heating (Map 8)

(deg day$^{-1}$)

This map is calculated from the expression

$$H = 2 \left[ H_1 \left( \frac{3}{4} - \sigma \right) + H_3 \left( \sigma - \frac{1}{4} \right) \right] 48$$

where $H_1$ and $H_3$ are the net temperature changes in the upper and lower layers, respectively, over a time interval $5\Delta t$ (the time interval over which the heating is calculated by means of the subroutine COMP 3). Here

$$H_1 = (\Delta T_1)^{CM} + (\Delta T_1)^{CP} + \left( \frac{A_1 + R_2 - R_0}{c_p} \frac{2g}{\pi} \frac{1}{48} \right) \frac{L}{c_p} PREC + \left( \frac{A_3 + R_4 - R_2 + F_4}{c_p} \frac{2g}{\pi} \frac{1}{48} \right)$$

$$H_3 = (\Delta T_3)^{CM} + (\Delta T_3)^{CP} + \frac{L}{c_p} PREC $$

where $(\Delta T_1)^{CM}$ and $(\Delta T_1)^{CP}$ are the temperature changes (over $5\Delta t$) due to middle-level and penetrating convective heating in the upper layer, respectively [with $(\Delta T_3)^{CM}$ and $(\Delta T_3)^{CP}$ similarly defined for the lower layer], $A_1$ and $A_3$ are the net rates of short-wave radiant-energy absorption in the two layers, $R_0$, $R_2$, and $R_4$ are the upward long-wave radiative flux at each level, $F_4$ is the upward flux of sensible heat from the surface, $L$ is the latent heat of condensation, and PREC is the large-scale condensation or precipitation rate. The factor $(2g/\pi)^{-1}$ represents the mass in each layer (per unit area), and the factor 48 (the number of times in a day the heating is calculated) converts to the desired units (see Chapter II, Sections F and G, and instructions 11410 to 11490, COMP 3, for further details).

For $\sigma = 1/4$ and $\sigma = 3/4$, this expression reduces to the net heat-induced temperature changes in the upper and lower layers, $H_1$ and $H_3$, respectively. For other $0 \leq \sigma \leq 1$ it represents the assignment of the layer's temperature change to its midpoint, and the subsequent linear interpolation and extrapolation in $\sigma$ (or p) space. This representation of the diabatic heating may also be generated for an arbitrary pressure, p, by replacing $\sigma$ in the above expression by $(p - p_A)/\pi$.

Level shown in map at right: $\sigma = 1/4$. 
Fig. 4.10 -- Total diabatic heating rate at $\sigma = 1/4$. The dashed line is 0 and the isoline interval is 5 deg day$^{-1}$.
Fig. 4.11. Total Heating (Map 8)

(deg day$^{-1}$)

This map is calculated from the expression

\[ H = 2 \left[ H_1 \left( \frac{3}{4} - \sigma \right) + H_3 \left( \sigma - \frac{1}{4} \right) \right] 48 \]

where $H_1$ and $H_3$ are the net temperature changes in the upper and lower layers, respectively, over a time interval $5\Delta t$ (the time interval over which the heating is calculated by means of the subroutine COMP 3). Here

\[ H_1 = (\Delta T_1)^{CM} + (\Delta T_1)^{CP} + \frac{A_1 + R_2 - R_0}{c_p} \frac{2g}{\pi} \frac{1}{48} \]

\[ H_3 = (\Delta T_3)^{CM} + (\Delta T_3)^{CP} + \frac{L}{c_p} \text{ PREC} + \frac{A_3 + R_4 - R_2 + F4}{c_p} \frac{2g}{\pi} \frac{1}{48} \]

where $(\Delta T_1)^{CM}$ and $(\Delta T_1)^{CP}$ are the temperature changes (over $5\Delta t$) due to middle-level and penetrating convective heating in the upper layer, respectively [with $(\Delta T_3)^{CM}$ and $(\Delta T_3)^{CP}$ similarly defined for the lower layer], $A_1$ and $A_3$ are the net rates of short-wave radiant-energy absorption in the two layers, $R_0$, $R_2$, and $R_4$ are the upward long-wave radiative flux at each level, $F4$ is the upward flux of sensible heat from the surface, $L$ is the latent heat of condensation, and PREC is the large-scale condensation or precipitation rate. The factor $(2g/\pi)^{-1}$ represents the mass in each layer (per unit area), and the factor 48 (the number of times in a day the heating is calculated) converts to the desired units (see Chapter II, Sections F and G, and instructions 11410 to 11490, COMP 3, for further details).

For $\sigma = 1/4$ and $\sigma = 3/4$, this expression reduces to the net heat-induced temperature changes in the upper and lower layers, $H_1$ and $H_3$, respectively. For other $0 \leq \sigma \leq 1$ it represents the assignment of the layer's temperature change to its midpoint, and the subsequent linear interpolation and extrapolation in $\sigma$ (or $p$) space. This representation of the diabatic heating may also be generated for an arbitrary pressure, $p$, by replacing $\sigma$ in the above expression by $(p - p_T)/\pi$.

Level shown in map at right: $\sigma = 3/4$. 
Fig. 4.11 -- Total diabatic heating rate at $\sigma = 3/4$. The dashed line is 0 and the isoline interval is 5 deg day$^{-1}$. 
Fig. 4.12. Large-Scale Precipitation Rate (Map 9)

\( \text{(mm day}^{-1} \text{)} \)

This map is calculated from the expression

\[
\text{PREC} = \left( \frac{\pi}{2g} \right) 48 \frac{10^2}{\rho_w}
\]

where the large-scale precipitation rate (PREC) is taken equal to the rate of generation of water vapor in excess of saturation (i.e., the condensation rate) in the lower layer, and is given by

\[
\text{PREC} = \begin{cases} 
[q_3 - q_s(T_3)](1 + \gamma_3)^{-1}, & q_3 > q_s(T_3) \\
0, & \text{otherwise}
\end{cases}
\]

where \( q_3 \) is the water-vapor mixing ratio at level 3, \( q_s(T_3) \) is the saturated mixing ratio at the ambient level-3 temperature \( T_3 \) (see Fig. 4.14), and the parameter \( \gamma_3 = L q_s(T_3) (c_p T_3^2)^{-1} \) 54.18 deg, with \( L \) the latent heat of condensation and \( c_p \) the dry-air specific heat at constant pressure. The factor \( \pi/2g \) represents the mass (per unit area) in the lower-layer air column (\( \sigma = 1 \) to \( \sigma = 1/2 \)). The factor 48 (the ratio of 1 day to 5\( \Delta t \)) represents the number of times per day the precipitation (PREC) is computed by means of the subroutine COMP 3. Together with the density of water, \( \rho_w = 1 \text{ g cm}^{-3} \), the factor \( 10^2 \) converts to the desired units. See Chapter II, Section F and instructions 8610 to 8690, COMP 3, for further details.
Fig. 4.12 -- Large-scale precipitation rate. The dashed line is 4 mm day$^{-1}$ and the isoline interval is 2 mm day$^{-1}$. 
Fig. 4.13. Sigma Vertical Velocity (Map 10)

(mb hr\(^{-1}\))

This map is calculated from the expression

\[ \pi^* = \frac{\dot{S}}{2n\nu} \]

where \( \dot{\sigma} = \dot{\sigma}_2 = d\sigma/dt \) at level 2 and \( \dot{S} \) is a measure of the difference in horizontal mass convergence between levels 1 and 3, given by Eq. (2.34), Chapter II, as

\[ \dot{S} = \frac{1}{2} \left[ \left( \frac{\partial u^*_3}{\partial x} + \frac{\partial v^*_3}{\partial y} \right) - \left( \frac{\partial u^*_1}{\partial x} + \frac{\partial v^*_1}{\partial y} \right) \right] \]

where \( u^* = n\nu u \) and \( v^* = m\nu v \) are weighted mass fluxes at the levels 1 or 3, and \( n \) and \( m \) are the meridional distance (y) and zonal distance (x) between \( u, v \) grid points. The sigma vertical velocity may also be written \( \pi^* = \omega - \sigma^* \), where \( \omega = dp/dt \) is the isobaric vertical velocity and \( \dot{\nu} = dp_S/dt \), with \( p_S \) the surface pressure. See Chapter II for further details of \( \dot{S} \), representing an integration of the equation of continuity. See instructions 4130 to 4550, COMP 1, for further details.
Fig. 4.13 -- Sigma vertical velocity. The dashed line is 0 and the isoline interval is 10 mb hr$^{-1}$. 
Fig. 4.14. Relative Humidity (Map 11) (percent)

This map is calculated from the expression

$$q_3 \frac{10^2}{q_s(T_3)}$$

where $q_3$ is the water-vapor mixing ratio at level 3 and $q_s(T_3)$ is the saturation mixing ratio at the ambient level-3 air temperature $T_3$.

Here $q_s(T_3)$ is given by

$$q_s(T_3) = \frac{0.622 e_s(T_3)}{0.1 p_3 - e_s(T_3)}$$

where $p_3$ is the (total) pressure at level 3, and the saturation vapor pressure $e_s(T_3)$ is given by the semi-empirical formula

$$e_s(T_3) = 10 \exp(8.4051 - 2353 \text{ deg}/T_3)$$

Both $p_3$ and $e_s$ here are in the units cb (centibar = $10^{-2}$ bar = 10 mb). These relationships permit a supersaturation of a few percent in very moist air.

All of the atmospheric humidity is carried in the model at level 3 (i.e., $q_1 \equiv 0$), so that Map 11 is always for the level $\sigma = 3/4$. 
Fig. 4.14 -- Relative humidity at $\sigma = 3/4$. The dashed line is 60 percent and the isoline interval is 20 percent.
This map is calculated from the expression

\[ q_3 \left( \frac{\pi}{2g} \right) \frac{10}{\rho_w} \]

where \( q_3 \), the mixing ratio at level 3, is interpreted as the average mixing ratio between the surface (\( \sigma = 1 \)) and level 2 (\( \sigma = 1/2 \)), and where the density of water, \( \rho_w \), is taken as 1 g cm\(^{-3} \), which together with the factor 10 serves to give the desired units. The factor \( \pi/2g \) represents the mass (per unit area) in the lower half of the air column (\( \sigma = 1 \) to \( \sigma = 1/2 \)), and results from the vertical integration of the water-vapor distribution.
Fig. 4.15 — Total precipitable water in column from $\sigma = 1$ to $\sigma = 1/2$. The dashed line is 1 cm and the isoline interval is 1 cm.
Fig. 4.16. Convective Precipitation Rate (Map 13)

(mm day$^{-1}$)

This map is calculated from the expression

$$\frac{(\Delta T_1)_{CM} + (\Delta T_1)_{CP} + (\Delta T_3)_{CM} + (\Delta T_3)_{CP}}{L/c_p} \frac{48 \cdot 10^2}{\rho_w}$$

where $(\Delta T_1)_{CM}$ and $(\Delta T_1)_{CP}$ are the temperature changes (over $5\Delta t$) due to middle-level and penetrating convective heat transport in the upper layer, respectively [with $(\Delta T_3)_{CM}$ and $(\Delta T_3)_{CP}$ similarly defined for the lower layer], $L$ is the latent heat of condensation, $c_p$ is the specific heat at constant pressure, $\rho_w = 1 \text{ g cm}^{-3}$ is the density of water, the factor $\pi/2g$ represents the mass in each layer (per unit area), and the factor 48 (the number of $5\Delta t$ intervals in one day) together with the factor $10^2$ serves to convert to the desired units. The quantity

$$\left[\frac{(\Delta T_1)_{CM} + (\Delta T_1)_{CP} + (\Delta T_3)_{CM} + (\Delta T_3)_{CP}}{L/c_p}\right]^{-1} = \text{Cl} + \text{PCl} + \text{C3} + \text{PC3}$$

in FORTRAN notation, and corresponds to the quantity PREC in Map 9 for the large-scale precipitation rate.

In the map shown on the right, the convective precipitation rate has a maximum of approximately 244 mm day$^{-1}$. This rate, however, lasts for a relatively short time, and, due to the nature of the computed convective heating, characteristically occurs at isolated grid points. See instructions 8700 to 8890, 9140 to 9390, COMP 3, and Chapter II, Subsection F.3, for further details.
Fig. 4.16 -- Convective precipitation rate. The dashed line is 100 mm day$^{-1}$ and the isoline interval is 50 mm day$^{-1}$. 
Fig. 4.17. Evaporation Rate (Map 14)

This map is calculated from the expression

\[
\frac{E_4}{\rho_w} \cdot 10 \text{ DAY} = \frac{C_D \rho_4}{\rho_w} \left( \left| V_s \right|^{\pi}_{100} + 2.0 \text{ m sec}^{-1} \right) \left[ \text{WET} \cdot q_s(T_g) + \frac{5418 \text{ deg} q_s(T_g)}{T^2_g} (TGR - T_g) - Q4 \right] 10^3 \text{ DAY}
\]

where \(E_4\) is the evaporation in g cm\(^{-2}\) sec\(^{-1}\), \(\rho_4\) is the surface air density, \(\rho_w = 1\) g cm\(^{-3}\) the density of water, WET a (calculated) ground wetness parameter, \(q_s(T_g)\) the saturated mixing ratio at the (computed) ground temperature \(T_g\), TGR a (computed) ground temperature parameter including the effects of radiation, and Q4 a measure of the mixing ratio at level 4. The surface drag coefficient \(C_D\) is given by

\[
C_D = \begin{cases} 
\min \left[ \left( 1.0 + 0.07 \left| \frac{V_s}{100} \right|^{\pi} \right) 10^{-3}, 0.0025 \right], & \text{if ocean} \\
0.002 + 0.006 \left( \frac{z_4}{5000} \text{ m} \right), & \text{otherwise}
\end{cases}
\]

with \(z_4\) the elevation of the surface. Here \(\left| V_s \right|^{\pi}_{100}\) is given in terms of the wind speeds at the four velocity points surrounding a pressure (or temperature) point by the expression (in \(\pi\)-centered notation)

\[
\left| V_s \right|^{\pi}_{100} = \frac{1}{2} \left[ \left| V_s \right|^{2}_{11} + \left| V_s \right|^{2}_{-11} + \left| V_s \right|^{2}_{-1-1} + \left| V_s \right|^{2}_{1-1} \right]^{\frac{1}{2}}
\]

where \(V_s = 0.7 |V_4|\) and \(V_4 = \frac{3}{2} V_3 - \frac{1}{2} V_1\) (the wind extrapolated to level 4). The additive term 2.0 m sec\(^{-1}\) is an empirical correction for gustiness, and the factors 10, 10\(^3\), and DAY (= 86,400) convert to the desired units.

The term Q4 is interpreted as the effective moisture just above the surface, and the terms in WET represent the effective surface moisture. The entire term in [ ] thus represents the vertical moisture gradient near the earth's surface. As shown in the map on the right, most of the evaporation occurs over the ocean [where the term \((TGR - T_g)\) is zero], although the evaporation is occasionally negative elsewhere (representing condensation on the surface). See instructions 11220 to 11290, COMP 3, and Chapter II, Subsection P.6, for further details.
Fig. 4.17 -- Surface evaporation rate. The dashed line is 10 mm day$^{-1}$ and the isoline interval is 5 mm day$^{-1}$. 
Fig. 4.18. Sensible Heat Flux (Map 15)
(10 ly day$^{-1}$)

This map is calculated from the expression

$$C_D \rho_4 c_p \left( \left| \frac{\hat{V}_s}{0} \right|^2 + 2.0 \text{ m sec}^{-1} \right) (T_g - T_4) \text{ 10 DAY}$$

where $\rho_4$ is the surface air density, $c_p$ the specific heat at constant pressure, $T_g$ the (computed) ground temperature (or an assigned ice or ocean surface temperature), and $T_4$ is the air surface temperature. The surface drag coefficient $C_D$ is given by

$$C_D = \begin{cases} 
\min \left[ \left( 1.0 + 0.07 \left| \frac{\hat{V}_s}{0} \right|^2 \right) 10^{-3}, 0.0025 \right], & \text{if ocean} \\
0.002 + 0.006(z_4/5000 \text{ m}), & \text{otherwise}
\end{cases}$$

with $z_4$ the elevation of the surface. Here $\left| \frac{\hat{V}_s}{0} \right|^2$ is given in terms of the wind speeds at the four velocity points surrounding a pressure (or temperature) point by the expression (in $\pi$-centered notation)

$$\left| \frac{\hat{V}_s}{0} \right|^2 = \frac{1}{2} \left[ \left| \frac{\hat{V}_s}{11} \right|^2 + \left| \frac{\hat{V}_s}{-11} \right|^2 + \left| \frac{\hat{V}_s}{-1-1} \right|^2 + \left| \frac{\hat{V}_s}{1-1} \right|^2 \right]$$

where $\frac{\hat{V}_s}{4} = 0.7 \left| \frac{\hat{V}_s}{4} \right|$ and $\frac{\hat{V}_4}{3} = \frac{3}{2} \frac{\hat{V}_3}{3} - \frac{1}{2} \frac{\hat{V}_1}{1}$ (the wind extrapolated to level 4). The additive term 2.0 m sec$^{-1}$ is an empirical correction for gustiness, and the factor 10 DAY ($= 10 \times 86,400$) converts to the desired units. The sensible heat flux (F4 in the FORTRAN code) is positive when ground temperature is greater than surface air temperature ($T_g > T_4$), representing a heat flux from the ground to the air. As shown in the map on the right, however, this flux is often negative. See instructions 11220 to 11290, COMP 3, and Chapter II, Subsection G.3, for further details.
Fig. 4.18 -- Surface sensible heat flux. The dashed line is 0 and the isoline interval is 100 ly day$^{-1}$. 
Fig. 4.18a. Lowest-Level Convection (Map 16)
(deg)

This map is calculated from the expression

\[
EX = \begin{cases} 
  h_4 - h_3^*, & \text{if } h_4 > h_3^* \text{ and } h_3 \leq h_1^* \\
  0, & \text{otherwise}
\end{cases}
\]

where the static-energy parameters are given by

\[
h_1^* = T_1 + \frac{\phi_1}{c_p} + \frac{L}{c_p} q_s(T_1)
\]

\[
h_3 = T_3 + \frac{\phi_3}{c_p} + \frac{L}{c_p} q_3
\]

\[
h_3^* = T_3 + \frac{\phi_3^*}{c_p} + \frac{L}{c_p} q_s(T_3)
\]

\[
h_4 = T_4 + \frac{L}{c_p} q_4
\]

where \(\phi = gz\) is the geopotential and \(q_s\) is the saturation mixing ratio. The condition \(h_4 > h_3^*\) thus ensures instability between levels 4 and 3, while the condition \(h_3 \leq h_1^*\) ensures stability between levels 3 and 1 (i.e., there is no middle-level convection). Hence \(EX \geq 0\), and represents the adjustment of the level-4 temperature due to convection. If \(h_4 < h_1^*\) the computed value of \(EX\) is regarded as due to low-level convection, and is used to modify both the lowest-level temperature \(T_4\) and lowest-level heating \(Q_4\). If \(h_4 \geq h_1^*\) the computed value of \(EX\) is regarded as due to penetrating convection, and is used to modify not only \(T_4\) and \(Q_4\) but the heating in the upper and lower layer as well. See Chapter II, Subsection F.3, and instructions 8700 to 9350, COMP 3, for further details.
Fig. 4.18a -- Lowest-level convection. The dashed line is 10.0 deg and the isoline interval is 2.0 deg.
Fig. 4.19. Long-Wave Heating in Layers (Map 19)  
(deg day\(^{-1}\))

This map is calculated from the expressions

\[
(R2 - R0) \left(\frac{2g}{\pi}\right) \frac{1}{c_p} \quad \text{if} \quad 0 \leq \sigma < 0.5
\]

\[
(R4 - R2) \left(\frac{2g}{\pi}\right) \frac{1}{c_p} \quad \text{if} \quad 0.5 \leq \sigma \leq 1
\]

for an arbitrary \(\sigma\) surface, where \(R0, R2, R4\) are the upward long-wave radiation fluxes at the levels \(\sigma = 0, 1/2, 1\), respectively. The difference \((R2 - R0)\) is thus the net long-wave radiation absorbed in the upper layer \(\sigma = 0\) to \(\sigma = 1/2\), and \((R4 - R2)\) is the net long-wave radiation absorbed in the lower layer \(\sigma = 1/2\) to \(\sigma = 1\). Usually this heating is negative, representing a net long-wave cooling. The factor \(\left(\frac{2g}{\pi}\right)^{-1}\) represents the air mass in either the upper or lower layer (per unit area), and \(c_p\) is the air's specific heat at constant pressure. Thus, depending upon whether \(\sigma < 1/2\) or \(\sigma \geq 1/2\), either one of two versions of this map is produced. See Chapter II, Section G, and instructions 9750 to 10230, COMP 3, for further details.

Layer shown in map at right: upper layer.
Fig. 4.19 -- Long-wave radiative heating rate in upper layer ($\sigma = 0$ to $\sigma = 1/2$). The dashed line is $-2.0$ deg day$^{-1}$ and the isoline interval is 0.5 deg day$^{-1}$.
Fig. 4.20. Long-Wave Heating in Layers (Map 19)
(deg day$^{-1}$)

This map is calculated from the expressions

$$(R2 - R0)(\frac{2g}{\pi}) \frac{1}{c_p} \quad \text{if} \quad 0 \leq \sigma < 0.5$$

$$(R4 - R2)(\frac{2g}{\pi}) \frac{1}{c_p} \quad \text{if} \quad 0.5 \leq \sigma \leq 1$$

for an arbitrary $\sigma$ surface, where $R0$, $R2$, $R4$ are the upward long-wave radiation fluxes at the levels $\sigma = 0$, $1/2$, $1$, respectively. The difference $(R2 - R0)$ is thus the net long-wave radiation absorbed in the upper layer $\sigma = 0$ to $\sigma = 1/2$, and $(R4 - R2)$ is the net long-wave radiation absorbed in the lower layer $\sigma = 1/2$ to $\sigma = 1$. Usually this heating is negative, representing a net long-wave cooling. The factor $(2g/\pi)^{-1}$ represents the air mass in either the upper or lower layer (per unit area), and $c_p$ is the air's specific heat at constant pressure. Thus, depending upon whether $\sigma < 1/2$ or $\sigma \geq 1/2$, either one of two versions of this map is produced. See Chapter II, Section G, and instructions 9750 to 10230, COMP 3, for further details.

Layer shown in map at right: lower layer.
Fig. 4.20 -- Long-wave radiative heating rate in lower layer ($\sigma = 1/2$ to $\sigma = 1$). The dashed line is $-2.0 \text{ deg day}^{-1}$ and the isoline interval is $0.5 \text{ deg day}^{-1}$. 
Fig. 4.21. Short-Wave Absorption (Heating) in Layers (Map 20)

(deg day\(^{-1}\))

This map is calculated from the expressions

\[
A_1(2g/\pi)^{1/2} \frac{1}{c_p} \quad \text{if} \quad 0 \leq \sigma \leq 0.5
\]

\[
A_3(2g/\pi)^{1/2} \frac{1}{c_p} \quad \text{if} \quad 0.5 < \sigma \leq 1
\]

if the cosine of the sun's zenith angle exceeds 0.01. These expressions are replaced by zero if the cosine of the sun's zenith angle is less than or equal to 0.01. Here \(A_1\) and \(A_3\) are the absorbed short-wave radiation in the upper layer (\(\sigma = 0\) to \(\sigma = 1/2\)) and lower layer (\(\sigma = 1/2\) to \(\sigma = 1\)), respectively, the factor \((2g/\pi)^{-1}\) represents the mass (per unit area) in each layer, and \(c_p\) is the specific heat at constant pressure. Thus, depending upon whether the arbitrary value of \(\sigma\) is ≤ 1/2 or > 1/2, either one of two versions of this map is produced. The value of \(A_1\) is the difference between the incoming solar radiation (that part subject to absorption) at the level \(\sigma = 0\) and the downward short-wave flux at the level \(\sigma = 1/2\). Similarly, \(A_3\) is the difference between the downward fluxes at the levels \(\sigma = 1/2\) and \(\sigma = 1\). In either version, the short-wave absorption is always positive (or zero) and represents the net short-wave heating within the layers. See Chapter II, Section G, and instructions 10430 to 11010, COMP 3, for further details.

Layer shown in map at right: upper layer.
Fig. 4.21 -- Short-wave radiative heating rate in upper layer (\( \sigma = 0 \) to \( \sigma = 1/2 \)). The dashed line is 2 deg day\(^{-1}\) and the isoline interval is 0.5 deg day\(^{-1}\).
Fig. 4.22. Short-Wave Absorption (Heating) in Layers (Map 20)
(deg day$^{-1}$)

This map is calculated from the expressions

\[ A_1 \left( \frac{2g}{\pi} \right) \frac{1}{c_p} \quad \text{if} \quad 0 \leq \sigma \leq 0.5 \]

\[ A_3 \left( \frac{2g}{\pi} \right) \frac{1}{c_p} \quad \text{if} \quad 0.5 < \sigma \leq 1 \]

if the cosine of the sun's zenith angle exceeds 0.01. These expressions are replaced by zero if the cosine of the sun's zenith angle is less than or equal to 0.01. Here $A_1$ and $A_3$ are the absorbed short-wave radiation in the upper layer ($\sigma = 0$ to $\sigma = 1/2$) and lower layer ($\sigma = 1/2$ to $\sigma = 1$), respectively, the factor $(2g/\pi)^{-1}$ represents the mass (per unit area) in each layer, and $c_p$ is the specific heat at constant pressure. Thus, depending upon whether the arbitrary value of $\sigma$ is $\leq 1/2$ or $> 1/2$, either one of two versions of this map is produced. The value of $A_1$ is the difference between the incoming solar radiation (that part subject to absorption) at the level $\sigma = 0$ and the downward short-wave flux at the level $\sigma = 1/2$. Similarly, $A_3$ is the difference between the downward fluxes at the levels $\sigma = 1/2$ and $\sigma = 1$. In either version, the short-wave absorption is always positive (or zero) and represents the net short-wave heating within the layers. See Chapter II, Section G, and instructions 10430 to 11010, COMP 3, for further details.

Layer shown in map at right: lower layer.
Fig. 4.22 — Short-wave radiative heating rate in lower layer \((\sigma = 1/2 \text{ to } \sigma = 1)\). The dashed line is 2 deg day\(^{-1}\) and the isoline interval is 0.5 deg day\(^{-1}\).
Fig. 4.23. Surface Short-Wave Absorption (Map 22)

(100 ly day$^{-1}$)

This map is calculated from the expression

\[ \frac{S_4}{100} \]

if the cosine of the sun's zenith angle is greater than 0.01, and is set equal to zero if the cosine of the sun's zenith angle is less than or equal to 0.01. Here $S_4$ is the short-wave radiation absorbed at the surface (or level 4). The effects of surface albedo, atmospheric moisture, and cloudiness are taken into account. The surface short-wave heating is always positive (or zero), and represents the net absorption of insolation at the surface. See Chapter II, Section G, and instructions 10430 to 11010, COMP 3, for further details.
Fig. 4.23 -- Short-wave radiation absorbed at the surface. The dashed line is 1000 ly day$^{-1}$ and the isoline interval is 200 ly day$^{-1}$. 
This map is calculated from the expression

\[ T_4 = 273.1 \text{ deg} \]

where \( T_4 \) is the air temperature at the surface (level 4). Since \( T_4 \), like other dependent temperature variables, is in deg K, this expression serves simply to convert the surface air temperature into the units deg C. The value of \( T_4 \) resembles the extrapolated value

\[ \frac{3}{2} T_3 - \frac{1}{2} T_1 \]

(where \( T_3 \) and \( T_1 \) are the air temperatures at levels 3 and 1, respectively), but also incorporates the surface air temperature adjustments introduced by low-level convection and latent heating. See Chapter II, Section G, and instructions 8970 to 9130 in subroutine COMP 3 for further details.
Fig. 4.24 -- Surface air temperature. The dashed line is 0 deg C and the isoline interval is 5 deg C.
This map is calculated from the ground-temperature \((T_{gr})\) dependence of the terms in the surface heat-balance equation, assuming the ground to be a perfect insulator of zero heat capacity:

\[
R_4 + \Gamma + H_E - S_g = 0
\]

Here the surface long-wave cooling \(R_4\) is given by \(\tilde{R}_4 + \sigma(T_{gr}^4 - T_4^4)\), the surface sensible heat flux \(\Gamma\) by \(C_p(T_{gr} - T_4)\), the latent heat flux from surface evaporation \(H_E\) by \(C_T(q_{se} - q_4)L/c_p\), and \(S_g\) is the solar radiation absorbed at the surface. Here \(\tilde{R}_4\) is a preliminary determination of the surface long-wave cooling, and \(T_{gr}\) is a revised or improved value of the ground temperature \(T_g\). For further details, see Chapter II, Subsection G.3.

Over ice- or snow-covered land and over sea ice, \(T_{gr}\) is not allowed to exceed \(T_o(= 273.1^\circ K)\). Over sea ice this balance is altered to include a heat flux into the sea ice given by \(-B(T_{gr} - T_o)\), where \(B\) is an assumed ice conduction coefficient. Over open ocean the ground temperature \(T_{gr}\) is taken equal to the assigned sea-surface temperature \(T_g = T_{G00}\) (see Fig. 3.14), and there is thus no ground-temperature correction to either the surface long-wave radiation \((R_4 = \tilde{R}_4)\) or to the surface saturated mixing ratio \(q_{se} = q_s\).
Fig. 4.25 -- Ground temperature. The dashed line is 0 deg C and the isoline interval is 5 deg C.
Fig. 4.26. Ground Wetness (Map 25)
(dimensionless)

This map is calculated from the expression $GW = 10 \text{ WET}$, where WET is assigned the value 1.0 (saturated) over ocean, ice, and snow surfaces, and is calculated over (bare) land surfaces according to

$$\text{WET} = (GW)_{\text{new}} = (GW)_{\text{old}} + (1 - \text{runoff}) \left( \frac{1}{2} \frac{\pi}{GWM} \right),$$

where

$$\Delta q_3 = (E - C)(2g/\pi)5\Delta t$$

is the total moisture change (over $5\Delta t$) including the effects of evaporation and both large-scale and convective condensation, and GWM is an assumed constant ground-water mass (= 30 g cm$^{-2}$). The runoff factor varies between 0 and 1, and is taken as 0.5 if $(GW)_{\text{old}} < 1$ (unsaturated surface), and as unity if $(GW)_{\text{old}} = 1$ (saturated), provided $(\Delta q_3)_{\text{TOTAL}} > 0$ in either case. If $(\Delta q_3)_{\text{TOTAL}} < 0$, representing an increase in level-3 moisture and a decrease of surface moisture, then the runoff is taken as zero. See Chapter II, Subsection F.5, for further details.

If $(GW)_{\text{new}} < 0$ it is set to zero, and if $(GW)_{\text{new}} > 1$ it is set to unity. The resulting wetness is then multiplied by 10 in order to scale the final GW from 0 to 10.
Fig. 4.26 -- Ground wetness, scaled 0 to 10. The dashed line is 6.0 and the isoline interval is 2.0.
Fig. 4.27. High Cloudiness (Map 26)
(dimensionless)

This version of Map 26 is calculated from the expression

$$CL1 = \min(-1.3 + 2.6RH_3, 1)$$

where \(RH_3\) is the level-3 relative humidity (as in Map 11). If \(CL \leq 0\) the sky is assumed to be clear and \(CL\) is reset to zero; otherwise \(CL1\) is taken as the fraction of the sky covered with high or type-1 clouds. This cloudiness measure may be identified with towering cumulus between the levels 3 and 1, and is associated with either middle-level or penetrating convection. If there is no such convection, there is no type-1 or high cloudiness (\(CL1 = 0\)). For identification, this cloudiness is assigned the index \(\sigma = 1/4\) in the map-generating program in Chapter VII. See Chapter II, Subsection F.6, for further details.
Fig. 4.27 -- High cloudiness, scaled ≤ 1. The dashed line is 0.5 and the isoline interval is 0.3.
Fig. 4.28. Middle Cloudiness (Map 26)
(dimensionless)

This version of Map 26 is calculated on the basis of \( CL2 = 1 \)
if there is large-scale precipitation (and if there is no penetrating
convection or high cloudiness, \( CL1 = 0 \)). Under all other conditions
\( CL2 = 0 \). Thus this measure of cloudiness is either 0 or 1 at all
points. We may regard \( CL2 \) as the fraction of the sky covered by
type-2 clouds, which are identified as heavy overcast between levels 3
and 2. For identification, this cloudiness is assigned the index
\( \sigma = 3/4 \) in the map-generating program in Chapter VII. See Chapter II,
Subsection F.6, for further details.
Fig. 4.28 -- Middle cloudiness, scaled 0 or 1. The dashed line is 0.5 and the isoline interval is 0.3.
Fig. 4.29. Low Cloudiness (Map 26)
(dimensionless)

This version of Map 26 is calculated from the expression

\[ CL3 = \min(-1.3 + 2.6RH_3, 1) \]

where RH_3 is the level-3 relative humidity (as in Map 11). If CL3 \leq 0 the sky is assumed to be clear and CL3 is reset to zero; otherwise CL3 is taken as the fraction of the sky covered with low or type-3 clouds. This cloudiness measure may be identified with shallow cumulus at level 3, and is associated with low-level convection. If there is no low-level convection, there is no low cloudiness (CL3 = 0); there is also no low cloudiness if there is any high cloudiness (as in Fig. 4.27). For identification, this cloudiness is assigned the index \( \sigma = 1 \) in the map-generating program in Chapter VII. See Chapter II, Subsection F.6, for further details.
Fig. 4.29 -- Low cloudiness, scaled ≤ 1. The dashed line is 0.5 and the isoline interval is 0.3.
Fig. 4.29a. Total Convective Heating in Layers (Map 28)

(deg day⁻¹)

This map is calculated from the expression

\[
2 \left\{ \left( \frac{\Delta T_1}{CM} + \frac{\Delta T_1}{CP} \right) \left( \frac{3}{4} - \sigma \right) + \left( \frac{\Delta T_3}{CM} + \frac{\Delta T_3}{CP} \right) \left( \sigma - \frac{1}{4} \right) \right\} \text{48}
\]

where \(\frac{\Delta T_1}{CM}\) and \(\frac{\Delta T_1}{CP}\) are the temperature changes (over 5Δt) due to middle-level and penetrating convective heating, respectively, in the upper layer [with \(\frac{\Delta T_3}{CM}\) and \(\frac{\Delta T_3}{CP}\) similarly defined for the lower layer]. The factor 48 converts to the desired units, and the factor 2 represents \((\sigma_3 - \sigma_1)^{-1}\). For \(\sigma\) other than \(\sigma_1 (= 1/4)\) and \(\sigma_3 (= 3/4)\), this map thus generates the convective heating rate by linear interpolation and extrapolation in \(\sigma\) (or \(p\)) space. If a \(p\) surface is requested, \(\sigma\) in the above expression is replaced by \((p - p_0)/\pi\). See Chapter II, Section F, and instructions 11410 to 11490, COMP 3, for further details.

Layer shown in map at right: upper layer.
Fig. 4.29a -- Total convective heating in the upper layer ($\sigma = 0$ to $\sigma = 1/2$). The dashed line is 0 and the isoline interval is 0.2 deg day$^{-1}$. 
Fig. 4.29b. Total Convective Heating in Layers (Map 28)

(deg day$^{-1}$)

This map is calculated from the expression

$$2 \left\{ \left[ \frac{(\Delta T_1)}{CM} + \frac{(\Delta T_1)}{CP} \right] \left(\frac{3}{4} - \sigma\right) + \left[ \frac{(\Delta T_3)}{CM} + \frac{(\Delta T_3)}{CP} \right] \left(\sigma - \frac{1}{4}\right) \right\} 48$$

where $(\Delta T_1)$ and $(\Delta T_1)$ are the temperature changes (over $5\Delta t$) due to middle-level and penetrating convective heating, respectively, in the upper layer [with $(\Delta T_3)$ and $(\Delta T_3)$ similarly defined for the lower layer]. The factor 48 converts to the desired units, and the factor 2 represents $(\sigma_3 - \sigma_1)^{-1}$. For $\sigma$ other than $\sigma_1$ (= 1/4) and $\sigma_3$ (= 3/4), this map thus generates the convective heating rate by linear interpolation and extrapolation in $\sigma$ (or $p$) space. If a $p$ surface is requested, $\sigma$ in the above expression is replaced by $(p - p_T)/\pi$. See Chapter II, Section F, and instructions 11410 to 11490, COMP 3, for further details.

Layer shown in map at right: lower layer.
Fig. 4.29b -- Total convective heating in the lower layer (σ = 1/2 to σ = 1). The dashed line is 0 and the isoline interval is 0.2 deg day$^{-1}$. 
This map is calculated from the expression

$$\frac{L}{c_p} (\text{PREC})^{48}$$

where PREC is the large-scale condensation (or precipitation) rate (as in Map 9), $L$ is the latent heat of condensation, and $c_p$ is the air’s specific heat at constant pressure. The factor 48 converts to the desired units. This latent heating applies to the lower layer only, as represented by level 3. See Chapter II, Subsection F.2, and instructions 8610 to 8690, COMP 3, for further details.
Fig. 4.29c -- Latent heating in the lower layer (\(\sigma = 1/2 \) to \(\sigma = 1\)). The dashed line is 1.0 deg day\(^{-1}\) and the isoline interval is 0.5 deg day\(^{-1}\).
Fig. 4.30. Surface Long-Wave Cooling (Map 30)

(100 ly day$^{-1}$)

This map is calculated from the expression

\[
\frac{R4}{100}
\]

where \( R4 \) is the net upward long-wave radiation at the earth's surface. See Chapter II, Subsection G.2, and instructions 10430 to 11010, COMP 3, for further details.
Fig. 4.30 -- Long-wave radiative flux at the surface. The dashed line is 100 ly day$^{-1}$ and the isoline interval is 50 ly day$^{-1}$. 
Fig. 4.31. Surface Heat Balance (Map 31)

(100 ly day$^{-1}$)

This map is calculated from the expression

$$(S_4 - R_4 - F_4)10^{-2} - (L_o \cdot E_4)10^{-3}$$

where $S_4$ is the short-wave radiation absorbed at the surface (as in Map 22), $R_4$ is the net upward long-wave radiation at the surface (as in Map 30), $F_4$ is the upward sensible heat flux from the surface (as in Map 15), and $E_4$ is the heat expended in evaporation from the surface (as in Map 14). Here $L$ is the latent heat of evaporation, $\rho_w$ is the density of water, and the factors $10^{-2}$ and $10^{-3}$ serve to convert to the desired units. A positive balance indicates a net downward energy flux at the surface. Since the ground temperature over land (and ice) is itself determined from the condition of a zero surface heat balance, the small but nonzero values for the heat balance seen here over the continents are the result of the use of spatially averaged temperatures in those portions of the subroutine COMP 3 that have been incorporated into the program for Map 30 (see Map Program Listing, Chapter VII, Section B). This imbalance is here less than 10 ly/day, or approximately one percent of the separate heat-balance components. The relatively small heat flux through the ice at the (fixed) locations of ice-covered ocean has also been neglected in producing this map. See Chapter II, Subsection G.3, for further details.
Fig. 4.31 -- Total heat balance at the surface. The dashed line is 0 and the isoline interval is 200 ly day$^{-1}$. 
2. Surface-Pressure Sequence

To illustrate the typical time behavior of the circulation simulated by the model, a 10-day sequence of the solution for sea-level pressure is presented in Fig. 4.32. These maps are from the same control experiment as those shown in Subsection A.1 above, and constitute a time series starting with Map 1 of Fig. 4.1. These maps show the sea-level pressure isolines at 5-mb intervals, with an additive 1000 mb understood. It is characteristic of the model's solutions that the sea-level pressure distribution maintains a synoptic-like structure as successive cyclone families are formed in the middle latitudes.
Fig. 4.32 -- Daily sequence of smoothed sea-level pressure. The dashed line is 1000 mb and the isoline interval is 5 mb (see Fig. 4.1).
Fig. 4.32 -- Continued.
Fig. 4.32 -- Continued.
Fig. 4.32 -- Continued.
Fig. 4.32 -- Continued.
V. PHYSICS DICTIONARY

PURPOSE

This list of terms permits easy entry into the model's physics and its numerical procedures without prior knowledge of specific mathematical or FORTRAN symbols. In this sense it complements the list of symbols and FORTRAN dictionary given in Chapter VIII. This list, of course, is by no means a complete one, but the authors have included those terms commonly associated with the numerical simulation of the general atmospheric circulation. For each term a brief description (and location) of its treatment in the model is given, together with any appropriate symbols, values, units, FORTRAN representations, and program locations.

LIST OF TERMS

Albedo

The albedo of the earth's surface, $\alpha_g$ (ALS), is assumed constant for two types of surface topography: 0.14 for bare land, 0.07 for ocean. The albedo of ice and of snow-covered land varies from about 0.40 to 0.90 and is dependent upon latitude and time of year (see instructions 10240 to 10410 in the FORTRAN listing), but does not depend in the present version upon the simulated circulation. The albedo of clouds, $\alpha_c$ (ALAC), used in the treatment of radiation varies between 0.6 and 0.7, depending upon the simulated clouds (see instructions 7620 to 7640 in the FORTRAN listing). The value of the albedo of the cloudless atmosphere for (Rayleigh) scattering, $\alpha_o$ (ALAO, instruction 10450), is a function of pressure and solar zenith angle, while for an overcast sky, $\alpha_{ac}$, it depends upon both $\alpha_o$ and $\alpha_c$ (see instructions 10650, 10750, 10880). See Chapter II, Section G, for further details.

Boundary Conditions

At the earth's surface ($\sigma = 1$) and at the assumed isobaric tropopause ($\sigma = 0$) the condition $\dot{\sigma} = d\sigma/dt = 0$ is imposed. This ensures no
motion through the surface $p = p_s$ at the ground (kinematic boundary condition), and no motion through the surface $p = p_T$ (free surface condition), where $p_T (= 200 \text{ mb})$ is the assumed tropopause pressure. There are no lateral boundary conditions in the global model, although there are some computational adjustments at the poles (see Chapter III). Over a water surface (ocean or lake) the surface temperature is fixed at a climatological mean value, whereas over a snow or ice surface (sea ice or glacier) the surface ground temperature, although in general calculated by the model, is not allowed to warm above 0 deg C.

Clouds

Clouds are simulated in the model both through large-scale condensation and through convection. The degree of cloudiness affects the short-wave radiation by reflection (with an assumed cloud albedo) and by partial absorption within the cloud by means of a fictitious water-vapor amount $u_c^*$. The cloudiness also affects the long-wave radiation balance (see Chapter II and subroutine COMP 3, instructions 9400 to 10230 and 10540 to 11200). The cloudiness parameters CL1, CL2, and CL3 represent: (1) either penetrating or midlevel convection, (2) large-scale condensation, and (3) low-level convection, respectively. These are combined into the total or effective cloudiness measure $CL$, which is the fraction of sky assumed to be cloud-covered ($0 \leq CL \leq 1$). The measures CL1 and CL3 also depend upon the humidity at level 3. See Chapter II, Subsection F.4, for further details and Figs. 4.27 to 4.29, Chapter IV, for typical distributions.

Condensation

Large-scale condensation (PREC) occurs mainly as a result of the lifting of saturated air; the model's only atmospheric moisture, $q_3$, is at the level $\sigma = 3/4$ and this is assumed representative of the average moisture in the layer $\sigma = 1/2$ to 1. Convective condensation (C1, C3, PCL, PC3) is parameterized in both the upper and lower levels, although moisture continues to be carried only at the level 3. Condensation (dew deposit) may also occasionally occur on the surface as
negative evaporation (E4). Since no cloud liquid-water content is carried, condensation is equivalent to precipitation in the model (see subroutine COMP 3, instructions 8620 to 8800, 9140 to 9360). See also Chapter II, Subsections F.2 and F.3, for further details; and Figs. 4.12 and 4.16, Chapter IV, for typical distributions.

Convection

Low-level convection is simulated under unstable conditions by altering the surface air temperature (level 4) by an amount necessary to restore the vertical lapse rate between levels 3 and 4 to a stable configuration. If the lapse rate between the surface and the upper level 1 is unstable, a penetrating convective heating is introduced in the heat budget of both the upper and lower layer, as well as at the surface, so as to restore stability. See Chapter II, Section F; and subroutine COMP 3, instructions 8700 to 8880, 8960 to 9390, for further details.

Convective Adjustment

As a result of advective temperature changes and diabatic heating at the levels 1 and 3, the vertical temperature lapse rate may become dry-adiabatically unstable. This is checked in a test for dry-adiabatic instability every 30 minutes, or every 5 time steps (before the heating), in subroutine COMP 3 (instructions 8180 to 8320), wherein the potential temperatures $\theta_1$ and $\theta_3$ are both set equal to the value $(T_1 + T_3)/(p_1^k + p_3^k)$, if prior to the adjustment $\theta_3 > \theta_1$. See Chapter II, Subsection F.1, for further details.

Coriolis Force

The Coriolis force (per unit mass), $f = 2\Omega \sin \varphi$, is computed for each latitude by means of a finite-difference approximation to the equality $\sin \varphi = -\frac{3\cos^2 \varphi}{2 \cos \varphi} \varphi$. This is performed in the subroutine MAGFAC (see instructions 14700 to 14750), wherein $F(J)$ is the Coriolis parameter. See Chapter III, Subsection C.5, for further details.
Diffusion Coefficient

The coefficient of lateral eddy diffusion is set equal to zero in the present version of the model. However, provision has been made for including a diffusion of horizontal momentum in the subroutine COMP 4 (see instructions 12270 to 12680), with horizontal diffusion coefficients dependent upon the local mesh sizes.

Drag Coefficient

Over the oceans the drag coefficient $C_D$ is a function of the surface wind speed, $\hat{V}_S$, and is given by $1.0 + 0.07|\hat{V}_S|10^{-3}$ or 0.0025, whichever is smaller. Over land (and ice or snow) $C_D$ is given by $0.002 + 0.006(z_4/5000 \text{ m})$, where $z_4$ is the height of the surface. This is computed as $CD$ in subroutine COMP 3 (see instructions 7910 to 7980). See Chapter III, Subsection C.10, for further details.

Evaporation

The surface evaporation rate, $E$, is locally computed every five time steps over both ocean and land as E4 in the subroutine COMP 3 (see instruction 11240). The evaporation is dependent upon the local surface wind speed and drag coefficient, the local surface air density and temperature, and the low-level vertical moisture gradient. The evaporation distribution is illustrated in Fig. 4.17, Chapter IV. See Chapter II, Subsection F.4, for further details.

Finite-Difference Grid

The present model's primary or $\pi$ grid consists of points spaced 5 deg longitude and 4 deg latitude over the globe, and is illustrated by the symbol (o) in Fig. 3.2. At the set of such points including the poles (but not the equator) the variables $\pi$, $T$, $\phi$, and $q$ are determined, while at the set of points 4 deg latitude apart including the equator (but not the poles) and displaced eastward 2-1/2 deg longitude relative to the $\pi$ grid, the horizontal speeds $u$ and $v$ are determined [the $u,v$ grid, illustrated by the symbol (+) in Fig. 3.2]. The
complete grid therefore consists of 6552 distinct data points at each of two levels, with additional information stored for the \( \pi \) grid at the surface. For computational convenience additional subgrids are defined in Chapter III (see Fig. 3.2).

**Friction**

The internal frictional force arising from the vertical shear stress of the horizontal wind between levels 1 and 3 is written
\[
\mu (\vec{V}_1 - \vec{V}_3)(z_1 - z_3)^{-1}(2g/\pi),
\]
where \( \mu = 0.44 \text{ mb sec} \) is an empirical shear-stress coefficient. This frictional force is applied with opposite signs in the equations of motion at levels 1 and 3. The frictional force at the earth's surface (which affects level 3 only) is written \( C_D \rho \vec{v}_s (|\vec{v}_s| + G)(2g/\pi) \), where \( C_D \) is the drag coefficient, \( \vec{v}_s \) the (extrapolated) surface wind, and \( G = 2.0 \text{ m sec}^{-1} \) an empirical correction for gustiness. These frictional forces are computed every fifth time step in subroutine COMP 3 (see instructions 11500 to 11620). See Chapter II, Section E, and Chapter III, Subsection C.10, for further details.

**Geopotential**

The geopotential, \( \phi \), of the sigma surfaces is used in the subroutine COMP 2 to compute a portion of the horizontal pressure gradient force (see instructions 5210 to 5700). The geopotential computation is based upon the assumption that the potential temperature is linear in \( p^k \) space; it is illustrated in Figs. 4.8 and 4.9, Chapter IV.

The geopotential of constant-pressure surfaces may also be calculated for interpretive purposes, as shown in Figs. 4.8a and 4.9a, Chapter IV.

**Grid-Point Separation**

The zonal (west/east) distance between grid points, \( \Delta \lambda \), is equal to 5 deg longitude (FORTRAN symbol DL\( \lambda \)), for which the actual distance varies with latitude as given by the map metric \( m \) (FORTRAN symbols DXU, DXP, in Fig. 3.4). The meridional (south/north) distance between grid
points, $\Delta \varphi$, is equal to 4 deg latitude (FORTRAN symbol DLAT), with
the equivalent distance given by the map metric n (FORTRAN symbols
DYU, DYP in Fig. 3.3). These variables are computed in the subroutine
MAGFAC (see instructions 14360 to 14850). See Chapter III, Section B,
for further details.

Ground Temperature

The temperature of the ground at the earth's surface (FORTRAN
symbol TG) is computed in subroutine COMP 3 (instructions 11010 to
11200) as a function of the surface radiation balance (short-wave ab-
sorption minus net long-wave emission), evaporation, and vertical
sensible heat flux. This is done under the assumption of no heat
transfer into the ground (zero heat capacity for bare land, snow-
covered land, or ice-covered land). Over an ice-covered ocean the
surface temperature is computed as for bare land, except that heat
flux through the ice is permitted. Ice- and snow-covered surfaces
are not allowed to become warmer than 0 deg C. Over water surfaces
the temperature is held at the assigned sea-surface temperature dis-
tribution (FORTRAN symbol TG00). See Chapter II, Section G, for fur-
ther details; and Fig. 4.25, Chapter IV, for a typical distribution.

Ground Wetness

The degree of wetness of the ground surface is measured by a di-
ensionless parameter (FORTRAN symbols WET and GW) varying between 0
and 1. This is computed in subroutine COMP 3 (instructions 11280 to
11390) as a function of the surface-moisture budget (precipitation,
evaporation, and runoff). Ice-, snow-, and water-covered surfaces have
a ground-wetness parameter equal to 1 (saturation). See Chapter II,
Subsection F.7, for further details; and Fig. 4.26, Chapter IV, for a
typical distribution.

Heat Balance

A net heating or cooling may occur in either the upper or lower
layers of the model from the absorption of short-wave (solar) radiation,
net long-wave radiation, the convective heating, and (in the lower layer only) through large-scale condensation and the surface flux of sensible heat. The sum of these effects may be termed the heat balance, which on the long-term average over the global domain should be approximately zero. At the earth's surface (over bare land or snow- or ice-covered land) a heat balance is assumed among the fluxes of short- and long-wave radiation, the upward sensible heat flux, and the latent heat used for surface evaporation. This balance is used to determine the ground temperature, and corresponds to a zero land heat capacity. A similar balance is assumed over ice-covered ocean surfaces, except that heat flux through the ice is permitted (snow and ice temperatures may not exceed 0 deg C). Over water surfaces there is no surface heat balance in the model because the water's surface temperature is fixed. The surface heat balance is illustrated in Fig. 4.31, Chapter IV. See Chapter II, Section G, for further details.

**Heating**

Diabatic heating occurs in the upper and lower layers of the model as a result of the radiation (both short- and long-wave) and the convective heating. In the lower layer there is also heating by large-scale condensation (PREC) and by the vertical (turbulent) flux of sensible heat (F4). These heat sources are computed every 5 time steps (= 30 min) in subroutine COMP 3 (instructions 11170 to 11310), and are used to change the temperature at levels 1 and 3. The total heating (in layers), surface sensible heat flux, long-wave heating (in layers), short-wave heating (in layers), surface short-wave absorption, and the surface long-wave cooling are illustrated in Figs. 4.10 and 4.11, 4.18, 4.19 and 4.20, 4.21 and 4.22, 4.23, and 4.30, respectively, of Chapter IV. See Chapter II, Section G, for further details.

**Ice**

The distribution of surface ice is prescribed in the present version of the model, and is shown in Figs. 3.13 and 3.14 for land ice and sea ice by the overprinted symbol I. The elevation of the land ice
is also shown in Fig. 3.13, while the sea ice is assumed to be at sea level. These ice locations are identified in the topography input deck (TDFG) in subroutine INIT 2 by the values \( \leq 10^5 \), with the amount below \( 10^5 \) equal to the ice surface's elevation above sea level (in \( 10^2 \) ft). In the computation of the heat balance over sea ice, the ice is assumed to be 300 cm thick (HICE) and to have a thermal conductivity (CTI) = 0.005 ly cm sec\(^{-1}\) deg\(^{-1}\), and is not allowed to be warmer than 0 deg C (TICE). Except for its albedo (and not being allowed to warm above 0 deg C), land ice is treated in the same manner as bare land with GW = 1.

**Long-Wave Radiation**

The upward long-wave radiative flux is computed at the tropopause (R0), at the level 2 (R2), and at the ground (R4), taking into account the atmospheric emissivity, transmissivity, and the presence of clouds. This is performed every 5 time steps in subroutine COMP 3 (instructions 9750 to 10220, 11040 to 11200). The net fluxes R2 - R0 and R4 - R2 contribute to the change of air temperature at levels 1 and 3, while the surface flux R4 contributes to the change of ground temperature and to the surface heat balance. These fields are illustrated in Figs. 4.19, 4.20, and 4.30 of Chapter IV. See Chapter II, Subsection G.2, for further details.

**Low-Level Convection**

The effect of relatively shallow or low-level convection on the surface temperature and moisture is parameterized in the model in terms of a generalized convection measure. There is no low-level convection unless the lapse rate is unstable between levels 3 and 4 (as measured by the temperature parameters HH4 and HH3S). In addition, the atmosphere must be stable between levels 1 and 3. Under these conditions the surface temperature (T4) and moisture (Q4) are adjusted to simulate low-level convective transports every 5 time steps in subroutine COMP 3 (see instructions 8700 to 8790, 9140 to 9350). See Chapter II, Section F, for further details.
Middle-Level Convection

This form of convection occurs if the atmosphere is unstable between levels 1 and 3, and alters the heat and moisture distribution at these levels. Midlevel clouds will be created if the level-3 relative humidity exceeds 50 percent. See subroutine COMP 3 (instructions 8810 to 8880) and Chapter II, Section F, for further details.

Moisture

The mixing ratio \( (Q_3) \) is computed at the lower level 3 in the model at the points of the \( \pi \) grid in the subroutine COMP 1 (instructions 3520 to 3740), and the moisture sources and sinks due to evaporation and condensation are computed every 5 time steps in subroutine COMP 3 (instructions 8330 to 8450). The upper model level 1 is considered dry, and the moisture advections are such that total moisture is conserved in the absence of sources and sinks. The surface moisture balance is computed in subroutine COMP 3 (instructions 8540 to 8590, 8970 to 9120, 11280 to 11410), and includes the effects of evaporation (E4), precipitation (PREC), ground wetness (GW), and runoff. The moisture distribution is illustrated in the form of the relative humidity at level 3 in Fig. 4.14, Chapter IV, and the total precipitable water is illustrated in Fig. 4.15, Chapter IV. See Chapter II, Section F, and Chapter III, Subsection C.9, for further details.

Momentum Advection

The horizontal advection of momentum is computed in subroutine COMP 1 (instructions 3750 to 4120) in a way which ensures momentum conservation and the conservation of kinetic energy and the square of relative vorticity (in the absence of sources and sinks). This is accomplished by keeping track of the momentum fluxes (PU, PV, FLUXU, FLUXV) between neighboring \( u,v \)-grid cells, and with special adjustment near the poles. The vertical advection of momentum is also computed in subroutine COMP 1 (instructions 4690 to 4860), and represents a momentum exchange between levels 1 and 3 through the large-scale vertical velocity (SD). See Chapter III, Subsections C.3 and C.4, for further details.
Penetrating Convection

Like low-level convection, penetrating or deep convection is parameterized by a convection measure. For penetrating convection to occur, the atmosphere must be unstable between levels 3 and 4 and between levels 1 and 4, but stable between levels 1 and 3. Under these conditions the temperatures at levels 1 and 3 are changed to reflect the vertical convective heat transport (see subroutine COMP 3, instructions 8700 to 8790, 9140 to 9350) with the surface temperature (T4) and moisture (Q4) also changed every 5 time steps. This convection (PC1, PC3) also contributes to the precipitation, although it is assumed that no moisture is carried to the upper level 1. See Chapter II, Subsection F.3, for further details.

Potential Temperature

The potential temperature \( \Theta = T(p_o/p)^\kappa \) (FORTRAN symbol TETA) is computed at various levels in the model for use in vertical stability tests and in the vertical interpolation in \( p^\kappa \) space for the temperature and geopotential heights at \( \sigma \) (or \( p \)) surfaces. Here \( p_o = 1000 \text{ mb} \) and \( \kappa = 0.286 \).

Precipitation

The large-scale precipitation rate (PREC) is computed every 5 time steps in the subroutine COMP 3 (instructions 8610 to 8690) as a result of the indicated supersaturation at level 3. The temperature at level 3 is also altered by the corresponding release of latent heat. An additional precipitation rate (CP) is due to middle-level and penetrative convective processes (C1, C3, PC1, PC3), which also result in the latent heating of the upper and lower layers (COMP 3, instructions 9140 to 9320, 11430 to 11480). The large-scale and convective precipitation rates are illustrated in Figs. 4.12 and 4.16, Chapter IV. See Chapter II, Subsections F.2 and F.3, for further details.
Pressure

The atmospheric pressure (PL) is computed at various levels in the model at the points of the $\pi$ grid, and is widely used in the numerical integrations (see subroutine COMP 3, instructions 8020 to 8160). The pressure of the earth's surface, $p_s$, (FORTRAN symbol P4) is carried as a dependent variable through the parameter $\pi$ (FORTRAN symbol P) = $p_s - p_T$, where $p_T = 200$ mb is the assumed tropopause pressure. The sea-level pressure (illustrated in Fig. 4.1, Chapter IV) is computed on the basis of an assumed lapse rate of 0.6 deg C/100 m between the surface and sea level. Other pressure parameters used are an average surface pressure ($PSF = 984$ mb), and a reference pressure ($PSL = 1000$ mb). The surface pressure tendency (FORTRAN symbol PT) is computed each time step in subroutine COMP 1 (instructions 4130 to 4540) as a result of the solution of the mass-continuity equation.

Pressure-Gradient Force

The pressure force terms in the equations of horizontal motion are calculated in subroutine COMP 2 (instructions 5210 to 6050) as a combination of the gradients of the geopotential, $\phi$, and the surface-pressure parameter, $\pi$. These computations use finite differences centered at the velocity points and are performed each time step. See Chapter III, Subsection C.6, for further details.

Radiation

The net radiative flux of both long- and short-wave radiation is computed for the levels 0, 2, and 4 bounding the upper and lower layers of the model, as well as at the ground. These fluxes depend upon atmospheric moisture (in the lower layer), cloudiness, scattering, reflection (from both the earth's surface and from clouds), the solar zenith angle, and absorption, and are computed every 5 time steps in subroutine COMP 3 (instructions 9750 to 11000). The radiation contributes to the temperature change at levels 1 and 3, as well as to the change of surface temperature. See Chapter II, Section G, for further details.
Sea-Surface Temperature

The temperature at the sea surface is prescribed in the present version of the model. The data shown in Fig. 3.14, Chapter III, approximate the annual mean sea-surface temperature, and have been used in most applications of the model. Any net energy from the radiation exchange and the fluxes of latent and sensible heat at the ocean surface is absorbed by the sea without changing the surface temperature. The sea-surface temperature is read by subprogram INIT 2 (instructions 16020 to 16530) as part of the topography data (FORTRAN symbol TGOO), and may be in either deg C or deg F (but not both).

Sensible Heat Flux

The (turbulent) flux of sensible heat at the earth's surface (FORTRAN symbol F4) is computed every 5 time steps in subroutine COMP 3 (instruction 11250) as a function of the surface wind speed and the low-level vertical temperature gradient (as measured by the difference between the ground, ocean, or ice temperature and the surface air temperature). This flux is illustrated in Fig. 4.18, Chapter IV, and is seen to be frequently negative, representing a sensible heat flux from the air to the ground. See Chapter II, Subsection G.3, for further details.

Short-Wave Radiation

The incoming short-wave or solar radiation is partitioned into a portion subject to scattering $S_o^S$ and a portion subject to absorption $S_o^A$. The latter component may be absorbed in each of the two model layers, depending upon the moisture and cloudiness, and the net absorbed short-wave radiation (FORTRAN symbols AS1 and AS3) is determined every fifth time step in subroutine COMP 3 (instructions 10430 to 11000); this is part of the diabatic temperature change at levels 1 and 3, as illustrated in Map 20, Chapter IV. The short-wave radiation reaching the surface is partly reflected (depending upon the albedo), and partly absorbed. The net surface insolation absorbed (FORTRAN symbol S4) is illustrated in Fig. 4.23, Chapter IV, and
contributes to the surface heat balance. See Chapter II, Subsection C.1, for further details.

Smoothing

There is relatively little explicit smoothing in the present version of the model, although there is considerable averaging in the finite-difference formulations. The subroutine AVRX is used to perform an effective zonal averaging of certain quantities at higher latitudes in subroutines COMP 1 and COMP 2. There is also a 9-point spatial smoothing of the diabatic heating at levels 1 and 3 which is performed in subroutine COMP 3 (instructions 11850 to 12020), and a similar smoothing of the temperature lapse rate in subroutine COMP 4 (instructions 12700 to 12860). See Chapter III, Section D, for further smoothing details, and Subsection C.1 for a discussion of the subroutine AVRX.

Snow Cover

In the present version of the model the snow cover on the earth's surface is prescribed. In the northern hemisphere, all land surfaces (except ice-covered land) north of the latitude defined by the parameter SNOWWN (see instruction 7460 in subroutine COMP 3) are assumed to be covered by snow. The southern boundary of this snow line averages at 60 deg N but varies in time with a period of one year and with an amplitude of 15 deg latitude, with maximum extent on January 25. In the southern hemisphere, a constant snowline SNOWS (see instruction 7470 in subroutine COMP 3) prescribes snow-covered land south of 60 deg S, but this is overridden in the model's present version, because all points south of 60 deg S are either ocean, sea ice, or land ice.

Solar Constant

The value of the solar constant is taken to be 2 ly min⁻¹ = 2880 ly day⁻¹. This value is modified in subroutine COMP 3 (instruction 7610) to take account of the seasonal variation of the earth/sun
distance in the calculation of the FORTRAN variable S0 (see instruction 15520 in subroutine SDET).

**Temperature**

The air temperature (T) is computed each time step in the model for levels 1 and 3 at the points of the η grid, and is widely used in the numerical integration (see instructions 8180 to 8310, subroutine COMP 3). A number of interpolations and extrapolations are made in p^K space for the temperatures and potential temperatures for use in the radiation and convection calculations. The surface air temperature (T4) is computed as a result of the surface heat and moisture balance (instructions 8960 to 9120, 9340, subroutine COMP 3), while the ground temperature itself (TG) is separately computed. The temperature at levels 1 and 3 is illustrated in Figs. 4.6 and 4.7, Chapter IV, and the surface air temperature is illustrated in Fig. 4.24, Chapter IV.

**Time**

Time is measured with respect to hour 0 for midnight at the Greenwich meridian (0 deg longitude), with day 400 corresponding to the 28 January declination of the sun.

**Time Step**

In the main integration of the model, the time step Δt is 6 minutes. The friction, heating, evaporation, and condensation source terms, however, are computed only every fifth time step (every 30 minutes) in the subroutine COMP 3. In each step of the 5-step sequence, a preliminary estimate of the new values of the dependent variables is first obtained, then followed by a final estimate in a modified backward-difference scheme. See Chapter III, Section A, for further details, and subroutine STEP (instructions 1850 to 2280). Once each day the total global mass is adjusted in subroutine CMP, and the solar declination and earth/sun distance are recalculated. In the present
version of the model, the output or history tape of the primary dependent variables is written every 6 hours.

Topography

The topography (TG00) of the earth's surface is prescribed as either water (with a fixed surface temperature), ice (with a maximum temperature of 0 deg C), or land (which may be snow-covered, depending upon the latitude and time of year). The elevation of all land points is prescribed (whether ice-covered, snow-covered, or bare), and is shown in Fig. 3.13, Chapter III; the assigned sea-surface and lake temperatures and ice locations are shown in Fig. 3.14, Chapter III. The topography is read into the program by the subroutine INIT 2, and the land elevation data is decoded in subroutine VPHI4.

Transmission Function

The transmission function for short-wave radiation (FORTRAN symbol TRSW; see subroutine COMP 3, instructions 10460 to 11000) is given by the empirical expression \(1 - 0.271(x)^{0.303}\), where \((x)\) is the effective water vapor concentration in a vertical atmospheric column (see subroutine COMP 3, instructions 9750 to 10230). The transmission function for long-wave radiation (FORTRAN symbol TRANS; see subroutine COMP 3, instructions 9910 to 10220) is given by the expression \([1 + 1.75(x)^{0.416}]^{-1}\). See Chapter II, Section G, for further details.

Tropopause

The tropopause in the model is assumed to be always at the pressure \(p_T = 200\) mb (FORTRAN symbol PTRQP), and is used in the definition of the tropospheric \(\sigma\)-coordinate system. At this level the boundary condition \(\dot{\sigma} = 0\) is applied.

Vertical Velocity

The \(\sigma\)-vertical velocity \(\dot{\sigma} = \dot{S}/2\)mm (FORTRAN symbol SD = \(\dot{S}\)) is computed in the model for the middle level 2 from the equation of
continuity as a result of the net horizontal mass convergence (see subroutine COMP 1, instructions 4320 to 4540). The vertical velocity is used to effect the vertical advection of momentum and temperature, and to determine the large-scale precipitation rate; it is illustrated in Fig. 4.13, Chapter IV. See Chapter III, Subsections C.1, C.2, and C.8, for further details.

Wind Velocity

The horizontal zonal and meridional wind speeds (FORTRAN symbols U and V) are computed each time step in the model at the points of the u,v grid, and are widely used in the program. These fields are illustrated in Figs. 4.2 to 4.5 in Chapter IV. In the subroutine COMP 1 a number of spatially averaged speeds and fluxes are defined for use in the horizontal advections of momentum, mass, heat, and moisture. The wind velocity at the earth's surface (US, VS) is found by linear extrapolation in p from levels 1 and 3 (see subroutine COMP 3, instructions 7490 to 7570), and is used in the determination of the surface friction, evaporation, and sensible heat flux. See Chapter III, Section C, for further details.
VI. LIST OF SYMBOLS

PURPOSE

In order to provide a complement to the physics dictionary presented in Chapter V, a comprehensive alphabetical listing and identification of all the symbols used in the discussion of the model's physics and numerics is given here. For each symbol a brief identification, typical value, units, and FORTRAN symbol (if any) is given. Those symbols which occur at more than one level in the model (as designated by the subscripts 1, 2, 3, or 4) are listed following the primary variable. Not separately listed are those symbols which occur with the superscripts \( \tau \) or \( n \) (denoting evaluation at time steps), those symbols which occur with the subscripts \( i \) and/or \( j \), those symbols with various combinations of numerical subscripts (denoting grid-point locations), or those symbols representing a local specialization of a previously defined symbol. In general, symbols which occur only in FORTRAN notation are also not listed here (see Chapter VIII).
<table>
<thead>
<tr>
<th>SYMBOL</th>
<th>MEANING</th>
<th>UNITS (and value for constants)</th>
<th>FORTRAN SYMBOL</th>
</tr>
</thead>
<tbody>
<tr>
<td>ρ</td>
<td>specific volume</td>
<td>cm$^3$ g$^{-1}$</td>
<td>--</td>
</tr>
<tr>
<td>ρ₁</td>
<td>albedo of cloudy atmosphere</td>
<td>--</td>
<td>ALAC</td>
</tr>
<tr>
<td>ρ₂</td>
<td>cloud albedo (subscripted by cloud type)</td>
<td>--</td>
<td>ALC1, ALC2, ALC3</td>
</tr>
<tr>
<td>ρ₃</td>
<td>albedo of earth's surface</td>
<td>--</td>
<td>ALS</td>
</tr>
<tr>
<td>ρ₄</td>
<td>albedo of clear atmosphere</td>
<td>--</td>
<td>ALA0</td>
</tr>
<tr>
<td>β</td>
<td>vertical shear stress parameter</td>
<td>0.13 mb$^2$ sec$^{-1}$</td>
<td>--</td>
</tr>
<tr>
<td>Γ</td>
<td>surface sensible heat flux</td>
<td>1y day$^{-1}$</td>
<td>F4</td>
</tr>
<tr>
<td>Γₜ</td>
<td>surface flux of static energy</td>
<td>1y sec$^{-1}$</td>
<td>--</td>
</tr>
<tr>
<td>γ</td>
<td>temperature lapse rate near surface</td>
<td>0.6 deg/100 m</td>
<td>--</td>
</tr>
<tr>
<td>γ₁</td>
<td>latent heating parameter</td>
<td>--</td>
<td>GAM</td>
</tr>
<tr>
<td>γ₂</td>
<td>= Lqₛ(cₚT$^2$)$^{-1}$ 5418 deg</td>
<td>--</td>
<td>G0SZ (= cos ζ)</td>
</tr>
<tr>
<td>γ₃</td>
<td>sun's zenith angle</td>
<td>radians</td>
<td>ETA</td>
</tr>
<tr>
<td>γₙ</td>
<td>entrainment factor</td>
<td>--</td>
<td>ETA</td>
</tr>
<tr>
<td>θ</td>
<td>potential temperature</td>
<td>deg K</td>
<td>TETA</td>
</tr>
</tbody>
</table>

The multiple listing is for symbols occurring with the subscripts 1, 2, 3, or 4; these denote evaluation at the respective model levels $σ = 1/4, 1/2, 3/4,$ or 1 (surface). The subscripts g and o also sometimes denote the ground or surface level.
<table>
<thead>
<tr>
<th>SYMBOL</th>
<th>MEANING</th>
<th>UNITS (and value for constants)</th>
<th>FORTRAN SYMBOL</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\bar{\theta}$</td>
<td>an average potential temperature</td>
<td>deg K</td>
<td>--</td>
</tr>
<tr>
<td>$\theta_d$</td>
<td>partial potential temperature</td>
<td>deg K</td>
<td>--</td>
</tr>
<tr>
<td>$\theta_E$</td>
<td>equivalent potential temperature</td>
<td>deg K</td>
<td>--</td>
</tr>
<tr>
<td>$\kappa$</td>
<td>thermodynamic ratio $R/c_p$</td>
<td>0.286</td>
<td>KAPA</td>
</tr>
<tr>
<td>$\lambda$</td>
<td>longitude, positive eastward from Greenwich</td>
<td>radians</td>
<td>--</td>
</tr>
<tr>
<td>$\Delta \lambda$</td>
<td>longitudinal spacing between grid points</td>
<td>$\pi/36$ radians ($\approx 5$ deg)</td>
<td>DLØN</td>
</tr>
<tr>
<td>$\mu$</td>
<td>vertical shear stress parameter</td>
<td>0.44 mb sec</td>
<td>--</td>
</tr>
<tr>
<td>$\Pi$</td>
<td>pressure area weighting $= \pi mn$</td>
<td>$2^2$ mb</td>
<td>FD(J,I)</td>
</tr>
<tr>
<td>$\Pi^u$</td>
<td>local four-point average of $\Pi$ centered on $u,v$ grid points</td>
<td>$2^2$ mb</td>
<td>FDU(J,I)</td>
</tr>
<tr>
<td>$\pi$</td>
<td>(1) surface pressure parameter $= p_s - p_T$</td>
<td>mb</td>
<td>SP,P(J,I)</td>
</tr>
<tr>
<td></td>
<td>(2) constant</td>
<td>3.14159</td>
<td>PI</td>
</tr>
<tr>
<td>$\pi_s$</td>
<td>surface pressure change $= \frac{dp_s}{dt}$</td>
<td>mb sec$^{-1}$</td>
<td>PT</td>
</tr>
<tr>
<td>$\pi_s$</td>
<td>standard value of $\pi$</td>
<td>800 mb</td>
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<tr>
<td>$\pi^u$</td>
<td>local four-point average of $\pi$ centered on $u,v$ grid points</td>
<td>mb</td>
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<tr>
<td>$\rho$</td>
<td>air density</td>
<td>g cm$^{-3}$</td>
<td>RHØ, RØ4</td>
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<td>UNITS (and value for constants)</td>
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<tr>
<td>$\rho_w$</td>
<td>water density</td>
<td>$1 \text{ g cm}^{-3}$</td>
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<tr>
<td>$\sigma$</td>
<td>Stefan-Boltzman constant</td>
<td>$1.171 \times 10^{-7}$</td>
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<td>$\sigma_1$</td>
<td>vertical coordinate</td>
<td>$1 \text{ ly day}^{-1} \text{ deg}^{-4}$</td>
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</tr>
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<td>$\sigma_3$</td>
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<td>$\delta$</td>
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<td>$\delta_2$</td>
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<td>$\tau$</td>
<td>time-step index</td>
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<td>$\tau_1$</td>
<td>intermediate variables in penetrating convection</td>
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<td>$\tau_2$</td>
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<td>$\tau_r$</td>
<td>relaxation time for cumulus convection</td>
<td>$3600 \text{ sec}$</td>
<td>TCNV</td>
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<tr>
<td>$\tau(u^*)$</td>
<td>long-wave transmission function</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$= [1 + 1.75(u^*)^{0.416}]^{-1}$</td>
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<tr>
<td>$\tilde{\tau}_A$</td>
<td>long-wave transmission above and below a given level</td>
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<td>$\tilde{\tau}_B$</td>
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<td>$\phi$</td>
<td>geopotential of sigma surface</td>
<td>$2 \text{ m sec}^{-2}$</td>
<td>PHI</td>
</tr>
<tr>
<td>$\phi_1$</td>
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</tr>
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<td>$\phi_3$</td>
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<tr>
<td>$\phi_4$</td>
<td>geopotential of $\sigma = 4$ surface</td>
<td>$2 \text{ m sec}^{-2}$</td>
<td>VPHI4</td>
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<td>FORTRAN SYMBOL</td>
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<td>$\varphi$</td>
<td>latitude, positive northward from equator</td>
<td>radians</td>
<td>LAT(J)</td>
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<td>$\Delta \varphi$</td>
<td>latitudinal spacing between grid points</td>
<td>$\pi/45$ radians (= 4 deg)</td>
<td>DLAT</td>
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<tr>
<td>$\psi$</td>
<td>arbitrary variable</td>
<td>--</td>
<td>--</td>
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<td>$\Omega$</td>
<td>earth's rotation rate</td>
<td>$2\pi$ radians/day</td>
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<td>$\omega$</td>
<td>pressure vertical velocity = $dp/dt$</td>
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<tr>
<td>$A$</td>
<td>absorbed short-wave radiation</td>
<td>1y day$^{-1}$</td>
<td>--</td>
</tr>
<tr>
<td>$A_1$</td>
<td>absorbed short-wave radiation in upper and lower layers</td>
<td>1y day$^{-1}$</td>
<td>AS1, AS3</td>
</tr>
<tr>
<td>$A_3$</td>
<td></td>
<td></td>
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<td>$A_v$</td>
<td>eddy diffusion coefficient</td>
<td>$m^2 sec^{-1}$</td>
<td>--</td>
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<tr>
<td>$\vec{A}$</td>
<td>arbitrary vector, whose latitudinal and longitudinal components are $A_\varphi$ and $A_\lambda$</td>
<td>--</td>
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<td>$A_e$</td>
<td>saturation vapor pressure constant</td>
<td>21.656</td>
<td>--</td>
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<tr>
<td>$A(u^*,z)$</td>
<td>short-wave absorption function ( = 0.271(u^* \cos \zeta)^{0.303} )</td>
<td>--</td>
<td>TRSW(X)</td>
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<td>$A'_\psi$</td>
<td>general representation for advection terms</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>$a$</td>
<td>earth's radius</td>
<td>( 6.3750 \times 10^6 ) m</td>
<td>RAD</td>
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<tr>
<td>$B$</td>
<td>conduction coefficient for ice</td>
<td>1y day$^{-1}$deg$^{-1}$</td>
<td>--</td>
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<td>$\tilde{B}$</td>
<td>generalized conduction coefficient</td>
<td>1y day$^{-1}$deg$^{-1}$</td>
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<td>$B_e$</td>
<td>saturation vapor pressure constant</td>
<td>5418 deg</td>
<td>--</td>
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<tr>
<td>$C$</td>
<td>condensation rate</td>
<td>( g ) cm$^{-2}$ sec$^{-1}$</td>
<td>--</td>
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<td>UNITS (and value for constants)</td>
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<td>C_1</td>
<td>ground temperature correction terms in long-wave radiation</td>
<td>1y day^{-1}</td>
<td>--</td>
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<td>C_D</td>
<td>surface drag coefficient</td>
<td>--</td>
<td>CD</td>
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<td>C_T</td>
<td>sensible and latent heat flux parameter</td>
<td>1y day^{-1}deg^{-1}</td>
<td>CSEN</td>
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<td>CL</td>
<td>cloudiness measure</td>
<td>--</td>
<td>CL</td>
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<tr>
<td>CLAT</td>
<td>degrees poleward of snowline</td>
<td>deg latitude</td>
<td>CLAT</td>
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<td>CONV</td>
<td>horizontal mass convergence</td>
<td>m^2 mb sec^{-1}</td>
<td>C0NV</td>
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<tr>
<td>c_P</td>
<td>dry air specific heat at constant pressure</td>
<td>0.24 cal g^{-1}deg^{-1}</td>
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<td>D_ψ</td>
<td>general representation for non-source terms</td>
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<td>D_π</td>
<td>general representation for mass advection terms</td>
<td>--</td>
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<tr>
<td>E</td>
<td>surface evaporation rate</td>
<td>g cm^{-2} sec^{-1}</td>
<td>E4</td>
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<tr>
<td>e_s</td>
<td>saturation vapor pressure</td>
<td>cb</td>
<td>ES, EG</td>
</tr>
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<td>F</td>
<td>modified Coriolis parameter</td>
<td>2 m sec^{-1}</td>
<td>FD(J,I)</td>
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<td>\hat{F}</td>
<td>horizontal vector frictional force (per unit mass)</td>
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<tr>
<td>F_X</td>
<td>eastward component of frictional force</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>F^+_1</td>
<td>--</td>
<td>--</td>
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<td>F^+_3</td>
<td>--</td>
<td>--</td>
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<tr>
<td>F_Y</td>
<td>northward component of frictional force</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>F^+_1</td>
<td>--</td>
<td>--</td>
<td></td>
</tr>
<tr>
<td>F^+_3</td>
<td>--</td>
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<tr>
<td>F₄</td>
<td>upward sensible heat flux from surface</td>
<td>1 ly day⁻¹</td>
<td>F₄</td>
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<td>Fᵥ</td>
<td>vertical heat flux at surface</td>
<td>1 ly day⁻¹</td>
<td>--</td>
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<td>f</td>
<td>Coriolis parameter = 2Ω sin φ</td>
<td>sec⁻¹</td>
<td>F(J)</td>
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<td>G</td>
<td>gustiness correction for surface wind</td>
<td>2 m sec⁻¹</td>
<td>G</td>
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<td>GW</td>
<td>ground wetness</td>
<td>--</td>
<td>GW</td>
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<td>GWM</td>
<td>maximum ground water</td>
<td>30 g cm⁻²</td>
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<tr>
<td>g</td>
<td>gravity</td>
<td>9.81 m sec⁻²</td>
<td>GRAV</td>
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<td>h/ᶜᵖ</td>
<td>static energy</td>
<td>deg K</td>
<td>--</td>
</tr>
<tr>
<td>h₃/ᶜᵖ</td>
<td>static energy at level 3</td>
<td>deg K</td>
<td>HH3</td>
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<td>h₄/ᶜᵖ</td>
<td>static energy at level 4</td>
<td>deg K</td>
<td>{ HH4, HH4P }</td>
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<tr>
<td>ᵇ₄/ᶜᵖ</td>
<td>intermediate stability parameter</td>
<td>deg K</td>
<td>HH4</td>
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<tr>
<td>Ḧ</td>
<td>diabatic heating rate (per unit mass)</td>
<td>cal g⁻¹ sec⁻¹</td>
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<tr>
<td>Ḥ₁</td>
<td>diabatic temperature change (over 5Δt) in layer</td>
<td>deg</td>
<td>H₁</td>
</tr>
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<td>Ḥ₃</td>
<td>diabatic temperature change (over 5Δt) in layer</td>
<td>deg</td>
<td>H₃</td>
</tr>
<tr>
<td>Ḥ</td>
<td>average of Ḥ₁, Ḥ₃</td>
<td>deg</td>
<td>H</td>
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<td>Ḥₑ</td>
<td>surface latent heat flux</td>
<td>1 ly day⁻¹</td>
<td>--</td>
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<tr>
<td>( h^*/c_p )</td>
<td>stability parameter</td>
<td>deg K</td>
<td>--</td>
</tr>
<tr>
<td>( h_1^*/c_p )</td>
<td>stability parameter at level 1</td>
<td>deg K</td>
<td>HH1S</td>
</tr>
<tr>
<td>( h_3^*/c_p )</td>
<td>stability parameter at level 3</td>
<td>deg K</td>
<td>HH3S</td>
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<tr>
<td>I</td>
<td>maximum value of ( i )</td>
<td>72</td>
<td>IM</td>
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<tr>
<td>i</td>
<td>zonal grid-point index</td>
<td>--</td>
<td>I</td>
</tr>
<tr>
<td>J</td>
<td>maximum value of ( j )</td>
<td>46</td>
<td>JM</td>
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<td>j</td>
<td>meridional grid-point index</td>
<td>--</td>
<td>J</td>
</tr>
<tr>
<td>K</td>
<td>moisture parameter</td>
<td>--</td>
<td>VAK</td>
</tr>
<tr>
<td>( \hat{k} )</td>
<td>vertical unit vector</td>
<td>--</td>
<td>--</td>
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<tr>
<td>L</td>
<td>latent heat of condensation</td>
<td>580 cal g(^{-1})</td>
<td>--</td>
</tr>
<tr>
<td>( \ell )</td>
<td>level index = 1 at ( \sigma_1 ), = 3 at ( \sigma_3 )</td>
<td>--</td>
<td>L</td>
</tr>
<tr>
<td>LR</td>
<td>nominal lapse rate</td>
<td>deg K</td>
<td>--</td>
</tr>
<tr>
<td>( = (\theta_1 - \theta_3)(p_2/p_0)^k )</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>M</td>
<td>vertical mass flux in cloud</td>
<td>g cm(^{-2}) sec(^{-1})</td>
<td>--</td>
</tr>
<tr>
<td>( M_b )</td>
<td></td>
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</tr>
<tr>
<td>( M_w/M_d )</td>
<td>ratio of the molecular weight of water vapor to dry air</td>
<td>0.622</td>
<td>--</td>
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<tr>
<td>m</td>
<td>map metric or zonal distance between grid points</td>
<td>m</td>
<td>DXU</td>
</tr>
<tr>
<td>n</td>
<td>(1) map metric or meridional distance between grid points</td>
<td>m</td>
<td>DYU</td>
</tr>
<tr>
<td></td>
<td>= ( a \Delta \lambda \cos \phi )</td>
<td></td>
<td>DXP</td>
</tr>
<tr>
<td></td>
<td>(2) arbitrary time step</td>
<td>--</td>
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<td>UNITS (and value for constants)</td>
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<tr>
<td>P</td>
<td>(1) pressure</td>
<td>mb</td>
<td>P</td>
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<tr>
<td>P₁</td>
<td>(2) polar grid-point index</td>
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<td>--</td>
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<tr>
<td>P₀</td>
<td>reference pressure</td>
<td>1000 mb</td>
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<tr>
<td>P_CM</td>
<td>precipitation rate from middle-level convection</td>
<td>mm day⁻¹</td>
<td>--</td>
</tr>
<tr>
<td>P_CP</td>
<td>precipitation rate from penetrating convection</td>
<td>mm day⁻¹</td>
<td>--</td>
</tr>
<tr>
<td>P_LS</td>
<td>large-scale precipitation rate</td>
<td>mm day⁻¹</td>
<td>--</td>
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<tr>
<td>Pₛ</td>
<td>surface pressure</td>
<td>mb</td>
<td>P₄</td>
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<tr>
<td>Pₜ</td>
<td>tropopause pressure</td>
<td>200 mb</td>
<td>PTRØP</td>
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<td>ΔPₐ_c</td>
<td>cloud pressure thickness</td>
<td>mb</td>
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<td>ΔPₐ_m</td>
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<tr>
<td>Q</td>
<td>rate of moisture addition (per unit mass)</td>
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<tr>
<td>q</td>
<td>mixing ratio</td>
<td>--</td>
<td>--</td>
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<tr>
<td>q₃</td>
<td>mixing ratio at level 3</td>
<td>--</td>
<td>Q₃₃</td>
</tr>
<tr>
<td>q₄</td>
<td>mixing ratio at level 4</td>
<td>--</td>
<td>Q₄</td>
</tr>
<tr>
<td>q₅</td>
<td>mixing ratio at ground</td>
<td>--</td>
<td>Q₅</td>
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<tr>
<td>Δq₃</td>
<td>mixing ratio change (at level 3)</td>
<td>--</td>
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<td>UNITS (and value for constants)</td>
<td>FORTRAN SYMBOL</td>
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<tr>
<td>$q_s$</td>
<td>saturated mixing ratio</td>
<td>--</td>
<td>QS</td>
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<tr>
<td>$q_{se}$</td>
<td>effective ground saturation mixing ratio</td>
<td>--</td>
<td>--</td>
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<tr>
<td>$R$</td>
<td>dry air specific gas constant</td>
<td>$287 \text{ m}^2\text{deg}^{-1}\text{sec}^{-2}$</td>
<td>RGAS</td>
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<td>$R'_{\psi}$</td>
<td>general representation for non-advective, non-source terms $= D_{\psi} - A_{\psi}$</td>
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<tr>
<td>$R'_{n}$</td>
<td>clear sky long-wave radiation at level $n$</td>
<td>$1\text{ly day}^{-1}$</td>
<td>R00, R20, R40</td>
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<tr>
<td>$R''_{n}$</td>
<td>overcast sky long-wave radiation at level $n$</td>
<td>$1\text{ly day}^{-1}$</td>
<td>R0C, R2C, R4C</td>
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<tr>
<td>$\tilde{R}_{n}$</td>
<td>weighted sum of $R'_n$, $R''_n$</td>
<td>$1\text{ly day}^{-1}$</td>
<td>R0, R2, R4</td>
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<tr>
<td>$R_0$</td>
<td>upward long-wave radiation flux at level $0 (\sigma = 0)$</td>
<td>$1\text{ly day}^{-1}$</td>
<td>R0</td>
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<td>$R_2$</td>
<td>upward long-wave radiation flux at level 2</td>
<td>$1\text{ly day}^{-1}$</td>
<td>R2</td>
</tr>
<tr>
<td>$R_4$</td>
<td>upward long-wave radiation flux at level 4 (surface)</td>
<td>$1\text{ly day}^{-1}$</td>
<td>R4</td>
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<td>$\text{RH}_3$</td>
<td>relative humidity (scaled 0 to 1)</td>
<td>--</td>
<td>RH</td>
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<td>$\text{RH}_4$</td>
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<td>$S$</td>
<td>dry static energy</td>
<td>$\text{cal g}$</td>
<td>--</td>
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<tr>
<td>$\dot{S}$</td>
<td>vertical velocity measure $= 2mm\pi\delta_2$</td>
<td>$\text{m mb sec}^{-1}$</td>
<td>SD(J,I)</td>
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<tr>
<td>SYMBOL</td>
<td>MEANING</td>
<td>UNITS (and value for constants)</td>
<td>FORTRAN SYMBOL</td>
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<tr>
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<td>----------------</td>
</tr>
<tr>
<td>((S^A)_{i}^{'})</td>
<td>flux of (S^A_o) at level (i) in clear sky</td>
<td>1y day(^{-1})</td>
<td>--</td>
</tr>
<tr>
<td>((S^A)_{i}^{''})</td>
<td>flux of (S^A_o) at level (i) in overcast sky</td>
<td>1y day(^{-1})</td>
<td>--</td>
</tr>
<tr>
<td>((S^A)_{cT1}^{''})</td>
<td>flux of (S^A_o) reflected from top of cloud type (1)</td>
<td>1y day(^{-1})</td>
<td>--</td>
</tr>
<tr>
<td>(S^u)</td>
<td>local four-point average of (S) centered on (u,v) grid points</td>
<td>(\text{mb sec}^{-1})</td>
<td>SDU</td>
</tr>
<tr>
<td>(S_o)</td>
<td>solar constant (after modification for earth-sun distance)</td>
<td>(~2880) 1y day(^{-1})</td>
<td>S(\Phi)</td>
</tr>
<tr>
<td>(S^s_o)</td>
<td>solar radiation subject to scattering</td>
<td>1y day(^{-1})</td>
<td>SS</td>
</tr>
<tr>
<td>(S^a_o)</td>
<td>solar radiation subject to absorption</td>
<td>1y day(^{-1})</td>
<td>SA</td>
</tr>
<tr>
<td>(S_g)</td>
<td>total solar radiation absorbed at ground</td>
<td>1y day(^{-1})</td>
<td>S4</td>
</tr>
<tr>
<td>(S^g)</td>
<td>flux of (S^s_g) absorbed by ground</td>
<td>1y day(^{-1})</td>
<td>--</td>
</tr>
<tr>
<td>(S^g)</td>
<td>flux of (S^a_g) absorbed by ground</td>
<td>1y day(^{-1})</td>
<td>--</td>
</tr>
<tr>
<td>(S_\psi)</td>
<td>general representation for source terms</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>(S_4)</td>
<td>short-wave radiation absorbed at the surface</td>
<td>1y day(^{-1})</td>
<td>S4</td>
</tr>
<tr>
<td>(T)</td>
<td>temperature</td>
<td>deg K</td>
<td>T</td>
</tr>
<tr>
<td>(T_1)</td>
<td></td>
<td></td>
<td>--</td>
</tr>
<tr>
<td>(T_2)</td>
<td></td>
<td></td>
<td>--</td>
</tr>
<tr>
<td>SYMBOL</td>
<td>MEANING</td>
<td>UNITS (and value for constants)</td>
<td>FORTRAN SYMBOL</td>
</tr>
<tr>
<td>--------</td>
<td>---------</td>
<td>--------------------------------</td>
<td>----------------</td>
</tr>
<tr>
<td>$T_0$</td>
<td>melting point of ice</td>
<td>273.1 deg K</td>
<td>TICE</td>
</tr>
<tr>
<td>$T_0$</td>
<td>tropopause temperature</td>
<td>deg K</td>
<td>TTRØP</td>
</tr>
<tr>
<td>$T_{4}$</td>
<td>air temperature at level 4</td>
<td>deg K</td>
<td>T4</td>
</tr>
<tr>
<td>$T_4$</td>
<td>(surface)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$T_{c1}$</td>
<td>air temperature in cloud</td>
<td>deg K</td>
<td>--</td>
</tr>
<tr>
<td>$T_{c3}$</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$\Delta T_1$</td>
<td>temperature change (of layer)</td>
<td>deg</td>
<td>--</td>
</tr>
<tr>
<td>$\Delta T_3$</td>
<td></td>
<td></td>
<td>--</td>
</tr>
<tr>
<td>$(\Delta T_1)_{CM}$</td>
<td>temperature change due to middle-level convection</td>
<td>deg</td>
<td>--</td>
</tr>
<tr>
<td>$(\Delta T_3)_{CM}$</td>
<td></td>
<td></td>
<td>--</td>
</tr>
<tr>
<td>$(\Delta T_1)_{CP}$</td>
<td>temperature change due to penetrating convection</td>
<td>deg</td>
<td>--</td>
</tr>
<tr>
<td>$(\Delta T_3)_{CP}$</td>
<td></td>
<td></td>
<td>--</td>
</tr>
<tr>
<td>$(\Delta T_3)_{LS}$</td>
<td>level-3 temperature change due to large-scale condensation (= PREC·L/c_p)</td>
<td>deg</td>
<td>--</td>
</tr>
<tr>
<td>$T_g$</td>
<td>ground temperature</td>
<td>deg K</td>
<td>{TG GT(J,I)}</td>
</tr>
<tr>
<td>$T_{gr}$</td>
<td>revised ground temperature</td>
<td>deg K</td>
<td>{TGR GT(J,I)}</td>
</tr>
<tr>
<td>$T_T$</td>
<td>tropopause temperature</td>
<td>deg K</td>
<td>TTRØP</td>
</tr>
<tr>
<td>$T^u$</td>
<td>local four-point average</td>
<td>deg K</td>
<td>--</td>
</tr>
<tr>
<td>$\overline{T}$</td>
<td>temperature centered on u,v-grid points</td>
<td>deg K</td>
<td>--</td>
</tr>
<tr>
<td>SYMBOL</td>
<td>MEANING</td>
<td>UNITS (and value for constants)</td>
<td>FORTRAN SYMBOL</td>
</tr>
<tr>
<td>--------</td>
<td>---------</td>
<td>-------------------------------</td>
<td>----------------</td>
</tr>
<tr>
<td>TD</td>
<td>lapse rate measure (= (T_3 - T_1)/2\pi)</td>
<td>(\text{deg mb}^{-1})</td>
<td>TD</td>
</tr>
<tr>
<td>t</td>
<td>time</td>
<td>(\text{sec, min, hr, or days})</td>
<td>--</td>
</tr>
<tr>
<td>(\Delta t)</td>
<td>time step</td>
<td>(6 \text{ min})</td>
<td>DTM</td>
</tr>
<tr>
<td>U</td>
<td>west/east advective flux</td>
<td>(\text{m}^2\text{mb sec}^{-1})</td>
<td>--</td>
</tr>
<tr>
<td>(\tilde{U})</td>
<td>southwest/northeast advective flux</td>
<td>(\text{m}^2\text{mb sec}^{-1})</td>
<td>--</td>
</tr>
<tr>
<td>(u)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(u_1)</td>
<td>zonal (eastward) wind speed</td>
<td>(\text{m sec}^{-1})</td>
<td>U</td>
</tr>
<tr>
<td>(u_3)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(u_4)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(u_n^*)</td>
<td>effective water vapor content in column (to level n)</td>
<td>(\text{g cm}^{-2})</td>
<td>(EFV, EFVT)</td>
</tr>
<tr>
<td>(u_\infty^*)</td>
<td>effective water vapor content in column (entire atmosphere)</td>
<td>(\text{g cm}^{-2})</td>
<td>EFVO</td>
</tr>
<tr>
<td>(u_{11}^*)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(u_{13}^*)</td>
<td>zonal mass flux (= n \pi u)</td>
<td>(\text{m}^2\text{mb sec}^{-1})</td>
<td>PU(J,I)</td>
</tr>
<tr>
<td>(u_{14}^*)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(u_{c1}^*)</td>
<td>cloud water vapor equivalent</td>
<td>(65.3 \text{ g cm}^{-2})</td>
<td>(EFVC1, EFVC2)</td>
</tr>
<tr>
<td>(u_{c2}^*)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SYMBOL</td>
<td>MEANING</td>
<td>UNITS (and value for constants)</td>
<td>FORTRAN SYMBOL</td>
</tr>
<tr>
<td>--------</td>
<td>---------</td>
<td>-------------------------------</td>
<td>----------------</td>
</tr>
<tr>
<td>$u_c^*$</td>
<td>cloud water vapor equivalent</td>
<td>$7.6 \text{ g cm}^{-2}$</td>
<td>EFVC3</td>
</tr>
<tr>
<td>$V$</td>
<td>south/north advective flux</td>
<td>$\frac{\text{mb}}{\text{m sec}^{-1}}$</td>
<td>--</td>
</tr>
<tr>
<td>$\tilde{V}$</td>
<td>southeast/northwest advective flux</td>
<td>$\frac{\text{mb}}{\text{m sec}^{-1}}$</td>
<td>--</td>
</tr>
<tr>
<td>$\hat{V}$</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$\hat{V}_1$</td>
<td>horizontal velocity vector</td>
<td>$\text{m sec}^{-1}$</td>
<td>--</td>
</tr>
<tr>
<td>$\hat{V}_2$</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$\hat{V}_3$</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$\hat{V}_4$</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$\hat{V}_s$</td>
<td>surface wind vector, $= 0.7\hat{V}_4$</td>
<td>$\text{m sec}^{-1}$</td>
<td>US, VS</td>
</tr>
<tr>
<td>$</td>
<td>\hat{V}_s</td>
<td>^{\Pi}$</td>
<td>local four-point root-mean-square surface wind speed centered at π points</td>
</tr>
<tr>
<td>$v$</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$v_1$</td>
<td>meridional (northward) wind speed</td>
<td>$\text{m sec}^{-1}$</td>
<td>V</td>
</tr>
<tr>
<td>$v_3$</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$v_1^*$</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$v_3^*$</td>
<td>meridional mass flux $= \frac{\text{mmb}}{\text{m sec}^{-1}}$</td>
<td>$\text{mmb sec}^{-1}$</td>
<td>PV(J,I)</td>
</tr>
<tr>
<td>$v_4^*$</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$W$</td>
<td>surface wind speed with gustiness correction</td>
<td>$\text{m sec}^{-1}$</td>
<td>WINDF</td>
</tr>
<tr>
<td>SYMBOL</td>
<td>MEANING</td>
<td>UNITS (and value for constants)</td>
<td>FORTRAN SYMBOL</td>
</tr>
<tr>
<td>--------</td>
<td>--------------------------------------------------------</td>
<td>---------------------------------</td>
<td>----------------</td>
</tr>
<tr>
<td>x</td>
<td>eastward coordinate (on rectangular projection)</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>y</td>
<td>northward coordinate (on rectangular projection)</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>z</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>z₁</td>
<td></td>
<td></td>
<td>ZZZ</td>
</tr>
<tr>
<td>z₃</td>
<td>height of sigma surface</td>
<td>m</td>
<td></td>
</tr>
<tr>
<td>z₄</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Δz</td>
<td>standard value of ( z₁ - z₃ )</td>
<td>5400 m</td>
<td>--</td>
</tr>
<tr>
<td>(^)</td>
<td>designation for preliminary estimate in time integration</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>(~)</td>
<td>designation for provisional value prior to incorporation of source terms in time integration</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>(−)</td>
<td>a smoothing operator denoting a horizontally averaged value</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>( N₀ )</td>
<td>an operator denoting the three-point longitudinal smoothing routine in AVRXY(K), which is automatically applied ( N₀ ) times</td>
<td>--</td>
<td>--</td>
</tr>
</tbody>
</table>
VII. THE FORTRAN PROGRAM

A listing of the computer program actually used in the numerical simulations is perhaps the most important part of the documentation. In the FORTRAN program listing given in Section A below the sequential numbering of all cards in the program deck is reproduced on the right-hand side of the listing to permit easy identification of specific instructions. Following the listing of the integration program and the common block, the program listing for the map routines is presented in Section B with a separate instruction card numbering.

A. INTEGRATION PROGRAM LISTING

1. Subprograms

The integration program itself is divided into a main or control routine and a number of subroutines. In the order of their appearance in the program, these subroutines (and an indication of their functions and initial program instruction numbers) follow:

COMMON -- lists variables' common and equivalence assignments
CONTROL -- controls program execution (0120)
OUTAPE -- reads and writes history tape (0800)
  GMP -- calculates global average surface pressure, and adjusts pressure for mass conservation (1250)
  VP24 -- decodes land elevation (1510)
  IPK -- packs data for output (1610)
  KEY -- logical key control (1770)
STEP -- controls sequence of time steps, and readies data for execution of subroutines COMP 1, COMP 2, COMP 3, and COMP 4 (1850)
COMP 1 -- calculates mass flux and convergence; horizontal advection of momentum, heat, and moisture; vertical advection of momentum and heat (2290)
COMP 2 -- calculates Coriolis and pressure-gradient forces (4880)
AVRX -- performs zonal smoothing (6780)
COMP 3 -- calculates radiative heating, convection, precipitation, surface and ground temperature, surface evaporation and sensible heat flux, surface friction; calculates selected data for output (7070)
COMP 4 -- calculates diffusion of momentum (suppressed in the present version); performs areal smoothing of the temperature lapse rate (12040)

INPUT -- reads input data and controls generation of selected constants (12880)

MAGFAC -- calculates map scale factors and Coriolis parameter (14350)

INSDET -- adjusts day, month, and seasonal sun position

SDET -- calculates solar zenith angle and related parameters (15190)

INIT 1 -- prepares for cold-start initial conditions (inoperative in the present version) (15620)

INIT 2 -- reads and encodes surface topography data (sea-surface temperature and land elevation) (15770)

2. Guide to the Main Computational Subroutines

The bulk of the computations involved in the solution of the main dynamical equations of the model, Eqs. (2.27) to (2.35), are performed in the subroutines COMP 1, COMP 2, COMP 3, and COMP 4. An outline of these calculations is given below in the sequence performed each time step in the program by the subroutines COMP 1 and COMP 2, followed by an outline for subroutines COMP 3 and COMP 4 which are performed every five time steps. The initial instruction location is cited for each major program subdivision.

<table>
<thead>
<tr>
<th>Calculation</th>
<th>Initial Instruction</th>
</tr>
</thead>
<tbody>
<tr>
<td>COMP 1</td>
<td></td>
</tr>
<tr>
<td>Formation of area-pressure-weighted variables</td>
<td>2540</td>
</tr>
<tr>
<td>Horizontal mass flux</td>
<td>2710</td>
</tr>
<tr>
<td>Zonal smoothing (AVRX)</td>
<td>2830</td>
</tr>
<tr>
<td>Horizontal polar mass flux</td>
<td>2970</td>
</tr>
<tr>
<td>Horizontal temperature advection</td>
<td>3260</td>
</tr>
<tr>
<td>Horizontal moisture advection</td>
<td>3390</td>
</tr>
<tr>
<td>Horizontal momentum advection</td>
<td>3770</td>
</tr>
<tr>
<td>Continuity equation (vertical velocity and surface pressure tendency)</td>
<td>4130</td>
</tr>
<tr>
<td>Calculation</td>
<td>Initial Instruction</td>
</tr>
<tr>
<td>-------------------------------------------------</td>
<td>---------------------</td>
</tr>
<tr>
<td><strong>COMP 1</strong></td>
<td></td>
</tr>
<tr>
<td>Vertical temperature advection</td>
<td>4560</td>
</tr>
<tr>
<td>Vertical momentum advection</td>
<td>4690</td>
</tr>
<tr>
<td><strong>COMP 2</strong></td>
<td></td>
</tr>
<tr>
<td>Coriolis force</td>
<td>5010</td>
</tr>
<tr>
<td>Pressure-gradient force</td>
<td>5220</td>
</tr>
<tr>
<td>Zonal smoothing (AVRX)</td>
<td>5970</td>
</tr>
<tr>
<td>Thermodynamic energy conversion</td>
<td>6070</td>
</tr>
<tr>
<td>Zonal smoothing (AVRX)</td>
<td>6210</td>
</tr>
<tr>
<td>Polar adjustment</td>
<td>6410</td>
</tr>
<tr>
<td>Return to unweighted variables</td>
<td>6580</td>
</tr>
<tr>
<td><strong>COMP 3</strong></td>
<td></td>
</tr>
<tr>
<td>Radiation and heating functions</td>
<td>7150</td>
</tr>
<tr>
<td>Surface wind magnitude</td>
<td>7490</td>
</tr>
<tr>
<td>Radiation constants</td>
<td>7590</td>
</tr>
<tr>
<td>Solar declination</td>
<td>7740</td>
</tr>
<tr>
<td>Surface topography (ocean, ice, bare land, snow-covered land)</td>
<td>7820</td>
</tr>
<tr>
<td>Pressure variables</td>
<td>8030</td>
</tr>
<tr>
<td>Temperature and moisture variables, and test for dry-adiabatic instability</td>
<td>8180</td>
</tr>
<tr>
<td>Ground temperature and wetness</td>
<td>8540</td>
</tr>
<tr>
<td>Large-scale precipitation</td>
<td>8610</td>
</tr>
<tr>
<td>Middle-level convection</td>
<td>8700</td>
</tr>
<tr>
<td>Preparation for air/earth interaction</td>
<td>8900</td>
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<tr>
<td>Surface temperature</td>
<td>8970</td>
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<tr>
<td>Penetrating and low-level convection</td>
<td>9140</td>
</tr>
<tr>
<td>Cloudiness</td>
<td>9400</td>
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<tr>
<td>Long-wave radiation</td>
<td>9750</td>
</tr>
<tr>
<td>Surface albedo</td>
<td>10240</td>
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<tr>
<td>Calculation</td>
<td>Instruction</td>
</tr>
<tr>
<td>----------------------------------------------------------------------------</td>
<td>-------------</td>
</tr>
<tr>
<td>COMP 3</td>
<td></td>
</tr>
<tr>
<td>Solar (short-wave) radiation</td>
<td>10430</td>
</tr>
<tr>
<td>Ground temperature</td>
<td>11020</td>
</tr>
<tr>
<td>Sensible heat flux and evaporation</td>
<td>11220</td>
</tr>
<tr>
<td>Moisture budget</td>
<td>11300</td>
</tr>
<tr>
<td>Total heating</td>
<td>11410</td>
</tr>
<tr>
<td>Surface friction</td>
<td>11500</td>
</tr>
<tr>
<td>Areal smoothing of heating</td>
<td>11850</td>
</tr>
<tr>
<td>COMP 4</td>
<td></td>
</tr>
<tr>
<td>Horizontal momentum diffusion (inoperative in present version)</td>
<td>12270</td>
</tr>
<tr>
<td>Areal smoothing of lapse rate</td>
<td>12700</td>
</tr>
</tbody>
</table>

3. Common and Equivalence Statements

Most of the variables and constants of the program are communicated between the subprograms via a common block, stored in the single array BCØMN. The following equivalents should be noted:

BCØMN(1)─BCØMN(800) equivalent to C(1)─C(800)

where C(K) is defined to be equivalent to all the constants and one-dimensional arrays [and MAPLST(3, 40)],

BCØMN(801)─BCØMN(67040) equivalent to QTØT(1,1,1)─QTØT(46,72,20)

where QTØT is equivalent to all the two- and three-dimensional arrays,

QTØT(1,1,1)─QTØT(46,72,9) equivalent to Q(1,1,1)─Q(46,72,9)

QTØT(1,1,10)─QTØT(46,72,20) equivalent to QT(1,1,1)─QT(46,72,11)
and

Q(J,I,1) equivalent to P(J,I)  surface pressure (π)
Q(J,I,2) equivalent to U(J,I,1)  level 1 zonal wind (u₁)
Q(J,I,3) equivalent to U(J,I,2)  level 3 zonal wind (u₃)
Q(J,I,4) equivalent to V(J,I,1)  level 1 meridional wind (v₁)
Q(J,I,5) equivalent to V(J,I,2)  level 3 meridional wind (v₃)
Q(J,I,6) equivalent to T(J,I,1)  level 1 temperature (T₁)
Q(J,I,7) equivalent to T(J,I,2)  level 3 temperature (T₃)
Q(J,I,8) equivalent to Q(J,I)  moisture (q₃)
Q(J,I,9) equivalent to TØPG(J,I)  surface elevation and ocean temperature

The array QT(J,I,K) for K = 1 to 8 is similarly equivalent to all the temporary and intermediate values of the above quantities, i.e., PT(J,I), UT(J,I,K), etc. Occasionally Q and QT are used in the program rather than the original variables, especially in the time steps where all Q quantities are treated at once (see, for example, instructions 1960 to 2220). The array QT is also equivalent to all other two- and three-dimensional arrays in the program not requiring permanent storage. The common, dimension, and equivalence statements are given on the immediately following pages.
CODE LISTING

*COMMON BLOCK FOR MINTZ-ARAKAWA TWO-LEVEL GENERAL CIRCULATION MODEL

*COMMON GWGT

* D I M E N S I O N

* BCOMN

* DIMENSION

* BCOMN(67040), C(800), QTOT(46,72,20), Q(46,72,9), QT(46,72,11)

* P(46,72), U(46,72,2), V(46,72,2), T(46,72,2), Q3(46,72)

* PT(46,72), UT(46,72,2), VT(46,72,2), TT(46,72,2), Q3T(46,72)

* FD(46,72), H(46,72,2), PU(46,72), TD(46,72)

* PHI(46,72), W(46,72), TOPOG(46,72)

* CONV(46,72), PV(46,72), SD(46,72)

* GM(46,72), GT(46,72), QD(46,72,9)

* WORK1(46,72), WORK2(46,72)

* TS(46,72), SN(46,72)

D I M E N S I O N

* LAT(46), DXU(46), DXP(46), DUY(46), DYP(46)

* SINL(46), COSL(46), AXU(46), AXV(46), AYU(46), AYV(46)

* DXYP(46), F(46), SIG(2), AMO(46), XL(9), MAPL(3,40)

C

D X V A N D D Y V A R E I N T E R M V A R I A B L E S O N L Y

* DXV(46), DYP(46)

E Q U I V A L E N C E

* (QTOT(1),Q(1)), (QTOT(29809),Q(1)), (BCOMN(1),C(1))

* (BCOMN(801),QTOT(1)), (Q(1),P(1)), (Q1(1),U(1))

* (Q1(1,1,6),T(1)), (Q1(1,1,8),O3(1))

* (Q1(1,1,9),TOPOG(1)), (Q3T(1),QD(1),PT(1))

* (OT(1,1,2),UT(1),WORK1(1))

* (OT(1,1,3),TS(1))

* (OT(1,1,4),VT(1),WORK2(1))

* (OT(1,1,5),SN(1))

* (OT(1,1,6),TT(1)), (Q(1,1,8),Q3T(1))

* (OT(1,1,9),CONV(1),SD(1))

* (OT(1,1,10),PHI(1),W(1))

* (OT(1,1,11),PU(1),FD(1),TD(1))

E Q U I V A L E N C E

* (C(1),JM), (C(2),IM), (C(3),JTP), (C(4),KTP), (C(5),LTP)

* (C(6),MTA), (C(7),NOUT), (C(8),RESTR), (C(9),TAU)

* (C(10),TAU1), (C(11),TAU0), (C(12),Taud), (C(13),TAE)

* (C(14),TAUH), (C(15),TAUC), (C(16),ID), (C(17),DT)

* (C(18),DLAT), (C(19),DLEN), (C(20),RAD), (C(21),RSDIST)

* (C(22),DCLK), (C(23),SIND), (C(24),COSD), (C(25),TOFDAY)

* (C(26),MNTDY), (C(27),DAYPYR), (C(28),RTPER), (C(29),SDEY)

* (C(30),SEYR), (C(31),ENYK), (C(32),APHEL), (C(33),DECMAX)

* (C(34),ECM), (C(35),DAY), (C(36),GRYV), (C(37),RGS)

* (C(38),KAP), (C(39),PSF), (C(40),PROP), (C(41),PSL)

* (C(42),TENV), (C(44),A), (C(45),NCYCLE)

* (C(46),NC3), (C(47),FM), (C(48),ED)

* (C(57),PI), (C(58),ZMM)

* (C(59),NPOL), (C(60),SPOL), (C(61),MRCH), (C(62),STAGJ)

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*, (C(63), STAG1), (C(64), SIG(1)), (C(66), AMONTH(1))

E Q U I V A L E N C E
*
(C(69), XLABL(1)), (C(78), LAT(1)), (C(124), DXU(1))
*
(C(170), DXP(1)), (C(216), DYU(1)), (C(262), DYP(1))
*
(C(308), DYP(1)), (C(354), F(1)), (C(400), SINL(1))
*
(C(446), COSL(1)), (C(492), AXU(1)), (C(538), AXV(1))
*
(C(584), AYU(1)), (C(630), AYV(1)), (C(676), MAPLST(1))
*
(C(797), NSTEP), (C(79R), DLIC)
*
(C(799), TREADY), (SINT, ISINT)
*
(DXV(1), DXP(1)), (DYV(1), DYP(1))

C
REAL LAT, KAPA, NPOL
LOGICAL KEYS*1, BIT, MAPGEN, RESTR, KEY, TREADY
COMMON /VKEYV/, KEYS(32)
INTEGER SDEDY, SDEYR

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C*******************************************************************************
C*******************************************************************************
CCONTROL
C*******************************************************************************
C*******************************************************************************
C*******************************************************************************
C*******************************************************************************
C*******************************************************************************
C*******************************************************************************
DD DISP=OLD,DSN=MS7774.ABN.COMMON
// LOGICAL EVENT, CHECK, PASS2, EVNTH, NOOUT, VIVA
DIMENSION CXXX(800)
EVENT(XTAU)=MOD(NSTEP,IFIX(XTAU/3600./DT+0.1)) .EQ. 0
PASS2=.FALSE.
DO 100 J=1,32
100 KEYS(J)=.FALSE.
200 NT=0
RESTRT=.FALSE.
VIVA=.TRUE.
CALL INPUT
C
C NSTEP=TAU/3600./DT+0.1
RESTRT=.FALSE.
C
C MAIN COMPUTATIONAL CONTROL
C
310 NSTEP=NSTEP+1
TAU=FLOAT(NSTEP)*ABS(DT)/3600.+1.*F-3
IF (TAU.GT.TAUE) GO TO 1200
TOFDAY=AMOD(TAU,ROTPER)
NOOUT=.NOT.((EVENT(TAUN) OR. KEY(-8))
IF (NOOUT OR. MOD(NSTEP,NC3) .EQ. 0) GO TO 320
NOOUT=.TRUE.
KEYS(8)=.TRUE.
320 CONTINUE
C
CALL STEP
IF (EVENT(24)) CALL GMP

C*******************************************************************************
C*******************************************************************************
C*******************************************************************************
C*******************************************************************************
C*******************************************************************************
C*******************************************************************************
C*******************************************************************************
C  VARIOUS CHECKING AND HISTORY OPTIONS

630 IF (EVENT(TAUH)) CALL SOFT
   INAY=TAU/ROTPER
   IF (EVENT(TAUH)) GO TO 1000
   GO TO 310
1000 CONTINUE
   READ (KTP) TAU
   IF (TAU,GT,0.0) GO TO 1100
   IF (ABS(TAU,TAUH+TAUX),GT,0.01) GO TO 1100
1001 CONTINUE
   BACKSPACE KTP
   WRITE (KTP) TAU, C
   CALL OUTAPE(KTP,2)
   PRINT 1005,TAU
1005 FORMAT (1X,WRITE TAPE ',F8.2)
   GO TO 310
1100 WRITE (MTP,1110) TAU,TAUX
1110 FORMAT (1X,'SOME MESS ON TAPE',1X,E12.5,1X,IR)
   CALL EXIT
1200 WRITE (MTP,1210) TAU
1210 FORMAT (1X,'TERMINATING AS REQUIRED AT TAU=',F8.2)
   STOP

C
9200 FORMAT(' WMSG020 MINTZ-ARAKAWA GLOBAL WEATHER MODEL NOW RUNNING')
9670 FORMAT(' WMSG040 (',A4,') SWITCHING FROM TAPE ',12,' TO TAPE ',12,' 2'ON DAY ',14,' / HOUR ',F6.3)
9680 FORMAT(' WMSG035 SIM TIME IS DAY ',14,' / HOUR ',F7.3)
9715 FORMAT (' WMSG036 (',A4,') HAS STOPPED AT DAY ',14,' / HOUR ',F7.3)

C
C
END
SUBROUTINE OUTAPE(K,I)

// DD DISP=OLD, DSN=MES727.ABN.COMMON
//
// DD *

IF(I.EQ.2) GO TO 20
READ (K) P
READ (K) U
READ (K) V
READ (K) T
READ (K) Q3
READ (K) TOPOG
READ (K) PT
READ (K) GW
READ (K) TS
READ (K) GT
READ (K) SN
READ (K) TT
READ (K) O3T
READ (K) SD
READ (K) H
READ (K) TD
RETURN

20 CONTINUE
WRITE (K) P
WRITE (K) U
WRITE (K) V
WRITE (K) T
WRITE (K) O3
WRITE (K) TOPOG
WRITE (K) PT
WRITE (K) GW
WRITE (K) TS
WRITE (K) GT
WRITE (K) SN
WRITE (K) TT
WRITE (K) O3T
WRITE (K) SD
WRITE (K) H
WRITE (K) TD
TAUX=ABS(TAU)
WRITE (K) TAU, C
BACKSPACE K
C THE NEGATIVE RECORD PREVENTS NOISE, MISSING RECORDS,
C AND MISSING TRAILER LABELS.
RETURN
END
SUBROUTINE CMP

/ *
// DD DISP=OLD,DSN=MESS727,ABN,COMMON
// DD *
DIMENSION ZM(146)
FIM=IM
DO 135 I=1,IM
  ZM(J)=0.0
DO 136 J=1,JM
  ZM(J)=ZM(J) + P(J,I)
135 ZM(J)=ZM(J)/FIM
  WTM=0.0
  ZMM=0.0
DO 137 J=1,JM
  WTM = WTM + ABS(DXYP(J))
136 ZMM = ZMM + ZM(J)*ABS(DXYP(J))
    ZMM=ZMM/WTM + PTRP
DELTAP = PSF - ZMM
DO 301 I=1,IM
DO 301 J=1,JM
301 P(J,I) = P(J,I) + DELTAP
WRITE(6,138) DELTAP
138 FORMAT(* PRESSURE ADDED = *,E16.8)
RETURN
END
FUNCTION VPHI4 (J, I)
C
/*
// DD DISP=OLD, DSN=MEIS727, ARN.COMMON
// DD *
VPHI4=0.
IF (TOPOG(J, I) .LT. 1.0) VPHI4=AMOD(-TOPOG(J, I) + 10.0, 10.0)
C
RETURN
END

FUNCTION IPK(IL, IR)
INTEGER IHALF(2)
EQUIVALENCE (IHALF(1), IWD)
IHALF(1)=IL
IHALF(2)=IR
IPK=IWD
RETURN
ENTRY IRH(IPKW)
IWD=IPKW
IRH=IHALF(2)
RETURN
ENTRY ILH(IPKW)
IWD=IPKW
ILH=IHALF(1)
RETURN
END

LOGICAL FUNCTION KEY(M)
LOGICAL KEYS(132)
COMMON /VKEYV/ KEYS
N=IABS(M)
KEY=KEYS(N)
IF (M .LT. 0) KEYS(N)=.FALSE.
RETURN
END
SUBROUTINE STEP
// DO DISP=OLD,DSN=MEST27,ABN,COMMON
// DO *
C
C MAIN LOOP OF INTEGRATION
C FORWARD STEP (CENTERED IN SPACE)
C
MRCH=1
DO 310 K=1,K
DO 310 I=1,IM
DO 310 J=1,JM
310 QT(J,I,K)=QT(J,I,K)
THRP=TAU/24.
PRINT 9999,TAU,THRP
9999 FORMAT (1X,*TIME=1,2X,FR,2,2X,F9.4)
CALL COMP1
CALL COMP2
DO 360 K=1,K
DO 360 I=1,IM
DO 360 J=1,JM
TEMP=QT(J,I,K)
QT(J,I,K)=QT(J,I,K)
360 QT(J,I,K)=TEMP
C
C BACKWARD STEP
C
NS=MOD(NSTEP,NCYCLF)
MRCH=2
IF(NS.EQ.1) MRCH=3
IF(NS.EQ.2) MRCH=4
CALL COMP1
CALL COMP2
DO 380 K=1,K
DO 380 I=1,IM
DO 380 J=1,JM
TEMP=QT(J,I,K)
QT(J,I,K)=QT(J,I,K)
380 QT(J,I,K)=TEMP
C
IF (MOD(NSTEP,NC3).NE.0 ) GO TO 400
CALL COMP4
CALL COMP3
400 RETURN
END
SUBROUTINE COMPL
/*
 // DD DISP=OLD, DSN=MES727.AHN.COMMON
 // DD *
 JMM1=JM-1
 TMM2=IM-2
 F1M=IM
 SIG1=SIG(1)
 SIG3=SIG(2)

 C
 C MRCH=1 CENTERED IN SPACE AND FORWARD IN TIME
 C MRCH=2 CENTERED IN SPACE AND BACKWARD IN TIME
 C MRCH=3 UP-RIGHT UNCENTERED IN SPACE AND BACKWARD IN TIME
 C MRCH=4 DOWN-LEFT UNCENTERED IN SPACE AND BACKWARD IN TIME
 C
 C TIME EXTRAPOLATION INTERVAL FOR ADVECTION TERMS
 C
 C TECO=DT
 IF(MRCH.EQ.1) TECO=0.5*DT
 C
 C PREPARATION FOR TIME EXTRAPOLATION
 C TRANSFORMATION TO AREA-PRESSURE WEIGHTED VARIABLES
 C QT CONTAINS VARIABLES TO WHICH TENDENCIES ARE TO BE ADDED
 C
 DO 2100 I=1,IM
 DO 2100 J=1,JM
 FD(J,I)=PT(J,I)DXYP(J)
 2100 Q3T(J,I)=Q3T(J,I)*FD(J,I)
 DO 2120 L=1,2
 DO 2120 I=1,IM
 IP1=MOD(I,IM)+1
 DO 2110 J=1,JM
 2110 TT(J,I,L)=TT(J,I,L)*FD(J,I)
 DO 2120 J=2,JM
 FDV=0.25*(FD(J,I)+FD(J,IP1)+FD(J,JM-1,I)+FD(J,JM-1,IP1))
 IF (J .EQ. 2) FDV=0.25*(FD(2,I)+FD(2,IP1))+FD(1,I)
 IF (J .EQ. JM) FDU=0.25*(FD(JM-1,I)+FD(JM-1,IP1))+FD(JM,I)
 VT(J,I,L)=UT(J,I,L)*FDU
 2120 VT(J,I,L)=VT(J,I,L)*FDU
 C
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C
C COMPUTING MASS FLUX * P  PU *
   * PV  UV *
C
2149 L=1
2150 DO 2160 I=1,IM
   IP1=MOD(I,IM)+1
   DO 2160 J=2,JMM1
   IF(MRCH * LE* 2) PU(J,1)=0.25*(DYU(J)*U(J+1,I)+DYU(J+1)*U(J+1,I,L))
   IF(MRCH * EQ* 3) PU(J,1)=0.5*DYU(J)*U(J+1,I,L)
   IF(MRCH * EQ* 4) PU(J,1)=0.5*DYU(J)*U(J+1,I,L)
2160 CONTINUE
C
   CALL AVRX(11)
C
   DO 2180 I=1,IM
   IP1=MOD(I,IM)+1
   IM1=MOD(I+IM2,IM)+1
   DO 2170 J=2,JMM1
   IF(MRCH * LE* 2) PV(J,1)=0.25*DXU(J)*(V(J+1,I,L)+V(J-1,I,L))
   IF(MRCH * EQ* 3) PV(J,1)=0.5*DXU(J)*V(J-1,I,L)*(P(J-1,L)+P(J-1,L))
   IF(MRCH * EQ* 4) PV(J,1)=0.5*DXU(J)*V(J-1,I,L)*(P(J,L)+P(J-1,L))
2170 CONTINUE
C
   EQUIVALENT PU AT POLES. PV(1,1) IS USED AS A WORKING SPACE.
C
   VM1=0.0
   VM2=0.0
   DO 2185 I=1,IM
   VM1=VM1+PV(2,I)
2185 VM2=VM2+PV(JM,1)
   VM1=VM1/FIM
   VM2=VM2/FIM
   PV(1,1)=0.0
   DO 2190 I=2,IM
2185 PV(1,1)=PV(1,1-1)+(PV(2,1)-VM1)
   VM1=0.0
   DO 2192 I=1,IM
2182 VM1=VM1+PV(1,I)
   VM1=VM1/FIM
   DO 2195 I=1,IM
2195 PV(I,1)=-(PV(1,1)-VM1)*3.0
   PV(1,1)=0.0
   DO 2200 I=2,IM
2200 PV(1,1)=PV(1,1-1)+(PV(JM,1)-VM2)
   VM2=0.0
   DO 2202 I=1,IM
2202 VM2=VM2+PV(1,I)
   VM2=VM2/FIM
   DO 2205 I=1,IM
2205 PV(JM,1)=(PV(1,1)-VM2)*3.0
C
C HORIZONTAL ADEPTION OF THERMODYNAMIC ENERGY AND MOISTURE EQUATIONS00003250

C

F XCO=0.5*TXCO
00003260
D 0 2220 I=1,IM
00003280
I P1=MOD(I,IM)+1
00003290
D 0 2210 J=2,JMM1
00003300
FLUX=FXCO*PU(J,I)
00003310
FLUX=FLUX*E(I,J)+T(I,IP1,L1)*T(J,IP1,L1)
00003320
IF (I.EQ.2 .OR. J.EQ.JMM1) .AND. FLUX.LT.0.0
* FLUX=FLUX*2.0*T(I,IP1,L1)
00003330
IF (I.EQ.2 .OR. J.EQ.JMM1) .AND. FLUX.GE.0.0
* FLUX=FLUX*2.0*T(J,IP1,L1)
00003340
TT(I,J,L)=TT(I,J,L)-FLUX
00003360
TT(I,J,IP1,L)=TT(I,J,IP1,L)+FLUX
00003370
IF (L.EQ.1) FLUX=-0.25*FLUX
00003380
IF (L.EQ.2) FLUX=1.25*FLUX
00003390
Q3M=Q3(J,I)+Q3(J,IP1)
00003400
IF(Q3M.LT.10.E-10) GO TO 2210
00003410
C 10.E-10 IS A RELATIVELY SMALL NUMBER
00003420
FLUXQ=FLUX*Q3M
00003430
IF(Q3(J,I,LT.Q3(J,IP1)) .AND. FLUX.GT.0.0)
* FLUXQ=FLUX*0.3(J,I)+Q3(J,IP1)/Q3M
00003440
IF(Q3(J,I,LT.Q3(J,IP1)) .AND. FLUX.LT.0.0)
* FLUXQ=FLUX*0.3(J,I)+Q3(J,IP1)/Q3M
00003450
Q3T(J,I)=Q3T(J,I)-FLUXQ
00003460
Q3T(J,IP1)=Q3T(J,IP1)+FLUXQ
00003470
2210 CONTINUE
00003480
D 0 2220 J=2,JM
00003490
FLUX=FXCO*PU(J,I)
00003500
FLUX=FLUX*(T(I,J,L)+T(J-1,I,L))
00003510
IF (J.EQ.2 .AND. FLUX.LT.0.0) FLUX=FLUX*2.0*T(2,I,L)
00003520
IF (J.EQ.2 .AND. FLUX.GT.0.0) FLUX=FLUX*2.0*T(J-1,I,L)
00003530
IF (J.EQ.2 .AND. FLUX.GE.0.0) FLUX=FLUX*2.0*T(J-1,I,L)
00003540
TT(I,J,L)=TT(I,J,L)-FLUX
00003550
TT(I,J-1,L)=TT(I,J-1,L)+FLUX
00003560
IF (L.EQ.1) FLUX=-0.25*FLUX
00003570
IF (L.EQ.2) FLUX=1.25*FLUX
00003580
Q3M=Q3(J,I)+Q3(J-1,I)
00003590
IF(Q3M.LT.10.E-10) GO TO 2220
00003600
C 10.E-10 IS AN ARBITRARY LOWER LIMIT
00003610
FLUXQ=FLUX*Q3M
00003620
IF(Q3(J,I,LT.Q3(J-1,I)) .AND. FLUX.GT.0.0)
* FLUXQ=FLUX*0.3(J,I)+Q3(J-1,I)/Q3M
00003630
IF(Q3(J,I,LT.Q3(J-1,I)) .AND. FLUX.GE.0.0)
* FLUXQ=FLUX*0.3(J,I)+Q3(J-1,I)/Q3M
00003640
Q3T(J,I)=Q3T(J,I)+FLUXQ
00003650
Q3T(J-1,I)=Q3T(J-1,I)-FLUXQ
00003660
2220 CONTINUE
00003670
C
00003680
HORIZONTAL ADOPTION OF EQUATION OF MOTION

FXC0 = TXC0 / 12.
FXC01 = TXC0 / 24.
DO 2320 I = 1, 1, IM
   IP = MOD(I, IM) + 1
   IM1 = MOD(I + IM2, IM) + 1
   DO 2310 J = 1, JM
   FLUX = FXCO * (PU(J, I) + PU(J - 1, I) + PU(J, IM1) + PU(J - 1, IM1))
   FLUXU = FLUX * (U(J, I) + U(J, IM1) + U(J, I + 1) + U(J, IM2))
   UT(J, I) = UT(J, I) + FLUXU
   UT(J, IM1) = UT(J, IM1) - FLUXU
   FLUXV = FLUX * (V(J, I) + V(J, IM1) + V(J, I + 1) + V(J, IM2))
   VT(J, I) = VT(J, I) + FLUXV
   2310 VT(J, IM1) = VT(J, IM1) - FLUXV
   DO 2320 J = 2, JMM1
   FLUX = FXCO * (PV(J, I) + PV(J, IP1) + PV(J + 1, I) + PV(J + 1, IP1))
   FLUXU = FLUX * (U(J + 1, I) + U(J + 1, IM1) + U(J + 1, I + 1) + U(J + 1, IM2))
   UT(J + 1, I) = UT(J + 1, I) + FLUXU
   UT(J + 1, IM1) = UT(J + 1, IM1) - FLUXU
   FLUXV = FLUX * (V(J, I) + V(J, IM1) + V(J, I + 1) + V(J, IM2))
   VT(J + 1, I) = VT(J + 1, I) + FLUXV
   2320 VT(J + 1, IM1) = VT(J + 1, IM1) - FLUXV
CONTINUITY EQUATION

DO 2400 I=1,IM
IM1=MOD(I+1,IM)+1
DO 2400 J=1,JM
IF (J.EQ.1) CONVM=-PV(2,I)*0.5
IF (J.EQ.JM) CONVM=PV(JM,I)*0.5
IF (J.GT.1 .AND. J.LT.JM) CONVM=-PV(J,1) -PV(J,IM1)
   +PV(J+1,1)-PV(J,1) )*0.5
   IF (L.EQ.1) CONV(J,1)=CONVM
   IF (L.EQ.2) PV(J,1)=CONVM
2400 CONTINUE
IF(L.EQ.2) GO TO 2410
L=2
GO TO 2150
2410 CONTINUE

CONV IS MASS CONVERGENCE AT L=1 AND PV IS THAT AT L=2.

2411 PB1=0.0
PB2=0.0
PB3=0.0
PB4=0.0
DO 2402 I=1,IM
PB1=PB1+CONV(I,1)
PB2=PB2+CONV(JM,1)
PB3=PB3+PV(1,1)
2402 PB4=PB4+PV(JM,1)
PB1=PB1/FIM
PB2=PB2/FIM
PB3=PB3/FIM
PB4=PB4/FIM
DO 2405 I=1,IM
CONV(JM,1)=PB1
PV(1,1)=PB3
2405 PV(JM,1)=PB4
DO 2420 I=1,IM
DO 2420 J=1,JM
PT=CONV(J,1)*PV(J,1)
SD(J,1)=CONV(J,1)-PV(J,1)
PT(J,1)=PT(J,1)+DT*PT/DYXP(J)
C ENERGY CONVERSION TERM IN THERMODYNAMIC ENERGY EQUATION

PL1=PTROP*SIG1*P(J,I)
PL3=PTROP*SIG3*P(J,I)
PK1=PL1/*KAPA
PK3=PL3/*KAPA
TETAM=0.5*(T(J,I,1)/PK1+T(J,I,2)/PK3)
TT(J,I,1)=T(J,I,1)+DT*(SIG1*KAPA*P(J,I)*T(J,I,1)*PIT/PL1
* -SD(J,I)*TETAM*PK1)
TT(J,I,2)=T(J,I,2)+DT*(SIG3*KAPA*P(J,I)*T(J,I,2)*PIT/PL3
* +SD(J,I)*TETAM*PK3)

2420 CONTINUE

C VERTICAL ADVECTION OF MOMENTUM

2500 FXCO=0.5*TEXCO
DO 2510 I=1,IM
   IP1=MOD(I,IM)+1
   DO 2510 J=2,JM
   SDU=0.25*(SD(J,I)+SD(J,IP1)+SD(J-1,I)+SD(J-1,IP1))
   IF (J.EQ. 2) SDU=0.25*(SD(2,I)+SD(2,IP1)+SD(1,I))
   IF (J.EQ. JM) SDU=0.25*(SD(JM-1,I)+SD(JM-1,IP1)+SD(JM,I))
   VAD=FXCO*SDU*(U(J,I,1)+U(J,I,2))
   UT(J,I,1)=UT(J,I,1)-VAD
   VAD=FXCO*SDU*(V(J,I,1)+V(J,I,2))
   VT(J,I,2)=VT(J,I,2)+VAD
2510 VT(J,I,2)=VT(J,I,1)-VAD

C RETURN

END
SUBROUTINE COMP2
/*
// DD DISP=OLD,DSN=MESS727.AKH.COMMON
// DD *
C
JM1=JM-1
IM2=IM-2
FIM=IM
TEXCO=DT
IF(MRCH,EQ,1) TEXCO=0.5*DT
C IF (KEY(31)) TEXCO=DT
HKGAS=RGAS/2.
C
C CORINLIS FORC
C
FXCO=0.125*TEXCO
DO 3140 L=1,2
DO 3110 I=1,IM
IM1=MOD(I+1,IM)+1
FD(1,I)=0.0
FD(JM1,I)=0.0
DO 3110 J=2,JM1
FD(J,J)=FD(J,J-1)
3110 FD(J,J)=FD(J,J-1)
* +.25*(D(U(J,IM1,L)+U(J+1,IM1,L)+U(J+1,IM1,L)+U(J+1,IM1,L))
* *(DXU(J)-DXU(J-1))
DO 3140 I=1,IM
IM1=MOD(I+1,IM)+1
DO 3140 J=2,JM
ALPHA=FXCO*(P(J,1)+P(J-1,1))*(FD(J,1)+FD(J-1,1))
UT(J,1,L)=UT(J,1,L)+ALPHA*V(J,1,L)
UT(J,IM1,L)=UT(J,IM1,L)+ALPHA*V(J,IM1,L)
VT(J,1,L)=VT(J,1,L)-ALPHA*U(J,1,L)
3140 VT(J,IM1,L)=VT(J,IM1,L)-ALPHA*U(J,IM1,L)
C PRESSURE GRADIENT
C
3200 DO 3340 L=1,Z
C COMPUTATION OF PHI
C
DO 3210 I=1,IM
DO 3210 J=1,JM
PHI4=VPHI4(J,1)
VP51=PHI(J,1)*0.25/(P(J,1)*0.75+PRTOP)
VP52=PHI(J,1)*0.25/(P(J,1)*0.75+PRTOP)
VPK1=((PHI(J,1)*0.25+PRTOP)/(P(J,1)*0.75+PRTOP))*KAPA
VPK3=1./VPK1
IF(L.EQ.2) GO TO 3205
COE1=(VP51*0.5*(VPK3-1.)/KAPA)*HRGAS
COE2=(VP3*0.5*(1.-VPK1)/KAPA)*HRGAS
PHI(J,1)=COE1*T(J,1,1)+COE2*T(J,1,2)+PHI4
GO TO 3210
3205 COE3=(VP51-0.5*(VPK3-1.)/KAPA)*HRGAS
COE4=(VP3-0.5*(1.-VPK1)/KAPA)*HRGAS
PHI(J,1)=COE3*T(J,1,1)+COE4*T(J,1,2)+PHI4
3210 CONTINUE
C GRADIENT OF PHI
C
FXCO=0.25*DT
FXCO=0.5*DT
DO 3220 I=1,IM
3220 PHI1(I,1)=0.
DO 3250 J=1,JM
IP1=MOD(I,1)+1
IM1=MOD(I+1,IM)+1
DO 3250 J=2,JM
TEMP1=(PHI(J,IP1)+PHI(J,1))-(PHI(J,1)-PHI(J,IP1))
PHI(J,1)=TEMP1
TEMP2=(PHI(J,1)+PHI(J-1,1))*(PHI(J,1)-PHI(J-1,1))*DXU(J)
IF(MRCH.EQ.3) GO TO 3230
IF(MRCH.EQ.4) GO TO 3240
C MRCH= 1 OR 2. CENTERED IN SPACE.
VT(J,J1,L)=VT(J,J1,L)-FXCO1*TEMP2
VT(J,IM1,J1,L)=VT(J,IM1,J1,L)-FXCO1*TEMP2
GO TO 3250
C MRCH=3. UP-RIGHT UNCENTERED.
3230 VT(J,IM1,J1,L)=VT(J,IM1,J1,L)-FXCO1*TEMP2
GO TO 3250
C MRCH=4. DOWN-LEFT UNCENTERED.
3240 VT(J,J1,L)=VT(J,J1,L)-FXCO1*TEMP2
3250 CONTINUE
C
C GRADIENT OF P
C SIGMA*P*ALPHA IS STORED AT PHI
C
DO 3260 I=1,IM
DO 3260 J=1,JM
3260 PHI(J,I)*SIG(L)*P(J,I)*RGAS*T(J,I,L)/(PTROP*SIG(L)*P(J,I))
DO 3290 I=1,IM
IP1=MOD(I,IM)+1
IM1=MOD(I+1,IM)+1
DO 3290 J=2,JM
TEMP1=(PHI(IP1,I)+PHI(J,I))*P(J,IP1)-P(J,I)
PU(J,I)=TEMP1+PU(J,I)
TEMP2=(PHI(J,I)+PHI(J-1,I))*P(J,I)-P(J-1,I)*DXU(J)
IF(MRCH.EQ.3) GO TO 3270
IF(MRCH.EQ.4) GO TO 3280
C MRCH = 1 OR 2, CENTERED IN SPACE
VT(J,I,L)=VT(J,I,L)-FXCO*TEMP2
VT(J,IM1,L)=VT(J,IM1,L)-FXCO*TEMP2
GO TO 3290
C MRCH=3, UP-RIGHT UNCENTERED
3270 VT(J,IM1,L)=VT(J,IM1,L)-FXCO*TEMP2
GO TO 3290
C MRCH=4, DOWN-LEFT UNCENTERED
3280 VT(J,I,L)=VT(J,I,L)-FXCO*TEMP2
3290 CONTINUE
C
CALL AVRX(11)
C
DO 3300 I=1,IM
DO 3300 J=2,JM
IF(MRCH.L.EQ.2) UT(J,I,L)=UT(J,I,L)-FXCO*DYU(J)
X = PU(J,I)+PU(J-1,I)
IF(MRCH.EQ.3) UT(J,I,L)=UT(J,I,L)-FXCO*DYU(J)*PU(J,I)
IF(MRCH.EQ.4) UT(J,I,L)=UT(J,I,L)-FXCO*DYU(J)*PU(J-1,I)
3300 CONTINUE
C ENERGY CONVERSION TERM IN THERMODYNAMIC EQUATION.
C SIGMA*P*ALPHA IS NOW STORED AT PHI
C
3310 FXCO=0.125*DI*KAPA/RGAS
FXCO=0.25*DI*KAPA/RGAS
C
DO 3320 I=1,IM
IP1=MOD(I,IM)+1
DO 3320 J=2,JMM1
IF(MRCH.LE.2) TEMP=FXCO*(U(J+1,I,L)*DYU(J+1)+U(J,I,L)*DYU(J))
IF(MRCH.EQ.3) TEMP=FXCO1*U(J+1,I,L)*DYU(J+1)
IF(MRCH.EQ.4) TEMP=FXCO1*U(J,I,L)*DYU(J)
3320 PU(J,I)=TEMP
C
CALL AVRX(I1)
C
DO 3330 I=1,IM
IP1=MOD(I,IM)+1
IM1=MOD(I+1,IM)+1
DO 3325 J=2,JMM1
PU(J,I)=PU(J,I)*(PHI(J,IP1)+PHI(J,I))*(P(J,IP1)-P(J,I))
TT(J,IP1,L)=TT(J,IP1,L)+PU(J,I)
3325 TT(J,I,L)=TT(J,I,L)+PU(J,I)
DO 3330 J=2,JM
IF(MRCH.LE.2) TEMP=FXCO*DUU(J)*(V(J,I,L)+V(J,I,M1,L))
IF(MRCH.EQ.3) TEMP=FXCO1*DUU(J)*V(J,I,L)
IF(MRCH.EQ.4) TEMP=FXCO1*DUU(J)*V(J,I,M1,L)
TT(J,I,L)=TT(J,I,L)+TEMP
3330 TT(J-1,I,L)=TT(J-1,I,L)+TEMP
3340 CONTINUE
C THIS IS THE END OF FORWARD OR CENTERED TYPE OF TIME EXTRAPOLATION
C ADJUSTMENT AT THE POLES
C
DO 3415 L=1,8
  IF(L.GT.1.AND.L.LT.6) GO TO 3415
  PB1=0.
  PB2=0.
DO 3405 I=1,IM
  PB1=PB1+QT(I,1,L)
  PB1=PB1/FIM
  PB2=PB2/FIM
DO 3410 I=1,IM
  QT(I,1,L)=PB1
  QT(JM,I,L)=PB2
3415 CONTINUE
3430 QT(JM,1,L)=PB2
C RETURN TO UNWEIGHTED VARIABLES
C
DO 3460 I=1,IM
DO 3460 J=1,JM
  FD(I,J)=PT(I,J)*DXYP(J)
3460 IF(JM,JM) = QT(J,1,L)/FD(J,1)
DO 3470 L=1,2
DO 3470 I=1,IM
  IP1=MOD(I,1,IM)+1
DO 3465 J=1,JM
3465 IF(JM,JM) = QT(J,1,L)/FD(J,1)
DO 3470 J=2,JM
  FDU=0.25*(FD(J,1)+FD(J,IP1)+FD(J-1,1)+FD(J-1,IP1))
  IF(J.EQ.2) FDU=0.25*(FD(2,1)+FD(2,IP1)+FD(1,1))
  IF(J.EQ. JM) FDU=0.25*(FD(JM-1,1)+FD(JM-1,IP1)+FD(JM,1))
UT(J,1,L)=UT(J,1,L)/FDU
3470 VT(J,1,L)=VT(J,1,L)/FDU
RETURN
C END
SUBROUTINE AVR(K)

* // DD DISP=OLD,DSN=MES727,ARN,COMMON
// DD *
C THIS SUBROUTINE USES UT(1,1,1) AS A WORKING SPACE
C
JMM1=JM-1
IIM2=IM-2
JE=JM/2+1
DEFF=DYP(JE)
DO 150 J=2,JMM1
DRAT=DEFF/DXP(J)
150 IF (DRAT.LT.1.) GO TO 150
ALP=0.125*(DRAT-1.)
NM=DRAT
FNM=NM
ALPHA=ALP/FNM
DO 150 N=1,NM
DO 120 I=1,IM
IP1=MOD(I,IM)+1
IM1=MOD(I+IIM2,IM)+1
120 UT(I,1,1)=QT(J,I,K)+ALPHA*(QT(J,IP1,K)+QT(J,IM1,K)-2.*QT(J,I,K))
DO 130 I=1,IM
130 QT(J,I,K)=UT(I,1,1)
150 CONTINUE
C
RETURN
END
SUBROUTINE COMP3

C

* DD DISP=OLD, DSN=MES727, ABN, COMMON
   DD *
   EQUIVALENCE (KKK, XXX)
   LOGICAL NOOUT, ICE, LAND, OCEAN, SNOW, KEY

C

TRANS(X)=1.0/(1.0+1.75*X**.416)
TRSW(X)=1.0-271*X**.303

C

JMM1=JM-1
JMM2=JM-2
JMM2=JM-2
IH=IM/2+1
FIM=IM
SIG1=SIG(1)
SIG3=SIG(2)
DSIG=SIG3-SIG1

C

GWM=30.,
DTC3=FLOAT(NC3)*DT
RCNV=DTC3/TCNV
CLH=580./24
P10K=1000.*KAPA
CTI=.005
CTID=.864E4*CTI
MICE=300.,
TICE=273.1

C

PM=PSL-PTROP
COE=GRAV*100./(10.5*PM*1000.0*0.24)
COE=COE*DTC3/(24.*3600.)
SCALE=COE*100.
TSPD=DAY/DTC3
SCALEP=TSPD*5*(10./GRAV)*100.
CONRAD=100.0/P1
CNRX=CONRAD*.01
FSDEDY=SOEDY
SNOWN=(60.*-15.*COS(.9863*(FSDEDY-24.)668)/CONRAD)/CONRAD
SNOWS=-60./CONRAD

C

SURFACE WIND MAGNITUDE

C

DO 10 I=1, IM
DO 10 J=2, JM
US=2.*(SIG3*U(J-1,2)-SIG1*U(J,1))*.07
VS=2.*(SIG3*V(J+1,2)-SIG1*V(J,1))*.07

10 FD(J,1)=US*US + VS*VS
WMAG1=SQR(T(.5*(FD(2,1)+FD(2,IM))))
WMAGJM=SQR(T(.5*(FD(JM,1)+FD(JM,IM))))
C RADIATION CONSTANTS
C
SO=28R0./RSDIST
ALC1=.7
ALC2=.6
ALC3=.6
STBO=1.171E-7
EFVC1=65.3
EFVC2=65.3
EFVC3=7.6
CPART=5*1.3071E7
ROT = TOFDAY/ROTPER*2.0*PI
C
C HEATING LOOP
C
DO 370 I=1,IM
IM1=MOD(I+IM2,IM)+1
IP1=MOD(I,IM)+1
FIM1=I-1
HACOS=COSD*COS(ROT+FIM1*DLON)
DO 360 J=1,JM
COSZ=SINL(J)*SIND*COSL(J)*HACOS
C
C SURFACE CONDITION
C
TOGO=TOPOG(J,1)
OCEAN=TOGO+GT*1.
ICE=TOGO+LEF.*-9.9E5
LAND=NOT.(ICE.OR.OCEAN)
SNOW=LAND.AND..(LAT(J),GE,SNOWN.OR.LAT(J),LE,SNOWS)
IF (.NOT.OCEAN) ZZZ=VPHI4(J,1)/GRAV
C
DRAG COEFFICIENT
C
IF (J.EQ.1) WMAG=WMAG1
IF (J.EQ.JM) WMAG=WMAGJM
IF (.LE.1.AND.,J,NE.JM) WMAG=SQR(.25*(FD(J,1)+FD(J+1,1))
X +FD(J+1,IM1)+FD(J+1,IM1))
CD = .002
IF (.NOT.OCEAN) CD=CD+0.006*ZZZ/5000.
IF (OCEAN) CD = AMIN1((1.0+0.07*WMAG)*.001+.0025)
CS = CD*100.
C4 = .24*CS*24.*3600.
FR1 = CD*(10.*GRAV)/(DSIG*PM)
C PRESSURES
C
SP=P(J,1)
CM=PM/SP
P4=SP+PTRP
P4K=P4**KAPA
PL1=SIG1*SP+PTRP
PL2=SIG2*SP+PTRP
PL3=SIG3*SP+PTRP
PL1K=PL1**KAPA
PL2K=PL2**KAPA
PL3K=PL3**KAPA
PTRK=PTRP**KAPA
DPLK=PL3K-PL1K
C TEMPERATURES AND TEST FOR DRY-ADIABATIC INSTABILITY
C
T1=T(J,1,1)
T3=T(J,1,2)
THL1=T1/PL1K
THL3=T3/PL3K
IF (THL1 .GT. THL3) GO TO 310
XX1=(T1+T3)/(PL1K+PL3K)
T1=XX1*PL1K
T3=XX1*PL3K
T(J,1,1)=T1
T(J,1,2)=T3
THL1=T1/PL1K
THL3=T3/PL3K
C MOISTURE VARIABLES
C
310 ES1=10.0**((8.4051-2353.0/T1)
ES3=10.0**((8.4051-2353.0/T3)
PLCB=.1*PL1
P3CB=.1*PL3
P4CB=.1*P4
QS1=.622*ES1/(PLCB-ES1)
QS3=.622*ES3/(P3CB-ES3)
GAM1=CLH*QS1/S418.5/T1**2
GAM3=CLH*QS3/S418.5/T3**2
Q3R=QS(J,1)
R3H=Q3R/QS3
C TEMPERATURE EXTRAPOLATION AND INTERPOLATION FOR RADIATION
C
ATEM=(THL3-THL1)/DPLK
BTEM=(THL1*PL3K-THL3*PL1K)/DPLK
TTROP=(ATEM*P4*P4K)**PTRK
T2=(ATEM*PL2K*BTEM)*P4K
C
GROUND TEMPERATURE AND WETNESS

Tg = Tg00

Wet = 1.0

IF (.not. OCEAN) Tg = GT(J,1)

IF (LAND) Wet = GW(J,1)

LARGE SCALE PRECIPITATION

Prec = 0.

IF (Q3R * LE * Q5S) GO TO 1060

Prec = (Q3R - Q5S) / (1. + GAM3)

T3 = T3 + CHM * Prec

THL3 = T3 / PL3k

Q3R = Q3R - Prec

CONVECTION

1060 TETA1 = THL1 * P10k

TETA3 = THL3 * P10k

SS3 = TETA3 * P4k / P10k

SS2 = SS3 + 0.5 * (TETA1 - TETA3) * PL2k / P10k

SS1 = SS2 + 0.5 * (TETA1 - TETA3) * PL2k / P10k

MH3 = SS3 + CHM * Q3R

MH3S = SS3 + CHM * Q5S

MH1S = SS1 + CHM * Q5S

MIDDLE LEVEL CONVECTION

C1 = 0.

C3 = 0.

EX = MH3 - MH1S

IF (EX * LE * 0.) GO TO 1065

C1 = RCNVE * EX / (2. * GAM1)

C3 = C1 * (1. + GAM1) * (SS2 - SS3) / (EX * (1. + GAM1) * (SS1 - SS2))

PREPARATION FOR AIR-EARTH INTERACTION

1065 ZL3 = 2000.

WINDF = 2.0 + WMAG

DRAW = CD * WINDF

EDV = ED / ZL3 * WMAG / 10.

DETERMINATION OF SURFACE TEMPERATURE

1070 RH4=2.*(WET/RH3/(WET+RH3))
    EG=10.*8.*(R4+253./T4)
    ED=AMIN1(EG,P4CB/1.662)
    QG=.622*EG/(P4CB-EG)
    DG=5418.*QG/TG**2
    HHG=11*QG*WET
    EDR=EDV/(EDV+DRAW)
    HH4=EDR+RH3*(1.-EDR)*HHG
    GAMG=CLH*DG
    T4=(HH4-RH4*(CLH*QG-GAMG+T4))/(1.+RH4*GAMG)
    IF (T4>P1OK/P4K,GT,TETA3) T4=TETA3*P4K/P1OK
    Q4=RH4*1OG+DG*(T4-TG)
    HH4=T4+CLH*Q4

PENETRATING AND LOW-LEVEL CONVECTION

PC1=0.
PC3=0.
EX=0.
IF (HH4.LE. HH35) GO TO 1077
IF (HH3.GT. HH15) GO TO 1077
EX = HH4-HH35
HH4P = HH4
HH4 = HH35
IF (HH4P .LT. HH15) GO TO 1076
ETA = 1.
TEMP1 = ETA*(HH35-HH15)/(1.+GAM1)+SS1-SS2
TEMP2 = ETA*(SS2-SS3) + (SS3-T4)
TEMP = EDR*TEMP1+(1.+GAM3)*TEMP2
IF (TEMP .LT. .001) TEMP=.001
CONVP = RCNV*EX/TEMP
PC1 = CONVP*TEMP1
PC3 = CONVP * TEMP2

1076 T4=T4-EX/(1.+RH4*GAMG)
    Q4=(HH4-T4)/CLH

1077 RD4=P4CB/(RGAS*T4)
    CSEN=CS4*R04*WINDF
    CEVA=CS*R04*WINDF

00008960 00008970 00008980 00008990 00009000 00009010 00009020 00009030 00009040 00009050 00009060 00009070 00009080 00009090 00009100 00009110 00009120 00009130 00009140 00009150 00009160 00009170 00009180 00009190 00009200 00009210 00009220 00009230 00009240 00009250 00009260 00009270 00009280 00009290 00009300 00009310 00009320 00009330 00009340 00009350 00009360 00009370 00009380 00009390
C CLOUDINESS

ICLOUD=1
CL=0.
CL1=0.
CL2=0.
CL3=0.
CLT=0.
CL = AMIN1(-1.3*2.6*RH3,1.)
IF (CL1 .LT. 0.* OR. PC1 .LT. 0.) CL1 = CL
IF (PREC .LT. 0.* AND. CL1 .EQ. 0. ) CL2 = 1.
IF (EX. LT. 0.* AND. PC1 .EQ. 0. ) CL3 = CL

+-----------------------------------------------+
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+-----------------------------------------------+
CL1  CL2  CL3

CL = AMAX1(CL1,CL2,CL3)
IF (CL .GE. 1.) ICloud = 3
IF (CL .LT. 1.* AND. CL .GT. 0.* ) ICloud = 2

ICLOUD=1 CLEAR, ICloud=2 PARTLY CLOUDY, ICloud=3 OVERCAST
C LONG WAVE RADIATION

1080 Q3RB=AMAX1(Q3R,1.*E-5)
    VAK=2.*ALOG(1.,7188-6/Q3RB)/ALOG(120.,/PL3)
    TEM1=.00102*PL3**2*Q3RB/VAK
    TEM2=TEM1*(PL4/PL3)**VAK
    EFV3=TEM2-TEM1
    EFV2=TEM2-TEM1*(PL2/PL3)**VAK
    EFV1=TEM2-TEM1*(PL1/PL3)**VAK
    EFVT=TEM2-TEM1*(PTROP/PL3)**VAK
    EFV0=TEM2-TEM1*(120./PL3)**VAK+2.*526E-5
    BLT=STB0*TTROP**4
    BL1=STB0*T1**4
    BL2=STB0*T2**4
    BL3=STB0*T3**4
    BL4=STB0*TG**4

C LONG WAVE RADIATION

ROC=0.
R2C=0.
R4C=0.

URT=BLT*TRANS(EFVO-EFVT)
UR2=BL2*TRANS(EFVO-EFV2)

GO TO (1090,1090,2000), ICLOUD

1090 R00=0.82*(URT+(BL4-BLT)*(1.+TRANS(EFVT))/2.)
    R20=0.736*(UR2+(BL4-BL2)*(1.+TRANS(EFV2))/2.)
    R40=BL4*(0.6*SORT(TRANS(EFVO))-0.1)
    IF (ICLOUD .EQ. 1) GO TO 2015

2000 IF (CL2 .LE. 0.) GO TO 2004
    CLT=CL2
    ROC=0.82*(URT+(BL2-BLT)*(1.+TRANS(EFVT-EFV2))/2.)*CLT
    R2C=0.736*UR2*CLT
    R4C=5*R2C
    GO TO 2006

2004 IF (CL3 .LE. 0.) GO TO 2006
    CLT=CL3
    ROC=0.82*(URT+(BL3-BLT)*(1.+TRANS(EFVT-EFV3))/2.)*CLT
    R2C=0.736*UR2+(BL3-BL2)*(1.+TRANS(EFV2-EFV3))/2.)*CLT

2006 IF (CL1 .LE. 0.) GO TO 2010
    CLM=AMAX1(CL1-CL1,0.)

C IN PRESENT VERSION, CLM AND THIS TEM ARE ALWAYS ZERO

TEM=0.
    IF (CLM < 0.001) TEM=CLM/CLT
    ROC=0.82*(URT+(BL1-BLT)*(1.+TRANS(EFVT-EFV1))/2.)*CL1*ROC*TEM
    R2C=R2C*TEM
    R4C=0.85*(UR2+(BL4-BL3)*(1.+TRANS(EFV3))/BL4-BL3)*CL

2010 R5C=0.85*(UR2+(BL4-BL3)*(1.+TRANS(EFV3))/BL4-BL3)*CL

2015 RO=ROC+(1.-CL)*R00
    R2=R2C+(1.-CL)*R20
    R4=R4C+(1.-CL)*R40
    DIRAD=4.*STB0*TG**3
C  SURFACE ALbedo
  IF (COSZ .LE. .01) GO TO 340
  SCOSZ=SO*COSZ
  ALS=.07
  IF (OCEAN) GO TO 335
  ALS=.14
  IF (LAT(J) .LT. SOWN) GO TO 327
  CLAT=(LAT(J)-SOWN)*CONRAD
  GO TO 330
  327 IF (LAT(J) .GT. SOWN) GO TO 328
  CLAT=(SOWN-LAT(J))*CONRAD
  ALS=.45*(1.+(CLAT-10.)**2)/(CLAT-30.)**2+(CLAT-10.)**2
  GO TO 335
  328 IF (LAND) GO TO 335
  CLAT=0.0
  330 ALS=.4*(1.+(CLAT-5.0)**2)/(CLAT-45.0)**2+(CLAT-5.0)**2
  C  SOLAR RADIATION
  ALAO=AMIN111.,.085-.247*ALOG10(COSZ/COLMR))
  SA=.349*SCOSZ
  SS=SCOSZ-SA
  ASOT=SA*TRSW(EFVO-EFVT)/COSZ
  AS2T=SA*TRSW(EFVO-EFV2)/COSZ
  FS2C=0.
  FS4C=0.
  S4C=0.
  GO TO (336,336,337), ICLD0
C CLEAR

336 FS20 = AS2T
FS40 = SA * TRSW(EFVO/COSZ)
S40 = (1. - ALCS) * (FS40 + (1. - ALAO) / (1. - ALAO * ALS) * SS)
IF (ICLOUD = EQ. 1) GO TO 341

C LARGE SCALE CLOUD

337 IF (CL2 .LE. 0.) GO TO 338
CLT = CL2
FS2C = AS2T * CLT
TEM5 = SA * (1. - ALC2) * TRSW((EFVO-EFV2)/COSZ + 1.66 * (EFVC2 * EFV3))
FS4C = (TEMPLATE + ALS * AS2T) * CLT
ALAC = ALC2 + ALAO - ALC2 * ALAO
S4C = (1. - ALS) * TEM5 / (1. - ALC3 * ALS) * (1. - ALAC) / (1. - ALAC * ALS) * SS * CLT
GO TO 339

C LOW LEVEL CLOUD

338 IF (CL3 .LE. 0.) GO TO 339
CLT = CL3
FS2C = AS2T * CLT
TEM5 = (EFVO - EFV3) / COSZ
TEM5 = SA * (1. - ALC3) * TRSW(TEM5 + 1.66 * (EFVC3 * EFV3))
FS4C = (TEMPLATE + ALS * SA * TRSW(TEM5)) * CLT
ALAC = ALC3 + ALAO - ALC3 * ALAO
S4C = (1. - ALS) * TEM5 / (1. - ALC3 * ALS) * (1. - ALAC) / (1. - ALAC * ALS) * SS * CLT
GO TO 340

C THICK CLOUD

339 IF (CL1 .LE. 0.) GO TO 341
CLM = AMAX1(CL1 - CL1, 0.)

C IN PRESENT VERSION, CLM AND THIS TEM ARE ALWAYS ZERO

TEMP = 0.
IF (CLT .GT. 0.) TEM = CLM / CLT
TEM5 = (EFVO - EFV1) / COSZ
TEM5 = SA * (1. - ALC1) * TRSW(TEMU + 1.66 * EFVC1) * CL1 + TEMB + FS2C * TEM
TEM5 = SA * (1. - ALC1) * TRSW(TEMU + 1.66 * (EFVC1 * EFV3))
FS4C = (TEMPLATE + ALS * CL1 * TEMB + FS4C * TEM)
ALAC = ALC1 + ALAO - ALC1 * ALAO
S4C = (1. - ALS) * TEM5 / (1. - ALC1 * ALS)
X + (1. - ALAC) / (1. - ALAC * ALS) * SS * CL1 + S4C * TEM

C MEAN CONDITION

341 FS2 = FS2C * (1. - CL) * FS20
FS4 = FS4C * (1. - CL) * FS40
S4 = S4C * (1. - CL) * S40
AS1 = AS0T * FS2
AS3 = FS2 - FS4
GO TO 345

340 S4 = 0.0
AS3 = 0.0
AS1 = 0.0
COMPUTATION OF GROUND TEMPERATURE

345 TGR=TG
   IF (OCEAN) GO TO 347
   BRAD=S4-R4
   TEM=O4
   IF (ICE.AND.ZIZ.LT.0.1) TEM=CTIO/HICE
   A1=CSEN*(T4+CLH*(Q4+DQG*(DGQ-TG*DQG)))
   A2=BRAD*4.*BL4+TEM*TICE
   B1=CSEN*(1.+CLH*DGQ*WET)
   B2=DIRAD+TEM
   TGR=(A1+A2)/(B1+B2)
   IF (LAND.OR.TGR.LT.TICE) GO TO 346
   TGR=TICE

346 DR4=DIRAD*(TGR-TG)
   R4=R4+DR4
   R2=R2+.8*(1.-CL)*TRANS(EVF2)*DR4
   RD=R0+.8*(1.-CL)*TRANS(EFVT)*DR4

347 GT(J,I)=TGR

SENSIBLE HEAT (LY/DAY) AND EVAPORATION (GM/CM**2/SEC)

E4=CEVA*(WET*(QG+DQG*(TGR-TG))-Q4)
F4=CSEN*(TGR-T4)
FK=RD4+FK1*WINDF

TOTAL HEATING AND MOISTURE BUDGET

QN=(C1+C3*PC1+PC3)/CLH*PREC-2.*E4*OTC3*GRAV/(SP*10.)
Q3(J,I)=Q3(J,I)-QN
   IF (NOT.LAND) GO TO 350
RUNOFF=0.
   IF (ON.OT,0.*.AND.WET.LT.1.) RUNOFF=.5*WET
   IF (ON.OT,0.*.AND.WET.GE.1.) RUNOFF=1.
   WET = GW(J,I)+(1.-RUNOFF)*QN+.5*SP/GRAV/GWM
   IF (WET.GT.1.) WET = 1.
   IF (WET.LT.0.) WET = 0.

350 GW(J,I) = WET

IF (Q3(J,I)+LT.0.) Q3(J,I)=0.
   IF (KEY(31)) GO TO 360

H1=(AS1+R2-R0)*COE1*COLMR+C1+PC1
H3=(AS3+R4-R2+F4)*COE1*COLMR+C3+PC3+PREC*CLH
H(J,I)=0.5*(H1+H3)
T(J,I,1)=T(J,I,1)+TEMP
T(J,I,2)=T(J,I,2)-TEMP
C  SURFACE FRICTION

352  IF (J EQ 1) GO TO 358

    COLMR=4*PM/(P(J,1)+P(J,1)+P(J-1,1)+P(J-1,1))
    DN 355 K=1,2
    K1=2*K
    K2=K+1
    TEMP=Q(J,1,K1)-Q(J,1,K2)
    Q(J,1,K1)=Q(J,1,K1)-FM*TEMP*COLMR#2*DTC3
    Q(J,1,K2)=Q(J,1,K2)+FM*TEMP*COLMR-FK*(Q(J,1,K2)-5*TEMP)*7
    *COLMR*DTC3

C

358 CONTINUE

C 358 IF (NODOUT) GO TO 360

C  PACK FOR OUTPUT

    WW=SD(J,1)#3600./12.0*DXYP(J)
    SCALE=SCALEU*COLMR
    KKK=IPK(IFIX(AS1*SCALE)+IFIX(AS3*SCALE))
    T(J,1,1)=XXX
    KKK=IPK(IFIX((R2-R0)*SCALE)+IFIX((R4-R2)*SCALE))
    VT(J,1,2)=XXX
    KKK=IPK(IFIX(F4)+IFIX(E4#100.#3600.#24.*))
    TT(J,1,2)=XXX
    KKK=IPK(IFIX(T4#10.)+IFIX(PREC*SCALEP*SP))
    Q3T(J,1)=XXX
    KKK=IPK(IFIX(EX#10.)+IFIX((C1+C3*PC1*PC3)#SP#SCALEP/CLM))
    U(J,1,2)=XXX
    KKK=IPK(IFIX(H1#100.#DAY/DTC3)+IFIX(H3#100.#DAY/DTC3))
    PT(J,1)=XXX
    KKK=IPK(IFIX(S4#10.)+IFIX(WW#100.))
    SD(J,1)=XXX

360 CONTINUE

370 CONTINUE

375 DO 377 I=1,IM
    DO 377 J=1,JM
    H(I,J,1)=H(I,J,1)+DXYP(J)

C

377 DO 390 I=1,IM
    IP1=MOD(I,IM)+1
    IM1=MOD(I+1,JMM2)+1
    DO 380 J=2,JMM1
    TEMP=H(J,1,1)+2*H(J,1,1)+H(J+1,1)+H(J+1,1)
    & +2*H(J,1,1)+4*H(J,1,1)+2*H(J,1,1)
    & +2*H(J-1,1,1)+2*H(J-1,1,1)+H(J-1,1,1)#+16*DXYP(J))
    T(J,1,1)=T(J,1,1)+TEMP

380 T(J,1,2)=T(J,1,2)+TEMP
    T(I,1,1)=T(I,1,1)+H(I,1,1)+DXYP(I)
    T(I,1,2)=T(I,1,2)+H(I,1,1)+DXYP(I)
    T(JM,1,1)=T(JM,1,1)+H(JM,1,1)+DXYP(IM)

390 T(JM,1,2)=T(JM,1,2)+H(JM,1,1)+DXYP(JM)

400 RETURN

END
SUBROUTINE COMP4

* DTC3=DT*FLOAT(NC3)
SIG1=SIG(1)
SIG3=SIG(2)
DSIG=SIG3-SIG1
JMM1=JM-1
JMM2=JM-2
IMM2=IM-2
FIM=IM
TSPD=DAY/DTC3
IF(A.EQ.0.) GO TO 92
C
DO 25 I=1,IM
DO 20 J=2,JM
20 PV(J,I)=DXYP(J)*P(J,I)
25 PV(1,I)=DXYP(1)*P(1,I)
C
DIFFUSION OF MOMENTUM
C
DO 30 I=1,IM
IP1=MOD(I,IM)+1
DO 30 J=2,JM
30 PU(J,I)=0.25*(PV(J,I)+PV(J-1,I)+PV(J,IP1)+PV(J-1,IP1))
DO 90 K=2,5
K1=MOD(K,2)
FL=MOD(K,2)*2+1
SIGCO=FL/2
DO 40 I=1,IM
IP1=MOD(I,IM)+1
DO 40 J=2,JM
40 PV(J,I)=SIGCO*(P(J,IP1)+P(J-1,IP1)-P(J,I)-P(J-1,I))
   * (/ (P(J,IP1)+P(J-1,IP1)+P(J,I)+P(J-1,I))
   * (Q(J,I,K1)-Q(J,I,K1+1)))

C
00012040
00012050
00012060
00012070
00012080
00012090
00012100
00012110
00012120
00012130
00012140
00012150
00012160
00012170
00012180
00012190
00012200
00012210
00012220
00012230
00012240
00012250
00012260
00012270
00012280
00012290
00012300
00012310
00012320
00012330
00012340
00012350
00012360
00012370
00012380
00012390
00012400
00012410
00012420
DO 50 I=1,IM
IM=MOD(I+1,IM)+1
DO 50 J=2,JM
TEMP=DTC3*(P(J,1)+P(J-1,1))*AXU(J)*DYU(J)/DXU(J)*0.5
* *(Q(J,1,K)-Q(J,1,K)+PV(J,1)+PV(J,1))
Q(J,1,K)=Q(J,1,K)-TEMP/PU(J,1)
50 Q(J,1,K)=Q(J,1,K)+TEMP/PU(J,1)
DO 60 I=1,IM
IP1=MOD(I,IM)+1
DO 60 J=2,JM
60 PV(J,1)=SIGCO*(P(J,1,IP1)+P(J,1)-P(J-1,1,IP1)-P(J-1,1))
* /P(J,1,IP1)+P(J,1)+P(J-1,1,IP1)+P(J-1,1))
* *(Q(J,1,K)-Q(J,1,K1+1))
DO 80 I=1,IM
IP1=MOD(I,IM)+1
DO 70 J=2,JMM1
TEMP=DTC3*(P(J,1,IP1)+P(J,1))*AYU(J)*DXU(J)*3/DYU(J)*0.5
* *(Q(J,1,K)+PV(J,1,1))/DXU(J-1)-(Q(J,1,K)-PV(J,1))/DXU(J1)/00012600
Q(J,1,K)=Q(J,1,K)-TEMP/(PU(J+1,1)*DXU(J1))
00012610
70 Q(J,1,K)=Q(J,1,K)+TEMP/(PU(J,1)*DXU(J))
TEMP=DTC3*P(J,1,1)*AYU(JM)*DXU(JM)/DYU(JM)*(Q(JM1,K)-PV(JM,1))
Q(JM1,K)=Q(JM1,K)-TEMP/PU(JM,1)
00012640
TEMP=DTC3*P(Z,1)*AYU(2)*DXU(2)/DYU(2)*(Q(Z,1,K)-PV(Z,1))
00012650
80 Q(Z,1,K)=Q(Z,1,K)-TEMP/PU(Z,1)
90 CONTINUE
92 CONTINUE
99 DO 100 I=1,IM
DO 100 J=1,JM
100 TD(J,1)=(T(J,1,2)-T(J,1,1))*5/P(J,1)
100 TD(J,1)=TD(J,1)+TD(J,1,1)+TD(J+1,1,1)+2*TD(J+1,1,1)+2*TD(J+1,1,1)/16.
2 +2*TD(J,1)+4*TD(J,1)+2*TD(J,1,1)
3 + TD(J-1,1,1)+2*TD(J-1,1,1)+TD(J-1,1,1))/16.
TDSM=(TD(J,1)+TDBAR-TD(J,1))/TSPD*PI*1
TBAR=(T(J,1,2)+T(J,1,1))*5
T(J,1,1)=TBAR-TDSM
110 T(J,1,2)=TBAR+TDSM
RETURN
END
SUBROUTINE

/*

// DD DISP=OLD, DSN=MS727,ABN,COMMON
//
C
EQUIVALENCE (XXX,KKK)
DIMENSION C1(800), IC1(800), IC(800), ALPH(8)
C
EQUIVALENCE (QT(1,1,10),C1(1),IC1(1)), (C1,IC(1))

LOGICAL JUMP
INTEGER KSET(32), BLANK/* */
EQUIVALENCE (XLEV,ILEV)

C
C INPUT PROGRAM
C
IF (KEY(11), OR, KEY(12)) GO TO 751
PI=3.1415926
SIG(1)=.25
SIG(2)=.75
DAYPPYR=365.
DECMAX=23.5/180.0*PI
ROTPER=24.0
EONX=173.0
APHEL=183.0
ECCN=0.0178

C HISTORY FILE
KTP=11
C CHECKPOINT FILE
LTP=1
C DATA CARD IMAGE FILE
INU=5
C OUTPUT (MAP) STREAM
MTP=6

C (1) READ (INU,50) ID,XLABL
C (2)
C TRST=1. : RESTART USING NEW TAPE
C TERM=0. : DO NOT TERMINATE OLD TAPE IF TRST=1.
READ (INU,80) TAUD,TAUD,TAUH,TAUE,TAUC
TAU=24.0*TAUE

C (4) READ (INU,82) DTM, NCYCLE, NC3
C (5) READ (INU,10) JM, IM, DLAT
C (6) READ (INU,80) AX
C (7) READ (INU,80) FMX, ED, TCNV

PING=PONG RESTART/OUTPUT OPTION

C

00012880
00012890
00012900
00012910
00012920
00012930
00012940
00012950
00012960
00012970
00012980
00012990
00013000
00013010
00013020
00013030
00013040
00013050
00013060
00013070
00013080
00013090
00013100
00013110
00013120
00013130
00013140
00013150
00013160
00013170
00013180
00013190
00013200
00013210
00013220
00013230
00013240
00013250
00013260
00013270
00013280
00013290
00013300
00013310
00013320
00013330
00013340
00013350
00013360
00013370
00013380
00013390
00013400
C (8)  READ (INU,80) RAD, GRAV, DAY
C (9)  READ (INU,80) RGAS, KAPA
C (10) READ (INU,80) PSL, PTROP
C (11) READ (INU,80) PSF
C (12) FOR POLAR MAPS, LATITUDE OF INSCRIBED CIRCLE
       READ (INU,80) DLIC
C (13) READ (INU,85) KSET
      DO 40 J=1,32
        KEYS(I,J)=KSET(J).NE.BLANK
        DT=DTM*60.0
        A=AX*1.0E5
        FIM=IM
        DLAT=DLAT*PI/180.0
        DLON=2.0*PI/FIM
        FIM=FIM*0.00001
      40
C      RAD=RAD*1000.0
      DAY=DAY*3600.0
C      CALL MAGFAC
      READ (INU,1199) MARK
      READY=.TRUE.
     125 READ (KTP) TAUH, C1
      IF (TAUX .LT. 0.0) GO TO 135
      TAU=TAUX
      TAUID=IFIX(TAUH/24.)
      TAUH=TAUX-24.*TAU
C      IF (KEY(I)) WRITE (MTP,9120) TAUID, TAUH
      C(22) = C(22)
      SDEY = IC(29)
      SDEYR = IC(30)
      CALL OUTAPE(KTP,1)
      IF (TAUX=TAUH) 125, 190, 190
     135 BACKSPACE KTP
     190 CONTINUE
      IF (((TRST.EQ.1).AND.(TERM.EQ.0))) GO TO 195
      TAUH=ABS(TAUH)
      WRITE (KTP) TAUH,C1
      BACKSPACE KTP
     195 CONTINUE
      IF (TRST.EQ.0.0) GO TO 202
      REWIND KTP
      KTP=11
      WRITE (KTP) TAU,C
      CALL OUTAPE (KTP,2)
     202 JUMP=.FALSE.
C
205 CALL INIT2(MARK)
206 CALL INSDET
   IF (JUMP) GO TO 300
250 CONTINUE
C
   IF (KEY(-20)) TAU=24.
   TAU=TGUI
   WRITE (MTP,1200) ID,XLABL
   WRITE (MTP,1201) TAUI,TAUI,TRST,TAUI
   WRITE (MTP,1201) TAUI,TAUD,TAUI,TAUE,TAUC
   WRITE (MTP,1201) DTM,DLAT,AX,FMX,ED,TCNV
   WRITE (MTP,1201) RAD,GRAv,DAY,Rgas,KAPA,PSL,PTROP,PSF,DLIC
   WRITE (MTP,1202) JN,IM,NCYCLE,NC3
   WRITE (MTP,1197) AX
   WRITE (MTP,1195) ED,TCNV
   WRITE (MTP,1196) FMX
C
300 TODAY=AMOD(TAU,R0TPER)
C
   WRITE (2) GW,GT,TS,SN
C
   REWIND 2
   RETURN
C
10 FORMAT (215,F10.0)
50 FORMAT (10A4)
57 FORMAT (I2,RA1,2F10.0,RA4)
82 FORMAT (F10.0,215)
80 FORMAT (5F10.0)
85 FORMAT (32A1)
1195 FORMAT (6H0 ED=,F5.2,7H0 TCNV=,F5.0)
1196 FORMAT (6H0 FM=,F4.2,8H0,00001)
1197 FORMAT(6H0 A=,F4.2,9H=100000.0)
1199 FORMAT (213)
9120 FORMAT (1X,2F10.2)
9731 FORMAT ('1TAPE',I4,' DOES NOT CONTAIN THE STARTING TIME')
9781 FORMAT ('0SWITCHING FROM TAPE ',I2,' TO TAPE ',I2)
1200 FORMAT (1H1,A4,2X,9A4)
1201 FORMAT (9F1X,E12.5)
1202 FORMAT (10(1X,I5))
END
* MAGFAC

* DD DISP=OLD, DSN=MEST27, ABN.COMMON
* DD *
C EQUAL LATITUDE DISTANCE PROJECTION
C
JMM1=JM-1
FJ=M
FJE=FJ/2.0*0.5
DO 410 J=2,JMM1
FJ=J

410 LAT(J)=DLAT*(FJ-FJE)
LAT(1)=PI/2.0
LAT(JM)=PI/2.0
C
DO 415 J=2,JM

415 DUY(J)=RAD*(LAT(J)-LAT(J-1))
DUY(1)=DUY(2)
DO 420 J=1,JM

420 DXP(J)=RAD*COS(LAT(J))*DLON
C
DO 430 J=2,JM

430 DXU(J)=0.5*(DXP(J)+DXP(J-1))
DXU(1)=DXU(2)
DO 440 J=2,JMM1

440 DYP(J)=0.5*(DUY(J+1)+DUY(J))
DYP(1)=DUY(2)
DYP(JM)=DUY(JM)
DO 445 J=2,JMM1

445 DXYP(J)=0.5*(DXU(J)+DXU(J+1))*DYP(J)
DXYP(1)=DXU(2)*DYP(1)*0.25
DXYP(JM)=DXU(JM)*DYP(JM)*0.25
DO 450 J=2,JMM1

450 F(J)=2.0*PI/DAY*(RAD/DXYP(J))*((COS(LAT(J-1))+COS(LAT(J)))*DXU(J))
F(JM)=(COS(LAT(J))+COS(LAT(J+1)))*DXU(J+1)/2.0
F(JM)=2.0*PI/(RAD/DXYP(JM))*((COS(LAT(JM-1))+COS(LAT(JM)))*DXU(JM))
F(JM)=2.0*PI/DAY*(RAD/DXYP(JM))*((COS(LAT(JM-1))+COS(LAT(JM)))*DXU(JM))
RETURN
END
C
C USED IN COMP4 ONLY
EXP1=4.0/3.0
DO 42 J=1,JM
AXU(J)=A*(DXU(J)/3.0E5)**EXP1
AXV(J)=A*(DXV(J)/3.0E5)**EXP1
AYU(J)=A*(DUY(J)/3.0E5)**EXP1
AYV(J)=A*(DYP(J)/3.0E5)**EXP1
RETURN
END
C
C

SUBROUTINE

INSDEQ

*  
/
DD DISP=OLD, DSN=MES727, ABN, COMMON
DD *
LOGICAL DCLK
C
DD 411 J=1, JM
SINL(J)=SIN(LAT(J))
COSL(J)=COS(LAT(J))
C
IF (KEY(11), OR, KEY(12)) GO TO 15
C
INU=5
READ (INU, 7) CLKSW, RSETSW, LDAY, Lyr
31 IF (RSETSW .NE. RESET) GO TO 14
SDDY=LDAY
SDEY=Lyr
DCLK=.FALSE.
CALL SDET
IF (CLKSW .NE. OFF) DCLK=.TRUE.
RETURN
C
15 DCLK=.FALSE.
CALL SDET
RETURN
C
7 FORMAT (A4, 6X, A4, 6X, I3, 7X, I4)
C
DATA RESET/4, HRESE/, OFF/4, OFF /
C
END
SUBROUTINE SOET

DIMENSION 2MONTH(3,12), MONTH(12)
LOGICAL DCLK
MAXDAY=DAPYR + 1.0E-2
IF (DCLK) SDERA=SDERA+1
IF (SDERA *LE. MAXDAY) GO TO 211
SDERA=SDERA-MAXDAY
SDERA=SDERA+1

211 J0YACC=0
DO 251 L=1,12
J0YACC=J0YAC+MONTH(L)
IF (SDERA *LE. J0YACC) GO TO 241
CONTINUE

251 MNTHDY=MONTH(L)-J0YACC+SDERA
AMONTH(1)=AMONTH(1,L)
AMONTH(2)=AMONTH(2,L)
AMONTH(3)=AMONTH(3,L)
DY=SDERA
SEASON=(DY-EONX)/DAPYR
DIST=(DY-AHEL1)/DAPYR

C EONX = JUNE 22
C AHELION = JULY 1
C ECCN = ORBITAL ECCENTRICITY
C
DEC=DECMAX*COS(2.0*PI*SEASON)
R5DIST=(1.0+ECCN*COS(2.0*PI*DIST))**2
SIND=SIN(DEC)
COSD=COS(DEC)

C DATA 2MONTH/1 JANUARY FEBRUARY MARCH APRIL 00015560
00015561 00015562 00015563 00015564 00015565
00015566 00015567 00015568 00015569 00015570
00015571 00015572 00015573 00015574 00015575
00015576 00015577 00015578 00015579 00015580
00015581 00015582 00015583 00015584 00015585
00015586 00015587 00015588 00015589 00015590
00015591 00015592 00015593 00015594 00015595
00015596 00015597 00015598 00015599 00015600
00015601 00015602 00015603 00015604 00015605
00015606 00015607 00015608 00015609 00015610
SUBROUTINE INIT1

* INIT1

/*/  
// DD DISP=OLD, DSN=MES727.ABN.COMMON  
// DD *  
C  
C  
C  
C  
C  
C  
C  
C  
C  
RETURN  
C  
END

SUBROUTINE INIT2 (MARK1)

* INIT2 (MARK1)

/*/  
// DD DISP=OLD, DSN=MES727.ABN.COMMON  
// DD *  
REAL METER  
DIMENSION HEIGHT (46)  
LOGICAL FAH  
C  
INU = 5  
IF (MARK1 .EQ. 0) GO TO 71  
C  
READ UNIT CARD FOR GEOGRAPHY  
C  
75 READ (INU,110) TEMSCL  
IF (TEMSCCL .EQ. FAREN) GO TO 86  
IF (TEMSCCL .EQ. CENTIG) GO TO 46  
STOP 19121  
86 FAH=.TRUE.  
GO TO 97  
46 FAH=.FALSE.  
GO TO 97  
19 WRITE (6,76)  
STOP  
97 CONTINUE
C READ GEOGRAPHY DECK
C OCEAN:  SEA SURFACE TEMPERATURE
C LAND:  -64
C SEA ICE OR LAND ICE:  -96
C
DO 15 IL=1,MARK1
READ (INU,102) (TOPOG(J,IL),J=1,15),IL1,(TOPOG(J,IL),J=16,30),IL2
X,(TOPOG(J,IL),J=31,46),IL3
IF (IL1,NE,IL2,OR,IL2,NE,IL3,OR,IL1,NE,IL) GO TO 19
15 CONTINUE
DO 23 IL=1,1M
DO 23 JL=1,JM
IF (TOPOG(JL,IL),LE,64.0) GO TO 23
IF (FAM) TOPOG(JL,IL)=(TOPOG(JL,IL)-32.0)*5./9.
TOPOG(JL,IL)*TOPOG(JL,IL)*273.0
23 CONTINUE
CNST=GRAV=30.48
MCST=1.

C READ UNIT CARD FOR TOPOGRAPHY
C
READ (INU,110) HSCL
IF (HSCL,NE,FEET,AND,HSCL,NE,METER) GO TO 78
IF (HSCL,EQ,METER) MCST=39.39/120.
CNST=CNST*MCST
DO 10 I=1,MARK1
10 CONTINUE
C READ TOPOGRAPHY DECK
READ (INU,101) (HEIGHT(J),J=1,25),IL1,(HEIGHT(J),J=26,JM),IL2
IF (IL1,NE,IL2,OR,IL2,NE,1) GO TO 19
DO 20 J=1,JM
IF (TOPOG(J,IL)+64.0) 60,50,20
50 TOPOG(J,IL)=HEIGHT(J)*CNST
GO TO 20
60 TOPOG(J,IL)=(HEIGHT(J)*CNST+10.05)
20 CONTINUE
10 CONTINUE
71 RETURN
78 WRITE (6,112) HSCL
STOP 19122
C
101 FORMAT (25F3.0,1X,14/21F3.0,13X,14)
102 FORMAT (15F4.1,18X,12/15F4.1,18X,12/16F4.1,14X,12)
110 FORMAT (A4)
111 FORMAT (1HL6X,2A6,40H NOT RECOGNIZED AS TEMPERATURE CONTROL.
112 FORMAT (1HL6X,2A6,36H NOT RECOGNIZED AS HEIGHT CONTROL.
76 FORMAT(*69H GEOGRAPHY DATA SEQUENCE ERROR, RELOAD GEOGRAPHY DECK)
9 AND PUSH START,/////)
DATA FAREN/4HFahr/,CENTIG/4HCENT/,FEET/4HFEET/,METER/4HMETER/
C
END
B. MAP PROGRAM LISTING

To facilitate the output of the primary dependent variables and auxiliary physical quantities, a number of routines for the production of analyzed maps have been prepared. Examples of these maps have been given in Chapters III and IV. The FORTRAN listing of the complete set of map routines is given below, with the cards in the program numbered sequentially for easy reference. Each of the map subroutines automatically computes the zonal average at each grid latitude, as well as the global average. The maps 2, 3, 4, 6, 8, 17, 18, 21, 27, and 28 may be produced for an arbitrary tropospheric $\sigma$ or $p$ surface by interpolation or extrapolation of the solutions at the basic levels $\sigma = 1/4$ and $\sigma = 3/4$, while the other maps refer only to fixed levels, layers, or quantities.

It may be noted from the model description (see Chapter III) that while the primary dependent variables are computed each time step, the source or forcing terms (such as the diabatic heating) are computed every fifth time step. In order that any of the maps, whether involving a dependent variable and/or forcing term, may be prepared at any time selected for map output, portions of the subroutines OUTAPE, VPHI4, AVRX, and COMP 1 have been made part of the map program, a new subroutine MAPGEN has been written, and a substantial portion of the subroutine COMP 3 has also been incorporated. In this way those maps involving heating or precipitation, for example, are explicitly computed from the data at the time requested for map output.

The complete list of maps and the levels associated with their output (in $\sigma$ coordinates) is shown below; examples of those maps marked by an asterisk (*) are given in Chapter IV, with Map 5 given in Chapter III, Section F.

* Map 1: Smoothed sea-level pressure ($\sigma = 1$)
* Map 2: Zonal wind component ($0 \leq \sigma \leq 1$)
* Map 3: Meridional wind component ($0 \leq \sigma \leq 1$)
* Map 4: Temperature ($0 \leq \sigma \leq 1$)
* Map 5: Topography (sea-surface temperature, land elevation, ice distribution)

* Map 6: Geopotential height ($0 \leq \sigma \leq 1$)

Map 7: Unsmoothed sea-level pressure ($\sigma = 1$)

* Map 8: Total diabatic heating ($0 \leq \sigma \leq 1$)

* Map 9: Large-scale precipitation rate

* Map 10: Sigma vertical velocity ($\sigma = 1/2$)

* Map 11: Relative humidity ($\sigma = 3/4$)

* Map 12: Precipitable water

* Map 13: Convective precipitation rate

* Map 14: Evaporation rate ($\sigma = 1$)

* Map 15: Sensible heat flux ($\sigma = 1$)

* Map 16: Lowest-level convection ($\sigma = 1$)

Map 17: Wind direction angle ($0 \leq \sigma \leq 1$)

Map 18: Wind direction vectors ($0 \leq \sigma \leq 1$)

* Map 19: Long-wave heating in layers ($\sigma = 0$ to $1/2$, $\sigma = 1/2$ to $1$)

* Map 20: Short-wave absorption (heating) in layers ($\sigma = 0$ to $1/2$, $\sigma = 1/2$ to $1$)

Map 21: Wind magnitude ($0 \leq \sigma \leq 1$)

* Map 22: Surface short-wave absorption (heating) ($\sigma = 1$)

* Map 23: Surface air temperature ($\sigma = 1$)

* Map 24: Ground temperature ($\sigma = 1$)

* Map 25: Ground wetness ($\sigma = 1$)

* Map 26: Cloudiness (high, middle, low)

Map 27: Pressure at sigma surfaces ($0 \leq \sigma \leq 1$)

* Map 28: Total convective heating in layers ($\sigma = 0 - 1/2$, $\sigma = 1/2 - 1$)
*Map 29: Latent heating ($\sigma = 1/2$ to 1)
*Map 30: Surface long-wave cooling ($\sigma = 1$)
*Map 31: Surface heat balance ($\sigma = 1$)
IF (TAU .LE. T1) GO TO 250
T1 = TAU
I = 1
IF (EJECT .NE. 0.0) GO TO 270
CALL COMP3
PRINT 107
EJECT = 1.0
00000580
00000590
00000600
00000610
00000620
00000630
00000640
00000650
00000660
00000670
00000680
00000690
00000700
00000710
00000720
00000730
00000740
00000750
00000760
00000770
00000780
00000790
00000800
00000810
00000820
00000830
00000840
00000850
00000860
MAPNO = MAP(I)
IF (MAPNO .EQ. 0.0) GO TO 250
SURF = SRF(I)
SINT = SNT(I)
DO 275 J = 1, 13
275 NAME(J) = JBLK
CALL MOPGEN (MAPNO)
DO 290 J = 1, JM
ZM2(J) = 0.0
FCNT = 0.0
DO 280 K = 1, IK
IF (TOPO(J, K) .LT. 1.0) GO TO 280
ZM2(J) = ZM2(J) + WORK2(J, K)
FCNT = FCNT + 1.0
280 CONTINUE
IF (FCNT .NE. 0.0) ZM2(J) = ZM2(J) / FCNT
290 CONTINUE
WRITE(9) TAU, ID, MAPNO, NAME, SURF, STAG1, STAGJ, SINT, WORK2, IM, ZM2, ZMM
PRINT 104, T2, MAPNO, SURF, NAME
I = I + 1
GO TO 270
END
SUBROUTINE OUTAPE

// DD DISP=OLD,D,DSN=MES727,ABN,COMMON
// DD *
  COMMON /COT/TAPIN
DATA BCTP/'TAPE'/
K=8
READ (K) P
READ (K) U
READ (K) V
READ (K) T
READ (K) Q3
IF (TAPIN.EQ.BCTP) READ (8) TOPOG
READ (K) PT
READ (K) GW
READ (K) TS
READ (K) GT
READ (K) SN
READ (K) TT
READ (K) Q3T
READ (K) SD
IF (TAPIN.NE.BCTP) RETURN
READ (K) H
READ (K) TD
RETURN
END

00000870
00000880
00000890
00000900
00000910
00000920
00000930
00000940
00000950
00000960
00000970
00000980
00000990
00010000
00010100
00010200
00010300
00010400
00010500
00010600
00010700
00010800
00010900
00011000
00011100
SUBROUTINE MAPGEN (MAPNO)

C DD DISP=OLD, DSN=MES727.ABN, COMMON
C DD * COMMON /SCIL/ RCTIL(2), ICTL(10)
C COMMON /COUT/ ZM(46), SURF, LEV, ISL, NAME(13)
C EQUIVALENCE (LEVEL, SURF)
C LOGICAL LEV
C MAPGEN=.TRUE.
C LEV=.FALSE.
C IF (SURF.LT.2,0) LEV=.TRUE.
C
C GO TO (301,302,303,304,305,306,307,308,309,310)
C * 311,312,313,314,315,316,317,318,319,320
C * 321,322,323,324,325,326,327,328,329,330,331), MAPNO
C
C 301 CALL MAP1
C GO TO 410
C 302 CALL MAP2
C GO TO 410
C 303 CALL MAP3
C GO TO 410
C 304 CALL MAP4
C GO TO 410
C 305 IF (KEY(18)) MAPGEN=.FALSE.
C CALL MAP 5
C GO TO 410
C 306 CALL MAP6
C GO TO 410
C 307 CALL MAP7
C GO TO 410
C 308 IF (NOUT.EQ.0) CALL COMP3
C NOUT=1
C CALL MAP8
C GO TO 410
C 309 IF (NOUT.EQ.0) CALL COMP3
C NOUT=1
C CALL MAP9
C GO TO 410
C 310 CALL MAP10
C GO TO 410
C 311 CALL MAP11
C GO TO 410
C 312 CALL MAP12
C GO TO 410
313 IF (NOOUT,EO,0) CALL COMP3
   NOOUT=1
   CALL MAP13
   GO TO 410
314 IF (NOOUT,EO,0) CALL COMP3
   NOOUT=1
   CALL MAP14
   GO TO 410
315 IF (NOOUT,EO,0) CALL COMP3
   NOOUT=1
   CALL MAP15
   GO TO 410
316 IF (NOOUT,EO,0) CALL COMP3
   NOOUT=1
   CALL MAP16
   GO TO 410
317 CALL MAP 2
   DO 3175 I=1,IM
   DO 3175 J=1,JM
3175 WORK1(J,I)=WORK2(J,I)
   CALL MAP 3
   CALL MAP 17
   GO TO 410
318 CALL MAP 2
   DO 3185 I=1,IM
   DO 3185 J=1,JM
3185 WORK1(J,I)=WORK2(J,I)
   CALL MAP 3
   CALL MAP 18
   GO TO 410
319 IF (NOOUT,EO,0) CALL COMP3
   NOOUT=1
   CALL MAP19
   GO TO 410
320 IF (NOOUT,EO,0) CALL COMP3
   NOOUT=1
   CALL MAP20
   GO TO 410
321 CALL MAP 2
   DO 3215 I=1,IM
   DO 3215 J=1,JM
3215 WORK1(J,I)=WORK2(J,I)
   CALL MAP 3
   CALL MAP 21
   GO TO 410
322 IF (NOOUT,EO,0) CALL COMP3
   NOOUT=1
   CALL MAP22
   GO TO 410
323 IF (NOOUT.EQ.0) CALL COMP3
    NOOUT=1
    CALL MAP23
    GO TO 410
324 CALL MAP24
    GO TO 410
325 CALL MAP 25
    GO TO 410
326 IF (NOOUT.EQ.0) CALL COMP3
    NOOUT=1
    CALL MAP26
    GO TO 410
327 CALL MAP27
    GO TO 410
328 IF (NOOUT.EQ.0) CALL COMP3
    NOOUT=1
    CALL MAP28
    GO TO 410
329 IF (NOOUT.EQ.0) CALL COMP3
    NOOUT=1
    CALL MAP29
    GO TO 410
330 IF (NOOUT.EQ.0) CALL COMP3
    NOOUT=1
    CALL MAP30
    GO TO 410
331 IF (NOOUT.EQ.0) CALL COMP3
    NOOUT=1
    CALL MAP 31
    GO TO 410
410 RETURN
C
    END
FUNCTION IPK(IL,IR)
INTEGER IHALF=2(2)
EQUIVALENCE (IHALF(1),IWD)
IHALF(1)=IL
IHALF(2)=IR
IPK=IWD
RETURN
ENTRY IRH(IPKWD)
IWD=IPKWD
IRH=IHALF(2)
RETURN
ENTRY ILH(IPKWD)
IWD=IPKWD
ILH=IHALF(1)
RETURN
END

FUNCTION VPHI4(J,I)
C
/*
// DD DISP=OLD,DSN=MES727.ABN.COMMON
// DD *
  VPHI4=0.
  IF (TOPOG(J,I).LT.1.0) VPHI4=AMOD(-TOPOG(J,I),10.E5)
C
RETURN
END

LOGICAL FUNCTION KEY(M)
LOGICAL KEYS=1(32)
COMMON /KEYV/ KEYS
N=IABS(M)
KEY=KEYS(N)
IF (M.LT.0) KEYS(N)=.FALSE.
RETURN
END
* SUBROUTINE MAP1 *

C DD DISP=OLD, DSN=HESS727.AEN.COMMON
C DD *
C COMMON /COUT/, ZM(46), SURF, LEV, ISL, NAME(13)
C
C LOGICAL LEV, STAGJ, STAGI, ISL
C DIMENSION NAMEL(13)
C
C C SEA LEVEL PRESSURE, MAP TYPE 1
C L1=1
C L2=2
C
C FIM=IM
C [MM=IM-2
C JMM=JM-1
C STAGJ=.FALSE.
C STAGI=.FALSE.
C SIG1=SIG(1)
C SIG3=SIG(2)
C FLR=5.1828/(30.48*GRAV)
C
C DO 110 J=1,NL
C 110 NAME(I)=NAMEL(I)
C
C DO 118 J=1,JM
C 118 ZM(J)=0.0
C
C DO 128 I=1,IM
C DO 128 J=1,JM
C PHI=VPHI(4,J,1)
C PJI=P(J,1)
C T4=ILM(Q3T(J,1))
C T4=T4/10.
C
C EXTRAPOLATED SURFACE AIR TEMPERATURE
C T1=T(I,J,L1)
C T3=T(J,L1,L2)
C T4=1.5*T3-0.5*T1
C RTM=RGI*(T4+FLR*PHI4)
C ACC=1.0*(PJI+PTR(O))/EXP(PHI4/RTM)-PSL
C ZM(J)=ZM(J)+ACC
C
C WORK1(J,1)=ACC
DO 148 I=1,IM
  IP1=MOD(I,IM)+1
  IM1=MOD(I+1,IM)+1
  WORK2(JM,I)=WORK1(JM,I)
  WORK2(I,1)=WORK1(1,I)
DO 148 J=2,IMM1
  WORKZ(J,1)=( WORK1(J+1,IM1)+2*WORK1(J+1,I) + WORK1(J+1,P1) )/16.
  + 2*WORK1(J,IM1) +4*WORK1(J,I) +2*WORK1(J,P1)
  + 2*WORK1(J-1,IM1)+2*WORK1(J-1,I) + WORK1(J-1,P1))
C
  ZMM=0.0
  WTM=0.0
DO 158 J=1,JM
  WTM=WTM+ABS(DXYP(J))
  ZM(J)=ZM(J)/F1M
158 ZMM=ZMM+ZM(J)*ABS(DXYP(J))
  ZMM=ZMM/WTM
  SPOL=ZM(J)
  NPDZ=ZM(JM)
C
DATA NAMEL/'SEA LEVEL PRESSURE SMOOTHED (MB-1000.)'
DATA NL/13/
RETURN
C
END
S U B R O U T I N E

* MAP2

// DD DISP=OLD, DSN=MES727.ABN.COMMON
// DD *

// LOGICAL LEV, STAGJ, STAGI, ISL
COMMON /COUT, 2M(46), SURF, LEV, ISL, NAME(13)
EQUIVALENCE (SURF, SIGL)
DIMENSION NAMEL(13)

C
C EAST-WEST (U) WIND COMPONENT, MAP TYPE 2
C
FIM=IM
STAGJ= 'TRUE.
STAGI= 'TRUE.

C
DO 110 J=1, NL
110 NAME(I)=NAMEL(I)

210 L1=1
L2=2
SIGL1=SIGL(1)
SIGL2=SIGL(2)
DSIG=1./(SIGL2-SIGL1)

C
IF (LEV) GO TO 310

C
PS=4.*(SURF-PTROP)

C
DO 220 I=1, IM
WORK2(I,J)=0.0
IP1=MOD(I, IM) + 1
DO 220 J=1, JM
SIGPS=PS/(J, 1) + P(J, IP1) + P(J-1, 1) + P(J-1, IP1)
SIGPS=SIGPS*(SIGL1-SIGL1)*U(J, I, L2)+(SIGL2-SIGPS)*U(J, I, L1))
GO TO 410

220 WORK2(J, I)=DSIG*DSIG1*U(J, I, L2)+U(J, I, L1)*DSIG2

310 DSIG1=(SIGL1-SIGL1)*DSIG
DSIG2=(SIGL2-SIGL1)*DSIG
DO 320 I=1, IM
WORK2(I, J)=0.0
DO 320 J=2, JM
WORK2(J, I)=DSIG1*U(J, I, L2)+U(J, I, L1)*DSIG2

320 WORK2(J, I)=DSIG1*U(J, I, L2)+U(J, I, L1)*DSIG2

C
C
C
410  ZM=M0.0
     WTM=0.0
     ZM(1)=0.0
     DO 430 J=2,JM
     SUM=0.0
     DO 420 I=1,IM
420  SUM=SUM+WORK2(J,I)
     CLAT=ABS(COS(.5*(LAT(J-1)+LAT(J))))
     ZM(J)=SUM/FIM
     WTM=WTM+CLAT
430  ZMM=ZM+ZM(J)*CLAT
     ZMM=ZM/MM/WTM
     SPOL=ZM(2)
     NPOL=ZM(JM)
C
     DATA NAMEL/*EAST-WEST (U) WIND COMPONENT (M/SEC)
     */
     DATA NL/13/
     RETURN
C
C
     END
SUBROUTINE

* MAP3

// DD DISP=OLD, DSN=KES727, ABN, COMMON
// DD =

LOGICAL LEV, STAGJ, STAG1, I1L
COMMON /COUT/ ZM(46), SURF, LEV, I1L, NAME(13)
EQUIVALENCE (SURF, SIGL)
DIMENSION NAMEL(13)

C NORTH-SOUTH (V) WIND COMPONENT, MAP TYPE 3
C
FIM=IM
STAGJ=.TRUE.
STAG1=.TRUE.
C
DO 110 I=1, NL
110 NAME(I)=NAMEL(I)
C
210 L1=1
L2=2
SIGL1=SIGL(1)
SIGL2=SIGL(2)
USIG=1./(SIGL2-SIGL1)
C
1F (LEV) GO TO 310
C
PS=4.*SURF-PTROP
DO 220 I=1, IM
I1=MOD(I, IM)+1
DO 220 J=1, JM
SIG=PS/(P(J, I)+P(J, I1)+P(J-1, I)+P(J-1, I1))
220 WORK2(J, I)=SIG*(SIGPS-SIGL1)*V(J, I, L2)+(SIGL2-SIGPS)*V(J, I, L1)
GO TO 410
C 310 DSIG1=(SIGL-SIGL1)*DSIG
       DSIG2=(SIGL2-SIGL1)*DSIG
       DO 320 I=1,IM
       DO 320 J=1,JM
  320 WORK2(J,1)=DSIG1*V(J,1,L2) + V(J,1,L1)*DSIG2
C
C 410 ZMM=0.0
       WTM=0.0
       DO 430 J=1,JM
       SUM=0.0
       DO 420 I=1,IM
       SUM=SUM+WORK2(J,I)
       CLAT=ABS(COS(LAT(J))
       ZM(J)=SUM/FIM
       WTM=WTM+CLAT
  430 ZMM=ZMM+ZM(J)*CLAT
       ZMM=ZMM/WTM
       SPOL=ZM(1)
       NPOL=ZM(JM)
C
C DATA NAME /* NORTH-SOUTH (V) WIND COMPONENT (M/SEC) */
DATA NL/13/
C
C RETURN
END
SUBROUTINE MAP4
  DD DISP=OLD, DSN=ME5727.ABN.COMMON
  DD *
  LOGICAL LEV, STAGJ, STAGI, ISL
  COMMON /COUT/ ZM(46), SURF, LEV, ISL, NAME(13)
  EQUIVALENCE (SURF, SIGL)
  DIMENSION NAMEL(13)
  C
  TEMPERATURE, MAP TYPE 4
  C
  VERTICAL INTERPOLATION IS WITH POTENTIAL TEMPERATURE
  C
  IN P**KAPPA SPACE.
  C
  FIM=IM
  STAGJ=.FALSE.
  STAGI=.FALSE.
  C
  DO 110 I=1, NL
   NAME(I)=NAMEL(I)
  110 NAME(I)=NAMEL(I)
  C
   L1=1
   L2=2
   SIGL1=SIGL(L1)
   SIGL2=SIGL(L2)
   PSK=SURF**KAPA
  C
   DO 220 J=1, JM
    SP=P(J, I)
    IF (LEV) PSK=(SIGL*SP*PTROP)**KAPA
    PL1=(SIGL1*SP*PTROP)**KAPA
    PL2=(SIGL2*SP*PTROP)**KAPA
    TPOTL1=T(J, I, L1)/PL1
    TPOTL2=T(J, I, L2)/PL2
    WORK2(J, I)=PSK/(PL2K-PL1K)*(TPOTL1*(PL2K-PSK) + (PSK-PL1K)*TPOTL2)
   220 WORK2(J, I)=PSK/(PL2K-PL1K)*(TPOTL1*(PL2K-PSK) + (PSK-PL1K)*TPOTL2)
   , + TKEL
C
C
410 ZMM=0.0
WIM=0.0
DO 430 J=1,JM
SUM=0.0
DO 420 I=1,IM
420 SUM=SUM+WORK2(J,I)
CLAT=ABS(DXYPI(J))
ZM(J)=SUM/FIM
WTM=WTM+CLAT
430 ZMM=ZMM+ZM(J)*CLAT
ZMM=ZMM/WTM
NPOL=ZM(JM)
SPOL=ZM(I)
C
C
DATA NAMEL='TEMPERATURE (DEGREES CENTIGRADE)' / 00005180
DATA NL/13/ 00005190
DATA TKEL/-273.1/ 00005200
C
RETURN
END
SUBROUTINE MAPS

// DD DISP=OLD,DSN=MES727,ABN,COMMON
// DD *
/
C
LOGICAL LEV, STAGJ, ISL
COMMON /COUT/, ZM(46), SURF, LEV, ISL, NAME(13)
EQUIVALENCE (SURF, SGL)
DIMENSION NAME1(13), NAME2(13)

C GEOGRAPHY, MAP TYPE 5
C
FIM = IM
FJM = JM
STAGJ=.FALSE.
STAGJ=.FALSE.
CNST=30.48*GRAV

C
DO 110 J=1, NL
NAME(I)=NAME1(I)
110 IF (.NOT.LEV) NAME(I)=NAME2(I)
C
DO 220 J=1, JM
DO 220 J=1, JM
TG=TORG(J, I)
IF (.NOT.LEV) GO TO 215
IF (TG.LT.1.0) GO TO 205
TG=TG-273.
GO TO 220
205 IF (TG+10.E5.EQ.0.01) GO TO 220
210 TG=10.E5
GO TO 220
215 IF (TG.GT.1.0) GO TO 210
TG=-TG
IF (TG.GT.9.E5) GO TO 218
TG=TG/CNST
GO TO 220
218 IF (TG.EQ.10.E5) GO TO 220
TG=-(10.E5+(TG-10.E5)/CNST)
GO TO 220

220 WORK2(J, I)=TG
C
WS=0.0
WN=0.0
DO 415 I=1, IM
WS=WS+WORK2(I, I)
415 WN=WN+WORK2(JM, I)
WS=WS/FIM
WN=WN/FIM
DO 420 I=1, IM
WORK2(I, I)=WS
420 WORK2(JM, I)=WN
C

2MM=0.0
WTM=0.0
DO 450 J=1,JM

SUM=0.0
CI=0.0
ZM(J)=0.0
DO 430 I=1,IM
W2=WORK2(J+1)
IF (.NOT.LEV) GO TO 425
IF (W2.GE.10.E5) GO TO 430
CI=CI+1.0
IF (W2.LT.0.0) GO TO 430
SUM=SUM+W2
GO TO 430

425 CI=CI+1.0
IF (W2.GE.10.E5) GO TO 430
IF (W2+10.E5.LE.0.0) W2=-(W2+10.E5)
SUM=SUM+W2
GO TO 430

430 CONTINUE

CLAT=ABS(COS(LAT(J))
IF (CI.GT.0.0) ZM(J)=SUM/CI
ZM(J)=SUM/FIM
WTM=WTM+CLAT

450 ZMM=ZMM+ZM(J)*CLAT
ZMM=ZMM/WTM
SPOL=ZM(1)
NPOL=ZM(JM)

C

DATA NAME1/ 'TOPOGRAPHY (OCEAN TEMP, DEG CENT) '/ 00006050
DATA NAME2/ 'TOPOGRAPHY (SURFACE ELEVATION, HECTOFEET) '/ 00006060
DATA NL/13/
RETURN
END
* * * * * * * * * * * *
  subroutine mapc
  common /coun/ im(46), surf, lev, isl, name(13)
  equivalent (surf, sigl)
  dimension name(13)

C GEOPOETENTIAL HEIGHT SURFACE,
C MAP TYPE 6
C
IM=IM-2
JM1=JM-1
STAGI=.false.
STAGJ=.false.
FIN=IM
L1=1
L2=2
PSK=SRF**KAPA
HR=RGAS/Z*
IM=IM-2
SIGL1=SIG(L1)
SIGL2=SIG(L2)
DO 110 I=1, NL
   NAME(I)=NAME(I)
110   DO 220 J=1, JM
      IF (J) 1, 1,
      IP1=MOD(J, IM)+1
      IM1=MOD(J+IM2, IM)+1
      DO 220 J=1, JM
         SP=P(J, I)
         PL1=(SIGL1*SP+PTROP)
         PL1K=PL1**KAPA
         PS1=(PL1-PTROP)/PL1
         PL2=(SIGL2*SP+PTROP)
         PL2K=PL2**KAPA
         PS2=(PL2-PTROP)/PL2
         IF (LEV) PSK=(SIGL*SP+PTROP)**KAPA
         PKDTK=KAPA*(PL2K-PL1K)**2*
         PLIKS=PL1K**2
         PL2KS=PL2K**2
         PSKS=PSK**2
         P1T2=PL1K*PL2K**2
         XT2=PS2+(PL2KS-PI2P2-PLIKS-2.*PSKS+4.*PLIK*PSK)/PKDTK/PL2K
         XT1=PS1+(PL2KS+PI2P2-PLIKS-4.*PL2K*PSK+2.*PSKS)/PKDTK/PL1K
         WORK2(J, I)=01*(XT1*T(J, I, L1)+XT2*T(J, I, L2))*HR+VPHI4(J, I)/GRAV
         220   WORK2(J, I)=01*(XT1*T(J, I, L1)+XT2*T(J, I, L2))*HR+VPHI4(J, I)/GRAV
  
00006100
00006110
00006120
00006130
00006140
00006150
00006160
00006160
00006170
00006180
00006190
00006200
00006210
00006220
00006230
00006240
00006250
00006260
00006270
00006280
00006290
00006300
00006310
00006320
00006330
00006340
00006350
C
410  ZMM=0.0
     WTM=0.0
     DO 430 J=1, JM
     SUM=0.0
     CLAT=ABS(DXYP(J))
     DO 420 I=1, IM
420  SUM=SUM+WORK2(J,I)
     ZM(J)=SUM/FIM
     WTM=WTM+CLAT
     DO 430 J=1, JM
430  ZMM=ZMM+ZM(J)*CLAT
     ZMM=ZMM/WTM
     SPOL=ZM(1)
     NPOL=ZM(JM)
C
DATA NAMEL/'GEOPOENTIAL HEIGHT (HECTOMETERS)'
DATA NL/13/
RETURN
END
SUBROUTINE MAP7
* 
// DO disp=old, dsn=RES727, ABN, COMMON
// DO *
C COMMON /COUT/ ZM(46), SURF, LEV, ISL, NAME(13)
 LOGICAL LEV, STAGJ, STAGI, ISL
 DIMENSION NAMEL(13)
C SURFACE PRESSURE, MAP TYPE 7
L1=1
L2=2
C F1M=1M
1M2=1M-2
JMM1=JM-1
STAGJ=.FALSE.
STAGI=.FALSE.
SIG1=SIG(1)
SIG3=SIG(2)
FLR=.5*1R28/(30.4*GRAV)
C DO 110 I=1,NL
110 NAME(I)=NAME(I)
C ZMM=0,0
DO 111 J=1,JM
111 ZM(J)=0,0
C DO 128 I=1,IM
IM=MOD(I+IM2,IM)+1
IP1=MOD(I,IM)+1
DO 128 J=1,JM
PHI4=VPHI4(J, I)
PJ1=P(J, I)
C T3=IHL3*TH3(J, I))
C T4=TT4/10.
C EXTRAPOLATED SURFACE AIR TEMPERATURE
T1=T(J, I, L1)
T3=T(J, I, L2)
T4=1.5*T3-0.5*T1
RTM=RGAS*(T4+FLR*PHI4)
ACC=(PJ1+PHI4)*EXP(PHI4/RTM)-PSL
ZM(J)=ZM(J)+ACC
128 WORK2(J, I)=ACC
C

C

WTM=0.0
DO 150 J=1,JM
ZM(J)=ZM(J)/FIM
WTM=WTM+ABS(DXYP(J))
150 ZMM=ZMM+ZM(J)*ABS(DXYP(J))
C ZMM IS GLOBAL MEAN SURFACE PRESSURE
ZMM=ZMM/WTM
SPOL=WORK2(1,1)
NPOL=WORK2(JM,1)
C

DATA NAMEL/'SEA LEVEL PRESSURE UNSMOOTHED (MB-1000.)'
DATA NL/13/
RETURN
C

END
* SUBROUTINE MAPR
// DD DISP=OLD,DSN=MES727,ABN,COMMON
// DD * COMMON /COUT/ ZM(46),SURF,LEV,ISL,NAM(13)
LOGICAL LEV, STAGJ, STAGI, ISL
EQUIVALENCE (SIGL,SURF)
DIMENSION NAM(13)
C TOTAL HEATING, MAP TYPE 8
C DIMENSION HZ1(100), HZ3(100)
FIM=IM
C STAGJ=.FALSE.,
STAGI=.FALSE.,
L1=1
L2=2
SIGL1=SIG(L1)
SIGL2=SIG(L2)
DSIG1=(SIGL2-SIGL1)
SURFMT=SURF-PTROP
IF (LEV) SIGX=SIGL
C DO 110 I=1,NL
110 NAME(I)=NAMEL(I)
C DO 220 J=1,IM
DO 220 J=1,IM
IF (.NOT.LEV) SIGX=SURFMT/P(J,1)
H1=ILH(PT(J,1))
H1=H1/100.
H3=IRH(PT(J,1))
H3=H3/100.
IF (J,NE.I) GO TO 220
HZ1(J)=H1
HZ3(J)=H3
220 WORK2(J,1)=DSIG*((SIGL2-SIGX)*H1 + (SIGX-SIGL1)*H3)
C
  DO 118 J=1,JM
  118 ZM(J)=0.0
C
  ZMM=0.0
  WTM=0.0
  DO 430 J=1,JM
  SUM=0.0
  CLAT=ABS(DXYP(J))
  DO 420 I=1,IM
  SUM=SUM+WORK2(J,I)
  ZM(J)=SUM/FIM
  WTM=WTM+CLAT
  420 SUM=SUM+WORK2(J,I)
  430 ZMM=ZMM+ZM(J)*CLAT
  WTM=ZMM/WTM
  SPOL=ZM(1)
  NPOL=ZM(JM)
C
  DATA NAMEL/"TOTAL HEATING (DEG CENT/DAY)"
  DATA NL/13/
  RETURN
C
  END
SUBROUTINE MAP9

// DD DISP=OLD,DSN= MES727,ABN.COMMON
// DD *
C
LOGICAL LEV, STAGI, STAGJ, ISL
DIMENSION NAMEL(13)
COMMON /COUT/ ZM(46), SURF, LEV, ISL, NAME(13)
EQUIVALENCE (SURF, SIGL)
C
C LARGE SCALE PRECIPITATION, MAP TYPE 9
C
FIM = IM
FJM = JM
STAGI=.FALSE.
STAGJ=.FALSE.
C
DO 110 I=1, NL
110 NAME(I)=NAMEL(I)
C
DO 220 I=1, IM
DO 220 J=1, JM
PLSC=IRH(Q3T(J, I))
220 WORK2(J, I)=PLSC/10.
C
ZMM=0.0
WTM=0.0
DO 450 J=1, JM
SUM=0.0
DO 430 I=1, IM
430 SUM=SUM + WORK2(J, I)
CLAT=ABS(0.85*SUM)
ZM(J)=SUM/FIM
WTM=WTM*CLAT
450 ZMM=ZMM+ZM(J)*CLAT
ZMM=ZMM/WTM
SPDL=ZM(1)
NPDL=ZM(JM)
C
DATA NAMEL/*LARGE SCALE PRECIPITATION (MM/DAY) */
DATA NL/13/ RETURN
END
* SUBROUTINE MAP10

* DD DSN=MES727.ABN.COMMON

DD *

LOGICAL LEV, STAGJ, STAGI, ISL
COMMON /COUT/ Z(46),SURF,LEV,ISL,NAME(13)
EQUVALENCE (SURF,SIGL)
DIMENSION NAME(13)
DIMENSION COMM(46,72)

C
C VERTICAL VELOCITY, MAP TYPE 10

C FIM=IM
IM2=IM-2
JMMI=JM-1
STAGJ=.FALSE.
STAGI=.FALSE.

C DO 110 I=1,NL
110 NAME(I)=NAME(I)

C 2149 L=1
2150 DO 2160 J=1,JM1
2160 PUI(J,L)=PUI(J,L)+(DYU(J)*U(J,I,L)+DYU(J)*U(J+1,I,L))
2160 CONTINUE

C CALL AVR(11)

C DO 2180 I=1,IM
2170 PUI(J,I)=PUI(J,I)*(P(J,I)+P(J,IP1))
2180 CONTINUE

C EQUIVALENT PU AT POLES. PV(I,1) IS USED AS A WORKING SPACE.

C VM1=0.0
VM2=0.0
DO 2185 I=1,IM
VM1=VM1+PV(2,I)
2185 VM2=VM2+PV(JM,I)
VM1=VM1/FIM
VM2=VM2/FIM
PV(1,1)=0.0
DO 2190 I=2,IM
2190 PV(1,I)=PV(1,I-1)+(PV(2,I)-VM1)
          VM1=0.0
          DO 2192 I=1,IM
2192 VM1=VM1+PV(1,I)
          VM1=VM1/FIM
          DO 2195 I=1,IM
2195 PU(I,1)=-(PV(1,I)-VM1)*3.0
          PV(1,1)=0.0
          DO 2200 I=2,IM
2200 PV(1,I)=PV(1,I-1)+(PV(JM,I)-VM2)
          VM2=0.0
          DO 2202 I=1,IM
2202 VM2=VM2+PV(1,I)
          VM2=VM2/FIM
          DO 2205 I=1,IM
2205 PU(JM,1)=(PV(1,1)-VM2)*3.0
          DO 2400 I=1,IM
1M1=MOD(I+IMM2,IM)+1
          DO 2400 J=1,IM
1M1=MOD(I+IMM2,IM)+1
          IF (J.EQ.1) CONVM=-PV(2,1)*0.5
          IF (J.EQ.JM) CONVM=PV(JM,1)*0.5
          IF (J.GT.1 .AND. J.LT.JM) CONVM=-PV(J,1)-PV(JM,1)
*           +PV(J-1,1)-PV(J-1,1)*0.5
          IF (L.EQ.1) CONMV(J,1)=CONVM
          IF (L.EQ.Z) PV(J,1)=CONVM
2400 CONTINUE
          IF (L.EQ.2) GO TO 2410
          L=2
          GO TO 2150
2410 CONTINUE
C
CONM IS MASS CONVERGENCE AT L=1 AND PV IS THAT AT L=2.

2411 PR1=0.0
PB2=0.0
PR3=0.0
PB4=0.0
DO 2402 I=1,1M
PB1=PR1+CONM(1,I)
PB2=PB2+CONM(1,I)
PB3=PB3+PV(1,I)
2402 PB4=PB4+PV(1,M,I)
PB1=PB1/FIM
PB2=PB2/FIM
PB3=PB3/FIM
PB4=PB4/FIM
DO 2405 I=1,1M
CONM(I,I)=PB1
CONM(JM,I)=PB2
PV(I,I)=PB3
2405 PV(JM,I)=PB4
DO 2420 J=1,1M
WW=CONM(J,M)-PV(J,I)
WORK2(J,I)=3600.0*WW/(2.0*DXYP(J))
2420 CONTINUE

C
410 ZMM=0.0
WTM=0.0
DO 430 J=1,1M
SUM=0.0
DO 420 I=1,1M
420 SUM=SUM+WORK2(J,I)
CLAT=ABS(DXYP(J))
ZM(J)=SUM/FIM
WTM=WTM+CLAT
430 ZMM=ZMM+ZM(J)*CLAT
ZMM=ZMM/WTM
NPOL=ZM(JM)
SPOL=ZM(I)

C
DATA NAMEL/'SIGMA VERTICAL VELOCITY (MB/HR)
C
DATA NL/13/
C
C
END
SUBROUTINE
AVRX(K)

/*
 */
// DO DISP=OLD, DSN=ME5727, ABN.COMMON
// DO *
C
THIS SUBROUTINE USES UT(1,i,1) AS A WORKING SPACE
C
JMM1=JM-1
IMM2=IM-2
JE=JM/2+1
DEFF=DYP(JE)
DO 150 J=2, JMM1
DRAT=DEFF/DXP(J)
IF (DRAT .LT. 1.) GO TO 150
ALP=0.125*(DRAT-1.)
NM=DRAT
FNM=NM
ALPHA=ALP/FNM
DO 150 N=1,NM
DO 120 I1=1,IM
IP1=MOD(I1,IM)+1
IM1=MOD(I1+1,IM)+1
120 UT(I1,I1)=QT(J,I1,K)+ALPHA*(QT(J,IP1,K)+QT(J,IM1,K)-2.*QT(I1,I1))
DO 130 I=1,IM
130 QT(I1,I)=UT(I1,I,1)
150 CONTINUE
C
RETURN
END
SUBROUTINE MAP1

* DD DISP=OLD,DSN=ME5727,ABN,COMMON DD *
// LOGICAL LEV, STAGI, STAGJ, ISL COMMON /COUT/ ZM(46), SURF, LEV, ISL, NAME(13)
EQUIVALENCE (SURF, SIGL)
DIMENSION NAMEL(13)
C RELATIVE HUMIDITY, MAP TYPE 11
C FIM = IM
FJM = JM
STAGI=.FALSE.
STAGJ=.FALSE.
C DO 110 I=1,NL
110 NAME(I)=NAMEL(I)
C DO 220 I=1,IM
DO 220 J=1,JM
ES3 = 10.*((R*(0.051-2353.0/T(J+1,2))
P3CB = 1.75*P(J,1)+PTR0P)/10.,0
Q3S = 6.22*ES3/(P3CB-ES3)
Q3R = Q3(J,1)
RH3 = Q3R/Q3S
WORK2(J,1) = RH3*100.
C S=0.0
WN=0.0
DO 415 I=1,IM
WS=WS+WORK2(I,1)
415 WS=WS/FIM
WN=WN/FIM
DO 420 I=1,IM
WORK2(I,1)=WS
420 WORK2(JM,1)=WN
C
ZMM=0.0
WTM=0.0
DO 450 J=1,JM
SUM=0.0
DO 430 I=1,IM
430 SUM=SUM + WORK2(J,I)
CLAT=ABS(DXYP(J))
ZM(J)=SUM/FIM
WTM=WTM+CLAT
450 ZMM=ZMM+ZM(J)*CLAT
ZMM=ZMM/WTM
NPOL=ZM(JM)
C
DATA NAMEL/*RELATIVE HUMIDITY (PERCENT)
DATA NL/13/
RETURN
END
SUBROUTINE MAP12

// DISP=OLD, DSN=HESS727.ABN.COMMON
// DO *
LOGICAL LEV, STAGI, STAGJ, ISL
COMMON /COUT/ ZM(46), SURF, LEV, ISL, NAMEL(13)
EQUIVALENCE (SURF, SIGL)
DIMENSION NAMEL(13)

C PRECIPITABLE WATER IN CM, MAP TYPE 12
C
FIM = 1M
STAGI = .FALSE.
STAGJ = .FALSE.

C DO 110 I=1, NL
110 NAMEL(I) = NAMEL(I)

C DO 220 J=1, JM
220 WORK2(J,J1) = G3(J, J1) * P(J, J1) * 0.5 * (10.0/GRAV)

C
410 WS = 0.0
   WN = 0.0
   DO 415 I = 1, IM
   WS = WS + WORK2(I, I)
   415 WS = WS/FIM
   WN = WN/FIM
   DO 420 J = 1, JM
   WORK2(I, J) = WS
   420 WORK2(J, J1) = WN

C
   ZMM = 0.0
   WTM = 0.0
   DO 450 J = 1, JM
   SUM = 0.0
   DO 430 I = 1, IM
   SUM = SUM + WORK2(J, I)
   CLAT = ABS(OXYP(J))
   ZM(J) = SUM/FIM
   WTM = WTM + CLAT
   430 DO 450 J = 1, JM
   ZMM = ZMM + ZM(J) * CLAT
   ZMM = ZMM / WTM
   SPOD = ZM(1)
   NPOD = ZM(JM)

C DATA NAMEL/*PRECIPITABLE WATER (CM)
DATA NL/13/
RETURN
END
SUBROUTINE MAP13

* 00011060
// 00011070
// 00011080
// DD DISP=OLD, DSN=MES727.ABN.COMMON
// 00011090
// DD 00011100
LOGICAL LEV, STAGI, STAGJ, ISL
COMMON /CNUT/ ZM(46), SURF, LEV, ISL, NAME(13)
EQUIVALENCE (SURF, SIGL)
DIMENSION NAMEL(13)
C 00011110
C 00011120
C 00011130
C 00011140
C 00011150
C 00011160
C 00011170
C 00011180
C 00011190
C 00011200
C 00011210
C 00011220
C 00011230
C 00011240
C 00011250
C 00011260
C 00011270
C 00011280
C 00011290
C 00011300
C 00011310
C 00011320
C 00011330
C 00011340
C 00011350
C 00011360
C 00011370
C 00011380
C 00011390
C 00011400
C 00011410
C 00011420
C 00011430
C 00011440
C 00011450
C 00011460
C 00011470
C 00011480
C 00011490
C 00011500
C 00011510
C 00011520
C 00011530
C 00011540
C 00011550
C 00011560
C 00011570
C 00011580

C CONVEXTIVE PRECIPITATION (MM/DAY) MAP TYPE 13
C
STAGI=*FALSE*,
STAGJ=*FALSE*,

FIM = 1M

C
DO 110 I=1, NL
110 NAME(I)=NAMEL(I)
C
DO 250 I=1, IM
DO 250 J=1, JM
CP=IRH(UT(J,1,2))

250 WORK2(J,1)=CP/10.
C
410 WS=0.0
WN=0.0
DO 415 I=1, IM
WS=WS+WORK2(I,1)
415 WN=WN+WORK2(JM, I)
WS=WS/FIM
WN=WN/FIM
DO 420 I=1, IM
WORK2(I,1)=WS
420 WORK2(JM, I)=WN
C
ZMM=0.0
WTM=0.0
DO 450 J=1, JM
SUM=0.0
DO 430 I=1, IM
430 SUM=SUM + WORK2(J, I)
CLAT=ABS(DXYP(J))
ZM(J)=SUM/FIM
WTM=WTM+CLAT
450 ZMM=ZMM+ZM(J)*CLAT
ZMM=ZMM/WTM
SPOL=ZM(1)
NPOL=ZM(JM)
C
DATA NAMEL/*CONVEXTIVE PRECIPITATION (MM/DAY)*/
DATA NL/13/
RETURN
END
S U R R O U T I N E

* MAP14
/
// DD DISP=OLD,DSN=MES727,ABN,COMMON
// DD *
C
LOGICAL LEY, STAGI, STAGJ, ISL
COMMON /COUT/ IM(46), SURF, LEV, ISL, NAME(13)
EQUIVALENCE (SURF, SIGL)
DIMENSION NAMEL(13)

C
EVAPORATION (E4 IN MM/DAY), MAP TYPE 14

C
STAGI=.FALSE.
F[IM]=IM
STAGJ=.FALSE.
IMM1=IM-1
IMM2=IM-2
JMM1=JM-1
JMM2=JM-2
DO 110 I=1,NL
110 NAME(I)=NAMEL(I)

C
DO 250 I=1,IM
DO 250 J=1,JM
E4=IMH(IJ1,2))

C
WS=0.0
WN=0.0
DO 415 I=1,IM
WS=WS+WORKZ(I,I)
415 WN=WN+WORKZ(JM,I)
WS=WS/FIM
WN=WN/FIM
DO 420 I=1,IM
WORKZ(I,I)=WS
420 WORKZ(JM,I)=WN
C

ZMM=0.0
WTM=0.0
DO 450 J=1,JM
SUM=0.0
DO 430 I=1,IM
SUM=SUM + WORK2(J,I)
CLAT=ABS(DXYP(J))
ZM(J)=SUM/FIM
WTM=WTM+CLAT
450 ZMM=ZMM+ZM(J)*CLAT
ZMM=ZMM/WTM
SPOL=ZM(1)
NPOL=ZM(JM)
C
DATA NAMEL/' EVAPORATION (MM/DAY)
DATA NL/13/
RETURN
END

00011980 00011990 00012000 00012010 00012020 00012030 00012040 00012050 00012060 00012070 00012080 00012090 00012100 00012110 00012120 00012130 00012140 00012150 00012160
* SUBROUTINE MAP15

C SENSIBLE HEAT FLUX (F4 IN TENS OF CAL*CM**2*DAY**-1) MAP 15

C

STAG1=.FALSE.
STAGJ=.FALSE.
FIM=1M
IM1=IM-1
IM2=IM-2
JM1=JM-1
JM2=JM-2
DO 110 I=1,NL
C NAME(I)=NAMEL(I)
C
C DO 350 I=1,IM
C DO 350 J=1,JM
C F4=1H(TT(J,I,2))
C
C 410 WS=0.0
C WN=0.0
C DO 415 I=1,IM
C WS=WS+WORK2(I,J)
C 415 WN=WN+WORK2(JM,J)
C WS=WS/FIM
C WN=WN/FIM
C DO 420 I=1,IM
C WORK2(I,I)=WS
C WORK2(JM,I)=WN
C
C ZMM=0.0
C WTM=0.0
C DO 450 J=1,JM
C SUM=0.0
C DO 430 I=1,IM
C SUM=SUM+WORK2(I,J)
C CLAT=ABS(DXYP(J))
C ZM(J)=SUM/FIM
C WTM=WTM+CLAT
C 450 ZMM=ZMM+ZM(J)*CLAT
C ZMM=ZMM/WTM
C SPOL=ZM(I)
C NPOL=ZM(JM)
C
C DATA NAMEL/SENSIBLE HEAT FLUX (10 CAL/CM**2/DAY)/
C DATA NL/13/
C RETURN
C
C END
SUBROUTINE MAP 16
// DD DISP=OLD,DSN=MES727,ABN,COMMON
// DD *
  LOGICAL LEV, STAGJ, STAG1, ISL
COMMON /COUT/ ZM(46), SURF, LEV, ISL, NAME(13)
EQUIVALENCE (SURF, SIGL)
DIMENSION NAMEL(13)
C
C LOW LEVEL CONVECTION (DEG) MAP TYPE 16
C
  F(1)=1M
  STAGJ=.FALSE.
  STAG1=.FALSE.
C
  DO 110 I=1, NL
  110 NAME(I)=NAMEL(I)
C
  DO 220 J=1, JM
  DO 220 J=1, JM
  FLSC=LM(T(J, I, 2))
  220 WORK2(J, I)=FLSC/10.
C
  ZM=0.0
  WTM=0.0
  DO 430 J=1, JM
  SUM=0.0
  DO 430 J=1, JM
  430 ZM=ZM+SUM+WORK2(J, I)
  CLAT=ABS(DXYP(J))
  ZM(J)=SUM/FI(M
  WTM=WTM+CLAT
  430 ZM=ZM+ZM(J)*CLAT
  ZM=ZM/WTM
  NPOD=ZM(JM)
  SPOD=ZM(1)
C
  DATA NAMEL/'LOW LEVEL CONVECTION (DEG CENT)
  DATA NL/13/
  RETURN
C
END
SUBROUTINE MAP_17

// DD DISP=OLD, DSN=ME5727, ABN, COMMON
// DD *
LOGICAL LEV, STAGJ, STAGI, ISL
COMMON /COUT/ ZM(N46), SURF, LEV, ISL, NAMF(N13)
EQUIVALENCE (SURF, SIGL)
DIMENSION NAMEL(N13)
C
C WIND DIRECTION, MAP TYPE 17
C (NORMALLY POLAR PROJECTED)
C
PID2=PI*0.5
PID2T3=PID2*0.3
PIT2=PI*0.2
RPID35=35./PIT2
C
DO 220 J=1, JM
DO 220 I=1, IM
WU=WORK1(I,J,1)
WV=WORK2(I,J,1)
K=1
IF (WU .GE. 0.) K=K+1
IF (WV .EQ. 0.) GO TO (103, 104), K
IF (WU .GE. 0.) K=K+2
IF (WU .EQ. 0.) K=K+4
ANG=ATAN(WU/WV)
GO TO (220, 101, 102, 102, 101, 101, 102, 102), K
101 ANG=ANG+PIT2
GO TO 220
102 ANG=ANG+PI
GO TO 220
103 ANG=PID2
GO TO 220
104 ANG=PID2T3
GO TO 220
220 WORK2(I,J,1)=ANG*RPID35+1.0
C
DO 110 I=1,NL
110 NAME(I)=NAMEL(I)
STAGJ=.TRUE.
STAGI=.TRUE.
FIM=IM
C
410 ZMM=0.0
WTM=0.0
DO 430 J=1,JM
SUM=0.0
DO 420 I=1,IM
420 SUM=SUM+WORK2(J,I)
CLAT=ABS(COS(LAT(J)))
ZM(J)=SUM/FIM
WTM=WTM+CLAT
430 ZMM=ZMM+ZM(J)*CLAT
ZMM=ZMM/WTM
SPOL=ZM(I)
NPOL=ZM(JM)
C
DATA NAMEL,'WIND DIRECTION'
DATA NL,13/
RETURN
C
C
END
SUBROUTINE MAP 1B

C // DD DISP=OLD, DSN=MES727.ABN.COMMON
C // DD *
C LOGICAL LEY, STAGJ, STAGI, ISL
C COMMON /COUT/, ZM(46), SURF, LEV, ISL, NAME(13)
C EQUIVALENCE (SURF, SIGL)
C DIMENSION NAMEL(13)
C
C MAP WIND DIRECTION, MAPTYPE 1B
C (MEANINGFUL ON CYLINDRICAL PROJECTION ONLY)
C
C P1D2=P1*,5
C P1D2T3=P1D2*3.
C P1T2=P1*2.
C PDT18=18./PI
C
C DO 220 J=1,1M
C DO 220 J=1,1M
C WU=WORK1(J,1)/DXU(J)
C WV=WORK2(J,1)/DYV(J)
C IF(WU.EQ.0. .AND. WV.EQ.0.) WV=1.
C ANG=ATAN2(WU,WV)
C IF(ANG.LT.0.) ANG=ANG+P1T2
C 220 WORK2(J,1)=AMOD(ANG*PDT18*18.,36.)
C
C DO 110 I=1,1N
C NAME(I)=NAMEL(I)
C FIM=1M
C STAGJ=.TRUE.
C STAGI=.TRUE.
C
C 410 ZMM=0.0
C WTM=0.0
C DO 430 J=1,1M
C SUM=0.0
C DO 420 I=1,1I
C SUM=SUM+WORK2(J,I)
C CLAT=ABS(COS(LAT(J)))
C ZM(J)=SUM/FIM
C WTM=WTM+CLAT
C 430 ZMM=ZMM+ZM(J)*CLAT
C ZMM=ZMM/WTM
C SPOL=ZM(J)
C NPOL=ZM(J)
C
C DATA NAMEL/*MAP WIND DIRECTION
C DATA NL/13/
C RETURN
C
C END
SUBROUTINE MAP19

// DD DISP=OLD,DSN=MEM777,ABN,COMMON
// DD *
COMMON /COUT/ ZM(161),SURF,LEV,ISL,Namel(13)
LOGICAL LEV, STAGJ, STAGI, ISL
DIMENSION NAMEL(13)
LOGICAL LHLF

C
C LONG WAVE COOLING, MAP TYPE 19

C
FIM=1M
STAGJ=.FALSE.
STAGI=.FALSE.

C
LHLF= SURF *LT. *.5
DO 110 I=1,NL
110 NAME(I)=NAMEL(I)
DO 118 J=1,JM
118 ZM(I,J)=0.0

C
DO 150 I=1,IM
DO 150 J=1,JM
IF (LHLF) GO TO 125
ACC=IRHIVT(J,1,2))
ACC=ACC/100.
GO TO 140
125 ACC=ILHIVT(J,1,2))
ACC=ACC/100.
140 ZM(I,J)=ZM(I,J)+ACC

C
ZMM=0.
WTM=0.0
DO 158 J=1,JM
WTM=WTM + ARS(DXYP(J))
ZM(I,J)=ZM(I,J)/FIM
158 ZMM=ZMM+ABS(DXYP(J))
ZMM=ZMM/WTM
SPOL=ZM(I,1)
NPOL=ZM(I,JM)

C
DATA NAMEL/'LONG WAVE HEATING IN LAYERS (DEG CENT/DAY)
DATA NL/13/
RETURN

C
END
SUBROUTINE MAP20

// DD DISP=OLD,DSN=ME5727,ABN,COMMON
// DD *
COMMON /COUT, ZM(46), SURF, LEV, ISL, NAME(13)
C
ABSORPTION OF INSOLATION, MAP TYPE 20
LOGICAL LEV, STAGJ, STAGI, ISL
DIMENSION NAME(13)
LOGICAL LHLF
C
FIM=1M
STAGJ=.FALSE.
STAGI=.FALSE.
C
LHLF= SURF *GT*.5
C
DO 110 I=1, NL
NAME(I)=NAME(I)
110
C
DO 118 J=1, JM
118 ZM(J)=0.
C
DO 150 J=1, IM
DO 150 J=1, JM
IF (LHLF) GO TO 125
ACC=ILH(11)+..(J,1)
ACC=ACC/100.
GO TO 140
125 ACC=IMH(11)+..(J,1)
ACC=ACC/100.
140 ZM(J)=ZM(J)+ACC
150 WNK2(J,1)=ACC
C
ZMM=0.0
WTM=0.0
DO 158 J=1, JM
WTM=WTM + ABS(DXYP(J))
ZM(J)=ZM(J)/FIM
158 ZMM=ZMM+ZM(J)*ABS(DXYP(J))
ZMM=ZMM/WTM
SPOL=ZM(1)
NPOL=ZM(JM)
C
DATA NAME/'ABSORPTION OF INSOLATION IN LAYERS (DEG CENT/DAY) '/
DATA NL/13/
RETURN
C
END
* SUBROUTINE MAP21 *
// DD DISP=OLD,DSN=MES727,ABN.COMMON
// DD *
LOGICAL LEV, STAGJ, STAGI, ISL
COMMON /COUT/ ZM(46), SURF, LEV, ISL, NAME(13)
EQUIVALENCE (SURF, SIGL)
DIMENSION NAME(13)
C WIND SPEED, MAP TYPE 21
C IMM2=IM-2
JMM1=JM-1
C DO 110 I=1,NL
110 NAME(I)=NAMEL(I)
C STAGJ=.TRUE.
STAGI=.TRUE.
C DO 330 J=1,IM
DO 330 J=2,JM
WIND=WORK2(J,1)**2+WORK1(J,1)**2
330 WORK2(J,1)=SORT(WIND)
C FIM=IM
ZMM=0.0
WTM=0.0
DO 430 J=2,JM
SUM=0.0
DO 420 J=1,IM
420 SUM=SUM+WORK2(J,1)
CLAT=ABS(COS(1.5*(LAT(J-1)+LAT(J)))
ZM(J)=SUM/FIM
WTM=WTM+CLAT
430 ZMM=ZMM+ZM(J)*CLAT
ZMM=ZMM/WTM
SPDL=ZM(2)
NPD1=ZM(JM)
C DATA NAME, 'MAGNITUDE OF THE VECTOR WIND (M/SEC)'
DATA NL/13/
RETURN
C END
SUBROUTINE MAP22

COMMON /COUT/ ZM(46),SURF,LEV,ISL,NAME(13)
LOGICAL LEV, STAGJ, STAGI, ISL
DIMENSION NAMEL(13)

C
SURFACE INSOLATION MAP TYPE 22
C
FIM=IM
STAGJ=.FALSE.
STAGI=.FALSE.

C
DO 110 I=1,NL
110 NAME(I)=NAME(I)1
C
DO 150 J=1,JM
150 ZM(J)=0.0
C
DO 275 I=1,IM
DO 275 J=1,JM
ACC=ILM(SO(J,1))
ACC=ACC/10.
ZM(J)=ZM(J)+ACC
275 WORK2(J,1)=ACC
C
ZMM=0.0
WTM=0.0
DO 158 J=1,JM
WTM=WTM + ABS(DXYP(J))
ZM(J)=ZM(J)/FIM
158 ZMM=ZMM+ZM(J)*ABS(DXYP(J))
ZMM=ZMM/WTM
SPOL=ZM(I)
NPOL=ZM(JM)
C
DATA NAMEL/'SURFACE INSOLATION ABSORPTION (100 CAL/CM**2/DAY) './
DATA NL/13/
RETURN
C
END
SUBROUTINE MAP 23

// DD DISP=ULD+DSN=MES727,AHN,COMMON
// DD =
LOGICAL LEV, STAGJ, STAGI, ISL
COMMON /COUT/ ZM(46), SURF, LEV, ISL, NAME(13)
EQUIVALENCE (SURF, SIGL)
DIMENSION NAMEL(13)

C SURFACE AIR TEMPERATURE, MAP TYPE 23
C
FIM=IM
STAGJ=.FALSE.
STAGI=.FALSE.

C UD 110 I=1, NL
110 NAME(I)=NAMEL(I)
C
DO 220 I=1, IM
DO 220 J=1, JM
TT4=ITH(I3T(J, I))
220 WORK2(J, I)=TT4/10. - TICE
C
410 ZMM=0.0
WMM=0.0
DO 430 J=1, JM
SUM=0.0
DO 420 I=1, IM
420 SUM=SUM+WORK2(J, I)
CLAT=AB(S(DXP(J)))
ZMJ=SUM/FIM
WMM=WMM*CLAT
430 ZMM=ZMM+ZMJ*CLAT
ZMM=ZMM/WMM
NPOL=ZMJ(JM)
SPOL=ZMJ(1)
C
DATA TICE/273.1/
DATA NAME/"SURFACE AIR TEMPERATURE (DEG CENT)"
DATA NL/13/

C RETURN
END
SUBROUTINE

 COMMON /COUT/, ZM(64), SURF,LEV, ISL, NAME(13)
 LOGICAL LEV, STAGJ, STAGI, ISL
 DIMENSION NAME(13)

 C
 C GROUND TEMPERATURE (DEG CENTIGRADE) MAP TYPE 24
 C
 FIM=0
 STAG=FALSE.
 STAG=FALSE.

 C
 DO 110 J=1, NL
 110 NAME(I)=NAME(I)

 C
 DO 150 J=1, JM
 150 ZM(J)=0.0

 C
 DO 275 J=1, IM
 275 ACC = GT(J, I) - TICE
 ZM(J)=ZM(J)+ACC
 WORK2(J, I)=ACC-.0001

 C
 ZMM=0.0
 WTM=0.0
 DO 158 J=1, JM
 WTM=WTM+ABS(DXYP(J))
 ZM(J)=ZM(J)/FIM
 158 ZMM=ZMM+ZM(J)*ABS(DXYP(J))
 ZMM=ZMM/WTM
 SPOL=ZM(I)
 NPOL=ZM(JM)

 C
 DATA TICE /273.1/
 DATA NAME/*GROUND TEMPERATURE (DEG CENT) */
 DATA NL/13/

 C
 RETURN
 END

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SUBROUTINE MAP25

* DD DISP=OLD, DSN=MES727, ABN, COMMON
// DO *
COMM0N /COUT/ ZM(46), SURF, LEV, ISL, NAME(I)
LOGICAL LEV, STAGJ, STAGI, ISL
DIMENSION NAMEL(I)

C WETNES, MAP TYPE 25
C
FIM=IM
JMM2=IM-2
JMM1=JM-1
STAGJ=.FALSE.
STAGI=.FALSE.

C DO 110 I=1, NL
110 NAME(I)=NAMEL(I)
C
ZMM=0.0
DO 118 J=1, JM
118 ZM(J)=0.0
C
DO 128 I=1, IM
DO 128 J=1, JM
ACC=GW(J, I)*10,
ZM(J)=ZM(J)+ACC
C
128 WORK2(J, I)=ACC
C
WTM=0.0
DO 158 J=1, JM
WTM=WTM + ARS(DXYP(J))
ZM(J)=ZM(J)/FIM
158 ZMM=ZMM+ZM(J)+ARS(DXYP(J))
ZMM=ZMM/WTM
SPOOL=ZM(I)
NDOL=ZM(JM)
DATA NAMEL,'GROUND WETNESS (SCAL) ZERO TO TEN')
   '/ DATA NL/13/}
C
RETURN
C
END
SUBROUTINE MAP26
// DD DISP=OLD, DSN=MESS7Z7.ANN.COMMON
// DD *
COMMON /CMOUT/ ZM(46), SURF, LEV, ILS, NAME(13)
LOGICAL LEV, STAGJ, STAGI, ISL
COMMON JEXCOM, CC(46, 72), CPC1(46, 72), CPC3(46, 72),
* PRLH(46, 72), SR4(46, 72)
DIMENSION NAME(13), NAMF2(13), NAMF3(13)
C
FIM=1
STAGJ=.FALSE.
STAGI=.FALSE.
C
K=1
IF (SURF, GT, 0.5) K=2
IF (SURF, EQ, 1.0) K=3
IF (SURF, GT, 1.0) K=4
DO 110 I=1, NL
NAME(I)=NAME(I)
IF (K, EQ, 2) NAME(I)=NAMF2(I)
IF (K, EQ, 4) NAME(I)=NAME3(I)
110 IF (K, EQ, 3) NAME(I)=NAME3(I)
C
DO 150 J=1, JM
150 ZM(J)=0.0
C
DO 275 J=1, JM
DO 275 J=1, JM
ACC=CC(J, 1, K)
IF (ACC, LT, 0.0) ACC=0.0
ZM(J)=ZM(J)+ACC
275 WORK2(J, 1)=ACC
C
ZMM=0.0
WTM=0.0
DO 158 J=1, JM
WTM=WTM + ABS(DXYP(J))
ZM(J)=ZM(J)/FIM
158 ZMM=ZMM+ZM(J)*ABS(DXYP(J))
ZMM=ZMM/WTM
SPOL=ZM(1)
NPOL=ZM(JM)
C
DATA NAME1/*HIGH CLOUDINESS
DATA NAME2/*MIDDLE CLOUDINESS
DATA NAME3/*LOW CLOUDINESS
DATA NL/*CLOUDINESS
RETURN
C
END
SUBROUTINE MAP27

// DD DISP=OLD, DSN= MES727, AKN, COMMON
//
// COMMON /COUT/ ZM(46), SURF, LEV, ISL, NAME(13)
LOGICAL LEV, STAGJ, STAGI, ISL
EQUIVALENCE (SIGL, SURF)
DIMENSION NAMEL(13)

C
F1M=1M
C
STAGJ=.FALSE.,
STAGI=.FALSE.,
C
DO 110 J=1, NL
110 NAME(I)=NAMEL(I)
C
DO 220 J=1, JM
DO 220 I=1, IM
220 WORK2(J, I)=PTROP+SURF*P(J, I)
C
DO 118 J=1, JM
118 ZM(J)=0.0
C
ZMM=0.0
WTM=0.0
DO 430 J=1, JM
SUM=0.0
CLAT=ABS(DXYP(J))
DO 420 J=1, IM
420 SUM=SUM+WORK2(J, I)
ZM(J)=SUM/F1M
WTM=WTM+CLAT
430 ZMM=ZMM+ZM(J)*CLAT
ZMM=ZMM/WTM
SPOL=ZM(I)
NPOL=ZM(JM)
C
DATA NAMEL/*PRESSURF AT SIGMA SURFACE
DATA NL/13/
RETURN
C
END
SUBROUTINE MAP2B

* Map2b

// DD DISP=OLD, DSN=MES727.ABN.COMMON
// DD *
COMMON /COUT/, ZM(46), SURF, LEV, ISL, NAMF(13)
LOGICAL LEV, STAG, STAGI, ISL
EQUIVALENCE (SIGL, SURF)
COMMON /EXCOM/CC(46, 72, 4), CPC1(46, 72), CPC3(46, 72),
* PRECLH(46, 72), SR4(46, 72)
DIMENSION NAMEI(13)
C
FIM=1
C
STAGJ=.FALSE.,
STAGI=.FALSE.,
L1=1
L2=2
SIGL=SIGL1
SIGL2=SIGL2
DSIG1=(SIGL2-SIGL1)
SURFMT=SURF-PTROP
IF (LEV) SIGX=SIGL
C
DO 110 I=1, NL
110 NAME(I)=NAMEF(I)
C
DO 220 J=1, JM
DO 220 J=1, JM
IF (.NOT.LEV) SIGX=SURFMT/P(J, I)
H1=CPC1(J, 1)
H3=CPC3(J, 1)
220 WORK2(J, I)=SIGX*(SIGL2-SIGX)*H1 + (SIGX-SIGL1)*H3
C
DO 118 J=1, JM
118 ZM(J)=0, 0
C
ZMM=0, 0
WTM=0, 0
DO 430 J=1, JM
SUM=0, 0
CLAT=ABS(DXYP(J))
DO 420 I=1, JM
420 SUM=SUM+WORK2(J, I)
ZMJ=SUM/FIM
WTM=WTM*CLAT
430 ZMM=ZMM+Z LJ, I)*CLAT
ZMM=ZMM/WTM
SPDL=ZM(I)
NPDL=ZM(JM)
C
DATA NAMEL/’TOTAL CONVECTIVE HEATING (DEG CENT/DAY) /
DATA NL/13/
RETURN
C
END
SUBROUTINE MAP29
* COMMON /COUT/: ZM(46), SURF, LEV, ISL, NAME(13)
   COMMON /EXCOM/: CC(46, 72, 4), CPC1(46, 72), CPC3(46, 72),
   * PRCLH(46, 72), SR4(46, 72)
DIMENSION NAMEL(13)
C
FIM=1
C
STAGJ=.FALSE.
STAGI=.FALSE.
L1=1
L2=2
SIGL1=SIG(L1)
SIGL2=SIG(L2)
SIG1=./SIGL2-SIGL1
SURFM=SIGN-PTRP
IF (LEV) SIGX=SIGL
C
ON 110 I=1,NL
110 NAME(I)=NAMEL(I)
C
ON 220 J=1,1M
220 IF (.NOT.LEV) SIGX=SIGN/P(J,1)
H1=0.0
H3=PRCLH(J,1)
220 WORK2(J,1)=DSIG*((SIGL2-SIGX)*H1 + (SIGX-SIGL1)*H3)
C
ON 118 J=1,1M
118 ZM(J)=0.0
C
ZMM=0.0
WTM=0.0
ON 430 J=1,1M
430 SUM=SUM+WORK2(J,1)
ZM(J)=SUM/FIM
WTM=WTM+CLAT
430 ZMM=ZMM+ZM(J)*CLAT
ZMM=ZMM/WTM
SPOL=ZM(J)
NPOL=ZM(J)
C
DATA NAMEL, "LATENT HEATING IN LAYER (DEG CENT/DAY)"
DATA NL/13/
RETURN
C
END
SUBROUTINE MAP3D

C COMMON /COUT/ ZM(46),SURF,LEV,ISL,NAME(13)
C LOGICAL LEV, STAGJ, STAGI, ISL
C COMMON /EXCM/CC(46,72,4),CPC1(46,72),CPC3(46,72),
C * PRCLH(46,72),SR4(46,72)
C DIMENSION NAME(13)
C
C FIM=IM
STAGJ=.FALSE.,
STAGI=.FALSE.,
C
DO 110 I=1,NL
110 NAME(I)=NAME(I+1)
C
DO 150 J=1,JM
150 ZM(J)=0.0
C
DO 275 I=1,IM
DO 275 J=1,JM
ACC=0.1*SR4(J,I)
ZM(J)=ZM(J)+ACC
275 WORK2(J,I)=ACC
C
ZMM=0.0
WTM=0.0
158 ZM(J)=ZM(J)/FIM
ZM(J)=ZM(J)+ABS(DXYP(I,J))
ZMM=ZMM+WPM
ZMM=ZM(J)/WPM
C
DATA NAME/ SURFACE LONG-WAVE COOLING (100 CAL/CM**2/DAY)/
DATA NL/13/
RETURN
C
END
**SUBROUTINE MAP**

// DD DISP=OLD, DSN=MEMS727, ABN, COMMON

// DD * COMMON /COUT/ ZM(46), SURF, LEV, ISL, NAME(13)
LOGICAL LEV, STAGJ, STAGI, ISL
COMMON /XCOM/CL(46, 72, 4), CPC1(46, 72), CPC3(46, 72),
* 
PRCLH(46, 72), SR4(46, 72)

DIMENSION NAMEL(13)

C

FIM=1M
STAGJ=.FALSE.
STAGI=.FALSE.

C

CALL MAP 22
DO 275 J=1, JM
DO 275 I=1, IM
275 WORK1(I, J)=WORK2(I, J)
CALL MAP 30
DO 280 J=1, JM
DO 280 I=1, IM
280 WORK1(I, J)=WORK1(I, J)-WORK2(I, J)
CALL MAP 15
DO 285 J=1, JM
DO 285 I=1, IM
285 WORK1(I, J)=WORK1(I, J)-0.5*WORK2(I, J)
CALL MAP 14
DO 290 J=1, JM
DO 290 I=1, IM
290 WORK2(I, J)=WORK1(I, J)-0.5*WORK2(I, J)
DO 150 J=1, JM
150 ZM(J)=0.0
DO 300 J=1, JM
DO 300 I=1, IM
300 ZM(I)=ZM(I)+WORK2(I, J)

C

ZMM=0.0
WTM=0.0
DO 158 J=1, JM
WTM=WTM + ABSDXYP(J)
ZM(J)=ZM(J)/FIM
158 ZMM=ZMM+ZM(J)*ABS(DXYP(J))
ZMM=ZMM/WTM
SPOL=ZM(1)
NPOL=ZM(JM)
DO 110 I=1, NL
110 NAME(I)=NAMEL(I)

C

DATA NAMEL /SURFACE HEAT BALANCE (100 CAL/CM**2/DAY)
DATA NL/13 /
RETURN

C

END
SUBROUTINE CMP3

* DD DISP=OLD, DSN=MES727, ABN, COMMON
* DD *
* EQUIVALENCE (KKK, XXX)
* LOGICAL ICE, LAND, OCEAN, SNOW, KEY
*CMP3 COMMON /EXCM/CC(46,72,4), CPC1(46,72), CPC3(46,72),
* PRCLM(46,72), SR4(46,72),
C TRANS(X)=1./(1.+1.75*X**.416)
C TRSW(X)=1.-.271*X**.303
C JMM1=JM-1
C JMM2=JM-2
C IH=IM/2+1
C IM=IM
C SIG1=SIG1
C SIG3=SIG3
C SIG=SIG3-SIG1
C GWM=30.
C DTC3=FLOAT(NC3)*DT
C RCN=RCN/TCNV
C CLH=CLH/24
C PDK=1000.*KAPA
C CTI=.005
C CTID=.64E4*CTI
C HICE=300.
C TICE=273.1
C PM=PSL-PTROP
C COE=GRAV*100./(0.5*PM*1000.*0.24)
C COE1=COE/DTC3/(24.*3600.)
C SCALE=COE*100.
C TSPD=DAY/DTCS3
C SCALEP=TSPD*5/(10./GRAV)*100.
C CONCAT=180./PI
C CNR=CONRAD*0.1
C FSDEY=SDEDY
C SDN=(60.*15.*COS((9863*(FSDEY-24,668)/CONRAD))/CONRAD)
C SDN=-60./CONRAD
C SURFACE WIND MAGNITUDE
C DO I=1,IM
C DO J=2,JM
C US2=*(SIG3*U(J,J,1)-SIG1*U(J,J,1))*.07
C VS2=*(SIG3*V(J,J,1)-SIG1*V(J,J,1))*.07
C FD(I,J)=US*US+VS*VS
C WMA1=SORT((FD(2,1), FD(2,J))
C WMAJ=SORT ((FD(J,1), FD(J,J)))

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00020940
C RADIATION CONSTANTS
C
SO=28.00/RSDIST
ALC1=.7
ALC2=.6
ALC3=.6
STRA=1.171E-7
EFVC1=65.3
EFVC2=65.3
EFVC3=7.6
CPART=5*1.3071E7
ROT=TOFDAY/ROTPER*2.0*PI
C
C HEATING LOOP
C
DO 370 I=1,IM
   IM=MOD(I+1,IMM2)+1
   IP=MOD(I+1,IM)+1
   FIM1=I-1
   HACOS=COSD*COS(ROT+FIM1*DLON)
   DO 360 J=1,JM
      COS2=SN(1,J)*SN(1,J)*COSL(1,J)*HACOS
C
C SURFACE CONDITION
C
TGO0=TOPOG(J,J)
OCEAN=IF(GO0,GT,1)
ICE=IF(GO0,LE,-9.9E5)
LAND=NOT.(ICE.OR.OCEAN)
SNOW=LAND,AND,.LT.,LE.SNOW)
LAND=LAND,AND,.NOT.,SNOW
IF (.NOT.,OCEAN) ZZZ=VPHI4(J,J)/GRAV
C
C DRAG COEFFICIENT
C
IF (J.EQ.1) WMAG=WMAG1
IF (J.EQ.JM) WMAG=WMAGJM
IF (J.LT.1.AND.J.LE.JM) WMAG=SORT(.25*(FD(J,J)+FD(J+1,J)))
C
CD = .002
IF (.NOT.,OCEAN) CD=CD+0.006#ZZZ/5000.
IF (OCEAN) CD = AMIN1((1.0+.07*WMAG),.001,.0025)
CS = CD*100.
CS4 = .24*CS24.*3600.
FK1 = CD*(10.*GRAV)/(DS150*PM)

C
PRESSURES

SP=P(J,J,1)
GOLM=PM/SP
P4=SP+PTROP
P4K=P4**KAPA
PL1=SIG1*SP+PTROP
PL2=0.5**SP+PTROP
PL3=SIG3*SP+PTROP
PL1K=PL1**KAPA
PL3K=PL3**KAPA
PL2K=PL2**KAPA
PTRK=PTROP**KAPA
DPLK=PL3K-PL1K

TEMPERATURES AND TEST FOR DRY-ADIABATIC INSTABILITY

T1=T(J,J,1)
T3=T(J,J,2)
THL1=T1/PL1K
THL3=T3/PL3K
IF (THL1 .GT. THL3) GO TO 310
XX1=(T1+T3)/(PL1K+PL3K)
T1=XX1*PL1K
T3=XX1*PL3K
THL1=T1/PL1K
THL3=T3/PL3K

MOISTURE VARIABLES

310 ES1=10.0**(R*.4051-2353.0/T1)
ES3=10.0**(R*.4051-2353.0/T3)
P1CB=1*PL1
P3CB=1*PL3
P4CB=1*P4
OS1=.622*ES1/(P1CB-ES1)
OS3=.622*ES3/(P3CB-ES3)
GAM1=CLH*OS1*5418./T1**2
GAM3=CLH*OS3*5418./T3**2
Q3R=Q3(J,J,1)
RM3=Q3R/OS3

TEMPERATURE EXTRAPOLATION AND INTERPOLATION FOR RADIATION

ATEM=(THL3-THL1)/DPLK
BTEM=(THL1*PL3K-THL3*PL1K)/DPLK
TTROP=(ATEM*PTRK+BTEM)*PTRK
T2=(ATEM*PL2K+BTEM)*PL2K
GROUND TEMPERATURE AND WETNESS

TG=TG00
WET=1.0
IF (.NOT.CCFAN) TG=GT(J,I)
IF (LAND) WET=GW(J,I)

LARGE SCALE PRECIPITATION

PREC=0.
IF (Q3R.LE.0.53) GO TO 1060
PREC=(Q3R-Q33)/(1.+GAM3)
T3=T3+CLM*PREC
THL3=T3/PL3K
Q3R=Q3R-PREC

CONVECTION

1060 TETA1=THL1*P10K
TETA3=THL3*P10K
SS3 = TETA3*P4K/P10K
SS2 = SS3 + 0.5*(TETA1-TETA3)*PL2K/P10K
SS1 = SS2 + 0.5*(TETA1-TETA3)*PL2K/P10K
HH3 = SS3 + CLH*Q3R
HH3S = SS3 + CLH*QS3
HH1S = SS1 + CLH*QS1

MIDDLE LEVEL CONVECTION

C1 = 0.
C3 = 0.
EX = HH3 - HH1S
IF (EX.LE.0.) GO TO 1065
C1 = RCVV*EX/(2.+GAM1)
C3 = C1*(1.+GAM1)/(SS2-SS3)/(EX+(1.+GAM1)*(SS1-SS2))

PREPARATION FOR AIR-EARTH INTERACTION

1065 ZL3 = 2000.
WINDF=2.0*WMAG
DRAW=CD*WINDF
EDV=ED/2L3*WMAG/10.
C DETERMINATION OF SURFACE TEMPERATURE

1070 RH4=2.*WET*RH3/(WET+RH3)
EG=10.**((8.*4051.-2353.)/TGU)
EG= AMIN1(EG,P4CR/1.662)
QG=.622*EG/(P4CR-EG)
QG=541.R.*QG/TG**2
HHG=TG+CLH+QG*WET
E2R=EDV/(EDV+DRAW)
HH4=E2R*HH3+(1.-E2R)*HHG
GAMG=CLH*QG
T4=(HH4-RH4*(CLH*QG-GAMG))/((1.+RH4*GAMG)
IF (T4>P1OK/P4K,GT,TETA3) T4=TETA3*P4K/P1OK
Q4=RH4*(QG+NOG*(T4-TG))
HH4=T4+CLH+Q4

C PENETRATING AND LOW-LEVEL CONVECTION

PC1=0.
PC3=0.
EX=0.
IF (HH4,LE.,HH3S) GO TO 1077
IF (HH3,GT.,HH1S) GO TO 1077
EX = HH4-HH3S
HH4P = HH4
HH6 = HH3S
IF (HH6P,LT.,HH1S) GO TO 1076
ETA = 1.
TEP1 = ETA*((HH3S-HH1S)/(1.+GAM1)+SS1-SS2)
TEP2 = ETA*(SS2-SS3) + (SS3-T4)
TEMP = EDV*TEMP1+(1.+GAM3)*TEMP2
IF (TEMP,LT.,.001) TEMP,.001
CONVP = RCONV*EX/TEMP
PC1 = CONVP*TEMP1
PC3 = CONVP * TEMP2

1076 T4=T4-EX/(1.+RH4*GAMG)
Q4=(HH4-T4)/CLH

C

1077 RO4=P4CR/(RGAS*T4)
CSEN=CS4*RO4*WINDF
CEVA=CS*RO4*WINDF

00022310
00022320
00022330
00022340
00022350
00022360
00022370
00022380
00022390
00022400
00022410
00022420
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00022500
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00022600
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00022630
00022640
00022650
00022660
00022670
00022680
00022690
00022700
00022710
00022720
00022730
00022740
C CLOUDINESS

ICLOUD=1
CL=0.
CL1=0.
CL2=0.
CL3=0.
CLT=0.

CL=AMIN1(-1.3+2.6*RH3,1.)
IF (CL1.GT.0. OR. PCL1.GT.0.) CL1=CL
IF (PREC.GT.0. AND. CL1.EQ.0.) CL2=1.
IF (EX.GT.0. AND. PCL1.EQ.0.) CL3=CL

***************************************************************************

C

****
*
*
*
*
*
****

C

*****

CL1 CL2 CL3

***************************************************************************

CL=AMAX1(CL1,CL2,CL3)
IF (CL .GE. 1.) ICLNUD=3
IF (CL .LT. 1. .AND. CL .LT. 0.) ICLNUD=2

C

ICLOUD=1 CLEAR, ICLNUD=2 PARTLY CLOUDY, ICLNUD=3 OVERCAST

C

LONG WAVE RADIATION


0380 Q3RB=AMAX1(Q3R,1.E-5)
VAK=2.*ALOG1(1.7188E-6/Q3RB)/ALOG(120.*PL3)

00621540

TEM1=0.0102*PL3**2*Q3RB/VAK
TEM2=TEM1*(P4/PL3)**VAK

00621549

EFV3=TEM2-TEM1

00621549

EFV2=TEM2-TEM1*(PL2/PL3)**VAK

00621549

FFV1=TEM2-TEM1*(PL1/PL3)**VAK

00621549

EFVT=TEM2-TEM1*(PTROP/PL3)**VAK

00621549

EFVO=TEM2-TEM1*(120./PL3)**VAK+2.526E-5

00621549

BLT=STB0**TROP**4

00621549

BL1=STB0**T1**4

00621549

BL2=STB0**T2**4

00621549

BL3=STB0**T3**4

00621549

BL4=STB0**T4**4

00621549
C LONG WAVE RADIATION
R0C=0.
R2C=0.
R4C=0.
UR1=BLT*TRANS(EFVO-EFVT)
UR2=BL2*TRANS(EFVO-EFVT)
GO TO 1090 (1990, 1990, 2000), ICLD 
1090 R0D=R2*D*(UR1+(DL4-HLT)+(1-TAST(EFVT)) /2.1 
R20=0.736*(UR2+(DL4-0L2)+(1-TAST(EFVT)) /2.1 
R40=0.6*SORT(TRANS(EFVO)-0.1) 
IF (ICLDD = EQ. 1) GO TO 2015 
2000 IF (CL2 .LE. 0.1) GO TO 2004 
CLT=CL2 
R0C=R2*(UR1+(BL2-CLT)+(1-TAST(EFVT-EFVT2)) /2.1*CLT 
R2C=0.736*UR2*CLT 
R2C=.5*R2C 
GO TO 2006 
2004 IF (CL3 .LE. 0.1) GO TO 2006 
CLT=CL3 
R0C=R2*(UR1+(BL3-CLT)+(1-TAST(EFVT-EFVT3)) /2.1*CLT 
R2C=0.736*UR2+(BL3-BL2)+(1-TAST(EFVT-EFVT3)) /2.1*CLT 
2006 IF (CL1 .LE. 0.1) GO TO 2010 
CLM=AMAX1(CLCL-CLL, 0.) 
C IN PRESENT VERSION, CLM AND THIS TEM ARE ALWAYS ZERO 
TEM=0. 
IF (CLT .GE. 0.01) TEM=CLM/CLT 
R0C=0.82*(UR1+(BL1-CLT)+(1-TAST(EFVT-EFVT1)) /2.1*CL1+R0C*TEM 
R2C=R2C*TEM 
2010 R4C=0.85*(CL1+(CL1-CL1)+(1-TAST(EFVT-EFVT3)) /2.1*CL 
2015 R0C+(1-CL)*R0D 
R2C=R2C*+1-CL)*R2D 
R4R4C+(1-CL)*R4D 
DIREC=45*STRD*TG**3 
C 
C SURFACE ALBEDO 
C 
IF (COSZ .LE. .01) GO TO 340 
SCOSZ=50*COSZ 
ALS=.07 
IF (OCM) GO TO 335 
ALS=.14 
IF (LATI .LT. SNOWN) GO TO 327 
CLAT=-(LATI-SNOWN)*CONRAD 
GO TO 330 
327 IF (LATI .GT. SNOWS) GO TO 328 
CLAT=(SNOWS-LATI)*CONRAD 
ALS=.45*(1+(CLAT-10.)*2)/(1+(CLAT-30.)*2+(CLAT-10.)*2) 
GO TO 335 
328 IF (LAND) GO TO 335 
CLAT=0. 
330 ALS=.4*(1+(CLAT-5.)*2)/(1+(CLAT-45.)*2+(CLAT-5.)*2)
C SOLAR RADIATION
C
335  ALAO=AMN(1. 0.015. 0.247*ALGO10*(COSZ/COLMR))
SA=349*SCOSZ
SS=SCOSZ-SA
AS0T=SA*TRSW(WFV0=WFVT)/COSZ
AS2T=SA*TRSW(WFV0=WFV2)/COSZ
FSZC=0.
FS4C=0.
SSC=0.
GO TO (336,336,337), ICLM

C CLEAR
336  FS20=AS2T
FS40=SA*TRSW(WFV0=COSZ)
S40=(1.-ALS)*(FS40+(1.-ALAO)/(1.-ALAO*ALS))*SS
IF (ICLoud .EQ. 1) GO TO 341

C LARGE SCALE CLOUD
337  IF (C12 .LE. 0.) GO TO 338
C1T=C12
FS2C=AS2T*C1T
FS4C=SA*(1.-ALC2)*TRSW(WFV0=WFV2)/COSZ+1.66*(EFVC2+EFV3)
S4C=(1.-ALS)*(TEMS/(1.-LAC2*ALS)+(1.-ALAC)/(1.-ALAC*ALS))*SS*C1T
GO TO 339

C LOW LEVEL CLOUD
338  IF (C13 .LE. 0.) GO TO 339
C1T=C13
FS2C=AS2T*C1T
FS4C=SA*(EFV0=EFV3)/COSZ
S4C=(1.-ALS)*(TEMS/(1.-ASC3)*SA*TRSW(TEMU))+1.66*(EFVC3+EFV3)
S4C=(1.-ALS)*(TEMS/(1.-ASC3*ALS)+(1.-ALAC)/(1.-ALAC*ALS))*SS*C1T
GO TO 341

C THICK CLOUD
339  IF (C14 .LE. 0.) GO TO 341
CLM=AMAX1(CL1-CL100,0.)
C IN PRESENT VERSION, CLM AND THIS TFM ARE ALWAYS ZERO
TEM=0.
IF (CL1 .GT. 0.) TEM=CLM/CLT
TEMS=EFV0=EFV1/COSZ
TEM1=ASC1*TRSW(TEMU)*SA/CL1
FSZC=SA*(1.-ASC1)*TRSW(TEMU1)+1.66*(EFVC1)*CL1+TEM+FS2C*TEM
FS4C=TEM1+TEM+FS4C*TEM
ALAC=ASC1+ALAC-ASC1*ALAO
S4C=(1.-ALS)*(TEMS/(1.-ASC1*ALS)
X=(1.-ALAC)/(1.-ALAC*ALS))*SS*CL1+S4C*TEM

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00023800
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00024110
00024120
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00024140
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00024160
00024170
00024180
00024190
00024200
00024210
00024220
00024230
00024240
00024250
C MEAN CONDITION

341 FS2=FS2C*(1.-CL)*FS0
    FS4=FS4C*(1.-CL)*FS0
    S4=S4C*(1.-CL)*S40
    AS1=AS0-T-FS2
    AS3=FS2-FS4
    GO TO 345

340 S4=0.0
    AS3=0.0
    AS1=0.0
COMPUTATION OF GROUND TEMPERATURE

345 TGR=TG
IF (OCEAN) GO TO 347
BRAD=S4-R4
TEM=0.
IF (ICE.AND.ZLZ.LT.0.1) TEM=CTID/HICE
A1=CSN*TOC+CLH*(Q4+WET*(DOG*TG-OG))
A2=BRAD+4.*RL4+TEM*TICE
B1=CSN*(1.+CLH*DOG&WET)
B2=DIRAD+TEM
TGR=(A1+A2)/(B1+B2)
IF (LAND.OR.TGR.LT.TICE) GO TO 346
TGR=TICE

346 DR4=DIRAD*(TGR-TG)
R4=R4+DR4
R2=R2+.8*(1.-CL)*TRANS(EFV2)*DR4
R0=R0+.8*(1.-CL)*TRANS(EFVT)*DR4
CONTINUE

SENSIBLE HEAT (LY/DAY) AND EVAPORATION (GM/CM²*2/SEC)

F4=CEVA*(WET*(QG+DOG*(TGR-TG)))-04
F4=CSN*(TGR-T4)
FK=R04*FK1*WINDF

TOTAL HEATING AND MOISTURE BUDGET

QN=(C3+PC3*PC3)/CLH*PREC=2.*E4*DTC3*GRAV/SP*10.9
IF (.NOT.LAND) GO TO 350
RUNOFF=0.
IF (QN,GT,0.) AND. WET.LT.1.) RUNOFF=.5*WET
IF (QN,GT,0.) AND. WET,GE,1.) RUNOFF=1.
WET = GW(J,1)+(1.-RUNOFF)*QN*5.*SP/GRAV/GWM
IF (WET,GT,1.) WET = 1.
IF (WET,LT,0.) WET = 0.

350 CONTINUE

SURFACE FRICTION

351 H1=(A51+R2-R0)*COF1*COLMR+C1+PC1
H3=(A53*R4-R2+F4)*COE1*COLMR+C3+PC3+PREC*CLH
H(J,J,1)=.5*(H1+H3)
TEMP=0.5*(H1-H3)

SURFACE FRICTION

352 CONTINUE

355 CONTINUE
C PACK FOR OUTPUT
C
WW=0.0
CC(J,1,1)=CL1
CC(J,1,2)=CL2
CC(J,1,3)=CL3
CC(J,1,4)=CL
CPC1(J,1)=(C1+PC1)*DAY/DT3
CPC2(J,1)=(C2+PC2)*DAY/DT3
CPC3(J,1)=(C3+PC3)*DAY/DT3
PRCLH(J,1)=PREQ*CLH*DAY/DT3
SR4(J,1)=R4
SCALE=SCALE*COLMR
KKK=IPK(IFIX(A5)*SCALE),IFIX(A5*SCALE))
TT(J,1,1)=XXX
KKK=IPK(IFIX((R2-R0)*SCALE),IFIX((R4-R2)*SCALE))
VT(J,1,2)=XXX
KKK=IPK(IFIX(F4),IFIX(F4*100.*3600.*24.*))
TT(J,1,2)=XXX
KKK=IPK(IFIX(T4*10.),IFIX(PREC*SCALEFP*SP))
Q3T(J,1)=XXX
KKK=IPK(IFIX(FX*10.),IFIX((C1+C3+PC1+PC3)*SP*SCALEFP/CLH))
UT(J,1,2)=XXX
KKK=IPK(IFIX(H1*100.*DAY/DT3),IFIX(H3*100.*DAY/DT3))
PT(J,1)=XXX
KKK=IPK(IFIX(S4/10.),IFIX(WW*100.))
SD(J,1)=XXX
360   CONTINUE
370   CONTINUE
375   CONTINUE
377   CONTINUE
380   CONTINUE
390   CONTINUE
400   RETURN
END
VIII. FORTRAN DICTIONARY

PURPOSE

In order to permit the efficient reading of the FORTRAN program and map routine listings, all of the FORTRAN variables used in the code are collected below. For each FORTRAN term a brief identification or meaning is given, together with the term's units (if any) and the location of its first appearance or definition in the program. The locations are not given for certain symbols of widespread use, and those FORTRAN symbols used only in the output map routines of Chapter VII, Section B, are not listed. Conventional FORTRAN notation has been used, with the equivalence in terms of the physical symbols of the model also given where appropriate.
<table>
<thead>
<tr>
<th>FORTRAN Symbol</th>
<th>Meaning</th>
<th>Units</th>
<th>Program Location</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>AX * 10^5, horizontal momentum diffusion coefficient (zero in present version)</td>
<td>m^2 sec^{-1}</td>
<td>13570 INPUT</td>
</tr>
<tr>
<td>ALAC</td>
<td>a_c = a_{c_1} + a_o - a_{c_1} a_o, albedo of cloudy atmosphere for Rayleigh scattering</td>
<td>--</td>
<td>10650 COMP 3</td>
</tr>
<tr>
<td>ALAO</td>
<td>a_o, albedo of clear sky for Rayleigh scattering</td>
<td>--</td>
<td>10450 COMP 3</td>
</tr>
<tr>
<td>ALC1</td>
<td>a_{c_1}, albedo of type 1 (penetrating convective) cloud, = 0.7</td>
<td>--</td>
<td>7610 COMP 3</td>
</tr>
<tr>
<td>ALC2</td>
<td>a_{c_2}, albedo of type 2 (middle-level overcast) cloud, = 0.6</td>
<td>--</td>
<td>7620 COMP 3</td>
</tr>
<tr>
<td>ALC3</td>
<td>a_{c_3}, albedo of type 3 (low-level convective) cloud, = 0.6</td>
<td>--</td>
<td>7630 COMP 3</td>
</tr>
<tr>
<td>ALP</td>
<td>(m/n - 1)/8, longitudinal smoothing parameter</td>
<td>--</td>
<td>6920 AVRX</td>
</tr>
<tr>
<td>ALPH(8)</td>
<td>identification parameter (not used)</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>ALPHA</td>
<td>(1) FXCO*(P(J,I)+P(J-1,I))*(FD(J,I)+FD(J-1,I)) Coriolis force parameter</td>
<td>m^2 mb</td>
<td>5160 COMP 2</td>
</tr>
<tr>
<td></td>
<td>(2) ALP/PMN, longitudinal smoothing weighting factor</td>
<td>--</td>
<td>6950 AVRX</td>
</tr>
<tr>
<td>ALS</td>
<td>a, surface albedo (0.07 for ocean, 0.14 for bare land, a defined function of latitude for ice and snow)</td>
<td>--</td>
<td>10290-10410 COMP 3</td>
</tr>
<tr>
<td>AMONTH(3)</td>
<td>name of month</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>APHEL</td>
<td>apihelion, 1 July (= 183.0)</td>
<td>day</td>
<td>13110 INPUT</td>
</tr>
<tr>
<td>FORTRAN Symbol</td>
<td>Meaning</td>
<td>Units</td>
<td>Program Location</td>
</tr>
<tr>
<td>---------------</td>
<td>---------</td>
<td>-------</td>
<td>-----------------</td>
</tr>
<tr>
<td>AS0T</td>
<td>$S^A_T$, flux at tropopause of solar radiation subject to absorption</td>
<td>1y day$^{-1}$</td>
<td>10480 COMP 3</td>
</tr>
<tr>
<td>AS1</td>
<td>$A_1$, insolation absorbed by upper layer ($= 0$ if cos $\zeta$ $\leq$ 0.01)</td>
<td>1y day$^{-1}$</td>
<td>10950 COMP 3</td>
</tr>
<tr>
<td>AS2T</td>
<td>$(S^A_2)'$, flux at level 2 of solar radiation subject to absorption ($= FS20$)</td>
<td>1y day$^{-1}$</td>
<td>10490 COMP 3</td>
</tr>
<tr>
<td>AS3</td>
<td>$A_3$, insolation absorbed by lower layer ($= 0$ if cos $\zeta$ $\leq$ 0.01)</td>
<td>1y day$^{-1}$</td>
<td>10960 COMP 3</td>
</tr>
<tr>
<td>ATEM</td>
<td>$(\theta_3 - \theta_1)/(p_3^K - p_1^K)$, temperature interpolation parameter</td>
<td>deg(mb)$^{-2\kappa}$</td>
<td>8490 COMP 3</td>
</tr>
<tr>
<td>AX</td>
<td>horizontal momentum diffusion coefficient ($= 0$ in present version)</td>
<td>$m^2$ sec$^{-1}$</td>
<td>13380 INPUT</td>
</tr>
<tr>
<td>AXU(J)</td>
<td>$A(DXU(J))/300$ km$^{4/3}$, zonal momentum diffusion coefficient (not used)</td>
<td>$m^2$ sec$^{-1}$</td>
<td>14800 MAGFAC</td>
</tr>
<tr>
<td>AXV(J)</td>
<td>$A(DXV(J))/300$ km$^{4/3}$, zonal momentum diffusion coefficient (not used)</td>
<td>$m^2$ sec$^{-1}$</td>
<td>14810 MAGFAC</td>
</tr>
<tr>
<td>AYU(J)</td>
<td>$A(DUY(J))/300$ km$^{4/3}$, meridional momentum diffusion coefficient (not used)</td>
<td>$m^2$ sec$^{-1}$</td>
<td>14820 MAGFAC</td>
</tr>
<tr>
<td>AYV(J)</td>
<td>$A(DYP(J))/300$ km$^{4/3}$, meridional momentum diffusion coefficient (not used)</td>
<td>$m^2$ sec$^{-1}$</td>
<td>14830 MAGFAC</td>
</tr>
<tr>
<td>Al</td>
<td>$c_T \left( T_4 + \frac{L}{c_p} \left( q_4 + WET \left[ T_g \frac{dq(T_g)}{dT} - q_s(T_g) \right] \right) \right)$</td>
<td>1y day$^{-1}$</td>
<td>11090 COMP 3</td>
</tr>
</tbody>
</table>

ground temperature parameter
<table>
<thead>
<tr>
<th>FORTRAN Symbol</th>
<th>Meaning</th>
<th>Units</th>
<th>Program Location</th>
</tr>
</thead>
<tbody>
<tr>
<td>A2</td>
<td>$S_4 - \tilde{R}_4 + 4\sigma T_4^d + \tilde{E}_T$, ground temperature parameter</td>
<td>1y day$^{-1}$</td>
<td>11100 COMP 3</td>
</tr>
<tr>
<td>BCOMMON (67040)</td>
<td>common block (see Chapter VII, Subsection A.3)</td>
<td>(various)</td>
<td>0140 COMMON</td>
</tr>
<tr>
<td>BIT</td>
<td>control parameter (not used)</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>BLANK</td>
<td>logical variable control</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>BLT</td>
<td>$\sigma T_T^4$, long-wave radiation parameter at tropopause</td>
<td>1y day$^{-1}$</td>
<td>9860 COMP 3</td>
</tr>
<tr>
<td>BL1</td>
<td>$\sigma T_1^4$, long-wave radiation parameter at level 1</td>
<td>1y day$^{-1}$</td>
<td>9870 COMP 3</td>
</tr>
<tr>
<td>BL2</td>
<td>$\sigma T_2^4$, long-wave radiation parameter at level 2</td>
<td>1y day$^{-1}$</td>
<td>9880 COMP 3</td>
</tr>
<tr>
<td>BL3</td>
<td>$\sigma T_3^4$, long-wave radiation parameter at level 3</td>
<td>1y day$^{-1}$</td>
<td>9890 COMP 3</td>
</tr>
<tr>
<td>BL4</td>
<td>$\sigma T_g^4$, long-wave radiation parameter at ground level</td>
<td>1y day$^{-1}$</td>
<td>9900 COMP 3</td>
</tr>
<tr>
<td>BRAD</td>
<td>$S_4 - \tilde{R}_4$, ground radiation balance (uncorrected for $T_g$)</td>
<td>1y day$^{-1}$</td>
<td>11060 COMP 3</td>
</tr>
<tr>
<td>BTEM</td>
<td>$(\theta_1 p_3^K - \theta_2 p_3^K)/(p_3^K - p_1^K)$, temperature interpolation parameter</td>
<td>deg(mb)$^{-1}$K</td>
<td>8500 COMP 3</td>
</tr>
<tr>
<td>B1</td>
<td>$C_T(1 + \gamma_g \text{ WET})$, ground temperature parameter</td>
<td>1y day$^{-1}$deg$^{-1}$</td>
<td>11110 COMP 3</td>
</tr>
<tr>
<td>FORTRAN Symbol</td>
<td>Meaning</td>
<td>Units</td>
<td>Program Location</td>
</tr>
<tr>
<td>----------------</td>
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</tr>
<tr>
<td>B2</td>
<td>$4\sigma T^3 + \tilde{B}$, ground temperature parameter ($\tilde{B} = 0$ unless over ice)</td>
<td>1y day$^{-1}$deg$^{-1}$</td>
<td>11120 COMP 3</td>
</tr>
<tr>
<td>C(K)</td>
<td>equivalence array (see Chapter VII, Subsection A.3)</td>
<td>(various)</td>
<td>0430 COMMON</td>
</tr>
<tr>
<td>CD</td>
<td>$C_D$, surface drag coefficient</td>
<td>--</td>
<td>7970-7980 COMP 3</td>
</tr>
<tr>
<td>CENTIG</td>
<td>identification for sea-surface temperature</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>CEVA</td>
<td>$100 C_D \rho A (</td>
<td>\vec{V}_s</td>
<td>^2 + G)$, surface evaporation parameter</td>
</tr>
<tr>
<td>CHECK</td>
<td>data control parameter (not used)</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>CL</td>
<td>max(CL1, CL2, CL3), fraction of sky covered by cloud</td>
<td>--</td>
<td>9700 COMP 3</td>
</tr>
<tr>
<td>CLAT</td>
<td>degrees poleward of snowline, used in surface albedo calculation $(\varphi_j \cdot \text{SNOWN,SNOWS-} \varphi_j) \cdot \text{CONRAD}$ for (northern, southern) hemisphere</td>
<td>deg lat</td>
<td>10330, 10360 COMP 3</td>
</tr>
<tr>
<td>CLH</td>
<td>$L/c_P$, latent heat to specific heat ratio $(= 580/.24)$</td>
<td>deg</td>
<td>7300 COMP 3</td>
</tr>
<tr>
<td>CLKSW</td>
<td>input identification</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>CLM</td>
<td>max(CL1 - CL1,0), cloud parameter (not used)</td>
<td>--</td>
<td>10130 COMP 3</td>
</tr>
<tr>
<td>CLT</td>
<td>0, CL2 or CL3, cloud parameter (not used)</td>
<td>--</td>
<td>10030 COMP 3</td>
</tr>
<tr>
<td>FORTRAN Symbol</td>
<td>Meaning</td>
<td>Units</td>
<td>Program Location</td>
</tr>
<tr>
<td>----------------</td>
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<td>------------------</td>
</tr>
<tr>
<td>CL1</td>
<td>(\min(-1.3 + 2.6 RH3, 1)), fraction of sky covered by type 1 (penetrative convective) cloud</td>
<td>--</td>
<td>9500 COMP 3</td>
</tr>
<tr>
<td>CL2</td>
<td>fraction of sky covered by type 2 (large-scale condensation) cloud (either 0 or 1)</td>
<td>--</td>
<td>9510 COMP 3</td>
</tr>
<tr>
<td>CL3</td>
<td>(\min(-1.3 + 2.6 RH3, 1)), fraction of sky covered by type 3 (low-level convective) cloud</td>
<td>--</td>
<td>9520 COMP 3</td>
</tr>
<tr>
<td>CNRX</td>
<td>0.01*CONS, unit conversion factor (not used)</td>
<td>deg/rad</td>
<td>7440 COMP 3</td>
</tr>
<tr>
<td>CNST</td>
<td>GRAV<em>30.48</em>HCST, unit conversion factor for surface elevation</td>
<td>--</td>
<td>16200, 16270 INIT 2</td>
</tr>
<tr>
<td>C&amp;E</td>
<td>(200 g/c_p (p_o - p_t)10^3), heat capacity of 1/2 unit column</td>
<td>deg (,\text{ly}^{-1})</td>
<td>7380 COMP 3</td>
</tr>
<tr>
<td>C&amp;E1</td>
<td>(1) (C&amp;E\times DTG/24\times 3600), unit conversion factor for heating terms</td>
<td>deg (,\text{day} , \text{ly}^{-1})</td>
<td>7390 COMP 3</td>
</tr>
<tr>
<td></td>
<td>(2) (\sigma_1 = \alpha_1/2T_1 + (c_p \theta_1/4T_1) \cdot [(p_3/p_o)^K - (p_1/p_o)^K]), level 1 geopotential parameter</td>
<td>(m^2\text{sec}^{-2}\text{deg}^{-1})</td>
<td>5360 COMP 2</td>
</tr>
<tr>
<td>C&amp;E2</td>
<td>(\sigma_3 = \alpha_3/2T_3 + (c_p \theta_3/4T_3) \cdot [(p_3/p_o)^K - (p_1/p_o)^K]), level 3 geopotential parameter</td>
<td>(m^2\text{sec}^{-2}\text{deg}^{-1})</td>
<td>5370 COMP 2</td>
</tr>
<tr>
<td>C&amp;E3</td>
<td>(\sigma_1 = \alpha_1/2T_1 - (c_p \theta_1/4T_1) \cdot [(p_3/p_o)^K - (p_1/p_o)^K]), level 3 geopotential parameter</td>
<td>(m^2\text{sec}^{-2}\text{deg}^{-1})</td>
<td>5400 COMP 2</td>
</tr>
<tr>
<td>C&amp;E4</td>
<td>(\sigma_3 = \alpha_3/2T_3 - (c_p \theta_3/4T_3) \cdot [(p_3/p_o)^K - (p_1/p_o)^K]), level 3 geopotential parameter</td>
<td>(m^2\text{sec}^{-2}\text{deg}^{-1})</td>
<td>5410 COMP 2</td>
</tr>
<tr>
<td>C&amp;LMR</td>
<td>((p_o - p_t)/(p_s - p_t)), column mass ratio (also redefined in 11530, COMP 3 with average (p_s - p_t))</td>
<td>--</td>
<td>8060 COMP 3</td>
</tr>
<tr>
<td>FORTRAN Symbol</td>
<td>Meaning</td>
<td>Units</td>
<td>Program Location</td>
</tr>
<tr>
<td>----------------</td>
<td>---------</td>
<td>-------</td>
<td>------------------</td>
</tr>
<tr>
<td>CØNRAĐ</td>
<td>180/PI, unit conversion factor</td>
<td>deg/radian</td>
<td>7430 COMP 3</td>
</tr>
<tr>
<td>CØNV(J,I)</td>
<td>CØNV, mass convergence at level 1</td>
<td>m² sec⁻¹ mb</td>
<td>4220 COMP 1</td>
</tr>
<tr>
<td></td>
<td>-(mm/2) V · rV, net mass convergence into cell surrounding r point (defined for poles in 4560, 4580 COMP 1)</td>
<td>m² sec⁻¹ mb</td>
<td>4180-4210 COMP 1</td>
</tr>
<tr>
<td>CØNVP</td>
<td>(h₄ - h₃)5Δτ(τ₄ - 1), penetrating convection parameter</td>
<td>--</td>
<td>9300 COMP 3</td>
</tr>
<tr>
<td>CØSD</td>
<td>cos ζ, cosine of solar declination</td>
<td>--</td>
<td>15540 SDET</td>
</tr>
<tr>
<td>CØSL(J)</td>
<td>cos φ_j, cosine of latitude</td>
<td>--</td>
<td>14960 INSDET</td>
</tr>
<tr>
<td>CØSZ</td>
<td>cos η, cosine of solar zenith angle</td>
<td>--</td>
<td>7800 COMP 3</td>
</tr>
<tr>
<td>CPART</td>
<td>0.5×1.3071×10⁻⁷, a constant (not used)</td>
<td>--</td>
<td>7690 COMP 3</td>
</tr>
<tr>
<td>CS</td>
<td>10²C_D, unit conversion factor</td>
<td>cm m⁻¹</td>
<td>7990 COMP 3</td>
</tr>
<tr>
<td>CSEN</td>
<td>C_r = 10²c_p C_D p₄ (</td>
<td>V_s</td>
<td>² + G) DAY, surface sensible heat flux parameter</td>
</tr>
<tr>
<td>CS4</td>
<td>10²c_p C_D DAY, surface sensible heat flux parameter</td>
<td>cm⁻¹ cal⁻¹ deg⁻¹ sec day⁻¹</td>
<td>8000 COMP 3</td>
</tr>
<tr>
<td>FORTRAN Symbol</td>
<td>Meaning</td>
<td>Units</td>
<td>Program Location</td>
</tr>
<tr>
<td>----------------</td>
<td>---------</td>
<td>-------</td>
<td>------------------</td>
</tr>
<tr>
<td>CTI</td>
<td>thermal conductivity of ice (= 0.005)</td>
<td>ly sec(^{-1}) cm deg(^{-1})</td>
<td>7320 COMP 3</td>
</tr>
<tr>
<td>CTID</td>
<td>thermal conductivity of ice (= 432)</td>
<td>ly day(^{-1}) cm deg(^{-1})</td>
<td>7330 COMP 3</td>
</tr>
<tr>
<td>CXXX(800)</td>
<td>data control parameter (not used)</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>C1</td>
<td>(\Delta T_1 = (h_3 - h_1^*) (2 + \gamma_1)^{-1} 5\Delta t, \text{ level 1})</td>
<td>deg</td>
<td>8870 COMP 3</td>
</tr>
<tr>
<td></td>
<td>temperature change due to mid-level convective latent heating</td>
<td></td>
<td></td>
</tr>
<tr>
<td>C1(800)</td>
<td>array identification</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>C3</td>
<td>(\Delta T_3 = (\Delta T_1) (1 + \gamma_1) (LR/2))</td>
<td>deg</td>
<td>8880 COMP 3</td>
</tr>
<tr>
<td></td>
<td>([h_3 - h_1^* + (1 + \gamma_1) (LR/2)]^{-1})</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>level-3 temperature change due to mid-level convective latent heating</td>
<td></td>
<td></td>
</tr>
<tr>
<td>DAY</td>
<td>hours in day (= 24), or sec in day (= 86,400)</td>
<td>hr, sec</td>
<td>13420, 13650 INPUT</td>
</tr>
<tr>
<td>DAYPYR</td>
<td>days in year (= 365)</td>
<td>day</td>
<td>13070 INPUT</td>
</tr>
<tr>
<td>DCLK</td>
<td>logical variable for day counter SDEDY</td>
<td>--</td>
<td>15050 INSDET</td>
</tr>
<tr>
<td>DEC</td>
<td>((23.5\pi/180) \cos[2\pi(DY-173.0)/365]), solar declination</td>
<td>radians</td>
<td>15510 SDET</td>
</tr>
<tr>
<td>DECMAX</td>
<td>(23.5\pi/180), maximum solar declination</td>
<td>radians</td>
<td>13080 INPUT</td>
</tr>
<tr>
<td>DEFF</td>
<td>(n = \Delta y), equatorial meridional mesh length</td>
<td>m</td>
<td>6880 AVRXX</td>
</tr>
<tr>
<td>SYMBOL</td>
<td>MEANING</td>
<td>UNITS</td>
<td>PROGRAM LOCATION</td>
</tr>
<tr>
<td>--------</td>
<td>------------------------------------------------------------------------</td>
<td>------------</td>
<td>------------------</td>
</tr>
<tr>
<td>DELTAP</td>
<td>correction for atmospheric mass loss (= PSF - ZMM)</td>
<td>mb</td>
<td>1430</td>
</tr>
<tr>
<td>DIRAD</td>
<td>$4\sigma T^3_{g'}$, long-wave radiation parameter at ground</td>
<td>$\text{ly day}^{-1}\text{deg}^{-1}$</td>
<td>10230</td>
</tr>
<tr>
<td>DIST</td>
<td>$(DY - 183.0)/365$, day of year parameter</td>
<td>--</td>
<td>15450</td>
</tr>
<tr>
<td>DLAT</td>
<td>$\Delta \Psi$, north/south grid-point separation (= 4 deg) (changed to radians in 13590, INPUT)</td>
<td>deg</td>
<td>13360</td>
</tr>
<tr>
<td>DLIC</td>
<td>input card identification (not used)</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>DLØN</td>
<td>$\Delta \lambda = 2\pi/72$, east/west grid-point separation (= 5 deg)</td>
<td>radians</td>
<td>13610</td>
</tr>
<tr>
<td>DPLK</td>
<td>$p^K_3 - p^K_1$</td>
<td>$(\text{mb})^K$</td>
<td>8160</td>
</tr>
<tr>
<td>DQQ</td>
<td>$B g T^{-2} = \gamma c/L$, approximate change of $q_s$</td>
<td>$\text{deg}^{-1}$</td>
<td>9040</td>
</tr>
<tr>
<td></td>
<td>$e^s_{g'} g' g' g' p \frac{dq_s(T_g')}{dT}$</td>
<td></td>
<td>COMP 3</td>
</tr>
<tr>
<td>DRAT</td>
<td>$n/m$, grid scale ratio</td>
<td>--</td>
<td>6900</td>
</tr>
<tr>
<td>DRAW</td>
<td>$C_D(</td>
<td>\mathbf{v}_s</td>
<td>+ c)$, surface wind drag parameter</td>
</tr>
<tr>
<td>DR4</td>
<td>$4\sigma T^3_{g'} (T_{g'} - T_g) = R_4 - \tilde{R}_4 = C_4$, surface long-wave radiation parameter</td>
<td>$\text{ly day}^{-1}$</td>
<td>11160</td>
</tr>
<tr>
<td>DSIG</td>
<td>$\sigma_3 - \sigma_1$, model sigma increment (= 1/2)</td>
<td>--</td>
<td>7250</td>
</tr>
<tr>
<td>FORTRAN Symbol</td>
<td>Meaning</td>
<td>Units</td>
<td>Program Location</td>
</tr>
<tr>
<td>---------------</td>
<td>--------------------------------------------------------------------------</td>
<td>-------</td>
<td>-----------------</td>
</tr>
<tr>
<td>DT</td>
<td>( \Delta t ) in sec (( = 360 ))</td>
<td>sec</td>
<td>13560 INPUT</td>
</tr>
<tr>
<td>DTC3</td>
<td>( 5\Delta t ), time interval between heating steps in COMP 3 (( = 1800 ))</td>
<td>sec</td>
<td>7280 COMP 3</td>
</tr>
<tr>
<td>DTM</td>
<td>( \Delta t ) in min (( = 6 ))</td>
<td>min</td>
<td>13340 INPUT</td>
</tr>
<tr>
<td>DXP(J)</td>
<td>( m = a\Delta \lambda \cos \varphi_j ), east/west distance between ( \pi ) (or u*) points</td>
<td>m</td>
<td>14570 MAGFAC</td>
</tr>
<tr>
<td>DXU(J)</td>
<td>( m = a\Delta \lambda (\cos \varphi_j + \cos \varphi_{j-1})/2 ), east/west distance between u,v (or v*) points</td>
<td>m</td>
<td>14610 MAGFAC</td>
</tr>
<tr>
<td>DXV(J,I)</td>
<td>zonal distance between ( \pi ) points (( = DXP ))</td>
<td>m</td>
<td>--</td>
</tr>
<tr>
<td>DXYP(J)</td>
<td>( m ), area of grid cell around ( \pi ) point (defined for polar points in 14680, 14690 MAGFAC)</td>
<td>m²</td>
<td>14670 MAGFAC</td>
</tr>
<tr>
<td>DY</td>
<td>( t ), day counter (( = SDEDY ))</td>
<td>day</td>
<td>14530 SDET</td>
</tr>
<tr>
<td>DYP(J)</td>
<td>( n = (\varphi_{j+1} - \varphi_{j-1})a/2 ), north/south distance between u,v (or v*) grid points (defined for polar points in 14640, 14650 MAGFAC)</td>
<td>m</td>
<td>14630 MAGFAC</td>
</tr>
<tr>
<td>DUY(J)</td>
<td>( n = a(\varphi_j - \varphi_{j-1}) ), north/south distance between ( \pi ) (or u*) grid points</td>
<td>m</td>
<td>14540 MAGFAC</td>
</tr>
<tr>
<td>DYV(J,I)</td>
<td>meridional distance between u,v points (( = DYP ))</td>
<td>m</td>
<td>--</td>
</tr>
<tr>
<td>ECCN</td>
<td>orbital eccentricity (( = 0.0178 ))</td>
<td>--</td>
<td>13120 INPUT</td>
</tr>
<tr>
<td>FORTRAN Symbol</td>
<td>Meaning</td>
<td>Units</td>
<td>Program Location</td>
</tr>
<tr>
<td>----------------</td>
<td>---------</td>
<td>-------</td>
<td>------------------</td>
</tr>
<tr>
<td><strong>ED</strong></td>
<td>constant used in air/ground interaction (= 10.0)</td>
<td>m</td>
<td>13400 INPUT</td>
</tr>
<tr>
<td><strong>EDR</strong></td>
<td>$\left(\left</td>
<td>\vec{V}_s\right</td>
<td>^n/2000\right)\left(\left</td>
</tr>
<tr>
<td><strong>EDV</strong></td>
<td>$\left</td>
<td>\vec{V}_s\right</td>
<td>^n/2000$, air/ground interaction parameter</td>
</tr>
<tr>
<td><strong>EFVC1</strong></td>
<td>$u_{c_1}^*$, effective water vapor for type 1 clouds (= 65.3)</td>
<td>g cm$^{-2}$</td>
<td>7660 COMP 3</td>
</tr>
<tr>
<td><strong>EFVC2</strong></td>
<td>$u_{c_2}^*$, effective water vapor for type 2 clouds (= 65.3)</td>
<td>g cm$^{-2}$</td>
<td>7670 COMP 3</td>
</tr>
<tr>
<td><strong>EFVC3</strong></td>
<td>$u_{c_3}^*$, effective water vapor for type 3 clouds (= 7.6)</td>
<td>g cm$^{-2}$</td>
<td>7680 COMP 3</td>
</tr>
<tr>
<td><strong>EFVT</strong></td>
<td>$u_T^* = p_3q_3g^{-1}(2 + K)^{-1}\left(p_4/p_3\right)^{2+K} - \left(p_4/p_3\right)^{2+K}$, effective water vapor in air column below tropopause</td>
<td>g cm$^{-2}$</td>
<td>9840 COMP 3</td>
</tr>
<tr>
<td><strong>EFVO</strong></td>
<td>$u_\infty^* = p_3q_3g^{-1}(2 + K)^{-1}\left(p_4/p_3\right)^{2+K} - \left(p_4/p_3\right)^{2+K}$ $+ 2.526 \times 10^{-5}$, effective water vapor in entire atmospheric column</td>
<td>g cm$^{-2}$</td>
<td>9850 COMP 3</td>
</tr>
<tr>
<td><strong>EFV1</strong></td>
<td>$u_1^* = p_3q_3g^{-1}(2 + K)^{-1}\left(p_4/p_3\right)^{2+K} - \left(p_4/p_3\right)^{2+K}$, effective water vapor in air column below level 1</td>
<td>g cm$^{-2}$</td>
<td>9830 COMP 3</td>
</tr>
<tr>
<td><strong>EFV2</strong></td>
<td>$u_2^* = p_3q_3g^{-1}(2 + K)^{-1}\left(p_4/p_3\right)^{2+K} - \left(p_2/p_3\right)^{2+K}$, effective water vapor in air column below level 2</td>
<td>g cm$^{-2}$</td>
<td>9820 COMP 3</td>
</tr>
<tr>
<td>FORTRAN Symbol</td>
<td>Meaning</td>
<td>Units</td>
<td>Program Location</td>
</tr>
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<td>----------------</td>
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<td>------------------</td>
</tr>
<tr>
<td>EFV3</td>
<td>$u^*_3 = \frac{2}{p_3} q_3 g^{-1} (2 + K)^{-1} [(p_4/p_3)^{2+K} - 1]$, effective water vapor in air column below level 3</td>
<td>g cm$^{-2}$</td>
<td>9810 COMP 3</td>
</tr>
<tr>
<td>EG</td>
<td>$e_s(T_g)$, saturation vapor pressure at ground temperature</td>
<td>cb</td>
<td>9020 COMP 3</td>
</tr>
<tr>
<td>EQNX</td>
<td>equinox, 22 June (= 173.0)</td>
<td>day</td>
<td>13100 INPUT</td>
</tr>
<tr>
<td>ES1</td>
<td>$e_s(T_1)$, saturation vapor pressure at level 1</td>
<td>cb</td>
<td>8350 COMP 3</td>
</tr>
<tr>
<td>ES3</td>
<td>$e_s(T_3)$, saturation vapor pressure at level 3</td>
<td>cb</td>
<td>8360 COMP 3</td>
</tr>
<tr>
<td>ETA</td>
<td>entrainment factor (= 1)</td>
<td>--</td>
<td>9250 COMP 3</td>
</tr>
<tr>
<td>EVENT</td>
<td>program control parameter</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>EVNTH</td>
<td>data control parameter (not used)</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>EX</td>
<td>(1) $h_3 - h^*_1 = HH3 - HH1S$</td>
<td>deg</td>
<td>8850 COMP 3</td>
</tr>
<tr>
<td></td>
<td>$= (L/c_p) [q_3 - q_s(T_1)] - LRc_p/L$, stability parameter for middle-level convection</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>(2) $h_4 - h^*_3 = HH4 - HH3S$, stability parameter for low-level convection</td>
<td>deg</td>
<td>9210 COMP 3</td>
</tr>
<tr>
<td>EXP1</td>
<td>empirical coefficient = 4/3</td>
<td>--</td>
<td>14780 MAGFAC</td>
</tr>
<tr>
<td>E4</td>
<td>$E = \rho_4 C_p (</td>
<td>\nabla_s</td>
<td>^n + G)(q_g - q_4)$, surface evaporation rate</td>
</tr>
<tr>
<td>FORTRAN Symbol</td>
<td>Meaning</td>
<td>Units</td>
<td>Program Location</td>
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<td>---------------</td>
<td>-------------------------------------------------------------------------</td>
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<tr>
<td>F(J)</td>
<td>$f = -2\Omega \partial (\cos \varphi_j) / \partial \varphi$, Coriolis parameter (defined for poles in 14740-14750 MAGFAC)</td>
<td>sec$^{-1}$</td>
<td>14710-14730 MAGFAC</td>
</tr>
<tr>
<td>FAH</td>
<td>logical variable for temperature input</td>
<td>--</td>
<td>--</td>
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<tr>
<td>FAREN</td>
<td>identification for sea-surface temperature</td>
<td>--</td>
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<tr>
<td>FD(J,I)</td>
<td>(1) $\Pi = m \Pi$, area-weighted pressure (about $\pi$ point)</td>
<td>m$^2$mb</td>
<td>2560</td>
</tr>
<tr>
<td></td>
<td>(2) $v_s^2$, square of surface wind speed</td>
<td>m$^2$sec$^{-2}$</td>
<td>7550</td>
</tr>
<tr>
<td></td>
<td>(3) $F = m \Pi - u \partial m / \partial y$, weighted Coriolis force</td>
<td>m$^2$sec$^{-1}$</td>
<td>5070-5120</td>
</tr>
<tr>
<td></td>
<td>(at $\pi$-points)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>FDU</td>
<td>$u^\Pi = \text{average } m \Pi \text{ at } u,v \text{ points} \text{ (defined for polar caps in 2650-2660 COMP 1)}$</td>
<td>m$^2$mb</td>
<td>2640</td>
</tr>
<tr>
<td>FEET</td>
<td>identification for topographic height</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>FIM</td>
<td>IM, maximum number of longitudinal grid points (= 72)</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>FIM1</td>
<td>I-1=i-1, longitudinal grid-point variable</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>FJ</td>
<td>J=j, longitudinal grid-point index</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>FJE</td>
<td>J index for equator (= 23$^2$)</td>
<td>--</td>
<td>14460 MAGFAC</td>
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<tr>
<td>FJM</td>
<td>JM, maximum number of latitudinal grid points (= 46)</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>FK</td>
<td>$\rho_c c_D g (</td>
<td>\vec{v}_s</td>
<td>^\Pi + G)(\sigma_3 - \sigma_1)^{-1}(p_o - p_T)^{-1}$, surface friction parameter</td>
</tr>
<tr>
<td>FORTRAN Symbol</td>
<td>Meaning</td>
<td>Units</td>
<td>Program Location</td>
</tr>
<tr>
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<tr>
<td>FK1</td>
<td>$gC_D(a_3 - a_1)^{-1}(p_o - p_T)^{-1}$, surface friction parameter</td>
<td>$\text{cm}^2 \text{g}^{-1}$</td>
<td>8010 COMP 3</td>
</tr>
<tr>
<td>FL</td>
<td>2MOD(K,2)+1, indicator for u,v data at levels 1 and 3</td>
<td>--</td>
<td>12350 COMP 4</td>
</tr>
<tr>
<td>FLUX</td>
<td>(1) $u \Delta t$, $v \Delta t$, mass flux parameters</td>
<td>$\text{m}^2 \text{mb}$</td>
<td>3310, 3520 COMP 1</td>
</tr>
<tr>
<td></td>
<td>(2) $-u \Delta t/4$, $-v \Delta t/4$, mass flux parameters at level 1</td>
<td>$\text{m}^2 \text{mb}$</td>
<td>3390, 3610 COMP 1</td>
</tr>
<tr>
<td></td>
<td>(3) $5u \Delta t/4$, $5v \Delta t/4$, mass flux parameters at level 3</td>
<td>$\text{m}^2 \text{mb}$</td>
<td>3610, 3620 COMP 1</td>
</tr>
<tr>
<td></td>
<td>(4) various momentum flux parameters</td>
<td>$\text{m}^2 \text{mb}$</td>
<td>3830, 3910, 3980, 4050 COMP 1</td>
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<tr>
<td>FLUXQ</td>
<td>FLUX*Q3M (and other definitions), moisture flux parameters</td>
<td>$\text{m}^2 \text{mb}$</td>
<td>3480, 3660 COMP 1</td>
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<tr>
<td>FLUXT</td>
<td>FLUX*(T(J,I,L)+T(J,IP1,L)) (and other definitions), temperature advection parameters</td>
<td>$\text{m}^2 \text{mb deg}$</td>
<td>3320-3580 COMP 1</td>
</tr>
<tr>
<td>FLUXU</td>
<td>FLUX*(U(J,I,L)+U(J,IM1,L)) (and other definitions), u-momentum advection parameters</td>
<td>$\text{m}^2 \text{sec}^{-1} \text{mb}$</td>
<td>3840-4060 COMP 1</td>
</tr>
<tr>
<td>FLUXV</td>
<td>FLUX*(V(J,I,L)+V(J,IM1,L)) (and other definitions), v-momentum advection parameters</td>
<td>$\text{m}^2 \text{sec}^{-1} \text{mb}$</td>
<td>3870-4090 COMP 1</td>
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<tr>
<td>FM</td>
<td>FMX*10^-5, a constant</td>
<td>--</td>
<td>13610 INPUT</td>
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<tr>
<td>FMX</td>
<td>constant (≈ 0.2)</td>
<td>--</td>
<td>13400 INPUT</td>
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<tr>
<td>FNM</td>
<td>NM, the integer part of DRAT</td>
<td>--</td>
<td>6940 AVRX</td>
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<tr>
<td>FORTRAN Symbol</td>
<td>Meaning</td>
<td>Units</td>
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<td>------------------</td>
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<tr>
<td>FSDEDY</td>
<td>t, day of year (= SDEDY)</td>
<td>day</td>
<td>7450</td>
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<td></td>
<td>COMP 3</td>
</tr>
<tr>
<td>FS2</td>
<td>$S_2^A + CL \alpha_{c_1} (S_{CT1}^A)^{''}$, total flux of $S_o^A$ at level 2</td>
<td>ly day$^{-1}$</td>
<td>10920</td>
</tr>
<tr>
<td></td>
<td>(plus reflected flux from type 1 cloud top)</td>
<td></td>
<td>COMP 3</td>
</tr>
<tr>
<td>FS2C</td>
<td>(1) AS2T*CLT, clear sky flux at level 2, times type 2 or 3 cloudiness</td>
<td>ly day$^{-1}$</td>
<td>10620, 10710</td>
</tr>
<tr>
<td></td>
<td>(2) CL $\left[ (S_2^A)^{''} + \alpha_{c_1} (S_{CT1}^A)^{''} \right]$</td>
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<td>COMP 3</td>
</tr>
<tr>
<td></td>
<td>flux of $S_o^A$ at level 2 (plus flux reflected from cloud top) times type 1 cloudiness</td>
<td>ly day$^{-1}$</td>
<td>10850</td>
</tr>
<tr>
<td>FS20</td>
<td>$(S_2^A)^{'}$, flux of $S_o^A$ at level 2 for clear sky</td>
<td>ly day$^{-1}$</td>
<td>10550</td>
</tr>
<tr>
<td>FS4</td>
<td>$S_4^A + CL \alpha_{c_1} (S_{CT1}^A)^{''}$, total flux of $S_o^A$ at level 4</td>
<td>ly day$^{-1}$</td>
<td>10930</td>
</tr>
<tr>
<td></td>
<td>(plus reflected flux from cloud top)</td>
<td></td>
<td>COMP 3</td>
</tr>
<tr>
<td>FS4C</td>
<td>CL $\left[ (S_4^A)^{''} + \alpha_{c_1} (S_{CT1}^A)^{''} \right]$, flux of $S_o^A$ reaching level 4 (plus flux reflected from cloud top)</td>
<td>ly day$^{-1}$</td>
<td>10640, 10740, 10870</td>
</tr>
<tr>
<td></td>
<td></td>
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<td>COMP 3</td>
</tr>
<tr>
<td>FS40</td>
<td>$(S_4^A)^{'}$, flux of $S_o^A$ at level 4 for clear sky</td>
<td>ly day$^{-1}$</td>
<td>10560</td>
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<td></td>
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<td>COMP 3</td>
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<tr>
<td>FXG$\theta$</td>
<td>(1) TEXP$\theta$/2, time-step factor for advection</td>
<td>sec</td>
<td>3270, 4710</td>
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<td></td>
<td>(other definitions in 3770, 5030 COMP 1)</td>
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<td>COMP 1</td>
</tr>
<tr>
<td></td>
<td>(2) DT/4, time-step factor for pressure force</td>
<td>sec</td>
<td>5470</td>
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<td>COMP 2</td>
</tr>
<tr>
<td></td>
<td>(3) $\Delta t/8c_p$, time-step factor in thermodynamic energy equation</td>
<td>m$^{-2}$sec$^{-3}$deg</td>
<td>6100</td>
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<td>FXO1</td>
<td>(1) TEKO/24, time-step factor for advection</td>
<td>sec</td>
<td>3780 COMP 1</td>
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<tr>
<td></td>
<td>(2) DT/2, time-step factor for pressure force</td>
<td>sec</td>
<td>5480 COMP 2</td>
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<tr>
<td></td>
<td>(3) AT/4c, time-step factor in thermodynamic energy equation</td>
<td>m^-2 sec^-3 deg</td>
<td>6110 COMP 2</td>
</tr>
<tr>
<td>F4</td>
<td>( T = C_T(T_g - T_4) ), surface sensible heat flux</td>
<td>ly day^-1</td>
<td>11250 COMP 3</td>
</tr>
<tr>
<td>GAMG</td>
<td>( \gamma_g = (L/c_p) B_g a_g (T_g) T_g^{-2} ), latent heat parameter</td>
<td>--</td>
<td>9080 COMP 3</td>
</tr>
<tr>
<td>GAM1</td>
<td>( \gamma_1 = (L/c_p) B_g a_g (T_1) T_1^{-2} ), latent heat parameter</td>
<td>--</td>
<td>8420 COMP 3</td>
</tr>
<tr>
<td>GAM3</td>
<td>( \gamma_3 = (L/c_p) B_g a_g (T_3) T_3^{-2} ), latent heat parameter</td>
<td>--</td>
<td>8430 COMP 3</td>
</tr>
<tr>
<td>GRAV</td>
<td>( g ), acceleration of gravity ( (= 9.81) )</td>
<td>m sec^-2</td>
<td>13420 INPUT</td>
</tr>
<tr>
<td>GT(J,I)</td>
<td>( T_g ), ground temperature ( (= T_{gr} ) after radiation correction</td>
<td>deg</td>
<td>11200 COMP 3</td>
</tr>
<tr>
<td>GW(J,I)</td>
<td>GW = WET, ground wetness ( (0 \leq GW \leq 1) )</td>
<td>--</td>
<td>11360 COMP 3</td>
</tr>
<tr>
<td>GWM</td>
<td>ground water mass ( (= 30) )</td>
<td>g cm^-2</td>
<td>7270 COMP 3</td>
</tr>
<tr>
<td>H(J,I,1)</td>
<td>(1) ( (H_1 + H_3)/2 ), average heating</td>
<td>deg</td>
<td>11450 COMP 3</td>
</tr>
<tr>
<td></td>
<td>(2) ( (H_1 + H_3)mn/2 ), area-weighted average heating</td>
<td>deg m^2</td>
<td>11870 COMP 3</td>
</tr>
<tr>
<td></td>
<td>[Note: H(J,I,2 not used.]</td>
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<table>
<thead>
<tr>
<th>FORTRAN Symbol</th>
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<th>Units</th>
<th>Program Location</th>
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<tbody>
<tr>
<td>HAC6S</td>
<td>$\cos d \cos (t + \lambda)$, solar zenith angle parameter</td>
<td>--</td>
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<td>COMP 3</td>
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<tr>
<td>H CST</td>
<td>unit conversion factor for surface elevation</td>
<td>--</td>
<td>16200, 16260</td>
</tr>
<tr>
<td></td>
<td>(* 1 if height in 10^2 ft)</td>
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<td>INIT 2</td>
</tr>
<tr>
<td>HEIGHT(J)</td>
<td>surface height data</td>
<td>ft, dm</td>
<td>16310</td>
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<td>INIT 2</td>
</tr>
<tr>
<td>HHG</td>
<td>$T_g + (L/c_p)q$, WET, ground equivalent temperature $g$</td>
<td>deg</td>
<td>9050</td>
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<td>COMP 3</td>
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<tr>
<td>HH1S</td>
<td>$h_1^* = \theta_3(p_s/p_o)^{K_3} + (\theta_1 - \theta_3)(p_2/p_o)^{K_2} + (L/c_p)q_s(T_1)$, level 1 stability parameter</td>
<td>deg</td>
<td>8790</td>
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<td>COMP 3</td>
</tr>
<tr>
<td>HH3</td>
<td>$h_3 = \theta_3(p_s/p_o)^{K_3} + (L/c_p)q_3$, level 3 stability parameter</td>
<td>deg</td>
<td>8770</td>
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<td>COMP 3</td>
</tr>
<tr>
<td>HH3S</td>
<td>$h_3^* = \theta_3(p_s/p_o)^{K_3} + (L/c_p)q_s(T_3)$, level 3 stability parameter</td>
<td>deg</td>
<td>8780</td>
</tr>
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<td>COMP 3</td>
</tr>
<tr>
<td>HH4</td>
<td>(1) $\tilde{h}_4$, low-level temperature parameter</td>
<td>deg</td>
<td>9070</td>
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<td>COMP 3</td>
</tr>
<tr>
<td></td>
<td>(2) $h_4 = T_4 + (L/c_p)q_4$, level 4 stability parameter</td>
<td>deg</td>
<td>9230</td>
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<td>COMP 3</td>
</tr>
<tr>
<td></td>
<td>(3) $h_3^*$, level 3 stability parameter</td>
<td>deg</td>
<td>9252</td>
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<td>COMP 3</td>
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<tr>
<td>HH4P</td>
<td>$h_4 = HH4$, level 4 stability parameter</td>
<td>deg</td>
<td>9220</td>
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<td>COMP 3</td>
</tr>
<tr>
<td>HICE</td>
<td>effective ice thickness (= 300)</td>
<td>cm</td>
<td>7340</td>
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<td>COMP 3</td>
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<td>Units</td>
<td>Program Location</td>
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<td>----------------</td>
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<tr>
<td>HRGAS</td>
<td>R/2, one-half the dry air gas constant</td>
<td>$\frac{2}{m^2 \cdot \text{sec} \cdot \text{deg}}$</td>
<td>4990 COMP 2</td>
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<td>HSCL</td>
<td>unit indicator for surface height</td>
<td>--</td>
<td>16240 INIT 2</td>
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<tr>
<td>H1</td>
<td>$H_1 = (A_1 + R_2 - R_0)(2g/\pi c_p)5\Delta t + (\Delta T_1)<em>{CM} + (\Delta T_1)</em>{CP}$, total heating at level 1 (over 5$\Delta t$ interval)</td>
<td>deg</td>
<td>11430 COMP 3</td>
</tr>
<tr>
<td>H3</td>
<td>$H_3 = (A_3 + R_4 - R_2 + \Gamma)(2g/\pi c_p)5\Delta t + (\Delta T_3)<em>{CM}$ + $(\Delta T_3)</em>{CP} + (\Delta T_3)_{LS}$, total heating at level 3 (over 5$\Delta t$ interval)</td>
<td>deg</td>
<td>11440 COMP 3</td>
</tr>
<tr>
<td>I</td>
<td>i, longitude grid-point index (I = 1 is $\lambda = 0$ at 180 deg W)</td>
<td>--</td>
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<tr>
<td>IC(800)</td>
<td>integer array (= C)</td>
<td>--</td>
<td>--</td>
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<tr>
<td>ICE</td>
<td>ice-cover location indicator</td>
<td>--</td>
<td>7860 COMP 3</td>
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<tr>
<td>ICI(800)</td>
<td>array identification (alternate to C)</td>
<td>--</td>
<td>--</td>
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<tr>
<td>ICLUD</td>
<td>cloud parameter (= 1 for clear, = 2 for partly cloudy, = 3 for overcast)</td>
<td>--</td>
<td>9430, 9710, 9720 COMP 3</td>
</tr>
<tr>
<td>ID</td>
<td>identification on input data card</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>IDAY</td>
<td>day number (= TAU/RỘTEPER)</td>
<td>--</td>
<td>0500 CONTROL</td>
</tr>
<tr>
<td>IH</td>
<td>IM/2 + 1, longitudinal grid-point parameter (= 37)</td>
<td>--</td>
<td>--</td>
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<td>FORTRAN Program</td>
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<td>Program Location</td>
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<td>IHALP(2)</td>
<td>two half words that form IWD</td>
<td>--</td>
<td>--</td>
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<tr>
<td>IL</td>
<td>(1) card identifier for topography</td>
<td>--</td>
<td>16320 INIT 2</td>
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<tr>
<td></td>
<td>(2) left half word in packed data</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
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<td>(3) index counter</td>
<td>--</td>
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<tr>
<td>ILEV</td>
<td>level identification parameter (not used)</td>
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<tr>
<td>ILH</td>
<td>entry point for left half word in IPKWD</td>
<td>--</td>
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<tr>
<td>IL1, IL2, IL3</td>
<td>temporary identification of topography cards</td>
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<td>IM</td>
<td>maximum number of east/west grid points (= 72)</td>
<td>--</td>
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<tr>
<td>IMM2</td>
<td>IM - 2, longitudinal grid-point index</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>IM1</td>
<td>I - 1, longitudinal grid-point index</td>
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<td>identification for card reader input</td>
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<td>IPKWD</td>
<td>pack data word (argument for ILH, IRH)</td>
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<td>IP1</td>
<td>I + 1, longitudinal grid-point index</td>
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<td>right half word in packed data</td>
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<td>entry point for right half word in IPKWD</td>
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<td>control parameter (not used)</td>
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<td>word containing two half words</td>
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<td>j, latitudinal grid-point index</td>
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<td>variable for day of month determination</td>
<td>--</td>
<td>15350</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>SDET</td>
</tr>
<tr>
<td>JE</td>
<td>JM/2 + 1, latitudinal grid-point index (= 24)</td>
<td>--</td>
<td>6870</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>AVRX</td>
</tr>
<tr>
<td>JL</td>
<td>index counter</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>JM</td>
<td>maximum number of north/south grid points (= 46)</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>JMM1</td>
<td>JM - 1, latitudinal grid-point index</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>JMM2</td>
<td>JM - 2, latitudinal grid-point index</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>JTP</td>
<td>variable input/output identification (not used)</td>
<td>--</td>
<td>--</td>
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<tr>
<td>JUMP</td>
<td>control parameter (not used)</td>
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<tr>
<td>K</td>
<td>level or variable indicator (in friction calculation</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td></td>
<td>K = 1 or 2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>KAPA</td>
<td>$\kappa = R/c_p$, thermodynamic ratio (= 0.286)</td>
<td>--</td>
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</tr>
<tr>
<td>KEYS(J)</td>
<td>logical control parameters (not used)</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>KKK</td>
<td>packed data location in COMP 3</td>
<td>--</td>
<td>11690</td>
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<td>COMP 3</td>
</tr>
<tr>
<td>KNT</td>
<td>variable input/output identification (not used)</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>KSET</td>
<td>array for KEY control characters (not used)</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>KTP</td>
<td>variable identification for history tape</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>FORTRAN Symbol</td>
<td>Meaning</td>
<td>Units</td>
<td>Program Location</td>
</tr>
<tr>
<td>----------------</td>
<td>-------------------------------------------------------------------------</td>
<td>-------</td>
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</tr>
<tr>
<td>K1</td>
<td>$2K$, identifier for $u_1$ or $v_1$</td>
<td>--</td>
<td>11550 COMP 3</td>
</tr>
<tr>
<td>K2</td>
<td>$2K + 1$, identifier for $u_3$ or $v_3$</td>
<td>--</td>
<td>11560 COMP 3</td>
</tr>
<tr>
<td>L</td>
<td>level indicator ($L = 1$ for level 1, $L = 2$ for level 3)</td>
<td>--</td>
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</tr>
<tr>
<td>LAND</td>
<td>land location indicator</td>
<td>--</td>
<td>7870 COMP 3</td>
</tr>
<tr>
<td>LAT(J)</td>
<td>$\varphi_j$, latitude of grid point</td>
<td>radians</td>
<td>14490 MAGFAC</td>
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<tr>
<td>LDAY</td>
<td>$t$, day numbering origin ($= 0$)</td>
<td>day</td>
<td>15010 INSDET</td>
</tr>
<tr>
<td>LTP</td>
<td>variable input/output identification (not used)</td>
<td>--</td>
<td>--</td>
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<tr>
<td>LYR</td>
<td>year (if reset from input)</td>
<td>year</td>
<td>15040 INSDET</td>
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<tr>
<td>M</td>
<td>logical KEY function argument</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>MARK</td>
<td>MARK 1, control number in topography deck ($= 0$ if deck not read)</td>
<td>--</td>
<td>13680 INPUT</td>
</tr>
<tr>
<td>MAPGEN</td>
<td>map generation identification</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>MAPLIST (3,40)</td>
<td>map list identification (not used)</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>MAXDAY</td>
<td>$\text{DAYPYR} \times 10^{-2}$, maximum allowed day in year ($= 365.01$)</td>
<td>day</td>
<td>15280 SDT</td>
</tr>
<tr>
<td>FORTRAN Symbol</td>
<td>Meaning</td>
<td>Units</td>
<td>Program Location</td>
</tr>
<tr>
<td>---------------</td>
<td>-------------------------------------------------------------------------</td>
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<tr>
<td>METER</td>
<td>identification for topographic height</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>MNTHDY</td>
<td>identification for day of month</td>
<td>day</td>
<td>--</td>
</tr>
<tr>
<td>MNTH(12)</td>
<td>days in each month (beginning with January)</td>
<td>day</td>
<td>--</td>
</tr>
<tr>
<td>MRCH</td>
<td>identifier for steps in time integration (= 1, 2, 3, or 4)</td>
<td>--</td>
<td>1920, 2120-2140</td>
</tr>
<tr>
<td></td>
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<td></td>
<td>STEP</td>
</tr>
<tr>
<td>MTP</td>
<td>variable identification for printed output</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>N</td>
<td>logical variable in KEYS array</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>NCYCLE</td>
<td>control parameter for MRCH (= 5)</td>
<td>--</td>
<td>13340 INPUT</td>
</tr>
<tr>
<td>NC3</td>
<td>number of time steps between uses of subroutine COMP 3 (= 5)</td>
<td>--</td>
<td>13340 INPUT</td>
</tr>
<tr>
<td>NM</td>
<td>integer part of DRAT</td>
<td>--</td>
<td>6930 AVRX</td>
</tr>
<tr>
<td>NOUT</td>
<td>map generation output parameter</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>NFOL</td>
<td>zonal mean at north pole</td>
<td>(various)</td>
<td>--</td>
</tr>
<tr>
<td>NS</td>
<td>control parameter for time integration</td>
<td>--</td>
<td>2110 STEP</td>
</tr>
<tr>
<td>NSTEP</td>
<td>control parameter for time integration</td>
<td>--</td>
<td>0280 CONTROL</td>
</tr>
<tr>
<td>OCEAN</td>
<td>ocean location indicator</td>
<td>--</td>
<td>7850 COMP 3</td>
</tr>
<tr>
<td>OFF</td>
<td>solar declination control parameter</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>FORTRAN Symbol</td>
<td>Meaning</td>
<td>Units</td>
<td>Program Location</td>
</tr>
<tr>
<td>----------------</td>
<td>---------</td>
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<td>-----------------</td>
</tr>
<tr>
<td>P(J,I)</td>
<td>$\pi = p_s - p_T$, surface pressure parameter</td>
<td>mb</td>
<td>--</td>
</tr>
<tr>
<td>PASS2</td>
<td>data control parameter (not used)</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>PB1</td>
<td>(1) CONV(1,I), parameter for south pole mass convergence</td>
<td>$m^2 \text{ sec}^{-1} \text{ mb}$</td>
<td>4320-4410 COMP 1</td>
</tr>
<tr>
<td></td>
<td>(2) QT(1,I,L), parameter for south pole calculations</td>
<td>(various)</td>
<td>6450-6500 COMP 2</td>
</tr>
<tr>
<td>PB2</td>
<td>(1) CONV(JM,I), parameter for north pole mass convergence</td>
<td>$m^2 \text{ sec}^{-1} \text{ mb}$</td>
<td>4330-4420 COMP 1</td>
</tr>
<tr>
<td></td>
<td>(2) QT(JM,I,L), parameter for north pole calculations</td>
<td>(various)</td>
<td>6460-6510 COMP 2</td>
</tr>
<tr>
<td>PB3</td>
<td>PV(1,I), parameter for south pole mass convergence</td>
<td>$m^2 \text{ sec}^{-1} \text{ mb}$</td>
<td>4340-4430 COMP 1</td>
</tr>
<tr>
<td>PB4</td>
<td>PV(JM,I), parameter for north pole mass convergence</td>
<td>$m^2 \text{ sec}^{-1} \text{ mb}$</td>
<td>4350-4440 COMP 1</td>
</tr>
<tr>
<td>PC1</td>
<td>$(\Delta T_1)_{CP} = (h_4 - h_3)^{\tau_1} 5\Delta t / \tau_T$, level 1 temperature change due to penetrating convection</td>
<td>deg</td>
<td>9310 COMP 3</td>
</tr>
<tr>
<td>PC3</td>
<td>$(\Delta T_3)_{CP} = (h_4 - h_3)^{\tau_2} 5\Delta t / \tau_T$, level 3 temperature change due to penetrating convection</td>
<td>deg</td>
<td>9320 COMP 3</td>
</tr>
<tr>
<td>PHI(J,I)</td>
<td>(1) $\phi_1$ or $\phi_3$, level 1 or 3 geopotential</td>
<td>$m^2 \text{ sec}^{-2}$</td>
<td>5380, 5420 COMP 2</td>
</tr>
<tr>
<td></td>
<td>(2) $\sigma_1 \pi a_1$ or $\sigma_3 \pi a_3$, pressure gradient parameter</td>
<td>$m^2 \text{ sec}^{-2}$</td>
<td>5760 COMP 2</td>
</tr>
<tr>
<td>PHI4</td>
<td>$\phi_4 = \text{VPHI4(J,I)}$, surface geopotential (= 0 if ocean)</td>
<td>$m^2 \text{ sec}^{-2}$</td>
<td>5300 COMP 2</td>
</tr>
<tr>
<td>FORTRAN Symbol</td>
<td>Meaning</td>
<td>Units</td>
<td>Program Location</td>
</tr>
<tr>
<td>----------------</td>
<td>---------</td>
<td>-------</td>
<td>-----------------</td>
</tr>
<tr>
<td>PI</td>
<td>constant π = 3.1415926</td>
<td>--</td>
<td>13040 INPUT</td>
</tr>
<tr>
<td>PIT(J,I)</td>
<td>-(mn/2)[\nabla \cdot (\vec{V}_1 + \vec{V}_3)] = \text{CONV}(J,I) + \text{PV}(J,I), net column mass convergence (= π tendency)</td>
<td>(m^2 \text{sec}^{-1} \text{mb})</td>
<td>4520 COMP 1</td>
</tr>
<tr>
<td>PK1</td>
<td>(p_1^\kappa), upper-level pressure to kappa power</td>
<td>((\text{mb})^\kappa)</td>
<td>4600 COMP 1</td>
</tr>
<tr>
<td>PK3</td>
<td>(p_3^\kappa), lower-level pressure to kappa power</td>
<td>((\text{mb})^\kappa)</td>
<td>4610 COMP 1</td>
</tr>
<tr>
<td>PL1</td>
<td>(p_1 = p_T + \sigma_1 \pi), level 1 pressure</td>
<td>mb</td>
<td>4580 COMP 1</td>
</tr>
<tr>
<td>PL1K</td>
<td>(p_1^\kappa), upper-level pressure to kappa power</td>
<td>((\text{mb})^\kappa)</td>
<td>8120 COMP 3</td>
</tr>
<tr>
<td>PL2</td>
<td>(p_2 = p_T + \pi/2), level 2 pressure</td>
<td>mb</td>
<td>8100 COMP 3</td>
</tr>
<tr>
<td>PL2K</td>
<td>(p_2^\kappa), middle-level pressure to kappa power</td>
<td>((\text{mb})^\kappa)</td>
<td>8140 COMP 3</td>
</tr>
<tr>
<td>PL3</td>
<td>(p_3 = p_T + \sigma_3 \pi), level 3 pressure</td>
<td>mb</td>
<td>4590 COMP 1</td>
</tr>
<tr>
<td>PL3K</td>
<td>(p_3^\kappa), lower-level pressure to kappa power</td>
<td>((\text{mb})^\kappa)</td>
<td>8130 COMP 3</td>
</tr>
<tr>
<td>PM</td>
<td>(p_O - p_T), standard tropospheric pressure depth (= 800)</td>
<td>mb</td>
<td>7370 COMP 3</td>
</tr>
<tr>
<td>PREC</td>
<td>((\Delta q)_{LS} = [q_3 - q_s(T_3)] \cdot [1 + (L/c_p) B e q_s(T_3) T_3^{-2}]^{-1}), level 3 moisture change due to large-scale condensation</td>
<td>--</td>
<td>8650 COMP 3</td>
</tr>
<tr>
<td>FORTRAN Symbol</td>
<td>Meaning</td>
<td>Units</td>
<td>Location</td>
</tr>
<tr>
<td>----------------</td>
<td>---------</td>
<td>-------</td>
<td>----------</td>
</tr>
<tr>
<td>PSF</td>
<td>reference global mean surface pressure (= 984)</td>
<td>mb</td>
<td>1430 COMP, 13480 INPUT</td>
</tr>
<tr>
<td>PSL</td>
<td>$P_0$, reference sea-level pressure (= 1000)</td>
<td>mb</td>
<td>13460 INPUT</td>
</tr>
<tr>
<td>PT(J,I)</td>
<td>$\pi + \Delta t PIT/\mu n$, updated $\pi$ value</td>
<td>mb</td>
<td>4540 COMP 1</td>
</tr>
<tr>
<td>PTRK</td>
<td>$P_T^k$</td>
<td>(mb)$^k$</td>
<td>8150 COMP 3</td>
</tr>
<tr>
<td>PTRQP</td>
<td>$P_T$, tropopause pressure (= 200)</td>
<td>mb</td>
<td>13460 INPUT</td>
</tr>
<tr>
<td>PU(J,I)</td>
<td>(1) $u^* = n \nu$, zonal mass flux (at $u^*$ points)</td>
<td>$m^2 sec^{-1} mb$</td>
<td>2780-2890 COMP 1</td>
</tr>
<tr>
<td></td>
<td>(2) TEMP 1, provisional pressure gradient parameter</td>
<td>$m^2 sec^{-2} mb$</td>
<td>5560 COMP 2</td>
</tr>
<tr>
<td></td>
<td>(3) TEMP, provisional term in energy equation (other provisional definition in 6270 COMP 2, 12320 COMP 4)</td>
<td>$sec^2 deg$</td>
<td>6190 COMP 2</td>
</tr>
<tr>
<td>PV(J,I)</td>
<td>(1) $v^* = m \nu v$, meridional mass flux (at $v^*$ points)</td>
<td>$m^2 sec^{-1} mb$</td>
<td>2910-2940 COMP 1</td>
</tr>
<tr>
<td></td>
<td>(2) $C\phi\nu\mu v$, mass convergence at level 2</td>
<td>$m^2 sec^{-1} mb$</td>
<td>4230 COMP 1</td>
</tr>
<tr>
<td></td>
<td>(3) polar PU equivalent (various definitions) (other definitions in COMP 4)</td>
<td>$m^2 sec^{-1} mb$</td>
<td>3050-3170 COMP 1</td>
</tr>
<tr>
<td>PlCB</td>
<td>$p_1/10$, level 1 pressure in centibars</td>
<td>cb</td>
<td>8370 COMP 3</td>
</tr>
<tr>
<td>P10K</td>
<td>$p_0^k$</td>
<td>(mb)$^k$</td>
<td>7310 COMP 3</td>
</tr>
<tr>
<td>FORTRAN Symbol</td>
<td>Meaning</td>
<td>Units</td>
<td>Program Location</td>
</tr>
<tr>
<td>----------------</td>
<td>---------</td>
<td>-------</td>
<td>------------------</td>
</tr>
<tr>
<td>P3CB</td>
<td>$p_3/10$, level 3 pressure in centibars</td>
<td>cb</td>
<td>8380 COMP 3</td>
</tr>
<tr>
<td>$p_4$</td>
<td>$p_4 = p_s + p_T$, surface pressure</td>
<td>mb</td>
<td>8070 COMP 3</td>
</tr>
<tr>
<td>P4CB</td>
<td>$p_4/10$, surface pressure in centibars</td>
<td>cb</td>
<td>8390 COMP 3</td>
</tr>
<tr>
<td>P4K</td>
<td>$p_4^c$</td>
<td>$(\text{mb})^c$</td>
<td>8080 COMP 3</td>
</tr>
<tr>
<td>Q(J,I,K)</td>
<td>equivalence array ($K = 1, 2, \ldots 9$; see Chapter VII, Subsection A.3)</td>
<td>(various)</td>
<td>2060 STEP</td>
</tr>
<tr>
<td>QD(J,I,9)</td>
<td>array identification (alternate to QT)</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>QG</td>
<td>$q_s(T_0)$, ground-level saturation mixing ratio</td>
<td>--</td>
<td>9030 COMP 3</td>
</tr>
<tr>
<td>QN</td>
<td>$\Delta q_3$, total level 3 mixing ratio change due to convection, condensation, evaporation</td>
<td>--</td>
<td>11300 COMP 3</td>
</tr>
<tr>
<td>QS1</td>
<td>$q_s(T_1)$, level 1 saturation mixing ratio</td>
<td>--</td>
<td>8400 COMP 3</td>
</tr>
<tr>
<td>QS3</td>
<td>$q_s(T_3)$, level 3 saturation mixing ratio</td>
<td>--</td>
<td>8410 COMP 3</td>
</tr>
<tr>
<td>QT(J,I,K)</td>
<td>equivalence array for temporary variables ($K = 1, 2, \ldots 8$; see Chapter VII, Subsection A.3)</td>
<td>(various)</td>
<td>2070 STEP</td>
</tr>
<tr>
<td>QT(J,I,20)</td>
<td>equivalence array (see Chapter VII, Subsection A.3)</td>
<td>(various)</td>
<td>0140 COMMON</td>
</tr>
<tr>
<td>FORTRAN Symbol</td>
<td>Meaning</td>
<td>Units</td>
<td>Program Location</td>
</tr>
<tr>
<td>----------------</td>
<td>------------------------------------------------------------------------</td>
<td>-------</td>
<td>------------------</td>
</tr>
<tr>
<td>Q3(J,I)</td>
<td>$q_3$, level 3 mixing ratio</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>Q3M</td>
<td>level 3 moisture parameter</td>
<td>--</td>
<td>3410, 3660 COMP 1</td>
</tr>
<tr>
<td>Q3R</td>
<td>$q_3 - (\Delta q_3)^{LS}$, level 3 mixing ratio after large-scale condensation</td>
<td>--</td>
<td>8680 COMP 3</td>
</tr>
<tr>
<td>Q3RB</td>
<td>$\max(q_3, 10^{-5})$, provision to insure $q_3 \geq 10^{-5}$</td>
<td>--</td>
<td>9770 COMP 3</td>
</tr>
<tr>
<td>Q3T(J,I)</td>
<td>$q_3^{II}$, pressure-area-weighted level 3 mixing ratio (also moisture flux at 3710, 3720 COMP 1)</td>
<td>$\text{m}^2\text{mb}$</td>
<td>2570 COMP 1</td>
</tr>
<tr>
<td>Q4</td>
<td>(1) $\text{RH4}[q_s(T_4) + (c_p/L)g(T_4 - T_g)]$, level 4 moisture parameter</td>
<td>--</td>
<td>9110 COMP 3</td>
</tr>
<tr>
<td></td>
<td>(2) $q_4 = q_s(T_3) + <a href="c_p/L">\delta_3(p_s/p_o)^K - T_4</a>$, level 4 mixing ratio</td>
<td>--</td>
<td>9350 COMP 3</td>
</tr>
<tr>
<td>RAD</td>
<td>$a$, earth's radius (= 6375) (redefined in m in 13640, INPUT)</td>
<td>km</td>
<td>13420 INPUT</td>
</tr>
<tr>
<td>RCNV</td>
<td>$D_{TC3/TGNV} = 5\Delta t / \tau_r = 1/2$</td>
<td>hr</td>
<td>7290 COMP 3</td>
</tr>
<tr>
<td>RESET</td>
<td>day and year control parameter</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>RGAS</td>
<td>$R$, gas constant for dry air (= 287)</td>
<td>$\text{m}^2\text{deg}^{-1}\text{sec}^{-2}$</td>
<td>13440 INPUT</td>
</tr>
<tr>
<td>RH3</td>
<td>$RH_3 = q_3/q_s(T_3)$, relative humidity at level 3</td>
<td>--</td>
<td>8450 COMP 3</td>
</tr>
<tr>
<td>FORTRAN Symbol</td>
<td>Meaning</td>
<td>Units</td>
<td>Program Location</td>
</tr>
<tr>
<td>----------------</td>
<td>---------</td>
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<td>------------------</td>
</tr>
<tr>
<td>RH4</td>
<td>$RH_4 = 2RH_3 \cdot GW(RH_3 + GW)^{-1}$, ground-level humidity measure</td>
<td>--</td>
<td>9000 COMP 3</td>
</tr>
<tr>
<td>RØT</td>
<td>$t = t \cdot 2\pi/24$ hr, hour of day (converted to radians)</td>
<td>radians</td>
<td>7700 COMP 3</td>
</tr>
<tr>
<td>RØTPER</td>
<td>period of solar rotation ($= 24.0$)</td>
<td>hr</td>
<td>13090 INPUT</td>
</tr>
<tr>
<td>RØ4</td>
<td>$\rho_4 = p_4 (RT_4)^{-1}$, air density at level 4 (surface)</td>
<td>g cm$^{-3}$</td>
<td>9370 COMP 3</td>
</tr>
<tr>
<td>RSDIST</td>
<td>square of the normalized earth/sun distance</td>
<td>--</td>
<td>15520 SDET</td>
</tr>
<tr>
<td>RSETSOW</td>
<td>input identification</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>RUNØFF</td>
<td>WET/2, fraction of rainfall which runs off</td>
<td>--</td>
<td>11340 COMP 3</td>
</tr>
<tr>
<td>RØ</td>
<td>(1) $\tilde{R}_o$, long-wave radiation parameter at tropopause</td>
<td>ly day$^{-1}$</td>
<td>10200 COMP 3</td>
</tr>
<tr>
<td></td>
<td>(2) $\tilde{R}_o = \tilde{R}_o + 0.8(1 - CL)(R_4 - \tilde{R}_4) \cdot \tau(u^*_o)$, net upward long-wave radiative flux at tropopause</td>
<td>ly day$^{-1}$</td>
<td>11190 COMP 3</td>
</tr>
<tr>
<td>ROC</td>
<td>$\tilde{R}_o^{\text{CL}}$, cloudy sky part of long-wave radiative flux at tropopause, times cloudiness (separately defined for cloud types 1, 2, 3)</td>
<td>ly day$^{-1}$</td>
<td>10040, 10100, 10170 COMP 3</td>
</tr>
<tr>
<td>ROO</td>
<td>$\tilde{R}_o'$, clear sky part of long-wave radiative flux at tropopause</td>
<td>ly day$^{-1}$</td>
<td>9980 COMP 3</td>
</tr>
<tr>
<td>FORTRAN Symbol</td>
<td>Meaning</td>
<td>Units</td>
<td>Program Location</td>
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<td>-------------------------------------------------------------------------</td>
<td>-----------</td>
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</tr>
<tr>
<td>R2</td>
<td>(1) $\tilde{R}_2$, long-wave radiation parameter at level 2</td>
<td>1y day$^{-1}$</td>
<td>10210 COMP 3</td>
</tr>
<tr>
<td></td>
<td>(2) $R_2 = \tilde{R}_2 + 0.8(1 - \text{CL})(\tilde{R}_4 - \tilde{R}_d) \cdot \tau(u_2^2)$, net upward long-wave radiative flux at level 2</td>
<td>1y day$^{-1}$</td>
<td>11180 COMP 3</td>
</tr>
<tr>
<td>R2C</td>
<td>$R_2^{\text{CL}}$, cloudy sky long-wave radiative flux at level 2, times cloudiness (separately defined for cloud types 1, 2, 3)</td>
<td>1y day$^{-1}$</td>
<td>10050, 10010, 10180 COMP 3</td>
</tr>
<tr>
<td>R20</td>
<td>$R_2'$, clear sky part of long-wave radiative flux at level 2</td>
<td>1y day$^{-1}$</td>
<td>9990 COMP 3</td>
</tr>
<tr>
<td>R4</td>
<td>(1) $\tilde{R}_4$, long-wave radiation parameter at level 4</td>
<td>1y day$^{-1}$</td>
<td>10220 COMP 3</td>
</tr>
<tr>
<td></td>
<td>(2) $R_4 = \tilde{R}_4 + \sigma T_g^3(T_g - T_0)$, net upward long-wave radiative flux at level 4 (surface)</td>
<td>1y day$^{-1}$</td>
<td>11170 COMP 3</td>
</tr>
<tr>
<td>R4C</td>
<td>$R_4^{\text{CL}}$, cloudy sky long-wave radiative flux at level 4 (ground), times cloudiness</td>
<td>1y day$^{-1}$</td>
<td>10190 COMP 3</td>
</tr>
<tr>
<td>R40</td>
<td>$R_4'$, clear sky part of long-wave radiative flux at level 4 (ground)</td>
<td>1y day$^{-1}$</td>
<td>10000 COMP 3</td>
</tr>
<tr>
<td>SA</td>
<td>$S_0^A = 0.349 S_0 \cos \zeta$, part of incoming solar radiation subject to absorption</td>
<td>1y day$^{-1}$</td>
<td>10460 COMP 3</td>
</tr>
<tr>
<td>SCALE</td>
<td>scale factor for layer radiative heating</td>
<td>deg 1y$^{-1}$</td>
<td>11680 COMP 3</td>
</tr>
<tr>
<td>SCALEP</td>
<td>scale factor for layer latent heating</td>
<td>mm day$^{-1}$ mb$^{-1}$</td>
<td>7420 COMP 3</td>
</tr>
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<td>Units</td>
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<td>----------------</td>
<td>------------------------------------------------------------------------</td>
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</tr>
<tr>
<td>SCALEU</td>
<td>$(10/c)(2g/\pi)$, scale factor for column heat capacity</td>
<td>deg ly$^{-1}$</td>
<td>7400 COMP 3</td>
</tr>
<tr>
<td>SCOSZ</td>
<td>$S_0 \cos \zeta$, total solar radiation at top of atmosphere</td>
<td>ly day$^{-1}$</td>
<td>10280 COMP 3</td>
</tr>
</tbody>
</table>
| SD(J,I)        | $(\text{mn}/2)[\upsilon \cdot \pi(\mathbf{V}_3 - \mathbf{V}_1)] = \text{CONV}(J,I) - \text{PV}(J,I)$,  
<pre><code>            | net mass convergence ($\mathbf{S} = 2\text{mn}\pi\delta$)               | $m^2\text{sec}^{-1}\text{mb}$ | 4530 COMP 1 |
</code></pre>
<p>| SDEDY          | day counter starting from origin LDAY                                  | day       | 15030 INSDET     |
| SDU            | $\mathbf{S}^u$, four-point average mass convergence                    | $m^3\text{sec}^{-2}\text{mb}$ | 4750 COMP 1     |
| SEASON         | $(\text{DY}-173.0)/365$, time parameter in solar declination           | --        | 15440 SDET       |
| SIG1           | $\sigma_1$, upper-level $\sigma$ value ($= 1/4$)                       | --        | 7230 COMP 3      |
| SIG3           | $\sigma_3$, lower-level $\sigma$ value ($= 3/4$)                      | --        | 7240 COMP 3      |
| SIGC0          | FL/2, level designator                                                 | --        | 12360 COMP 4     |
| SIND           | $\sin \zeta$, sine of solar declination                               | --        | 15530 SDET       |
| SINL(J)        | $\sin \varphi_j$, sine of latitude                                    | --        | 14950 INSDET     |
| SINT           | control parameter (not used)                                           | --        | --               |</p>
<table>
<thead>
<tr>
<th>FORTRAN Symbol</th>
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<th>Units</th>
<th>Program Location</th>
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</thead>
<tbody>
<tr>
<td>SN(J,I)</td>
<td>identification for VT(1,1,2)</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>SNOW</td>
<td>designator for snow-covered land</td>
<td>--</td>
<td>7880 COMP 3</td>
</tr>
<tr>
<td>SNOWN</td>
<td>snowline in northern hemisphere (varies ±15° about 60 deg N)</td>
<td>radians</td>
<td>7460 COMP 3</td>
</tr>
<tr>
<td>SNOWS</td>
<td>snowline in southern hemisphere (= 60 deg S)</td>
<td>radians</td>
<td>7470 COMP 3</td>
</tr>
<tr>
<td>SP</td>
<td>$P(J,I) = \tau$, surface pressure parameter</td>
<td>mb</td>
<td>8050 COMP 3</td>
</tr>
<tr>
<td>SPOL</td>
<td>zonal mean at south pole</td>
<td>(various)</td>
<td>--</td>
</tr>
<tr>
<td>SS</td>
<td>$S^S_o = 0.65 S_o \cos \tau$, part of incoming solar radiation subject to scattering</td>
<td>ly day$^{-1}$</td>
<td>10470 COMP 3</td>
</tr>
<tr>
<td>SS1</td>
<td>$\theta_3 (p_s/p_o)^{\kappa} + (\theta_1 - \theta_3)(p_2/p_o)^{\kappa}$, convective stability parameter</td>
<td>deg</td>
<td>8760 COMP 3</td>
</tr>
<tr>
<td>SS2</td>
<td>$\theta_3 (p_s/p_o)^{\kappa} + \frac{1}{2} (\theta_1 - \theta_3)(p_2/p_o)^{\kappa}$, convective stability parameter</td>
<td>deg</td>
<td>8750 COMP 3</td>
</tr>
<tr>
<td>SS3</td>
<td>$\theta_3 (p_s/p_o)^{\kappa}$, convective stability parameter</td>
<td>deg</td>
<td>8740 COMP 3</td>
</tr>
<tr>
<td>STAGI</td>
<td>logical variable for zonal map staggering</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>STAGJ</td>
<td>logical variable for meridional map staggering</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>STBØ</td>
<td>$\sigma$, Stefan-Boltzman constant</td>
<td>ly day$^{-1}$ deg$^{-4}$</td>
<td>7650 COMP 3</td>
</tr>
<tr>
<td>FORTRAN Symbol</td>
<td>Meaning</td>
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<td>---------</td>
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<td>------------------</td>
</tr>
<tr>
<td>S0</td>
<td>$S_0$, solar constant (modified for earth/sun distance)</td>
<td>1 y day$^{-1}$</td>
<td>7610 COMP 3</td>
</tr>
<tr>
<td>S4</td>
<td>$S_g = (1 - CL)S'_g + CL S''_g$, total flux of short-wave radiation absorbed by the ground</td>
<td>1 y day$^{-1}$</td>
<td>10940 COMP 3</td>
</tr>
<tr>
<td>S4C</td>
<td>$S''_g$, cloudy sky part of short-wave radiation absorbed by the ground (defined separately for cloud types 1, 2, 3)</td>
<td>1 y day$^{-1}$</td>
<td>10660, 10760, 10890 COMP 3</td>
</tr>
<tr>
<td>S40</td>
<td>$S'_g$, clear sky part of short-wave radiation absorbed by the ground</td>
<td>1 y day$^{-1}$</td>
<td>10570 COMP 3</td>
</tr>
<tr>
<td>T(J,I,L)</td>
<td>level 1 or level 3 temperature (also for temperature after heating and smoothing in 11470, 11980, COMP 3); $L = 1$ denotes $T_1$, $L = 2$ denotes $T_3$</td>
<td>deg</td>
<td>8280 COMP 3</td>
</tr>
<tr>
<td>TAU</td>
<td>time in hr</td>
<td>hr</td>
<td>--</td>
</tr>
<tr>
<td>Tauc</td>
<td>input identification (not used)</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>TAUD</td>
<td>frequency of recalculation of solar declination ($= 24$)</td>
<td>hr</td>
<td>13310 INPUT</td>
</tr>
<tr>
<td>TAUE</td>
<td>day of integration end</td>
<td>day, hr</td>
<td>13310, 13320 INPUT</td>
</tr>
<tr>
<td>TAUH</td>
<td>frequency of history tape storage ($= 6$)</td>
<td>hr</td>
<td>13310 INPUT</td>
</tr>
<tr>
<td>TAUI</td>
<td>$TAUD \cdot 24 + TAUH$, starting time (in hr)</td>
<td>hr</td>
<td>13290 INPUT</td>
</tr>
<tr>
<td>TAUID</td>
<td>starting time</td>
<td>day</td>
<td>13730 INPUT</td>
</tr>
<tr>
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<td>Units</td>
<td>Program Location</td>
</tr>
<tr>
<td>----------------</td>
<td>-------------------------------------------------------------------------</td>
<td>--------</td>
<td>------------------</td>
</tr>
<tr>
<td>TAUH</td>
<td>hour of starting time</td>
<td>hr</td>
<td>13740</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>INPUT</td>
</tr>
<tr>
<td>TAU9</td>
<td>output interval (= 24)</td>
<td>hr</td>
<td>13310</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>INPUT</td>
</tr>
<tr>
<td>TAUX</td>
<td>starting time parameter</td>
<td>hr</td>
<td>13700</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>INPUT</td>
</tr>
<tr>
<td>TBAR</td>
<td>( (T_1 + T_3) / 2 ), average temperature</td>
<td>deg</td>
<td>12830</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>COMP 4</td>
</tr>
<tr>
<td>TCNV</td>
<td>relaxation time for cumulus convection (= 3600)</td>
<td>sec</td>
<td>13400</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>INPUT</td>
</tr>
<tr>
<td>TD(J,1)</td>
<td>( (T_3 - T_1) / 2π ), vertical temperature (lapse-rate) parameter</td>
<td>deg mb(^{-1})</td>
<td>12740</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>COMP 4</td>
</tr>
<tr>
<td>TDBAR</td>
<td>smoothed value of TD</td>
<td>deg mb(^{-1})</td>
<td>12790</td>
</tr>
<tr>
<td></td>
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<td></td>
<td>COMP 4</td>
</tr>
<tr>
<td>TDSM</td>
<td>weighted TD parameter</td>
<td>deg</td>
<td>12820</td>
</tr>
<tr>
<td></td>
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<td></td>
<td>COMP 4</td>
</tr>
<tr>
<td>TEM</td>
<td>( \tilde{h} ), conduction coefficient for ice (also defined as</td>
<td>ly day(^{-1})deg(^{-1})</td>
<td>11080</td>
</tr>
<tr>
<td></td>
<td>cloudiness parameters in COMP 3 but not used)</td>
<td></td>
<td>COMP 3</td>
</tr>
<tr>
<td>TEMB</td>
<td>short-wave radiative flux reflected from type 1 cloud top</td>
<td>ly day(^{-1})</td>
<td>10840</td>
</tr>
<tr>
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<td></td>
<td>COMP 3</td>
</tr>
<tr>
<td>TEMP</td>
<td>(1) intermediate parameter in thermodynamic energy conversion</td>
<td>sec(^2)deg</td>
<td>6160–6340</td>
</tr>
<tr>
<td></td>
<td>calculation</td>
<td></td>
<td>COMP 2</td>
</tr>
<tr>
<td></td>
<td>(2) ( \tau ), penetrating convection parameter</td>
<td>deg</td>
<td>9280</td>
</tr>
<tr>
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<td></td>
<td>COMP 3</td>
</tr>
<tr>
<td></td>
<td>(3) ( (H_1 - H_3) / 2 ), heating parameter</td>
<td>deg</td>
<td>11460</td>
</tr>
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<td></td>
<td>COMP 3</td>
</tr>
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<td>Meaning</td>
<td>Units</td>
<td>Program Location</td>
</tr>
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</tr>
<tr>
<td><strong>TEMP</strong></td>
<td>(4) vertical wind shear ((u_1 - u_3)) or ((v_1 - v_3))</td>
<td>(\text{m sec}^{-1})</td>
<td>11570 COMP 3</td>
</tr>
<tr>
<td></td>
<td>(5) (\overline{H^A}), averaged heating</td>
<td>(\text{deg})</td>
<td>11930-11950 COMP 3</td>
</tr>
<tr>
<td><strong>TEMP1</strong></td>
<td>(1) intermediate parameter in pressure gradient calculation</td>
<td>(\text{m}^2 \text{sec}^{-2} \text{mb})</td>
<td>5550, 5810 COMP 2</td>
</tr>
<tr>
<td></td>
<td>(2) (\tau_1 = (h_3^* - h_1^*)(1 + \gamma_1)^{-1} + LR/2), penetrating convection parameter</td>
<td>(\text{deg})</td>
<td>9260 COMP 3</td>
</tr>
<tr>
<td><strong>TEMP2</strong></td>
<td>(1) intermediate parameter in pressure gradient calculation</td>
<td>(\text{m}^3 \text{sec}^{-2} \text{mb})</td>
<td>5570, 5830 COMP 2</td>
</tr>
<tr>
<td></td>
<td>(2) (\tau_2 = \theta_3 (p_4/p_0)^K - T_4 + LR/2), penetrating convection parameter</td>
<td>(\text{deg})</td>
<td>9270 COMP 3</td>
</tr>
<tr>
<td><strong>TEMS</strong></td>
<td>((S_4^A)^n), flux of (S_0^A) reaching level 4 through clouds (defined separately for cloud types 1, 2, 3)</td>
<td>(\text{ly day}^{-1})</td>
<td>10630, 10730, 10860 COMP 3</td>
</tr>
<tr>
<td><strong>TEMSCL</strong></td>
<td>sea-surface temperature unit indicator</td>
<td>--</td>
<td>15910 INIT 2</td>
</tr>
<tr>
<td><strong>TEMU</strong></td>
<td>((u_3^* - u_1^* or u_2^*)) sec (\tau), parameter for transmission of (S_0^A) through type 1 or type 3 clouds</td>
<td>(\text{g cm}^{-2})</td>
<td>10720, 10830 COMP 3</td>
</tr>
<tr>
<td><strong>TEM1</strong></td>
<td>(p_3^2 q_3 (2 + K)^{-1} g^{-1}), water vapor parameter</td>
<td>(\text{g cm}^{-2})</td>
<td>9790 COMP 3</td>
</tr>
<tr>
<td><strong>TEM2</strong></td>
<td>(p_3^2 q_3 (2 + K)^{-1} g^{-1}(p_4/p_3)^{2+K}), water vapor parameter</td>
<td>(\text{g cm}^{-2})</td>
<td>9800 COMP 3</td>
</tr>
<tr>
<td><strong>TETAM</strong></td>
<td>(\theta_2 p_0^{-K}), temperature parameter</td>
<td>(\text{deg mb}^{-K})</td>
<td>4620 COMP 1</td>
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</tr>
<tr>
<td>TETA1</td>
<td>$\theta_1$, level 1 potential temperature</td>
<td>deg K</td>
<td>8720 COMP 3</td>
</tr>
<tr>
<td>TETA3</td>
<td>$\theta_3$, level 3 potential temperature</td>
<td>deg K</td>
<td>8730 COMP 3</td>
</tr>
<tr>
<td>TEXCO</td>
<td>DT, time step (= 360) (also defined as DT/2 in 2480 COMP 1, 4970 COMP 2 for advective terms)</td>
<td>sec</td>
<td>2470 COMP 1, 4960 COMP 2</td>
</tr>
<tr>
<td>TG</td>
<td>$T_g$, ground temperature (original)</td>
<td>deg K</td>
<td>8560 COMP 3</td>
</tr>
<tr>
<td>TGR</td>
<td>(1) $T_{gr} = T_g$ if ocean, $T_{gr} = T_o$ if ice or snow and $T_{gr} &gt; T_o$ (2) $T_{gr} = (A1 + A2)/(B1 + B2)$, ground temperature (revised)</td>
<td>deg K</td>
<td>11040 COMP 3, 11130 COMP 3</td>
</tr>
<tr>
<td>TG00</td>
<td>$T_0$P0G, ocean surface temperature or surface geopotential</td>
<td>deg or $^2$ m sec$^{-2}$</td>
<td>7840 COMP 3</td>
</tr>
<tr>
<td>THL1</td>
<td>$\theta_1 p_o^{-K}$, level 1 temperature parameter</td>
<td>deg mb$^{-K}$</td>
<td>8220 COMP 3</td>
</tr>
<tr>
<td>THL3</td>
<td>$\theta_3 p_o^{-K}$, level 3 temperature parameter</td>
<td>deg mb$^{-K}$</td>
<td>8230 COMP 3</td>
</tr>
<tr>
<td>THRSP</td>
<td>time in days and fractions (= TAU/24)</td>
<td>day</td>
<td>1970 STEP</td>
</tr>
<tr>
<td>TICE</td>
<td>$T_o$, melting point of ice (= 273.1)</td>
<td>deg K</td>
<td>7350 COMP 3</td>
</tr>
<tr>
<td>TFDAY</td>
<td>$t =$ time of day counter (Greenwich hours)</td>
<td>hr</td>
<td>14120 INPUT</td>
</tr>
<tr>
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</tr>
<tr>
<td>TJPW(J,L)</td>
<td>surface topography indicator</td>
<td>deg or m sec 2</td>
<td>16090 INIT 2</td>
</tr>
<tr>
<td>TRANS(X)</td>
<td>$\tau(x) = (1 + 1.75x^{0.416})^{-1}$, slab transmission function for long-wave radiation ($x = u_n^*$ in g cm$^{-2}$)</td>
<td>--</td>
<td>7150 COMP 3</td>
</tr>
<tr>
<td>TREADY</td>
<td>integration control parameter (not used)</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>TRST</td>
<td>tape output control parameter</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>TRSW(X)</td>
<td>$1 - 0.271x^{0.303}$, transmission function for short-wave radiation ($x = u_n^*$ in g cm$^{-2}$)</td>
<td>--</td>
<td>7160 COMP 3</td>
</tr>
<tr>
<td>TS(J,L)</td>
<td>identification for UT(1,1,2)</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>TSPD</td>
<td>DAY/DTC3, number of source (COMP 3) calculations per day (= 48)</td>
<td>--</td>
<td>7410 COMP 3</td>
</tr>
<tr>
<td>TT(J,L)</td>
<td>(1) T, temperature</td>
<td>deg K</td>
<td>1960 STEP</td>
</tr>
<tr>
<td></td>
<td>(2) TH, pressure-area-weighted temperature</td>
<td>m$^2$ deg mb</td>
<td>2620 COMP 1</td>
</tr>
<tr>
<td>TTRP</td>
<td>$T_1$ or $T_0$, tropopause temperature (extrapolated from $T_1$ and $T_3$ in p$^*$ space)</td>
<td>deg K</td>
<td>8510 COMP 3</td>
</tr>
<tr>
<td>T1</td>
<td>$T_1$, level 1 temperature (redefined if convective adjustment occurs)</td>
<td>deg K</td>
<td>8200, 8280 COMP 3</td>
</tr>
<tr>
<td>T2</td>
<td>$T_2$, level 2 temperature</td>
<td>deg K</td>
<td>8520 COMP 3</td>
</tr>
<tr>
<td>FORTRAN Symbol</td>
<td>Meaning</td>
<td>Units</td>
<td>Program Location</td>
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<td>----------------</td>
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<tr>
<td>T3</td>
<td>( T_3 ), level 3 temperature (redefined if convective adjustment or large-scale condensation occurs in 8660, COMP 3)</td>
<td>deg K</td>
<td>8210, 8270</td>
</tr>
<tr>
<td>T4</td>
<td>( T_4 ), air temperature at level 4 (redefined if convection occurs in 9340, COMP 3)</td>
<td>deg K</td>
<td>9090</td>
</tr>
<tr>
<td>U(J,I,L)</td>
<td>( u ), zonal wind speed (( L = 1 ) designates ( u_1 ), ( L = 2 ) designates ( u_3 ))</td>
<td>m sec(^{-1})</td>
<td>--</td>
</tr>
<tr>
<td>URT</td>
<td>( \sigma_T^4(u_* - u_1^*) ), total long-wave flux at tropopause from atmosphere above tropopause</td>
<td>1y day(^{-1})</td>
<td>9950</td>
</tr>
<tr>
<td>UR2</td>
<td>( \sigma_T^4(u_* - u_2^*) ), total long-wave flux at level 2 from atmosphere above level 2</td>
<td>1y day(^{-1})</td>
<td>9960</td>
</tr>
<tr>
<td>US</td>
<td>( u_s = 0.7(3u_3 - u_1)/2 ), surface zonal wind speed</td>
<td>m sec(^{-1})</td>
<td>7530</td>
</tr>
<tr>
<td>UT(1,I,1)</td>
<td>provisional variable during zonal smoothing</td>
<td>--</td>
<td>7000</td>
</tr>
<tr>
<td>UT(J,I,L)</td>
<td>(1) ( u^H ), pressure-area-weighted zonal wind speed</td>
<td>m mb sec(^{-1})</td>
<td>2670</td>
</tr>
<tr>
<td></td>
<td>(2) ( u^H ), value after Coriolis force calculation</td>
<td>m mb sec(^{-1})</td>
<td>5170</td>
</tr>
<tr>
<td>V(J,I,L)</td>
<td>( v ), meridional wind speed (( L = 1 ) designates ( v_1 ), ( L = 2 ) designates ( v_3 ))</td>
<td>m sec(^{-1})</td>
<td>--</td>
</tr>
<tr>
<td>VAD</td>
<td>( \text{TEXCO} \frac{1}{2} u_2 v_2 / 2 ), vertical advection of ( u,v ) momentum</td>
<td>m sec(^{-1}) mb</td>
<td>4780, 4810</td>
</tr>
<tr>
<td>FORTRAN Symbol</td>
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<tr>
<td>VAK</td>
<td>$2 + K$, parameter for effective water amount</td>
<td>--</td>
<td>9780 COMP 3</td>
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<tr>
<td>VIVA</td>
<td>data control parameter (not used)</td>
<td>--</td>
<td>--</td>
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<td>VKEYV</td>
<td>name of labeled common block (KEYS)</td>
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<td>VM1</td>
<td>polar mass flux parameters (various definitions)</td>
<td>--</td>
<td>2990-3120 COMP 1</td>
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<tr>
<td>VM2</td>
<td>polar mass flux parameters (various definitions)</td>
<td>--</td>
<td>3000-3210 COMP 1</td>
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<tr>
<td>VPNI4(J,I)</td>
<td>$\phi_4$, surface (level 4) geopotential ($= 0$ if ocean)</td>
<td>$m^2 sec^{-2}$</td>
<td>1570 VPNI4</td>
</tr>
<tr>
<td>VPK1</td>
<td>$(p_1/p_3)^K$, level 1 geopotential parameter</td>
<td>--</td>
<td>5330 COMP 2</td>
</tr>
<tr>
<td>VPK3</td>
<td>$(p_3/p_1)^K$, level 3 geopotential parameter</td>
<td>--</td>
<td>5340 COMP 2</td>
</tr>
<tr>
<td>VPS1</td>
<td>$\sigma_1 p_1$, level 1 pressure gradient parameter</td>
<td>--</td>
<td>5310 COMP 2</td>
</tr>
<tr>
<td>VPS3</td>
<td>$\sigma_3 p_3$, level 3 pressure gradient parameter</td>
<td>--</td>
<td>5320 COMP 2</td>
</tr>
<tr>
<td>VS</td>
<td>$v_s = 0.7(3v_3 - v_1)/2$, surface meridional wind speed</td>
<td>$m sec^{-1}$</td>
<td>7540 COMP 3</td>
</tr>
<tr>
<td>VT(J,I,L)</td>
<td>(1) $vM^u$, pressure-area-weighted meridional wind speed</td>
<td>$m^3 sec^{-1} mb$</td>
<td>2680 COMP 1</td>
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<tr>
<td></td>
<td>(2) $vM$, value after Coriolis force calculation</td>
<td>$m^3 sec^{-1} mb$</td>
<td>5190 COMP 2</td>
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<tr>
<td>W(J,I)</td>
<td>temporary variable for H, PV, PHI, QT</td>
<td>(various)</td>
<td>--</td>
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<tr>
<td>WET</td>
<td>GW, ground wetness (scaled 0 to 1)</td>
<td>--</td>
<td>11360 COMP 3</td>
</tr>
<tr>
<td>WINDF</td>
<td>$</td>
<td>\mathbf{V}_{s}</td>
<td>^2 + G$, surface wind speed with gustiness correction ($G = 2.0 \text{ m sec}^{-1}$)</td>
</tr>
<tr>
<td>WMAG</td>
<td>$</td>
<td>\mathbf{V}_{s}</td>
<td>^2$, surface wind speed (root-mean-square value)</td>
</tr>
<tr>
<td>WMAGJM</td>
<td>$</td>
<td>\mathbf{V}_{s}</td>
<td>^2$, surface wind speed for north pole</td>
</tr>
<tr>
<td>WMAG1</td>
<td>$</td>
<td>\mathbf{V}_{s}</td>
<td>^2$, surface wind speed for south pole</td>
</tr>
<tr>
<td>WORK1(J,I)</td>
<td>temporary array in map routines</td>
<td>(various)</td>
<td>1760 MAPGEN</td>
</tr>
<tr>
<td>WORK2(J,I)</td>
<td>temporary array in map routines</td>
<td>(various)</td>
<td>1760 MAPGEN</td>
</tr>
<tr>
<td>WTM</td>
<td>$</td>
<td>\mathbf{m}</td>
<td>$, area weighting factor magnitude</td>
</tr>
<tr>
<td>WW</td>
<td>$2\mathbf{m} \cdot \phi$, vertical velocity measure</td>
<td>m$^2$ mb hr$^{-1}$</td>
<td>11670 COMP 3</td>
</tr>
<tr>
<td>XLABL(9)</td>
<td>input character identification</td>
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<td>XLEV</td>
<td>level identification parameter (not used)</td>
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<tr>
<td>XXL</td>
<td>$(T_1 + T_3)/(p_1^K + p_3^K)$, convective adjustment parameter</td>
<td>deg mb$^{-K}$</td>
<td>8250 COMP 3</td>
</tr>
<tr>
<td>FORTRAN Symbol</td>
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<td>Units</td>
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<td>packed data location (= KKK)</td>
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<td>11700 COMP 3</td>
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<tr>
<td>ZL3</td>
<td>average height of level 3 (= 2000)</td>
<td>m</td>
<td>8920 COMP 3</td>
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<tr>
<td>ZM(J)</td>
<td>zonal mean at latitude $\varphi_j$</td>
<td>(various)</td>
<td>1360 GMP</td>
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<tr>
<td>ZMM</td>
<td>global mean</td>
<td>(various)</td>
<td>1420 GMP</td>
</tr>
<tr>
<td>ZM$\text{MONTH}(3,12)$</td>
<td>names of months</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>ZZZ</td>
<td>$\psi_g/g$, height of surface (level 4) (= 0 if ocean)</td>
<td>m</td>
<td>7900 COMP 3</td>
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</tbody>
</table>
REFERENCES


