Low-Cost Options for Airborne Delivery of Contraband into North Korea

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Key findings

- Modeling suggests that when balloons are launched under favorable wind conditions, they can potentially penetrate deep into North Korea.
- Based on anecdotal reports, the balloons do not fly far across the border very often.
- It may be that the balloons are "saturating" the border area with leaflets but not fulfilling their full potential to reach larger areas of the country.
- Activist groups can probably improve their success rate by choosing launch conditions more judiciously, with the aid of high-altitude wind forecasts.
- Adding pressure relief valves to prevent overpressurization of the balloons seems like a cheap improvement that could enable better flight times and better penetration.
- The use of powered drones has begun with hexacopters and could be extended to longer-range drones.
- A balloon-released glider is a more exotic but not entirely undemonstrated concept that could combine some of the more attractive features of balloons and controlled drones.

SUMMARY ■ For a number of years, various activist groups in South Korea have used hydrogen balloons to carry information and political, religious, and humanitarian materials across the border into North Korea. In the past, going back to the Korean War, the South Korean government itself used to launch propaganda balloons. For reasons of diplomacy, however, the South Korean government gave up sending balloons in 2005, leaving private individuals and nongovernmental organizations (NGOs) in South Korea to fly their own. The North Korean government strongly resents the balloons and in October 2014 opened fire on one of them with an anti-aircraft gun, causing South Korean forces to return fire when anti-aircraft bullets landed inside South Korea.

The NGOs' balloon delivery techniques have evolved over time and are continuing to evolve—several NGOs have made an overt point of seeking new technological means to pursue their missions. In 2015, one organization announced that it would begin using hexacopter drones to smuggle material into North Korea. In this report, we review open source reporting to assess the technical state of low-cost private unmanned air vehicles—balloons and drones—as a means of delivering material into North Korea, focusing on the following:

- What is known about the technical characteristics of the Korean NGO balloons?
- What can be said about the probable effectiveness of the balloons?
- Could North Korea shoot down the balloons, if it made a concerted effort to do so?
- In an era of personal drones, what technical improvements are likely in the use of unmanned air vehicles by Korean NGOs?

We used a combination of modeling and simulation, historical analyses, and engineering assessments of commercially available technologies to address these questions and assess likely near-term technological options for low-cost unmanned air vehicles. The current balloons could be made more reliable and successful at very little cost if the Korean NGOs chose launch conditions more carefully, with the aid of high-altitude wind forecasts, and if the balloons had pressure relief valves to prevent premature bursting. More-expensive drone platforms are already in use for short-range flights and could be extended to longer ranges; because these platforms are relatively expensive, their success may depend on finding undefended entry and exit points. Finally, balloon-released gliders are a speculative concept that could combine some advantages of balloons (low cost, high altitude, long range, expendability) with the advantage of drones (accurate delivery).

FLYING BALLOONS INTO NORTH KOREA

> At the beginning, the operation was primitive. We put one leaflet per a small balloon that children play with. After three years passed, there had not been serious reaction. Making a hundred of balloons was enough to cause bruise on the fingers. Necessity to develop larger balloons was urgent. But what used to be government's job was not simple for mere defectors. And our conviction created miracle. In July 2005, we invented chemically aired large balloon.
>
> In the early years, we only spent less than one gas can and sent only ten thousand pieces, but now we can send one million leaflets at once, spending fifty something gas cans. In just a month, North Korea started to complain officially. We did not expect such fast reaction.
>
> Technology got better, and now it is more advanced than that government used.
>
> *—Lee Min-Bok, "On Balloon Leaflets to North Korea" (2008)*

In the last decade, a number of nongovernmental organizations (NGOs)—many led by North Korean defectors—have taken up launching hydrogen balloons into North Korea. These groups include the North Korean Christian Association (NKCA) and the Campaign for Helping North Koreans in Direct Way (NKDW), both founded by Lee Min-Bok; the Fighters for Free North Korea (FFNK), led by Park Sang-Hak; the North Korea People's Liberation Front, founded by Choi Jung-hoon; North Korea Peace, founded by Lee Ju-Seong; and Voice of the Martyrs (VOM) Korea, previously known as Seoul USA, led by Rev. Eric Foley.

As suggested in Table 1, different NGOs have very different philosophies and goals, and they choose to send different types of contraband into North Korea. Many of the balloons carry explicitly political messages critical of the Democratic People's Republic of Korea regime or encouraging North Koreans to defect. Others carry religious messages. Some offer messages of hope and encouragement without any explicit political or religious commentary. In addition to leaflets, various NGOs also send money, noodles, Choco Pies, medicine, socks, small radios, and video discs and flash drives loaded with South Korean movies and television shows (Chang, 2012; Bae, 2014; Evans, 2014; Choe, 2015). Christian groups send religious tracts, Bibles, and marshmallow Peeps (Lee, 2013; Dillmuth, 2015; Smith, 2011). Collectively, the NGOs are launching thousands of balloons and millions of leaflets per year.

Table 1. Some NGOs Noted for Launching Balloons into North Korea

NGO	Lead Organizer	Characteristic Balloon Payloads
NKCA NKDW	Lee Min-Bok	Pro-Christian leaflets (but not Bibles) Leaflets criticizing North Korean government Video discs, including the movie *The Interview* Small radios Dollar bills Medicine Instant noodles Pens
FFNK	Park Sang-Hak	Political, secular leaflets denouncing DPRK government Video discs, including the movie *The Interview* Flash drives containing all of Korean-language Wikipedia Small radios
North Korea Peace	Lee Ju-Seong	Socks Apolitical goodwill messages
VOM Korea	Eric Foley	New Testament Bibles Marshmallow Peeps

SOURCES: Bae (2014), Chang (2012), Dillmuth (2015), McDonald (2011), Smith (2011).

Effect of Balloon Campaigns

The Korean NGOs' belief in the effectiveness of their balloon launches is sustained partly by the testimony of North Korean defectors who decided to escape based on information delivered by balloon. Bradley K. Martin, an American journalist with several decades of experience covering Korea, interviewed North Korean defectors in the 1990s who made statements such as:[1]

- Kim Kwang-choon: "The South Koreans would send up balloons filled with those materials during the night. They were supposed to explode after two hours—usually around Kaesong. So I would pick them up. I had to give them to State Security, but while picking them up I got to see the materials."
- Chung Seong-san: "I think the balloon-drop strategy is very effective. They mostly come in July or August. North Koreans always look up to the sky then: 'Maybe today I'll be lucky.'"
- Ko Chung-song: "I've read [leaflets dropped by balloon] myself, although you're forbidden to read them. . . . If anyone is seen picking up one of the leaflets to read it, someone will tattle and the person reading it will go to prison."
- Kim Nan-joon: "A balloon dropped a copy of Saenal [New Day]. One of the articles dealt with the July declaration of Roh Tae-woo. After reading that, I decided I had to go to South Korea."
- Kim Kil-song: "Just continue the drops of propaganda leaflets and the propaganda broadcasts through DMZ [demilitarized zone] loudspeakers." (all quotes from Martin, 2004)

The Korean NGOs also point to the furious reaction of the North Korean government as evidence that the balloon campaigns are worthwhile. North Korea has repeatedly threatened to launch a "merciless attack" on the balloon launch sites and nearby villages (Choe, 2012). The South Korean Joint Chiefs of Staff have stated, "If the North uses the civic group's leaflet-sending as an excuse and makes any provocative action south of the Military Demarcation Line, our military will powerfully and sternly counter it. A civic group's leaflet-sending is part of the people's rights and freedom of speech. We cannot regulate this forcibly and we want to say once again that the civilians are making their independent judgments" (quoted in Ser, 2015). However, opposition politicians have called for the Park Geun-hye administration to "strongly control the activists" (Ser, 2015). In October 2014, North Korean forces fired about ten antiaircraft rounds at an NGO balloon (Choe, 2014; Kang, 2015). South Korean military forces returned fire because bullets were falling inside South Korea.

In April 2015, South Korean police halted a launch of balloons carrying leaflets and video copies of *The Interview*, an American comedy lampooning Kim Jong-Un, intercepting FFNK activists at a rest stop on their way to the border, presumably to prevent any danger of North Korean retaliation to residents living near the chosen launch site (Bond, 2015). In the same month, however, police observed but made no attempt to halt other balloon launches with similar payloads when the launches were made without publicity from remote areas ("Balloon Activist Sends 'Thousands of Copies' of The Interview to North Korea," 2015).

North Korea has issued death threats against the leaders of balloon-launching NGOs, declaring that Lee Min-Bok is "less than a beast" and "human garbage" (Park, 2014), and that it would "bleed [Park Sang-Hak] out and gut his intestines" (Ser, 2015). In response, the South Korean police increased protection of Park Sang-Hak in February 2016 (Ser, 2016).

Since January 12, 2016, North Korea has been sending its own leaflets by balloon (Jeong Yong-Soo and Sarah Kim, 2016). The North Korean balloons carry about 10,000 leaflets each, denouncing the U.S. and South Korean governments and demanding that South Korea halt propaganda broadcasts into North Korea (Jeon and Park, 2016). North Korea also has a history of sending drone aircraft into South Korean airspace. In 2014, three crashed drones were found that had been launched from North Korea and programmed to fly using the Global Positioning System (GPS) and to take pictures of strategic South Korean facilities (Rowland, 2014). On January 13, 2016, a North Korean drone flew "tens of meters" across the border before retreating from South Korean machine gun fire (Kang, 2016).

In response to various North Korean provocations in 2016, the South Korean government reportedly considered renewing its own balloon launches, which have been suspended since 2005 (Jeong Yong-Soo and Kim So-Hee, 2016). However on July 4, 2017, President Moon Jae-in gave instructions to look for legal ways to block NGOs from launching leaflet balloons (Lee, 2017).

Study Questions

This is an aeronautically minded analysis of the capability of nonstate actors to penetrate North Korean airspace in the present and in the near future. We relied on open source reporting and on physics simulations to answer the questions outlined in the following sections.

What Is Known About the Technical Characteristics of the Korean NGO Balloons?

What can they carry? How high do they fly? How much does a balloon cost? We review media reports (which can sometimes be inconsistent) and arrive at an engineering description of the balloons that is consistent with the bulk of the reporting and with the laws of physics.

What Can Be Said About the Probable Effectiveness of the Balloons?

It is difficult to be certain what happens to the NGO balloons, but our modeling suggests that when balloons are launched under favorable wind conditions, they can potentially penetrate deep into North Korea, an intuitively attractive capability. It is probably the case that some Korean NGO balloons are launched even when conditions are not good (i.e., from poor launch sites at unfavorable times of year), and these are not likely to be effective.

From anecdotal reports, it appears that the balloons do not often fly very far across the border. It may be that the balloons are "saturating" the border area with leaflets but not fulfilling their full potential to reach larger areas of the country. These unnecessarily short flights, in turn, might be due in some cases to overpressurization of the balloons, a problem that amateur balloonists around the world have often faced. If these speculations are all correct, then adding pressure relief valves to the balloons could enable the Korean NGO balloons to fly farther and reach greater regions of North Korea.

It is instructive to compare the Korean NGO activities with similar balloon campaigns used in the 1950s to carry leaflets across the Iron Curtain into Communist Europe. Controversies and questions about the Korean balloon campaigns today have close parallels with debates over European balloon campaigns at the time. The European campaigns, however, were secretly funded by the U.S. Central Intelligence Agency (CIA) and were conducted on a larger scale than today's Korean NGO efforts. It seems very probable that the CIA-funded balloons did have an effect in spreading information and shaping opinion in Communist Europe. However, those balloons were eventually phased out in favor of radio broadcasts.

Could North Korea Shoot Down the Balloons, If It Made a Concerted Effort to Do So?

Our analysis suggests the answer is marginally yes. The Korean NGO balloons typically fly at an altitude of around 3,000 m, where they can be engaged by North Korean antiaircraft guns. The economic exchange is very roughly even; i.e., shooting down the balloons is neither drastically cheaper nor drastically more expensive than launching the balloons, so a "war of attrition" would be about equally expensive for both sides.

However, if the NGOs believed that their balloons were frequently being shot down, they could simply fly the same balloons with smaller payloads at higher altitudes (e.g., 6,000 m) that most North Korean antiaircraft guns cannot reach. North Korea would have to use aircraft to intercept the balloons, which would be very expensive. This would, however, reduce the number of leaflets delivered per balloon. Our modeling found that at Baengnyeong Island and Imjingak, two launch sites favored by NGOs, the winds at the higher altitudes were favorable less often than the winds at lower altitudes; therefore, a shift to higher altitudes might require the NGOs to be more judicious in selecting launch times or to select different launch sites.

In an Era of Personal Drones, What Technical Improvements Are Likely in the Use of Unmanned Air Vehicles by Korean NGOs?

The Korean NGOs have a distinct history of seeking out improvements in their delivery techniques, so vehicle improve-

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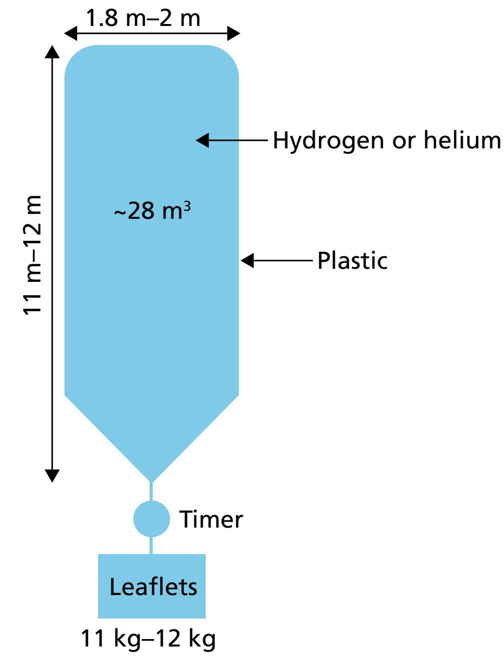
ments are likely to continue. Significantly, some NGOs have begun using GPS trackers to assess their balloons' flight performance. One NGO has begun using hexacopter drones to smuggle material across the border. We provide an engineering assessment of which developments are most promising.

THE PHYSICAL CHARACTERISTICS OF KOREAN NGO BALLOONS

Most Korean NGOs are currently using large cylindrical balloons made from clear plastic. Cylindrical balloons have two important characteristics, from the point of view of the NGOs: They are relatively cheap and easy to fabricate, but they can be made large enough to carry fairly large quantities of pamphlets or other goods. Cylindrical balloons also gain altitude rapidly after launch. Figure 1 is adapted from a diagram on the FFNK website that illustrates the concept. The original FFNK diagram did not explicitly specify the volume of the balloon, but it showed the approximate height and diameter, suggesting a volume of around 28 cubic meters.[2] This size of balloon is represented in column C of Table 2, which spells out estimated balloon material weights and costs.

The reported balloon sizes vary significantly, perhaps because there is genuine variation among groups or perhaps because the reporting is inaccurate. Post (undated) described a North Korea Peace balloon as "an opaque cigar about thirty feet tall and six feet in circumference," but the accompanying photograph shows a balloon that is much wider (so "circumference" is possibly a mistake for "diameter"). Higginbotham (2014) described the FFNK balloons as "33 feet long and 7 feet wide," but in that case the balloons in the accompanying photographs appear somewhat

Figure 1. Cylindrical Balloon Concept



SOURCE: Adapted from FFNK (2015).

Table 2. Estimated Balloon Material Weight and Cost

Reported Balloon Size	A[a]	B[b]	C[c]	D[b]
Height (m)	7	10	11.5	10
Diameter (m)	2	1.7	1.87	2.1
Volume (m^3)	17.5	20	28	30
Surface area (m^2)	44	54	68	67
Balloon skin mass (kg)	6.6	8.1	10	10
Balloon skin cost ($)	57	70	88	88
Hydrogen mass (kg) to fully inflate at 3,000 m altitude	1.1	1.3	1.7	1.9
Hydrogen cost ($) to fully inflate at 3,000 m altitude	5.5	6.3	8.7	9.6
Helium mass (kg) to fully inflate at 3,000 m altitude	2.2	2.4	3.5	3.8
Helium cost ($) to fully inflate at 3,000 m altitude	47	54	75	82
Approximate payload (kg) at 3,000 m altitude	8.2	8.9	13	15
Cost of balloon plus hydrogen ($) per kg of payload at 3,000 m altitude	7.6	8.5	7.2	6.3
Maximum supportable superpressure (pascals [Pa])	4,800	5,600	5,100	4,500

NOTE: Each column represents a different size balloon, as indicated in the first two rows.
[a] Park (2014).
[b] Higginbotham (2014).
[c] FFNK (2015).

narrower than 7 ft in diameter. The dimensions stated by Higginbotham would correspond to a volume of 30 cubic meters, but based on photographs, a total volume of about 20 cubic meters may be more accurate. These two size estimates are represented in columns B and D of Table 2.

Finally, Park Ju-Min (2014) reports that Lee Min-Bok's balloons are 7 m tall and carry payloads of under 8 kg to altitudes of 3,000 m. This relatively small balloon is represented in column A of Table 2.

Lee Min-Bok releases balloons based on winds at 3,000 m as forecast by the Korea Aviation Meteorological Agency (Bae, 2014). North Korea Peace also appears to aim for an altitude of 3,000 m (Post, undated). FFNK balloons are intended to fly at an altitude of 2,500 m (Choe, 2006).

The balloons are cheaply made of "double-walled greenhouse plastic." This appears to refer to a polyethylene film of about 6-mil or 150-micron thickness, with a mass of about 0.15 kg/m^2 and a retail cost of about $1.30 per square meter.[3] Standard greenhouse polyethylene film can support a maximum stress of 31.9 megapascals (MPa) (AT Films, 2007), implying that the cylindrical balloons can contain a "superpressure" (i.e., internal gas pressure in excess of the ambient air pressure) of 4,500 to 5,600 Pa, as shown in Table 2.[4] This is about 6.4–8.0 percent of the expected air pressure at 3,000 m altitude.

Table 2 indicates that plastic film makes up the largest material cost of each balloon, while the hydrogen necessary for inflation is relatively inexpensive.[5] Using helium instead, for operational safety, would modestly decrease the carrying capacity and approximately double the cost of each balloon.[6]

The material costs estimated here are roughly consistent with the statement by Lee Min-Bok that his balloons cost 100,000 South Korean won (KRW), or $87 (Bae, 2014), and the claim by Jung Jin-Heon (2014) that a full-size balloon costs about 120,000 KRW, or $105, if we assume that these statements are referring only to material costs. Park Sang-Hak claims that each balloon costs $500 to launch (Farivar, 2014; Higginbotham, 2014), which might also be true after one considers the operational costs of manufacturing, transporting, and launching the balloons with their payloads.

Lee Min-Bok claims that before he developed cheap methods of balloon construction and spread them to various NGOs, the South Korean Ministry of National Defense spent about 3 million KRW, or $2,700, for each of its psychological warfare balloons (Bae, 2014).

Timers

Both mechanical timers and chemical timers (such as a glue that dissolves after a given time) are said to be employed to drop the payload after three to four hours. Seoul USA reportedly used a small amount of acid to eventually eat through a metal ring to release the payload (Smith, 2011). The NKCA equips its balloons with a mechanical device that releases the leaflets intermittently instead of all at once (Jung, 2008). Lee Ju-Sung of North Korea Peace sets a timer to release cords and open a box of socks after three hours (Glionna, 2011; Post, undated). These intended release times should be recalled when considering simulated balloon flights in a later section.

Payloads

Leaflets are sometimes printed on vinyl to reduce their weight and make them resistant to moisture. A typical balloon is said to carry up to 60,000 vinyl leaflets the size of a postcard (Jung, 2008). An 8-kg payload could contain only about 8,000 leaflets of the same size if printed on ordinary paper. The weight of the vinyl leaflets suggests that they are printed on plastic of around 0.5 mil thickness, similar to a grocery store bag.

Alternatively, a balloon with an 8-kg payload could carry about 130 lightweight Bibles (VOM Korea, 2011) or about 100 pairs of socks (Glionna, 2011). At about $100 per balloon, the minimum cost of the balloon is only about $1 per pair of socks, or $1 per 600 vinyl leaflets. This relatively attractive cost ratio is worth bearing in mind when comparing balloons with other conceivable ways of moving material into North Korea. The chief drawback is the lack of certainty as to where the material will arrive. We will examine effectiveness in the next section.

EFFECTIVENESS OF BALLOON FLIGHTS

Balloons Compared with Other Means of Delivering Information

Balloons are not the only means of delivering information or contraband to North Korea. Some other activist NGOs, such as the North Korea Strategy Center or North Korea Intellectuals Solidarity, use ground-based or boat-based methods to smuggle material across the border (Greenberg, 2015a). However, balloons have certain advantages:

- Whereas other methods expose couriers to danger, the balloon launchers are in little danger (unless the location of the balloon launches is made obvious *and* North Korea eventually makes good on its retaliatory threats).
- The weight of material carried by the balloons is respectable; a similar weight carried by individual smugglers would be difficult to conceal.
- Individuals in North Korea may be exposed to the balloon's message involuntarily or lured by the balloon's prize of food or money, even if they would not, for example, take steps to listen to radio broadcasts from the South or try to obtain subversive material from another North Korean.
- At least in principle, balloons have the capability to deliver messages directly to North Koreans far from the border.

The chief disadvantage of balloons is the relative lack of control over their trajectories. Thus, the physical question of where the balloons land is an important consideration in their effectiveness.

Regions of North Korea Reachable by Balloon

As already mentioned, Bradley K. Martin (2004) interviewed a number of North Korean defectors in the 1990s who had been influenced by South Korean balloons landing in the border region near the DMZ. However, Jung Jin-Heon (2014) reported that in field research among North Korean defectors in 2006–2007, he rarely met anyone who had directly encountered South Korean leaflets. A large majority of North Korean defectors come from the region bordering China, presumably because the Chinese border is easier to cross, and leaflet balloons seldom reach those regions.

Eric Foley (VOM Korea, 2014) related an anecdote from a North Korean who traveled to China: "She told us that people go down to the border area, which is white with flyers, she said, and they go down there to be able to gather these flyers for fuel, originally, but then they start to read the flyers, and that's how many of them come to hear the Gospel for the first time."

The balloons are said to typically make it only a few miles over the border, but sometimes can land as far away as Pyongyang (Farivar, 2014). As already noted, many of the NGOs aim for flight times of three to four hours, but Vu (2007) reported typical flight times between 20 minutes and one hour. A February 2015 FFNK balloon launch that was tracked by GPS landed close to the launch site inside South Korea ("Launching Balloons into North Korea: Propaganda over Pyongyang, 2015). Another balloon launch tracked by GPS flew for 50 minutes and landed 19 miles from the launch site, 16 miles inside the North Korea border (VOM Korea, undated).

The choice of launch locations is a point of contention. Choosing to launch balloons from highly visible sites, such as Imjingak, has the drawback that police or counterprotestors may prevent the launch, especially with advance publicity. Wind direction may also make such sites poor starting points to fly balloons into North Korea. On the other hand, creating a spectacle on the south side of the border may be useful to attract media attention and obtain donations and support. Park Sang-Hak of FFNK has been criticized repeatedly for conducting high-profile launches that may not be effective in actually delivering leaflets to North Korea. Park has stated that FFNK invites the press to about 30 percent of its balloon launches (Kang Jin-Kyu, 2014). He has also estimated that only 30 percent of his balloons actually get across the border (Han and Kim, 2012).

Lee Min-bok stated that all of the NKCA and NKDW balloon launches are conducted in secrecy and suggested that the government should prohibit public balloon launches (Bae, 2014). He also claimed that "the best place for leaflet launch is Baengnyeong Island" (Han and Kim, 2012).

To assess where NGO balloons are likely to deliver their payloads, we modeled horizontal balloon flights from Imjingak (37.8895° N, 126.7402° E) and from Baengnyeong Island (37.9590° N, 124.6654° E). Balloon trajectories were computed using the Hybrid Single-Particle Lagrangian Integrated Trajectory (HYSPLIT) model developed by the National Oceanic and Atmospheric Administration's Air Resources Laboratory (Stein et al., 2015; Rolph, Stein, and Stunder, 2017).

In this assessment, we did not model the initial balloon ascent, but we assumed that each balloon had ascended to a stable altitude of 3,000 m and simulated the rest of the balloon flight from there, with horizontal motion due to winds and subsequent changes in altitude corresponding to any changes in atmospheric pressure (see Draxler, 1996). We simulated trajectories for 8,760 balloons released on the hour, every hour, every day in the year 2015. The meteorological data came from the Global Data Assimilation System, in data grids with one-degree resolution in longitude and latitude.

Figure 2. Days with Favorable Winds in 2015

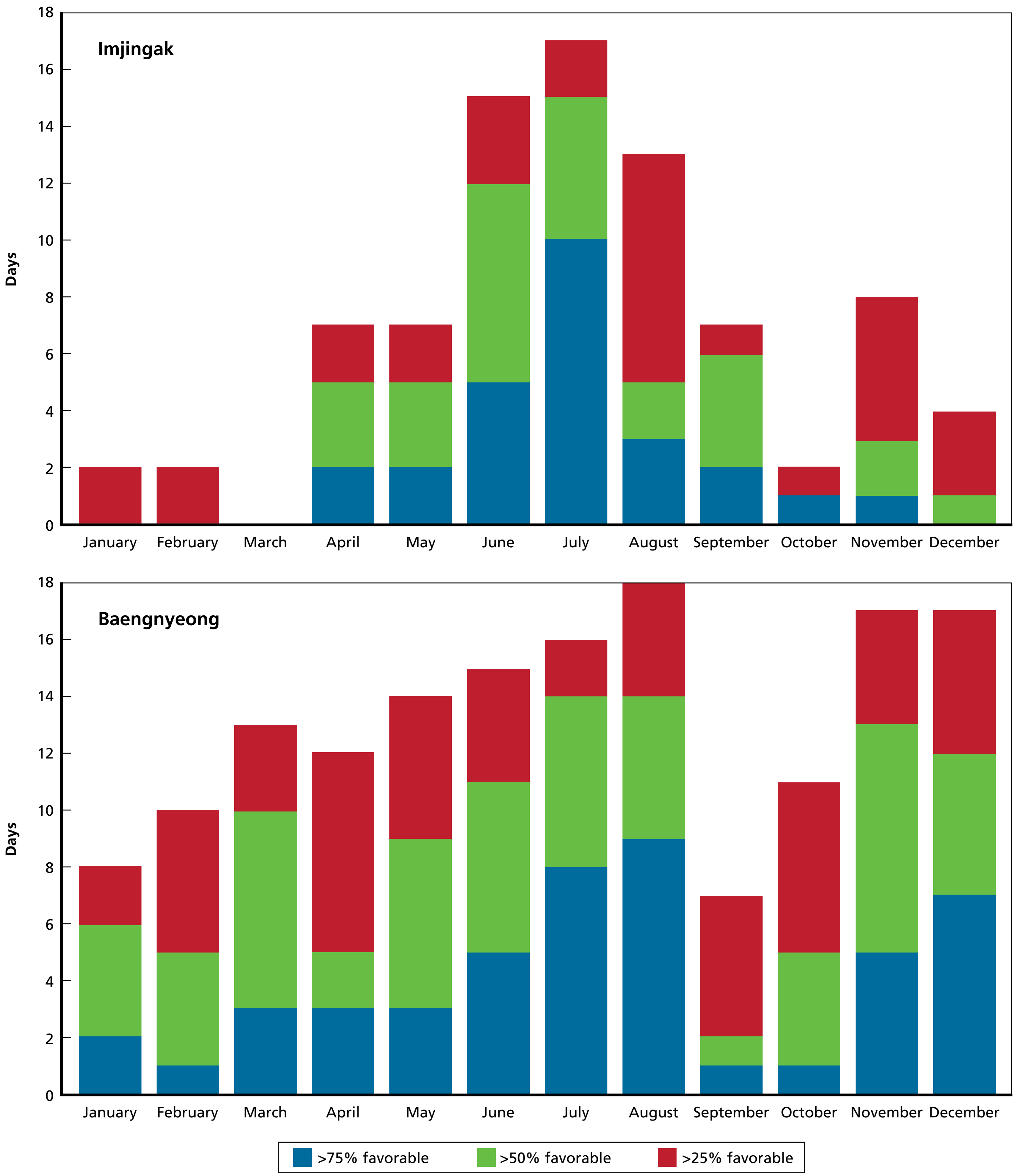
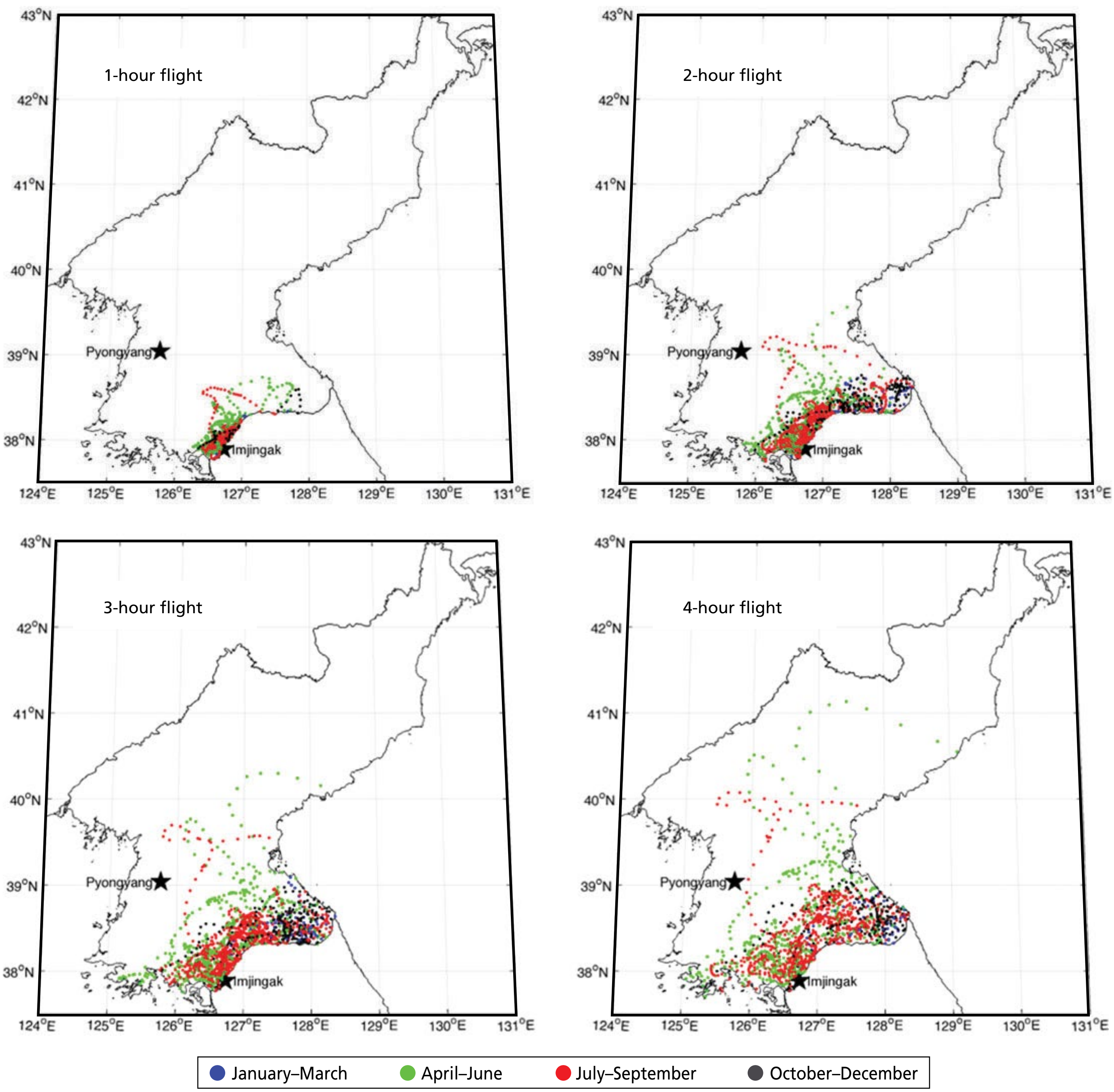


Figure 2 shows the number of days in 2015 that were favorable for launch from each location. If 24 balloons were launched in a day at one-hour intervals, a day was considered at least 75 percent favorable if at least 18 of the balloons were predicted to be inside North Korea after four hours' flight, at least 50 percent favorable if at least 12 of the balloons were inside North Korea after four hours' flight, and so on. (Of course, no one would expect NGOs to actually launch balloons blindly and robotically at one-hour intervals. An NGO balloon launch might be completely successful on a day with a single short favorable window, as long as all balloons were launched during that window. However, days when winds are consistently favorable for many hours are presumably more likely to lead to operationally successful launches.) Figures 3–6 show where the balloons entering North Korea would be projected to arrive after flight times of one to eight hours.

We draw the following observations from Figures 2–6:

Figure 3. Simulated Destinations of Balloons Launched from Imjingak (1–4-Hour Flight at 3,000 m)



- In the summer months of June through September, conditions at Baengyeong Island and at Imjingak were about equally favorable. However, there were almost no launch opportunities from Imjingak in the winter months, whereas there were at least a few good days each month all year long from Baengnyeong Island.
- Park Sang-Hak's self-assessed 30-percent success rate for FFNK balloons is likely the result of launching on unfavorable days—higher success rates should be achievable by launching more judiciously on favorable days. For example, because there were very few favorable launch opportunities from Imjingak in February 2015, hopes should never have been high for FFNK's February 2015 launch from the mainland (which, indeed, resulted in balloons landing inside South Korea).
- The majority of balloons launched from Imjingak remained in a southern region close to the border—but there were occasional opportunities for a balloon to be carried near

Figure 4. Simulated Destinations of Balloons Launched from Imjingak (5–8-Hour Flight at 3,000 m)

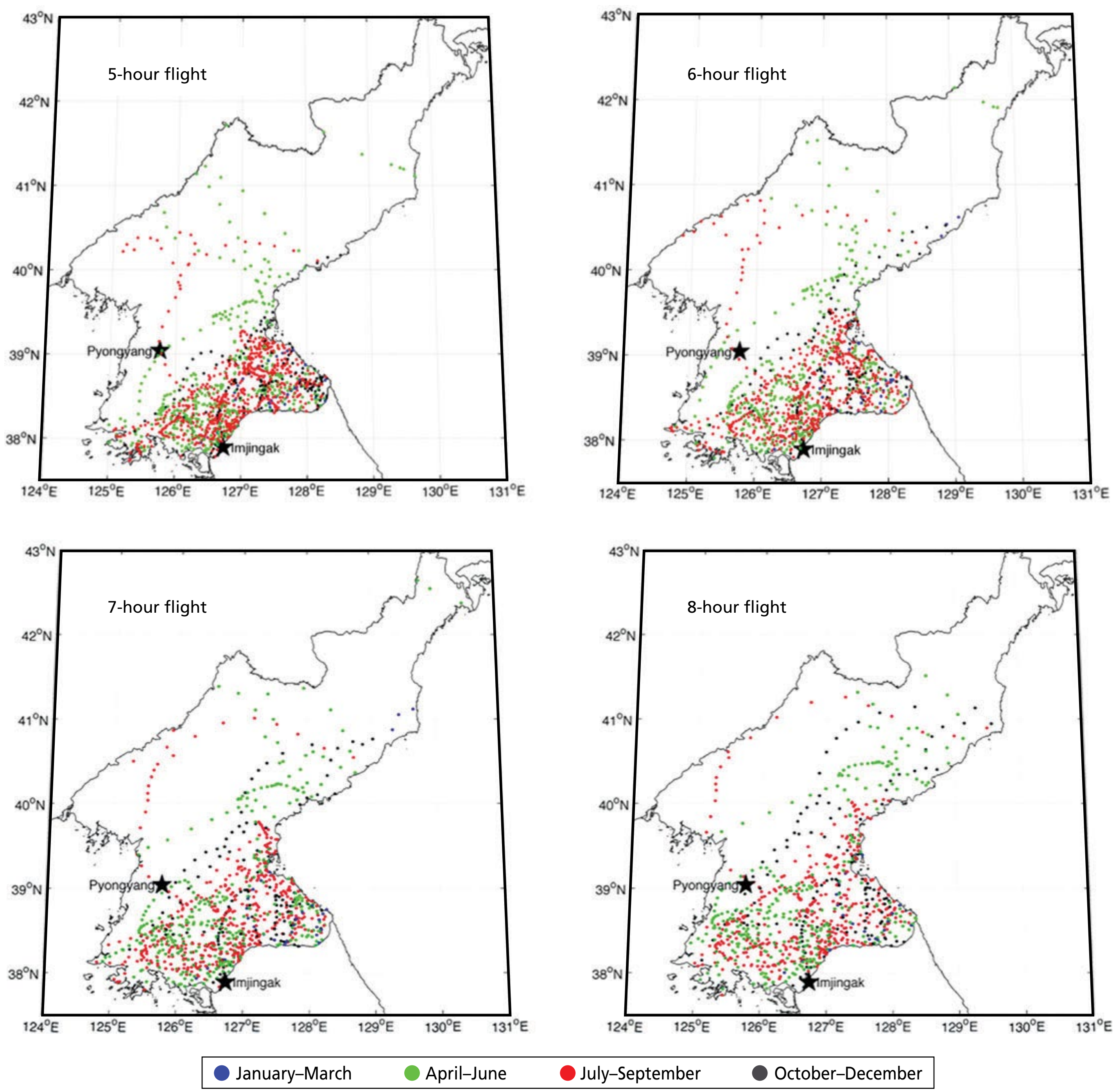
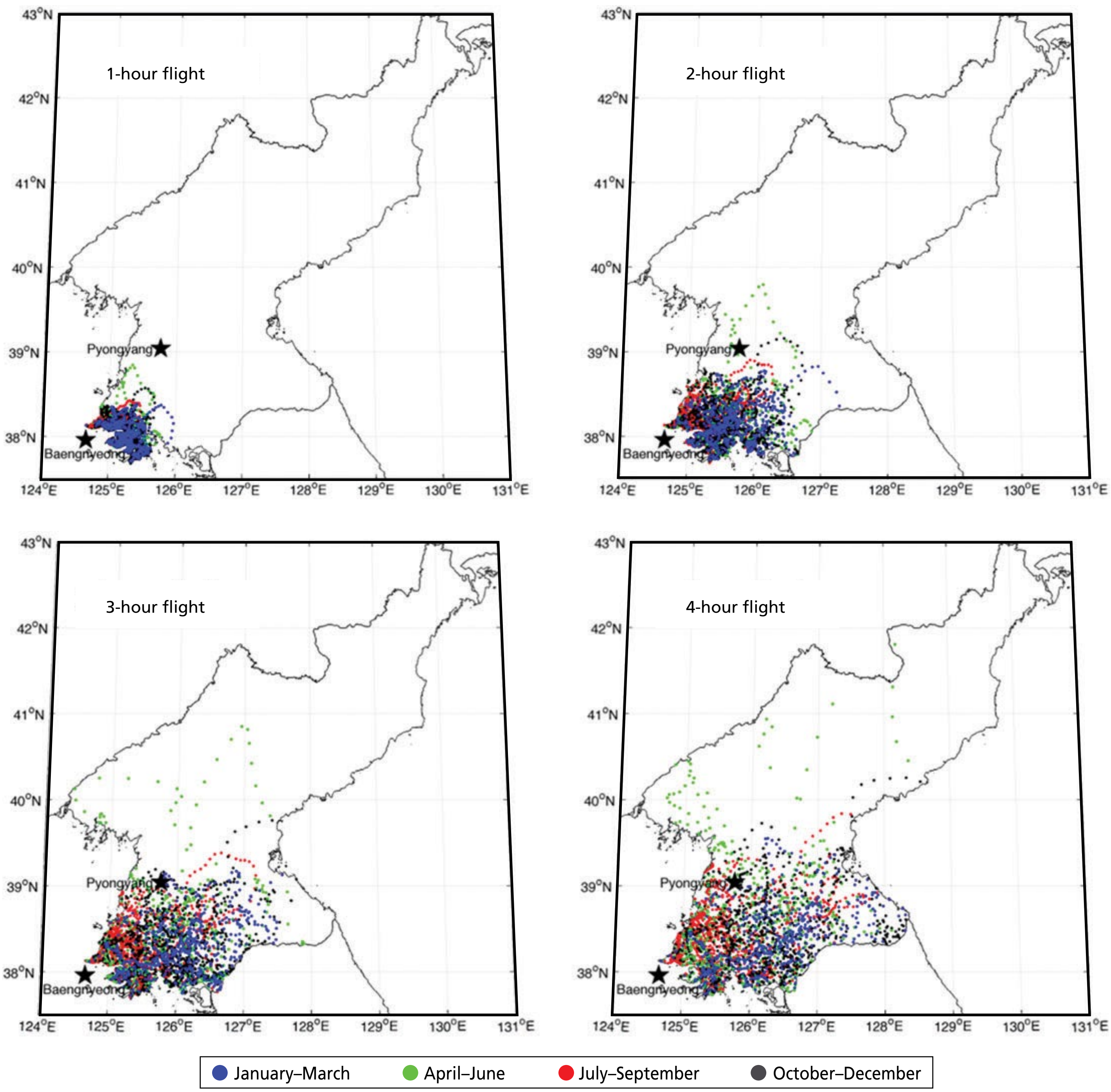


Figure 5. Simulated Destinations of Balloons Launched from Baengnyeong (1–4-Hour Flight at 3,000 m)

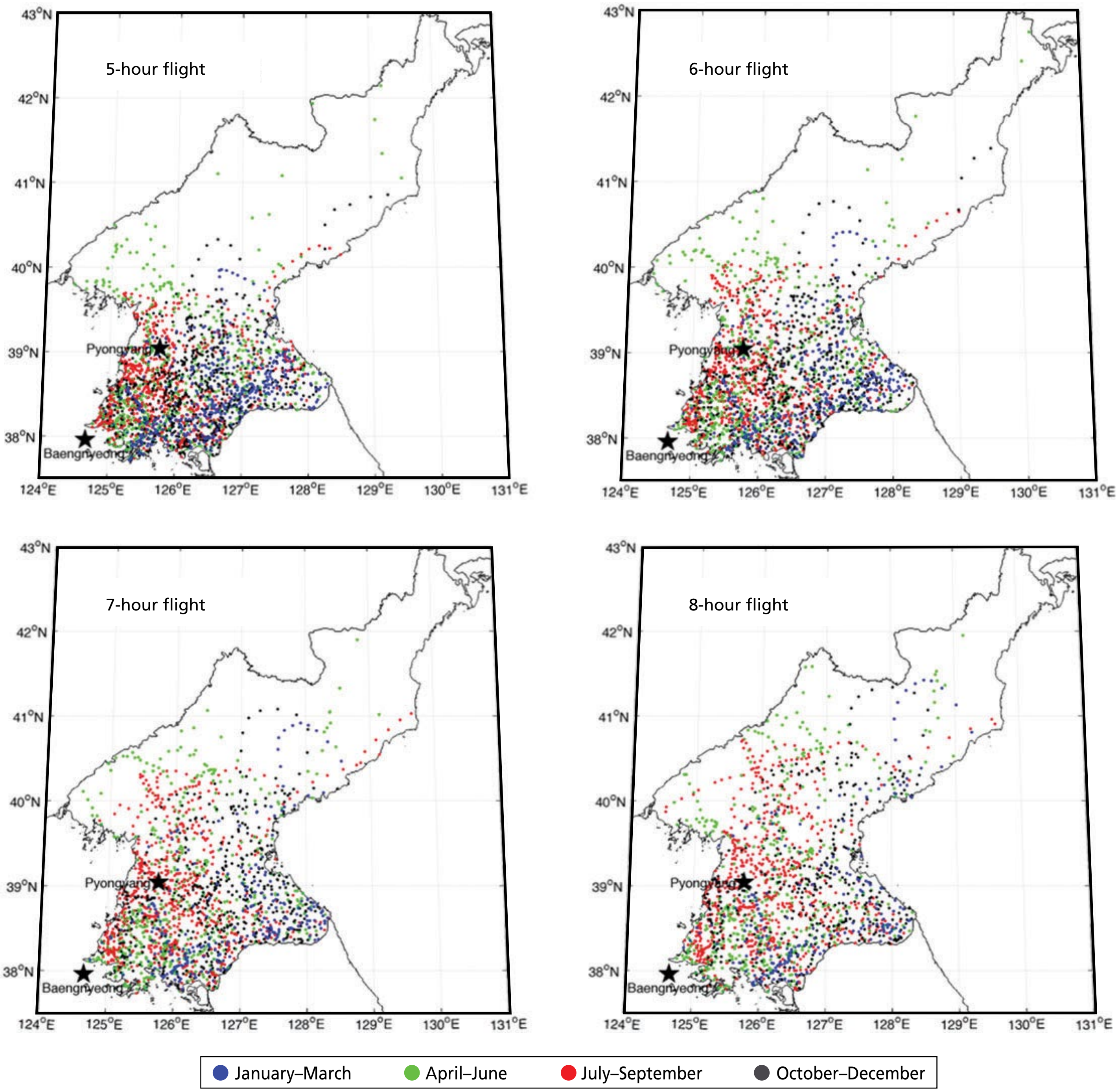


Pyongyang or further north. Generally speaking, balloons launched from Baengnyeong Island were distributed across a larger region. Regardless of launch site, longer balloon flight durations would enable reaching a greater range of destinations in North Korea instead of merely saturating the border region.

Comparison with Cold War Balloons in Central and Eastern Europe

It is interesting to compare the Korean balloons with balloons funded by the CIA and launched by the Free Europe Press (FEP) to deliver propaganda across the Iron Curtain in a series of operations between 1953 and 1955. FEP used several different types of balloons, but those most similar to the ones used by Korean NGOs were polyethylene pillow-shaped

Figure 6. Simulated Destinations of Balloons Launched from Baengnyeong (5–8-Hour Flight at 3,000 m)



balloons of sizes up to 10 × 13 ft, carrying between one and eight pounds (0.5–3.6 kg) of leaflets, and flying at altitudes of 6,000–9,000 m (Steiner, 1991). These balloons used blocks of dry ice as timers: The weight of the ice kept a carton of leaflets upright until the ice sublimated, at which time the carton of leaflets would tip over and be spilled. The timing of the leaflet drop could be calibrated by adjusting the size of the dry ice block (Michie, 1963).

This polyethylene-pillow type of balloon was used in Operation Focus to fly leaflets from West Germany over neutral Austria into Communist Hungary. It was chosen to enable long-range flight of hundreds of miles, in contrast with shorter-range rubber balloons that burst or ruptured at high altitude and were used to drop leaflets over Czechoslovakia (Michie, 1963).

Balloon Altitude Control Methods as a Key to Extending Range

Balloons Intended to Ascend to Rupture

As a balloon rises, the atmospheric pressure external to the balloon falls. If the balloon is not vented, the gas inside the balloon will either increase in volume (if the balloon is slack or extensible) or place stress on the skin of the balloon. Meteorological sounding balloons made of latex are designed to rise and expand until they burst. They typically rise at about 300 m per minute and, depending on size, burst at altitudes between 20 and 40 km (Hwoyee, undated; High Altitude Science, undated), implying flight durations of between one and two hours.

This type of balloon was used by FEP in the 1950s to send leaflets into Communist Czechoslovakia in Operation Prospero and Operation Veto (Michie, 1963). The bursting of the balloon itself was the release mechanism that dropped the payload of leaflets. In 2014, VOM Korea adopted the same strategy and began using latex weather balloons of this type to deliver Bibles, moving away from the cylindrical plastic balloons used by other Korean NGOs (VOM Korea, 2014). As previously mentioned, VOM Korea (undated) reports that one of its balloons flew for 50 minutes and landed 19 miles from the launch site and 16 miles inside North Korea. VOM Korea's website does not explicitly state that that balloon was latex and designed to ascend to the bursting point, but that would be generally consistent with the timeline and the flight duration.

Simple Superpressure Balloons

The plastic cylindrical balloons used by NKCA, FFNK, and North Korea Peace are intended to stay aloft for at least three or four hours at an approximately constant altitude before their payloads are released by some type of timing device. As far as can be determined from photographs, the balloons are fully sealed bags and are therefore depending on a "superpressure" strategy to keep a constant altitude.[7] In this approach, the balance among payload weight, initial lifting gas pressure, and balloon skin strength is chosen so that the balloon becomes fully inflated somewhat below the intended operating altitude. As the balloon continues to rise to the operating altitude, the pressure inside the balloon exceeds the outside atmospheric pressure; the difference is called the *superpressure*. Because the volume of the superpressure balloon does not change with small perturbations in altitude, superpressure balloons can, in principle, stay aloft for multiple days, even weeks.

A superpressure balloon requires that the balloon skin is strong enough to contain the excess pressure without stretching or bursting. As noted in Table 2, the Korean NGO's polyethylene balloons can contain a superpressure in the range of 4,500 to 5,600 Pa, or between 6.4 percent and 8.0 percent of the expected ambient pressure at 3,000 m altitude. This margin is not very large when compared with, for instance, the changes in pressure that may occur inside the balloon due to changes in temperature over the course of a day (Yajima et al., 2009).

Amateurs in the ballooning community outside South Korea have often found it difficult in practice to realize long flight times with superpressure balloons (Bowen, 2011). Failures to precisely calibrate the launch conditions, take into account pressure increases related to solar absorption, or correctly construct the balloon seams often lead to the balloons bursting. If the NGO balloons are sometimes falling short of their planned flight durations, it may be because the margin for error with the superpressure approach is too small. In other contexts, superpressure balloons are often constructed of Mylar film, which is about three times stronger (DuPont Teijin Films, 2003) and would provide three times more margin of safety than the greenhouse film used by Korean NGOs, but would cost ten times as much.

Consider again the polyethylene balloons launched by FEP into Hungary in Operation Focus:

> For the plastic pillows, girls in the "circulation department" loaded leaflets in the cardboard boxes, while men . . . inflated the balloons with hydrogen, attached the loaded boxes and the dry ice containers and then, moving to the open doorways, gave each balloon a slight push to send it up and away, headed for the Iron Curtain. (Michie, 1963)

Contrast this with with the rubber balloons launched into Czechoslovakia in Operation Prospero and Operation Veto:

> The rubber balloons are launched just outside the trucks. . . . Unlike the gently drifting pillows, they streak upwards with great force. The rubber balloon crews call them "goomies." At 30,000 feet, well over Czechoslovakia the rubber balloons explode releasing thousands of leaflets.
>
> —*Abbot Washburn to the Penn Yan, N.Y.,* Chronicle-Express, *September 20, 1951 (Friedman, undated)*

It is significant that the "pillow" balloons, which were simple superpressure balloons intended to fly for long distances, only gently drifted upward with a push, whereas the rubber balloons, intended to explode at 30,000 feet, had considerable free lift and ascended rapidly from ground level. The free lift at ground level is proportional to the superpressure at the balloon's intended maximum altitude; a powerful upward acceleration from ground level, therefore, suggests that the balloon will be highly stressed and perhaps ruptured by the superpressure at high altitude. In photos and videos of FFNK balloon launches in South Korea (e.g., "Launching Balloons into North Korea: Propaganda over Pyongyang," 2015), the polyethylene balloons appear to be significantly inflated at launch and to depart from the ground with significant velocity. Thus, while the balloons are *intended* to be simple superpressure balloons and not to burst until after a timer has released the leaflets, it may be that, in at least some cases, they are overinflated, making them likely to rupture on ascent.

In light of all this, it is interesting to consider that Vu (2007) reported that balloons launched by Lee Min-bok's NKCA had typical flight times between 20 minutes and an hour, that Lee Min-bok asserted that "the recent [antiaircraft gun] engagement occurred because one of the balloons I sent up on Oct. 10 lacked gas and flew low" (Bae, 2014), and that VOM Korea is investing in a more precise hydrogen metering device (Dillmuth, 2015).

It is interesting to note that the balloons of Operation Focus carried only a fraction of the payload that Korean NGO balloons carry and flew two or three times higher. Because absolute air pressures are lower at higher altitude, the required superpressure is also lower compared with the strength of the balloon skin, and there is less chance that a properly inflated superpressure balloon will be accidentally ruptured by unanticipated pressure variations. The Korean NGO balloons could likewise fly twice as high (6,000 m) if they each carried half as many leaflets and might be less likely to burst. An altitude of 6,000 m would also take the balloons out of reach of most North Korean antiaircraft guns.[8]

However, in addition to the reduction in payload delivered per balloon, another drawback to seeking higher altitudes is that the winds may be less favorable on average, partly depending on the launch location. (Presumably, the 3,000 m operating altitude of the Korean NGO balloons was chosen with wind direction as a primary criterion.) For example, Figure 2 showed that July 2015 was a favorable month for launching balloons into North Korea at 3,000 m altitude from both Baengnyeong Island and from Imjingak. Table 3 shows that there were fewer launch opportunities with favorable winds at 6,000 m altitude: this was true of both launch sites, but Imjingak was more severely affected than Baengyeong Island.

Zero-Pressure Balloons

Another strategy to avoid balloon rupture is to eliminate stress on the balloon skin by creating a one-way duct or valve that will release lifting gas from the balloon if the interior gas pressure at the duct exceeds that in the atmosphere outside. A balloon of this type will not burst. The lifting gas of this type of balloon does not have to be as carefully metered at launch because the balloon can be "excessively" inflated at ground level and the excess gas will be vented at altitude. Amateurs have generally had more success flying zero-pressure balloons than superpressure balloons for flights of less than 24 hours (Bowen, 2011).

The downside is that after a zero-pressure balloon has vented some lifting gas through the duct, it is no longer stable against a loss of altitude—a drop will lead to higher atmospheric pressure that will reduce the balloon volume, which will lead to a further loss of buoyancy. For example, balloons lose about 10 percent of their buoyancy because of lower pressure at night, and this "sunset effect" would tend to make zero-pressure balloons crash at sunset (Yajima et al., 2009).[9]

Either a latex or polyethylene balloon could be converted to a zero-pressure balloon by the addition of a $20 lightweight

Table 3. Days in July 2015 with Favorable Winds at Different Altitudes from Different Sites

Launch Site	Balloon Altitude	Number of Days with 75%+ Favorable Wind[a]	Number of Days with 50%+ Favorable Wind	Number of Days with 25%+ Favorable Wind
Baengnyeong Island	3,000 m	8	14	16
Baengnyeong Island	6,000 m	4	6	12
Imjingak	3,000 m	10	15	17
Imjingak	6,000 m	1	2	5

SOURCE: Simulation using HYSPLIT with Global Data Assimilation System data for July 2015.

[a] A day with "75%+ favorable wind" means that if balloons were flown at that altitude from that launch site on that day at regular one-hour intervals, then 75 percent of the balloons would be projected to be inside North Korea after a four-hour flight.

pressure relief valve at the neck of the balloon. Since NGO balloons would benefit from flying more reliably for periods of up to 24 hours but do not necessarily need to fly through sunset, a zero-pressure design appears to be a good option for carrying out flights deep into North Korea, and more NGOs may adopt such a design in future. A zero-pressure balloon can operate at any altitude, whether that altitude is chosen for the most favorable wind direction or to avoid antiaircraft defenses.

VULNERABILITY TO ANTIAIRCRAFT GUNS

As previously mentioned, North Korea fired about ten antiaircraft rounds at an NGO balloon in October 2014 (Kang, 2015). We considered the chances of success of this strategy. North Korean antiaircraft guns include the ZPU-1, ZPU-2, and ZPU-4 towed antiaircraft guns, originally Soviet Army designs but now locally built in North Korea. The ZPU guns fire 14.5-mm ammunition with a projectile weight of 64.4 g, a muzzle velocity of 1000 m/s, maximum altitude of 5,000 m, and maximum range of 8,000 m (Jane's, 2015). From these figures, we estimated the overall envelope in which the ZPU guns could hit balloons, illustrated in Figure 7. To plot the bullet trajectories for various firing angles as shown in Figure 7, it was necessary to make some assumptions about the drag coefficient of the 14.5-mm bullets. Our assumed drag profile, shown in Figure 8, is a "typical" bullet drag profile described by Carlucci and Jacobson (2014), but reduced by 25 percent to achieve the stated maximum altitude and maximum range with the stated muzzle velocity.

Shots from a gun of this caliber might typically be dispersed over an angle with standard deviation of about 1.2 milliradians in both bearing and elevation (Pugh, 2004), so even assuming the gunner has corrected for wind and trained the gun on the balloon with maximum accuracy, one would expect to take a number of shots to hit a balloon that is 2 m in diameter, as illustrated in Figure 9. The number of shots in Figure 9 is a low estimate—a gunner might need initial calibration shots, and wind conditions could increase the dispersion of the bullets. It is quite plausible, then, that ten shots from the North Korean gun would be needed to bring down one balloon at a range of a few thousand meters. From an economic standpoint, the exchange would appear to be roughly even; i.e., the cost of the ammunition fired would be of the same order of magnitude as the cost of the balloon.

However, if North Korea began frequently shooting down the balloons, the NGOs could adjust their strategies to make

Figure 7. ZPU Anti-Aircraft Fire Trajectories

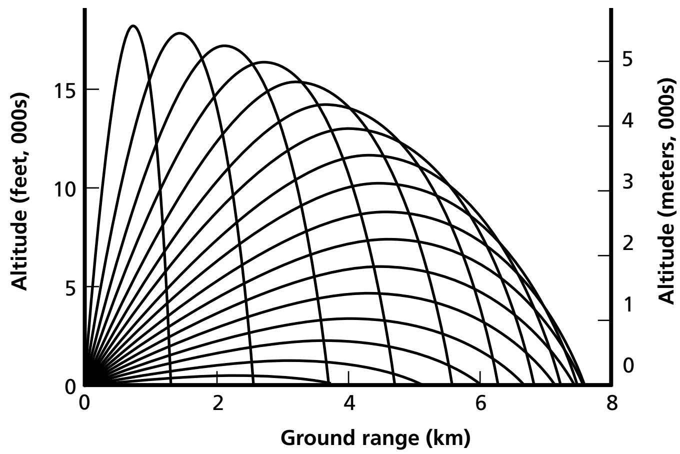
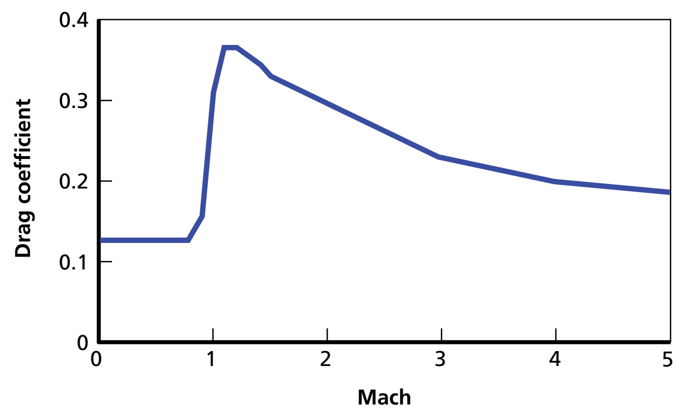
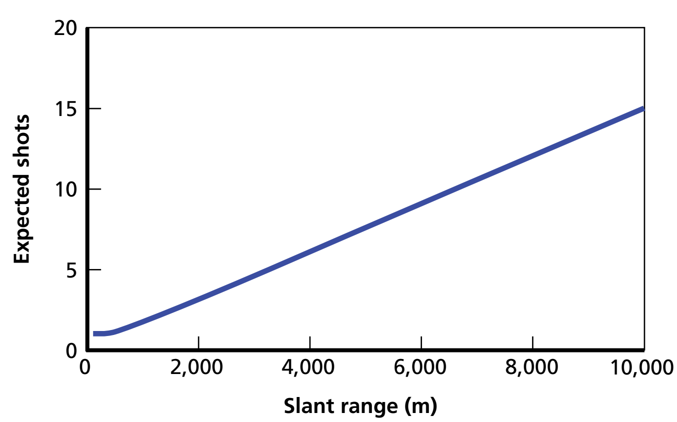


Figure 8. Assumed Drag Coefficient for 14.5 x 114 mm Antiaircraft Bullet



SOURCE: Based on drag coefficient for a "typical" bullet per Carlucci and Jacobson (2014).
NOTE: We reduced the drag coefficient by 25 percent to obtain reported ZPU range and altitude performance.

Figure 9. Expected Shots to Hit a 2-m-Diameter Balloon as a Function of Range



SOURCE: Typical antiaircraft gun precision estimated from Pugh (2004).

defense more expensive for North Korea. Although simple to construct, the tall cylindrical balloons are not an inherently efficient shape to begin with, in terms of material weight for a given payload. One consequence of this is that the NGOs could cut the polyethylene cylinders to a shorter height (but equal diameter) and launch a larger number of smaller balloons at the same altitude, carrying smaller individual payloads but the same total payload of leaflets in aggregate, and with about the same overall material cost. This could make it several times more difficult and expensive for North Korea to shoot down all the balloons.

Another, perhaps more effective, alternative would be for the NGOs to fly smaller loads of leaflets at 6,000 m altitude, above the reach of the ZPU antiaircraft guns. As already described, this would have some operational costs for the NGOs, reducing the efficiency of their leaflet delivery, but it would require North Korea to use low-speed aircraft to engage the balloons, at great expense.

DIRECTIONS OF TECHNOLOGICAL DEVELOPMENT

A number of Korean NGOs have experimented and improved their balloon techniques over time and are actively interested in further improvement. In considering what future developments are likely, recall that the material costs of the current balloons are on the order of $100, that the total cost of launching each balloon is $500 according to Park Sang-hak, and that Park Sang-hak's own estimate is that only 30 percent of his balloons successfully cross into North Korea. Therefore, technological improvements to the balloons that substantially improve the effectiveness of leaflet delivery might be worthwhile even if they cost up to a few hundred dollars per balloon and/or take up a significant fraction of the payload weight of the balloon.

More-Reliable Balloons

An obvious difficulty is the poor knowledge of what happens to any given balloon after launch. Different NGOs are obtaining some feedback by attaching tracking devices to some balloons ("Launching Balloons into North Korea: Propaganda over Pyongyang," 2015; VOM Korea, undated).

A satellite GPS tracker sometimes employed by balloon hobbyists weighs 118.3 g, including the weight of four AAA batteries, and costs $100 with a one-year tracking contract (Spot LLC, undated). The weight, therefore, is modest compared with the payload of NGO balloons, but it would be expensive to track every balloon. However, tracking one balloon in a launched flotilla is probably an affordable and effective proxy to tracking all launched balloons.

Some of the NGOs we have mentioned are also exploring using meteorological software to predict the flight path of their balloons (Gryboski, 2015) and attempting to influence their balloons' directions by varying the payload mass and hydrogen volume (Dillmuth, 2015). As we have demonstrated, meteorological software to predict balloon trajectories at high altitude is freely available and can make a significant difference in identifying favorable launch times.

Without the feedback that could come from systematic tracking, it is difficult to be sure how far the balloons are really traveling on average. But based on the small amount of anecdotal data available, it seems that typical penetration distances may be quite short and only the southern border region of North Korea may be frequently reached by leaflet balloons. However, as illustrated in Figures 4 and 6, there is the theoretical potential to do much better and reach much larger regions of the country if balloons could remain aloft for even a significant fraction of a day.

As discussed earlier, superpressure balloons might remain aloft for longer if the balloon payload weight and the amount of hydrogen lifting gas were both reduced so that the balloon had an equilibrium flight altitude of 6,000 m or higher, similar to that of the successful Operation Focus balloons used in Europe during the Cold War. However, this would halve the number of leaflets or other goods carried per balloon, and the prevailing winds on the Korean peninsula may be less favorable at higher altitudes.

A possibly better solution is to install a cheap, lightweight pressure relief valve or sleeve at the neck of each balloon so that the balloon will never rupture because of excess internal pressure. This would reduce the danger of operator error in balloon launching because the balloon could be "overfilled" with hydrogen (which is cheap) and the result will not be failure of the balloon. A balloon of this type should be able to stay aloft until sunset.

Hexacopters

Since April 2015, the group No Chain, founded by Jung Gwang-il, has been delivering secure-data cards and flash drives from China to North Korea by hexacopter drones that can follow a predetermined route and drop their payloads at a designated point (Anna, 2015; Park, 2016; Jung, 2016), where they can be retrieved by contacts inside North Korea (Nordlinger, 2016). Since May 2016, No Chain has said that the hexacopter deliveries continue but declined to say what country they are launched from (Park, 2016).

The DJI Spreading Wings S900 is representative of a large, commercially available hexacopter available at a cost of $1,850 (DJI, undated). The DJI S900 can hover with a 2-kg payload for 18 minutes powered by a 6S 12000 mAh battery. The maximum speed of the unladen DJI S900 is 16 m/s. Therefore, an upper limit on the flight radius of the hexacopter is 8.6 km (17 km round-trip). At maximum power draw, however, the battery would be exhausted in six minutes, resulting in a flight radius of 2.9 km (5.8 km round-trip). The actual maximum operating radius of the hexacopter is somewhere between these two distances. All these distances are beyond the typical 1–2 km line-of-sight control range and would require some automatic GPS-following flight by the hexacopter.

North Korea has intermittently jammed GPS signals since 2010, seemingly often in reaction to U.S.-South Korea joint military exercises (Shim, 2016). Most recently, South Korea complained in April 2016 that North Korea was jamming GPS from Pyongyang and from four other locations—Haeju, Yonan, Kumgang, and Kaesong—near North Korea's southern border (Nichols, 2016). GPS jamming could disrupt hexacopter operations across the southern border, although one could imagine technical workarounds, such as flight by dead reckoning or a second controller on the North Korean side that reacquires control of the hexacopter after it has crossed the DMZ. In any case, performing a round-trip across the 4-km width of the DMZ would be somewhat challenging for a commercial hexacopter, and flying across the China–North Korea border is presumably easier.

Commercial hexacopters may be a useful way for two groups close to the border to exchange material—in this way, they may provide a method of cross-border smuggling that is safer than ground-based smuggling (Jung, 2016). However, hexacopters will not provide the deep penetration into North Korea that balloons are potentially capable of providing.

Fixed-Wing Powered Unmanned Air Vehicles

Fixed-wing drones would be a natural variation on the hexacopter concept that could achieve increased range, penetrating 100 km—or conceivably farther—into North Korean airspace, but would require greater vehicle cost and some greater operator ability. Northward-flying drones would mirror the small fixed-wing drones that North Korea is known to have flown into South Korea. However, considering that the costs of these vehicles run to thousands of dollars, the Korean NGOs could not readily afford to lose them. The success of this risky strategy would depend on the ability of the drone to repeatedly fly over North Korean defenses and return.

Gliders

Releasing a glider from a high-altitude balloon has repeatedly been demonstrated by hobbyists (e.g., Windestål, 2013) and students (Siepierski and Kissel, 2015), so it would be a plausible innovation for the Korean NGOs to adopt. A decent glider might conservatively travel a distance equal to ten times the distance of fall, so a glider could travel 30 km from a balloon at 3,000 m altitude, or proportionally farther from a balloon at higher altitudes. Hobbyist autopilot electronics, at a cost on the order of $200, could guide the glider to a relatively precise landing destination. The additional expense might have no point for quasi-random leaflet drops, but might be worthwhile for new types of delivery—for example:

- Messages could be tailored to specific audiences.
- Ongoing messages that arrive with some reliability repeatedly in the same neighborhood might be more effective.
- Contraband could be delivered to an agreed location, as with the hexacopter, but balloon-borne gliders could penetrate much deeper into North Korea than a hexacopter can.

Balloon-borne gliders could give a capability fairly similar to long-range fixed-wing drones and do so more cheaply. (If fixed-wing drones are reliably able to penetrate North Korean defenses, then they could be cheaper by flying and returning many times. On the other hand, if defenses are somewhat formidable, then expendable one-use gliders might be a more attractive idea.) The somewhat costlier glider-balloons would presumably be mixed with the existing cheaper balloons to complicate North Korea's responses.

Smart Balloons

Some NGOs focused on North Korea have reached out to Silicon Valley for help in developing other technologies to deliver information, including the possibility of "smart balloons" that would have some guidance system to enable more effective targeting (Greenberg, 2015b).

Active Control of Altitude

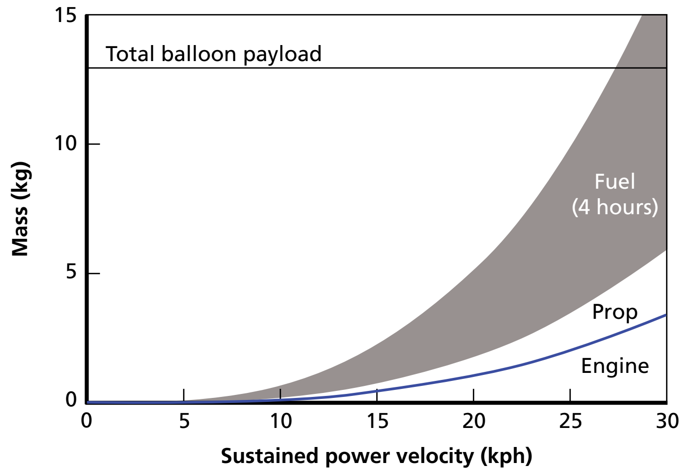
Active balloon altitude adjustment via a valve controlled by, for example, an Arduino microcontroller has been demonstrated by amateur balloonists and student groups (Basta et al., 2014; Siepierski and Kissel, 2015; Sushko et al., 2017). Dynamic adjustment of altitude to find a level with favorable wind direction is the main technique that manned balloons use to steer and is also the technique used by the automated communication balloons under development in Google's Project Loon. By taking a very circuitous route, a long-duration balloon can be steered with some precision to its destination: Google asserts that by making altitude adjustments as frequently as once every 15 minutes, it was able in early 2015 to fly a balloon for 10,000 km and arrive within 0.5 km of a desired point (Simonite, 2015). For balloon flights lasting less than one day, however, this technique does not offer much ability to counter the gross effects of prevailing wind direction and would seldom be able to turn an unfavorable launch day on the Korean peninsula into a favorable one.

Google's long-duration, controllable Project Loon balloons cost tens of thousands of dollars each—hundreds of times more than the simple balloons launched by Korean NGOs. It is not likely, therefore, that the NGOs will field an equally sophisticated technology in the foreseeable future. In the very long run, however, if Project Loon is successful and enters mass production, it is imaginable that Google or some other actor employing the same technology could steer long-endurance balloons through North Korean airspace. An interesting side effect of accepting very long, circuitous routes to the destination in North Korea is that the original launch of the balloon could occur anywhere in the world.

Dirigibles

Small motors could be added to the balloons currently being used to give them a method of horizontal propulsion. Small gasoline engines intended for model aircraft have a weight-to-power ratio of about 0.5 kg/kW and fuel consumption of about 0.4 kg/kWh. The mass of a gearbox and propeller together are estimated at 0.45 kg/kW and have a combined efficiency of η = 82 percent (Noth, 2008). Assuming that the balloon has the dimensions given in Figure 2 or Column C of Table 2 and that the coefficient of drag is equal to 1, Figure 10 shows the mass of the required engine/propeller/gearbox and the fuel mass required to drive the balloon at a given velocity at 3,000 m altitude for four hours. As shown in Figure 10, the balloon could be propelled at a velocity of more than 15 kph for four hours (or 80 km total distance) with a moderate fraction of the balloon's payload given over to propulsion and fuel. If the entire payload were given over to propulsion, a speed of about 27 kph could be sustained relative to the wind for four hours.[10] Only slow airspeeds would be achievable with the cylindrical balloons currently used because they are not aerodynamically shaped to be towed through the air. A model aircraft engine large enough to push the cylindrical balloon at 20 kph would cost about $200. A hobbyist GPS autopilot would also cost about $200. There would be additional costs for propellers, rudders, etc. These costs are of the same order of magnitude as the baseline cost of a leaflet balloon, but overall the cost and complexity of this approach are unattractive for the rather anemic performance gained.

Figure 10. Mass of Propulsor and Fuel to Sustain Cylindrical Balloon Velocity for Four Hours



Alternatively, if the NGOs switched to using aerodynamically streamlined balloons with a "blimp" shape, much lower drag and much higher speeds would be possible (Zahm, 1928). Commercially available unmanned blimps (Airship Solutions, undated; Nimbus Dirigibles, undated) can achieve airspeeds of 35–65 kph and would be less at the mercy of prevailing winds. However, the greater structural complexity of a streamlined blimp comes at a high cost. Commercially available outdoor blimps that could carry payloads comparable to the existing NGO balloons cost about $5,000 before the addition of any motors or steerable control surfaces (BlimpWorks, undated), so the cost of each balloon would be at least an order of magnitude greater than with the current methods. While blimps could enable precision delivery at longer ranges than a hexacopter, they would be expensive and relatively visible, and it would be worthwhile from North Korea's point of view to shoot them down.

There are much cheaper ways of making the balloons more effective (such as pressure relief valves), and if precision delivery is desired, the hexacopter and glider options will likely be more precise and stealthier, as well as cheaper (assuming the hexacopter survives to be used multiple times).

CONCLUSIONS

There is not much objective data to assess the success rate of balloons flown into North Korea. What anecdotal data are available are not always encouraging and suggest that the balloons often travel only a few miles over the North Korean border. This is somewhat puzzling, because conceptually similar balloons were successfully used to deliver propaganda to Communist Hungary in 1954 and reportedly were accurately and reliably flown for hundreds of miles. One reason might be that the Korean balloons are not always launched under favorable wind conditions. Another reason might be that sealed polyethylene balloons should contain only the minimum amount of lifting gas to provide a gentle takeoff. Photo and video evidence suggest that some balloons launched by Korean activists may be overfilled with lifting gas and are likely to burst in the lower atmospheric pressure prevailing at high altitudes. It is possible that these balloons would fly farther with more careful metering of lifting gas. Another attractive possibility would be to add a pressure relief valve so that any excess lifting gas is vented without rupturing the balloon. This would eliminate a difficult burden on launching personnel to allocate exactly the right amount of lifting gas.

The Korean NGOs that launch balloons into North Korea are explicitly interested in assessing the performance of the balloons (e.g., by GPS tracking) and in obtaining better control through predictive software or through guided vehicles, such

Table 4. Options for Low-Cost Airborne Delivery on Korean Peninsula

Technology	Demonstrated Employment	Estimated Cost	Advantages/Disadvantages
Simple superpressure polyethylene balloon at 3,000 m altitude[a]	• Technique currently used by most Korean activist groups • Conceptually similar to balloons used by CIA in Cold War Hungary	$100/balloon (materials)	• Most favorable payload-to-cost ratio • Multiday flights theoretically possible, but balloons might burst in flight much sooner than intended
Flying with reduced payload at 6,000 m altitude	• Employed by CIA in Cold War Hungary	Reduces payload by half	• Reduces chance of balloon bursting in flight, if lifting gas is appropriately measured • Avoids antiaircraft guns • May face generally less favorable wind layer over Korean peninsula
Latex balloon intended to burst at high altitude	• Standard meteorological balloons • Now used by VOM Korea to carry Christian materials • Conceptually similar to balloons used by CIA in Cold War Czechoslovakia	$150/balloon (materials)	• Suitable for relatively short flights • May give more consistent performance
GPS balloon tracking	• Employed by VOM Korea and FFNK	+$100 for tracker	• Provides means of feedback to assess success of other improvements
Software and high-altitude wind data to predict balloon flights	• Employed by North Korean Christian Alliance and VOM Korea	Freely available	• Useful to choose optimal launch sites and times and avoid wasted launches • More software may be available for latex-type balloons
Zero-pressure balloon with pressure relief valve	• Successfully demonstrated by amateur balloonists, but not necessarily by Korean activists yet	+$20 for pressure relief valve	• Prevents balloon from inadvertently bursting • Reduces need for precise metering of hydrogen at launch • May enable daylong flights • Balloons are likely to descend with falling temperature at sunset

Table 4—Continued

Technology	Demonstrated Employment	Estimated Cost	Advantages/Disadvantages
Hexacopter drone	• Utilized by No Chain group to cross China–North Korea border	$1,850/drone	• Can deliver payloads to precise locations • Low-flying and less visible than balloons • Suitable for very short hops back and forth across border • Lacks range and might have difficulty crossing DMZ
Fixed-wing drone	• Demonstrated by amateurs, but not by Korean activists yet	$5,000/drone	• Could provide precise deliveries over long ranges • Danger of losing expensive platform to North Korean defenses
Active control of balloon altitude	• Demonstrated at a simple level by amateur balloonists • Demonstrated at a sophisticated level by Google Project Loon	+$200 for GPS and microcontroller	• Provides marginal degree of steerability • Probably not of great use for single-day flights
Glider released from balloon	• Demonstrated by amateurs, but not by Korean activists yet	+$200 for glider with autopilot	• Like hexacopter, offers possibility for delivery of material to precise locations • Glider can penetrate much deeper into North Korea than hexacopter (but cannot return)
Dirigible	• Speculative	+$500 for guidance and propulsion +$5,000 for aerodynamic blimp	• Aerodynamic shaping of the balloon is expensive, but otherwise performance is anemic • Overall, a weaker idea than fixed-wing drones or gliders, which could provide destination control at less cost

SOURCES: Park (2014); FFNK (2015); Michie (1963); Bae (2014); VOM Korea (undated); VOM Korea (20140; "Launching Balloons into North Korea: Propaganda over Pyongyang" (2015); Yajima et al. (2009); Anna (2015); DJI (undated); Windestål (2013).

[a] Superpressure balloons are intended to maintain a positive internal pressure in flight without bursting. We do not here envision high-cost, highly engineered balloons but relatively simple pressurized bags.

as hexacopters. It seems very likely, therefore, that the airborne delivery of material into North Korea will improve. We assessed a variety of more-or-less plausible developments, summarized in Table 4. One idea that to our knowledge has not yet been tried by Korean NGOs but has been demonstrated to some degree by hobbyists—and is therefore plausible to implement in Korea—is payload delivery by a guided glider released from a high-altitude balloon. This idea is attractive because it combines some of the appeal of balloons—low cost, high altitude, long range—with the precision guidance of a drone.

To reiterate the most attractive ideas that could enable more effective airborne delivery of material deep into North Korea:

- Korean NGOs can probably improve their success rate by choosing launch conditions more judiciously, with the aid of high-altitude wind forecasts.
- Adding pressure relief valves to prevent overpressurization of the balloons seems like a cheap improvement that could enable better flight times and better penetration.
- The use of powered drones has begun with hexacopters and could be extended to longer-range drones. Because these platforms are relatively expensive, their success may depend on finding relatively undefended points to enter and exit North Korea.
- A balloon-released glider is a more exotic but not entirely undemonstrated concept that could combine some of the more attractive features of balloons and controlled drones.

NOTES

[1] Given the time period, the balloons these defectors encountered were likely sent by the South Korean government.

[2] Empirically, the volume of a cylindrical balloon of height *h* and radius *r* with "pillow ends" is approximately: $V \approx r^2 \pi h - 4.5\, r^3$ (Grass, 1962).

[3] This cost is based on an informal survey of greenhouse supply sources. Costs could be lower if the plastic were purchased in industrial quantities.

[4] The stress on the skin of a cylindrical balloon in the circumferential direction is $S_{circ} = \Delta P\, r/t$, where *r* is the radius of the balloon and *t* is the skin thickness (Grass, 1962). The stress in the axial direction is half as much: $S_{axial} = \Delta P\, r/(2t)$.

[5] Retail cost estimate of hydrogen gas from Siler (2008).

[6] The cost estimate of helium gas is from the U.S. Geological Survey (2015). Some news reports (for example, Kang, 2015; Kang Seung-Woo, 2014; Glionna, 2011) do refer to the NGOs' balloons as "helium-filled," but these reports are likely simply mistaken about the lifting gas in the bulk of balloon activity.

[7] In modern ballooning parlance, the term *superpressure balloon* may suggest a highly engineered system designed to achieve very high altitudes. We are, however, referring to the simple plastic bags at 3,000 m altitude used by Korean NGOs. By using the term, we do not mean to imply anything except that the balloon has an internal pressure higher than the external pressure at its cruising altitude.

[8] The altitude performance of North Korean antiaircraft guns will be addressed later.

[9] This descent could be halted by releasing some ballast or some of the payload (e.g., leaflets) and allowing the balloon to rise again to a new equilibrium altitude. If the balloon manages to fly through the night by releasing payload, then rising temperatures at sunrise would tend to push it back to higher altitudes; the balloon would fly higher than before, because of the reduced payload weight; more lifting gas would be vented; and at sunset the balloon would fall again. For the mission of delivering payloads from South Korea to North Korea, a multiday flight duration should not be necessary, so we do not need to consider the complexity of managing a multiday zero-pressure flight.

[10] The choice of a four-hour flight duration is arbitrary; a longer or shorter flight could be planned with a proportional change in the amount of fuel.

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About This Report

This report attempts to assess, based on open source reporting, the technological state of efforts by activists in South Korea to use balloons or small drones to air-drop political, religious, and humanitarian materials into North Korea, as well as how those efforts are likely to evolve as unmanned drone technology continues to improve and proliferate.

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