Breaking the Ice

Navigation in the Arctic

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Arctic navigation is becoming increasingly important, because oil exploration and normal shipping in the region are both on the rise. Navigation integrity is particularly important, because an accident could be very damaging to the sensitive Arctic environment. Thus, this article investigates the Arctic extension of space-based augmentation systems (SBAS) such as WAAS, EGNOS, and MSAS. More specifically, it analyzes the potential benefit of adding new SBAS reference stations for the far North, use of Iridium satellites to broadcast integrity information to the users, and multi-constellation GNSS to improve vertical performance.

The Arctic houses an estimated 90 billion barrels of undiscovered, technically recoverable oil and 44 billion barrels of natural gas liquids according to the U.S. Geological Survey. These potential energy reserves represent 13 percent of the untapped oil in the world.

Russia, Canada, and the United States plan to explore the Arctic for extensive drilling soon. At the same time, the Arctic is becoming more accessible to normal shipping because of global climate change. New summer sea lanes have already opened up, and projections of sea ice loss suggest that the Arctic Ocean will likely be free of summer sea ice sometime between 2060 and 2080.

The combination of undiscovered oil and climate change are driving a dramatic increase in the demand for navigation in the Arctic. In this article, we examine different approaches to improve accuracy and enable integrity in the Arctic, including the addition of more satellite-based augmentation system (SBAS) reference stations in or near the Arctic, integration of Iridium satellites with GNSS, and use of multi-constellation GNSS.

Russian nuclear ice breaker heading to the North pole.

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More SBAS Reference Stations

The Arctic is a sensitive environment, and thus navigation should have high integrity. For this reason, we are interested in extending SBAS coverage to serve this region.

At present, none of the three operational SBAS provide meaningful service in the far North. In fact, **Figure 1** shows the current SBAS availability coverage with vertical alert limit (VAL) equal to 35 meters, and horizontal alert limit (HAL) equal to 40 meters.

Figure 1 is based on two of the currently operating SBASes: the U.S. Wide Area Augmentation System (WAAS) and the European Geostationary Navigation Overlay Service (EGNOS). **Figure 2** shows the locations of the existing WAAS and EGNOS reference stations. The lack of adequate integrity coverage (less than 50 percent of the time) in the Arctic, as indicated by the

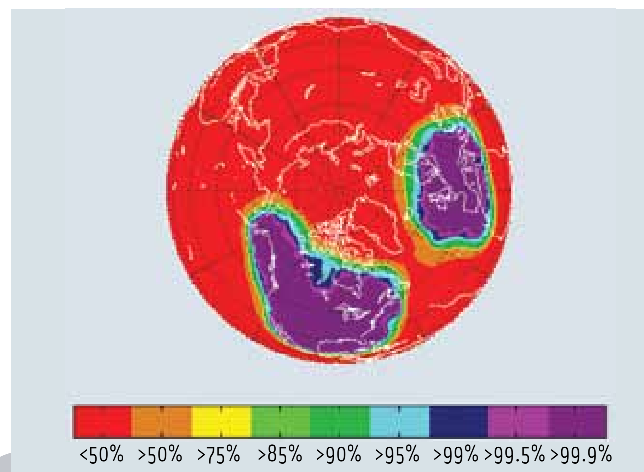

FIGURE 1 Current availability in the Arctic with VAL= 35 m and HAL=40m.

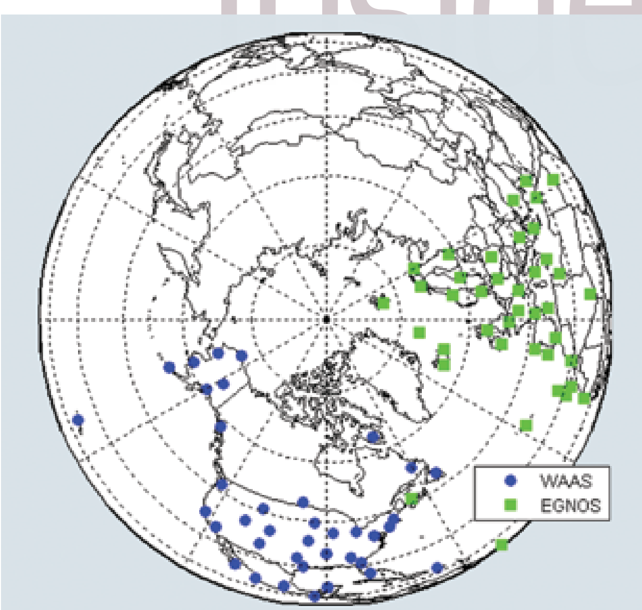

FIGURE 2 Locations of current WAAS and EGNOS reference stations

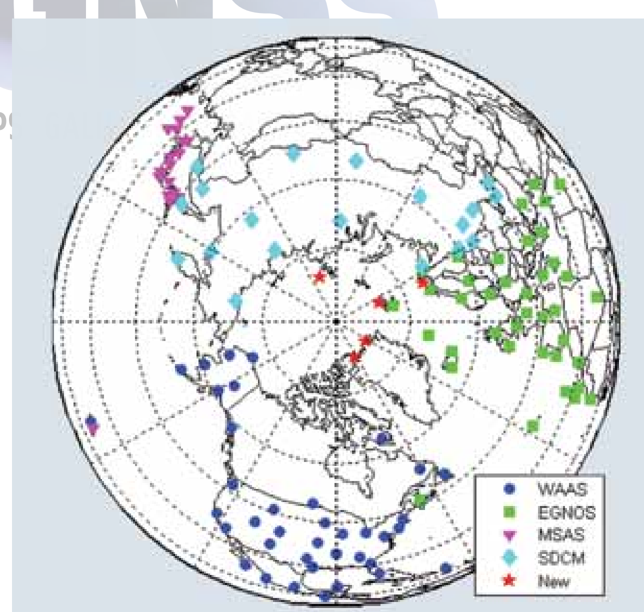

FIGURE 3 Reference stations from WAAS, EGNOS, MSAS, SDCM, and 5 additional stations.

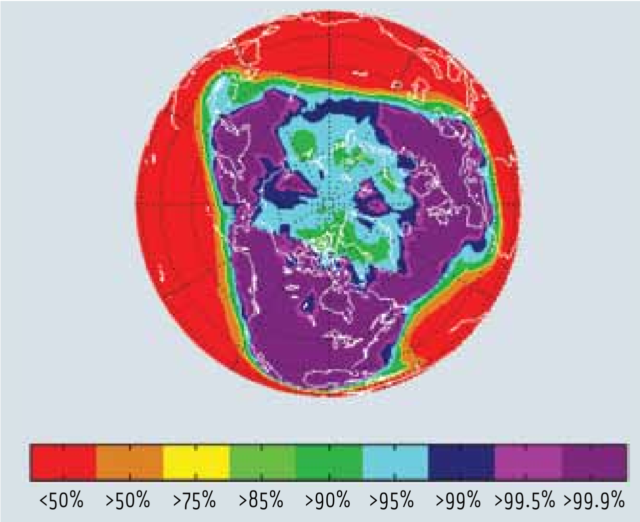

FIGURE 4 Both horizontal and vertical availability with VAL= 35 m and HAL=40m, assuming user connectivity and reference stations in Figure 3

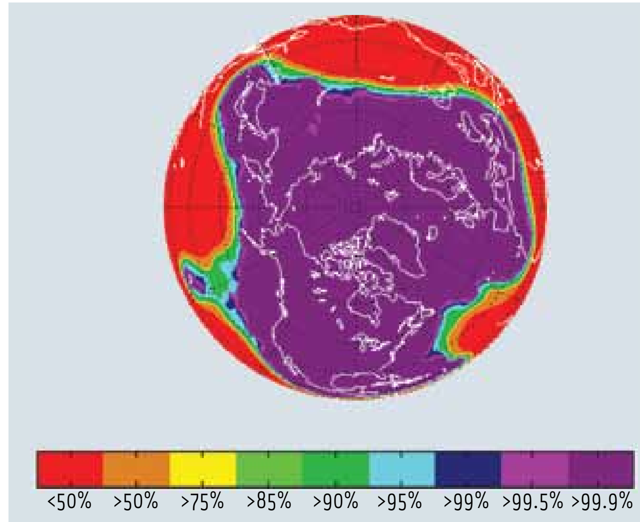

FIGURE 5 Horizontal availability with HAL= 40 m , assuming user connectivity and reference stations in Figure 3

red-colored areas in Figure 2, is due to the availability of too few reference stations.

Of course, we can extend integrity into the Arctic by adding reference stations to those shown in Figure 2. For example, we could include the reference stations of the Russian System of Differential Correction and Monitoring (SDCM) and Japan's MTSAT Satellite-based Augmentation System (MSAS), and add five new reference stations, the locations of which are shown in **Figure 3**.

For the purposes of our analysis, we assume that all these references stations provide the same measurement quality as current WAAS reference stations. We also assume the availability of continuous user connectivity, that is, the user is always able to receive the SBAS corrections.

Although SBAS GEO coverage is limited in the Arctic, other ways exist with which to maintain the connectivity, such as using low earth orbit (LEO) satellites. We will address this topic in more detail in the next section.

Figure 4 shows the horizontal and vertical availability with user connectivity based on using the configuration of reference stations presented in Figure 3. Again, we set VAL to 35 meters, and HAL to 40 meters. Availability has been improved from no availability coverage to greater than 90 percent coverage in the Arctic region. In the case of seafaring navigation (as opposed to airborne navigation), we can relax the vertical requirement. **Figure 5** shows the availability when there is only the horizontal requirement of 40 meters. As shown, the horizontal availability exceeds 99.9 percent throughout the Arctic.

Iridium for SBAS Messages

The second requirement for ensuring integrity in the Arctic is *continuous connectivity* — in other words, how the SBAS messages are delivered seamlessly to users. Currently, WAAS uses geosynchronous orbit (GEO) satellites to broadcast error corrections. Because the GEO satellites are located directly above the Earth's equator, WAAS GEO coverage does not include the Arctic. **Figure 6** illustrates this lack of SBAS connectivity.

Iridium satellites are a promising alternative for communicating and broadcasting SBAS messages to the Arctic. The constellation of Iridium satellites is shown in **Figure 7**. This con-

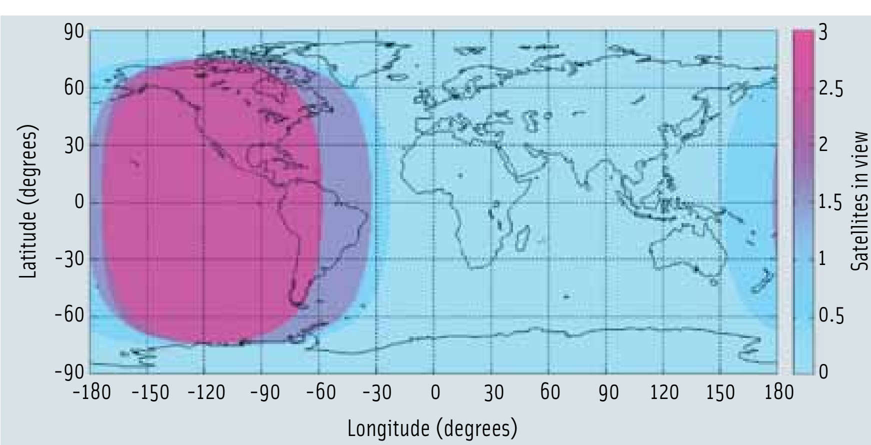

FIGURE 6 WAAS GEO satellite coverage with minimum elevation angle of 6.35 degrees. Courtesy of Tyler Reid.

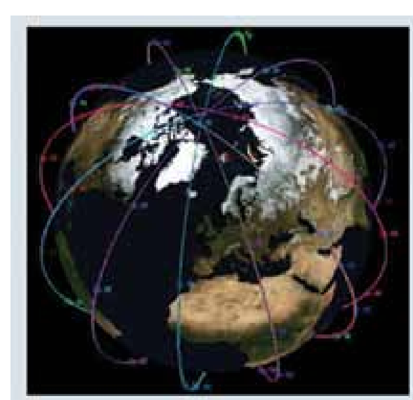

FIGURE 7 Constellation of Iridium satellites. Courtesy of Tyler Reid.

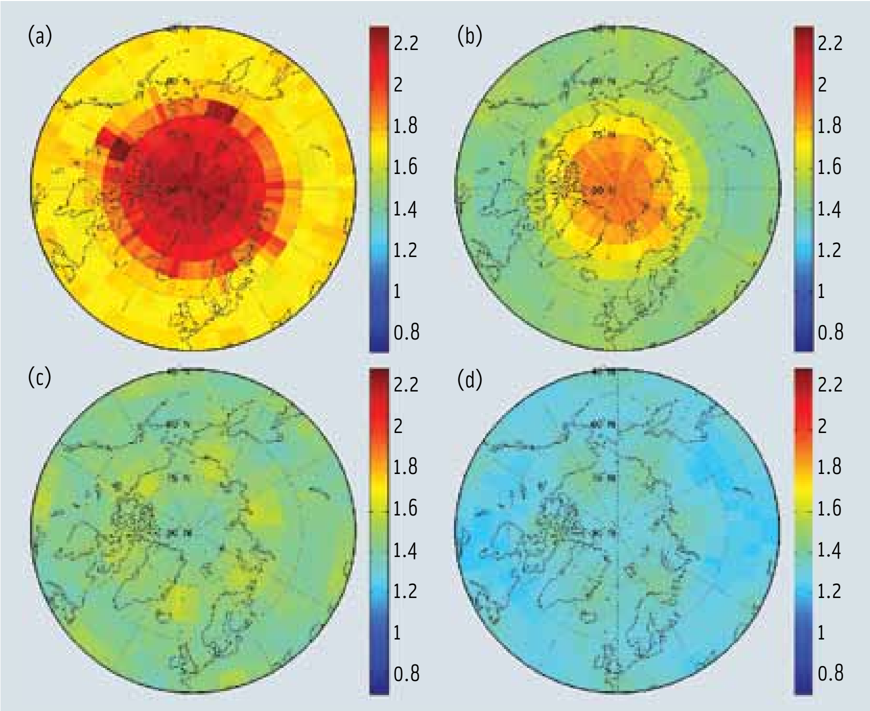

FIGURE 8 VDOP improvement in the Arctic with the help of Iridium satellites (a). 24 GPS satellites. (b) 31 GPS satellites. (c) 24 GPS and Iridium satellites. (d) 31 GPS and Iridium satellites

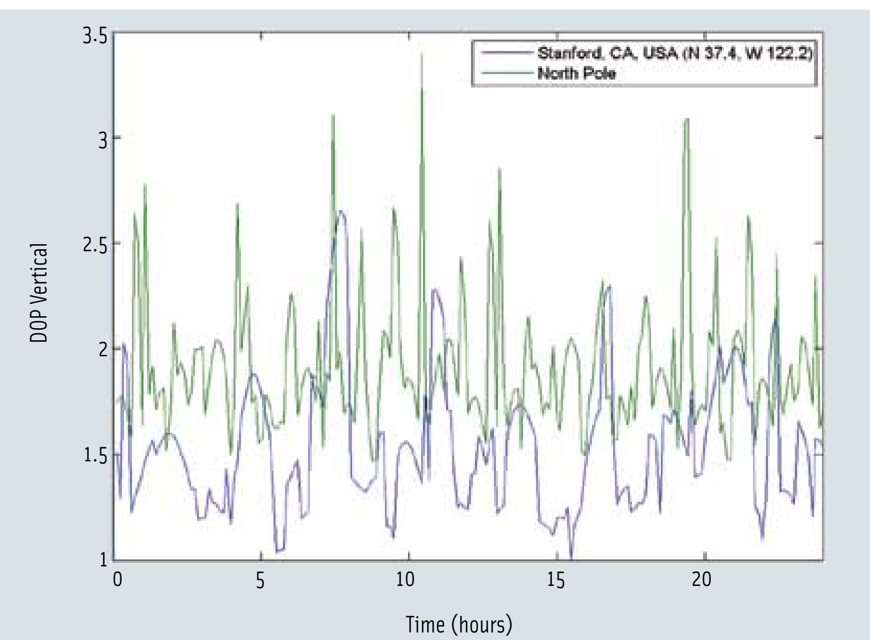

FIGURE 9 Vertical DOP at the North Pole and Stanford, California, USA

stellation includes 66 active satellites in low Earth orbit at an altitude of approximately 781 kilometers (485 miles) with an 86.4-degree inclination. The orbital period is about 100 minutes.

The over-the-pole design of Iridium orbits ensures very good high-elevation satellite visibility in the Arctic. Because Iridium satellites already provide voice and data services to satellite phones and integrated transceivers around the globe, Iridium is a strong candidate for enabling SBAS linkage to Arctic users.

Note that the current practice of Iridium satellites is to shut off redundant beams when near the poles to avoid inter-satellite interference. Due to the low earth orbit and thus short orbital period, the satellites are in view for only about 10 minutes. Therefore, the challenge of using Iridium satellites for communication in the polar region is to accommodate fast switching among the transmitting satellites.

As a bonus, Iridium satellites could improve the vertical dilution of precision (VDOP) if the Iridium satellites also broadcast ranging signals. VDOP is a measure of how well the positions of the satellites are arranged to generate the vertical component of the positioning solution. Higher VDOP values mean less certainty in the solutions and can be caused if the satellites have low elevation angles in relation to users.

Figure 8 shows the VDOP improvement in the Arctic using Iridium. We simulate two scenarios with and without additional Iridium satellites: using 31 GPS satellites, the number of healthy satellites in the current GPS constellation, and 24 GPS satellites, the baseline requirement for GPS. If we only have the GPS constellation available, VDOP values in the Arctic are about 2.1 and 1.8 for 24 and 31 GPS satellites, respectively — worse than the average VDOP values elsewhere on Earth (1.7 and 1.5 for 24 and 31 GPS satellites, respectively) as shown in Figure 8 (a) and (b).

With added Iridium satellites, the VDOP values increase to 1.6 from 2.1 for 24 GPS satellites, and to 1.3 from 1.8 for 31 GPS satellites. Moreover, the VDOP values are more even over the Earth's surface. For both scenarios of 24 and 31 GPS satellites, adding Iridium satellites improves VDOPs in the Arctic.

Multiple Constellations for High Availability of Integrity

A third issue, although not as critical as the first two, is the VDOP degradation encountered in the Arctic. Because GPS satellites are in an orbital plane of 55 degree inclination, not enough satellites are visible at high elevation angles for users in the Arctic. For this reason, VDOPs in the Arctic are worse (i.e., higher) than those close to the equator.

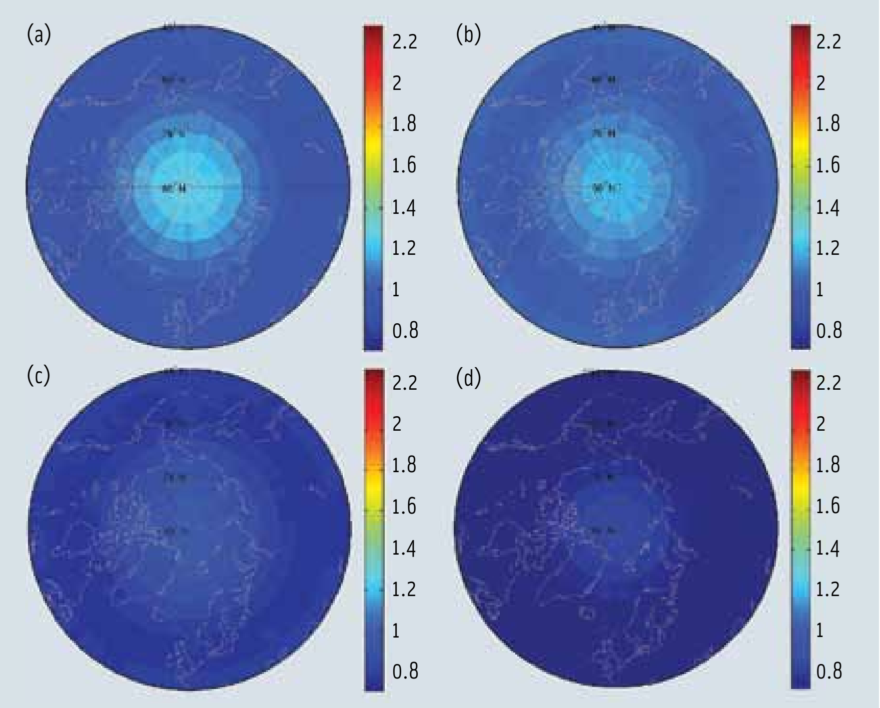

FIGURE 10 VDOP improvement in the Arctic using two or more constellations. (a) 31 GPS + 30 Compass MEO satellites. (b) 31 GPS + 24 GLONASS satellites. (c) 31 GPS + 30 Compass + 30 Galileo satellites. (d) 31 GPS + 30 Compass + 30 Galileo + 24 GLONASS satellites.

See **Figure 9** for a comparison of VDOPs at the North Pole and at Stanford, California. In contrast, HDOPs in the Arctic may be better than elsewhere due to this special satellite geometry.

Besides using Iridium, another approach would be to use multiple GNSS constellations, that is, some combination of GPS, Compass, Galileo, and GLONASS. **Figure 10** shows the significant VDOP improvement in the Arctic using two or more constellations. The VDOP values reduce to below 1.3 with the help of multiple constellations.

If using only two constellations, adding GLONASS to GPS is the most beneficial combination. GLONASS satellites orbit at 19,100 kilometers (11,842 miles) altitude with a 64.8-degree inclination. Compared to the 55-degree inclination of the GPS orbital planes, the GLONASS constellation produces better coverage in high latitudes. The VDOP improvement in the Arctic is more dramatic using three or even all four constellations.

Conclusion

This article identified a need for high-integrity navigation in the Arctic and analyzed techniques to extend SBAS coverage to this important region. We show that the current network of reference stations can be augmented to provide Arctic integrity with high availability. Moreover, Iridium satellites could provide a broadcast channel to the SBAS users. Multiple GNSS constellations significantly improve VDOPs and thus reduce vertical positioning errors in the Arctic.

Acknowledgment

The authors would like to thank the Federal Aviation Administration's Satellite Navigation Program Office and the Boeing Company for supporting this research.

Additional Resources

[1] Evans, J.V., "Satellite Systems for Personal Communications," *Proceedings of the IEEE*, Volume: 86, Issue: 7, 1998

[2] United States Geological Survey, "90 Billion Barrels of Oil and 1,670 Trillion Cubic Feet of Natural Gas Assessed in the Arctic," USGS, July 2008

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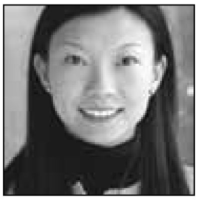

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