

# GNSS Integrity in the Arctic



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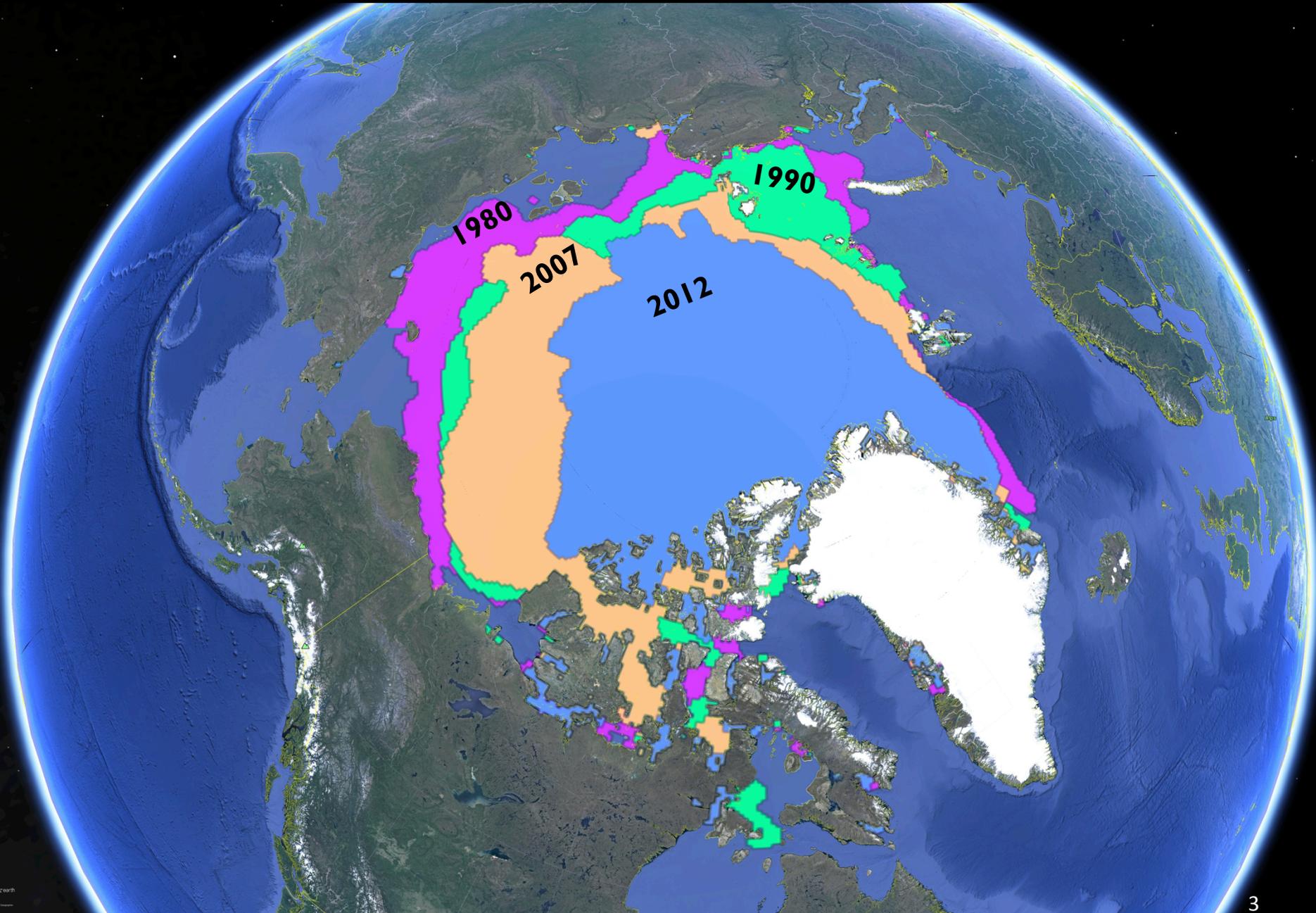
ION GNSS+ 2015  
September 17, 2015  
Tampa, FL

# Introduction

- The summer Arctic sea ice extent has decreased by more than 50% since 1980.
- There is estimated to be a large amount of untapped natural resources in the Arctic, particularly oil (13% of the world's undiscovered reserves) and natural gas (30%).
- Many motivators such as tourism, fishing, resource exploration/exploitation, and shipping are attracting operations in the Arctic.
- Achieving navigation safety in the Arctic is critical to avoid accidents which could result in loss of life or environmental disasters.



# Summer Arctic Sea Ice





Wikimedia Commons



asme



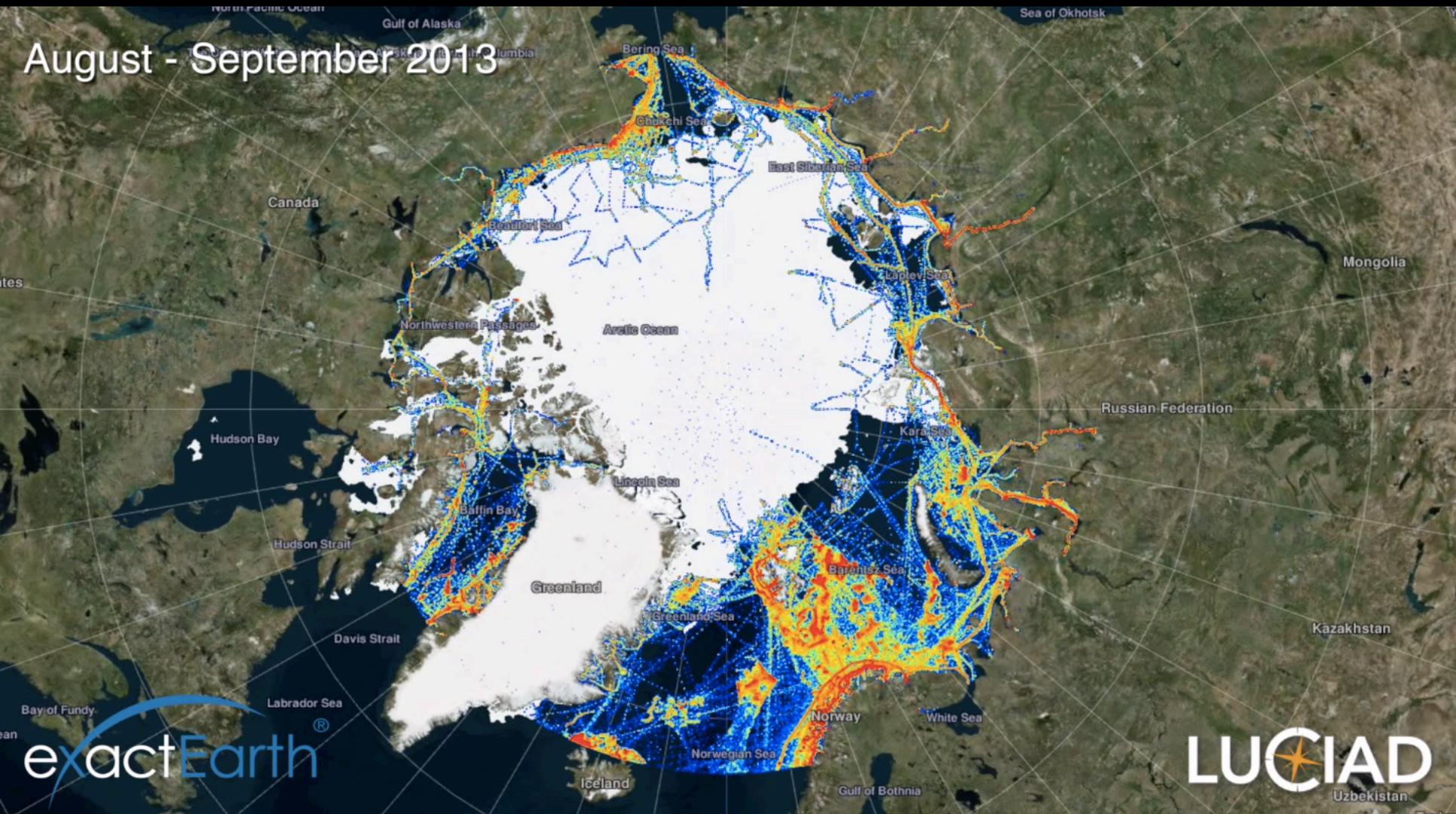
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# Arctic Marine Traffic

August - September 2013

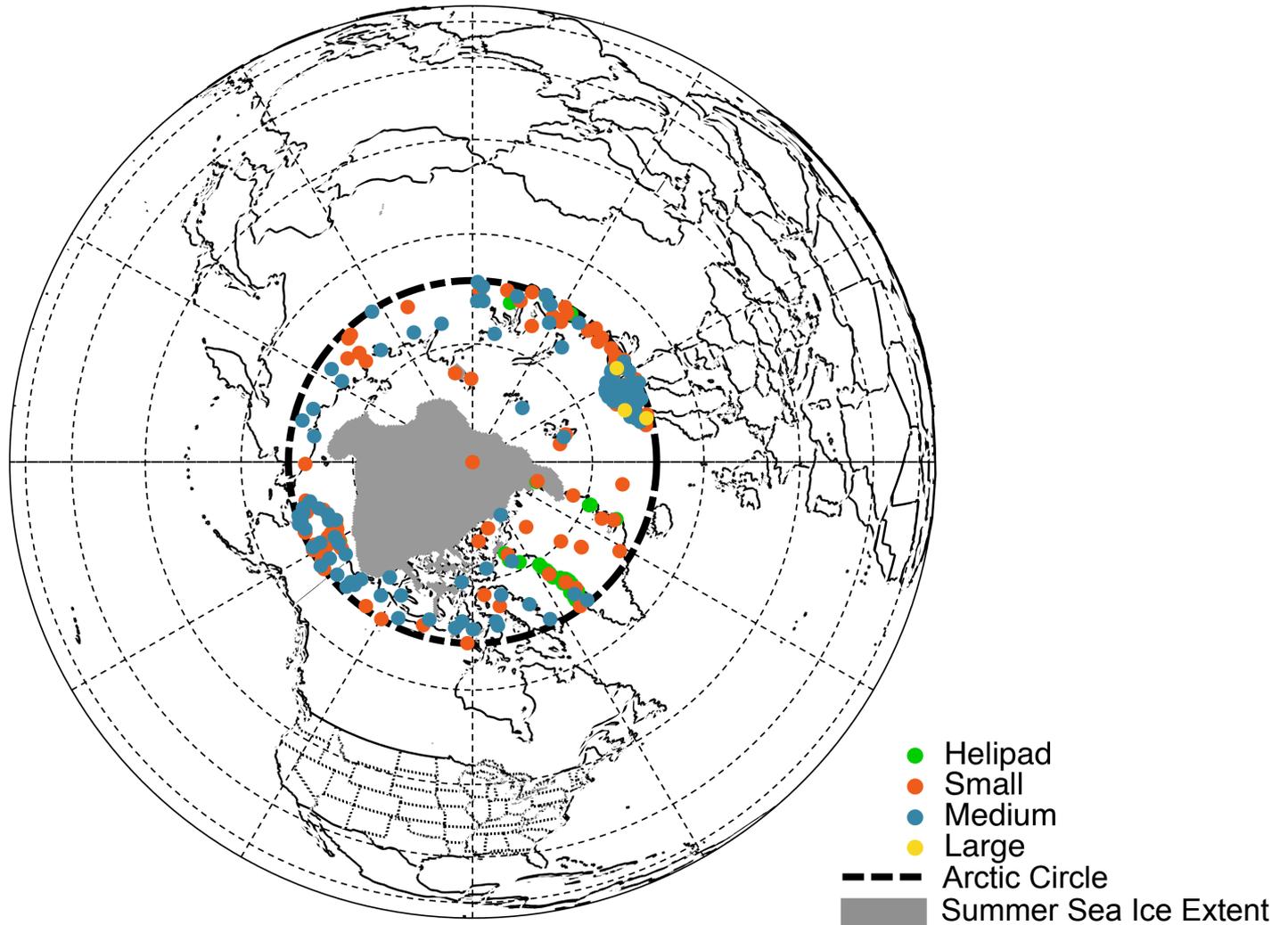


exactEarth®

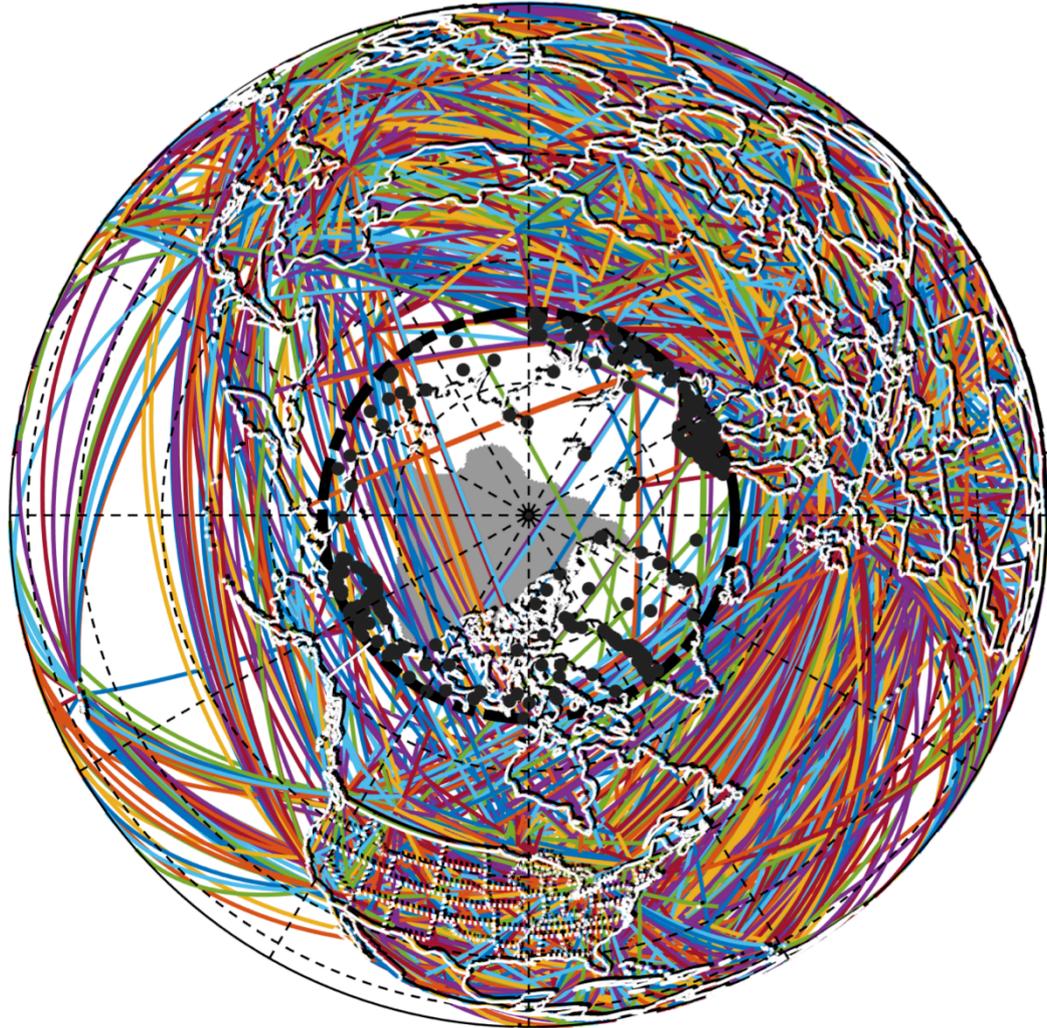
LUCIAD  
Uzbekistan

(Exact Earth - <https://www.youtube.com/watch?v=Fjerjleg49s>)

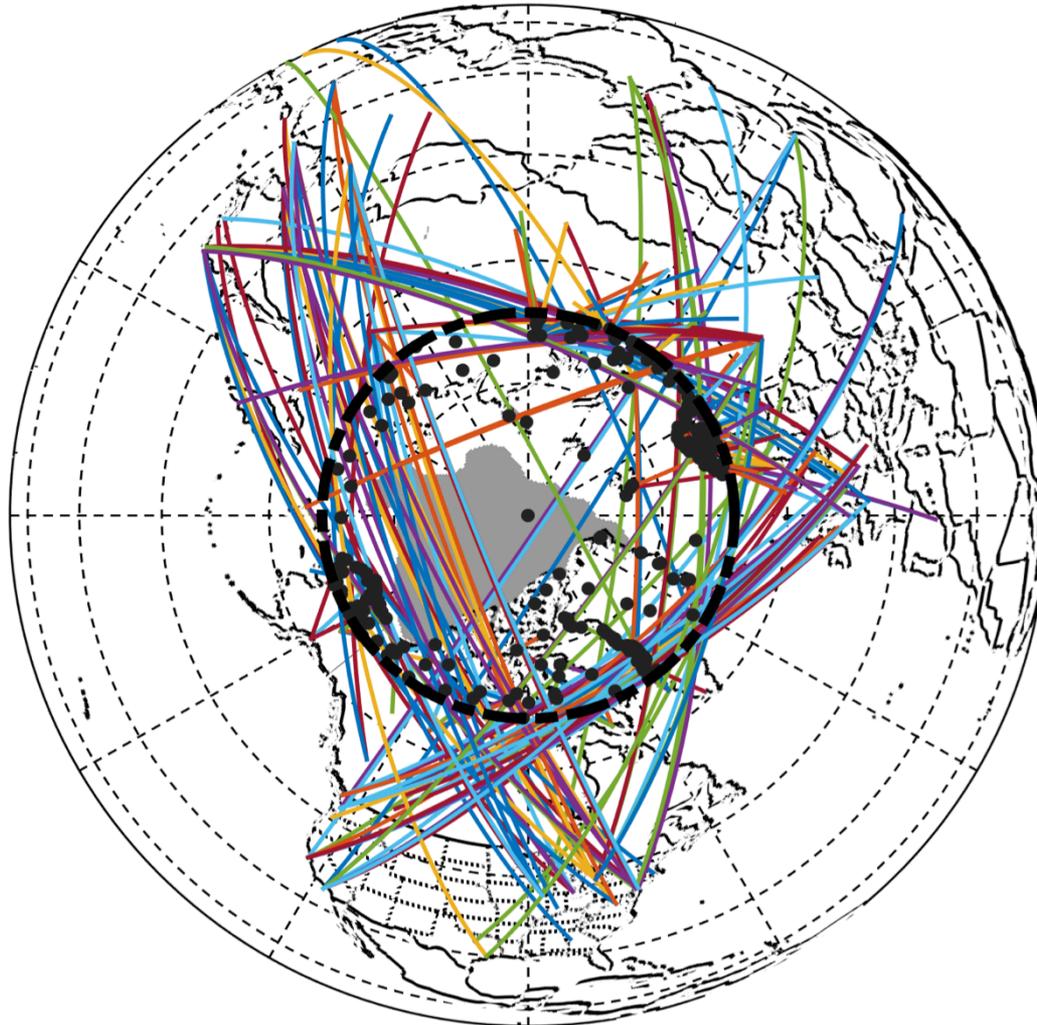
## Arctic Airports



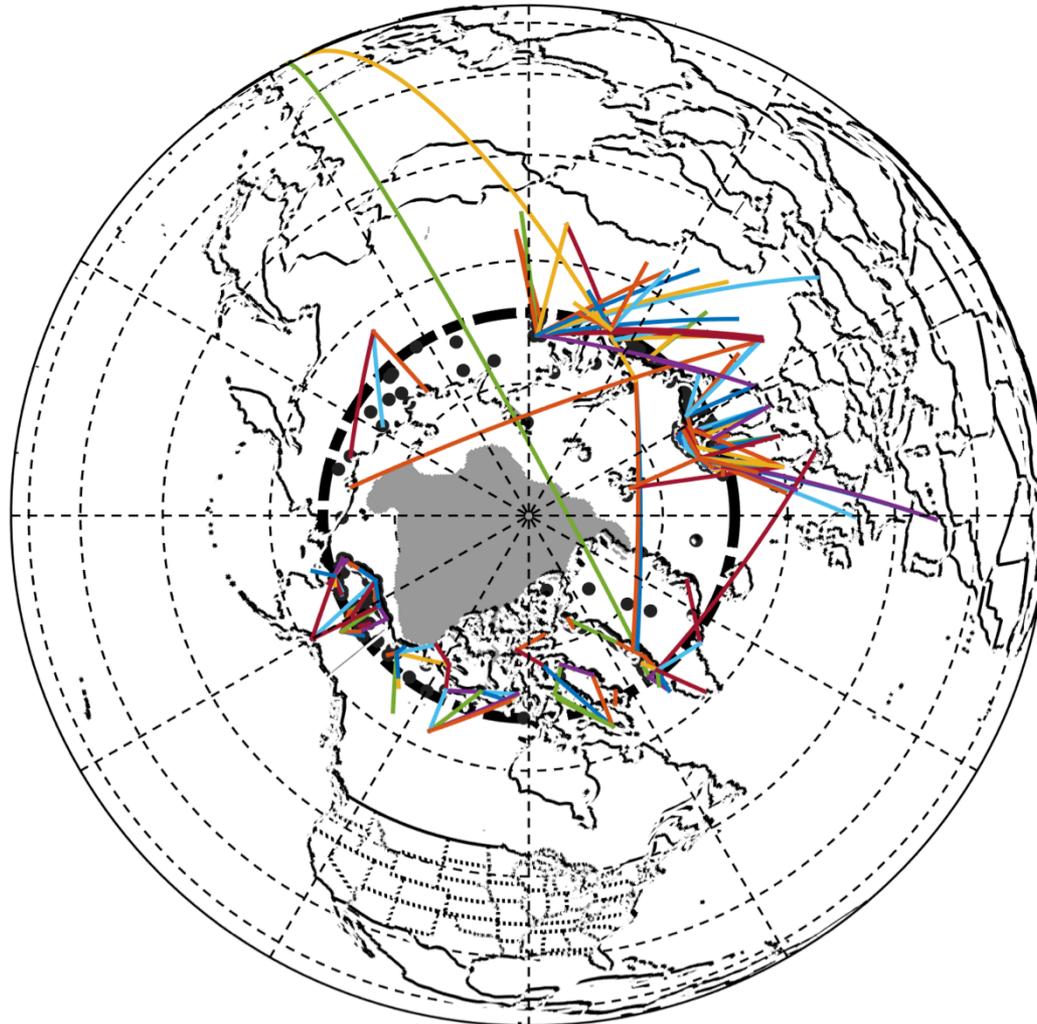
# All Routes



## All Routes Through The Arctic



## Arctic Point of Origin or Destination



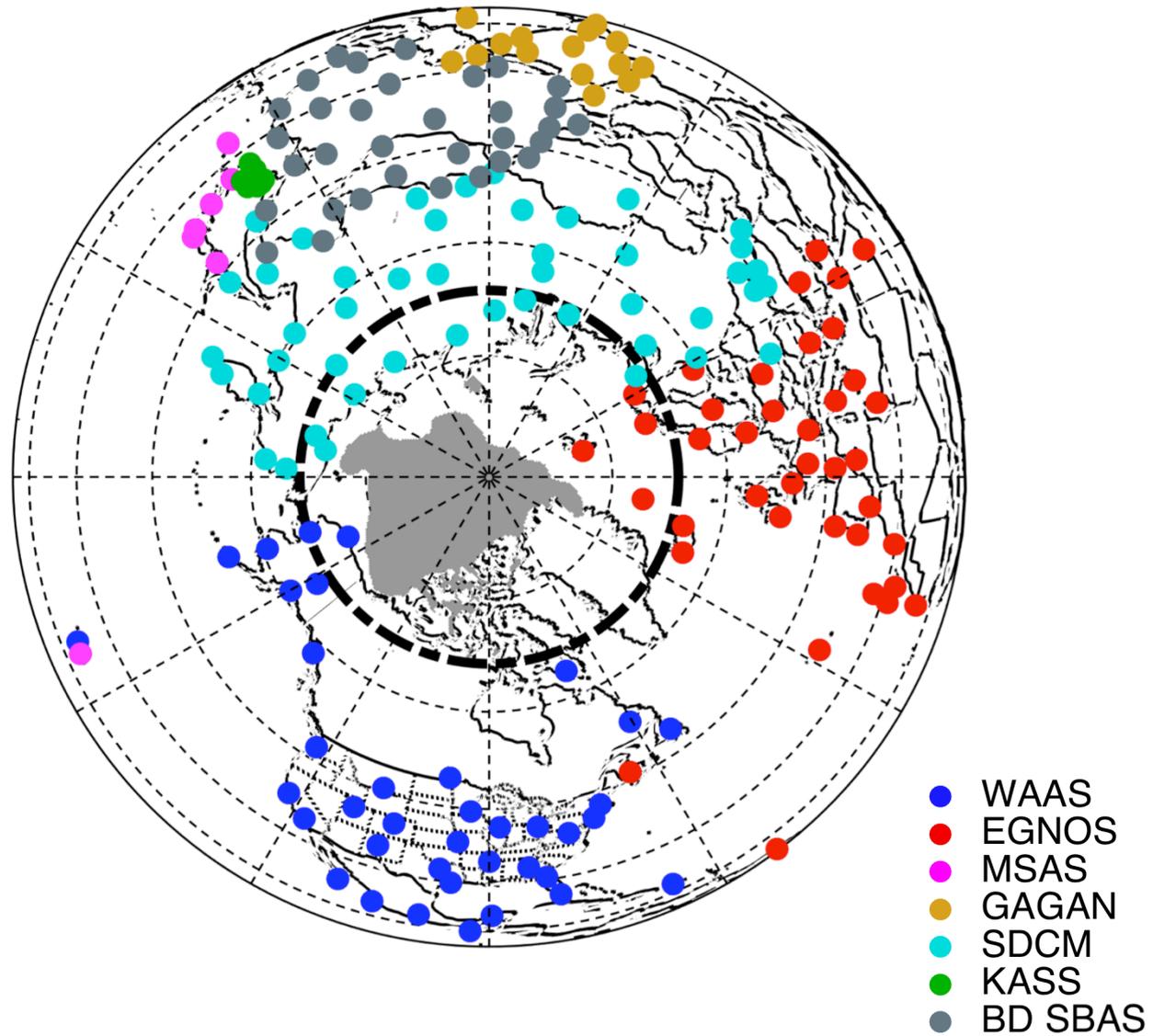
# Navigation Integrity

**SBAS:** Satellite Based Augmentation Systems require ground-based and space-based infrastructure deliver GNSS corrections in real-time.

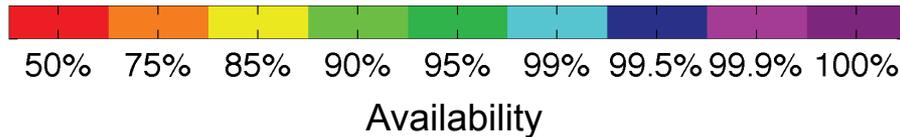
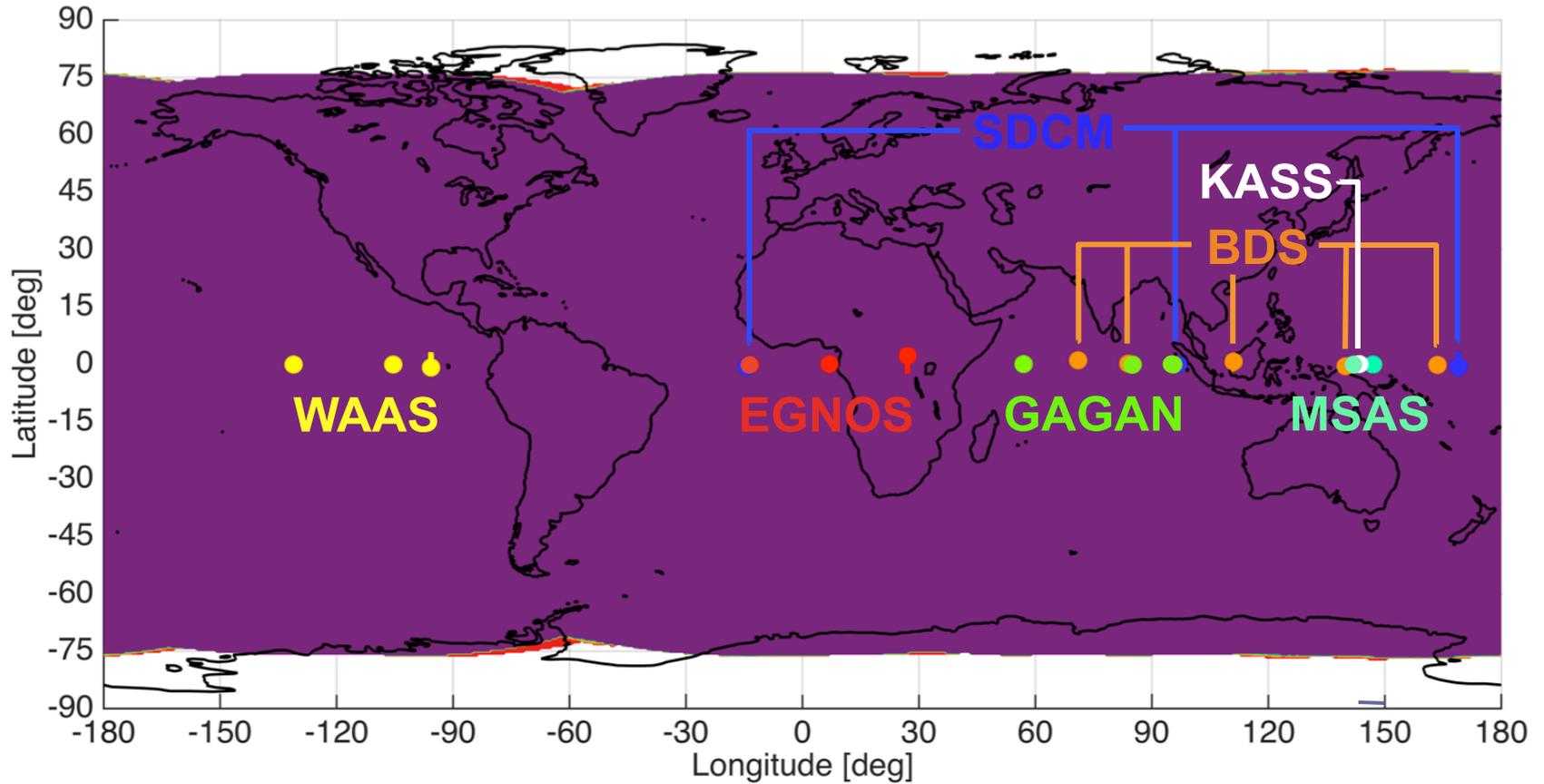
**ARAIM:** Advanced Receiver Autonomous Integrity Monitoring is self-contained.



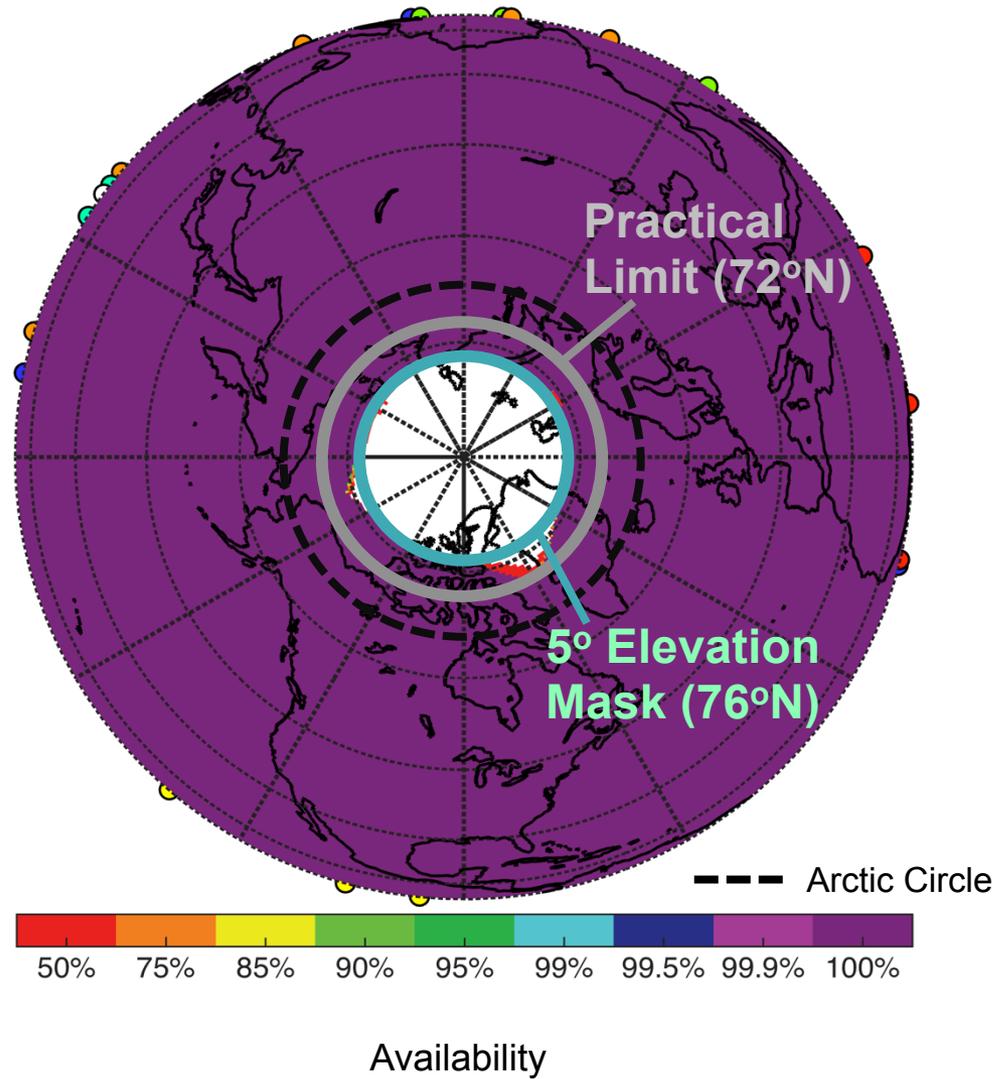
## SBAS Reference Stations



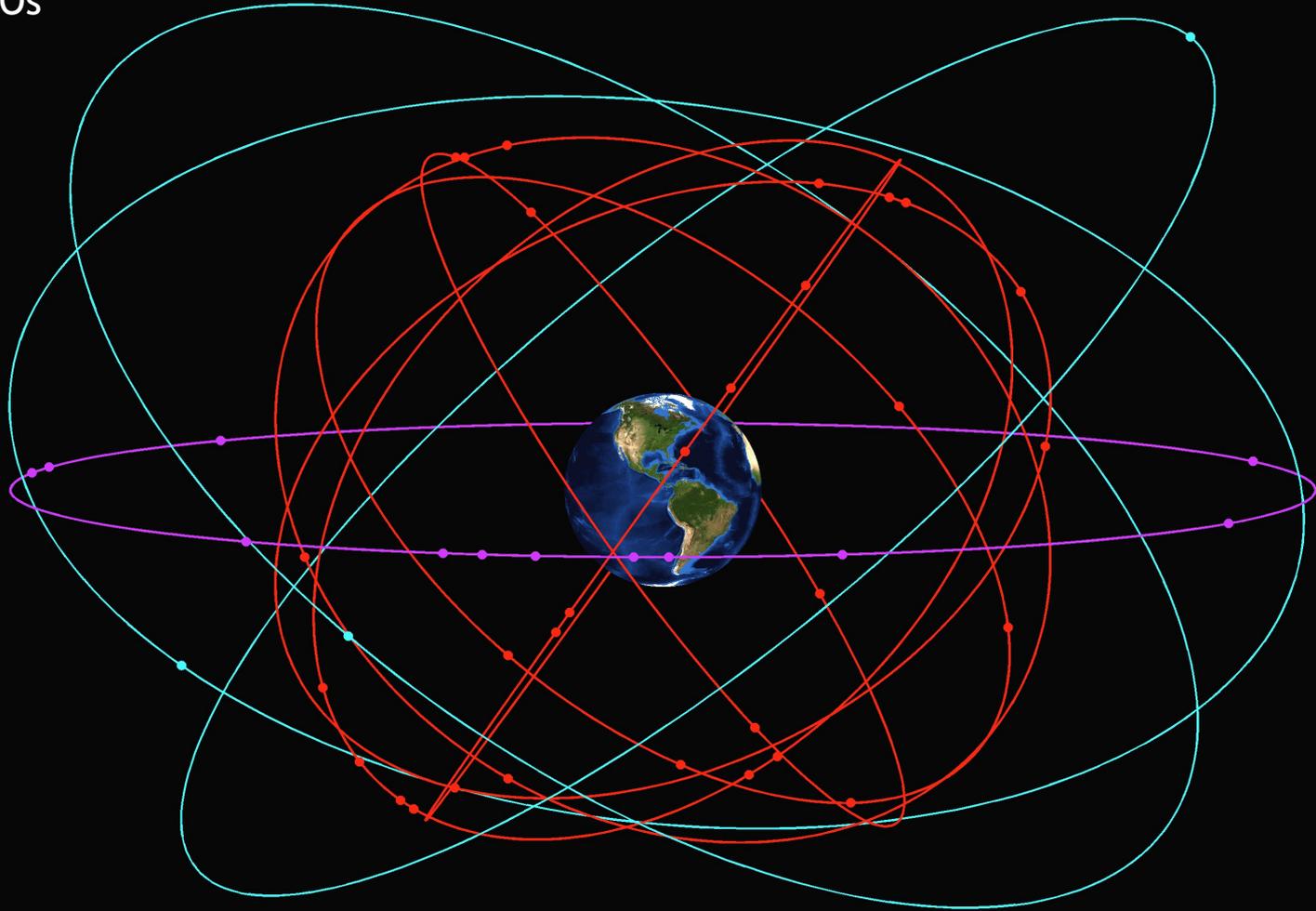
# Coverage of SBAS GEOs



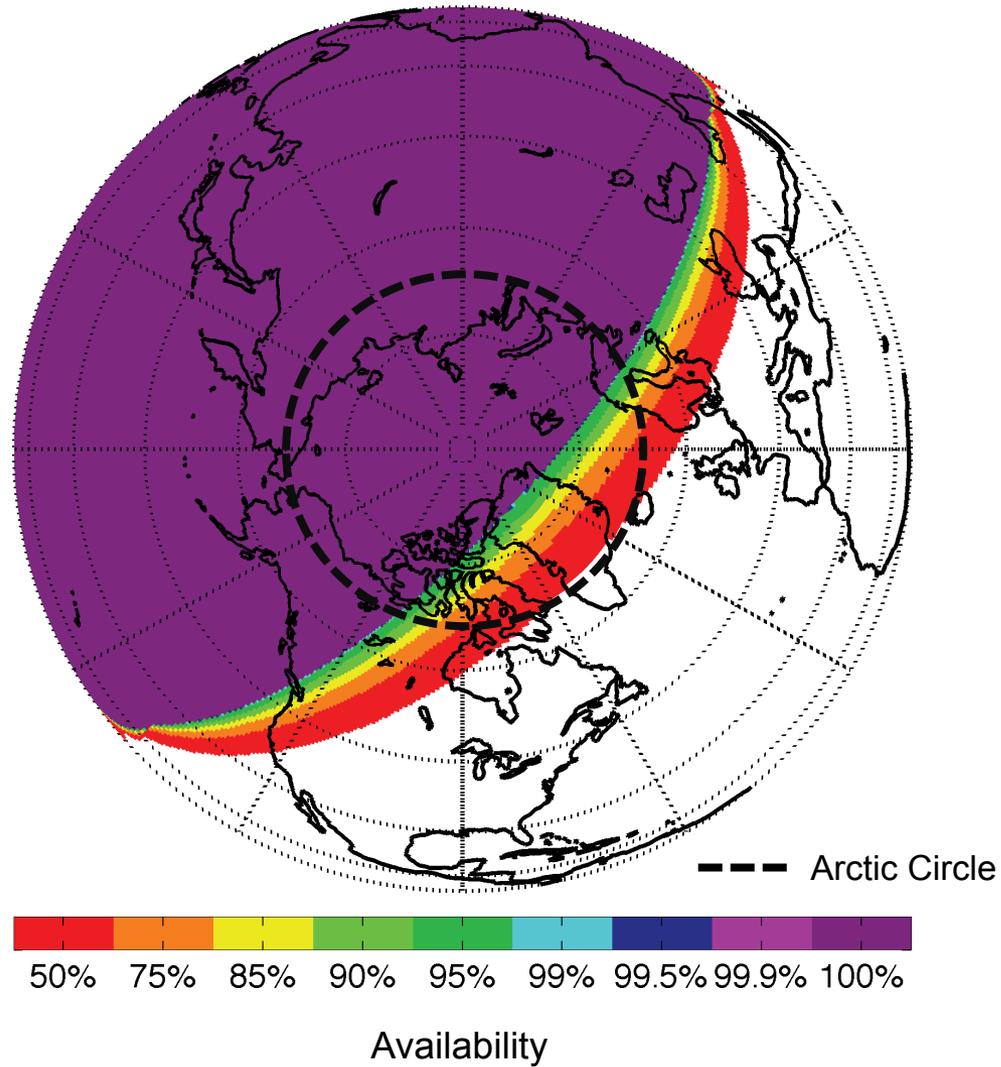
## Coverage of SBAS GEOs



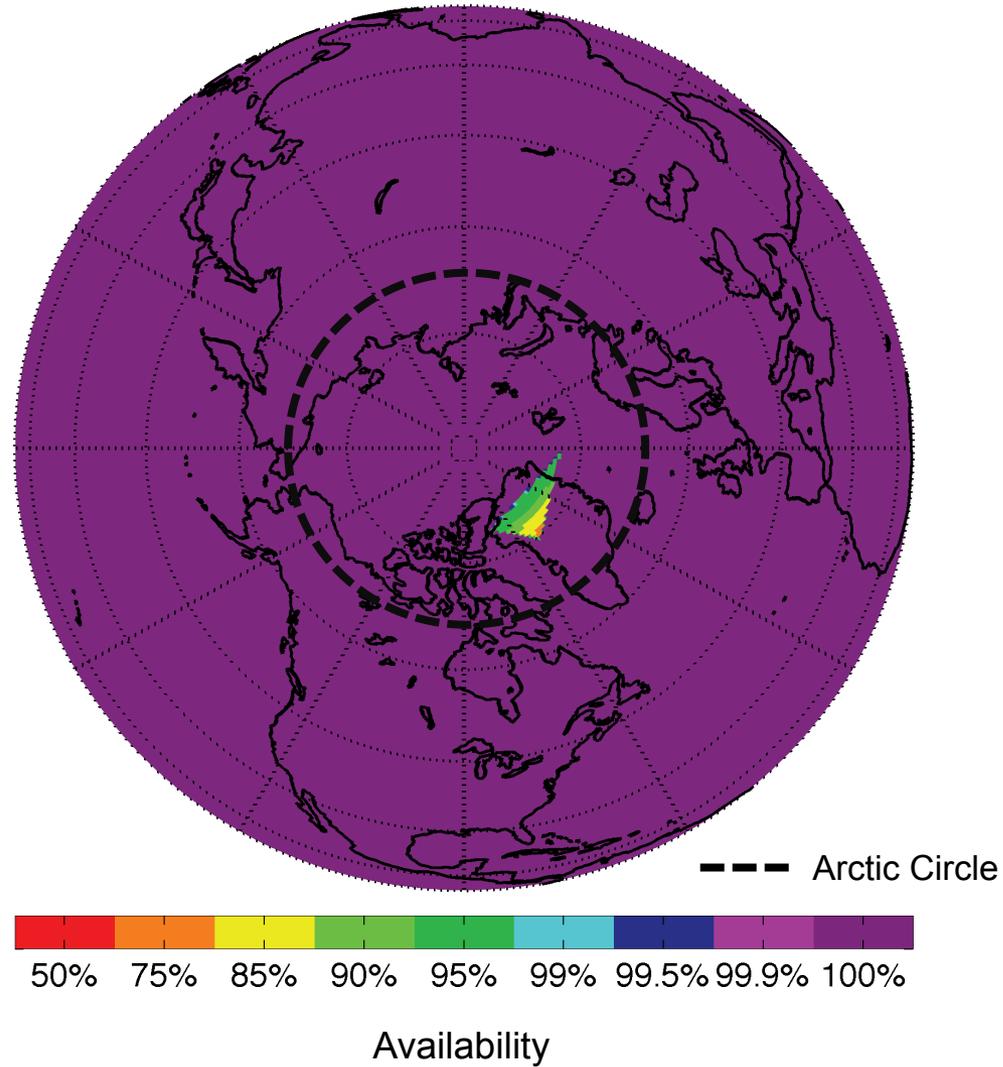
- GPS
- SBAS GEOs
- QZSS



# Coverage of QZSS Constellation



## Coverage of QZSS Constellation + SBAS GEOs



**Svalbard Airport, Longyear (78.25° N)**

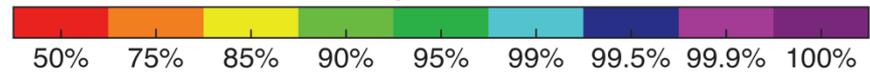
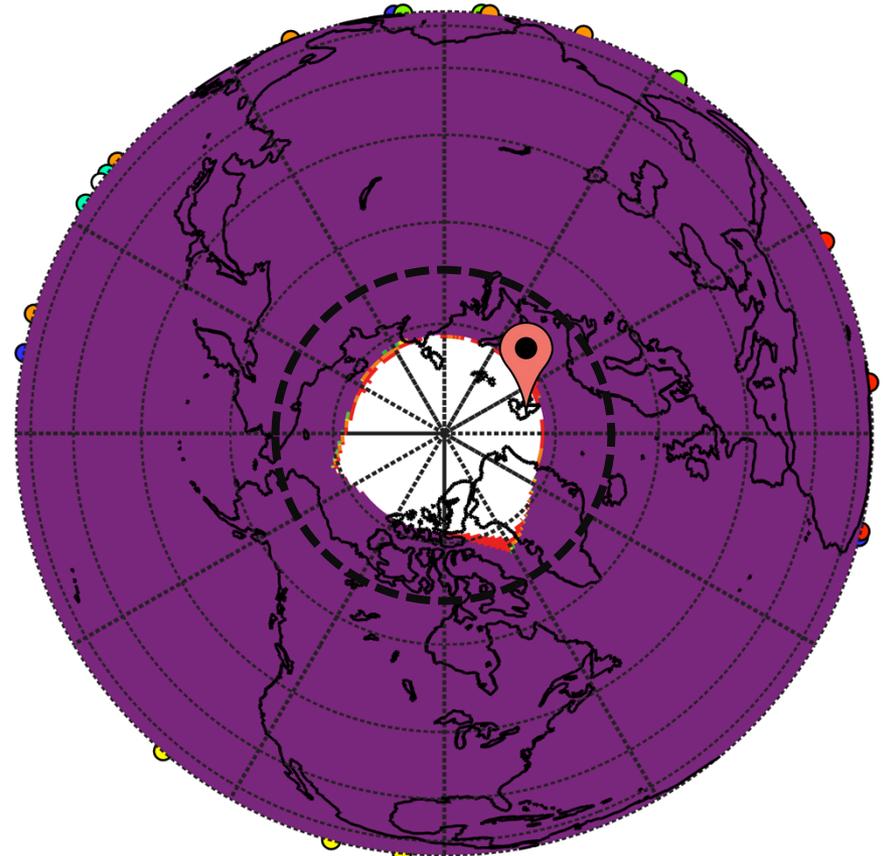
**Northernmost Airport with Publicly Scheduled Flights**



(Source: Wikimedia Commons)



# Svalbard Airport





Svalbard Airport

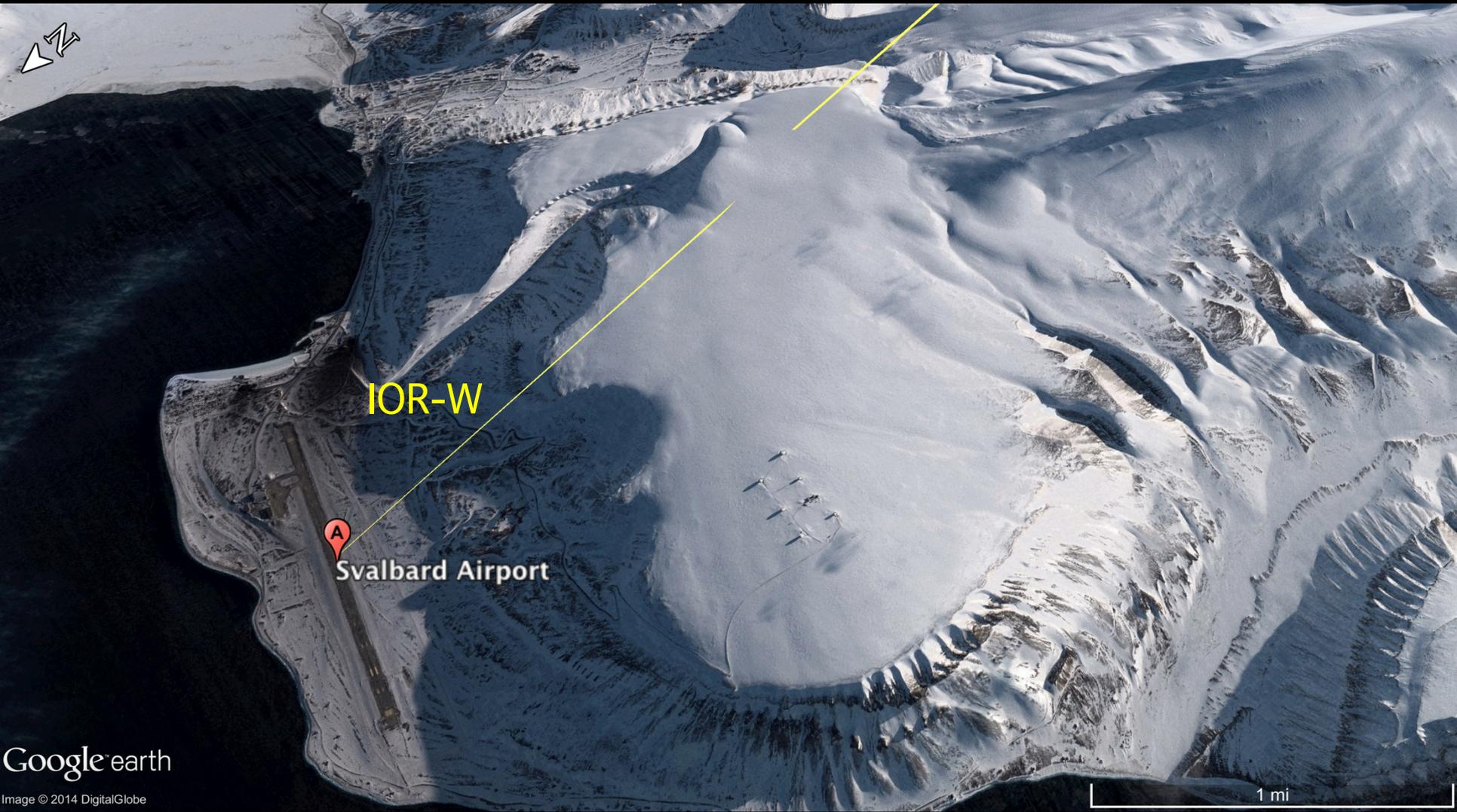
QZSS

IOR-W

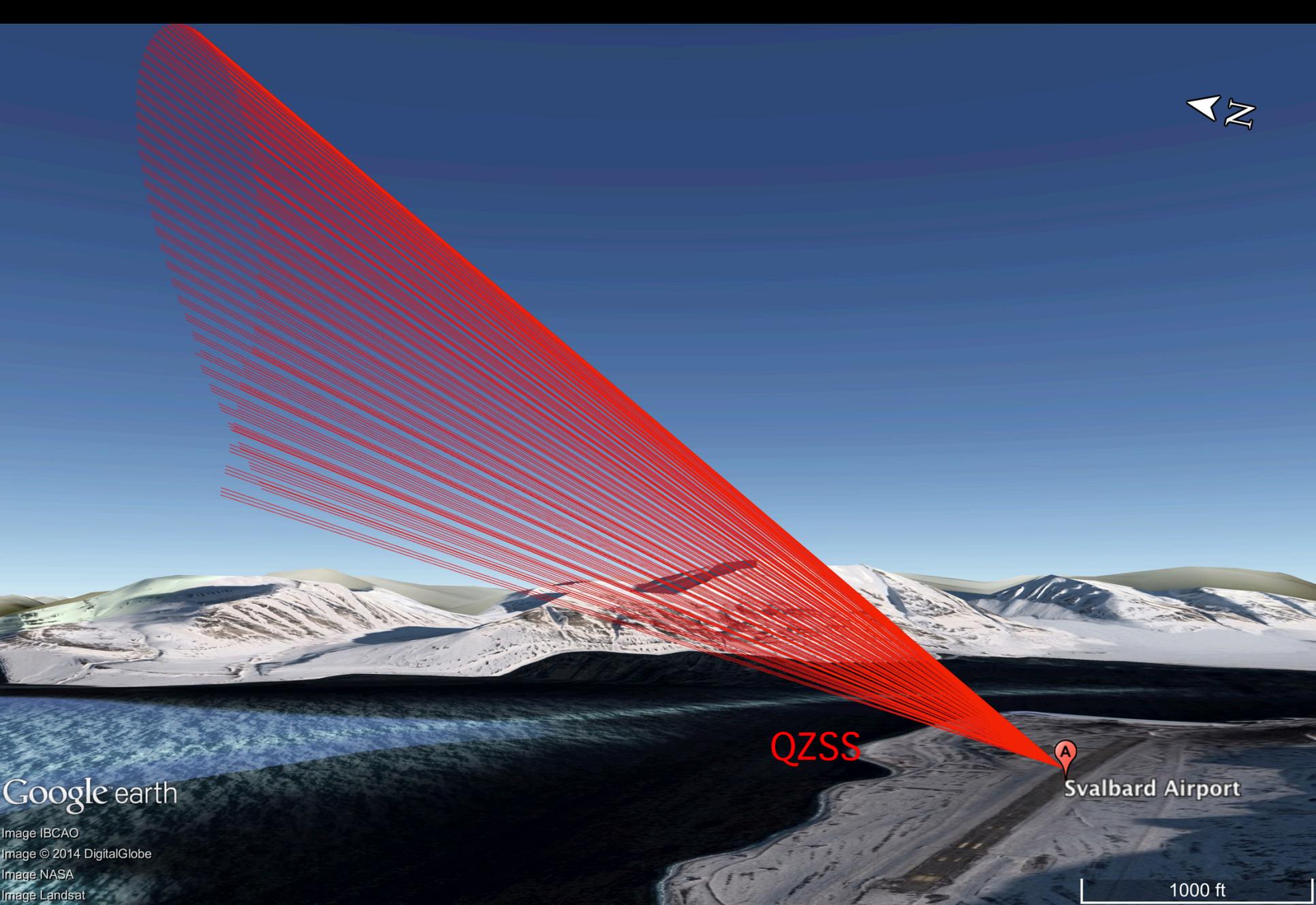
5 mi

Google earth

Image NASA  
Image © 2014 DigitalGlobe  
Image IBCAO  
Data Stockholm University



IOR-W (EGNOS, PRN 126) Blocked by Terrain Even When Above a 5° Elevation



Google earth

Image IBCAO  
Image © 2014 DigitalGlobe  
Image NASA  
Image Landsat

QZSS

Svalbard Airport

1000 ft

QZSS always above 8.3° elevation, as high as 25°

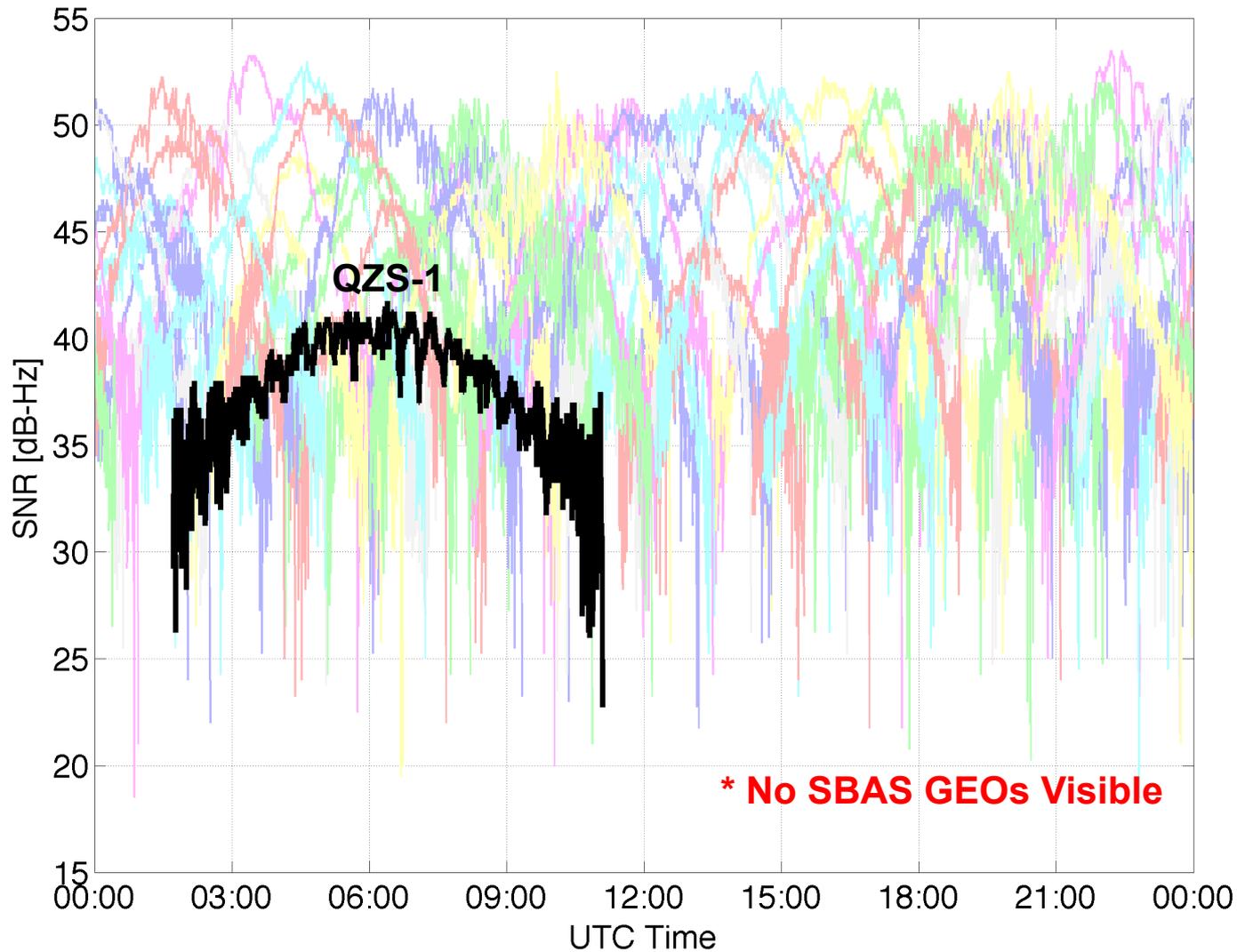
**NYA2**  **Alesund Airport**

**Svalbard Airport**

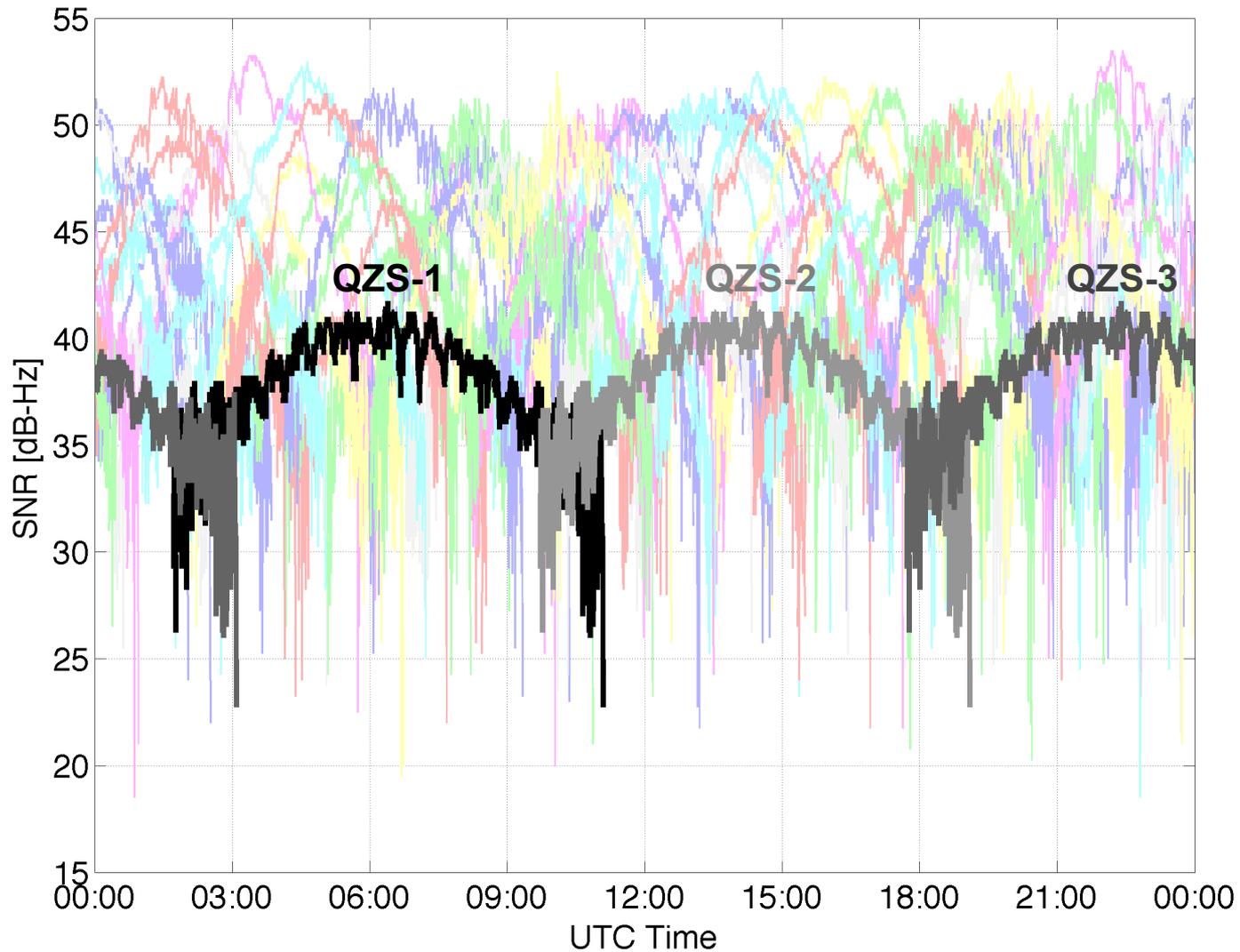
Svalbard



## Signal to Noise Ratio at IGS Station NYA2 Ny-Ålesund, Svalbard (78.86 N)



## Signal to Noise Ratio at IGS Station NYA2 Ny-Ålesund, Svalbard (78.86 N)





# Marine Navigation Requirements

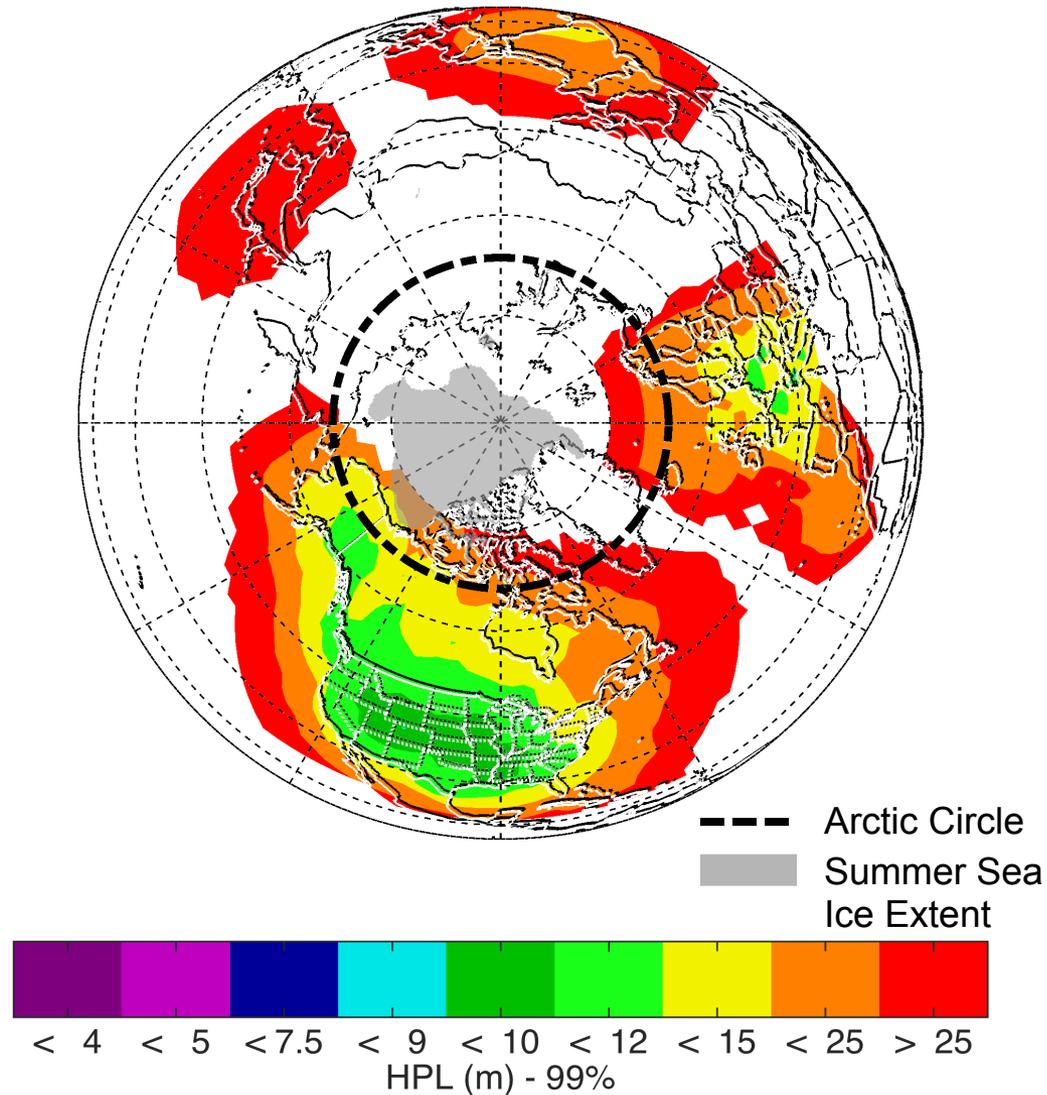
	Horizontal Accuracy [m]	Alert Limit (HAL) [m]	Time to Alarm [seconds]	Integrity Risk (per 3 hours)
Ocean	10	25	10	10 <sup>-5</sup>
Coastal				
Ice Navigation*	5	10 - 12	10	10 <sup>-5</sup>
Hydrography	1-2	2.5 - 5	10	10 <sup>-5</sup>
Port	1	2.5	10	10 <sup>-5</sup>
Exploration / Drilling				

International Maritime Organization, "Revised Maritime Policy and Requirements for a Future Global Navigation Satellite System (GNSS)," A.915(22), 2002.



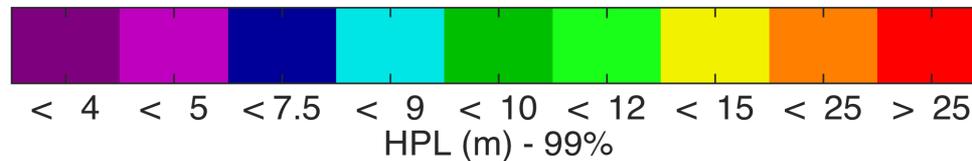
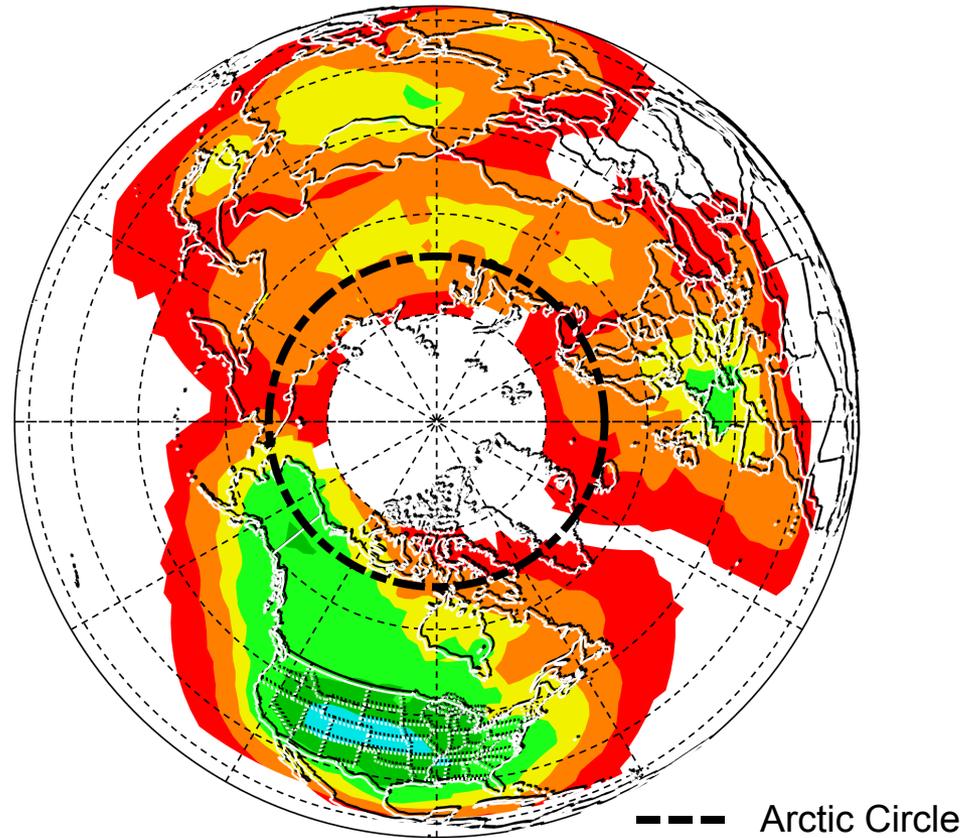


## Single Frequency 2015 WAAS + EGNOS + MSAS + GAGAN

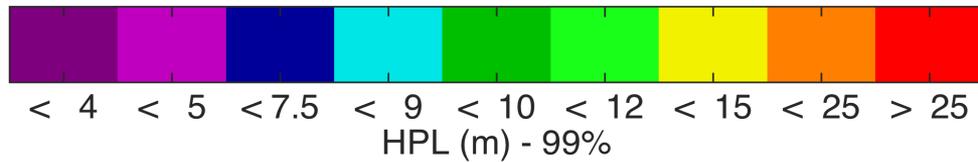
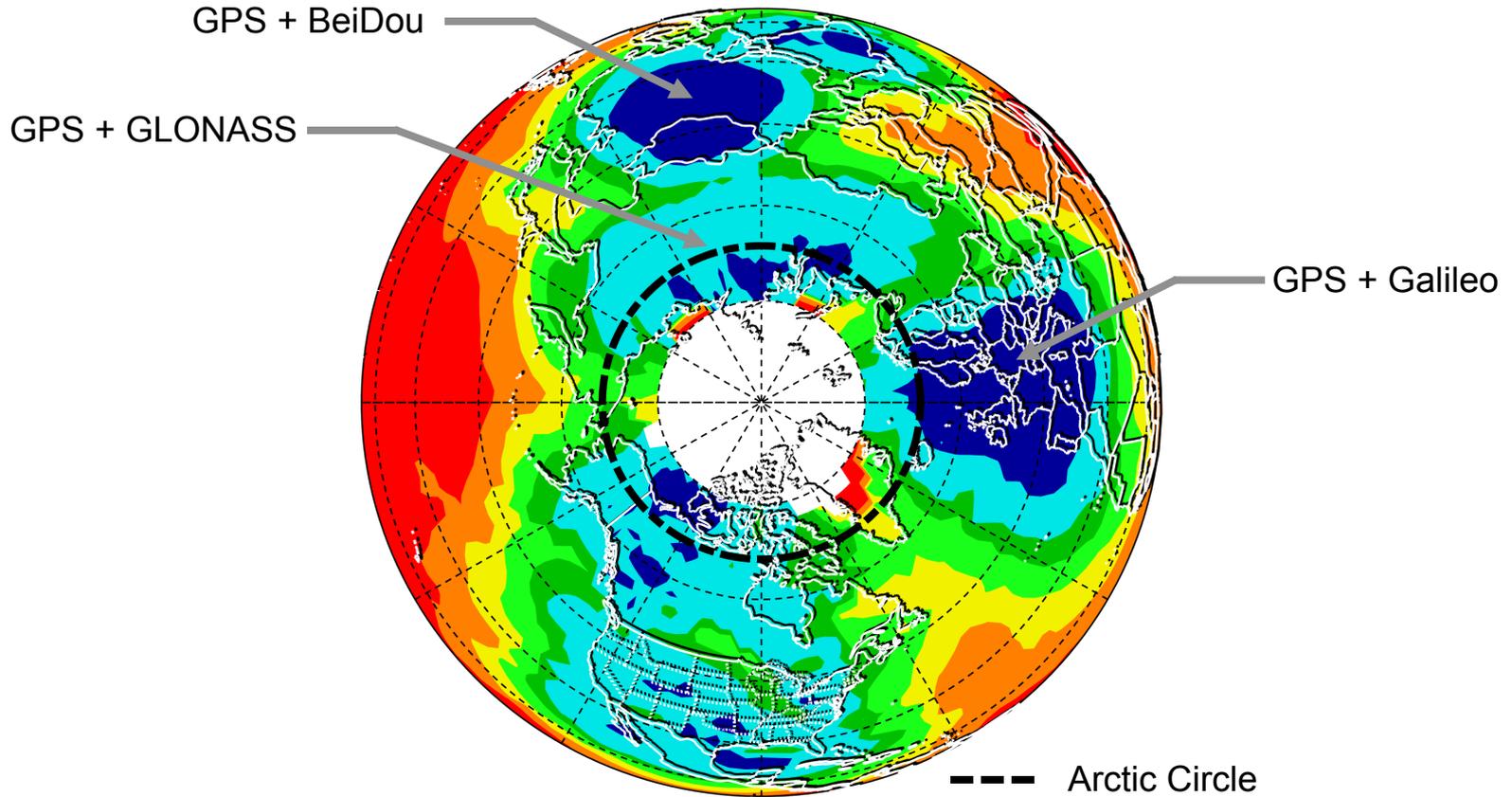


# Single Frequency 2021

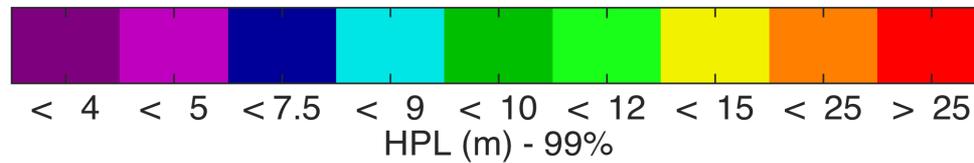
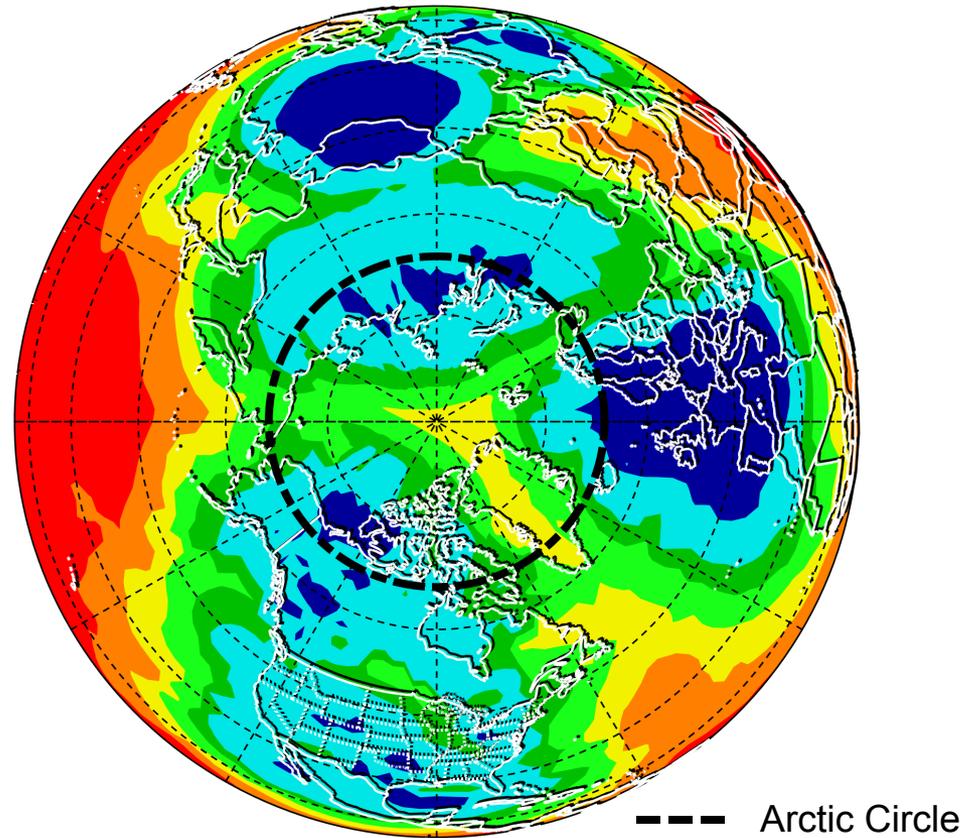
## WAAS + EGNOS + MSAS + GAGAN + SDCM + KASS + BD SBAS



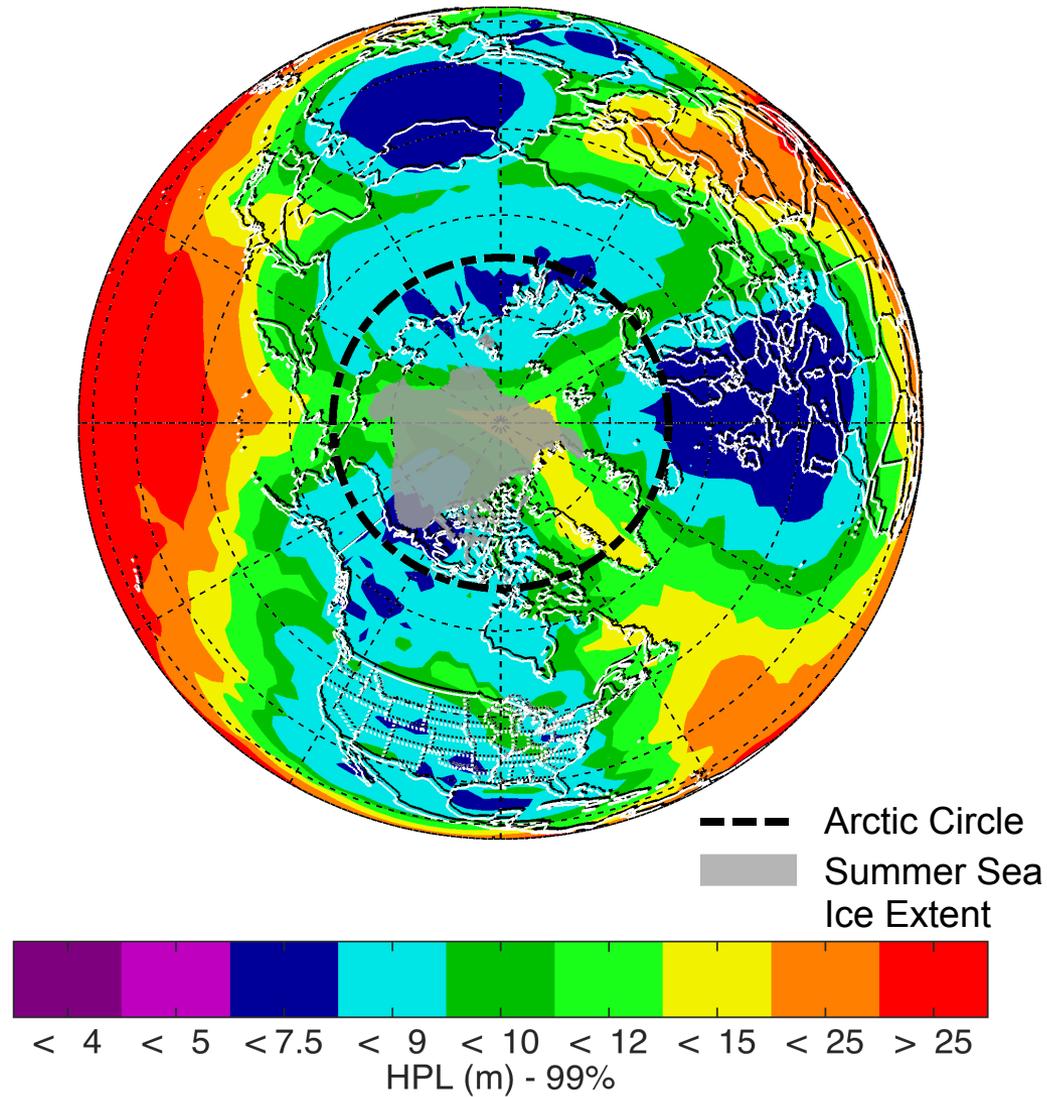
# Dual Frequency 2026 Planned



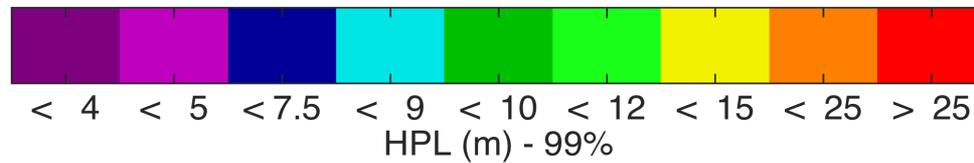
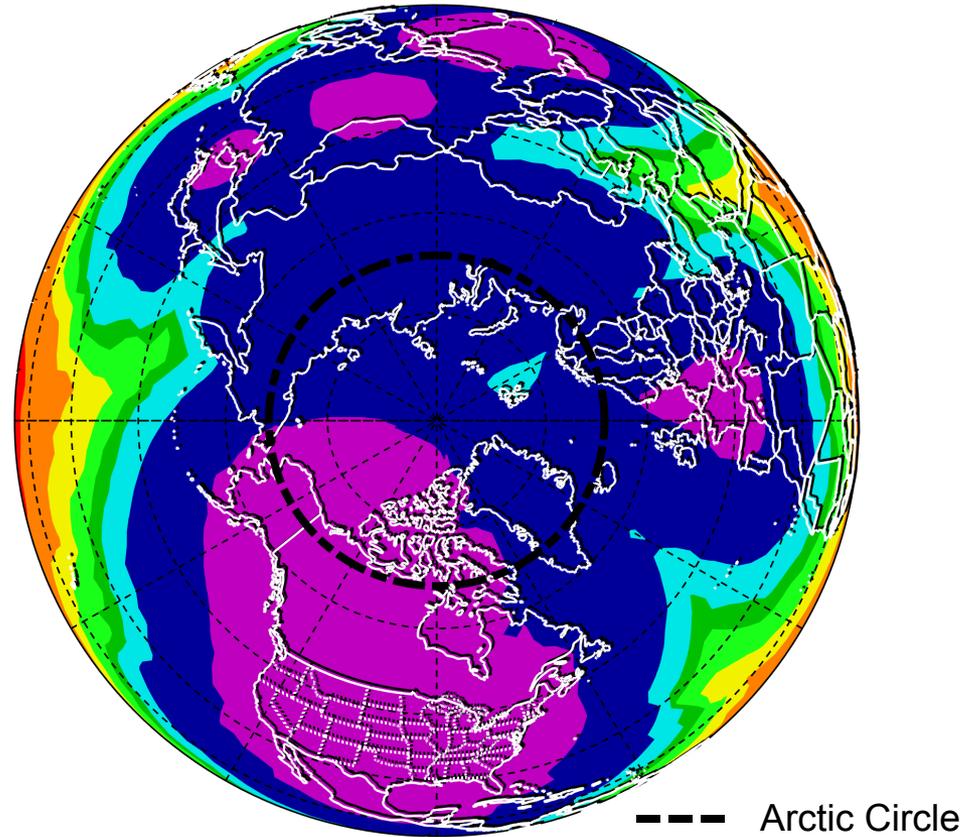
## Dual Frequency 2026 + Arctic Comm Planned



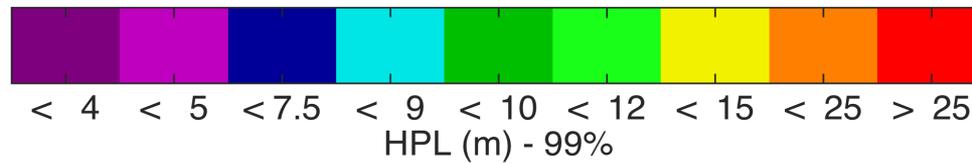
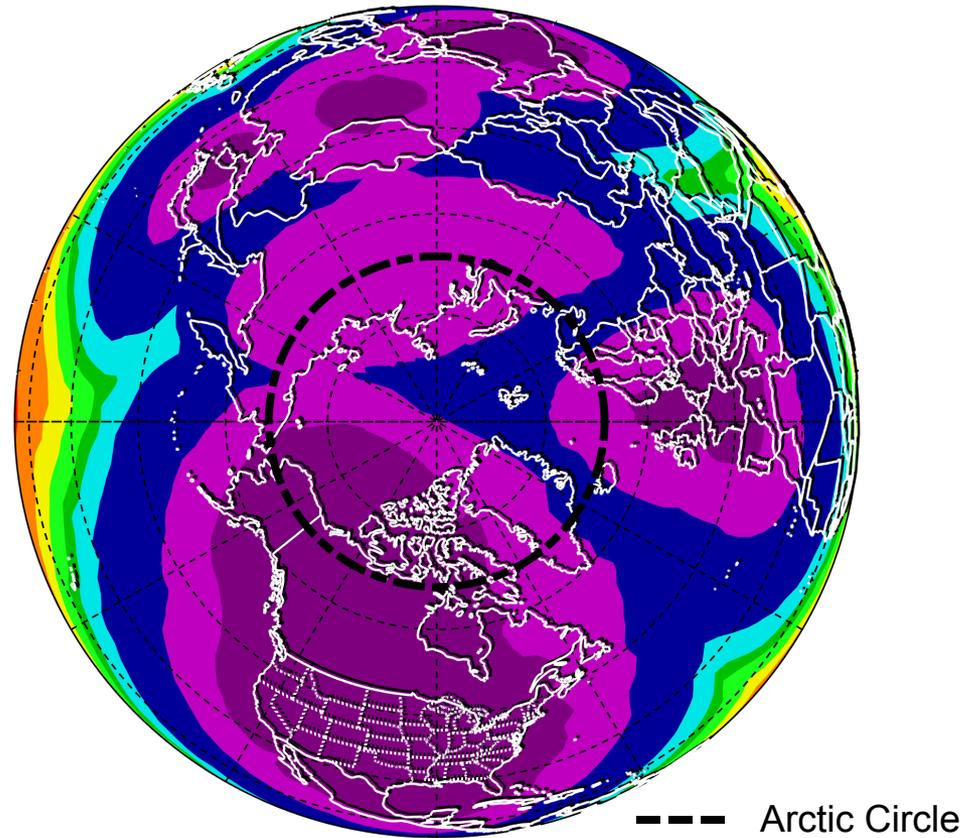
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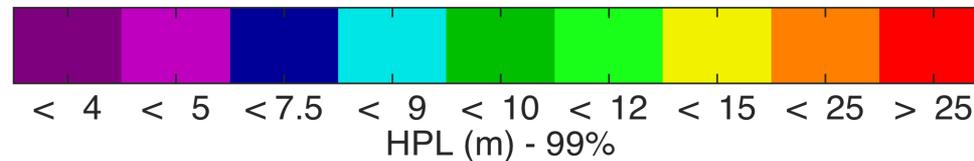
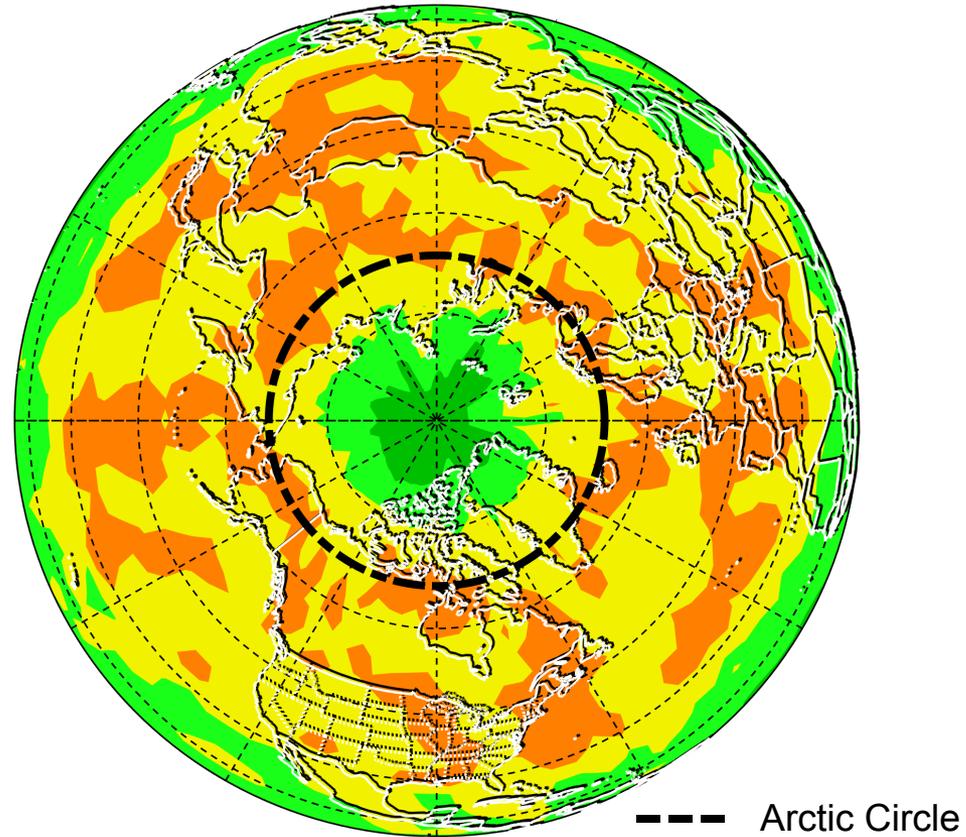
## Dual Frequency Planned +1 Constellation



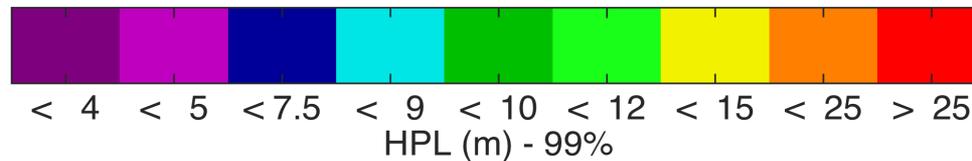
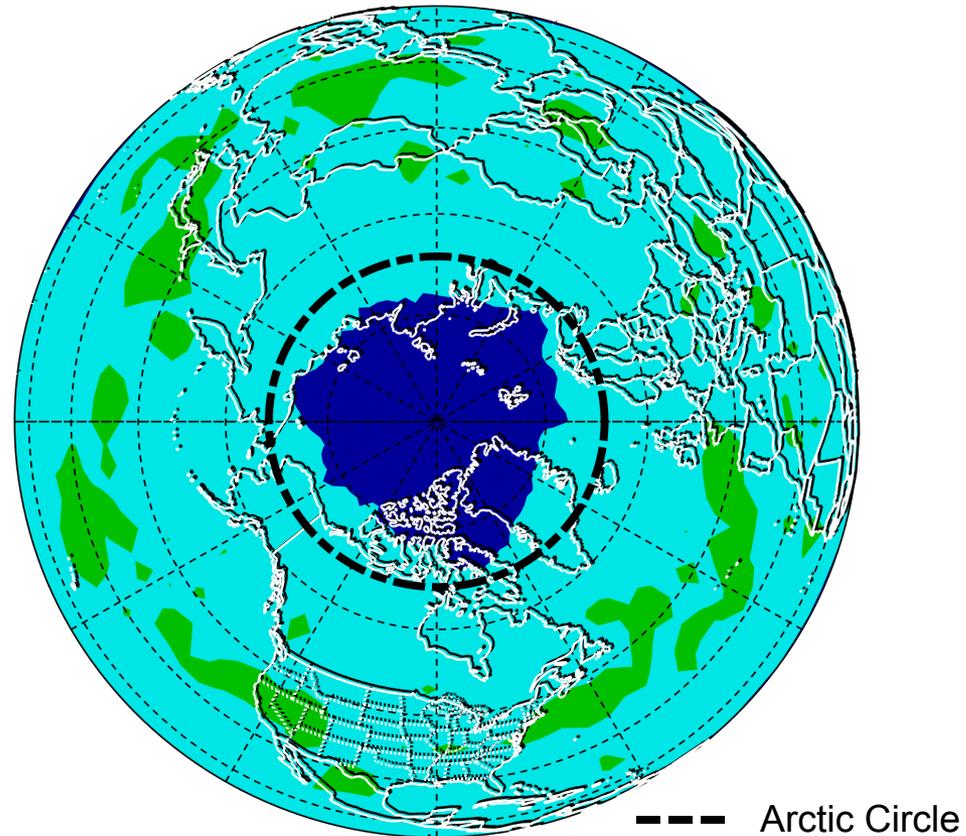
## Dual Frequency Planned +2 Constellations



## ARAIM (Horizontal) 2029 Dual Frequency GPS + Galileo

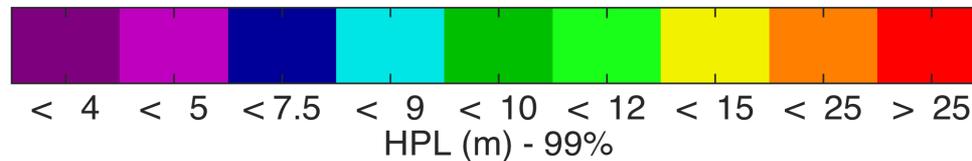
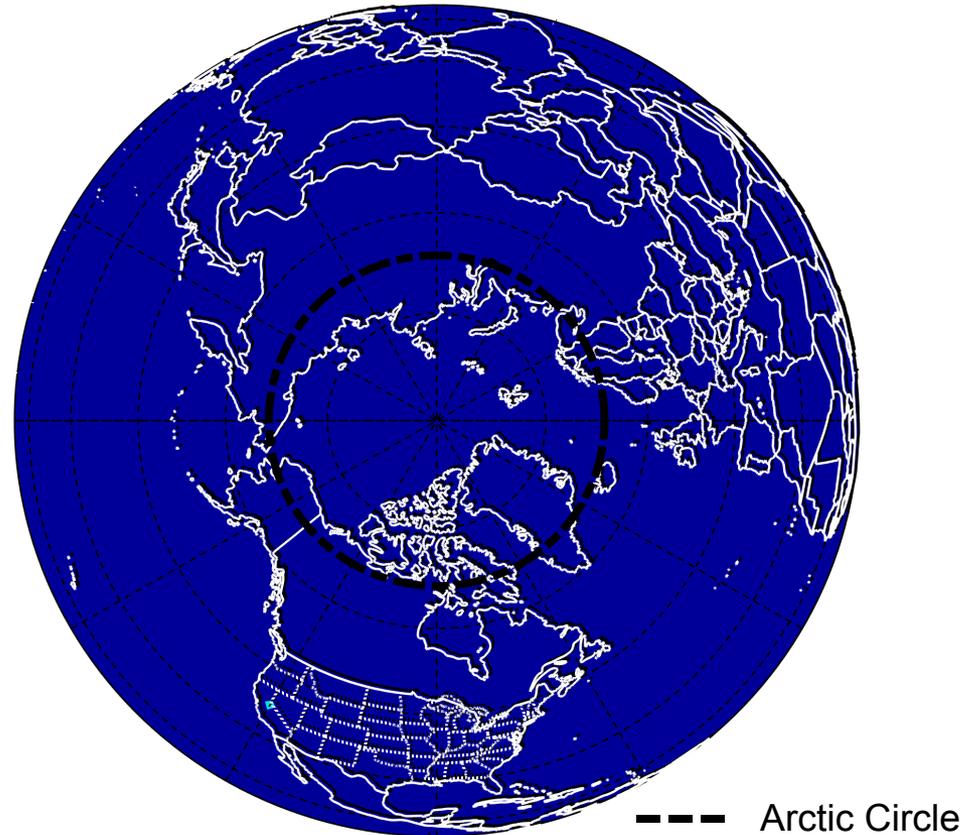


# ARAIM (Horizontal) 2029 Dual Frequency GPS + Galileo + GLONASS



# ARAIM (Horizontal) 2029

## Dual Frequency GPS + Galileo + GLONASS + BeiDou



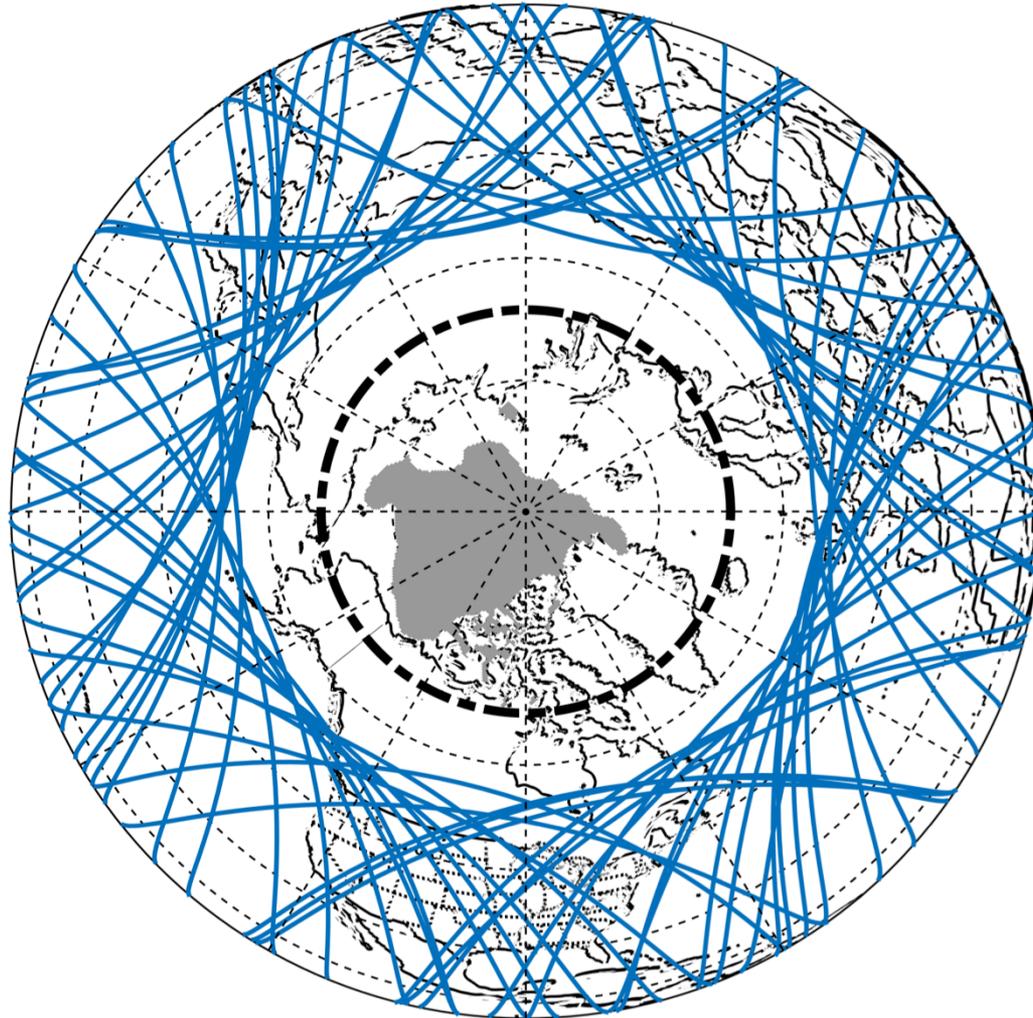


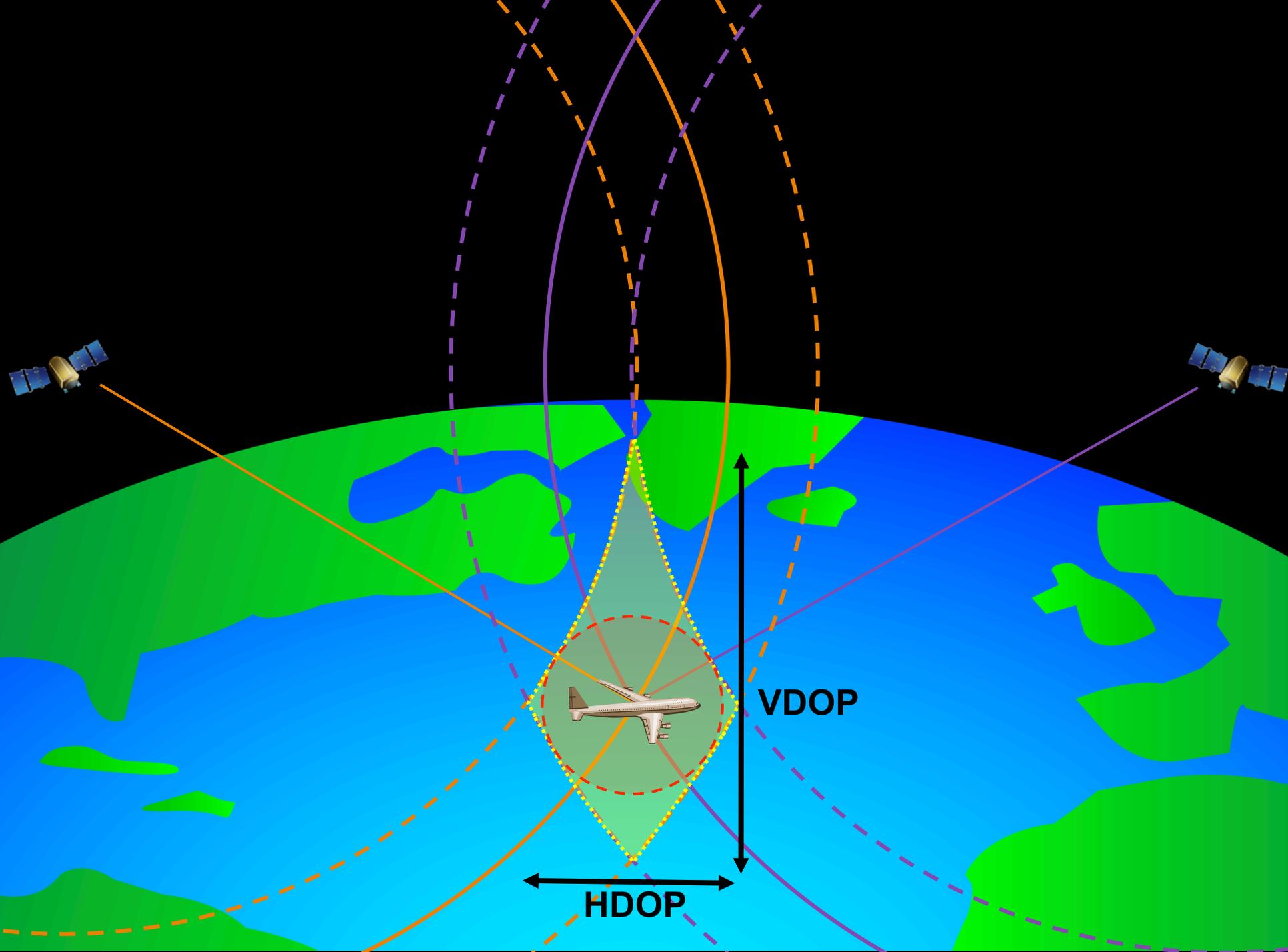
# Aviation Navigation Requirements

	Horizontal Alert Limit (HAL) [m]	Vertical Alert Limit (VAL) [m]	Time to Alarm [seconds]	Integrity Risk
LNAV	556	-	10	$10^{-7}$ per hour
LNAV / VNAV	556	50	10	$2 \times 10^{-7}$ per approach
LPV	40	50	6.2	$2 \times 10^{-7}$ per approach
LPV 200	40	35	6.2	$2 \times 10^{-7}$ per approach

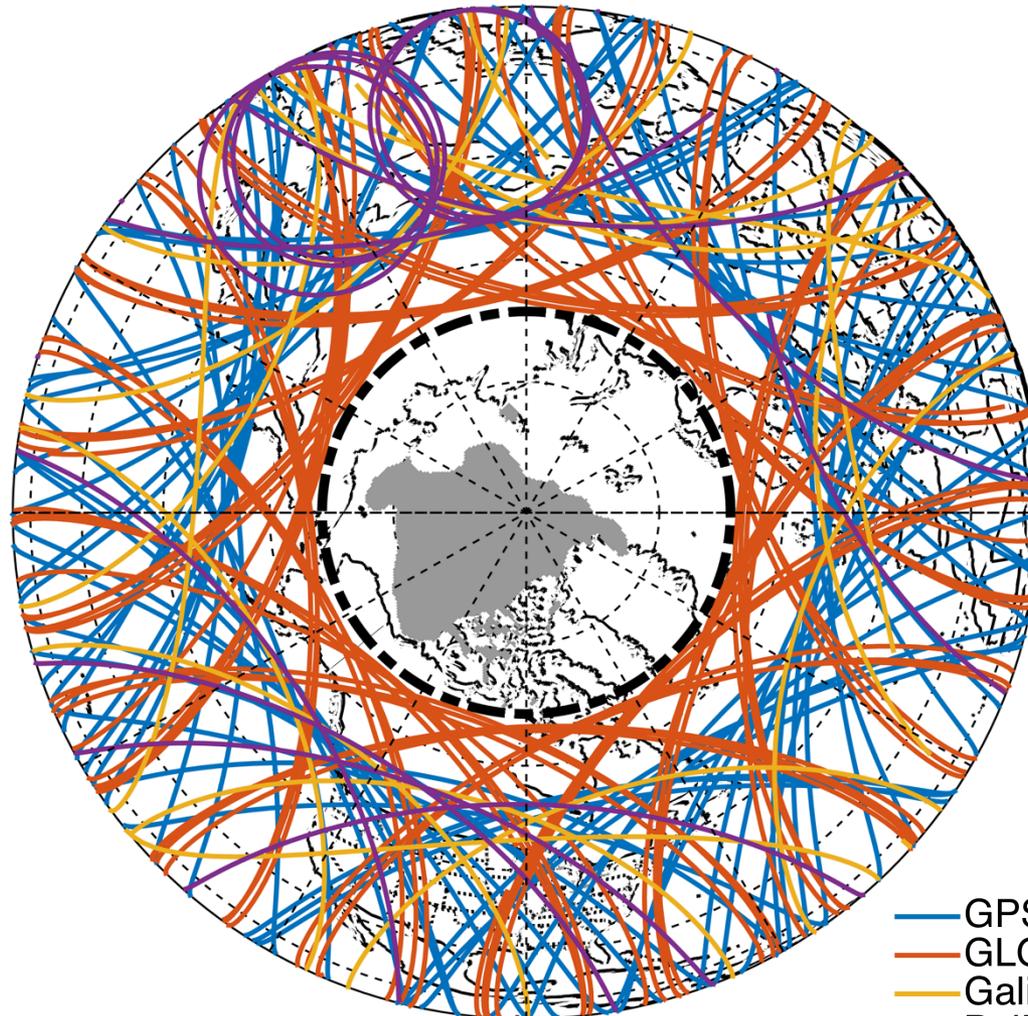


# GPS Groundtracks





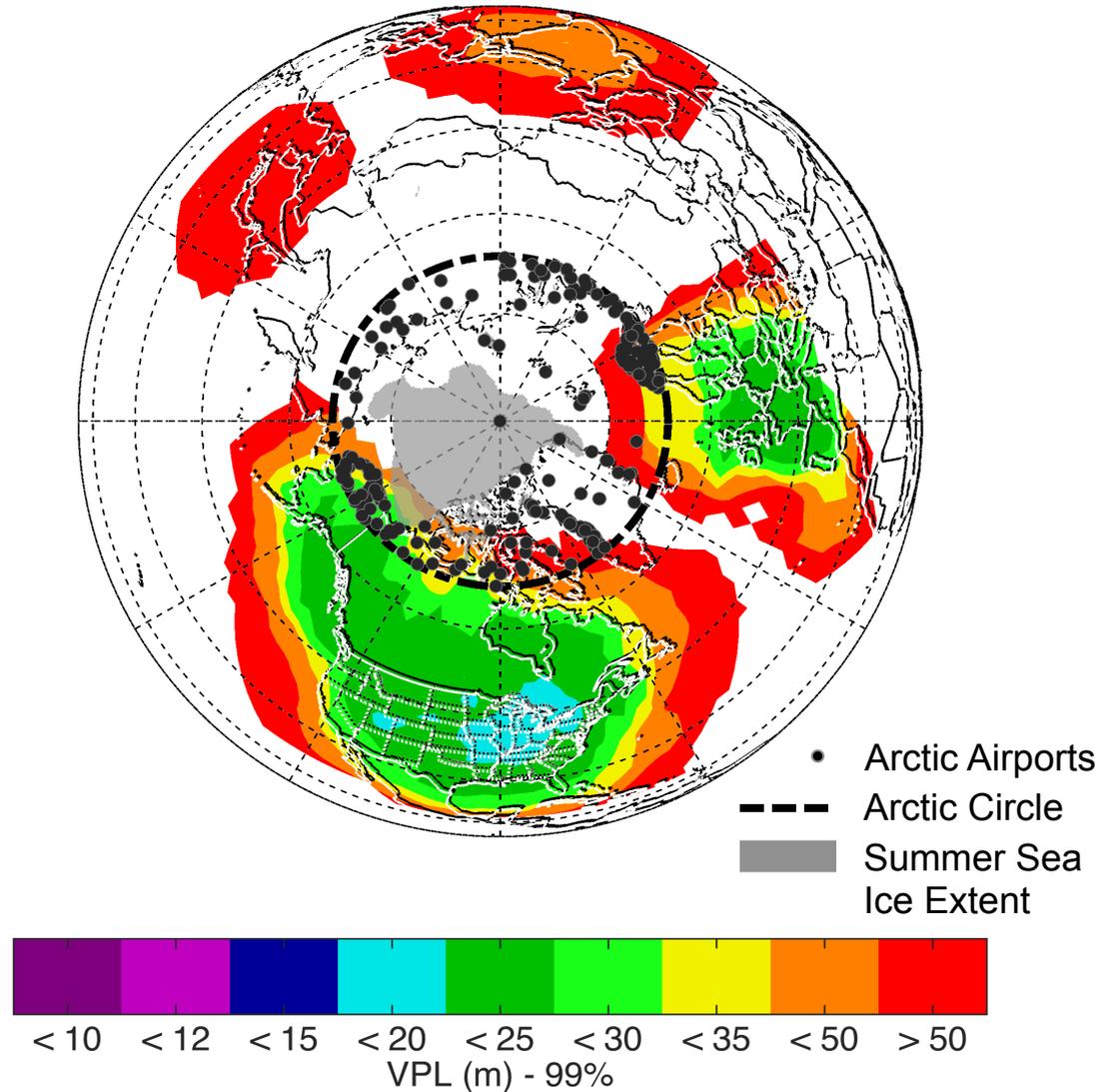
## All Current GNSS Groundtracks



- GPS
- GLONASS
- Galileo
- BeiDou

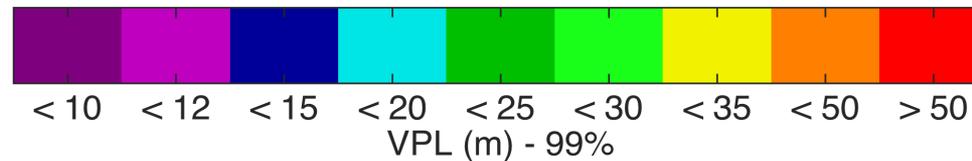
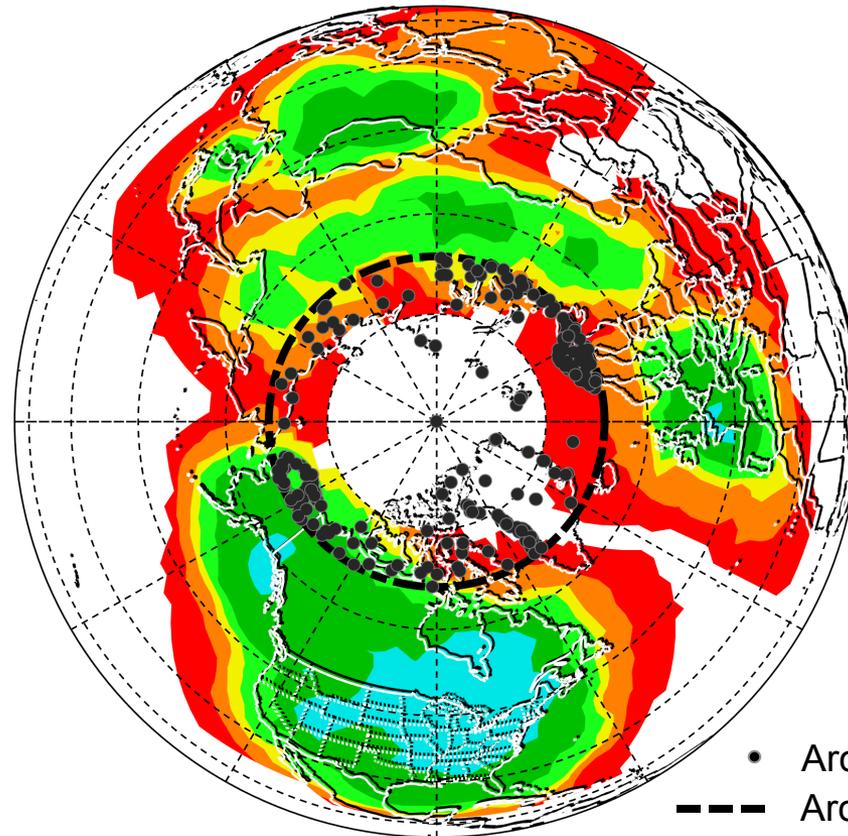


## Single Frequency 2015 WAAS + EGNOS + MSAS + GAGAN

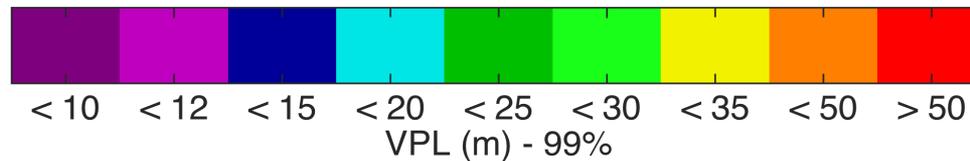
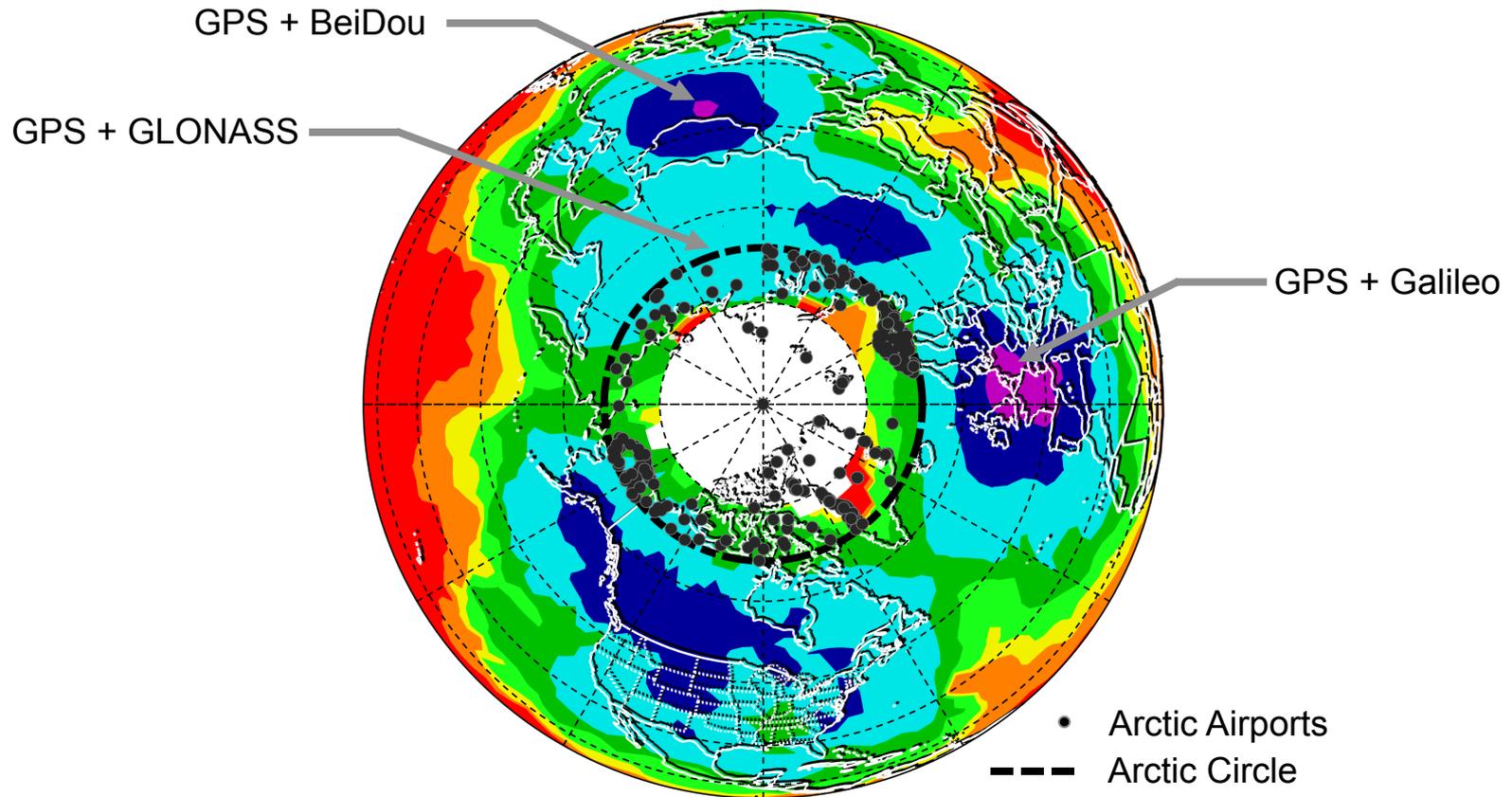


# Single Frequency 2021

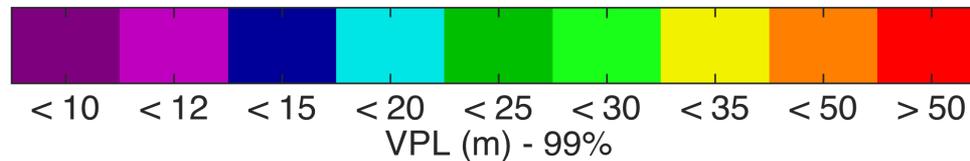
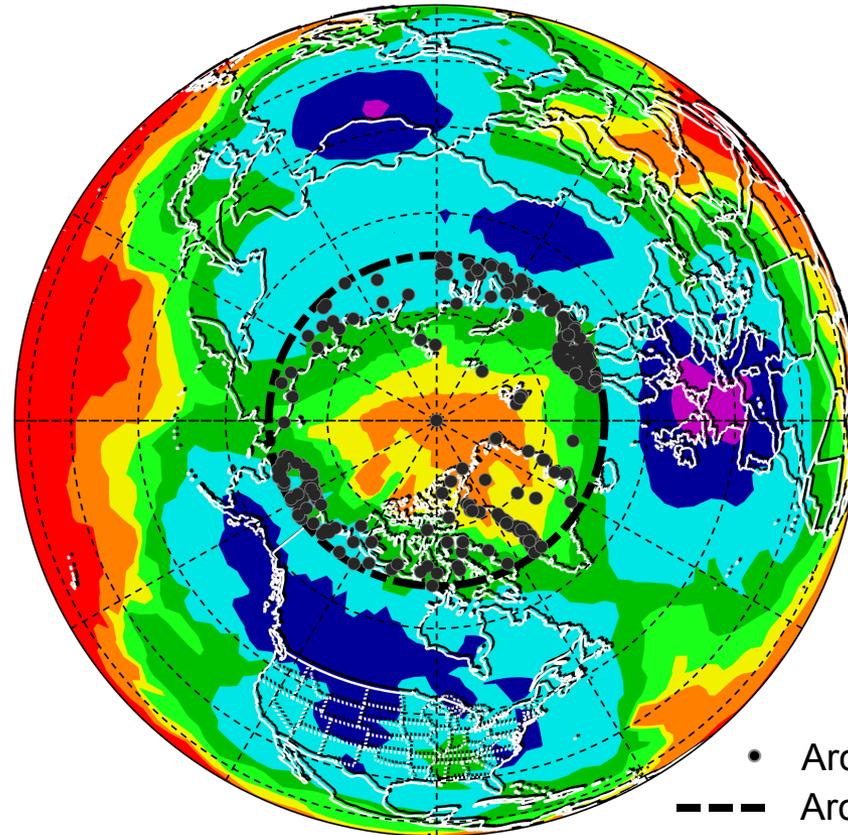
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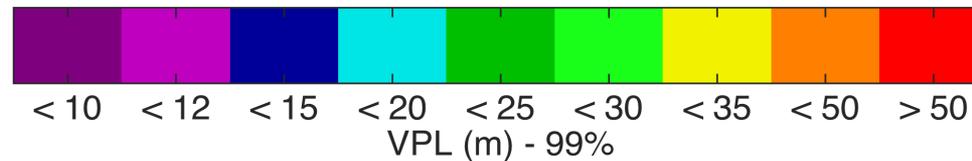
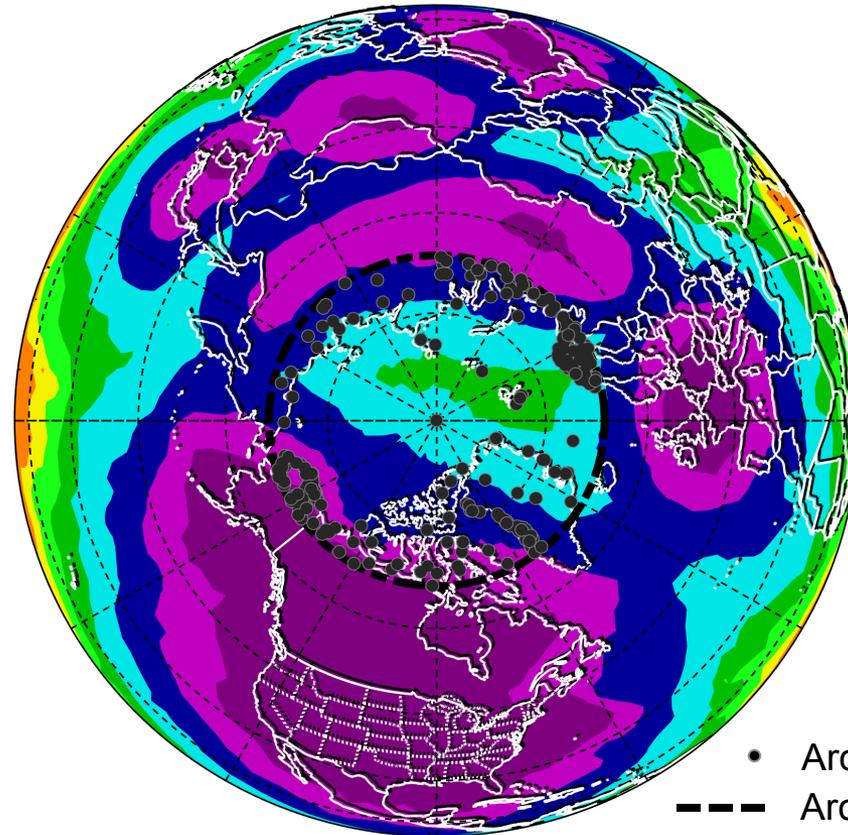
## Dual Frequency 2026 Planned



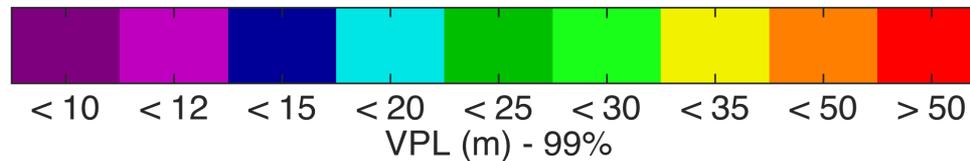
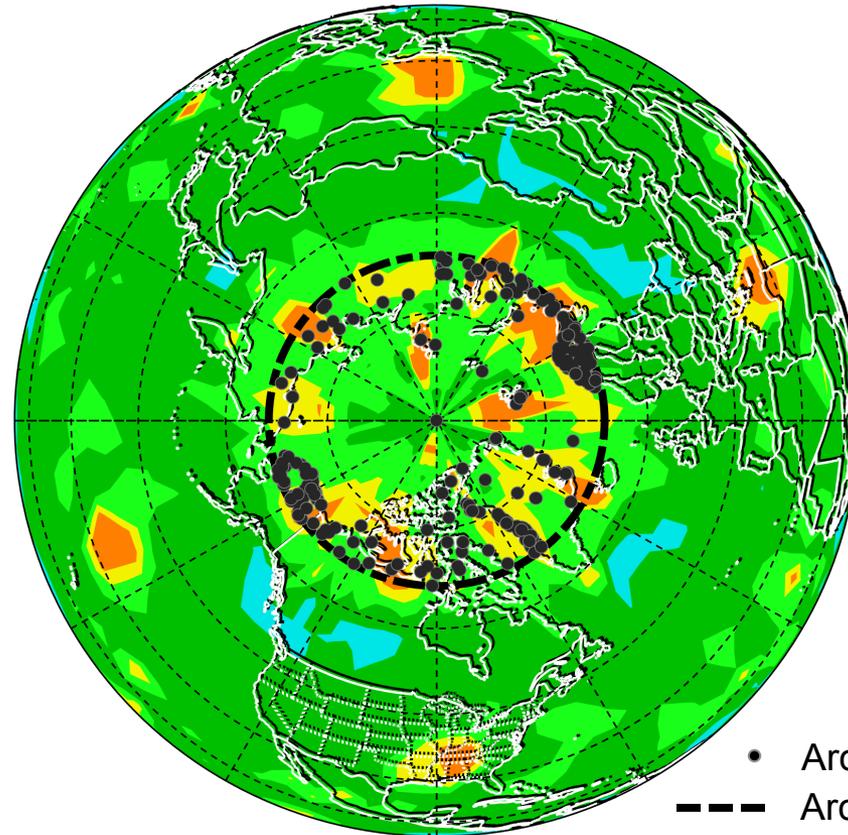
## Dual Frequency 2026 + Arctic Comm Planned



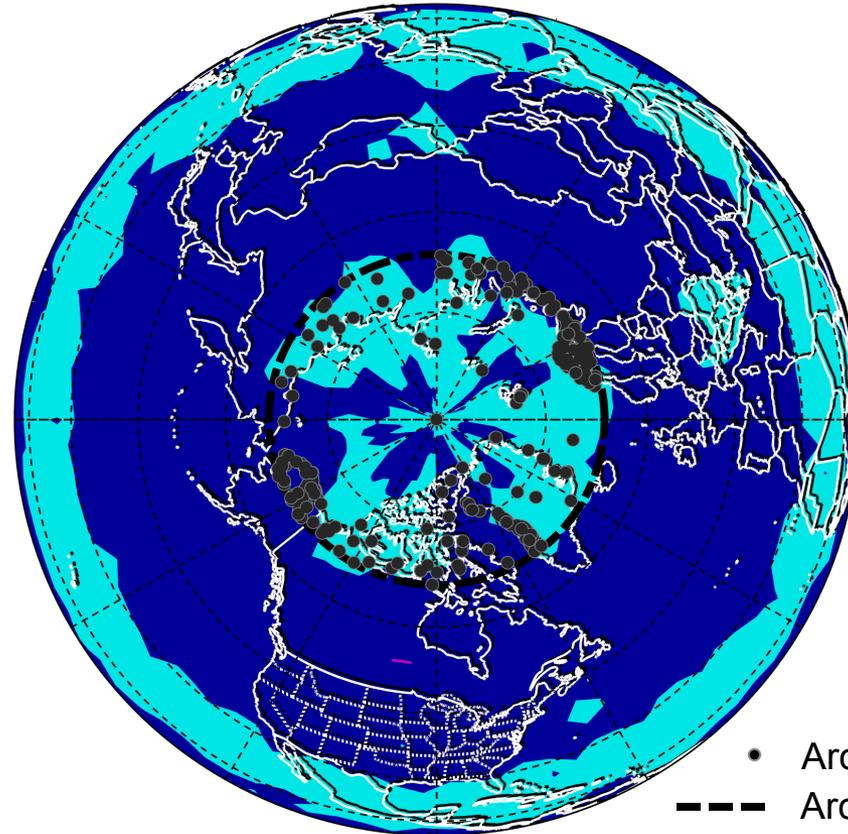
## Dual Frequency Planned +1 Constellation



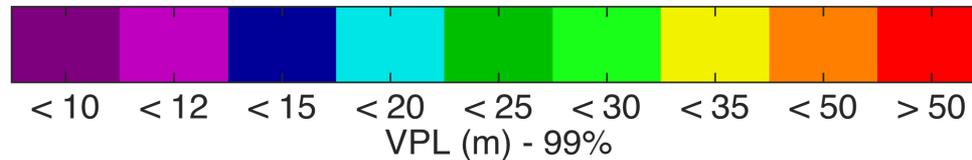
## ARAIM (Vertical) 2029 Dual Frequency GPS + Galileo



# ARAIM (Vertical) 2029 Dual Frequency GPS + Galileo + GLONASS



- Arctic Airports
- - - Arctic Circle



# Conclusion

- Navigation integrity in the Arctic is critical in ensuring activities there be carried out as safely as possible.
- GNSS navigation integrity in the Arctic for both maritime and aviation applications is achievable with different levels of service being offered by SBAS and ARAIM.
- Our ultimate goal is to offer safer navigation in the hopes of preventing catastrophic accidents in the future.



# Acknowledgements



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The opinions presented here are my own and do not necessarily reflect the opinion of any other person or organization.