Multi-constellation Navigation for Air & Sea:
Advanced Receiver Autonomous Integrity Monitoring

for the Space-Based Position, Navigation & Time Advisory Board

by Per Enge, Stanford University*
on October 30, 2015

based on work of the ARAIM Technical Subgroup Within
Working Group C of the EU/US Bilateral Activity on GNSS

*Funded by the Federal Aviation Administration Under
Cooperative Agreement 12-G-003

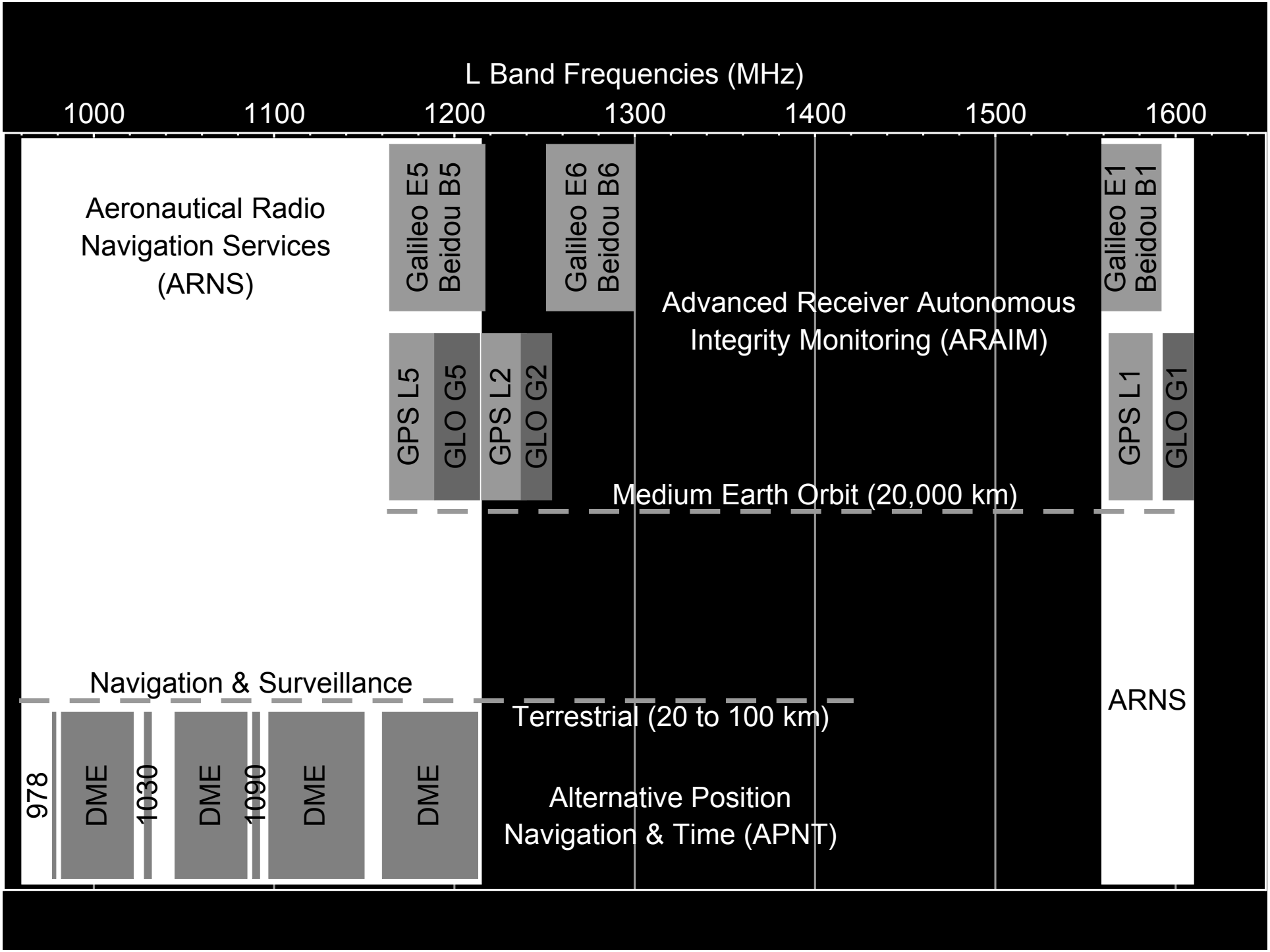
Disclaimer

The opinions expressed in this presentation may only belong to the speakers.

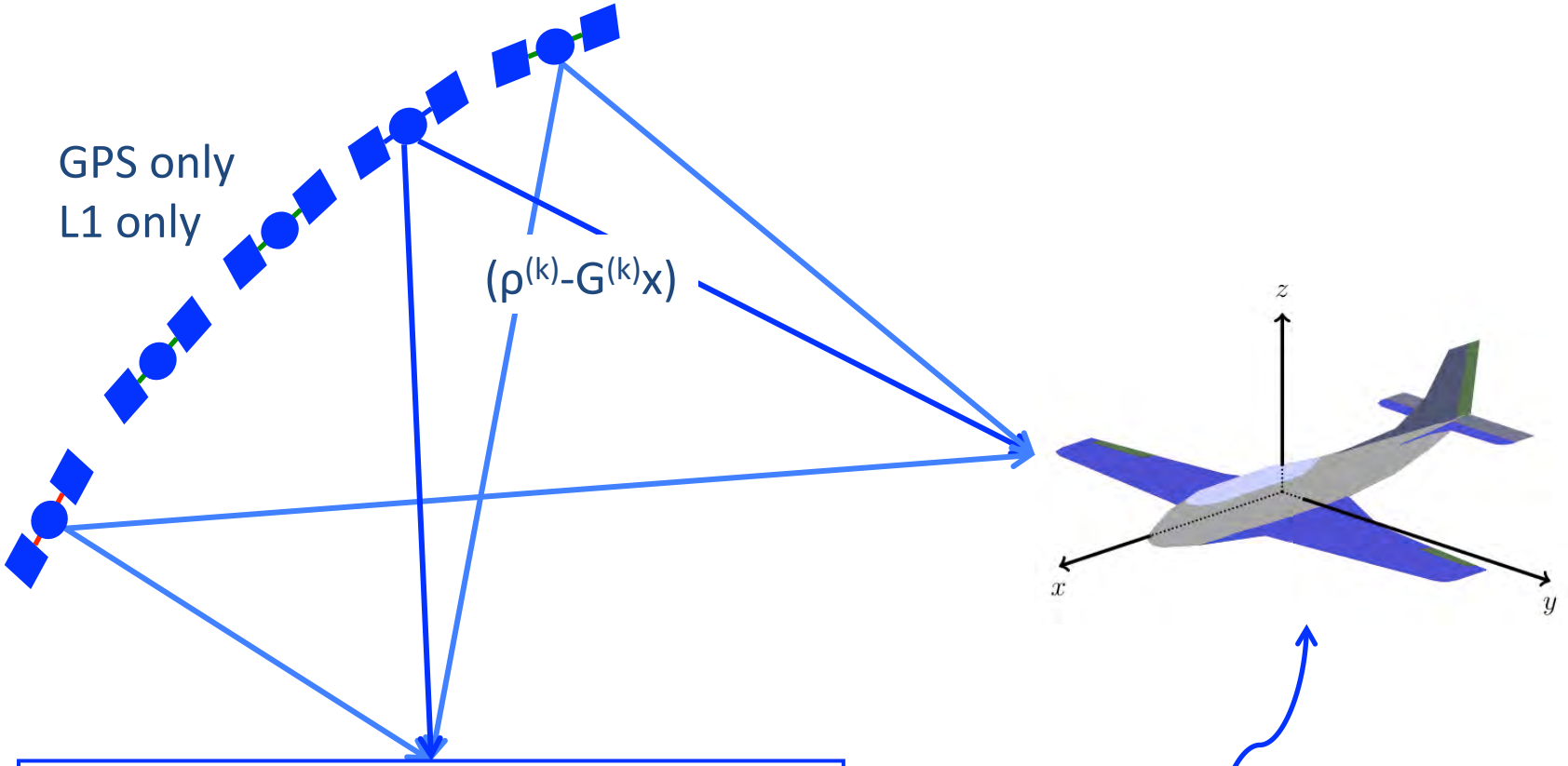
These thoughts do not necessarily correspond to any present or future view of the

- U.S. government, or
- Federal Aviation Administration, or
- Working Group C, or the
- European Commission

The mistakes are certainly mine alone.


L Band Frequencies (MHz)
1000
1100
1200
1300
1400
1500
1600
Aeronautical Radio Navigation Services (ARNS)
Galileo E5 Beidou B5
Galileo E6 Beidou B6
Galileo E1 Beidou B1
Advanced Receiver Autonomous Integrity Monitoring (ARAIM)
GPS L5
GLO G5
GPS L2
GLO G2
GPS L1
GLO G1
Medium Earth Orbit (20,000 km)
Navigation & Surveillance
Terrestrial (20 to 100 km)
ARNS
978
DME
1030
DME
1090
DME
DME
Alternative Position Navigation & Time (APNT)

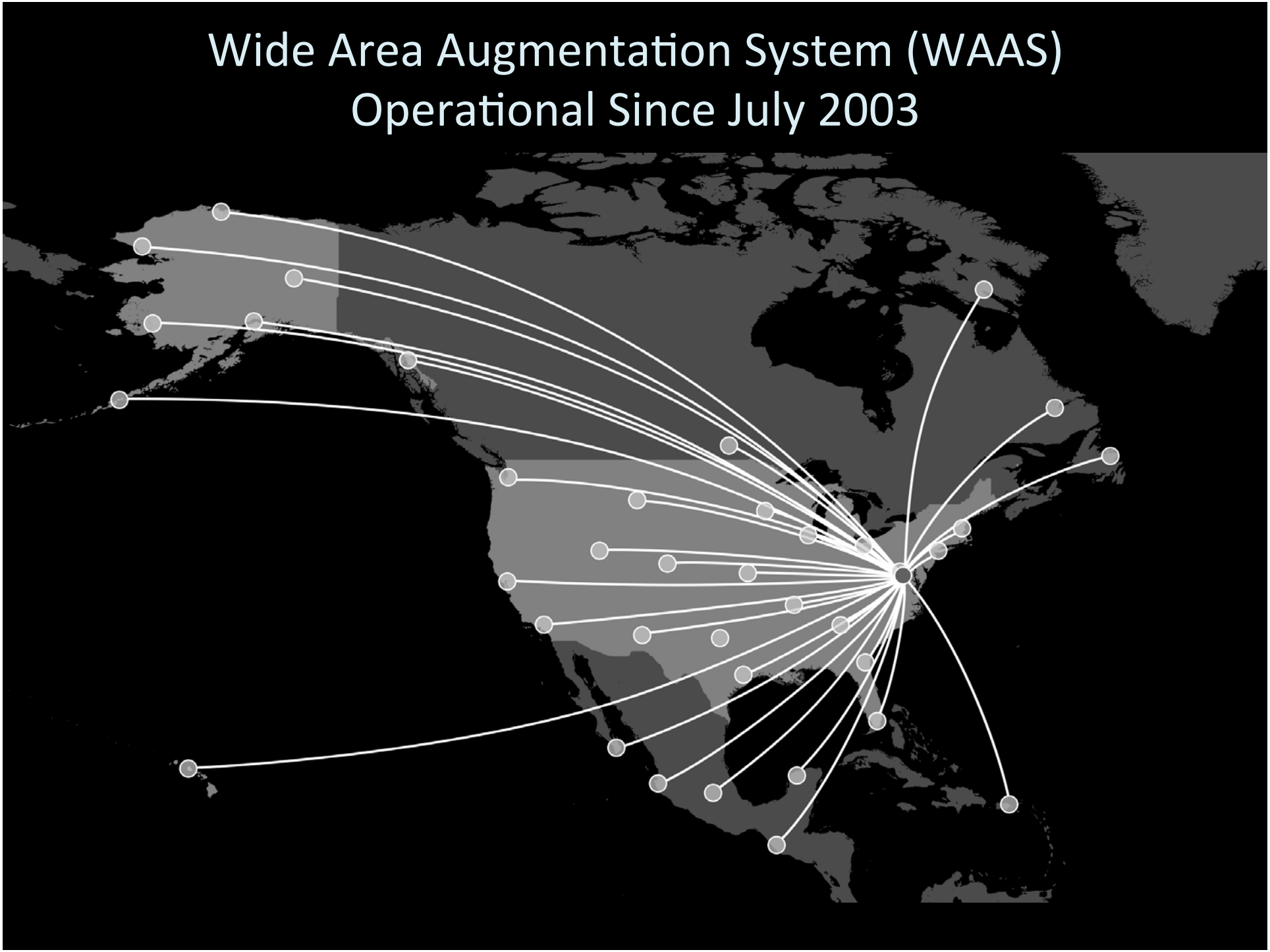
Receiver Autonomous Integrity Monitoring (RAIM) Supports Lateral Navigation for 100,000's of Aircraft



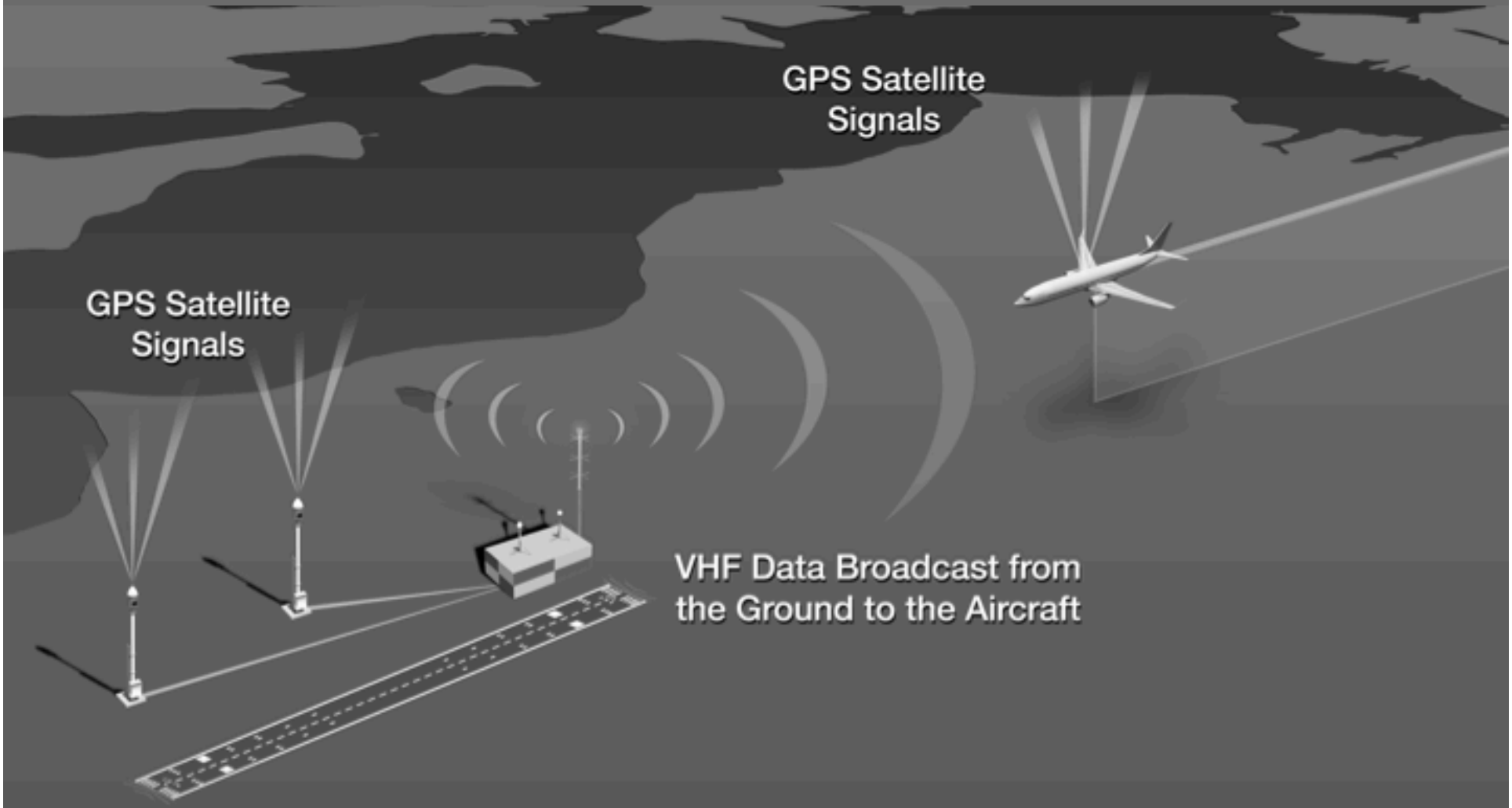
GPS Ground Control Segment
- GPS reference stations
- GPS commitments & history on P_{sat}
- GPS history on P_{const}

RAIM Dispatch Check

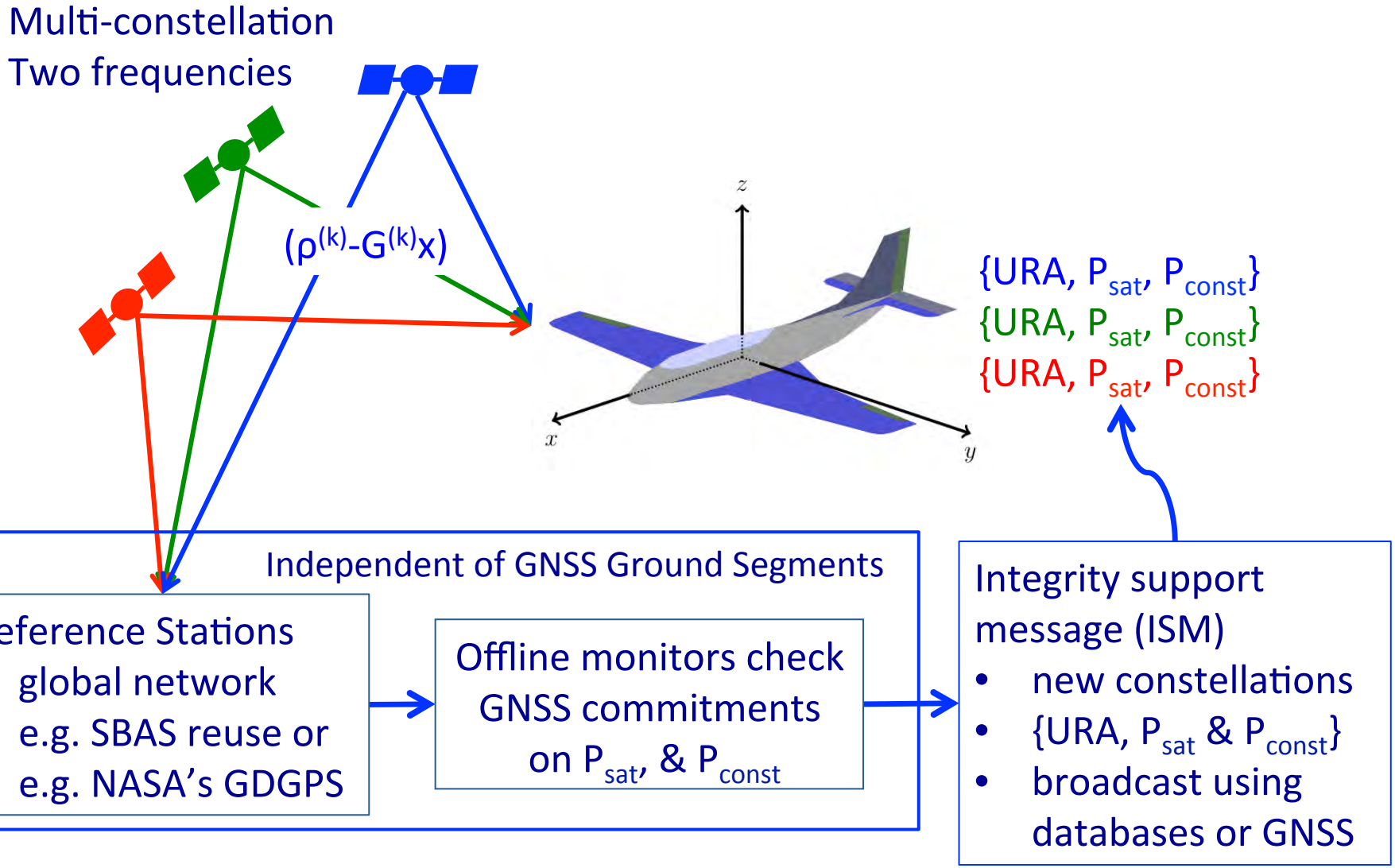
Wide Area Augmentation System (WAAS)
Operational Since July 2003



Ground Based Augmentation System



Advanced RAIM (aka Almost RAIM) to Support Lateral + Vertical Navigation Worldwide



ARAIM Benefits

Horizontal ARAIM in the Near Term Based on One Frequency

- Before dual frequency GPS + dual frequency Galileo
- e.g. single frequency GPS + single frequency GLONASS
- Two constellations with very different P_{sat} & P_{const}

ARAIM to Support Artic Navigation with High Integrity

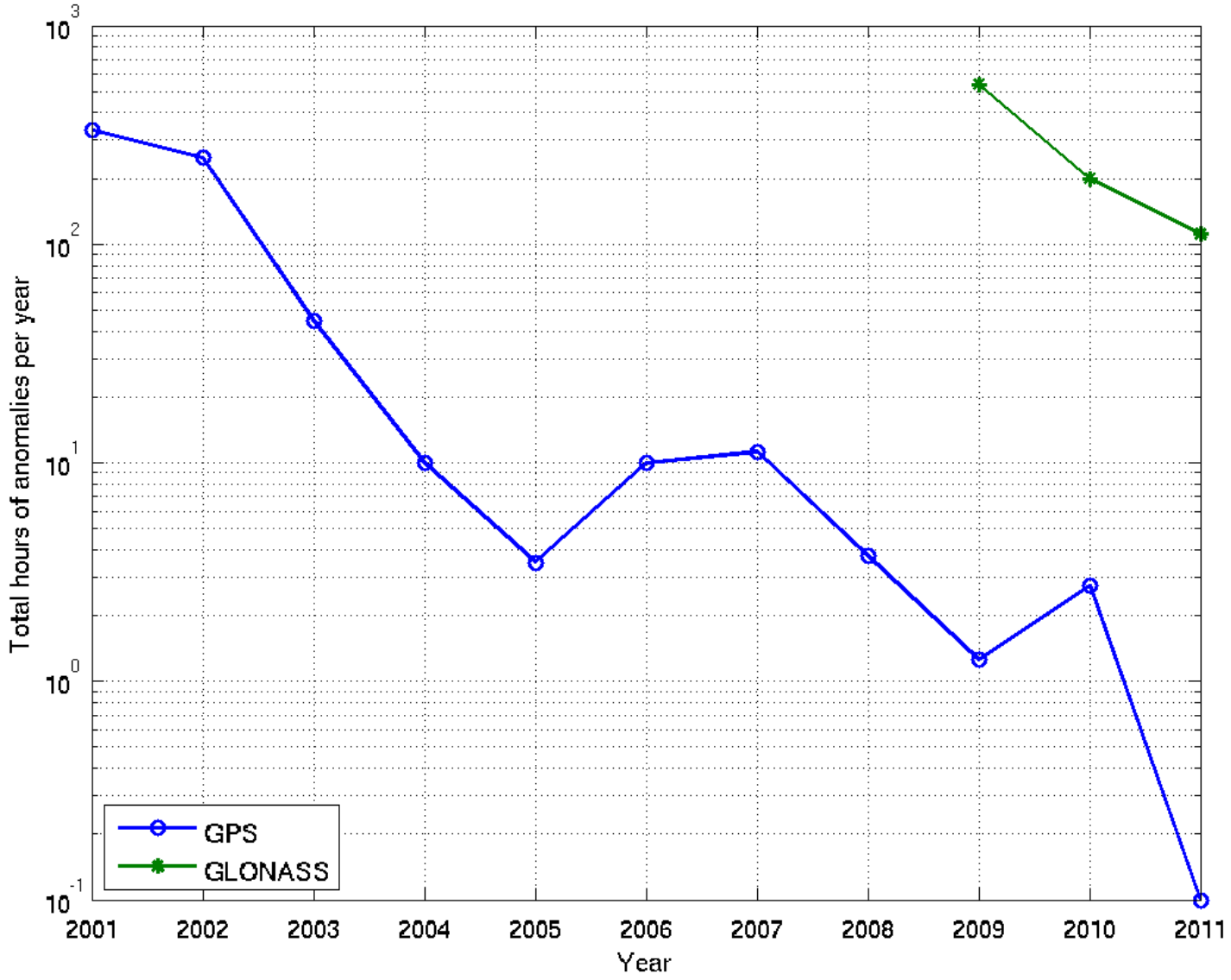
- Energy exploration, eco-tourism & shipping
- Ship speed is doubled in ice cracks
- SBAS GEOs do not cover the poles

Vertical ARAIM Worldwide Without GEOs

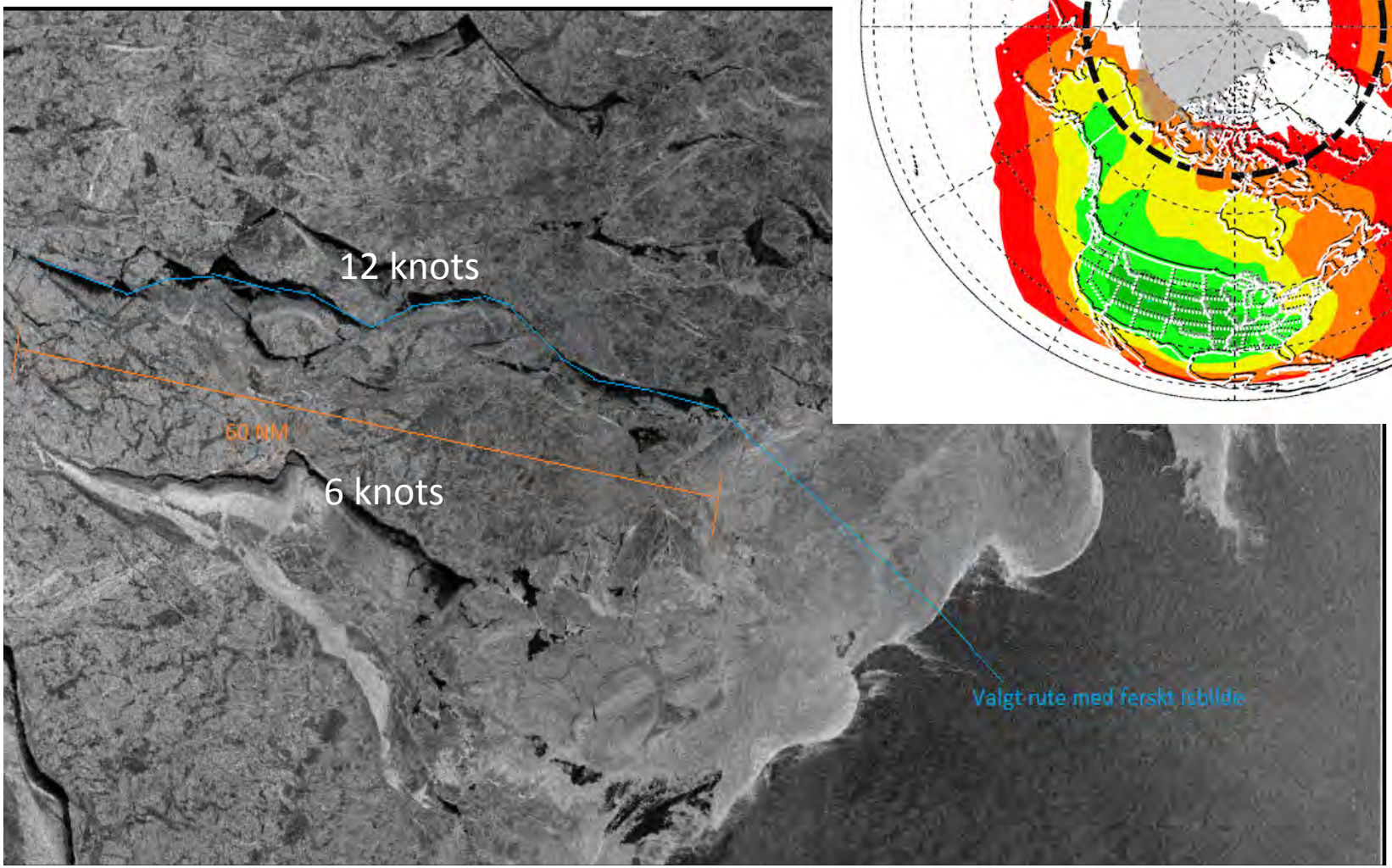
ARAIM to Harden GNSS Receivers

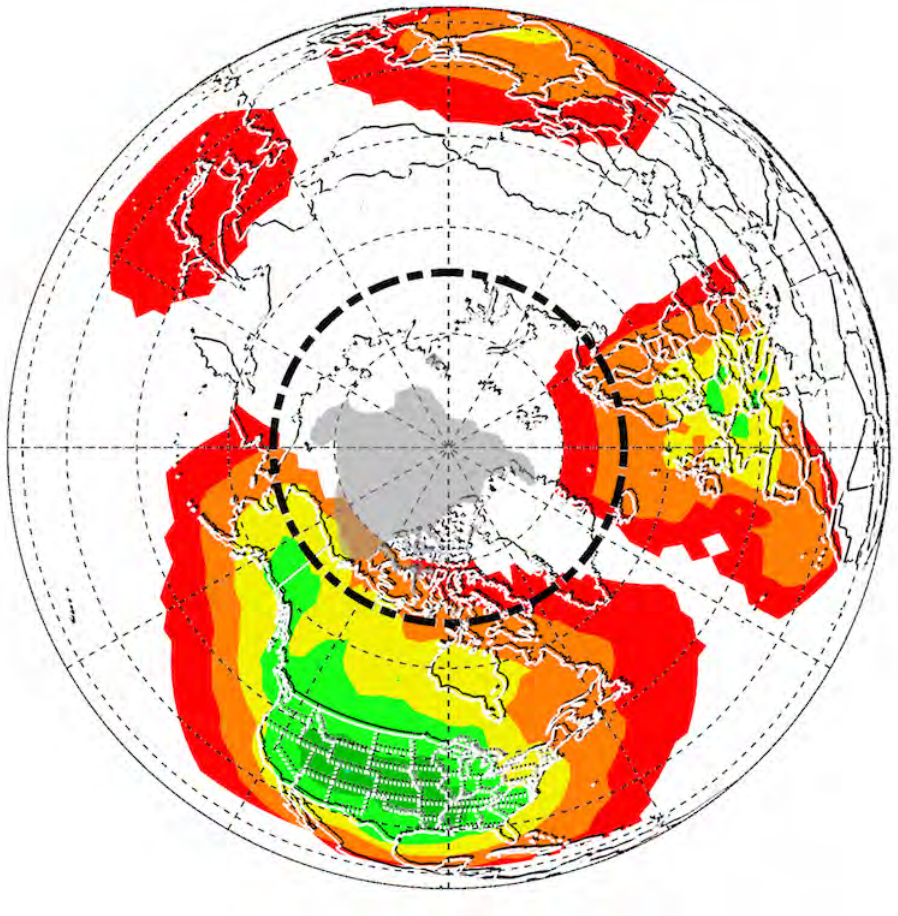
- Does not need GEOs
- Does not need low SVs

Bathtub Challenge (from Liang Heng)



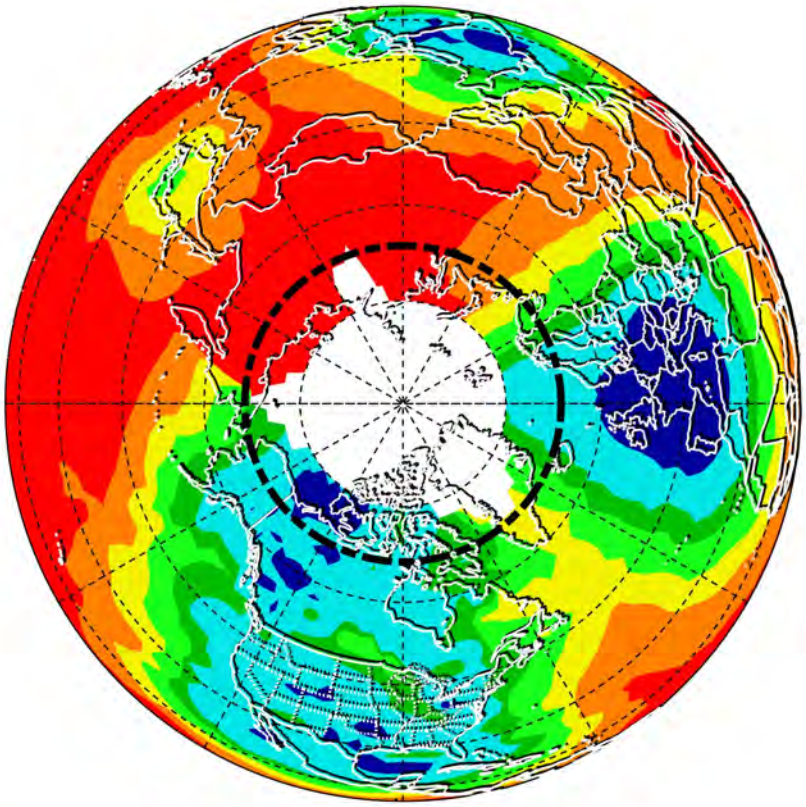
Benefit From Following a Crack in the Ice

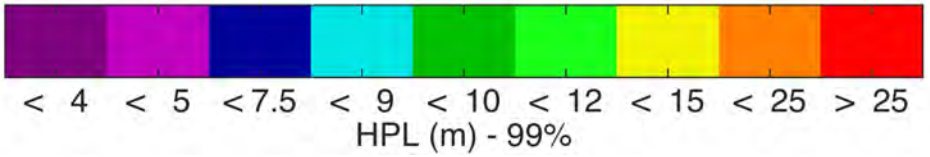




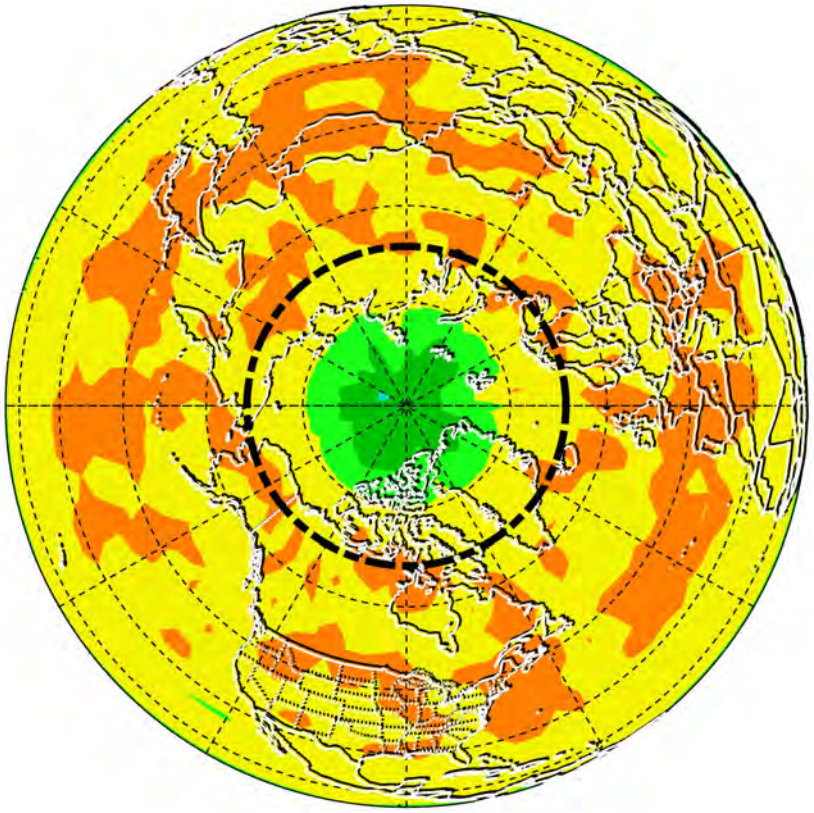
Polar Coverage of Dual Frequency SBAS & ARAIM

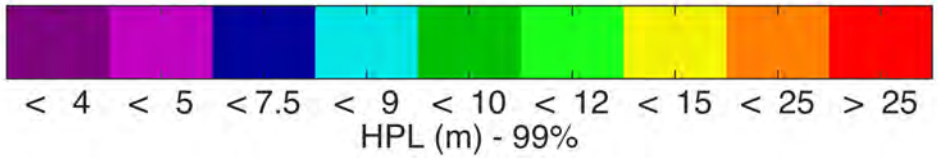
24 GPS +24 Galileo



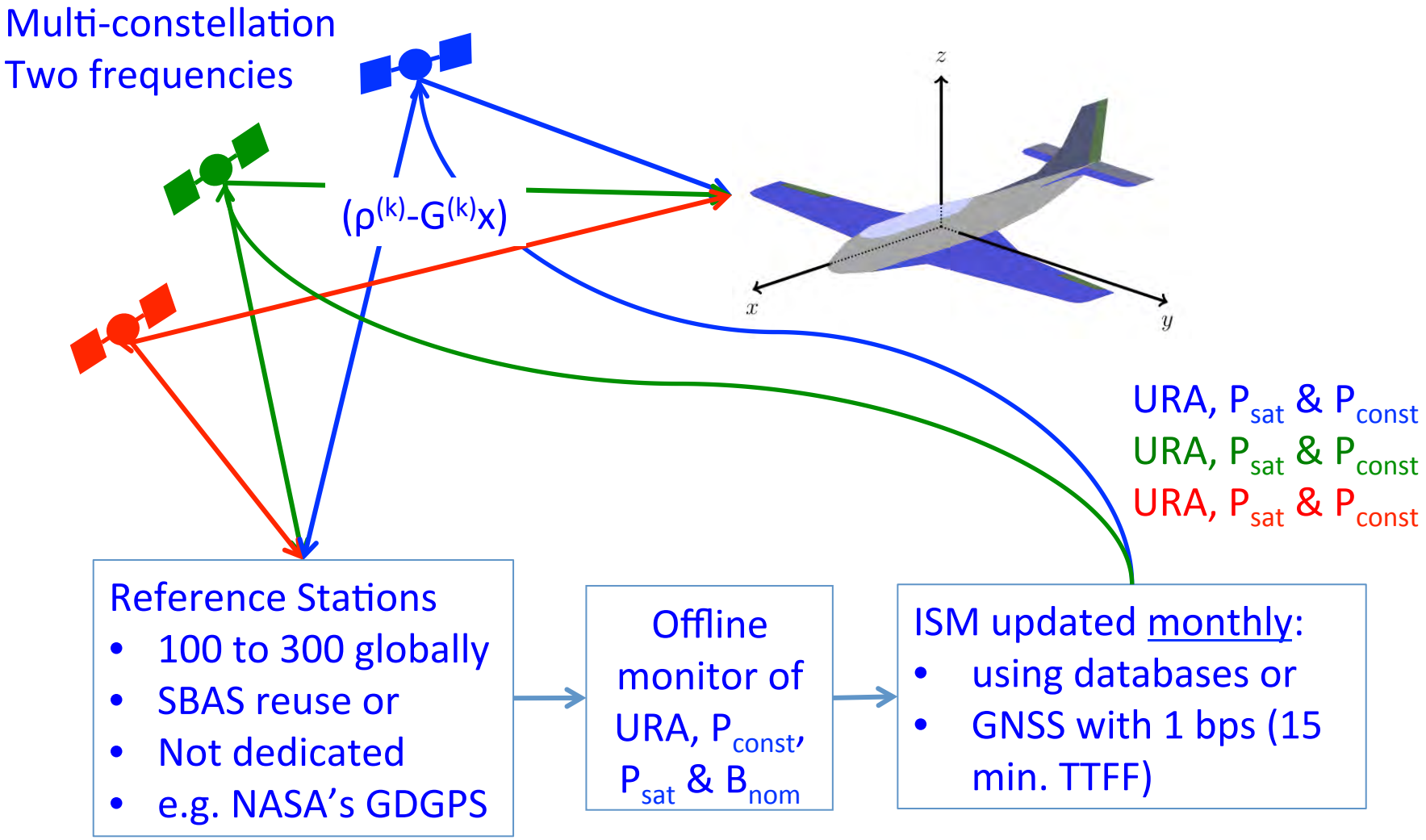


24 GPS +24 Galileo

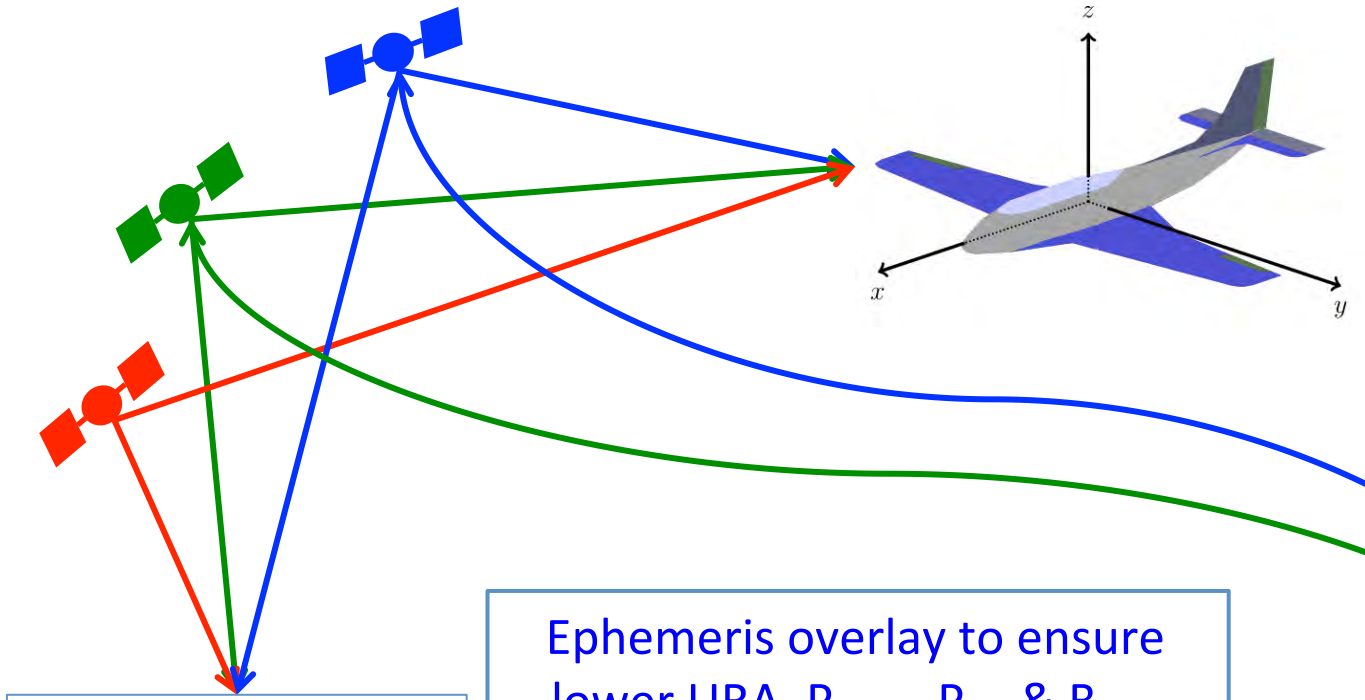




Offline ARAIM Uses the Ephemeris & Clock Data Broadcast by the Core Constellations



Online ARAIM Replaces the Ephemeris & Clock Data (ECD) Generated by the Core Constellations



ECD, URA, P_{sat} & P_{const}
ECD, URA, P_{sat} & P_{const}
ECD, URA, P_{sat} & P_{const}

Reference Stations
- 15-20 globally
- SBAS reuse
- 3 rcvrs/station

Ephemeris overlay to ensure lower URA, P_{const}, P_{sat} & B_{nom}

Orbit & clock estimator

Online monitor

Offline monitor

ISM update 12 minutes
- ECD, URA, P_{sat} & P_{const}
- GNSS data rate < 6 bps

Multi-constellation for Toughening Air Navigation example is based on RNP 0.3

Constellation	GPS only Mask=5°	GPS only Mask=15°	GPS+Galileo Mask=5°	GPS+Galileo Mask=15°
Depleted with 23 satellites	99.1%	0%	100%	69.3%
Baseline with 24 satellites	100.0%	2.3%	100%	100%
"Optimistic" with 27 satellites	100.0%	19.0%	100%	100%

Small part of aviation portfolio for intentional interference and spoofing
Please see Ken Alexander briefing to RTCA in October, 2015.


Seeking orderly adoption of new constellations for aviation
Vertical guidance worldwide
Tough against RFI (still requires quiet background)
Tough against frailties of new constellation