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Invent the Future

A Multi-Constellation Analysis of Global Navigation Satellite System (GNSS) Signals in the Equatorial Region

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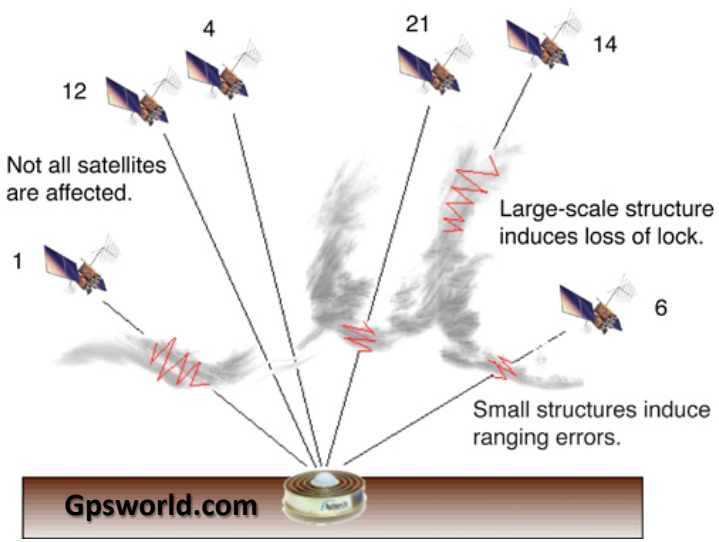
Outline

- Introduction
- Background
  - Scintillation
  - GNSS Signals
- Data acquisition from Lihue, HI
- Results & analysis
  - 1/2017-present
  - 3/27/2017
- Conclusions

Scintillation

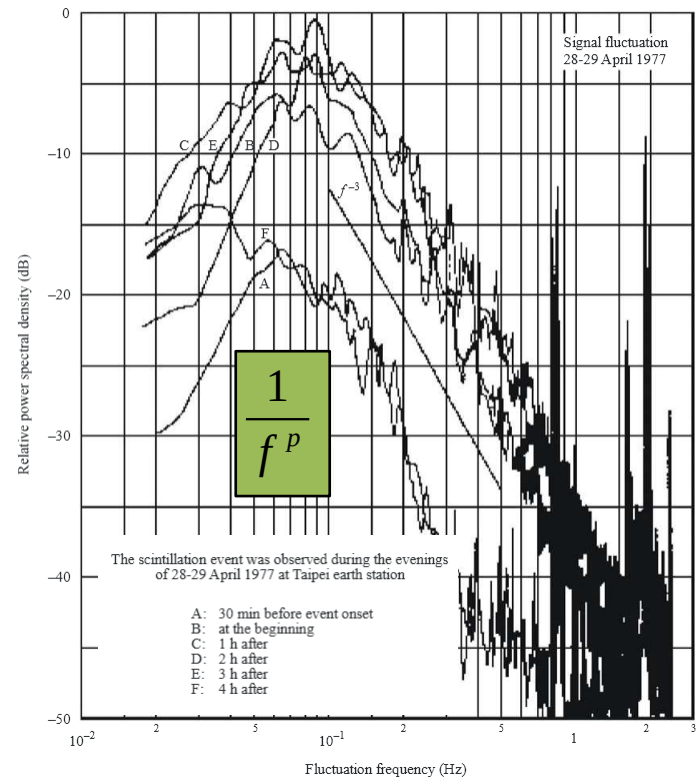
- TEC along travel path
  - Phase shift
  - Time advance
  - Phase variations along a wave front leads to interference
- Previous research suggests
  - Amp: prominent at low lats
  - Phase: prominent at high lats
- Metrics: S4, σ_ϕ, p



Channel Fluctuation Example (ITU-R P.531-12)

FIGURE 8

Power spectral density estimates for a geostationary satellite (Intelsat-IV) at 4 GHz



$$S_4 = \frac{\langle I^2 \rangle - \langle I \rangle^2}{\langle I \rangle^2}, \quad \sigma_\phi^2 = \langle \phi^2 \rangle - \langle \phi \rangle^2$$

Can severely degrade GNSS performance

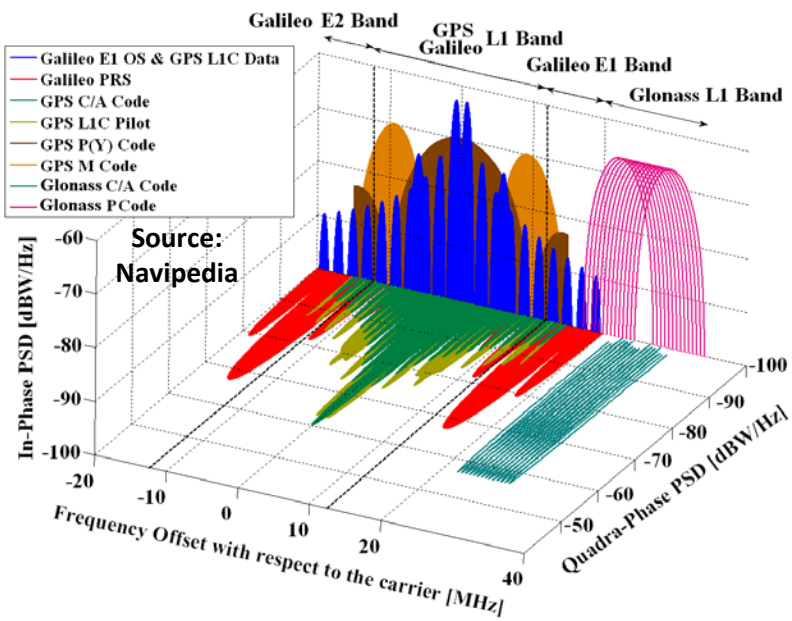
Introduction

- Increased availability of Global Navigation Satellite System (GNSS) constellations
  - Enhanced spatial diversity
  - New opportunities for scintillation studies
  - Similar bands but different signal structures
- Objectives
  - Investigate the frequency and constellation dependence on scintillation and Ionospheric measurements
  - Consider reasons for observed differences and implications
  - Gauge value from community of this research direction

First attempts to analysis data being acquired in Hawaii
High excursion scintillation for legacy systems (GPS & GLONASS)

GNSS Signals: Overview of Analyzed Constellations

System	Bands (GHz)	Modulation	Encoding	Chips	Chip Rate (MHz)
GPS (USA)	L1 (1.575), L2 (1.227), L5 (1.176)	BPSK, BOC, TMBOC	CDMA	1023	1.023
GLONASS (Russia)	G1 (1.598 –1.609), G2 (1.242–1.251)	BPSK	CDMA/FDMA	511	0.511
Galileo (EU)	E1 (1.575), E5a (1.176), E5b (1.207)	CBOC/BPSK, AltBOC/8-PSK	CDMA	4092-102300	1.023, 10.23
BeiDou (China)	B1 (1.561), B2 (1.207)	QPSK	CDMA	2046	2.046



Potential impact of signal differences

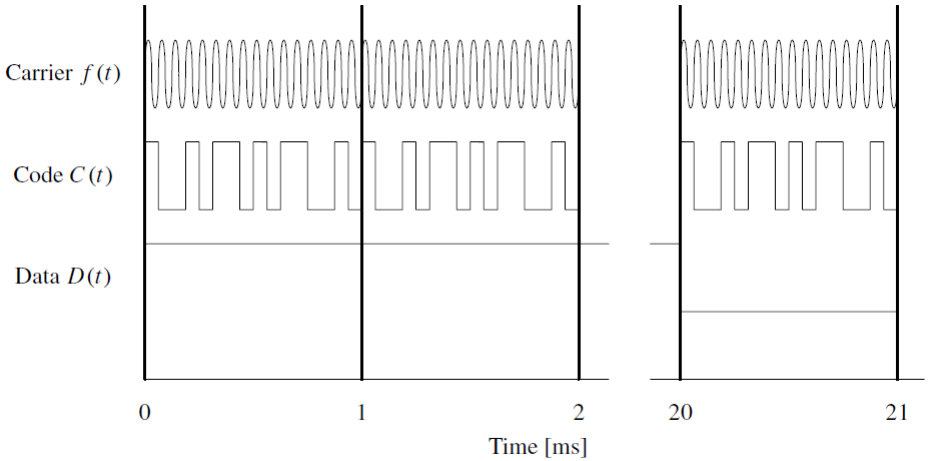
- Integration, doppler & ranging accuracy
- Increased processing options for newer constellations
- Noise bandwidth and range resolution
- Spread spectrum & interference mitigation

Differences may impact measurements used to interpret Ionospheric conditions

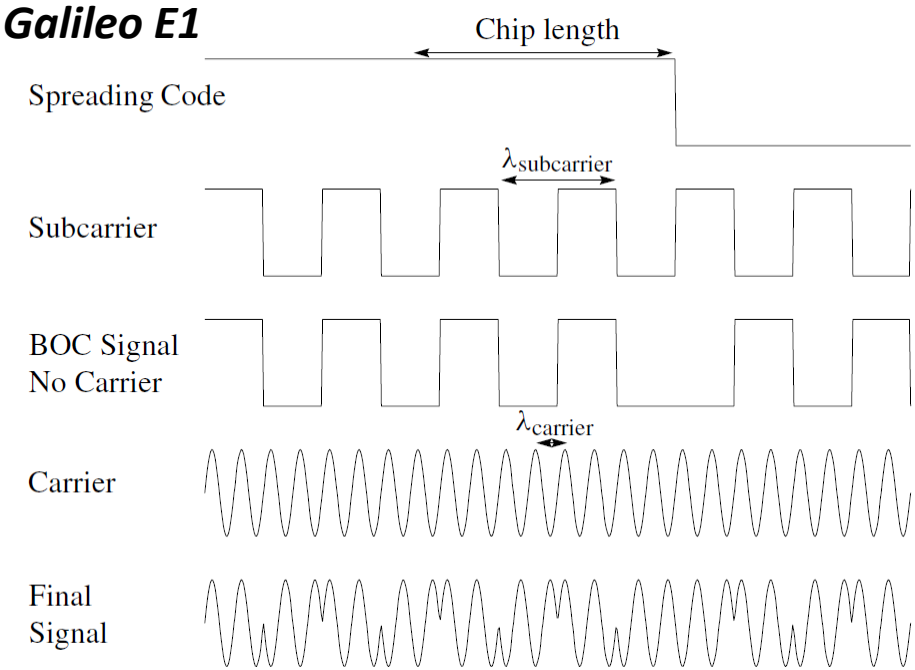
C. J. Hegarty and E. Chatre, "Evolution of the Global Navigation SatelliteSystem (GNSS)," in Proceedings of the IEEE, vol. 96, no. 12, Dec. 2008.
European GNSS (Galileo) Open Service Signal In Space Interface Control Document (OS SIS ICD), Issue 1.2, European Union, 2015
BeiDou Navigation Satellite System Signal-In-Space Interface Control Document , 2013.)

GNSS Signals: GPS L1 & Galileo E1 Signals

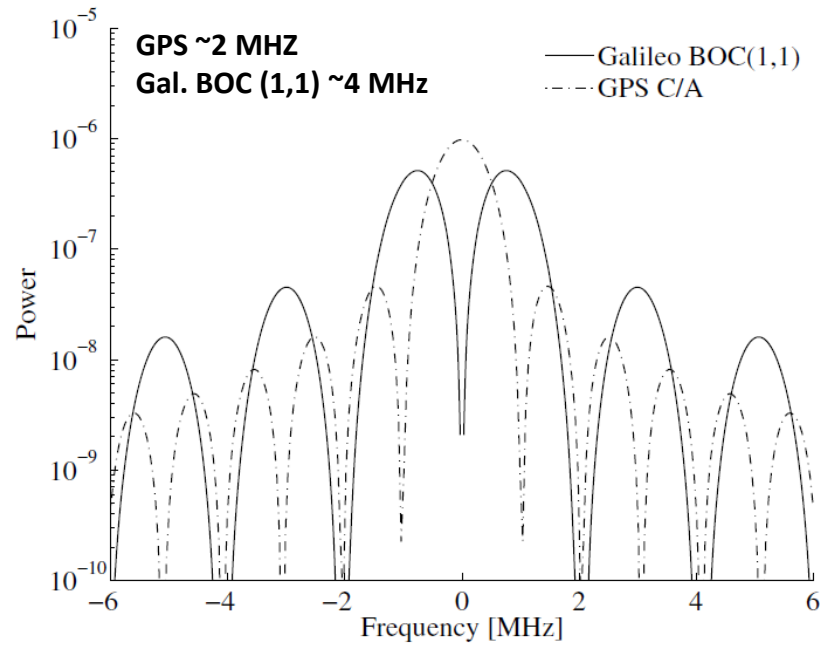
GPS L1



Galileo E1



K. Borre, *et al.*, in *A Software-Defined GPS and Galileo Receiver: A Single-Frequency Approach*, 1st ed., 2007.



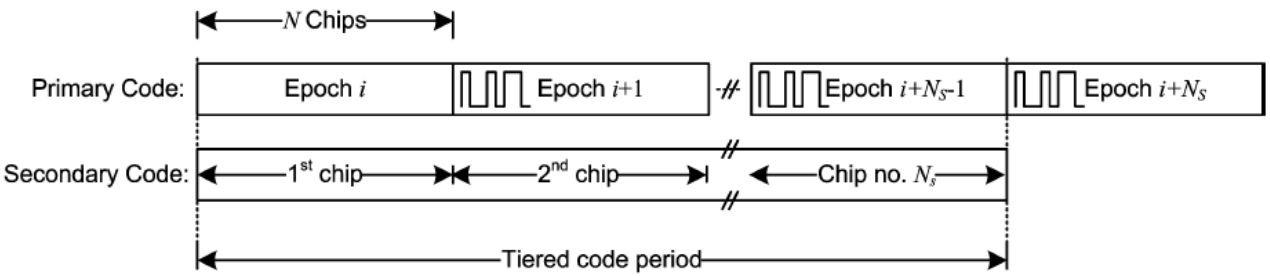
Sub & Binary Offset Carrier (BOC) mod.

- Enables spectrum manipulation for enhanced interference mitigation

Advanced signals not traditionally used by GPS & GLONASS

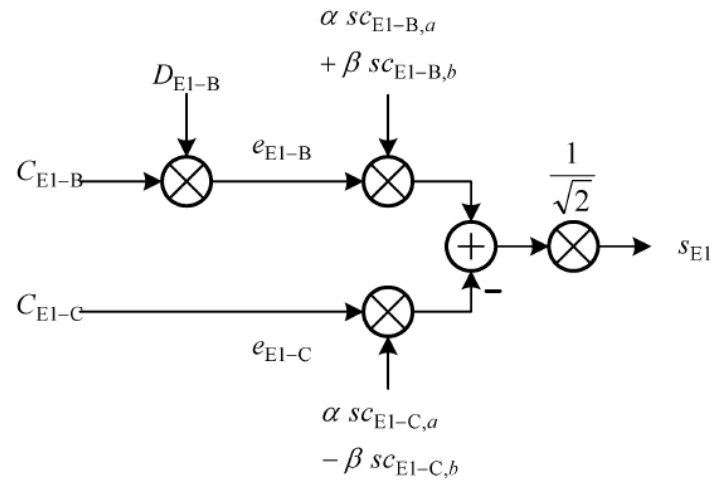
Potentially reduce impact of multipath interference conditions leading to Ionospheric scintillation

GNSS Signal: Galileo E1 Pilot Signal



Galileo E1 channels

- E1A (encrypted)
- E1B (data)
- E1C (pilot, no data)



Tiered code

- Variable length for weak signals
- Up to 7 dB of additional integration for improved signal-to-interference ratio (*SIR*)
- Enables transfer function estimate

$$SIR = \frac{\mathbf{h}^{\mathbf{H}}\mathbf{t}^{*}\mathbf{t}'\mathbf{h}}{\mathbf{h}^{\mathbf{H}}\mathbf{S}_{\mathbf{I}}\mathbf{h}}$$

$\mathbf{h} = \text{transfer function}$

$\mathbf{t} = \text{signal}$

$\mathbf{S}_{\mathbf{I}} = \text{Interference covariance}$

Pilot channel signals utilized by newer constellations

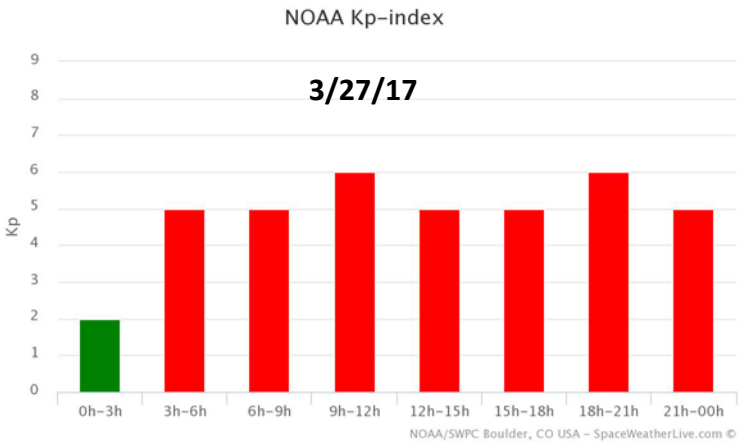
Significant potential for improving Ionospheric measurements

European GNSS (Galileo) Open Service Signal In Space Interface Control Document (OS SIS ICD), Issue 1.2, European Union, 2015

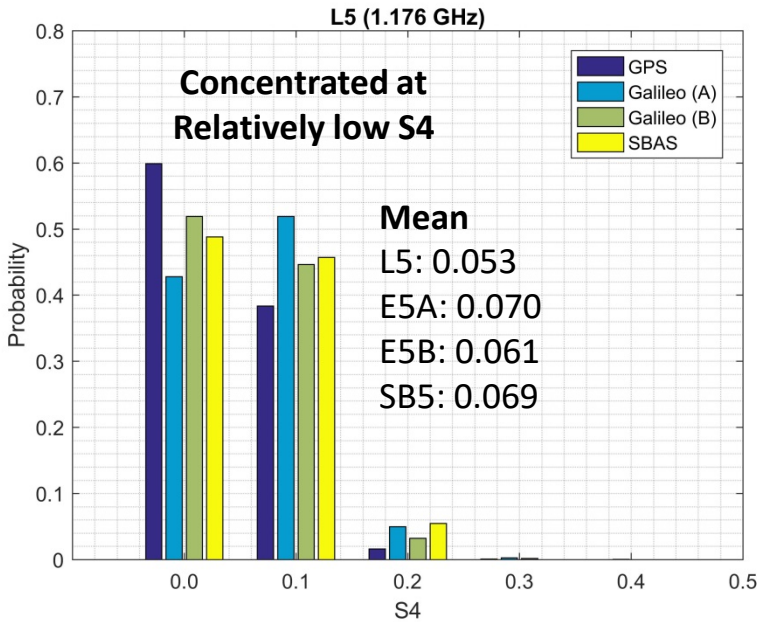
Data Acquisition & Processing

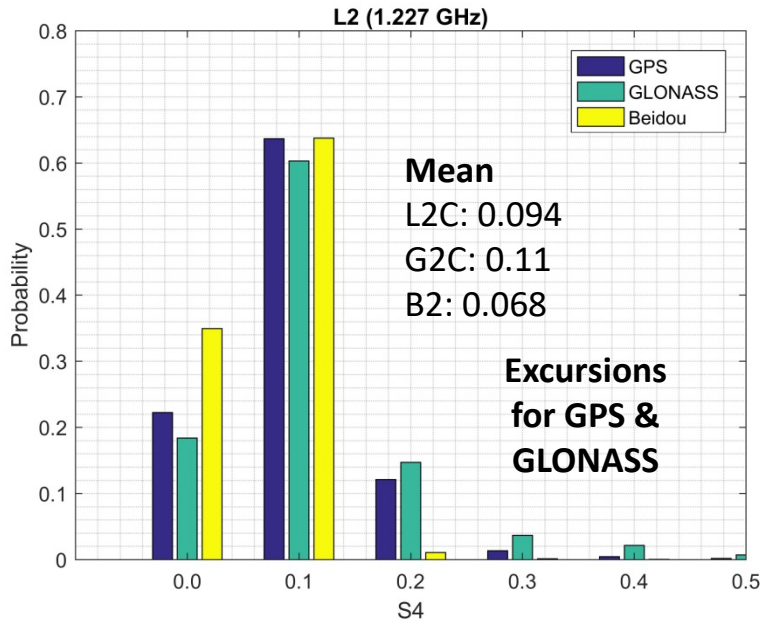
- Septentrio PolaRx5S receiver in Lihue, Hawaii
- Scintillation data acquired
  - GPS (L1CA, L2C, L5)
  - GLONASS (L1CA, L2C)
  - GALILEO (L1BC, E5a, E5b)
  - Beidou (B1, B2)
  - SBAS (L1CA, L5)
- Acquisition parameters
  - Correlation interval: 20 ms
- Analysis periods
  - 1/2017-present
  - During a storm on 3/27

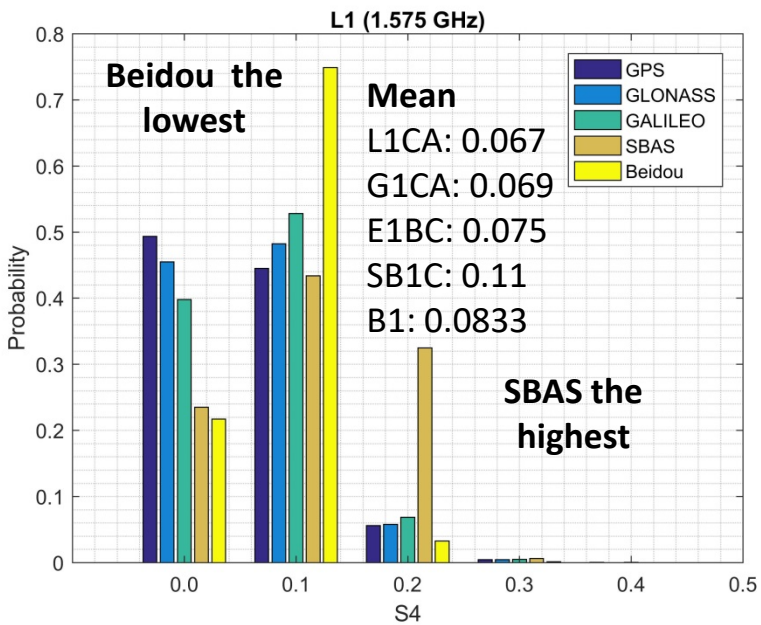
Binary and processed files logging; can be made available

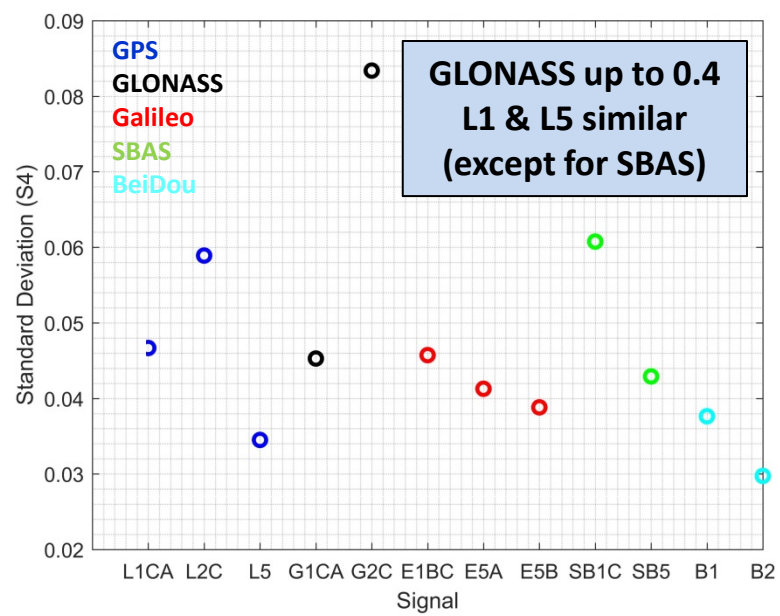


Results & Analysis: Lihue, HI, 1/2017-Present (S4)

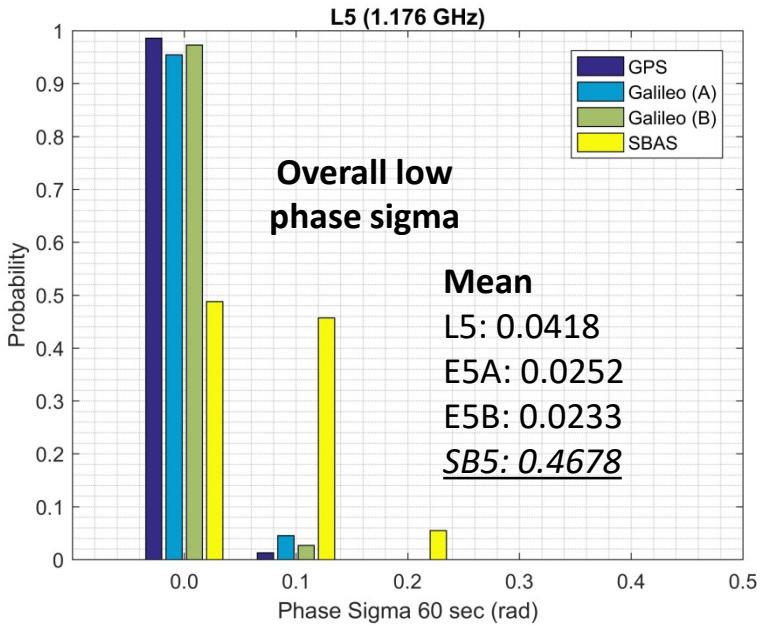


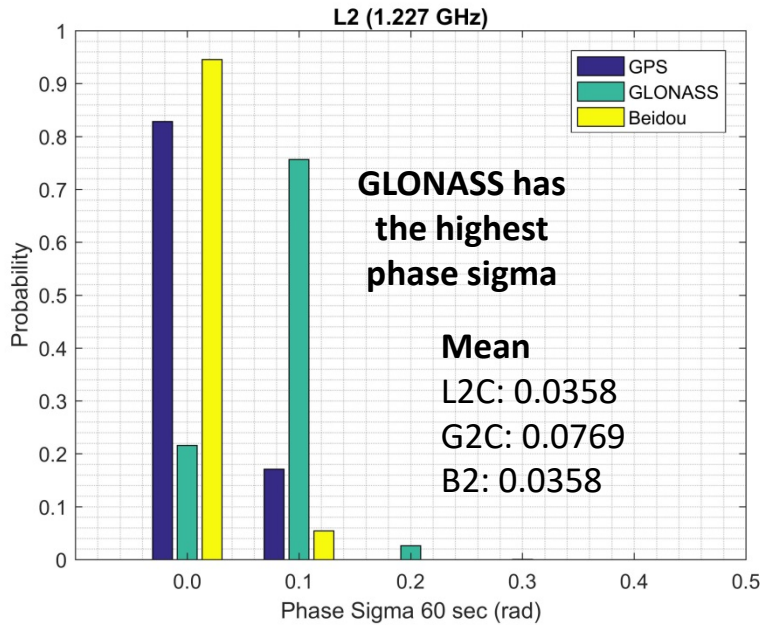


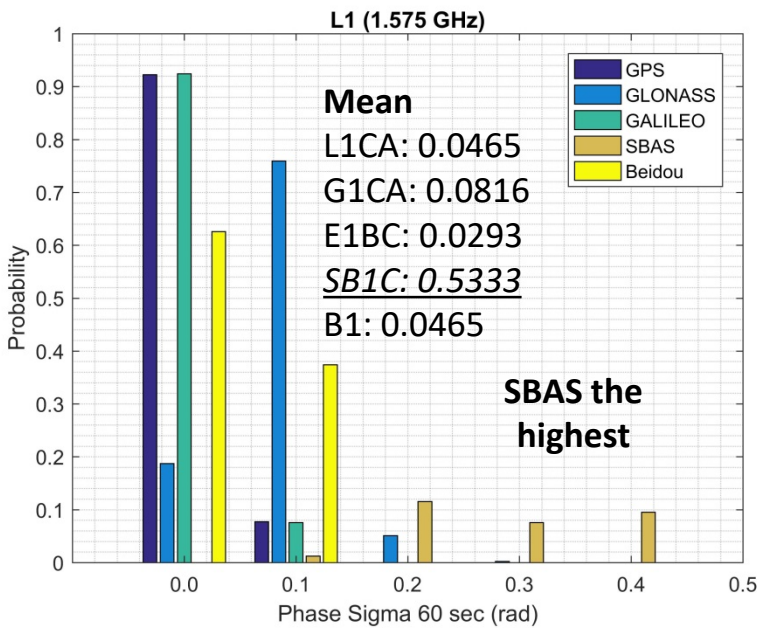


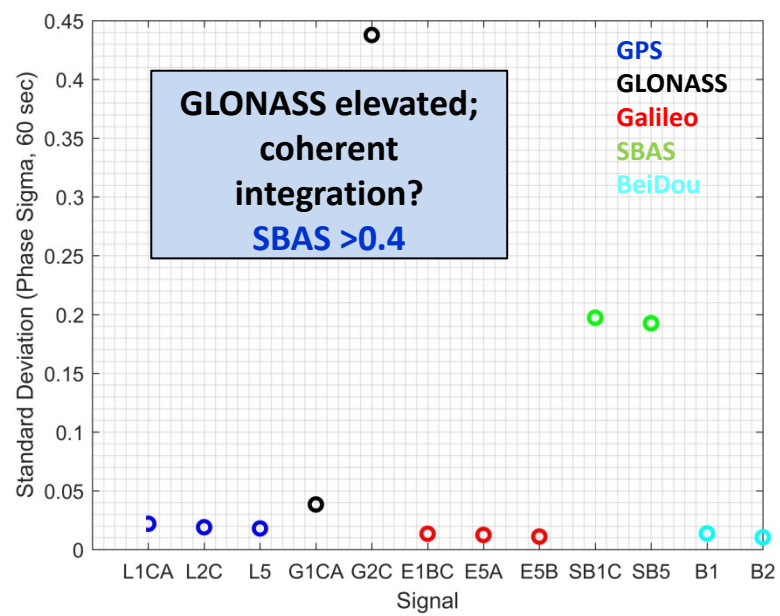


Results & Analysis: Lihue, HI, 1/2017-Present (Phase Sigma)

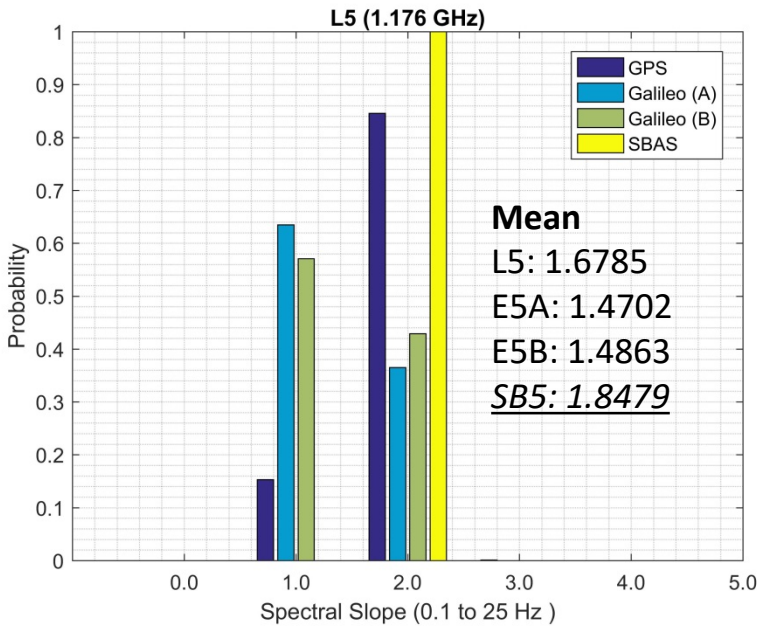


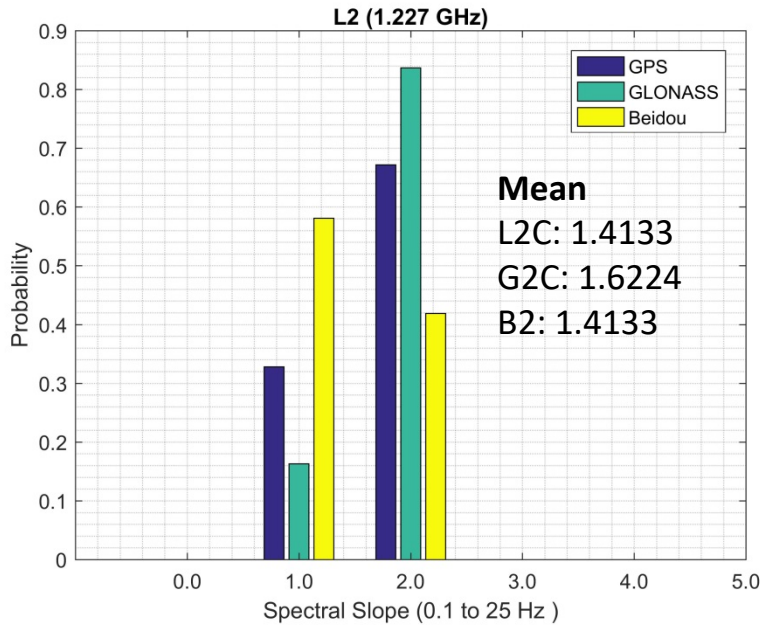


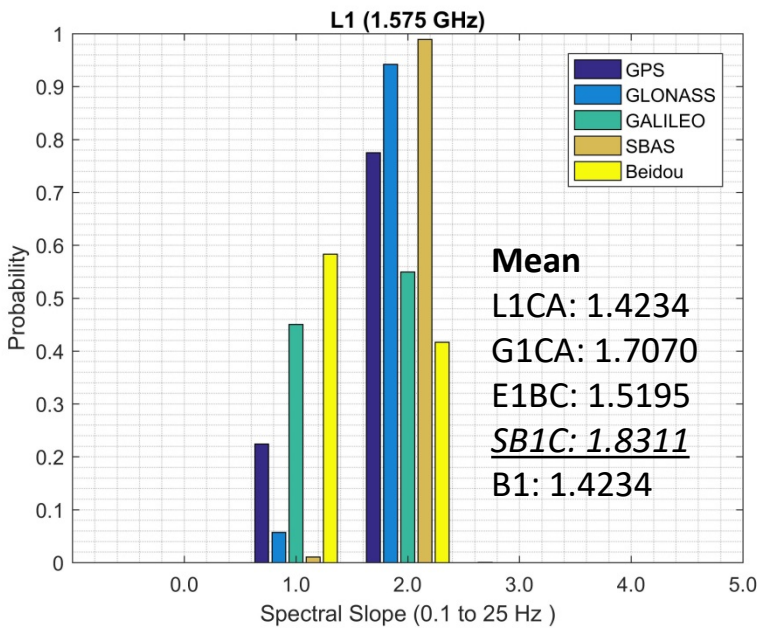


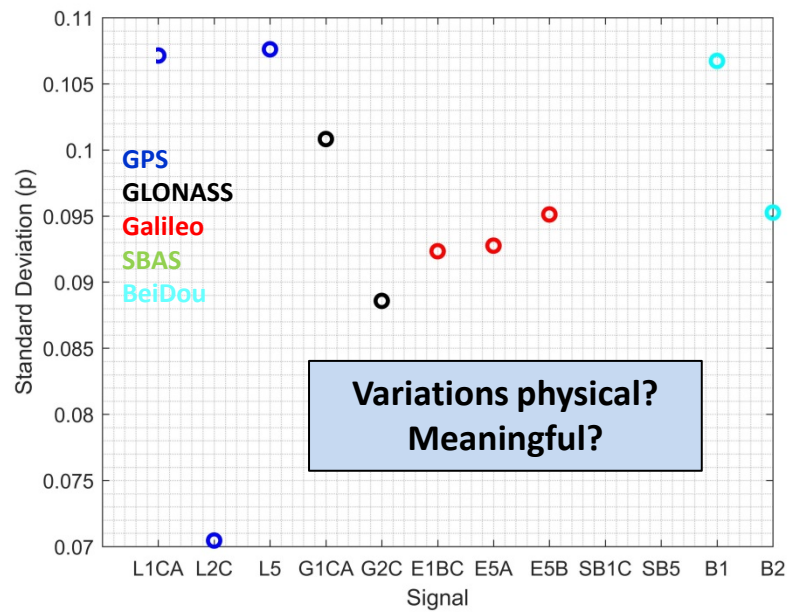


Results & Analysis: Lihue, HI, 1/2017-Present (Spectral Slope)

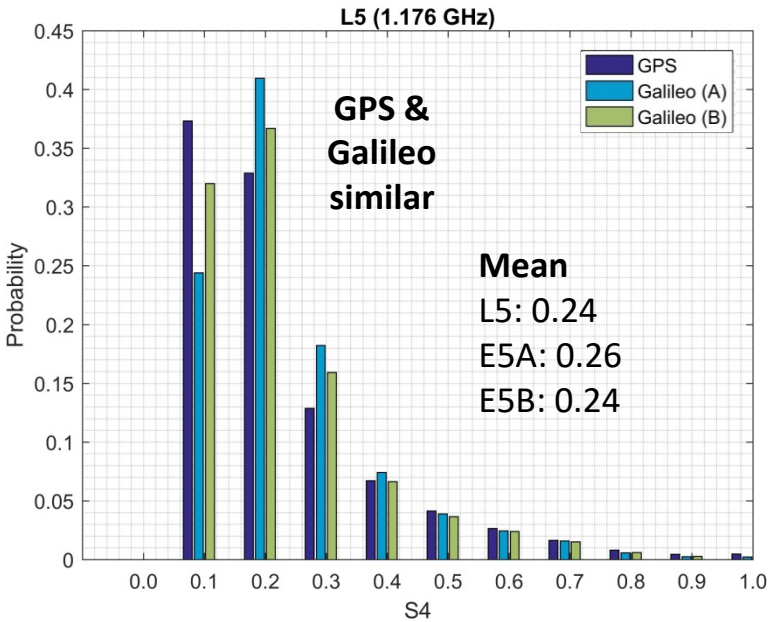


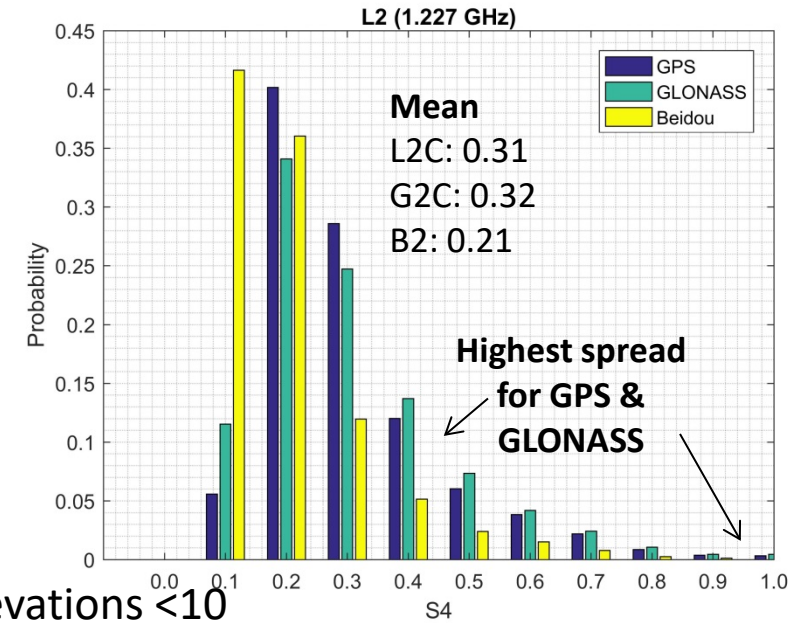




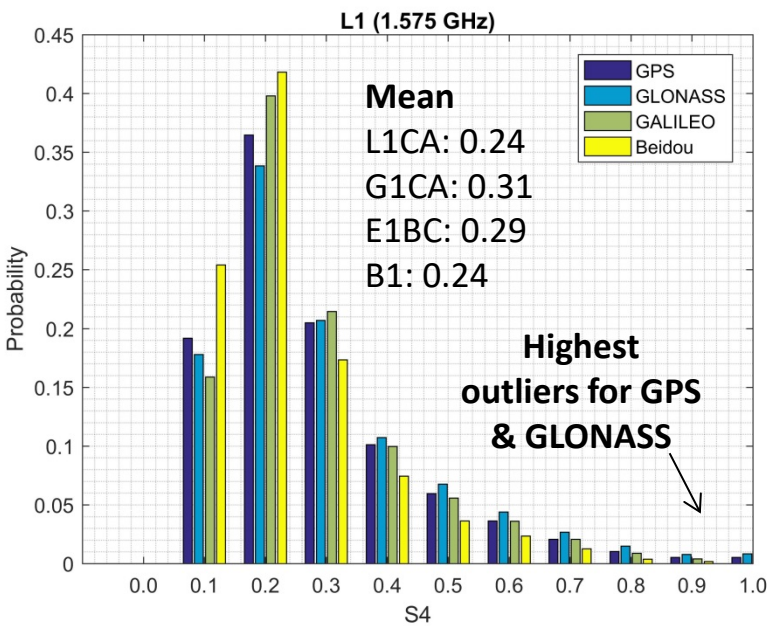


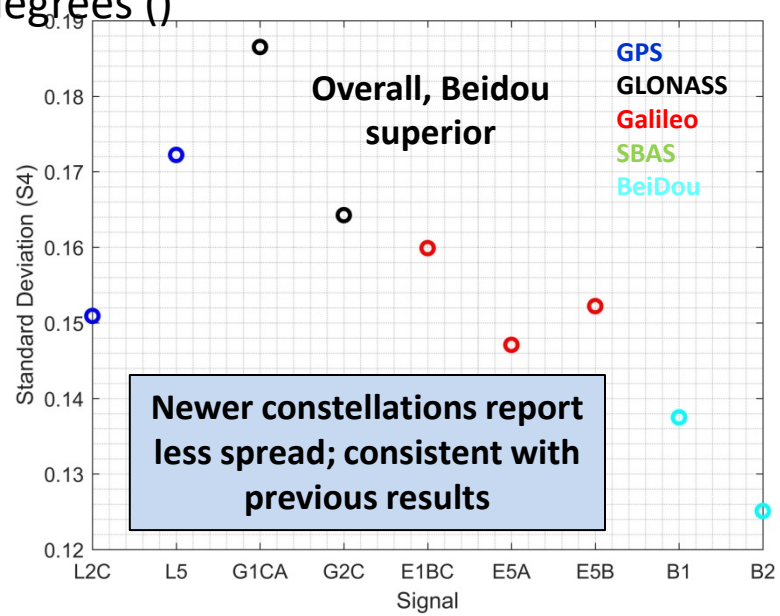
Results & Analysis: Lihue, HI, 1/2017-Present (S4, EL<10 deg; high S4)



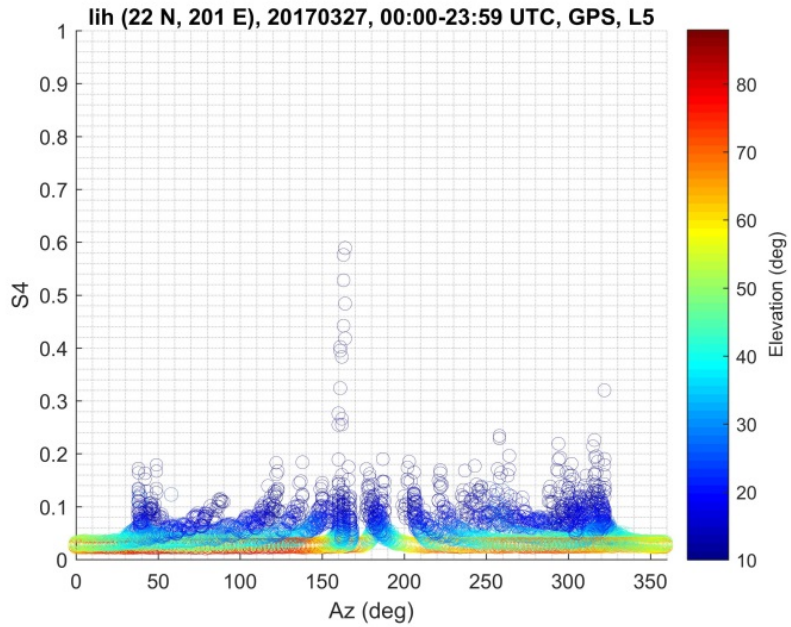


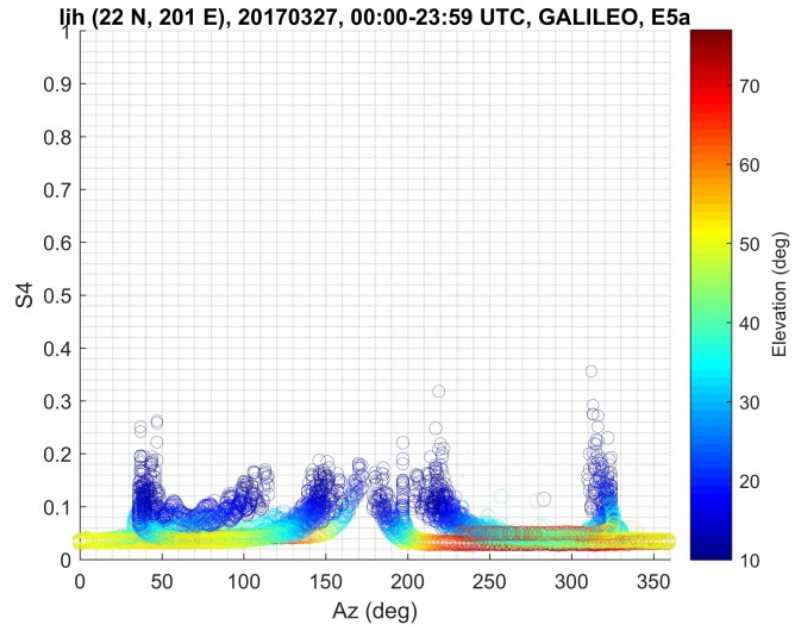
Elevations <10 degrees ()

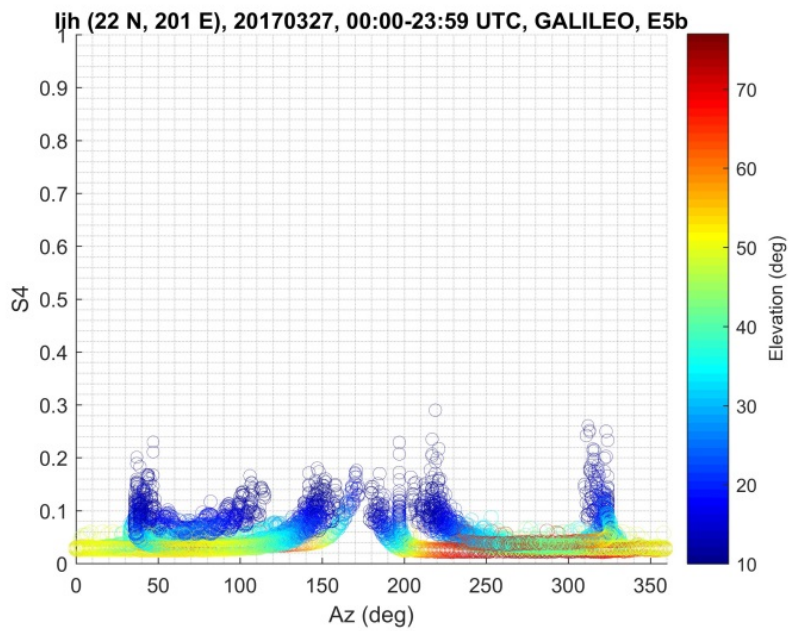




Results & Analysis: 3/27/2017 (L5, 1.176 GHz)





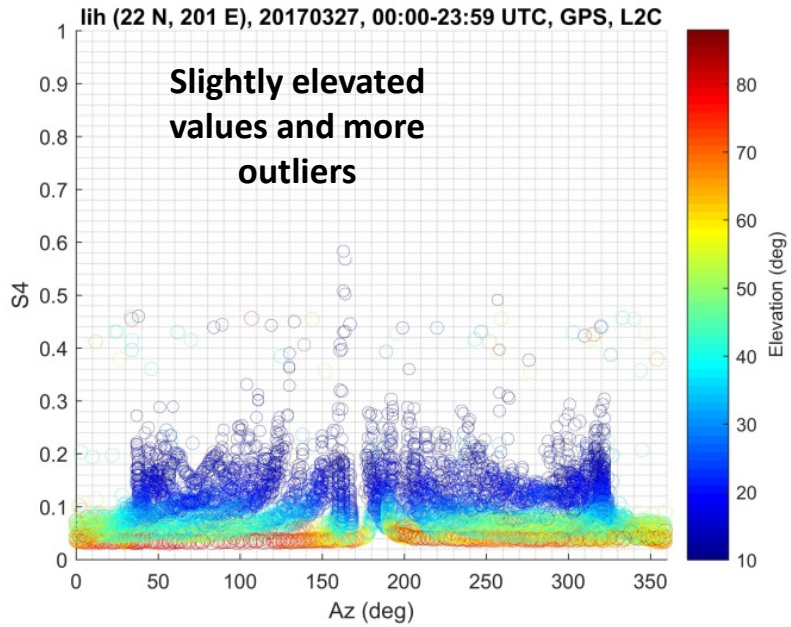


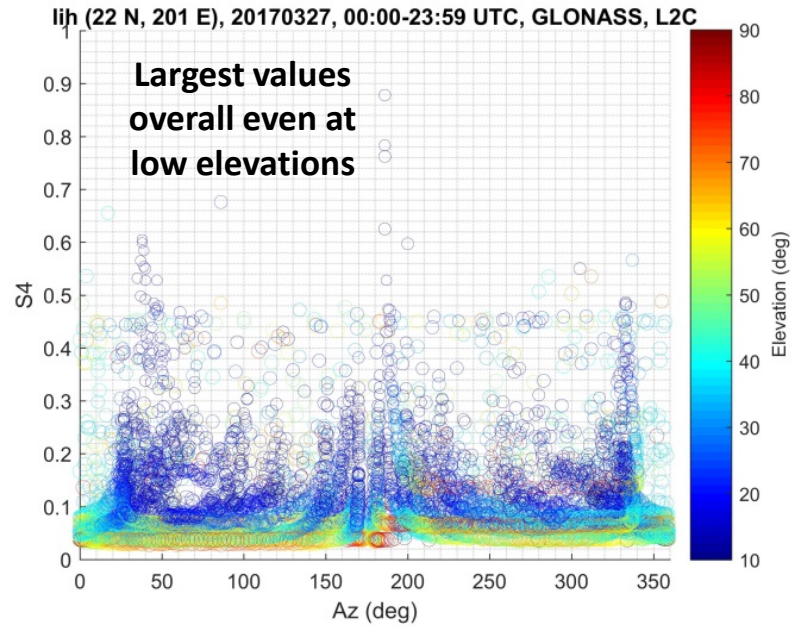
Galileo consistently reported lowest scintillation values at L5

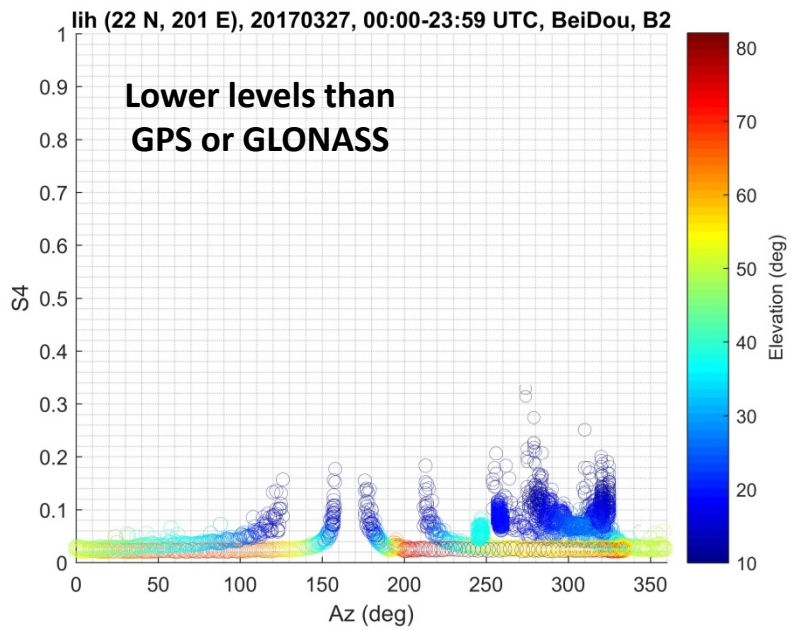
Results consistent with previous work

M. Jean, J. Conroy, W. Scales, Multi-Constellation GNSS Scintillation at Mid-Latitudes, IES 2017

Results & Analysis: 3/27/2017 (L2, 1.227 GHz)







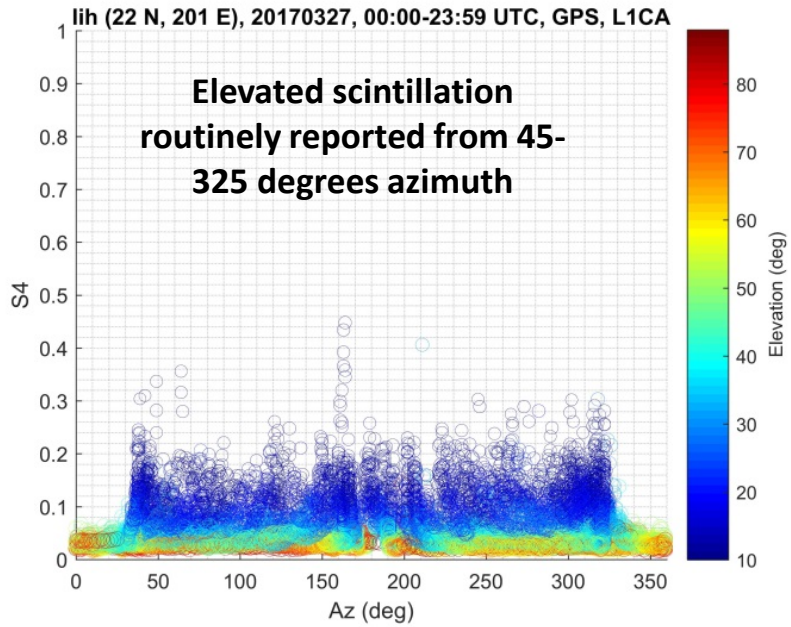
Notable difference in S4 excursions between constellations

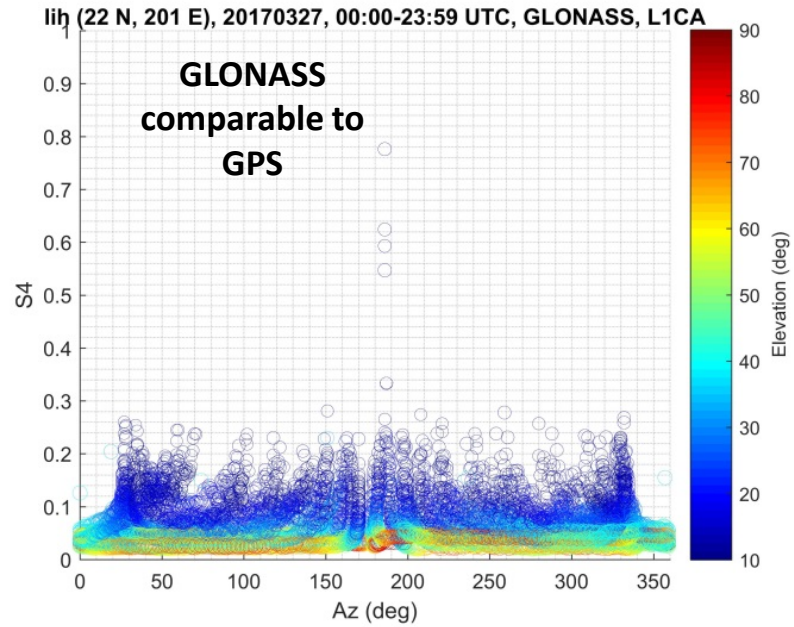
Beidou reported lowest scintillation

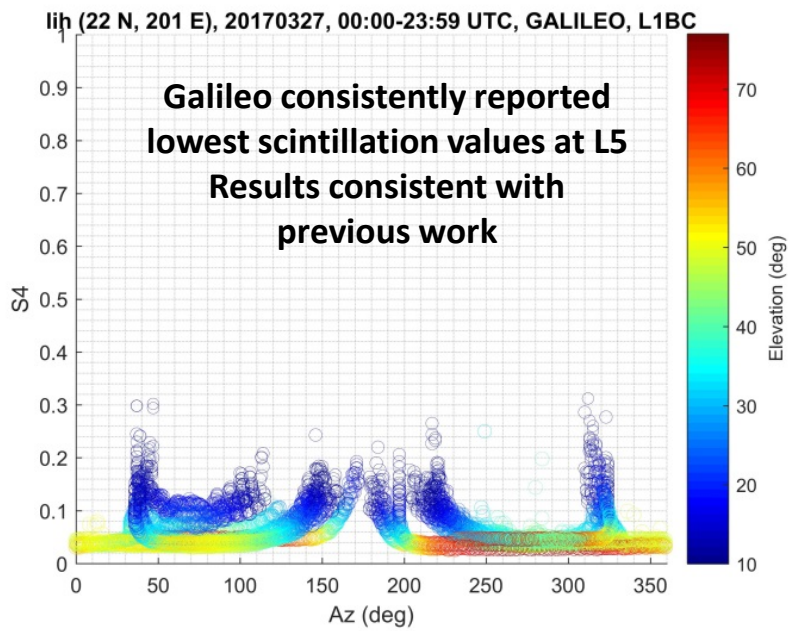
GLONASS higher than GPS;

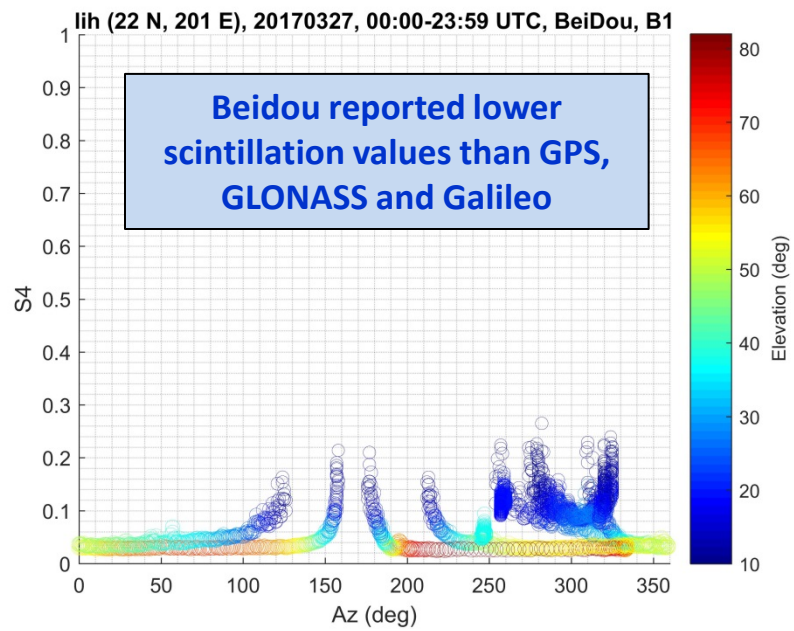
Results consistent with previous work

Results & Analysis: 3/27/2017 (L1, 1.575 GHz)

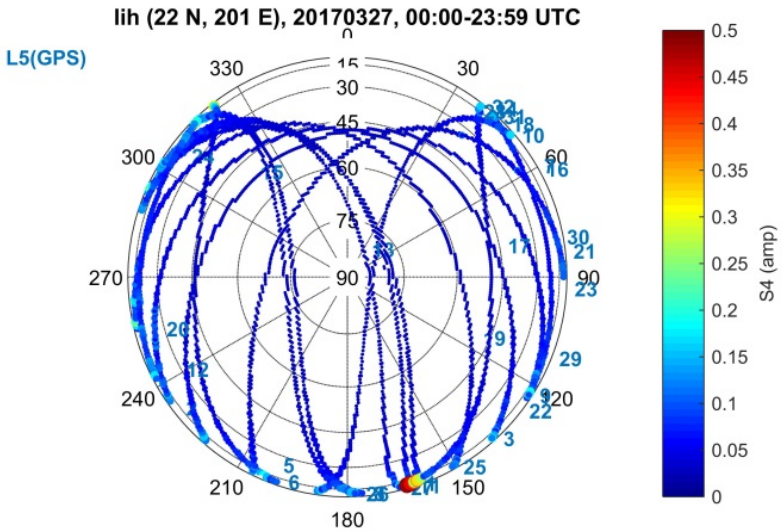


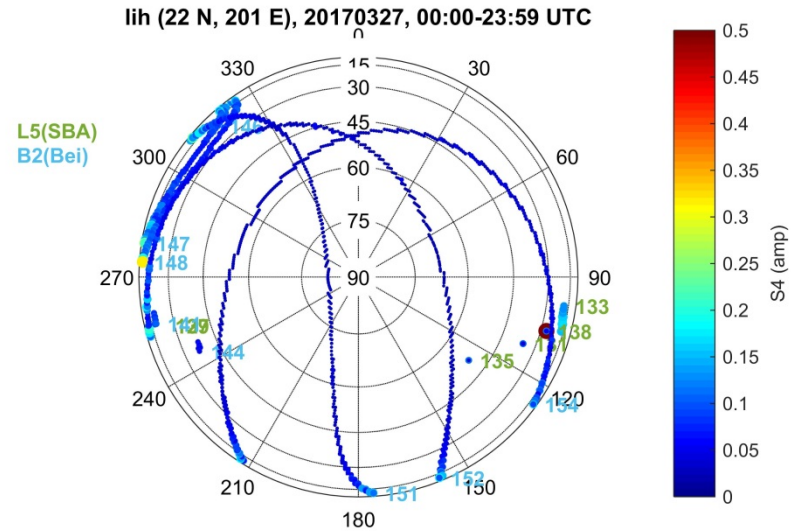




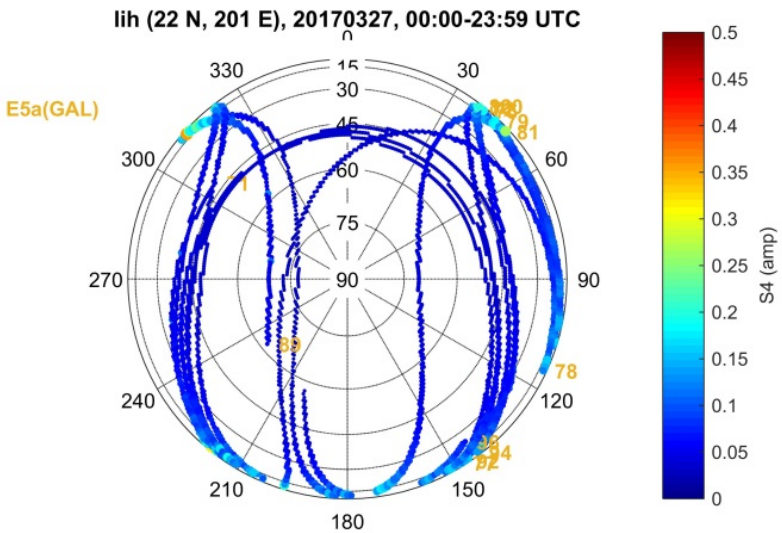


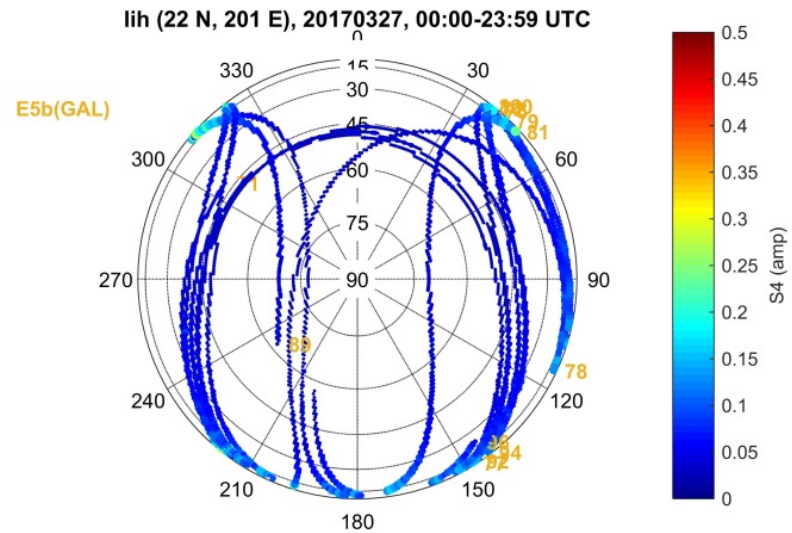
Results & Analysis: 1/2017-Present (L5, 1.176 GHz)



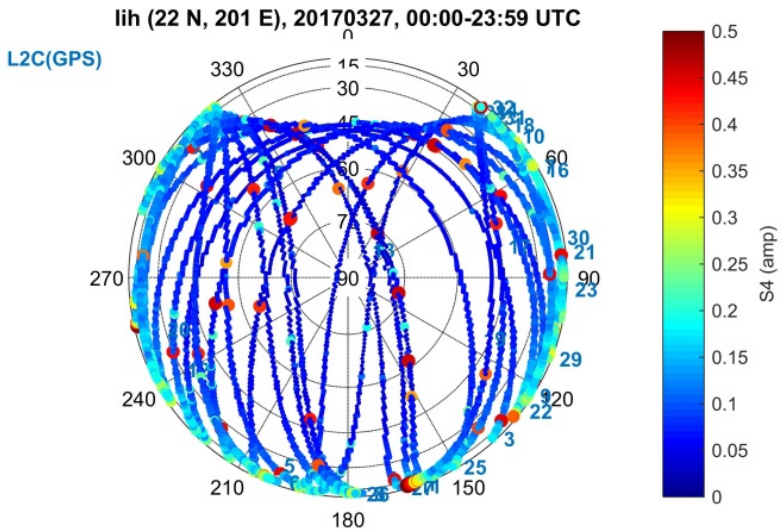


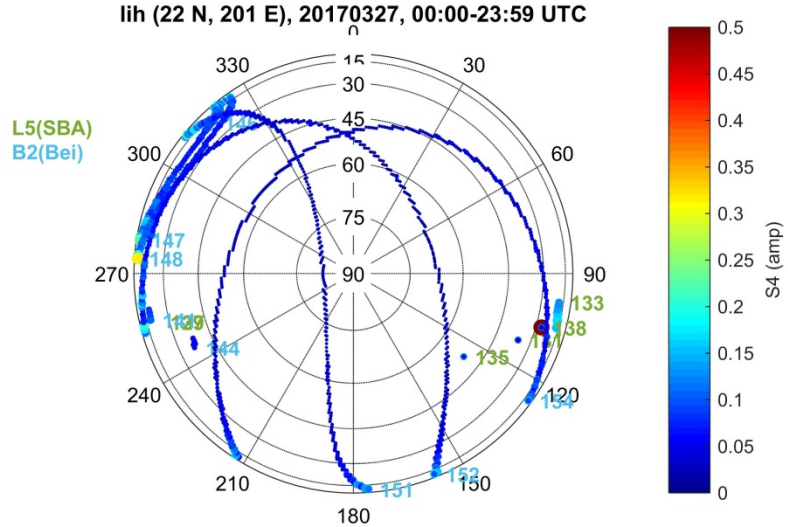
L5 band: lowest scintillation

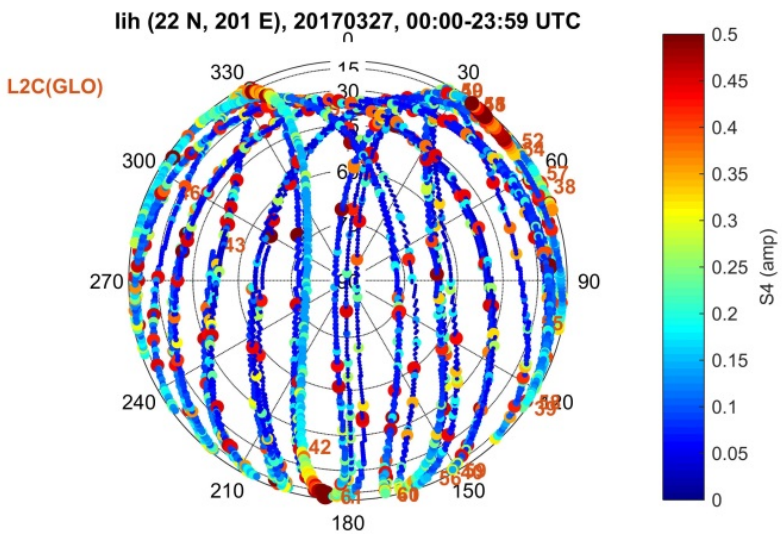




Results & Analysis: 1/2017-Present (L2, 1.227 GHz)

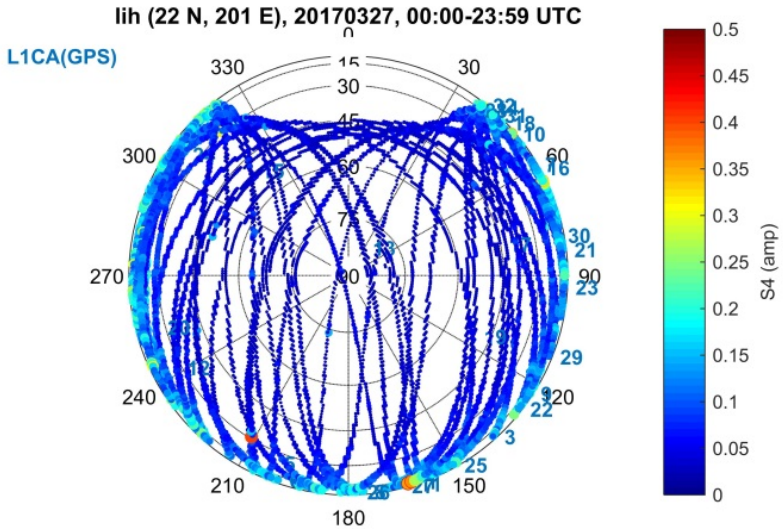


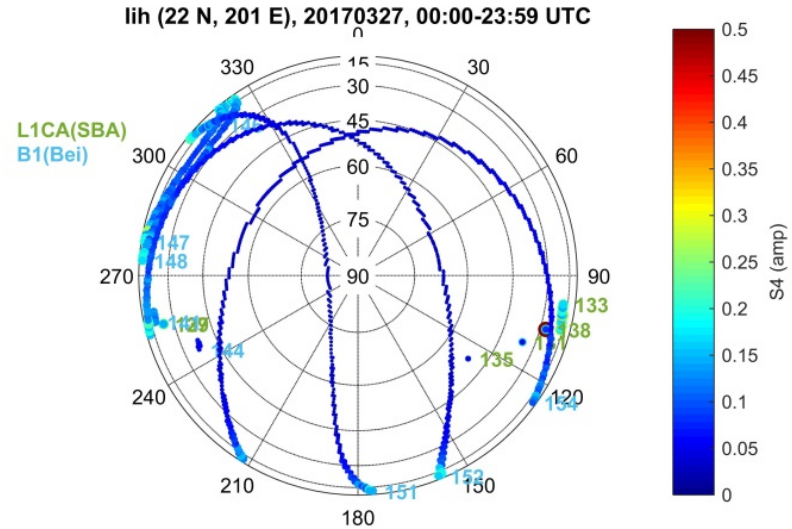




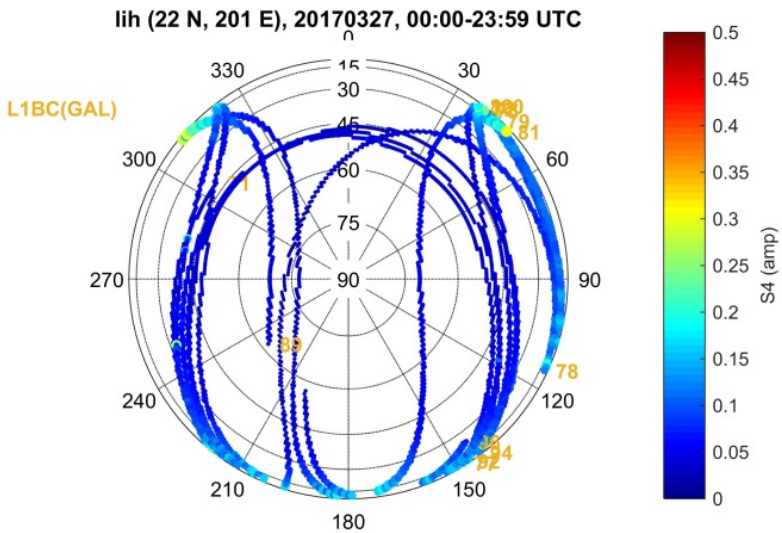
L2 band: highest scintillation
SBAS: hot spot
Galileo and Beidou: lowest scintillation
Result of ionosphere or hardware?

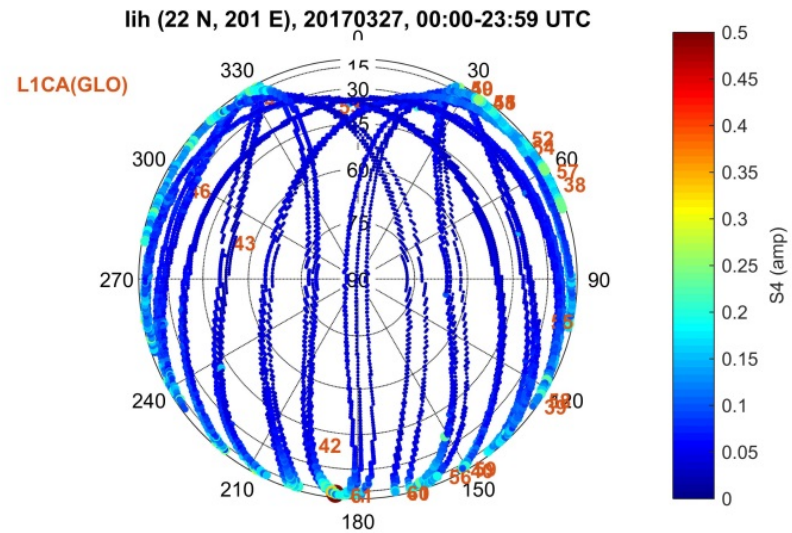
Results & Analysis: 1/2017-Present (L1, 1.575 GHz)





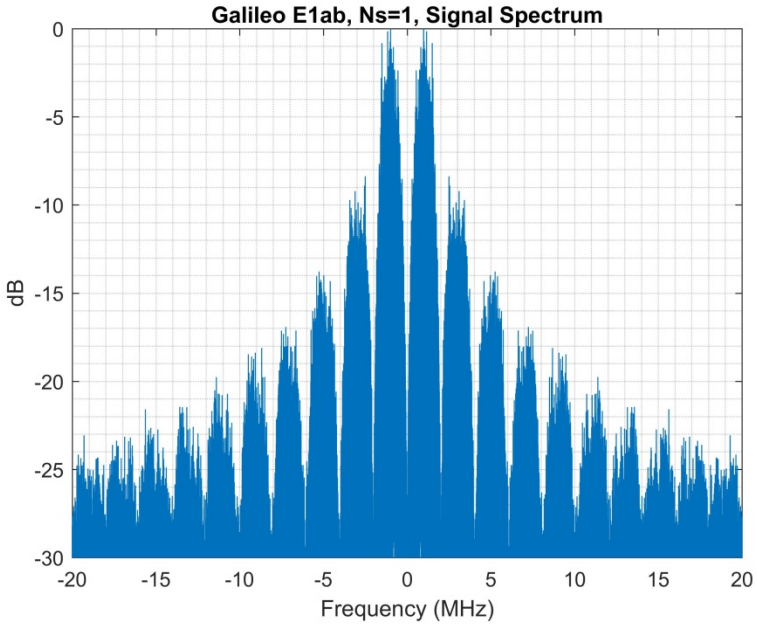
Newer signals resistant to scintillation; need to more data

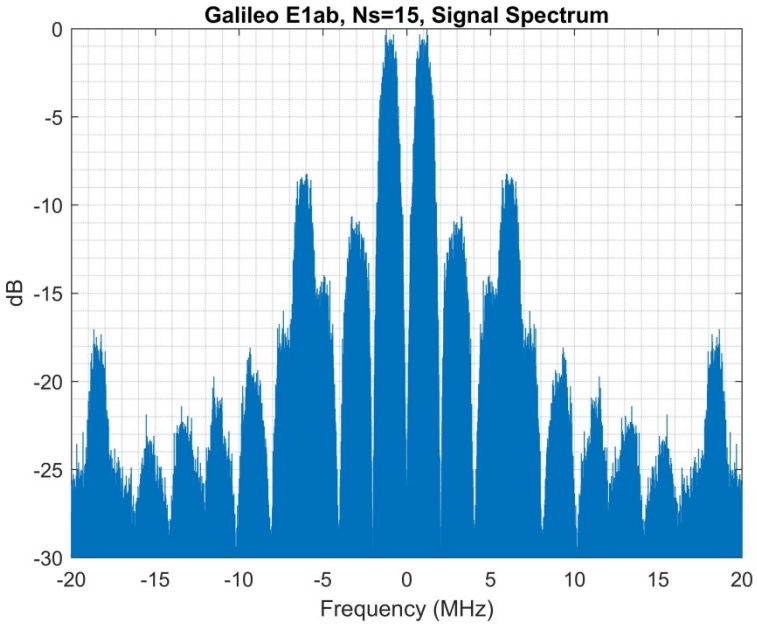


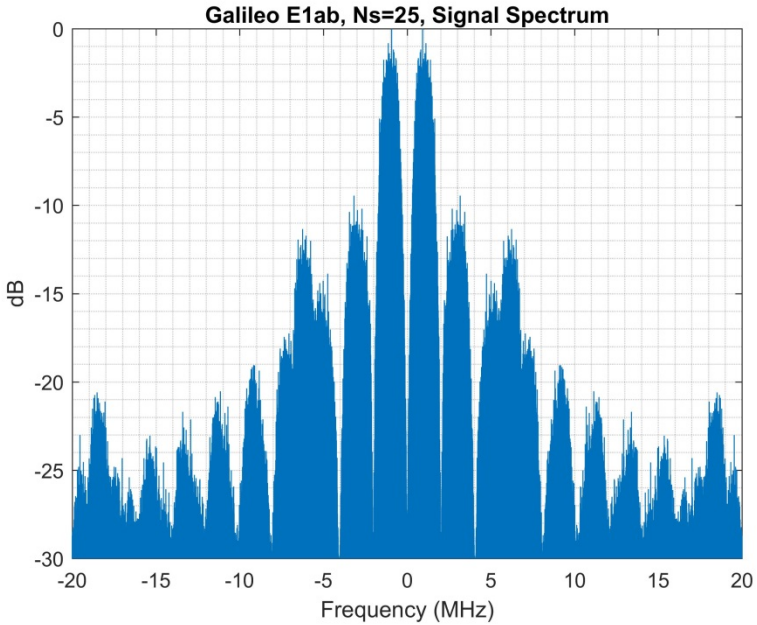


Consistent with two receivers at two latitudes

Future Work: Signal Modeling







Variation of Galileo spectrum with length of tiered code and/or BOC

Need to incorporate frequency dependent scintillation

Conclusions

- New constellations such as Galileo and BeiDou
  - Consistently reported lowest scintillation values even under multipath conditions
  - Results consistent with previous work
- L1 and L5 band comparable scintillation; less than L2
- Signal simulation and frequency dependent scintillation
  - Needed to understand the underpinnings

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