International Monitoring of Ionosphere

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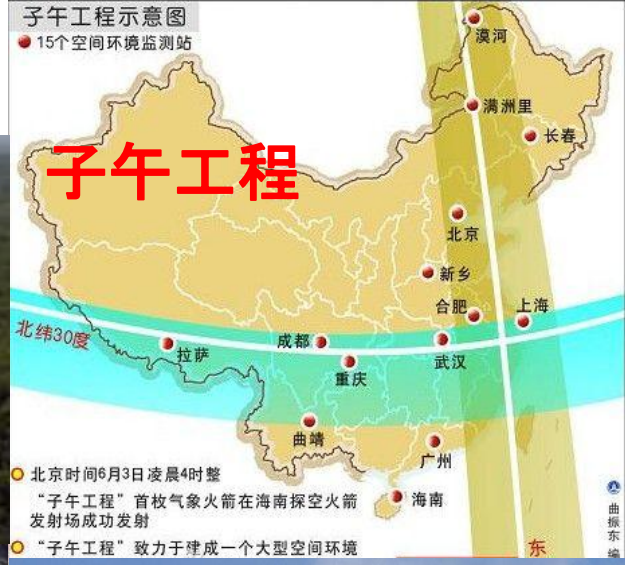
Presentation Outline

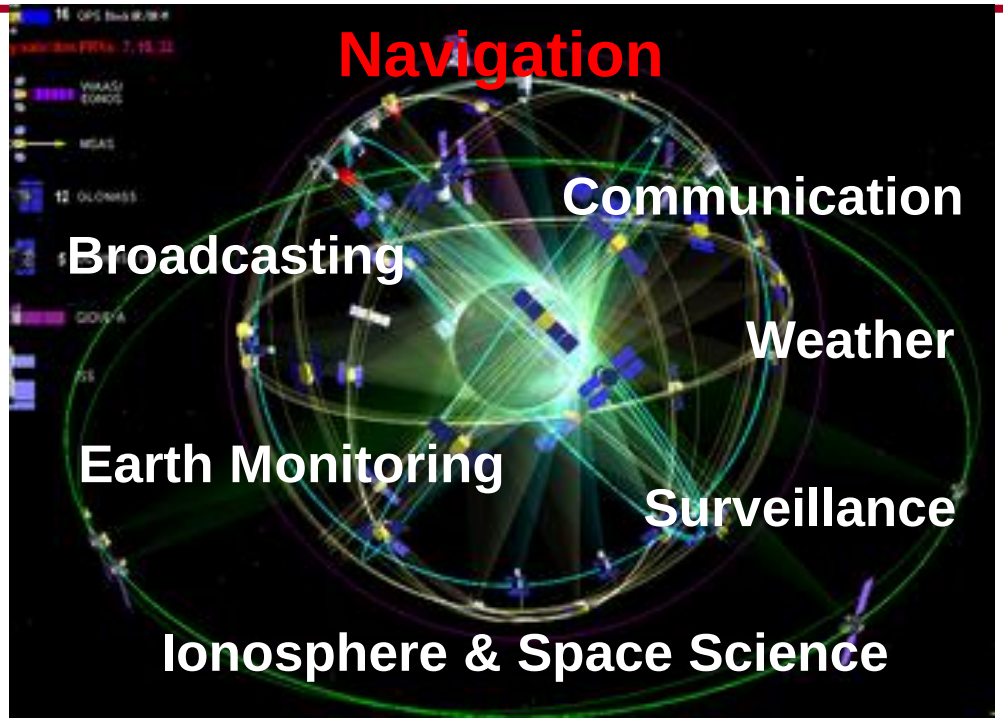
1. **Background: ionosphere vs. GNSS**
2. **Challenges in Synergizing Space Weather – GNSS Studies**
3. **New Generation of GNSS Space Weather Monitoring Systems**
4. **Results Highlight**

Remote Sensing of Ionosphere



Growth in Spaced Based Systems

AE *DNA* *DE* *DORIS* *CHAMP* *C/NOFS* *CITRIS* *GOES* *SAC-S* *SIRIS*

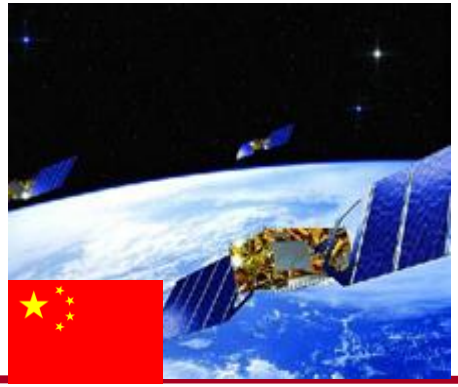


ATS1 *ATS3* *ATS6* *ETSII* *CRABEX* *CERTO* *COSMIC* *TOPEX*

GPS

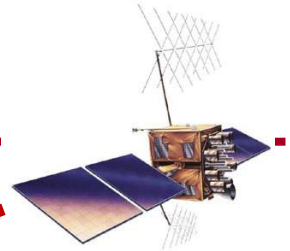
GLONASS

Beidou



Galileo

GNSS & Ionosphere



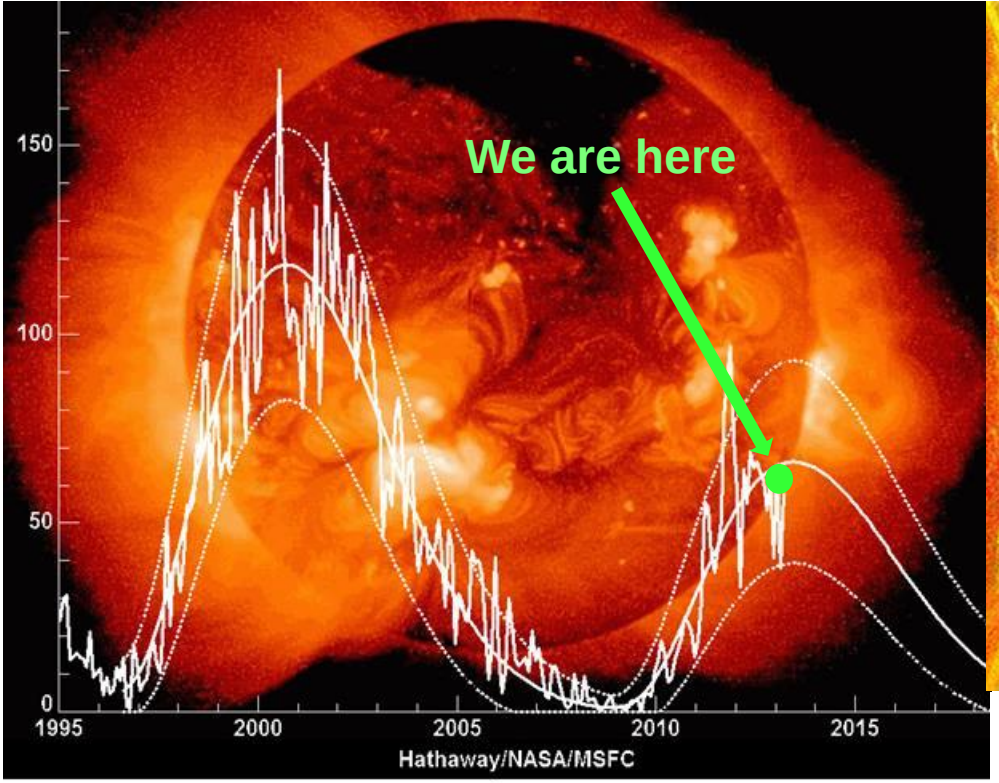
Ionosphere:
Dynamic
Difficult to model
Introduces error, disruptive

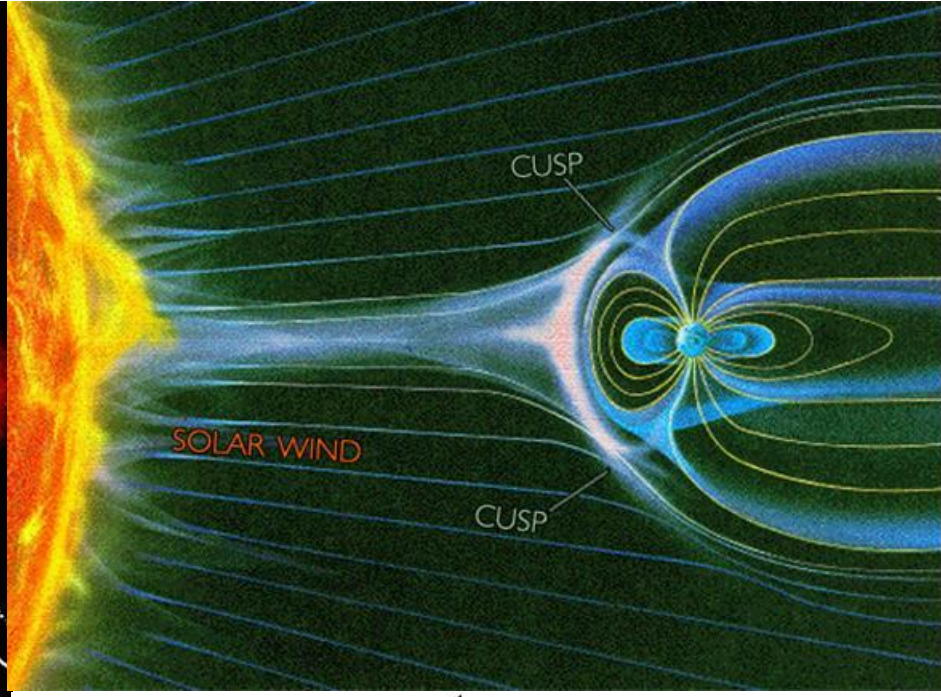
GNSS:
Passive
Well defined signals
Global coverage, distributed

Ionosphere

By 2023:
>160 GNSS satellites
>400 signals

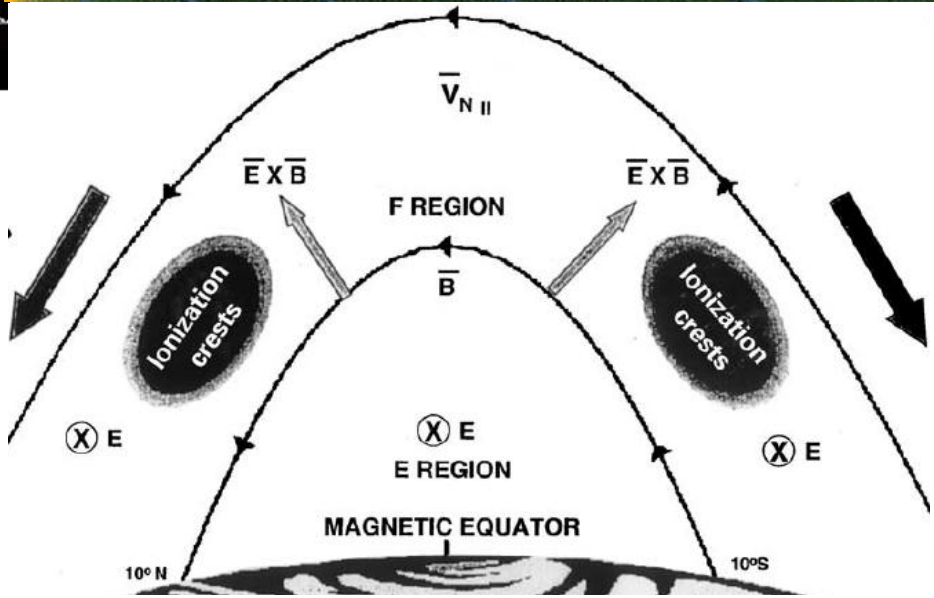
1. **Ionosphere** impacts **GNSS** performances
2. **GNSS** offers an excellent means to study **ionosphere**





High latitude:
Mainly driven by **solar and magnetosphere** activities

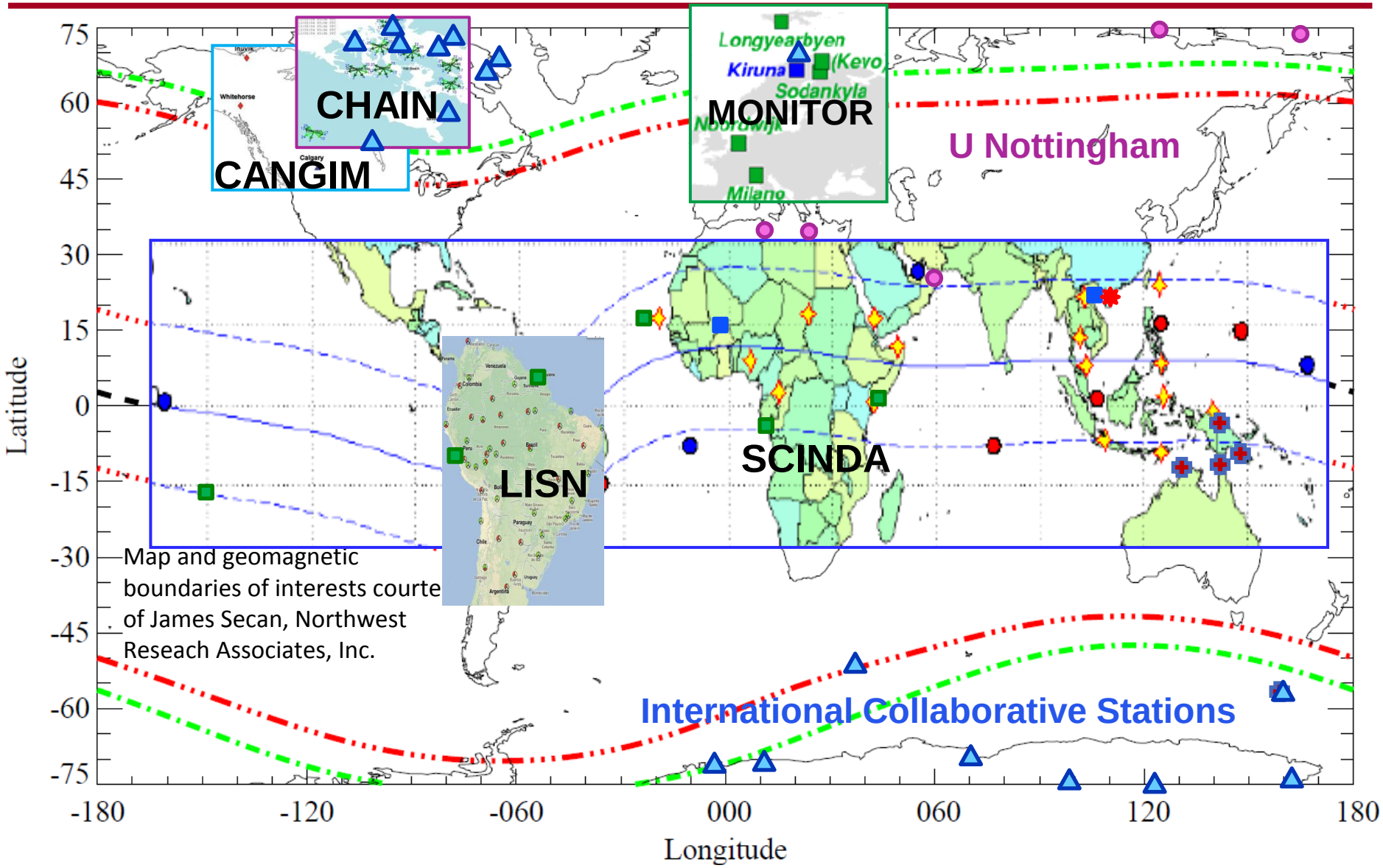
Low latitude:
Ionosphere internal mechanisms
+ modulation by solar activities



Basu, S. et al, "Specification and forecasting of scintillations in communication & navigation links: current status and future plans," J. Atmos. Solar-Terr. Phy., 2002.

New Generation of GNSS Space Weather Monitoring Systems

Existing GNSS Space Weather Monitoring Systems



Map and geomagnetic boundaries of interests courte of James Secan, Northwest Reseach Associates, Inc.

Issues

1. **Accuracy**

$$(Iono\ Effects + Other\ Errs) \otimes h(t) = Observed\ Effects$$

$$Iono\ Effects \neq Observed\ Effects$$

2. **Availability**

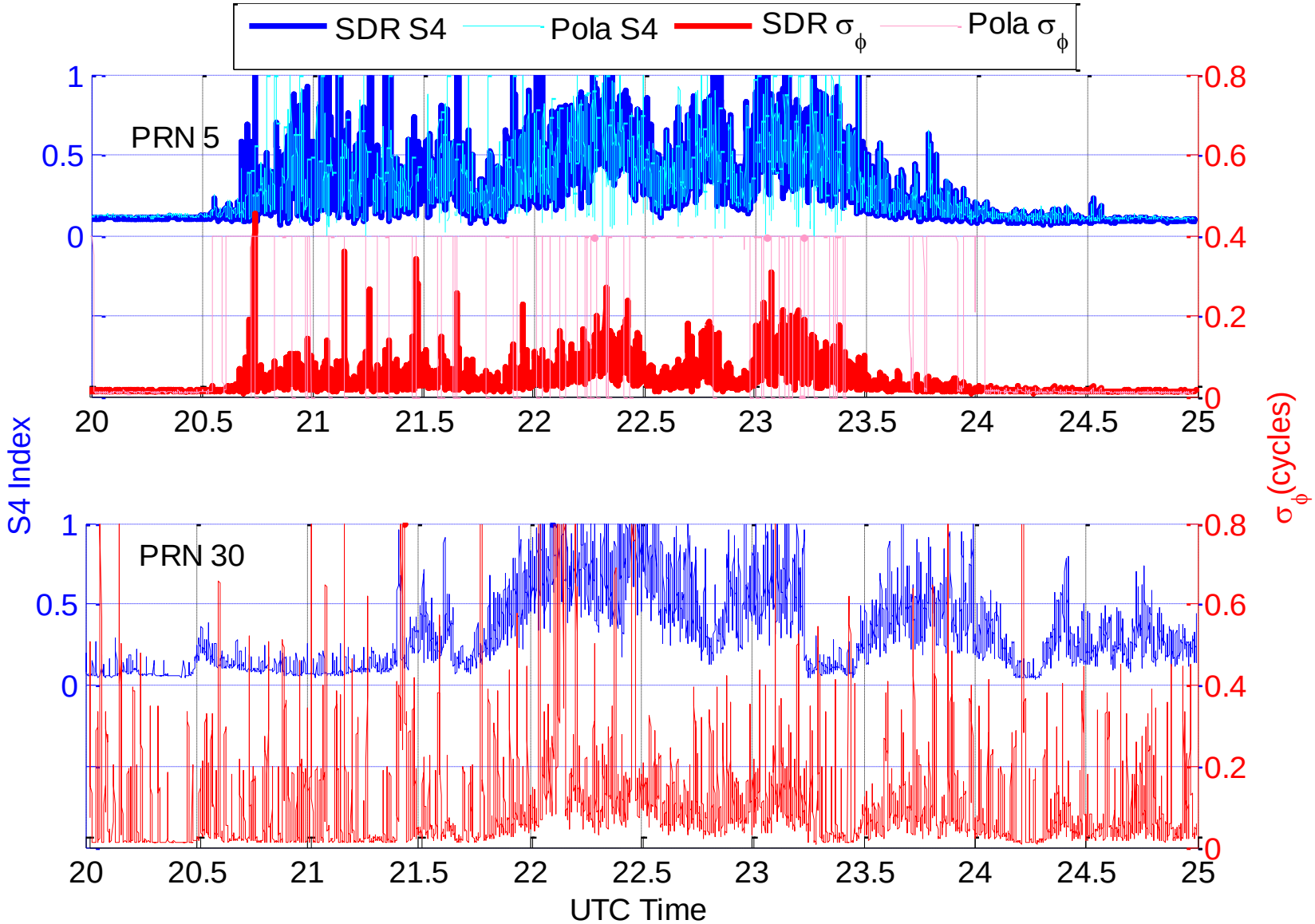
Receivers cease to function during strong space weather events. Critical data are lost when needed most.

3. **Repeatability**

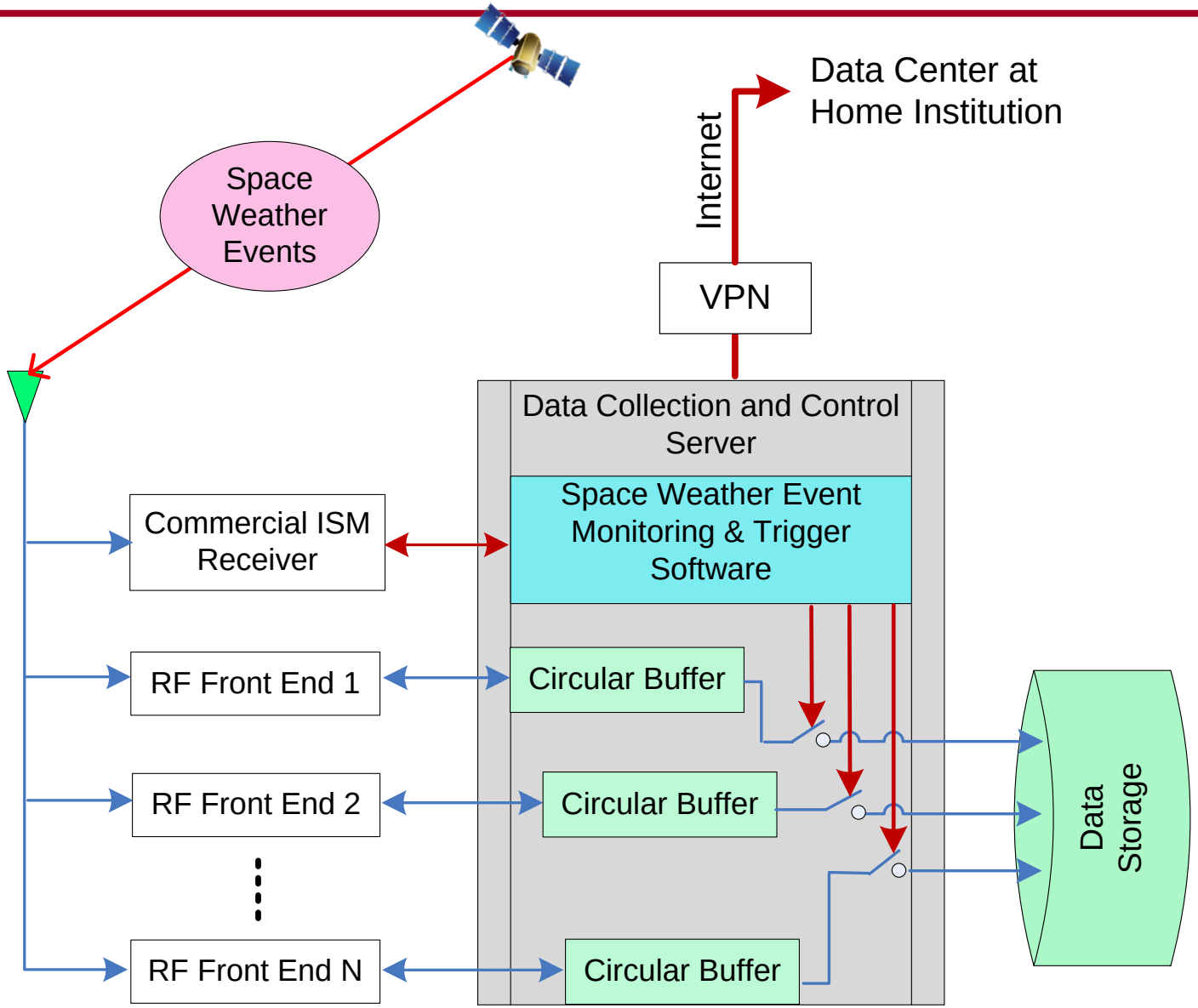
Receiver processing is irreversable → Iono effects are wiped out during processing

High quality, raw GNSS signals are needed for space weather studies and robust GNSS receiver development

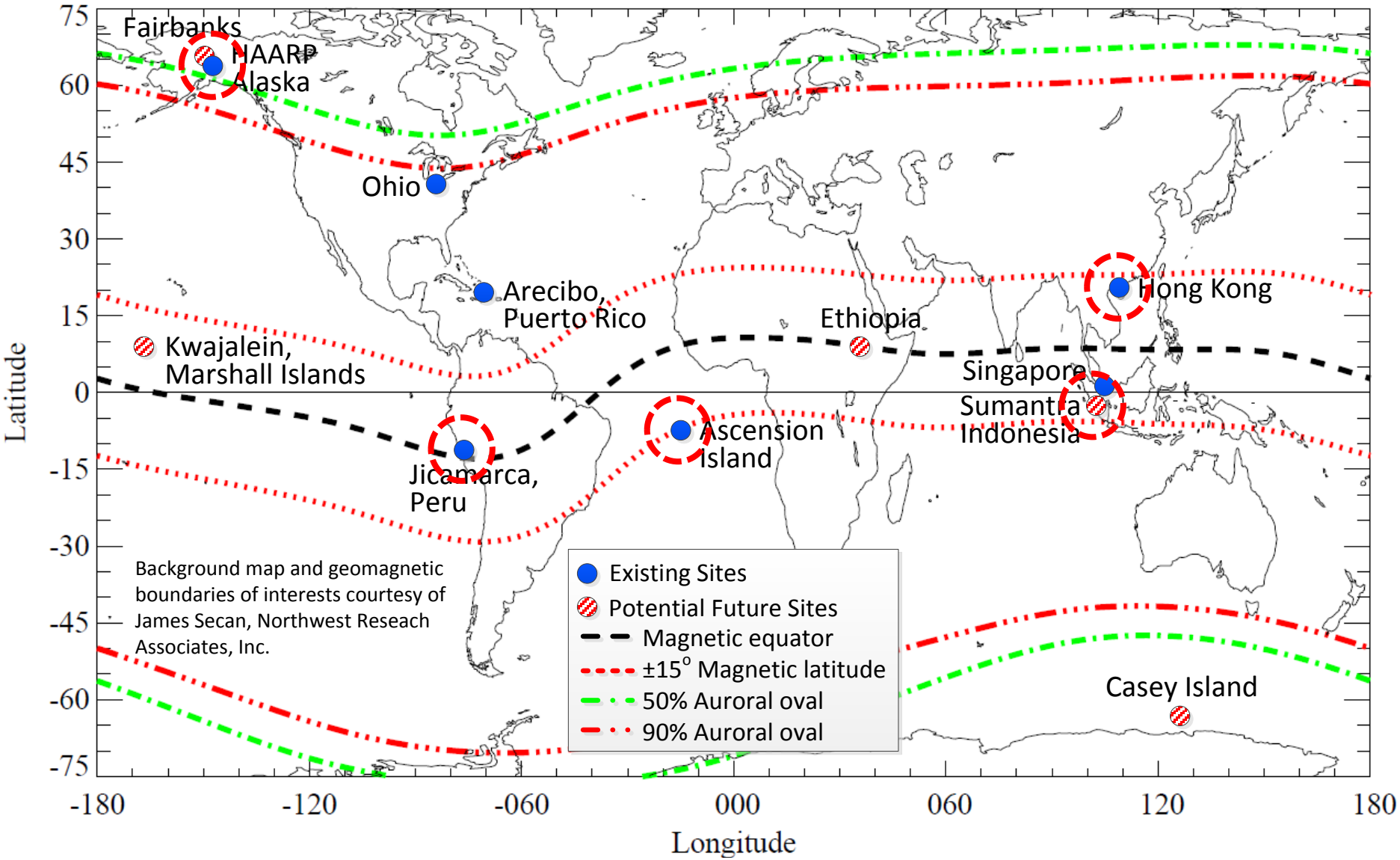
Ascension Island: 3/10/2013, Beidou GEO PRN 5



Event Driven Multi-Constellation IF Data Collection System

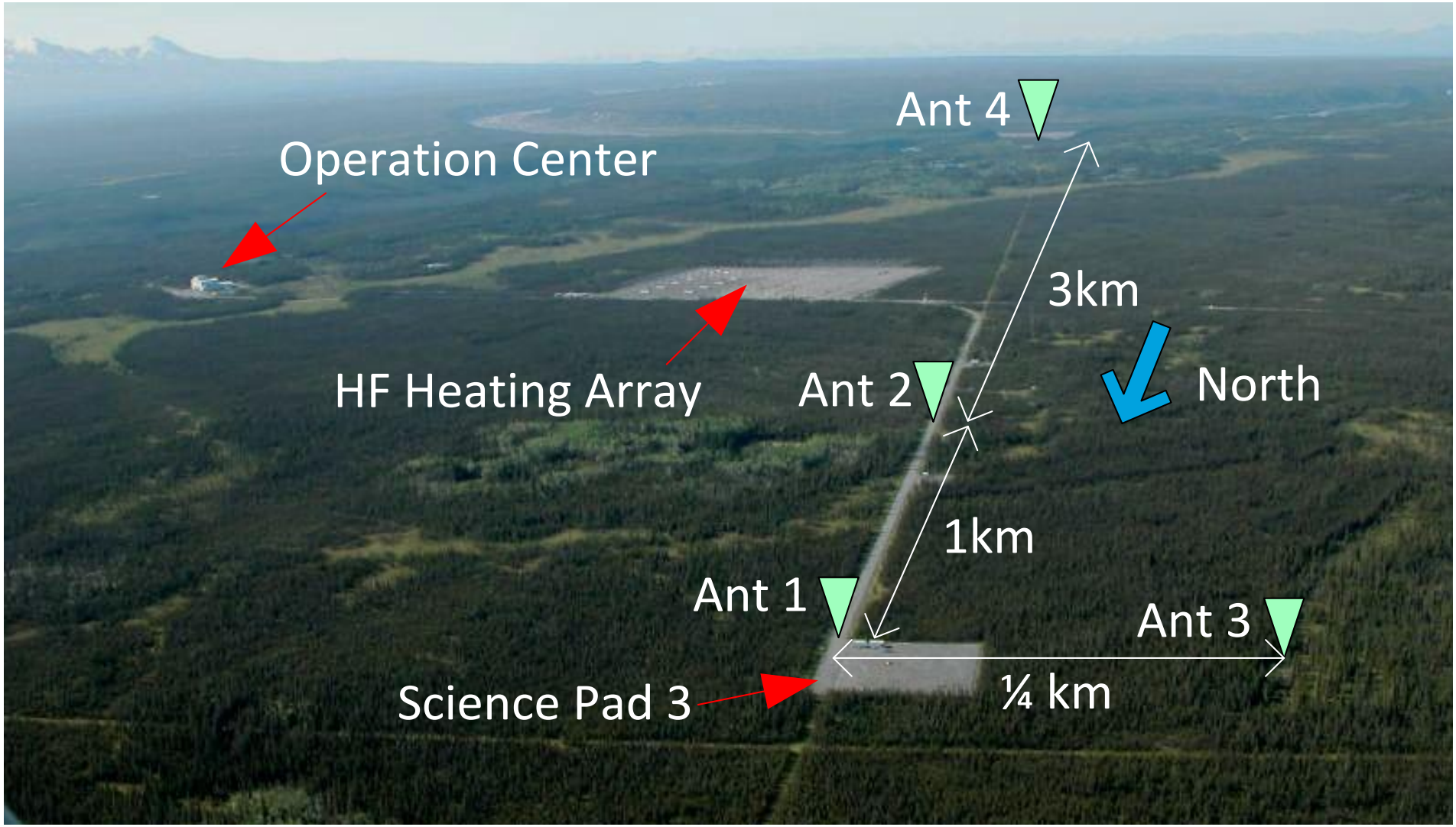


A Global Scintillation Data Collection Network

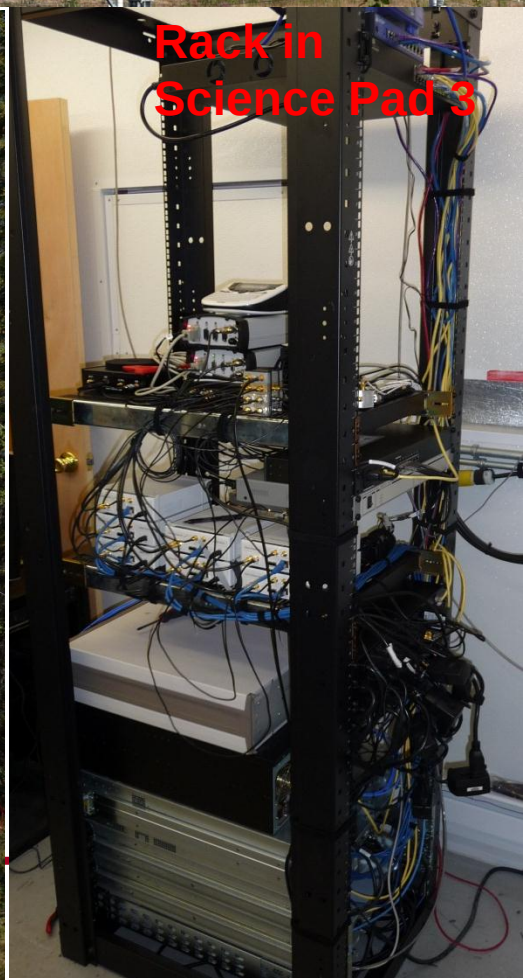


HAARP (Gakona, Alaska)

Lat: 62.39º, Lon: 145.15ºW



Receiver on Antenna 4




Hong Kong

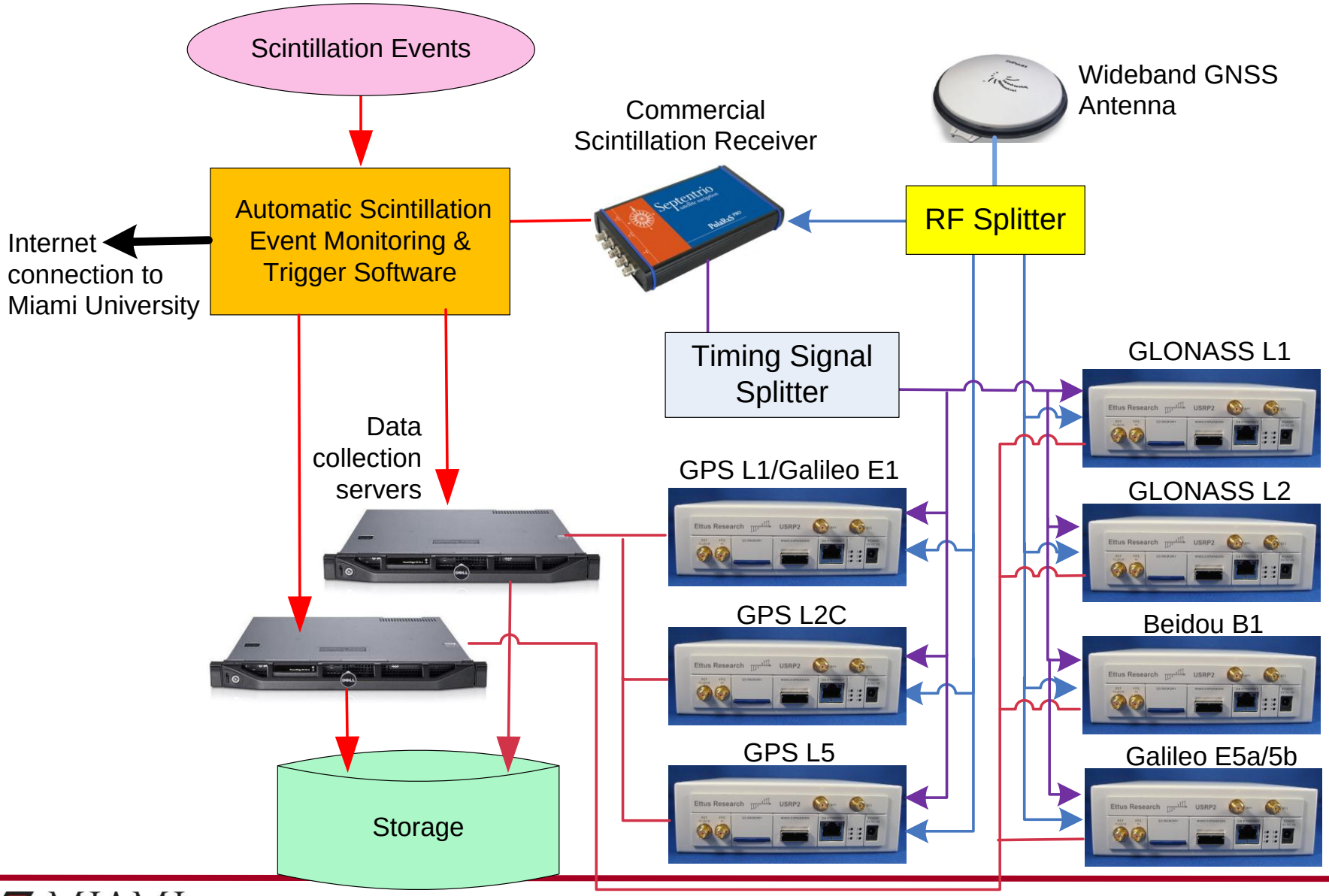

Jicamarca, Peru


Puerto Rico

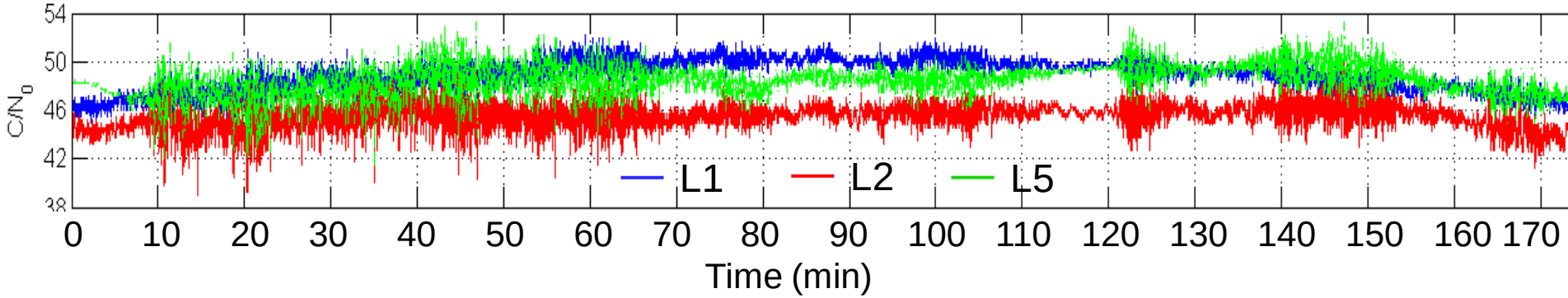

Ascension
Island


Singapore

Peru: Summer 2013 Deployment

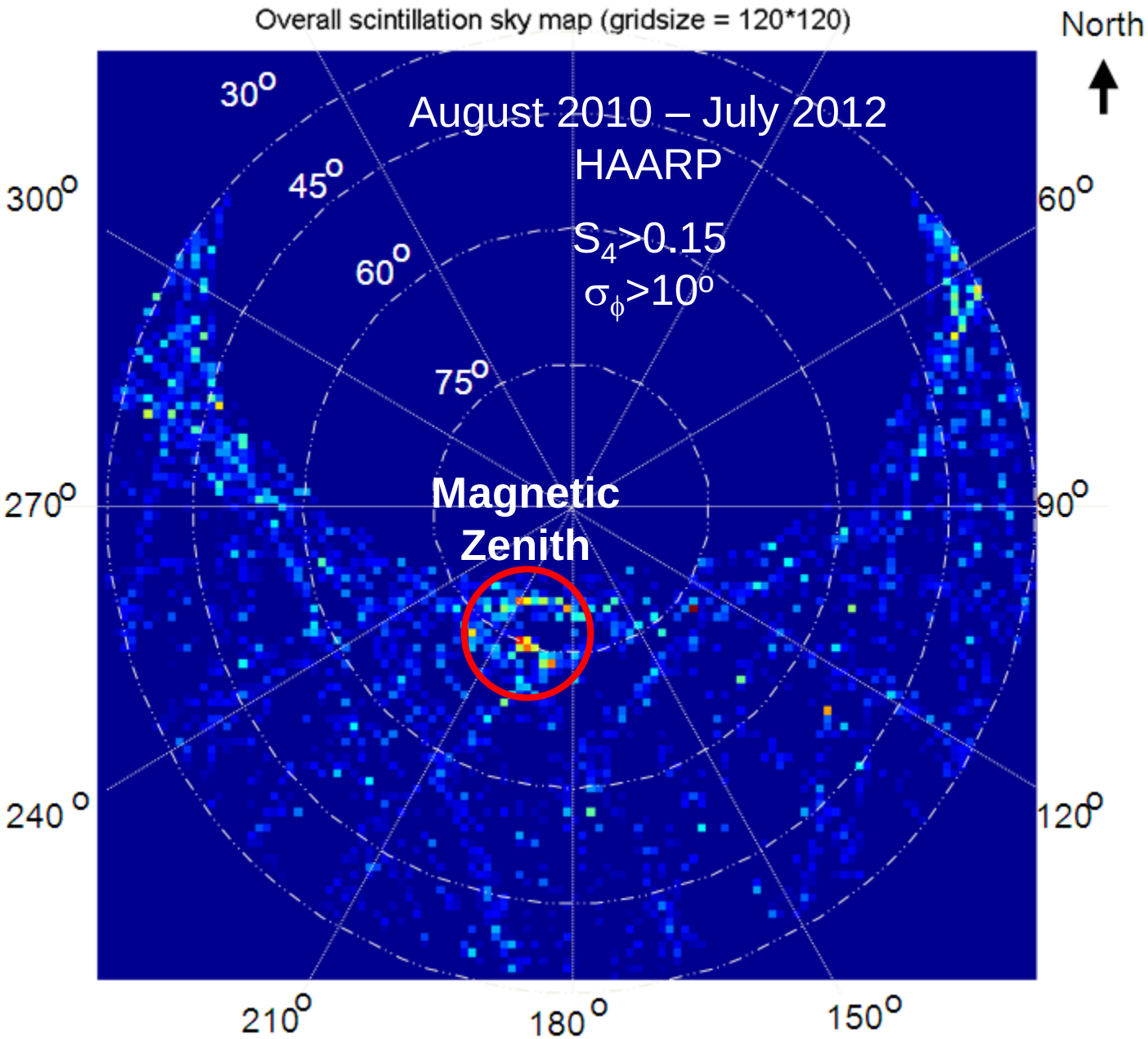


GNSS Characterization of Ionosphere Events



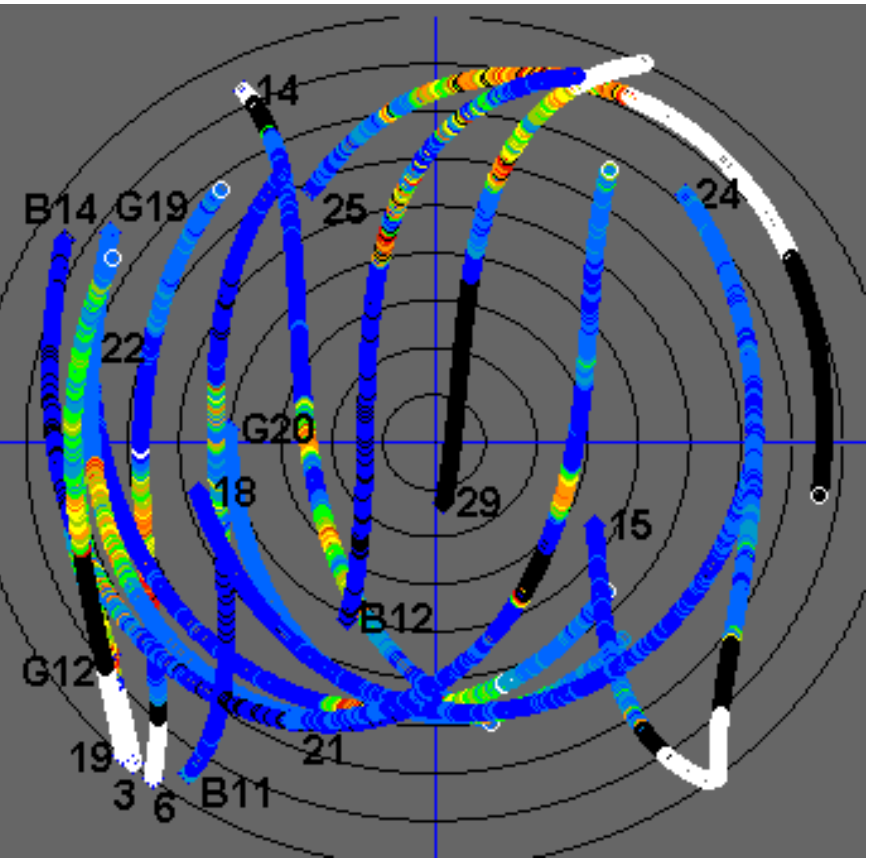
Peru, 3/11/2013, 13:30 UTC

High Latitude Scintillation Spatial Distribution

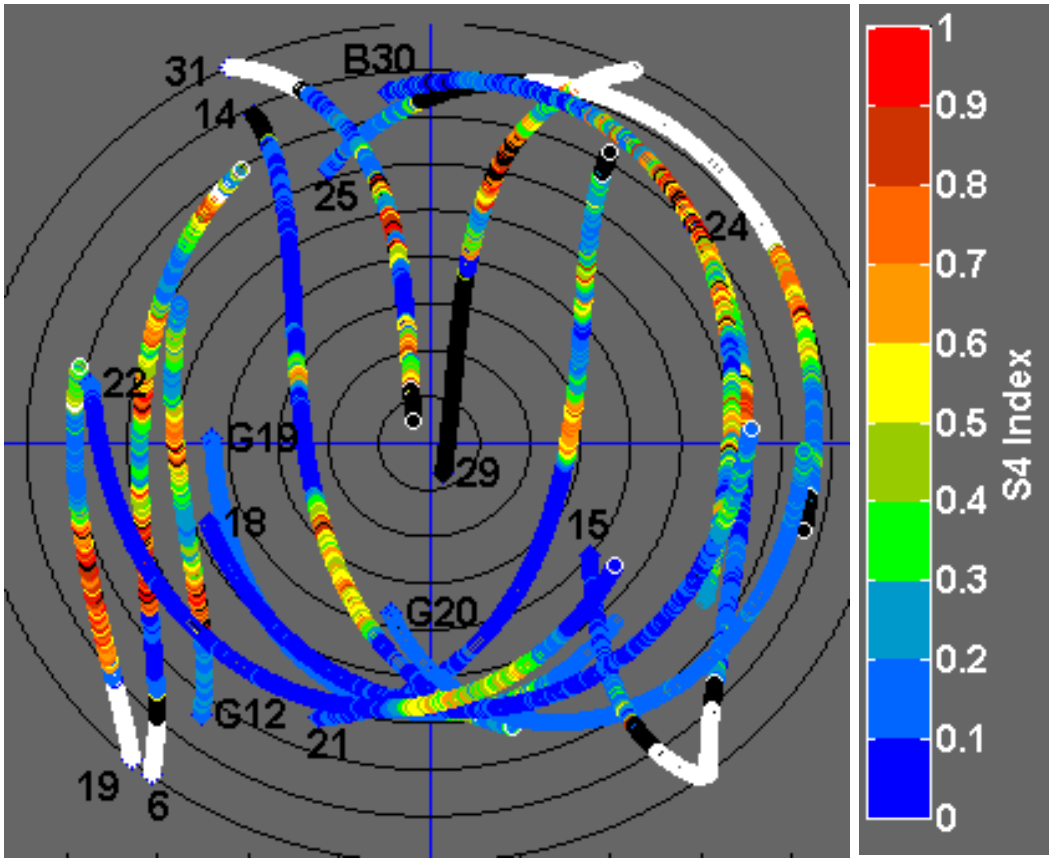


Equatorial Scintillation Spatial Distribution

Ascension Island: GPS, Galileo, Beidou
(in process of adding GLONASS results)

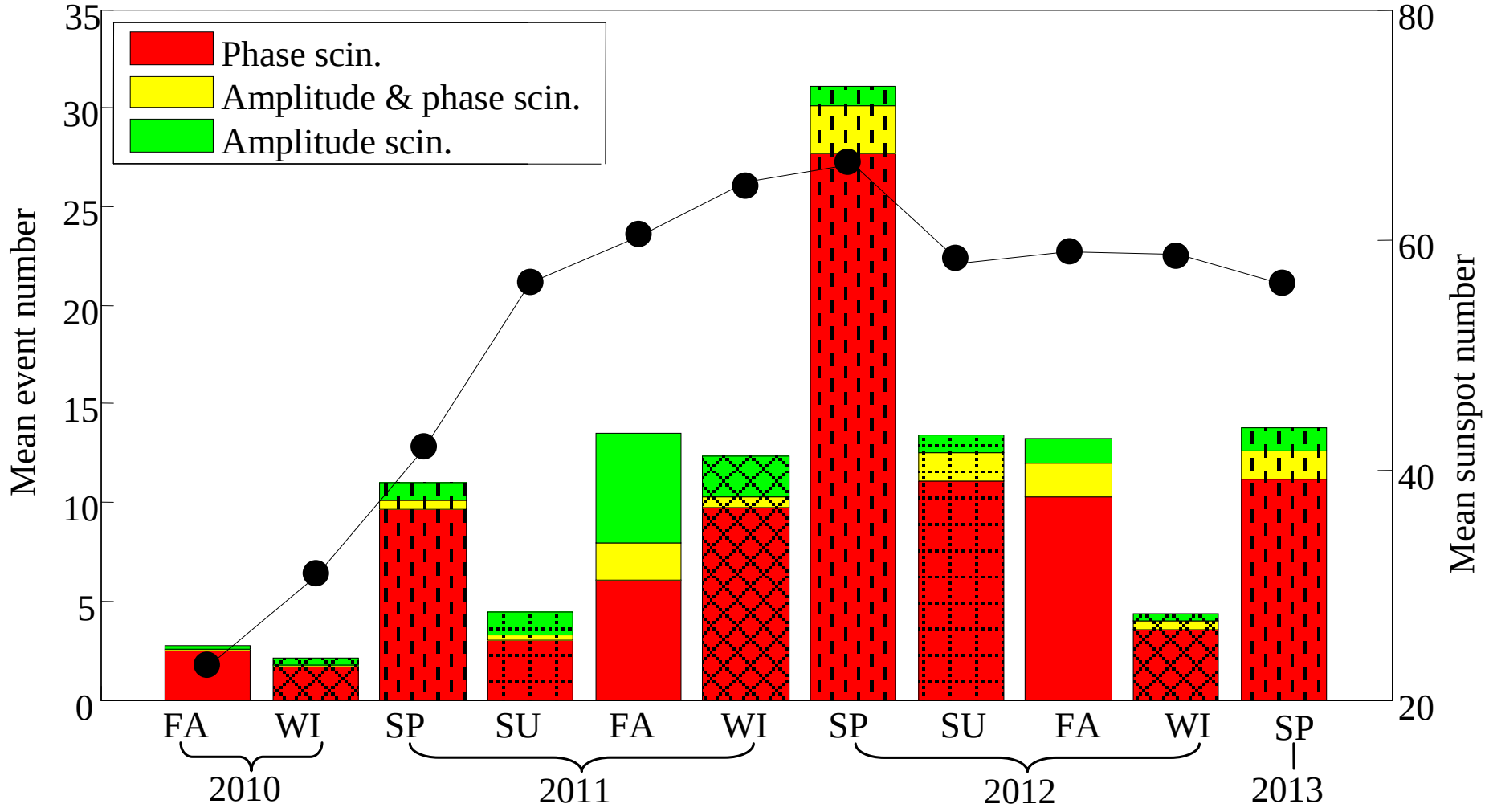


March 7, 2013

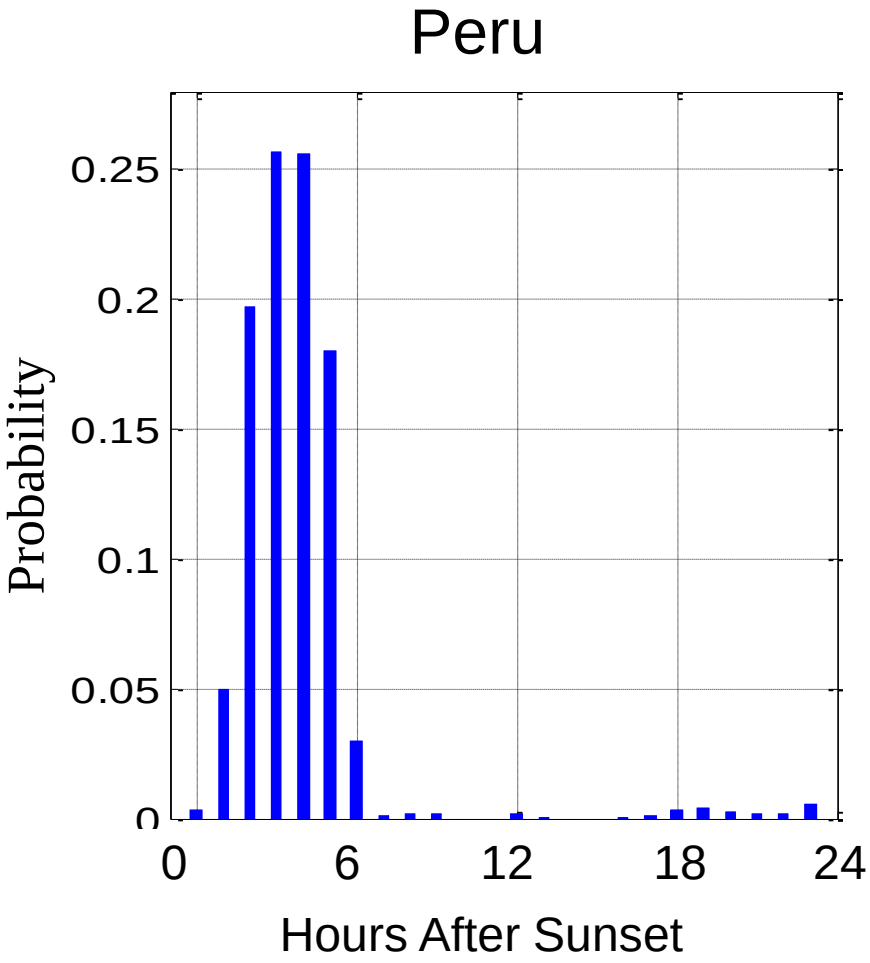


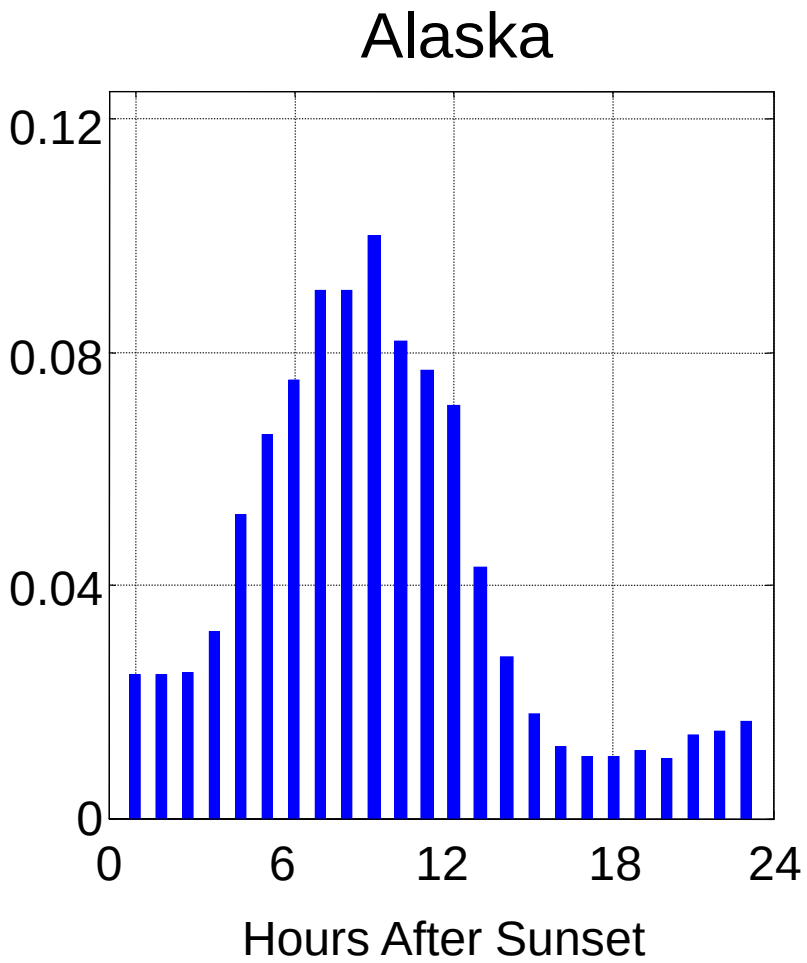
March 10, 2013

High Latitude Scintillation Seasonal Distribution

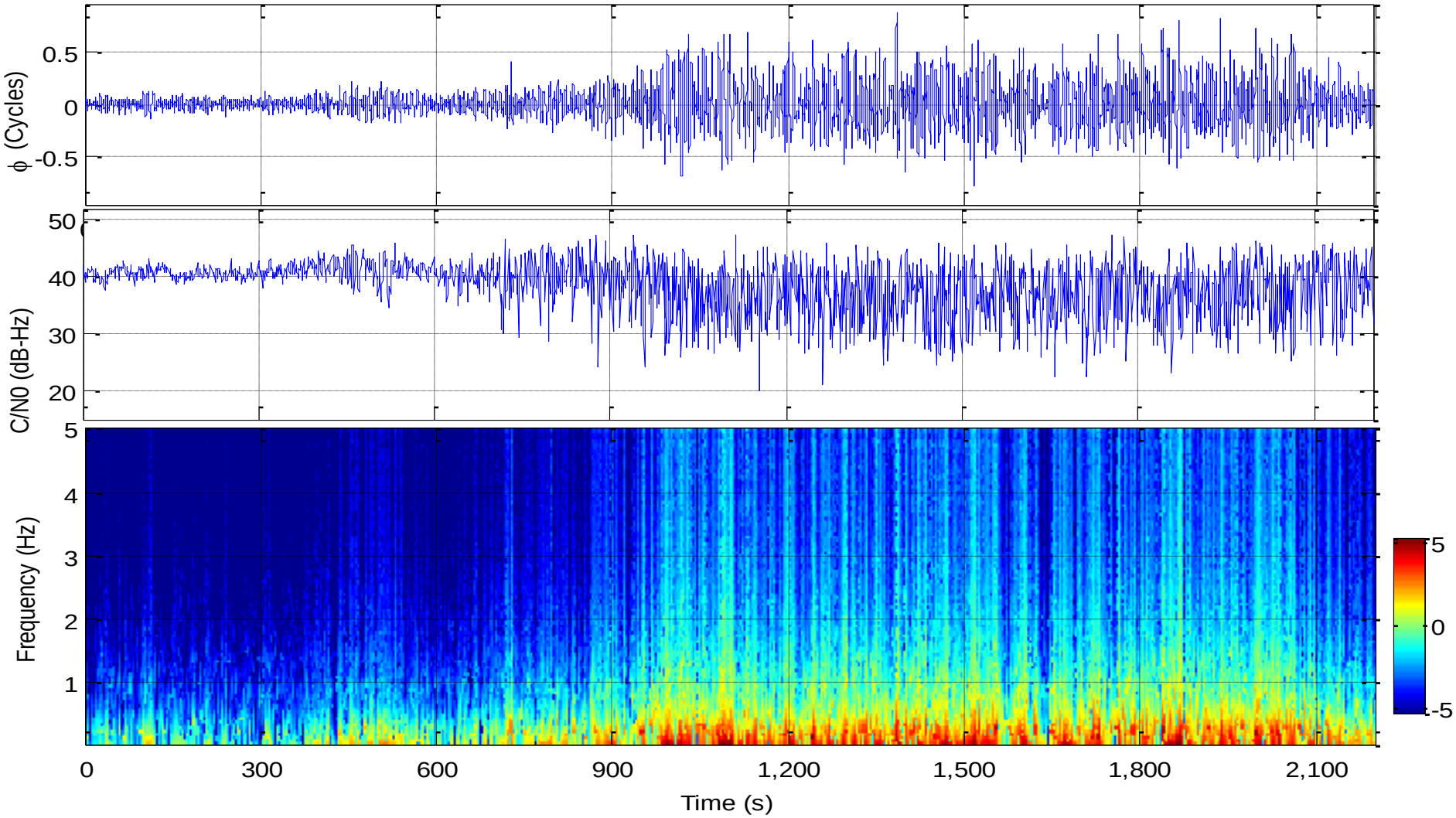


Diurnal Pattern





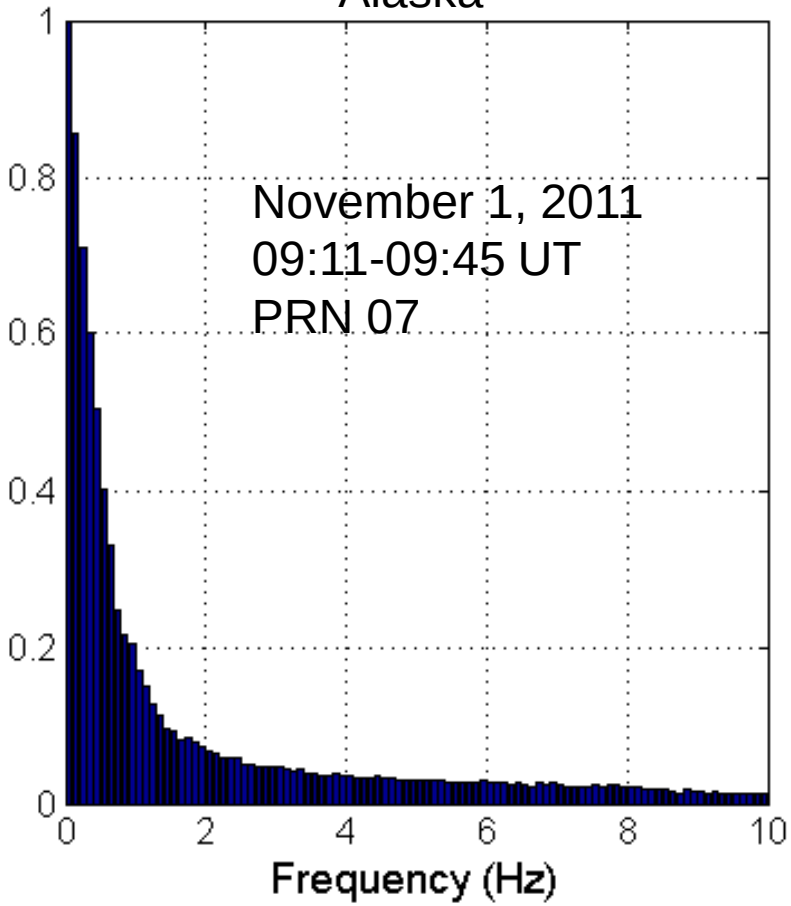
Adaptive Joint Time-Frequency Analysis



Scintillation Induced Frequency Variation Distributions

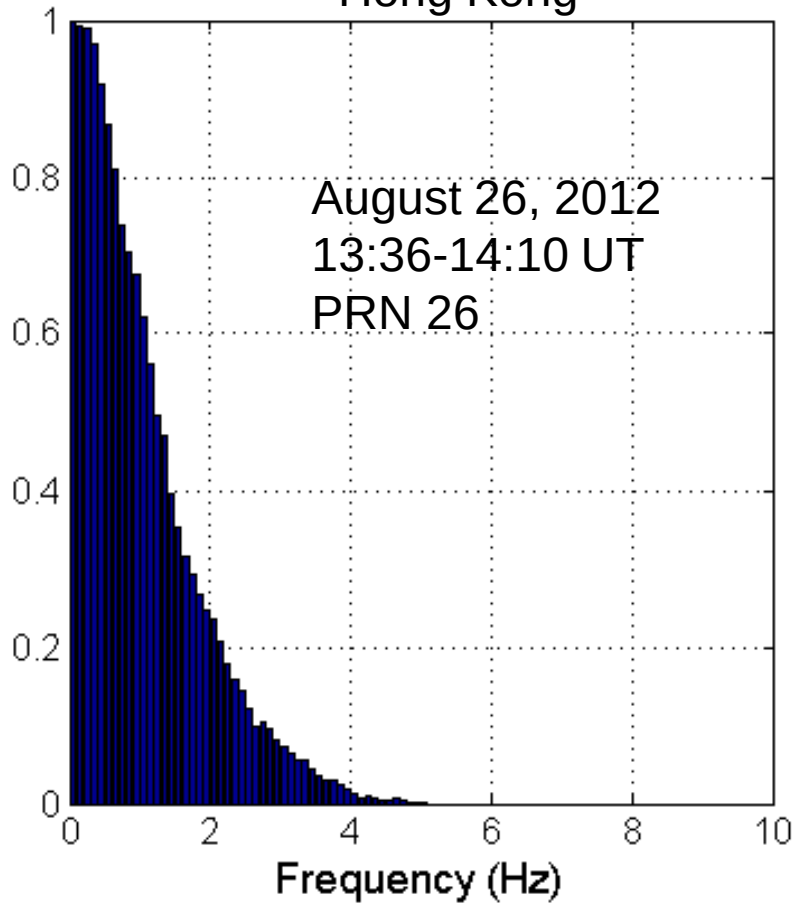
High Latitude

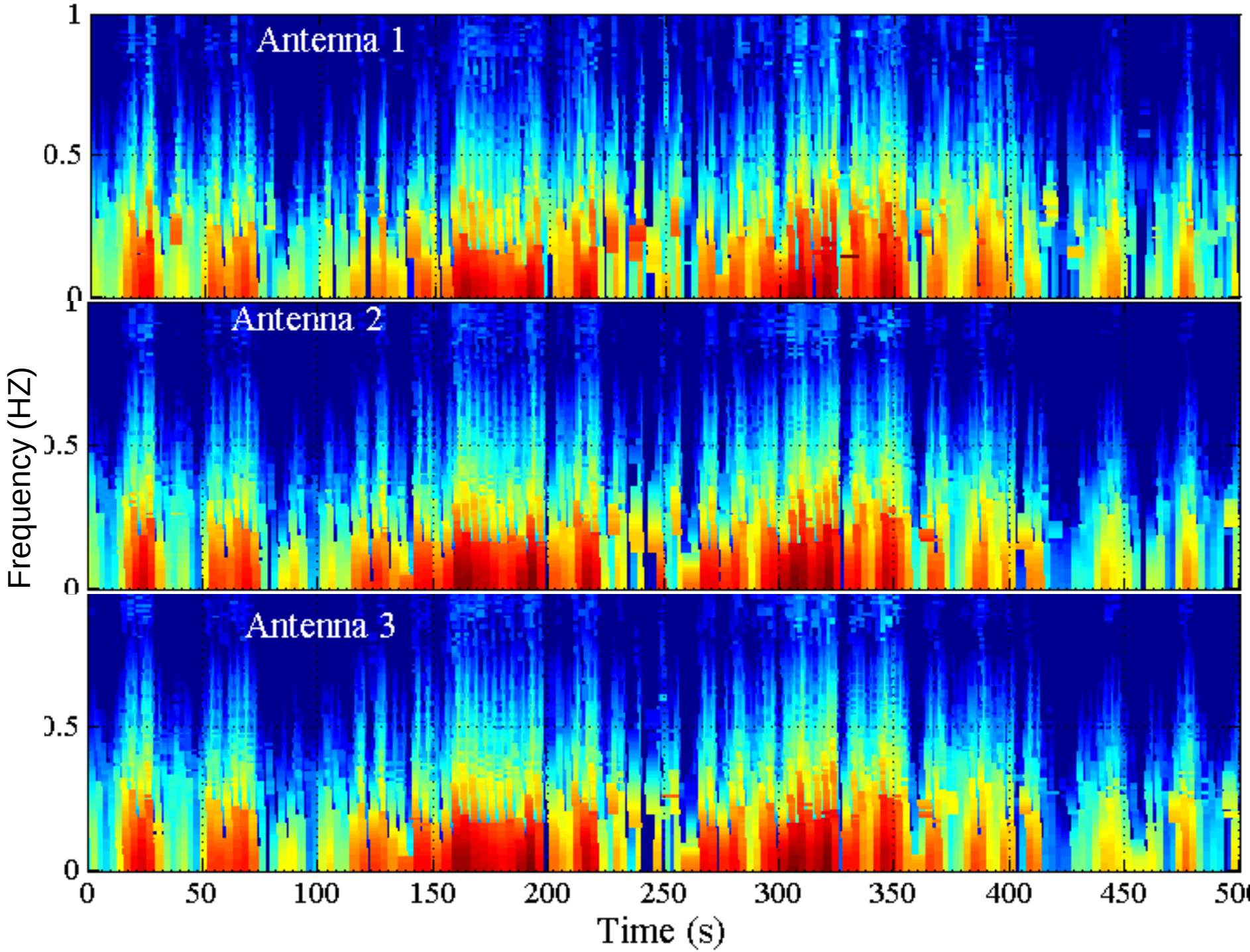
Alaska



Low Latitude

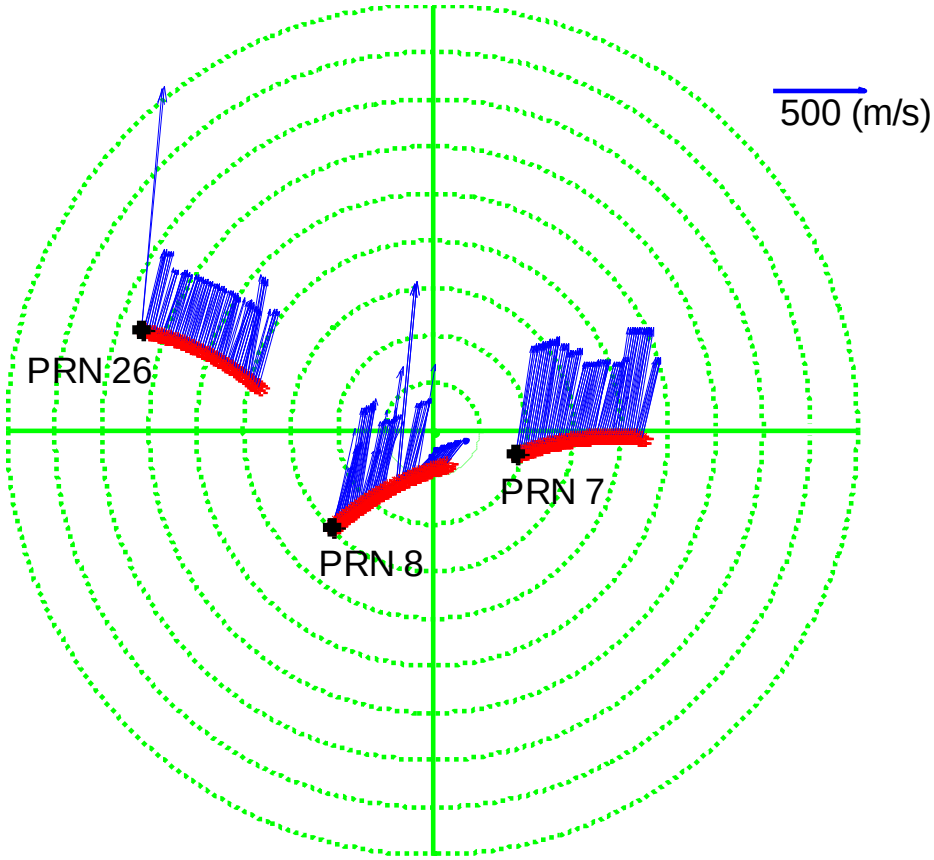
Hong Kong




Antenna 1
Antenna 2
Antenna 3
Frequency (HZ)
Time (s)
1
0.5
0
0.5
0
0.5
0
0
50
100
150
200
250
300
350
400
450

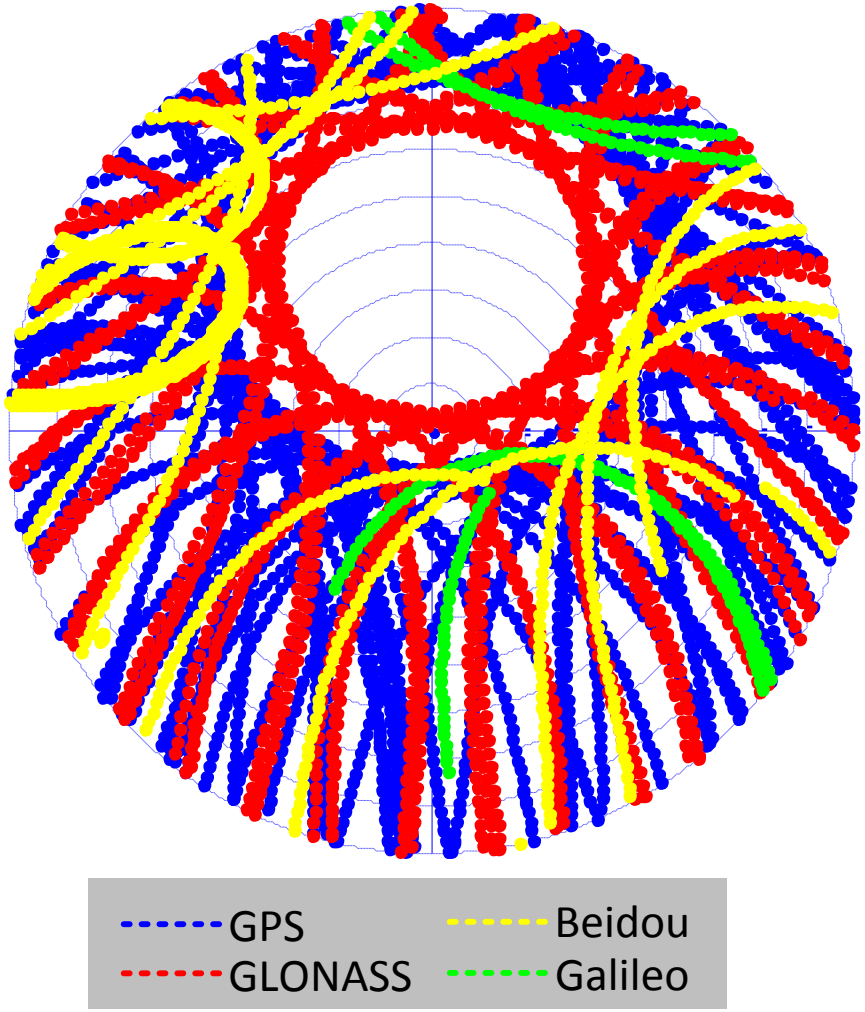
High Resolution Drift Velocity Mapping

10/13/2012, HAARP, AK

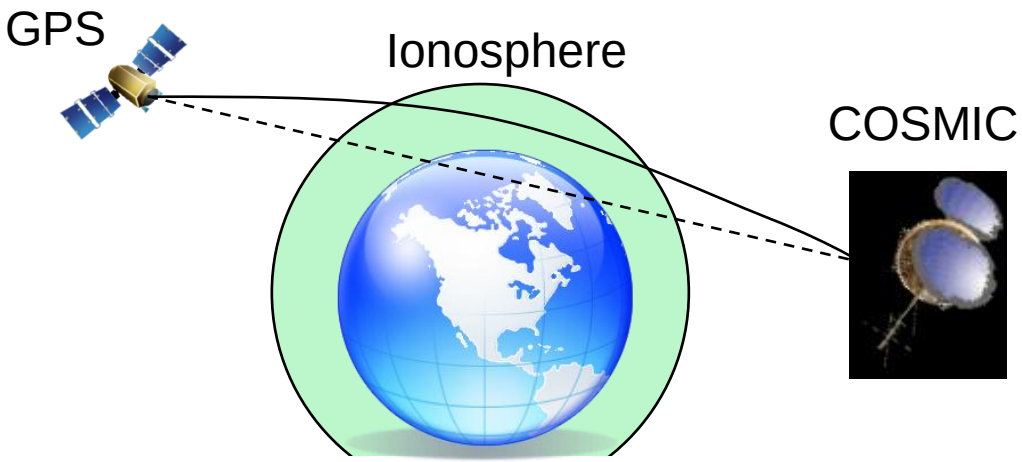


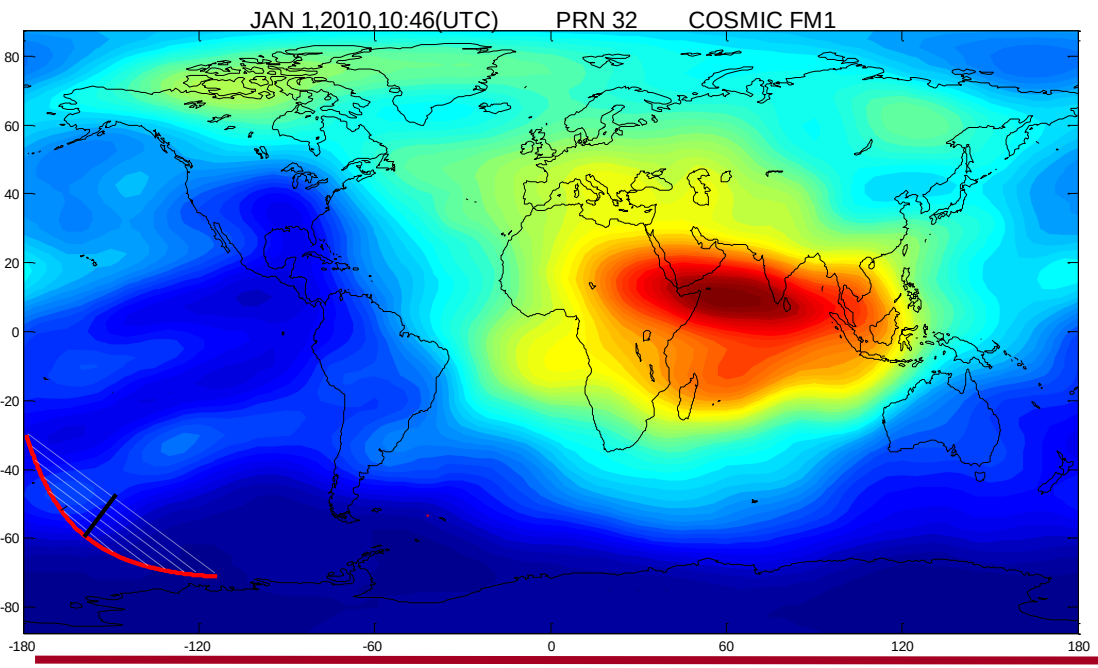
11:54:17-12:54:17 UTC

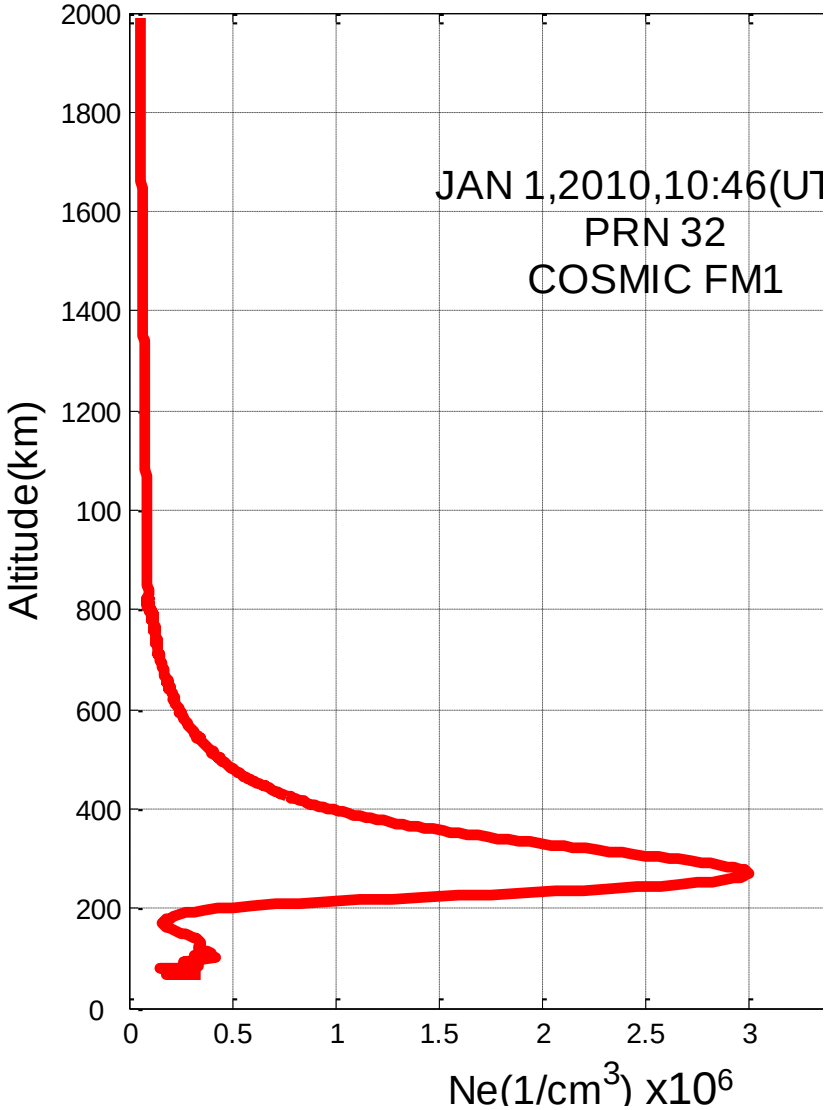
09/03/2013, HAARP, AK



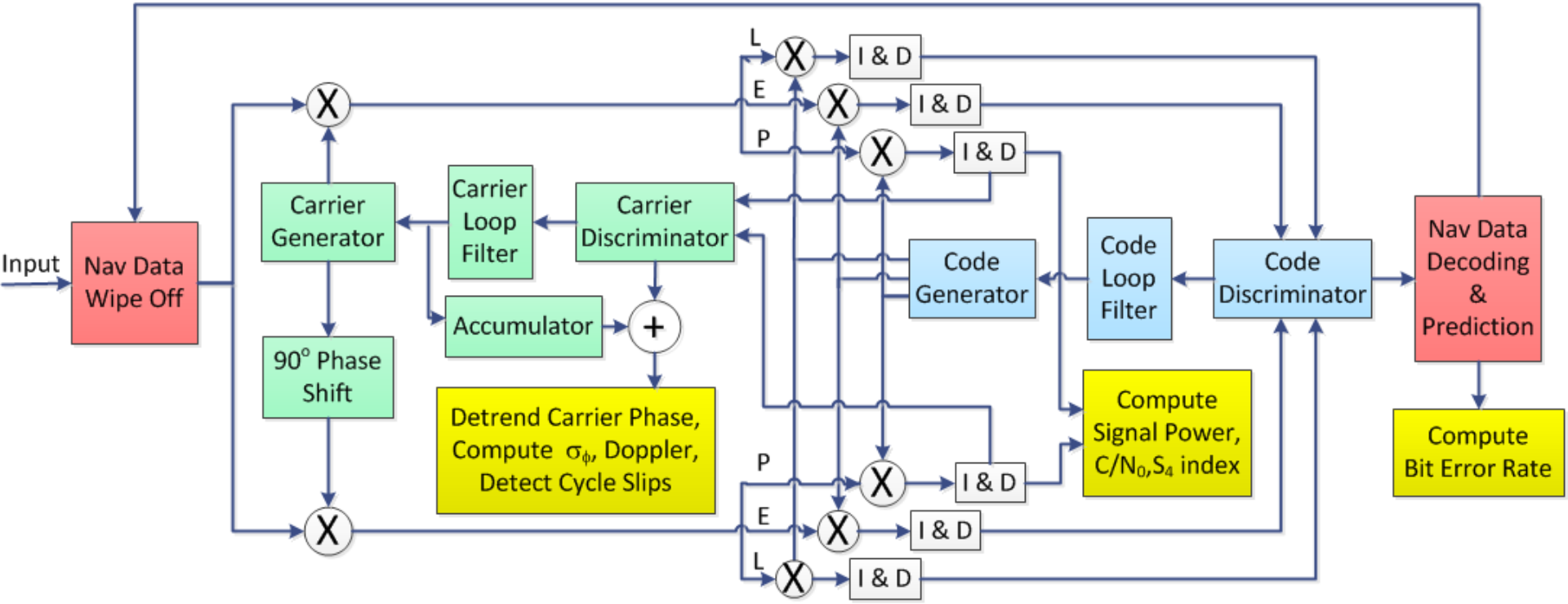
Radio Occultation: Singapore Collaboation



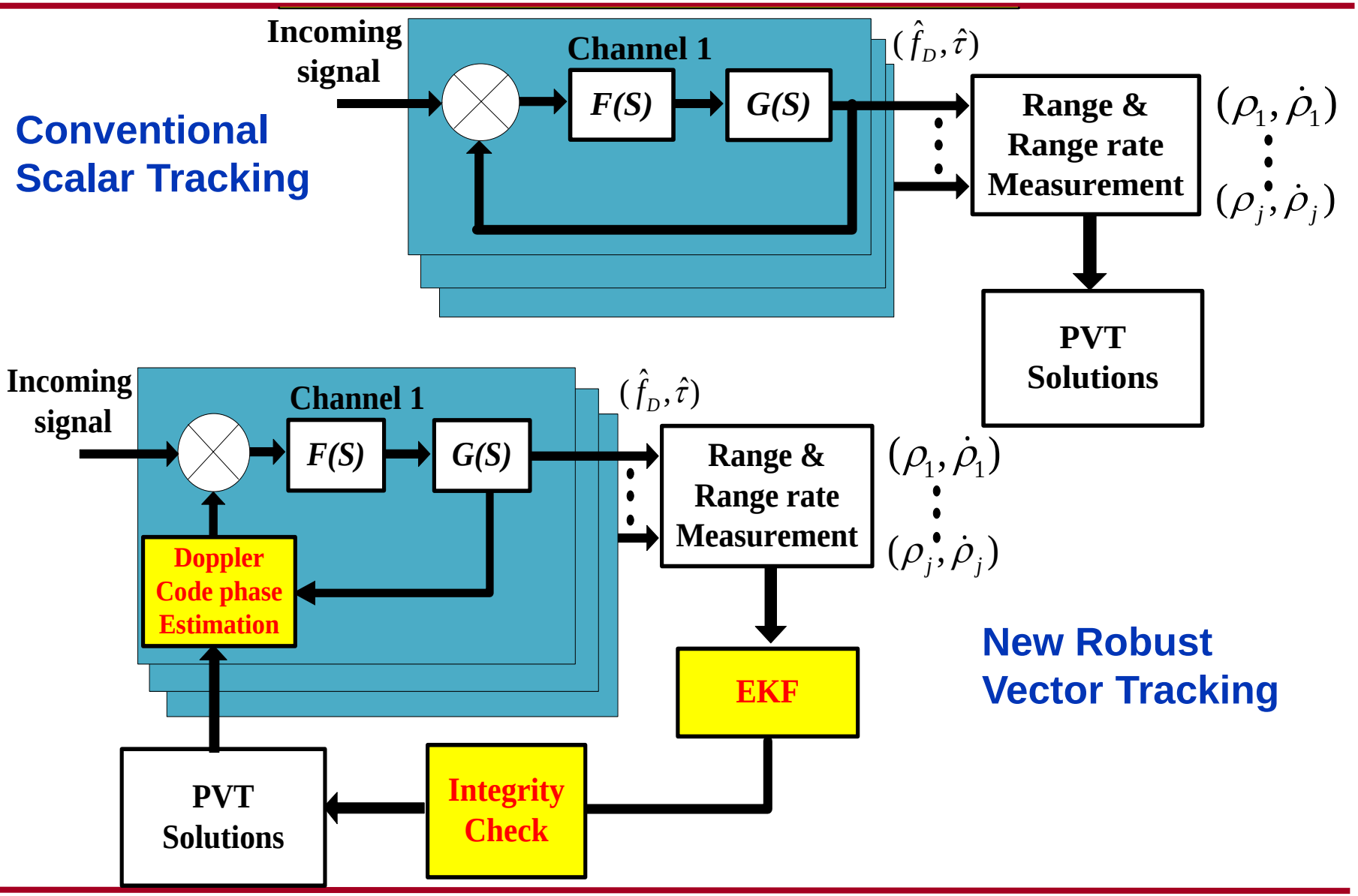




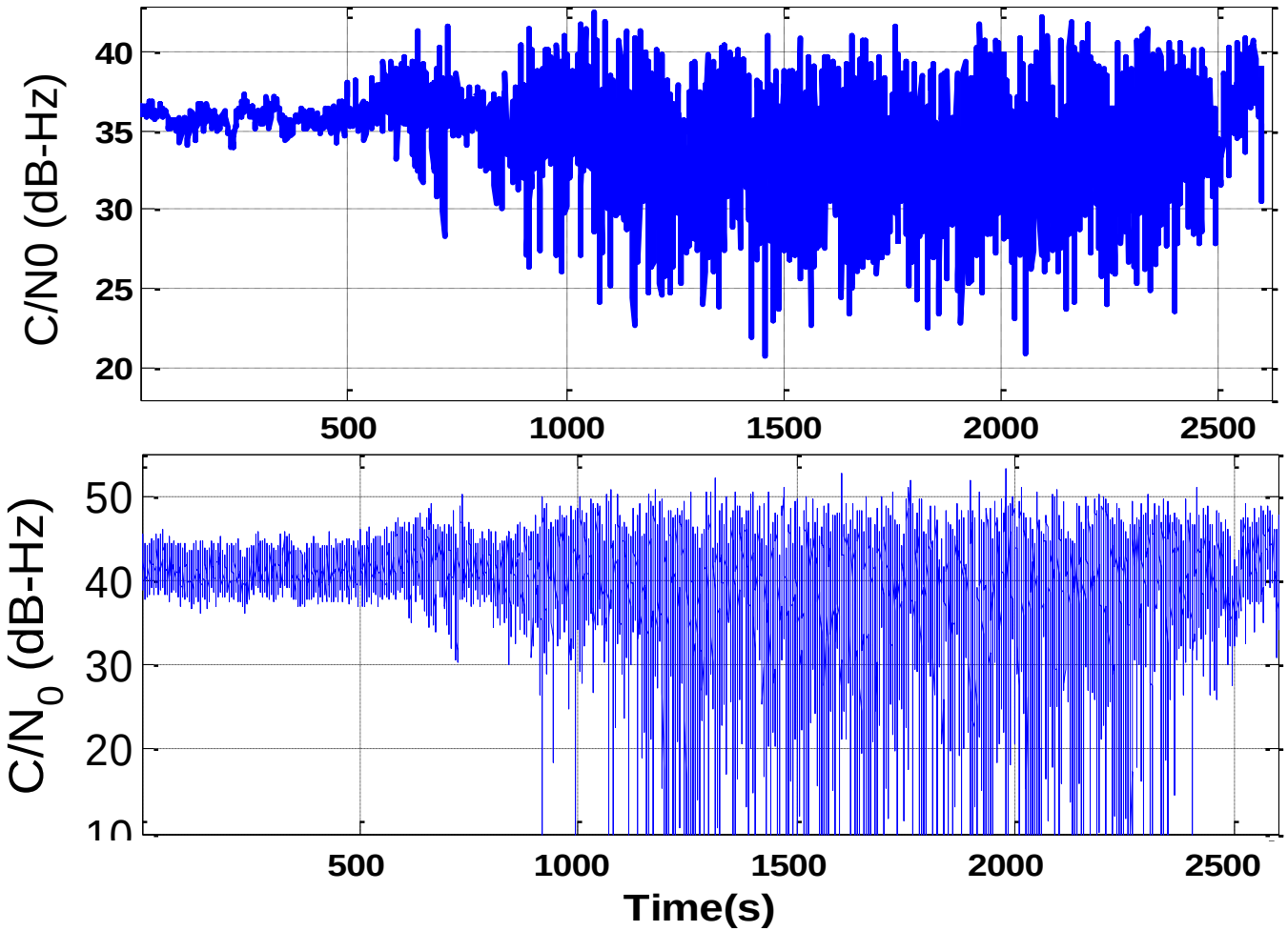
High Sensitivity GNSS



Robust Receiver Tracking: Vector Loop vs. Scalar Loop



Ascension Island Data Vector Tracking



VTL
(TI= 1ms;
PLL: 2nd order
BW = 15 Hz)

STL
(TI = 10ms;
PLL: 3rd order
BW = 3 Hz)

Computation performance is a major challenge!!!

Conclusions

- **Space weather will have increasing impact on GNSS applications**
  - **Efficient and robust GNSS technologies are needed to mitigate space weather effects for assured navigation**
- **GNSS will be a major enabler for space weather studies**
  - **Accurate receiver processing algorithms are critical to preserve true space weather signature on GNSS signal parameters**
- **Many challenges and opportunities**

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  - Arecibo Observatory, Puerto Rico
  - HAARP, Alaska
  - Jicamarca Radio Observatory, Peru
  - Equatorial Atmosphere Radar, Indonesia
  - Poker Flat, Alaska

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Collaborators:	Frank van Graas, Wouter Pelgrum (Ohio University) Dave Anderson (NOAA), Eric Vinande and Jeff Hebert (AFRL)