ATMOSPHERIC & SPACE TECHNOLOGY RESEARCH ASSOCIATES

SCIENCE + TECHNOLOGY + APPLICATIONS // *Bringing it all together*

A new GPS sensor for monitoring ocean wave dynamics and space weather from remote buoys and ships

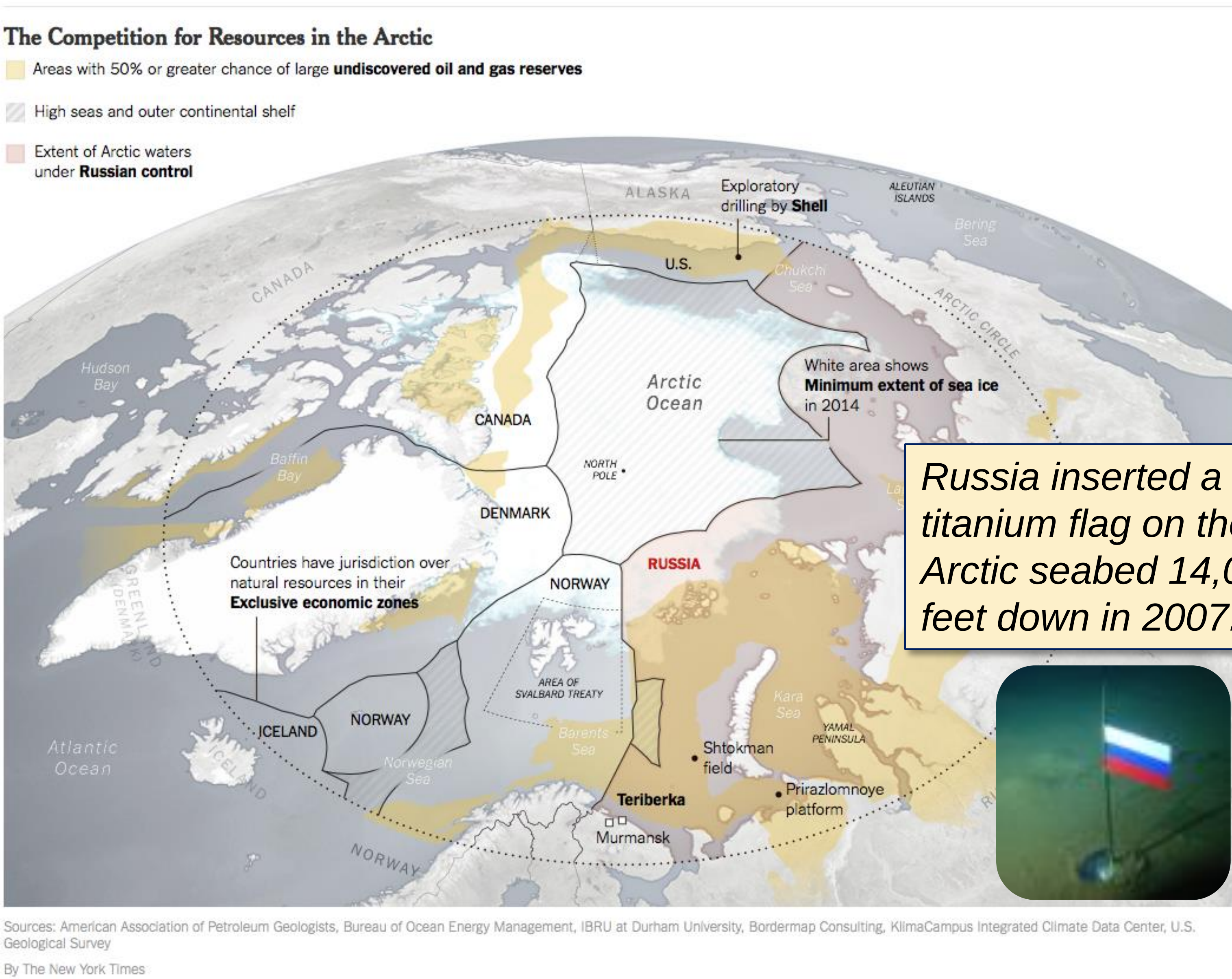
Joe Kunches, Irfan Azeem, Geoff Crowley, Adam Reynolds

ASTRA, Boulder, CO

September 15, 2015

Contact: *jkunches@astraspace.net*

Arctic Sovereignty and Resources



Russia inserted a titanium flag on the Arctic seabed 14,000 feet down in 2007.

Arctic Operations

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❖ Technology
❖ Applications
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AW&ST, Aug. 18, 2015

Looming Challenges

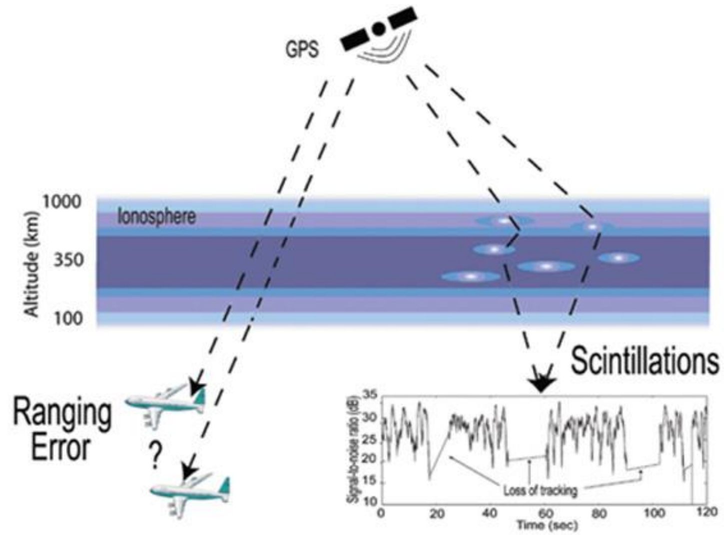
In the water or above it:

- ***Where am I?***

- ***Can I survive the pounding sea?***

Ionospheric error is the single largest error source for GNSS

- **Refractive errors from bulk TEC**
- **Diffractive errors from scintillation**



71% of earth's surface is ocean

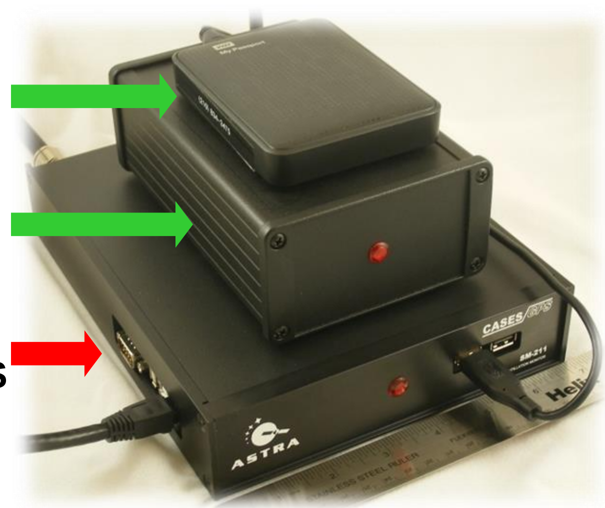
Real time oceanic GNSS-based ionospheric measurements needed for critical incident response plans

ASTRA's Operational GPS Array

Array of CASES receivers deployed in Alaska:

- Kaktovik (70.1° N, 143.6° W)
- Toolik (68.6° N, 149.6° W)
- Fort Yukon (66.6° N, 145.2° W)
- Poker Flat (65.1° N, 147.4° W)
- Eagle (64.8° N, 141.2° W)
- Gakona (62.4° N, 145.2° W)

6 additional CASES in a tight grid at Poker Flat



Real-time GPS Data Product

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❖ Technology
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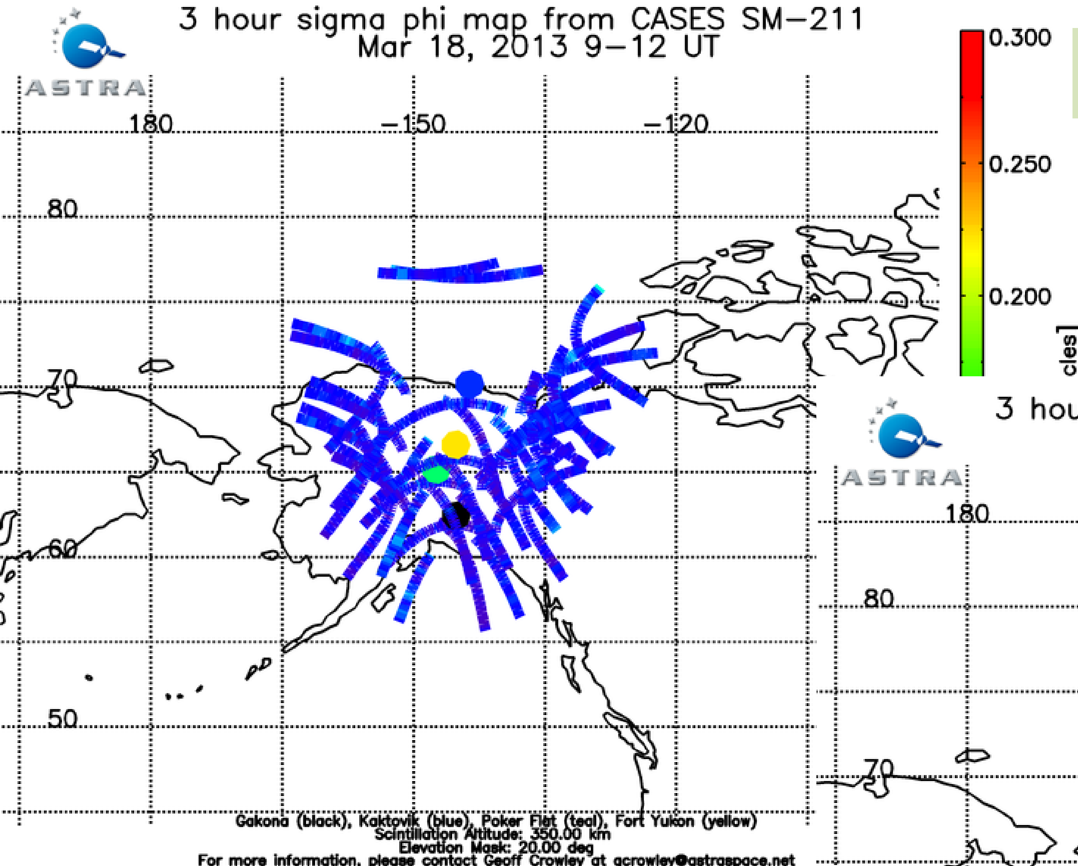
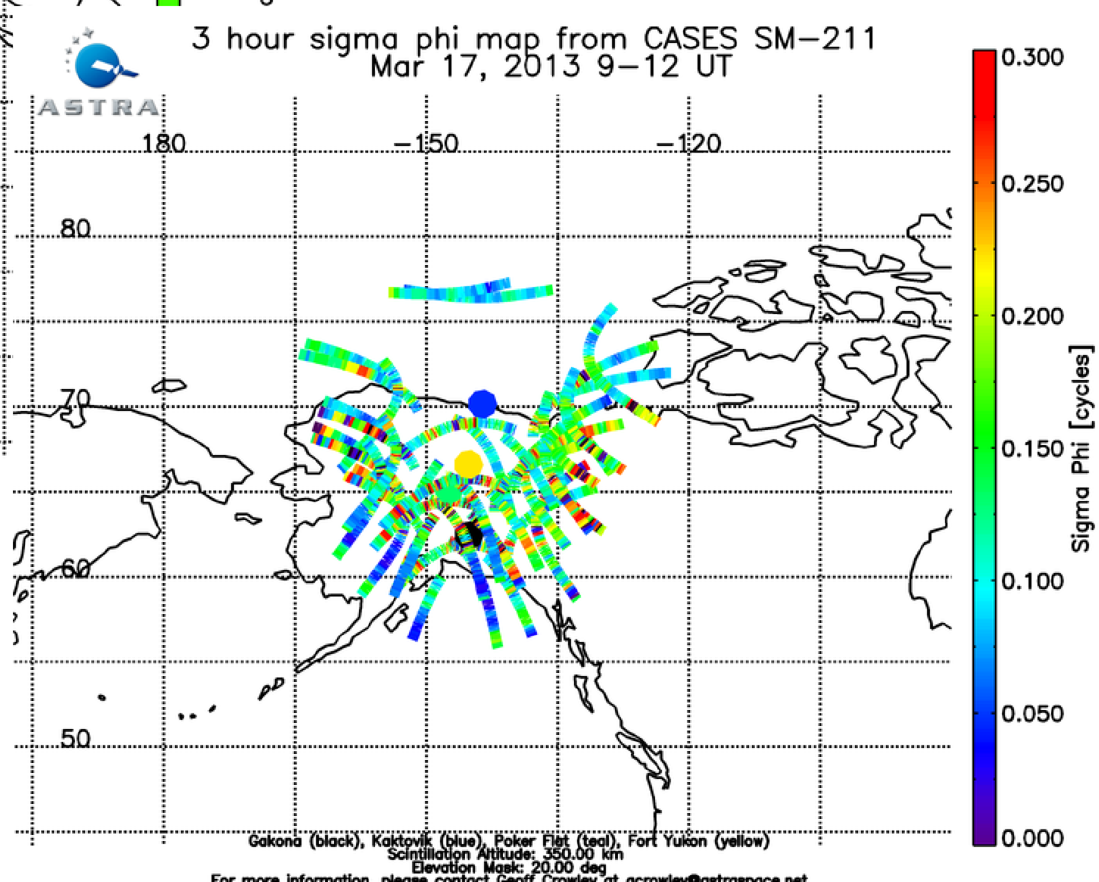
http://cases.astraspace.net

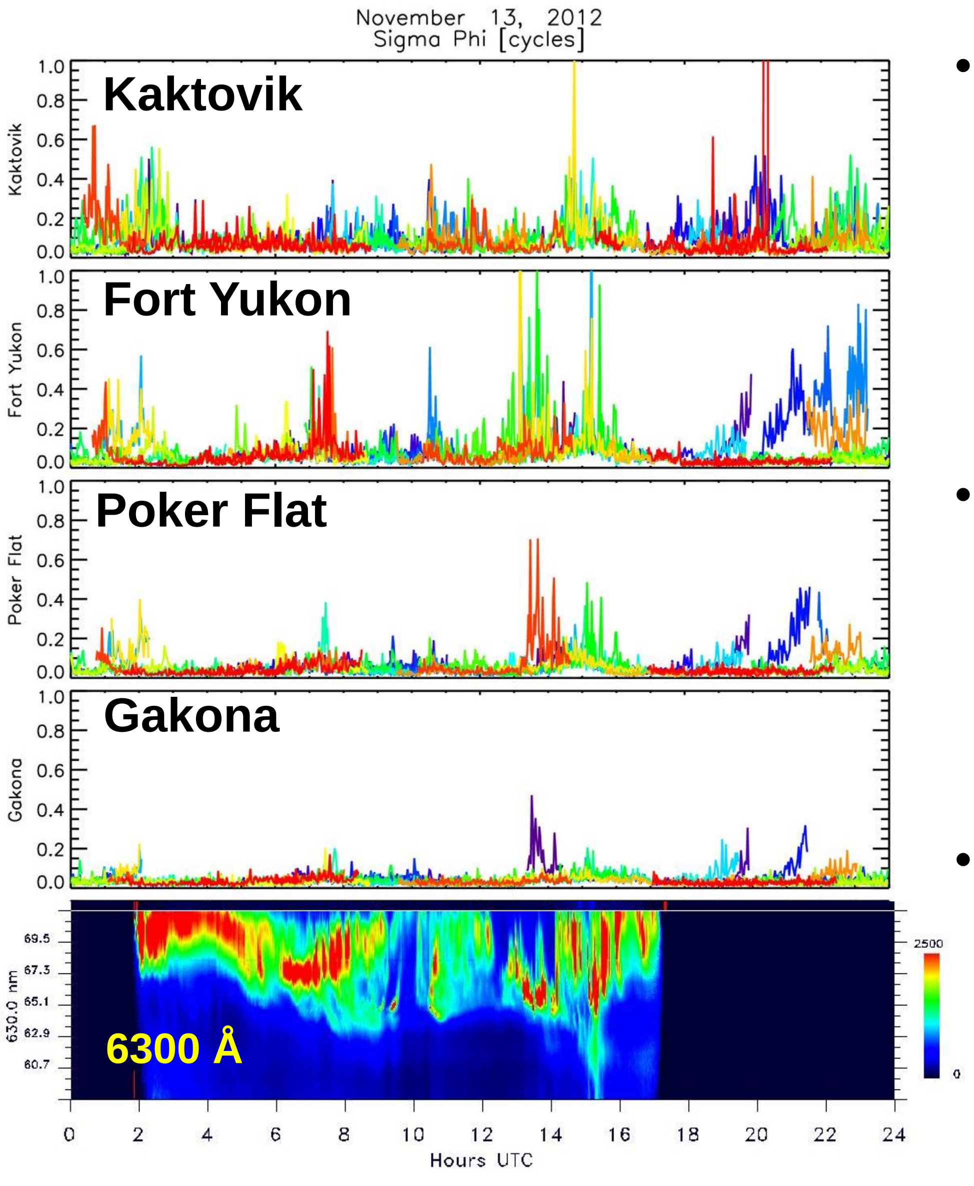


Quiet Conditions

Active Conditions



24 hr Example: Nov. 13, 2012



- **Auroral activity was located poleward of Poker Flat (65.1° N) and most of the moderate phase scintillation values were also seen at or poleward of Poker Flat.**
- **At 1300 UT the aurora drifted towards lower latitudes with the equatorward edge of the aurora extending to latitudes near Gakona.**
- **The phase scintillation data from the Gakona site also show increased scintillation during this period characterized by the auroral equatorward transition.**

Ionospheric Monitoring from a ocean platform

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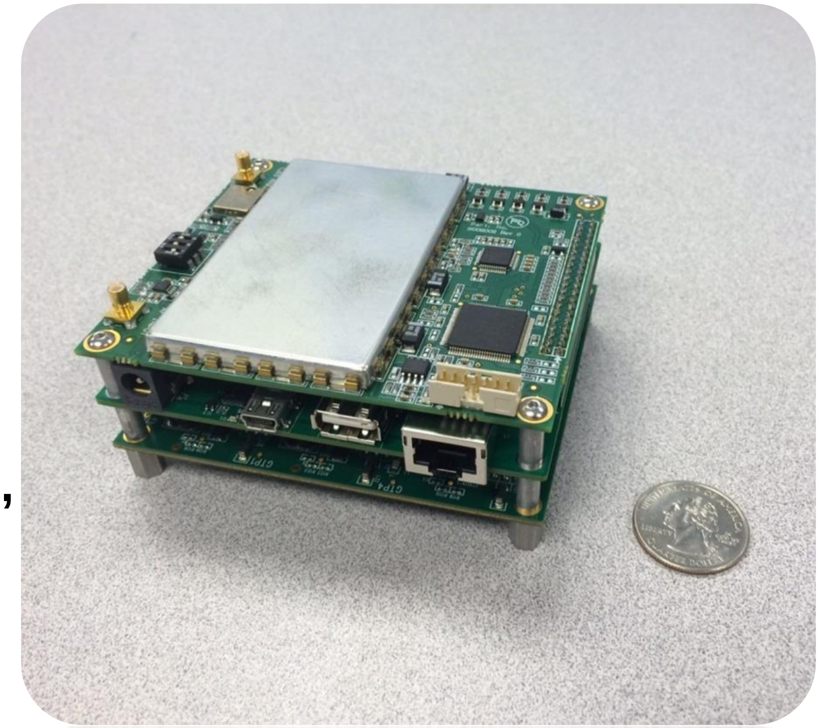
"No one else in the World has done this…"

– recent quote from Technical Director of a multi-Billion dollar International Commercial Services company that provides marine data services

- Successful validation of GAMMA in field tests - Hawaii and Peru
- Near real-time space situational awareness from moving platform
- Programmable data latency (Nominal 5 minutes)
- TEC, scintillation data products, and system's heath status
- Ground link via Iridium or cell towers.

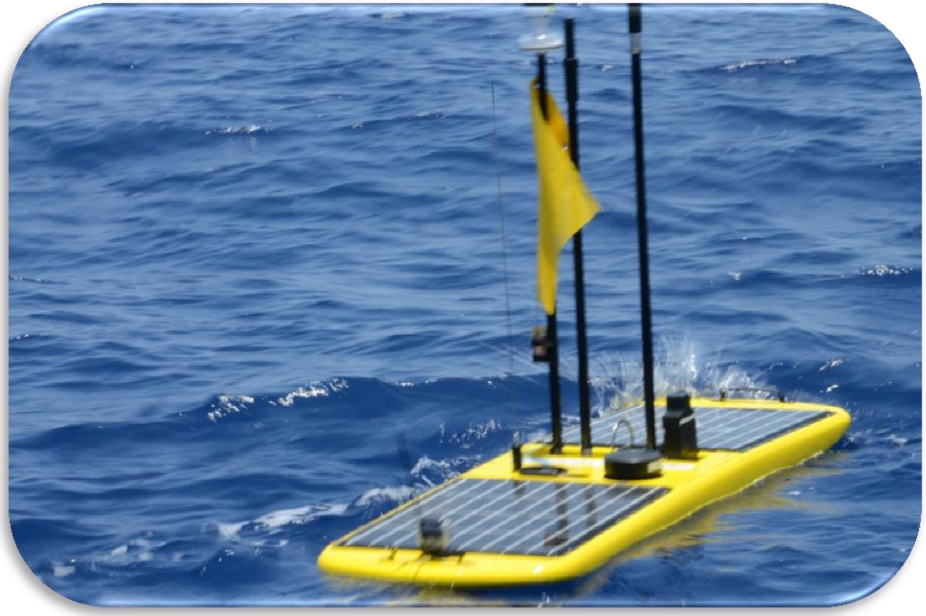
GAMMA Software GPS Rx

- **Software GPS Rx that provides continuous ionospheric TEC and scintillation parameters from oceanic regions**
- **Capabilities:**
  - **Tracks GPS L1 and L2C signals –** ***even through deep signal fades***
  - **Fully reconfigurable including data-rates, PLL and DLL bandwidths, etc.**
  - **Operates at low power (~4.5 W)**
  - **Compensates for buoy motion on scintillation measurements … & other data products**



GAMMA GPS Receiver: RFE, on-board DSP and SBC interface unit

GAMMA GPS Field Tests

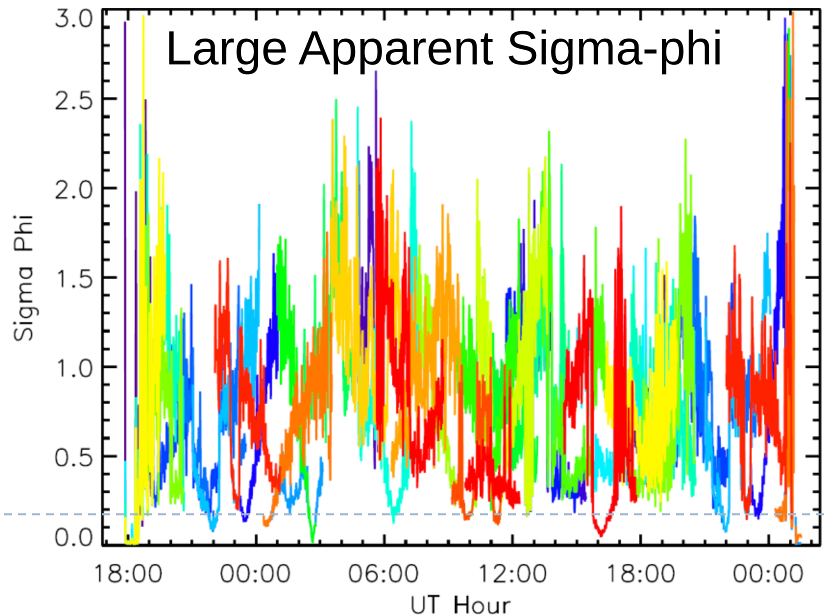


- **Successful field tests in Hawaii (2013, 2014) and Peru (2015)**
- **Fully-processed real-time ionospheric TEC and scintillation parameters**

Motion Causes Artificial Sigma-Phi

- GPS measurements of ionospheric TEC and scintillation from moving platforms, such as ocean buoys, are extremely challenging
- Motion creates large phase variations that look like phase scintillation
- Creates a significant problem when attempting to measure real scintillation from a moving platform
- PLL bandwidth of standard GPS receivers too narrow to maintain satellite lock
- Current GPS phase scintillation techniques cannot discriminate between antenna motion and ionospheric irregularities

Without Motion Correction

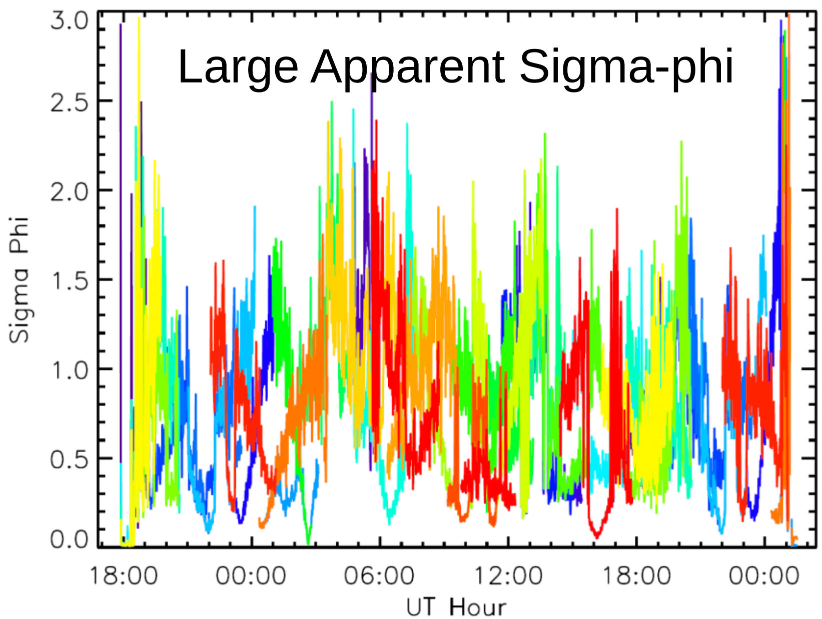


Removing Motion Effect from Sigma-Phi

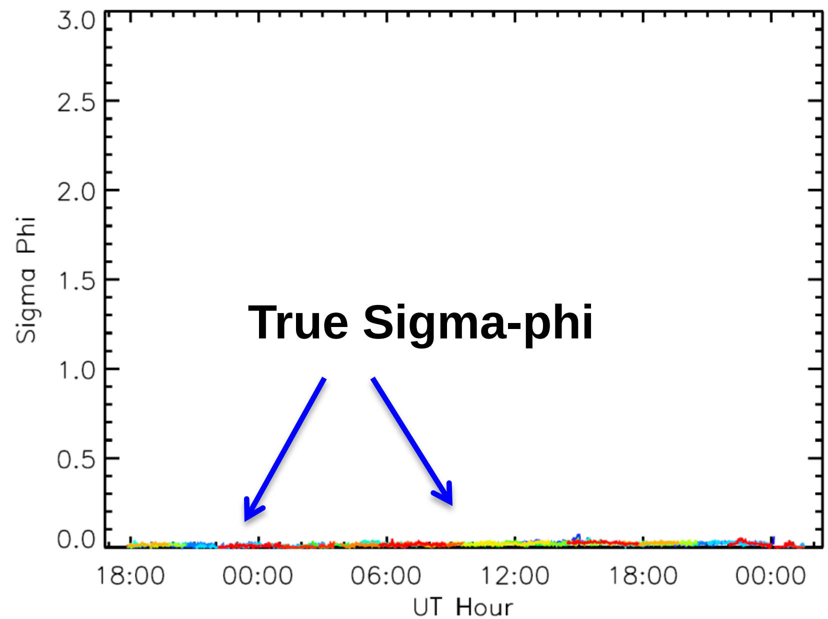
Solution:

- **Use the integrated carrier phase to calculate antenna motion over the scintillation window**
- **Use this information to remove the effect from the integrated carrier phase**
- **Re-calculate sigma phi using corrected integrated carrier phase**

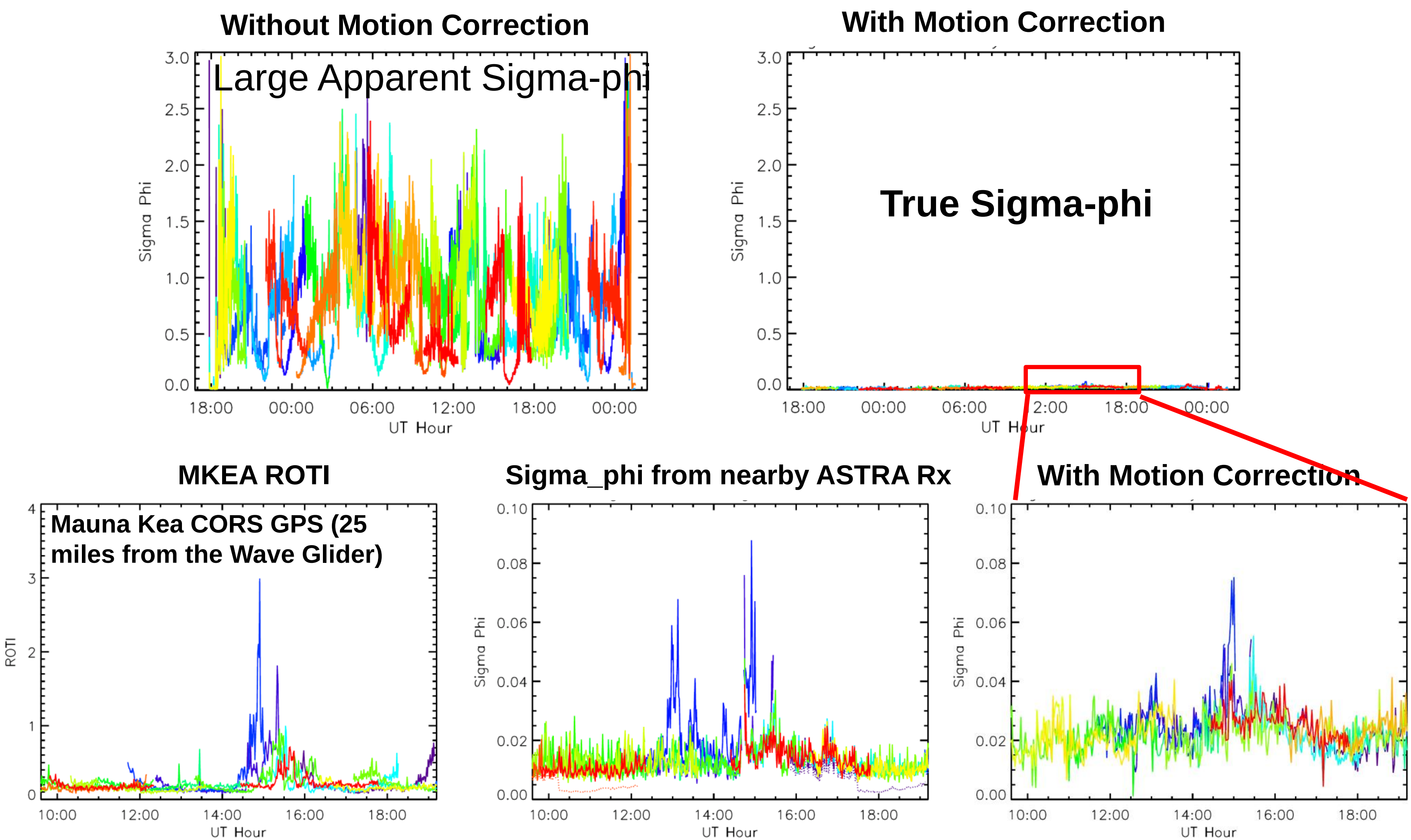
Without Motion Correction



With Motion Correction

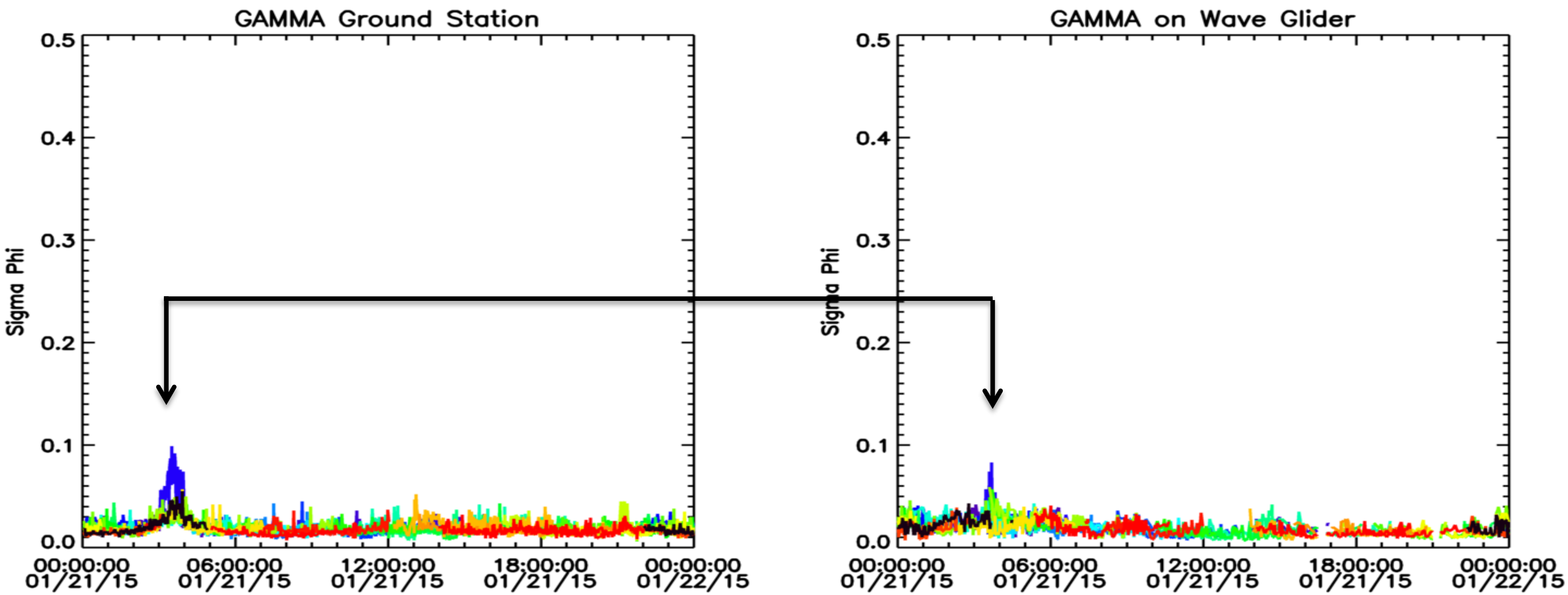


Validation against Land-based Receivers



Validation in Peru

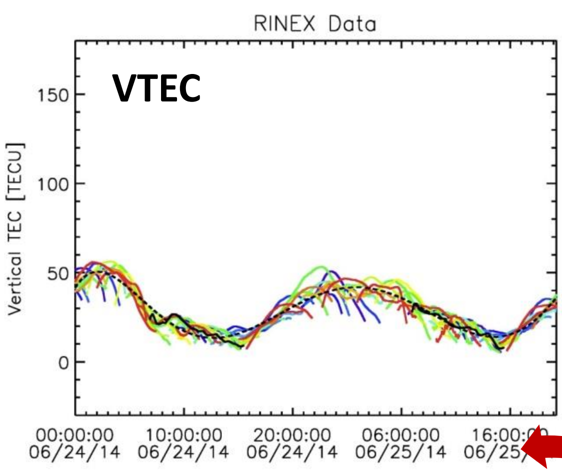
- **Wave Glider deployed 11 miles off the coast of Lima**
- **Scintillation event recorded by GAMMA from 0300 to 0400 UT on Jan 21 coincides well with the σ_φ increase measured by the ground-based GAMMA receiver in Lima at the same time.**

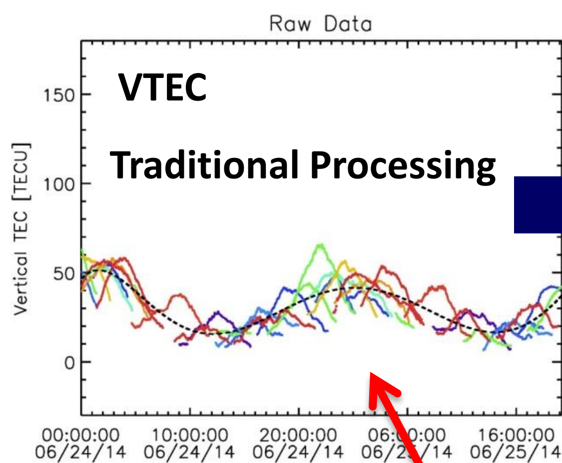


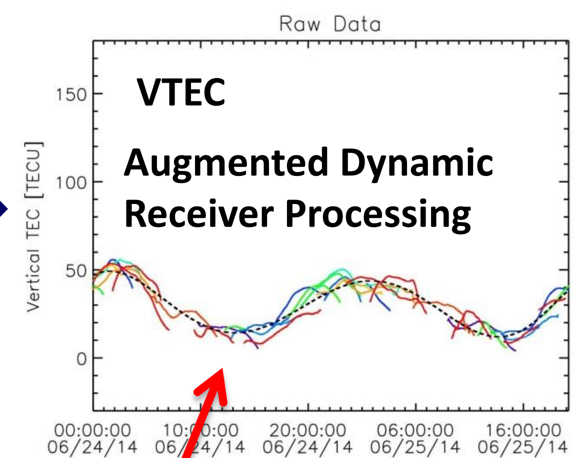
VTEC from a Buoy (Hawaii)

Land Based Measurement:
Mauna Kea CORS GPS (25 miles from the Wave Glider)

GAMMA GPS receiver on the ocean







Vertical TEC from the CORS receiver at Mauna Kea.

Vertical TEC from GAMMA on the Wave Glider.

VTEC in Peru

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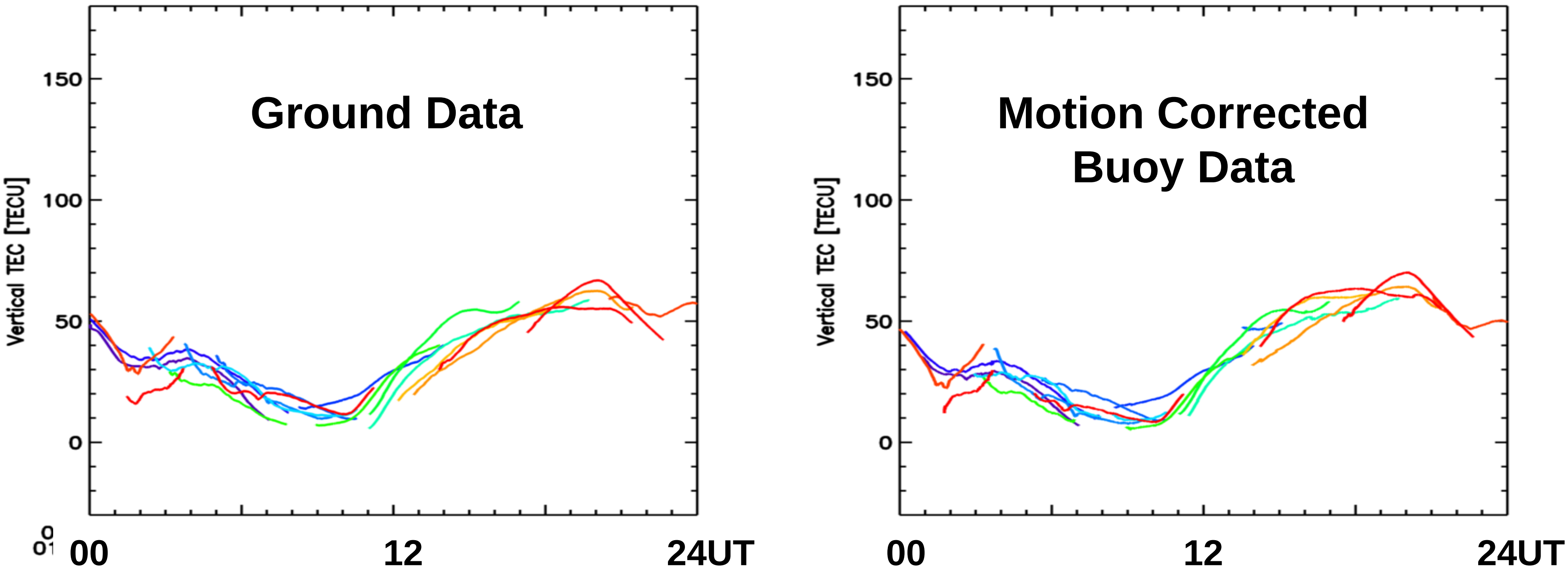
- **GAMMA on buoy in good agreement with receiver on shore in Lima, Peru**



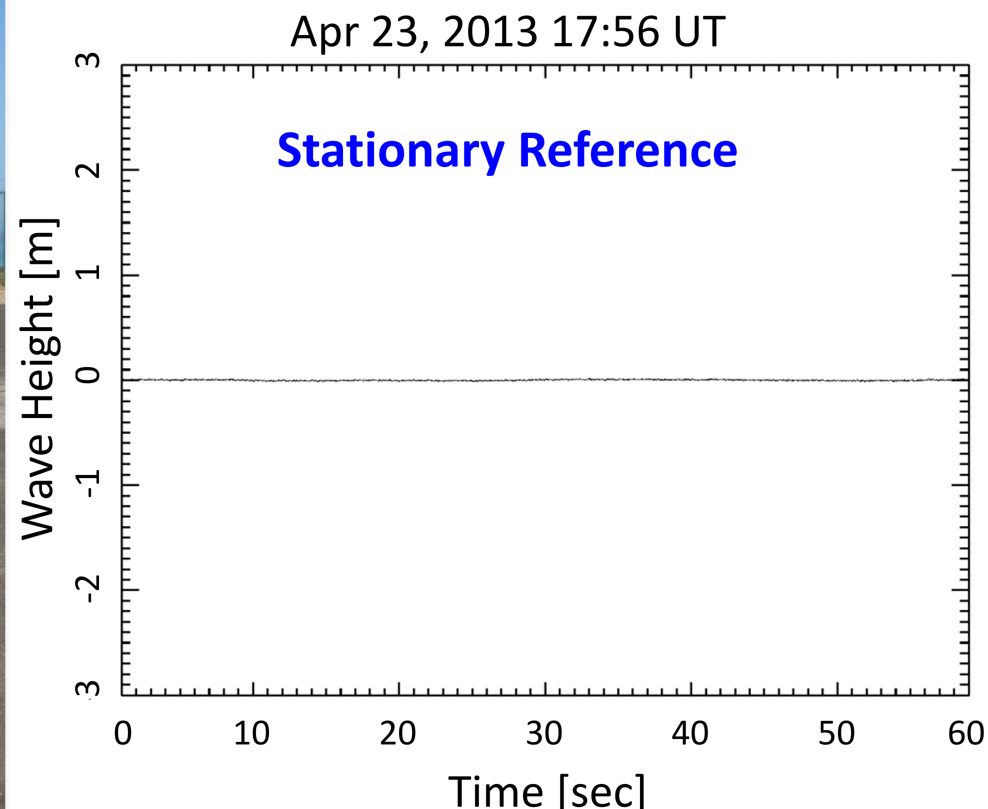
Additional Benefit: Wave Height

- Scintillation measurements require removing buoy motion

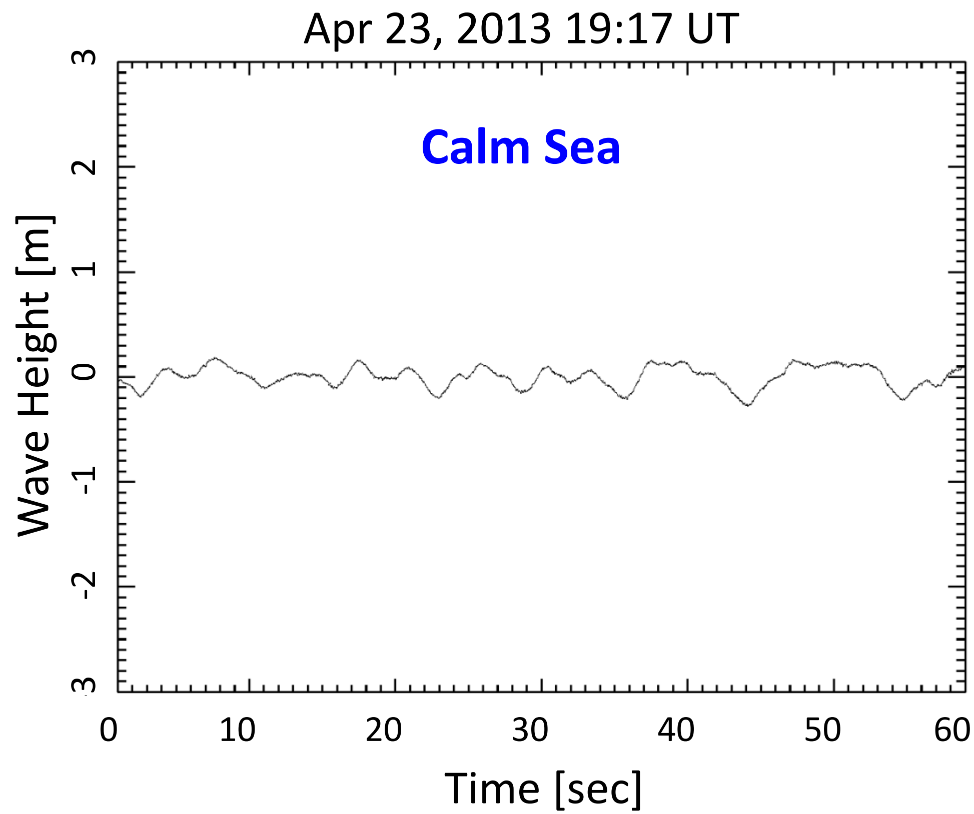
- The buoy motion is the sea state –

…GAMMA measures ocean waves too.

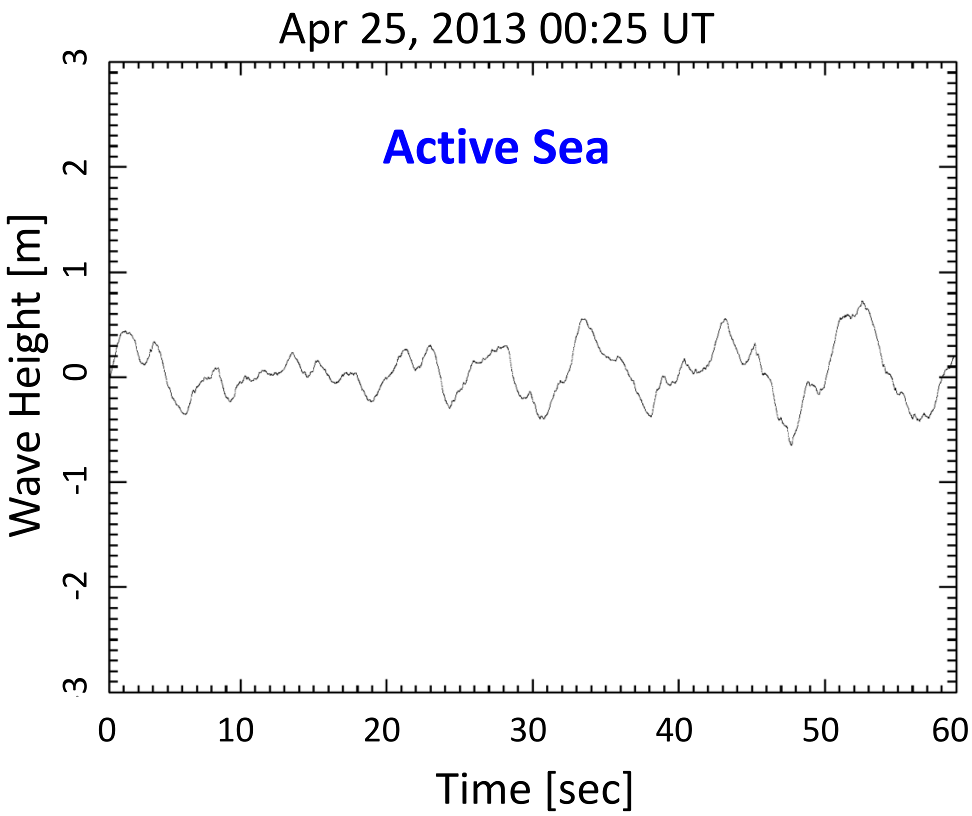
Initial Results from ASTRA Wave Height Algorithm



Initial Results from ASTRA Wave Height Algorithm



Initial Results from ASTRA Wave Height Algorithm



ASTRA's GAMMA receiver on a buoy:

- Can make sea state measurements in remote locations

- Can potentially provide early warning input to tsunami propagation forecasts

Concept for Real-time Ionospheric Monitoring Over Oceanic Regions

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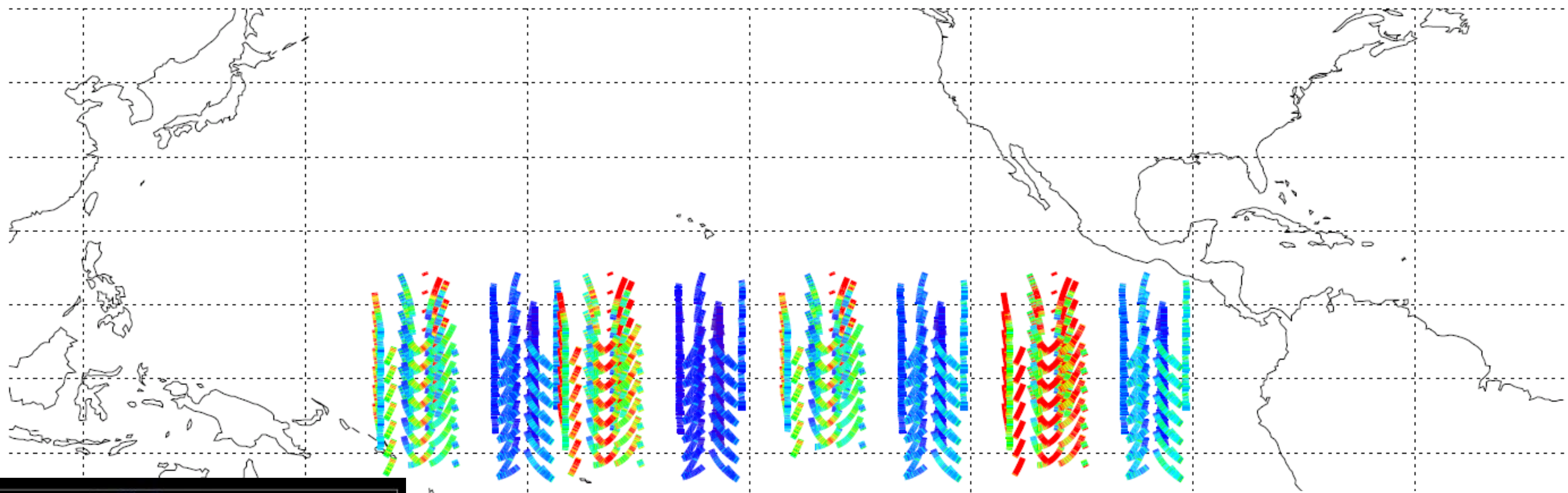
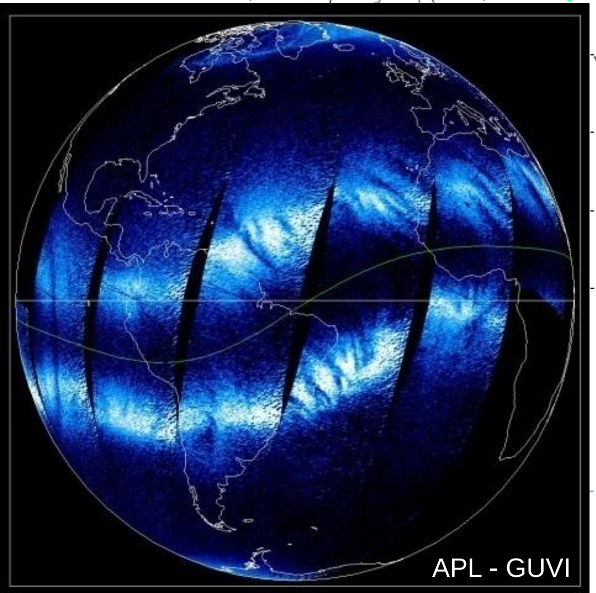
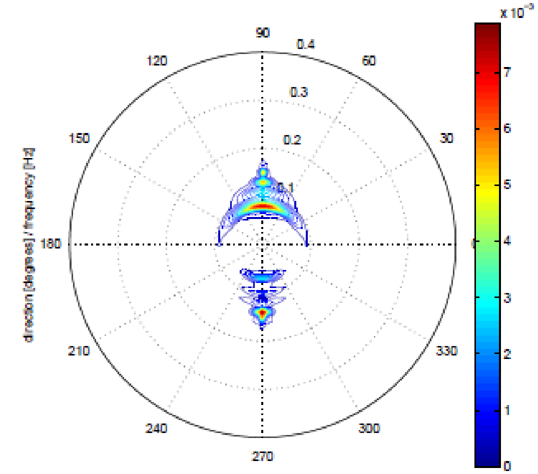






Directional ocean wave spectrum m^2s / deg

Wave Dynamics…
& Space Weather

Arctic PNT needs are demanding…

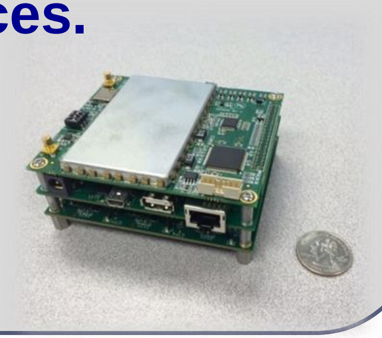
Oceanic operations need to know:
- Position
- Sea state

From a buoy

…or other moving platform

ASTRA GAMMA

Measures ionospheric error sources.



GAMMA also measures seas.

Pursuing Air Force SBIR follow-on funding through Com. Readiness Program (CRP)

Contact us ASAP to participate

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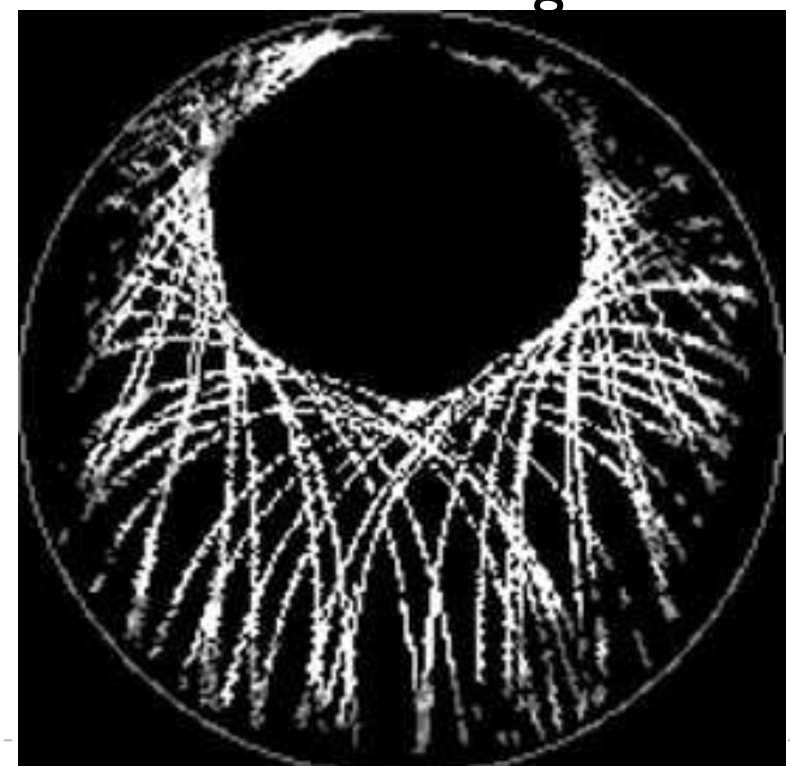
Backup Slides

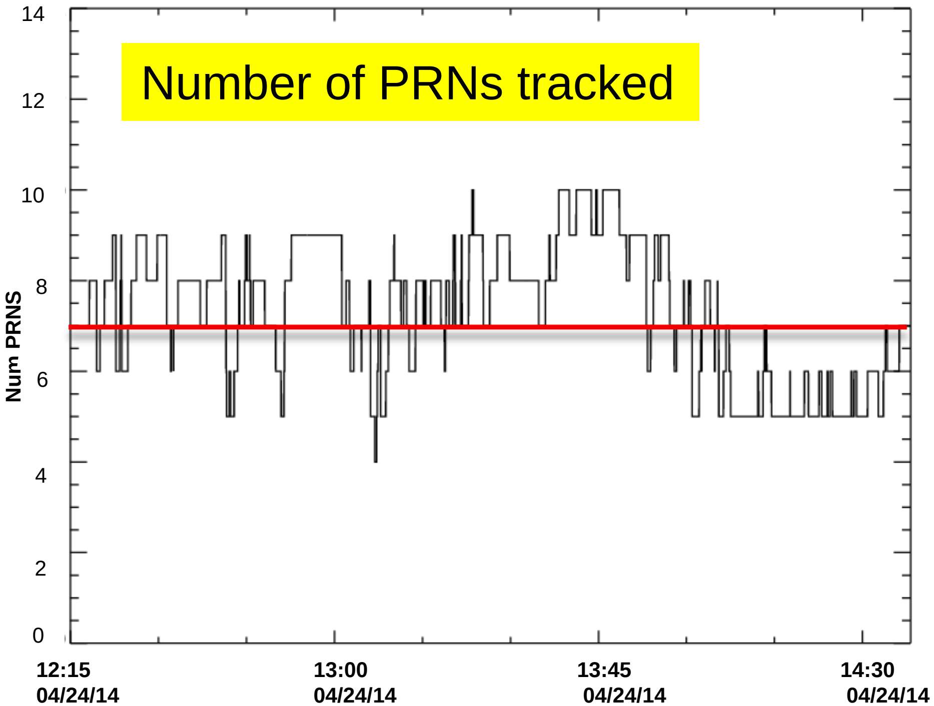
Consequences of a 55º Inclination

- From high latitudes, all satellites relatively low on the horizon even Glonass
- Must look through "thick"



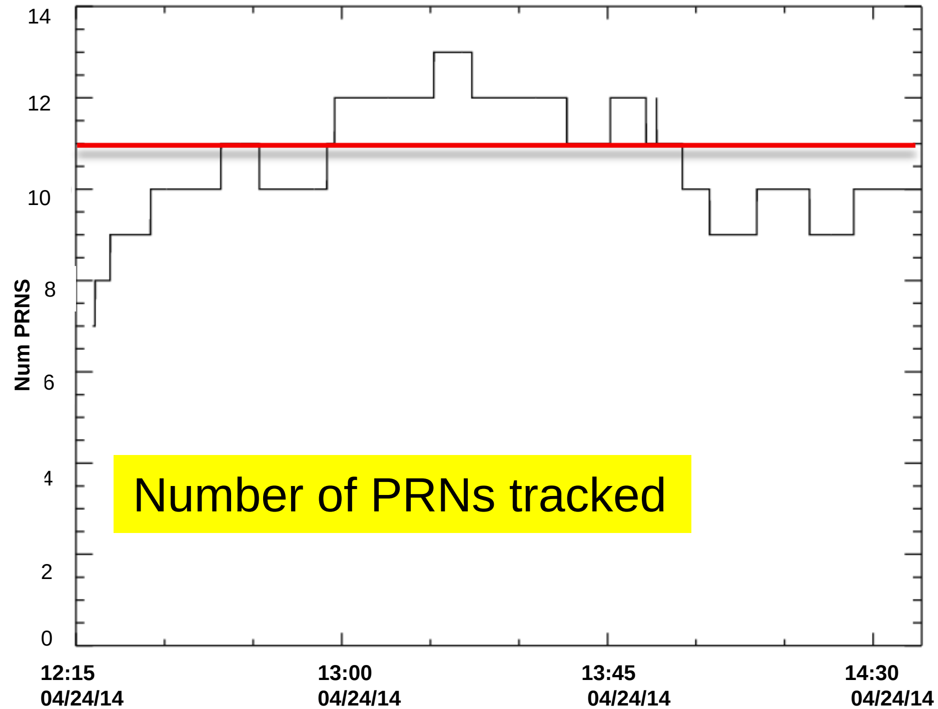
GPS Acquisition Strategy

Set 52



- EML chip spacing = 0.1
- PLL bandwidth = 7.5 Hz
- DLL bandwidth = 0.1 Hz

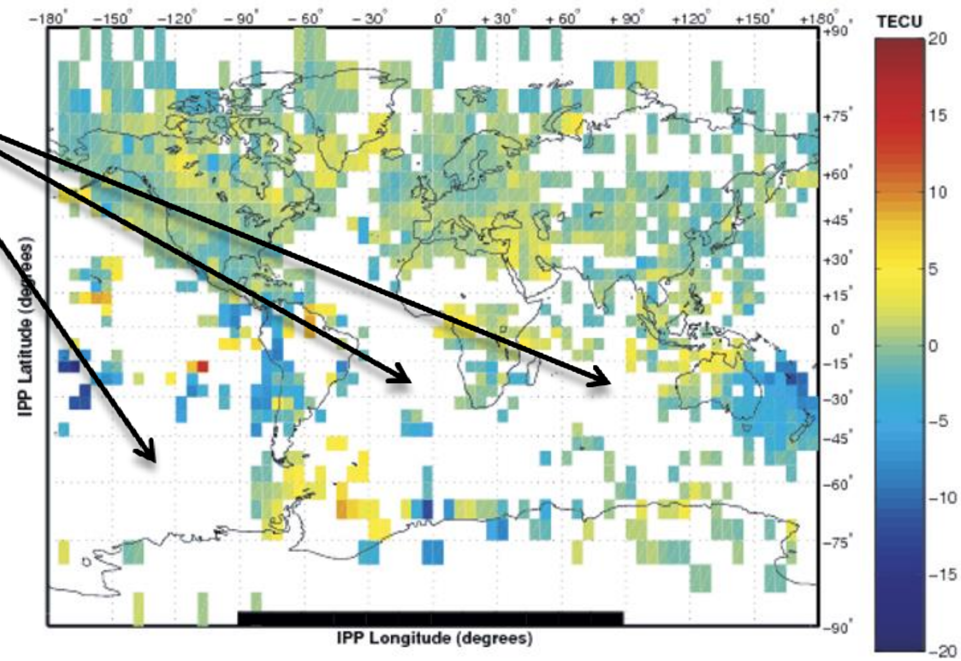
Set 83



- EML chip spacing = 0.1
- PLL bandwidth = 40 Hz
- DLL bandwidth = 0.05 Hz

Motivation

- **Ionospheric variability can have a significant impact various RF systems, including communications, navigation, and surveillance operations.**
- **Lack of data from oceanic regions hinders our ability for global ionospheric specification and scintillation forecasting.**
- **Traditional ground-based ionospheric monitoring systems have not permitted coverage of large ocean areas or on-demand theater coverage.**



- **Technology Need**
  - ➢ **Inexpensive, lightweight, low-power, and robust ionospheric monitoring system that can fill data gaps in coverage.**

Summary

- Existing GPS receivers are not able to provide ionospheric TEC and scintillation measurements from mobile platforms
  - Requirements for different PLL and DLL bandwidths than usually used on static systems
- We have developed a software GPS receiver with the capability to dynamically change receiver bandwidths based on the sea state
- New algorithm to calculate phase scintillation and remove antenna motion
- 3 successful field tests (Hawaii and Peru)
- Multi-day tests supported by ground instrumentation
- Validated TEC and phase scintillations measurements from ground GPS receivers
- Upcoming field tests in May and June (Hawaii and Australia)