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

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September 15, 2015

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

3 hour sigma phi map from CASES SM-211
Mar 18, 2013 9-12 UT

Active Conditions

quiet Conditions

http://cases.astraspacenet
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.
“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 health status
- Ground link via Iridium or cell towers.
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
- 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
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
Validation against Land-based Receivers

With Motion Correction

Validation against Land-based Receivers

Without Motion Correction

Large Apparent Sigma-phi

True Sigma-phi

Sigma_phi from nearby ASTRA Rx

MKEA ROTI

Mauna Kea CORS GPS (25 miles from the Wave Glider)
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 $\sigma_\phi$ increase measured by the ground-based GAMMA receiver in Lima at the same time.
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.

Traditional Processing

Augmented Dynamic Receiver Processing
- 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

Wave Height [m]

Stationary Reference

Apr 23, 2013 17:56 UT

Time [sec]
Initial Results from ASTRA Wave Height Algorithm

Calm Sea

Wave Height Algorithm

Wave Height [m]

Time [sec]

Apr 23, 2013 19:17 UT
Initial Results from ASTRA Wave Height Algorithm

Wave Height [m]

Time [sec]

Active Sea

Apr 25, 2013 00:25 UT
Potential Real-Time Applications

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

Directional ocean wave spectrum

APL - GUVI

Bringing It All Together
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
Backup Slides
GPS: Consequences of a 55° Inclination

- From high latitudes, all satellites relatively low on the horizon even Glonass
- Must look through “thick”
GPS Acquisition Strategy

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

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

Number of PRNs tracked
Motivation

- Ionospheric variability can have a significant impact on 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)