Air Force Research Laboratory

Novel Techniques for the use of GNSS Radio Occultation for Specification of the Ionospheric Scintillation Environment

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SCIENCE & TECHNOLOGY

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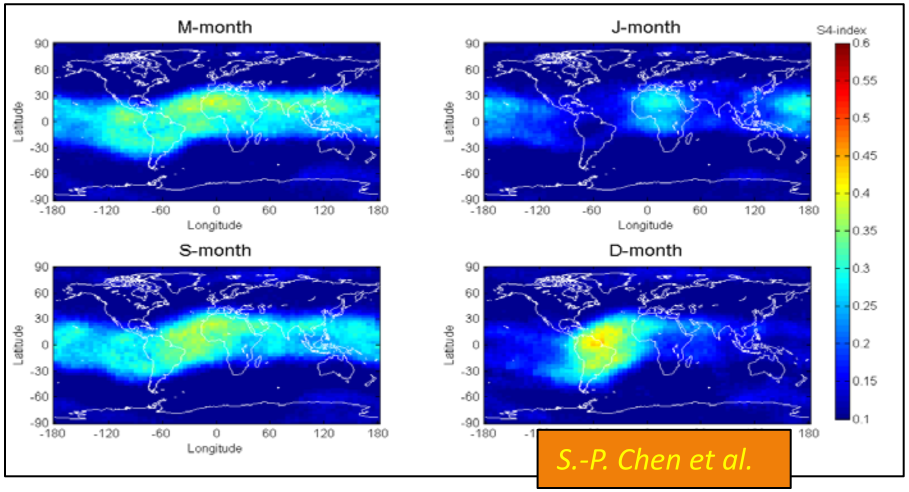
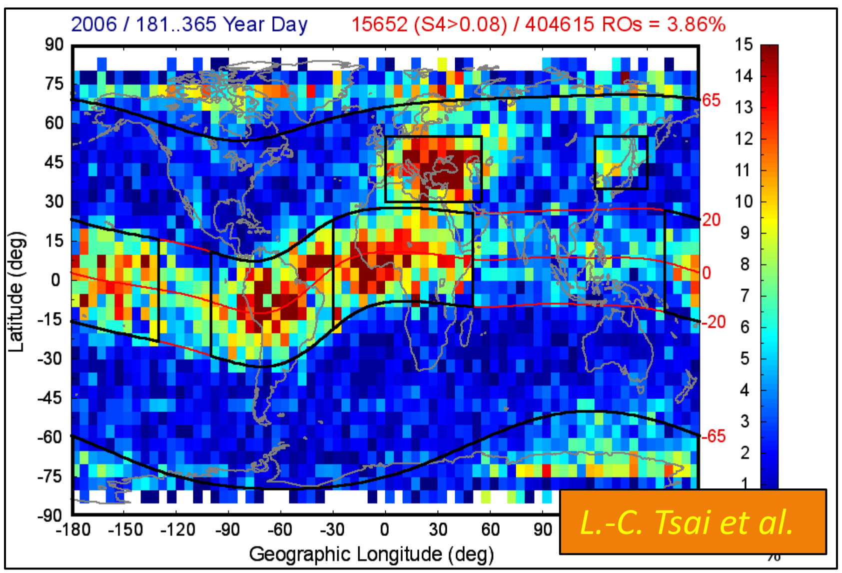
GNSS RO for Scintillation Environment Specification

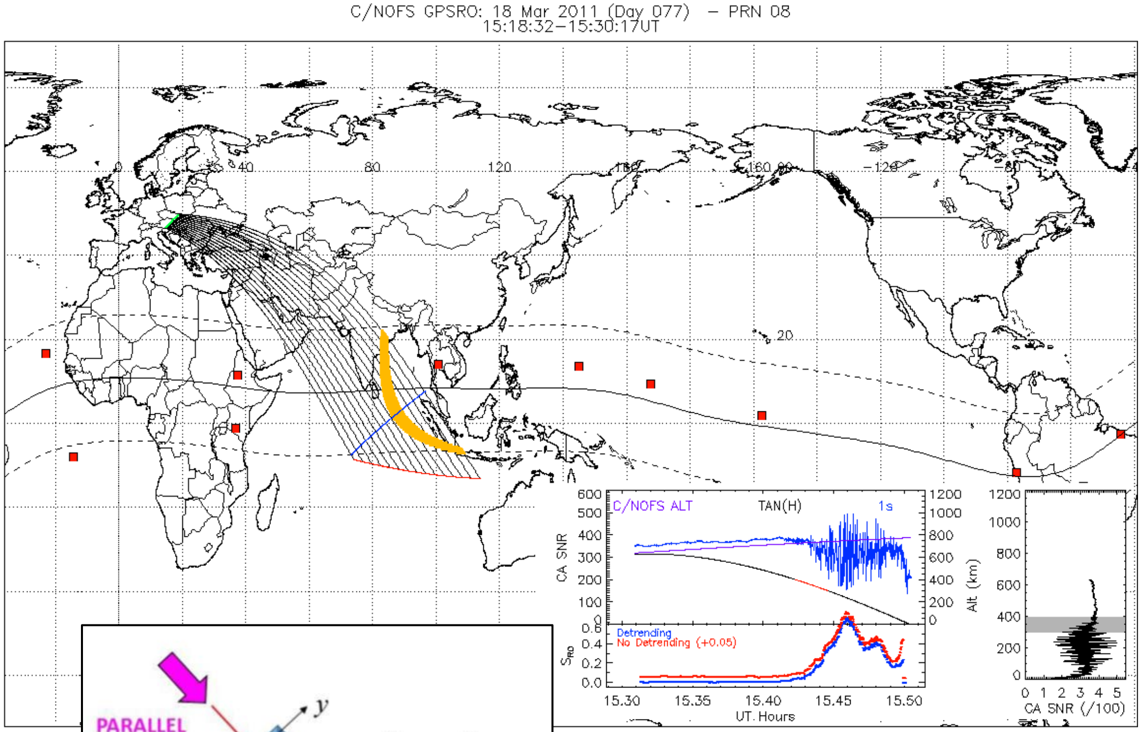


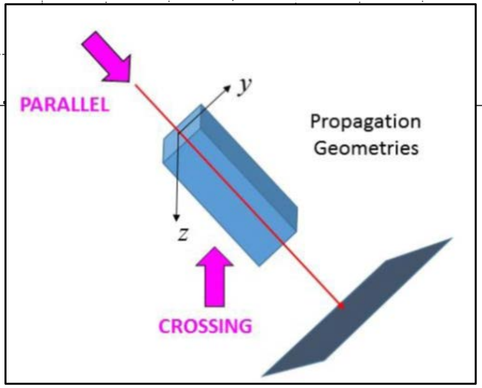


- A number of studies have demonstrated the use of GPS RO measurements from LEO satellites to map the global distribution of scintillation
- Typically, these studies associate the scintillating regions with the occultation **Tangent Point**
  - ✓ Often a single value for the TP at a specific altitude (350km) is used to characterize the event
- Comparisons with ionospheric models, *in-situ* measurements, and/or ground-based observations have shown that these techniques represent the climatological global distribution of scintillation reasonably well

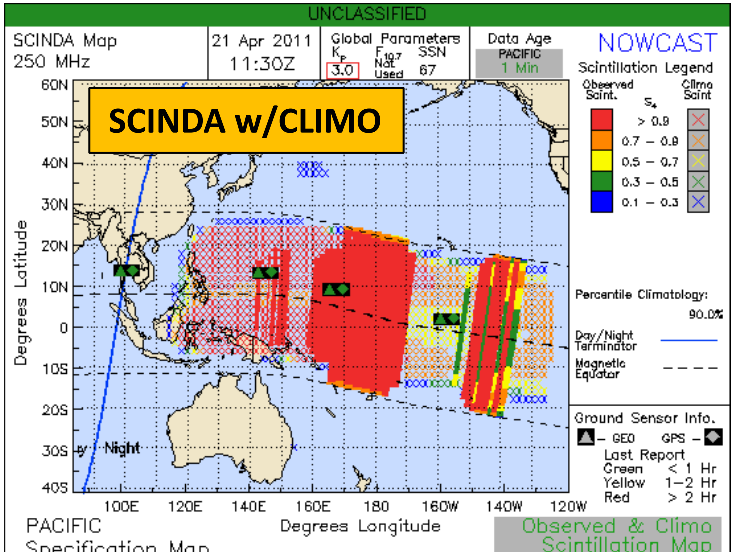
GNSS RO for Scintillation Environment Specification

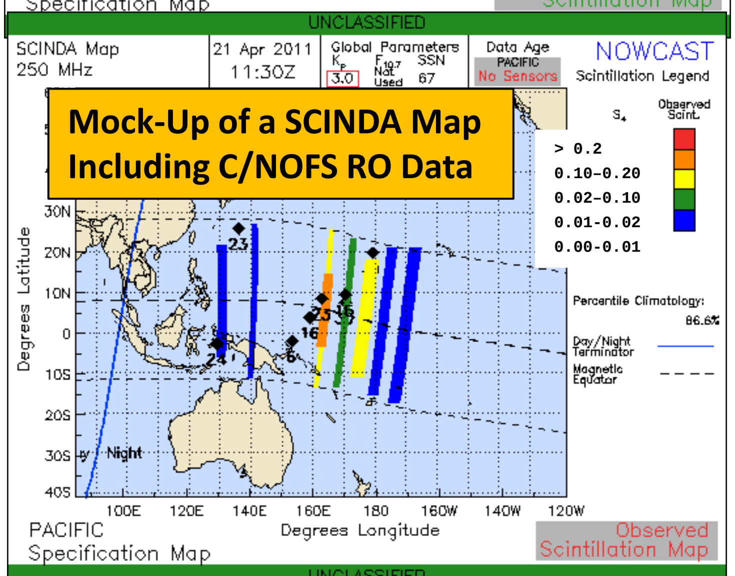
- Accurately geolocating the scintillating regions is a complex task due to…
  - ✓ The long slant paths over which the RO events are observed
  - ✓ Multiple pierce points through the F-Region ionosphere
  - ✓ Potential for interaction with multiple turbulent structures
  - ✓ Varying propagation geometry with respect to **B**





Why Do We Care?





Primary Objective:
Ground-based sensors provide first-hand knowledge of the local scintillation environment but coverage is limited due to geographical considerations.
Can we fill in the gaps providing global coverage with RO?

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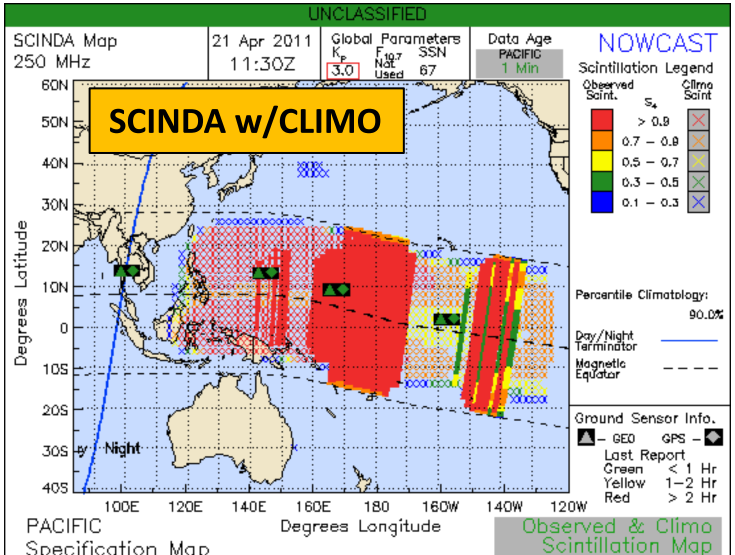

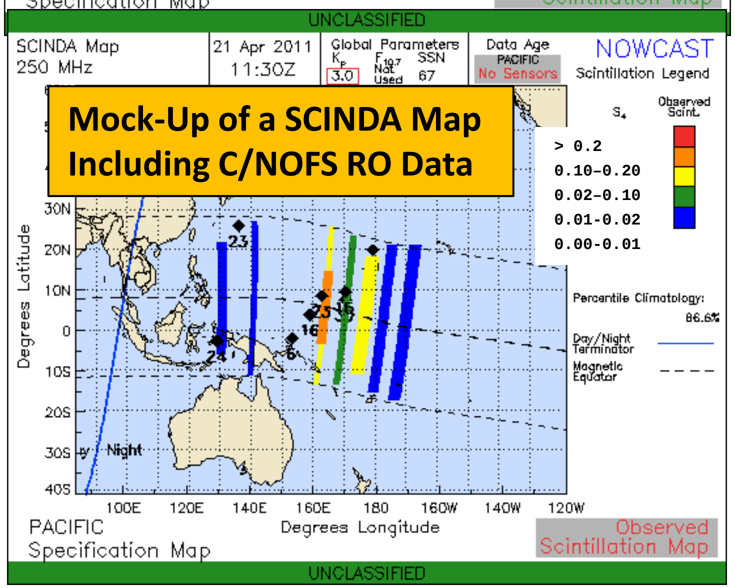

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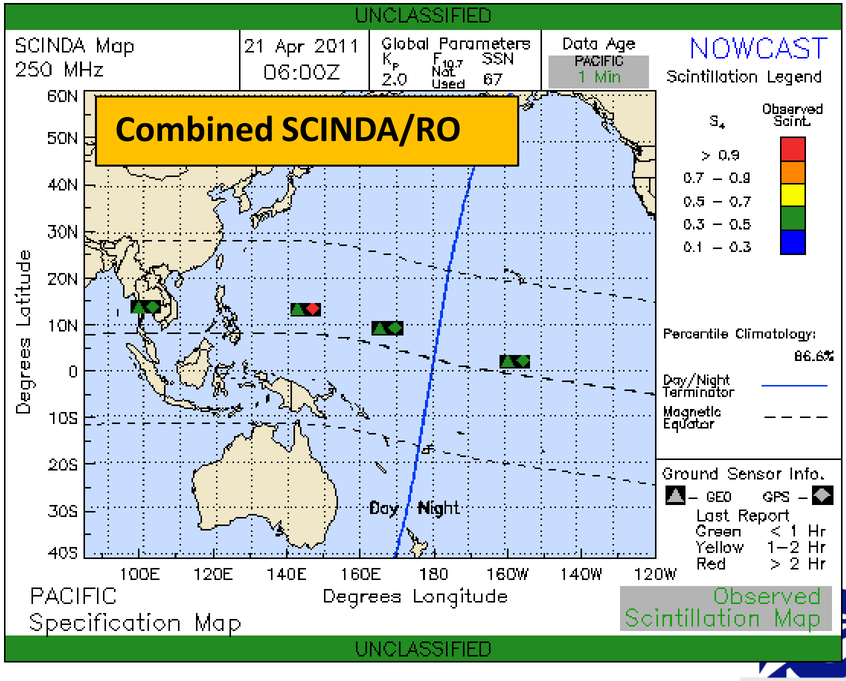
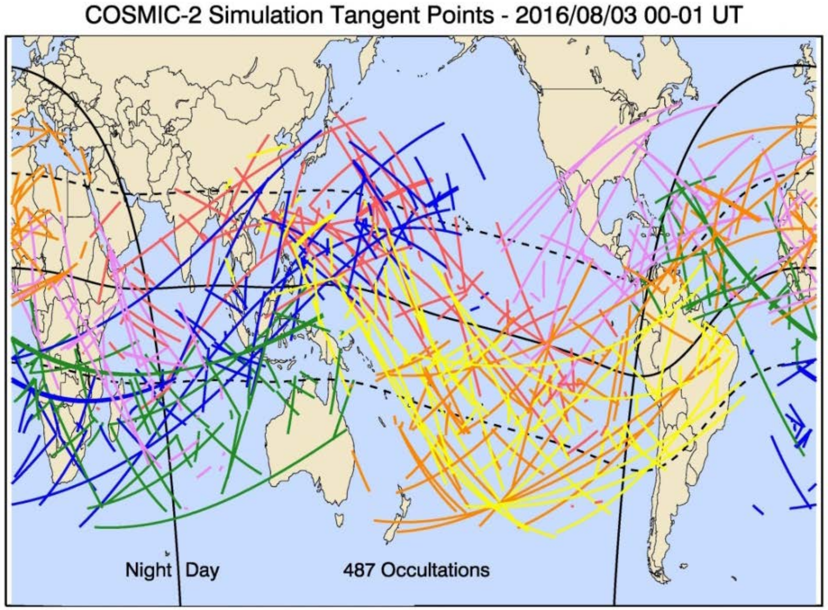
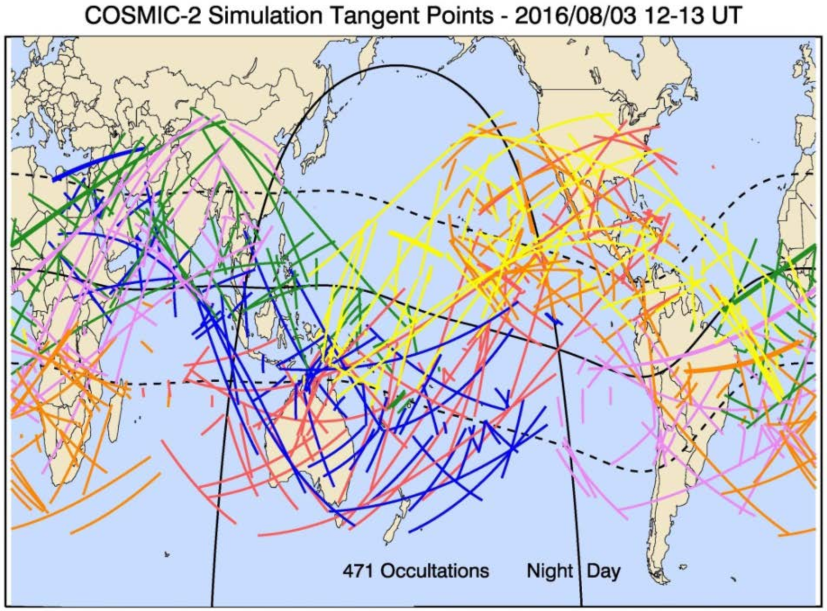


COSMIC-2

Global Occultation Coverage for two different hour periods with COSMIC-2 (includes GLONASS)





<u>COSMIC-2</u>

- **6 satellites**
- **Multi-GNSS capabilities**
- **Fore & Aft sensors**

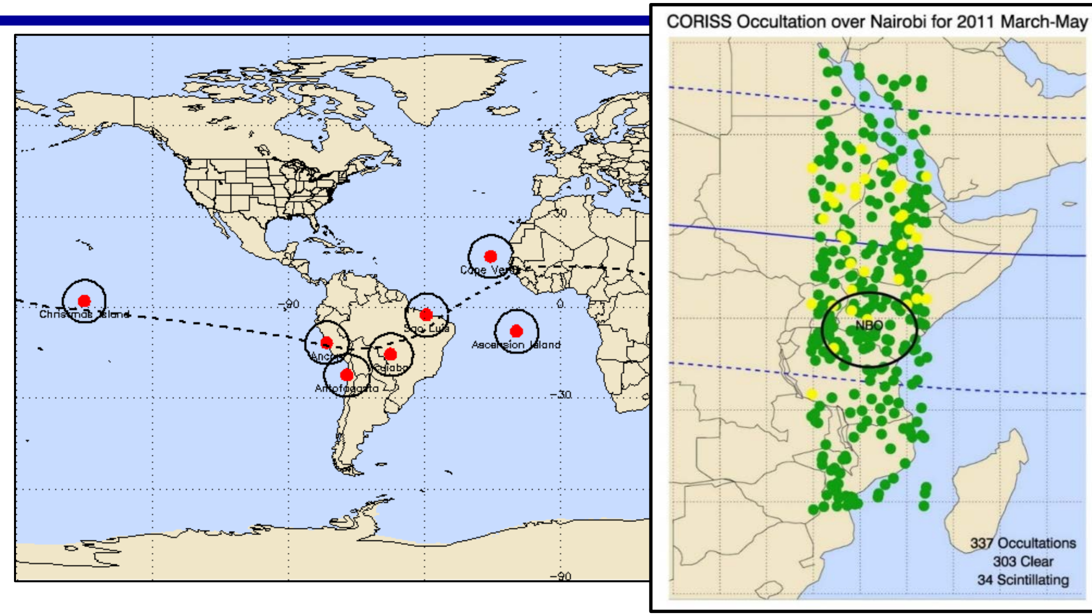
Significant expansion of coverage compared with C/NOFS

Multi-Phased Approach

1. Statistical Tangent Point Analysis (TPA) Study
2. Parameterized Constraint Analysis (PCA)
   – Quantify empirical & physical constraints that can be imposed on RO data sets
3. Irregularity Parameter Estimation (IPE)
   – Minimization technique to fit observations to model spectra
4. Back-propagation
   – Propagate high rate complex signal backwards in time to minimize amplitude fluctuations and determine effective phase screen location
   – Requires continuous hi-rate phase
5. Configuration Space Model
   – Addresses continuously changing propagation with respect to **B** and propagation parallel to **B**, not currently included in phase screen theory

Statistical Tangent Point Analysis

- **CORISS**
  C/NOFS Occultation Receiver for Ionospheric Sensing and Specification
- **SCINDA**
  AFRL Scintillation Network Decision Aid (VHF & GPS)



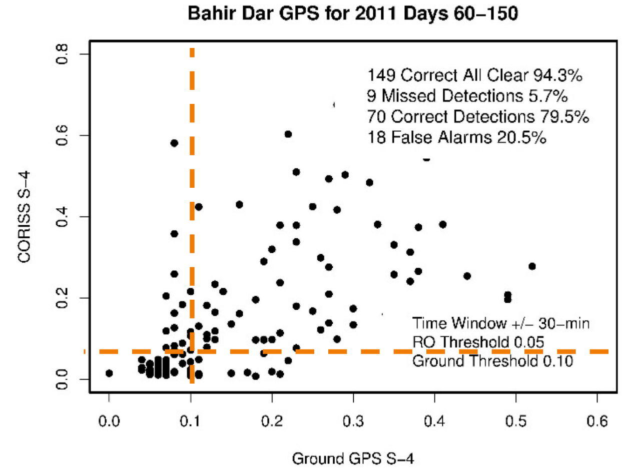
- Identified available high-rate (50 Hz) data sets from C/NOFS CORISS sensor and selected ~90-day periods in 2009 and 2011 for comparison of scintillation observations with VHF & GPS data from SCINDA ground stations

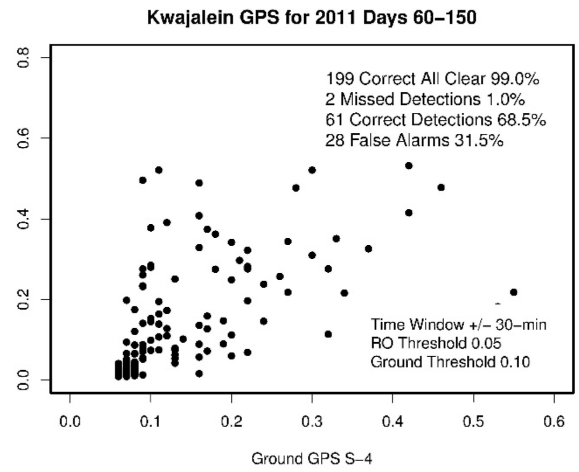
- Developed a set of metrics for comparison of space-based and ground-based data sets
  - ✓ Scintillation intensity thresholds
  - ✓ Spatial considerations (ex. 350 km TP within +/- 5^{o} of station)
  - ✓ Temporal considerations (ex. time window to allow for propagation)

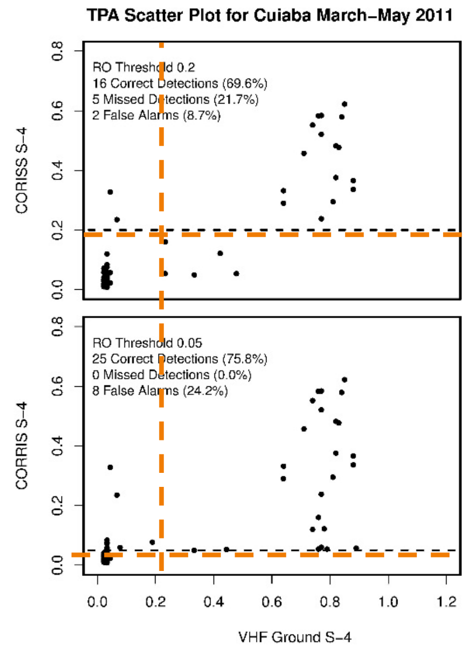
Statistical Tangent Point Analysis

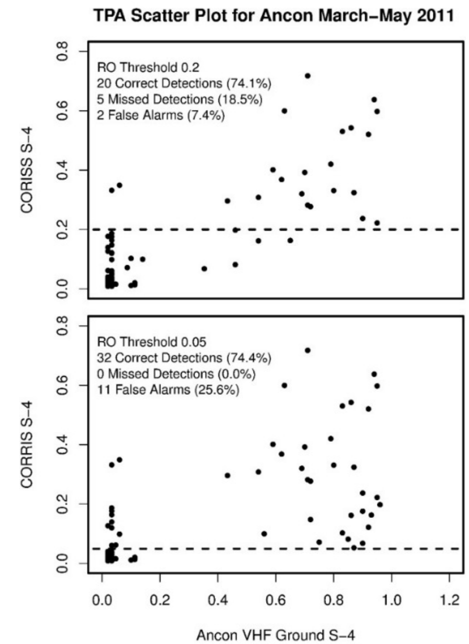
SAMPLE RESULTS

- S_4 Scatter Plots
  Ground-vs-Space
- Grouped into several categories
  - ✓ Correct All Clear
  - ✓ Missed Detections
  - ✓ Correct Detections
  - ✓ False Alarms
- Comparison with two SCINDA GPS stations (top)
- Comparison with two SCINDA VHF stations (bottom)
  - ✓ Top panels: RO Threshold high (strong scintillation only)
  - ✓ Bottom panels: RO Threshold low









TPA Summary for 2011 Period

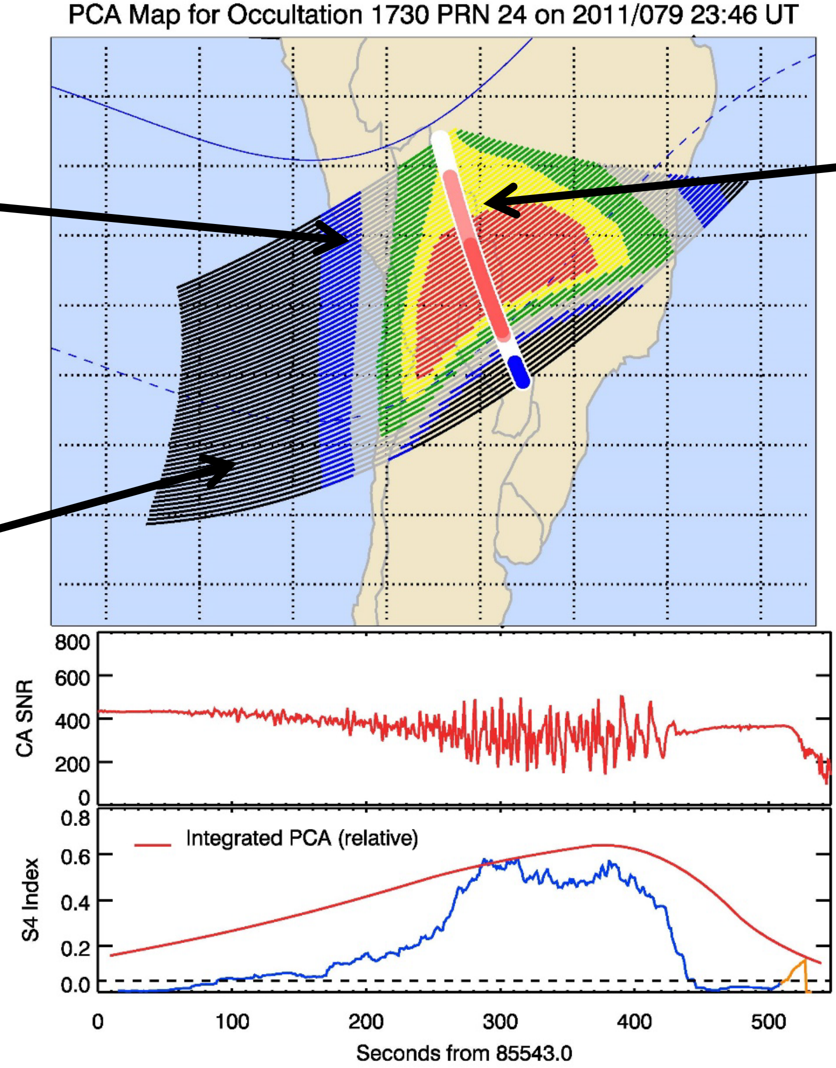
Station	Mag Lat	Missed Detections			False Alarms		
		VHF	GPS	Both	VHF	GPS	Both
Ancon	0.3°	5%	4%	3%	7%	21%	7%
Bahir Dar	3.4°	12%	6%	4%	46%	7%	0%
Kwajalein	4.2°	9%	3%	3%	25%	28%	17%
Guam	6.0°	6%	6%	4%	0%	11%	0%
Bangkok	6.2°	12%	6%	7%	0%	9%	0%
Cuiaba	8.0°	3%	1%	1%	6%	12%	6%
Nairobi	9.4°	5%	4%	2%	8%	7%	0%
Antofagasta	12.0°	6%	2%	1%	15%	31%	9%
Ascension Island	16.5°	3%	3%	2%	60%	47%	43%

- Criteria are ± 30 minutes and ± 5° in longitude from 350 km tangent point
- Missed detections refer to TPA not detecting scintillation observed on ground
- False alarms refer to TPA detecting scintillation not observed on the ground
- For most locations TPA provides 80-90% correct detection within 1-hr/10° boundaries from the tangent point; no quantitative equivalent S4 information

PCA Visualization Maps

Color-code shows quantitative probability value (e.g., red > 0.9, yellow > 0.75, green > 0.5)

The extent of each ray path below 1,500 km altitude



The white bar shows the tangent point; pink area shows region of enhanced RO S4 while blue indicates no S4 data.

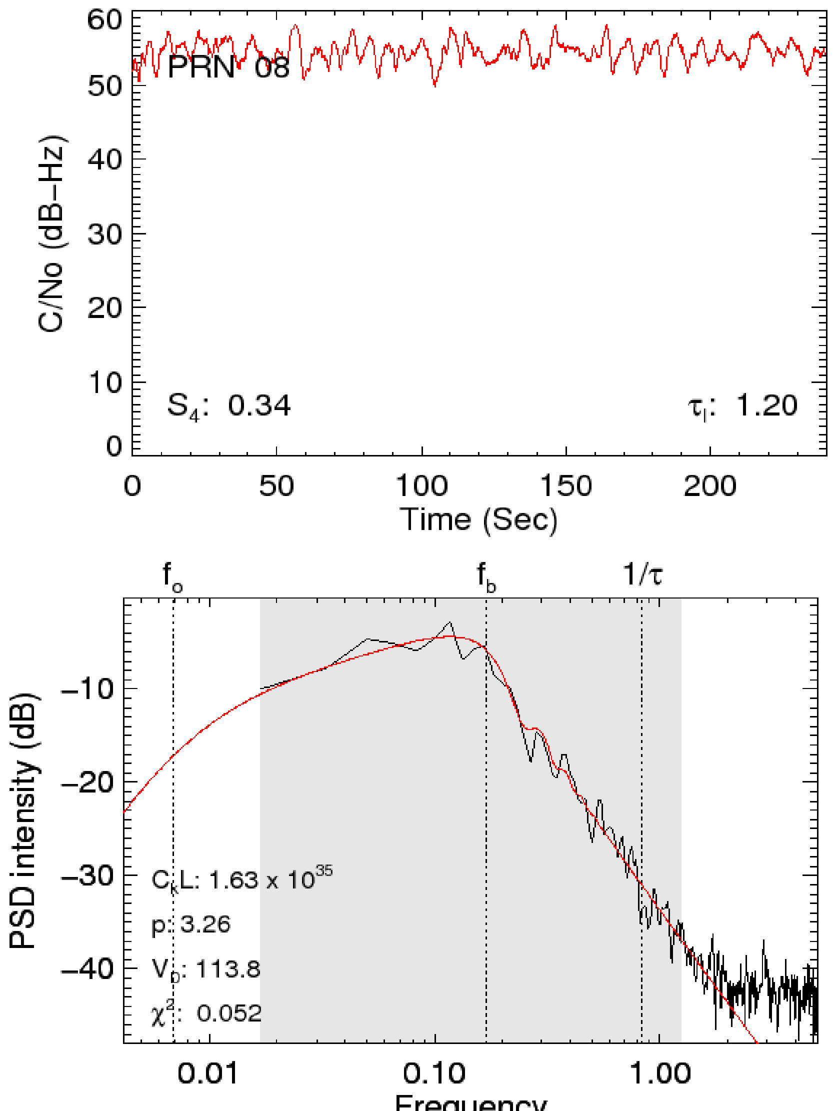
PCA quantifies the favorability for sampling irregularity regions for a given RO

Irregularity Parameter Estimation

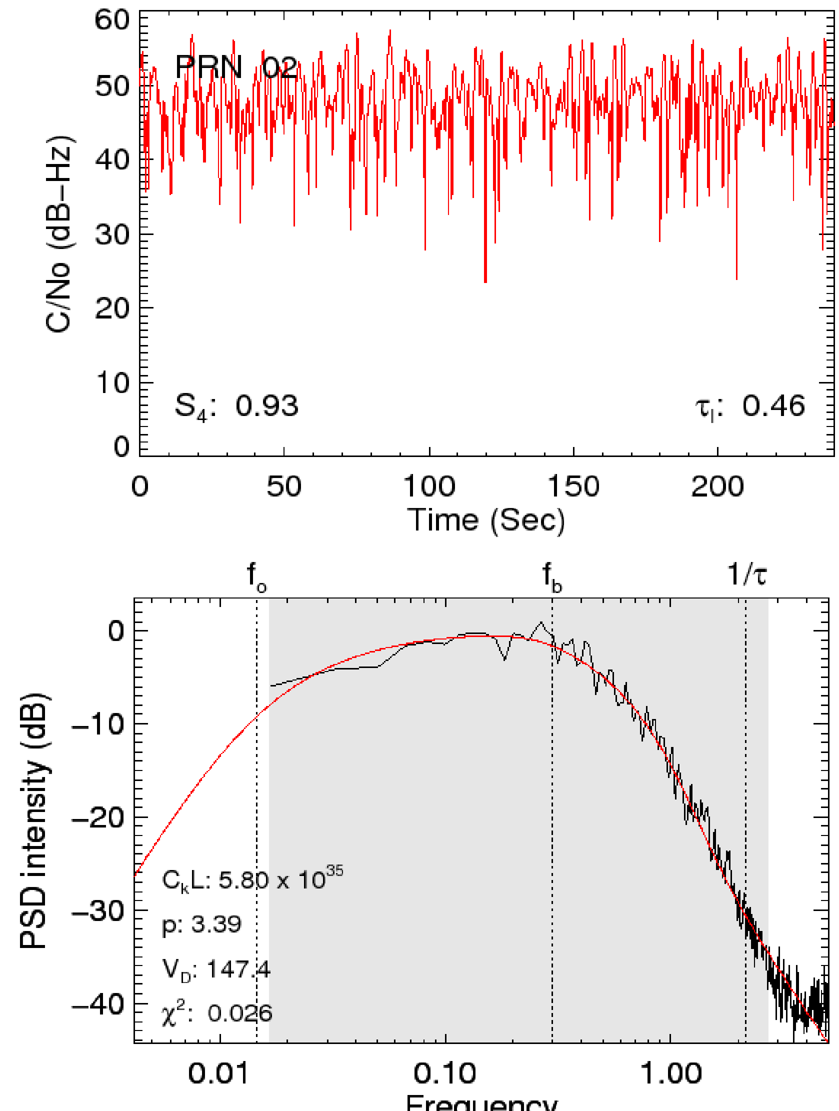
- Irregularity Parameter Estimation (IPE): Minimization technique to fit observations to model spectra to deduce irregularity amplitude and effective drift velocity
  - Requires only amplitude data
  - Model based on phase screen theory; geometry impacts accuracy
  - Applied to case studies; initial results promising but routine performance characteristics currently unknown

Two Examples of IPE Analysis

Weak Scatter Example

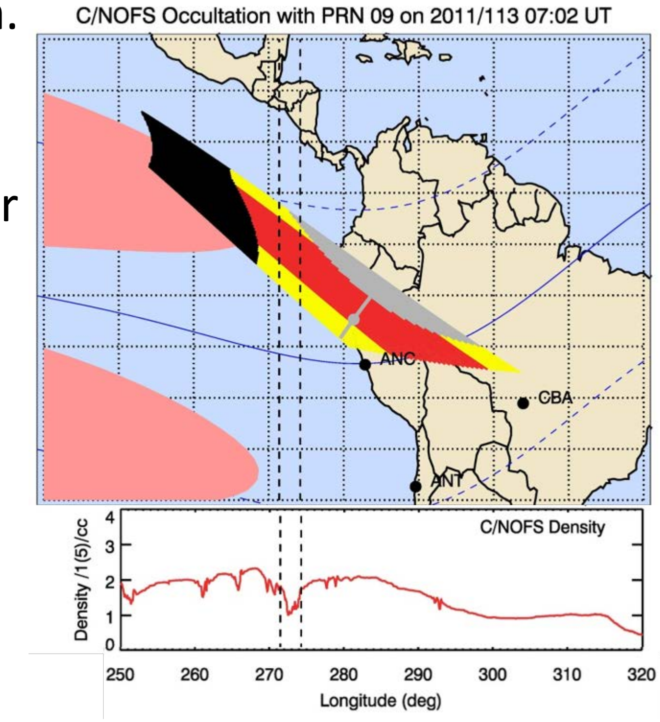


Strong Scatter Example

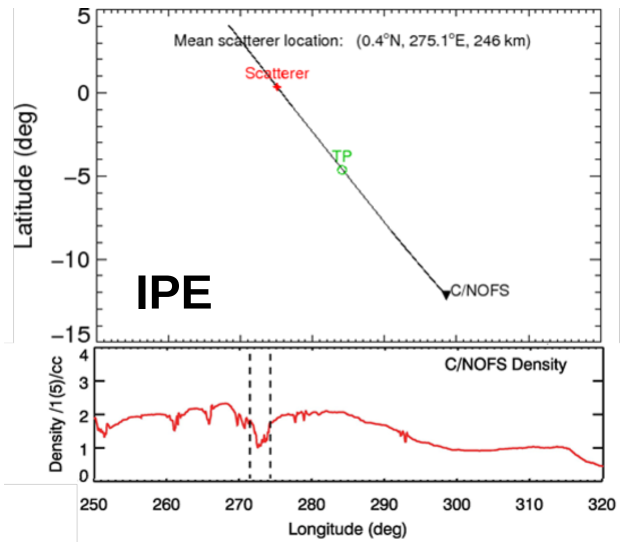


Statistical Tangent Point Analysis

- Case Study: **FALSE ALARM**
- Example:
  - ✓ Scintillation detected on RO event over South Am.
  - ✓ Scatterer at any location along RO path link (red)
  - ✓ Tangent Point (gray) maps to longitude if ANC
  - ✓ Comparison with *in-situ* densities from PLP sensor indicate scatterer is > 10° to the west
  - ✓ Test using **IPE Technique** confirms



> 1,000 km error in geolocation with TP



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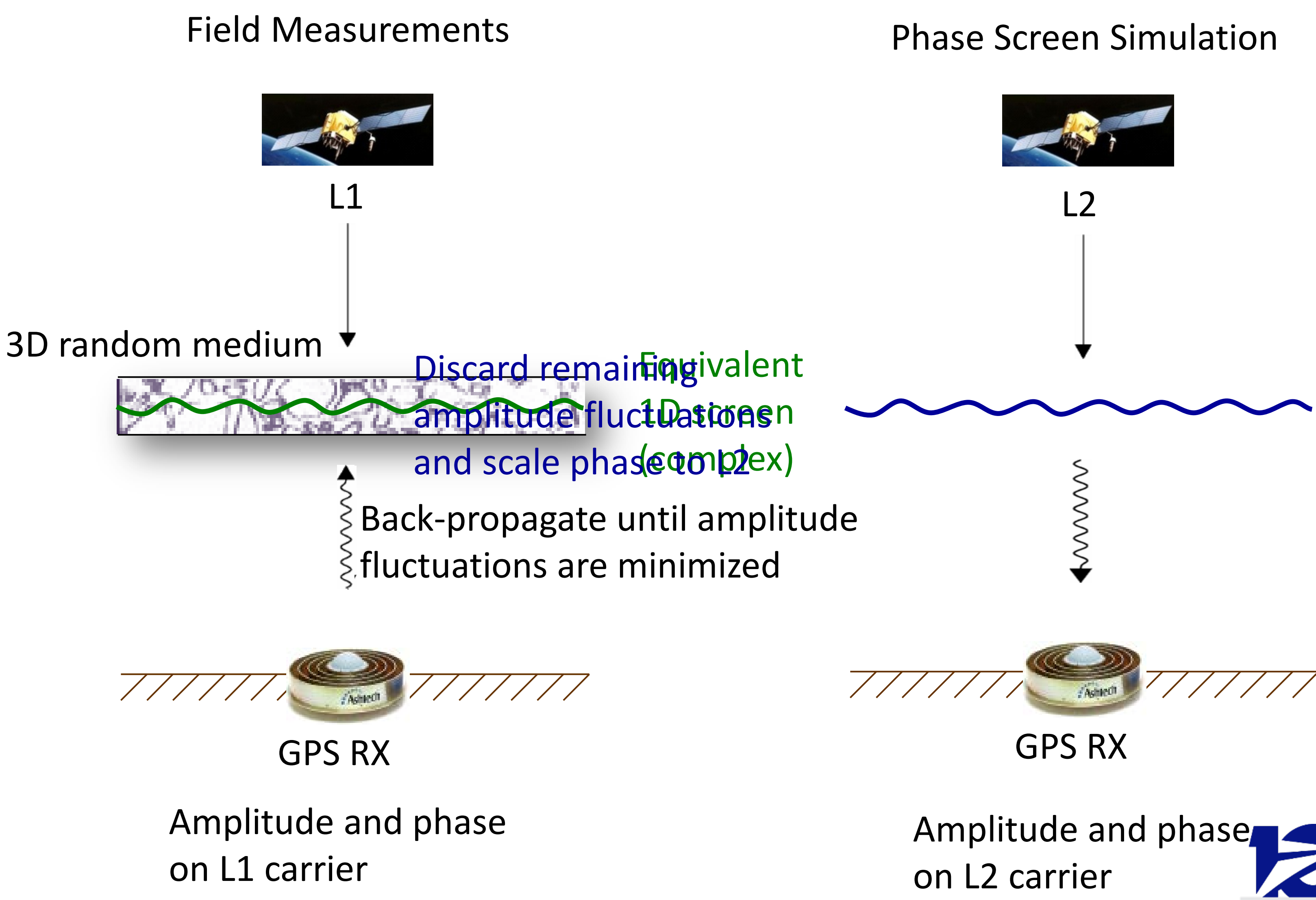
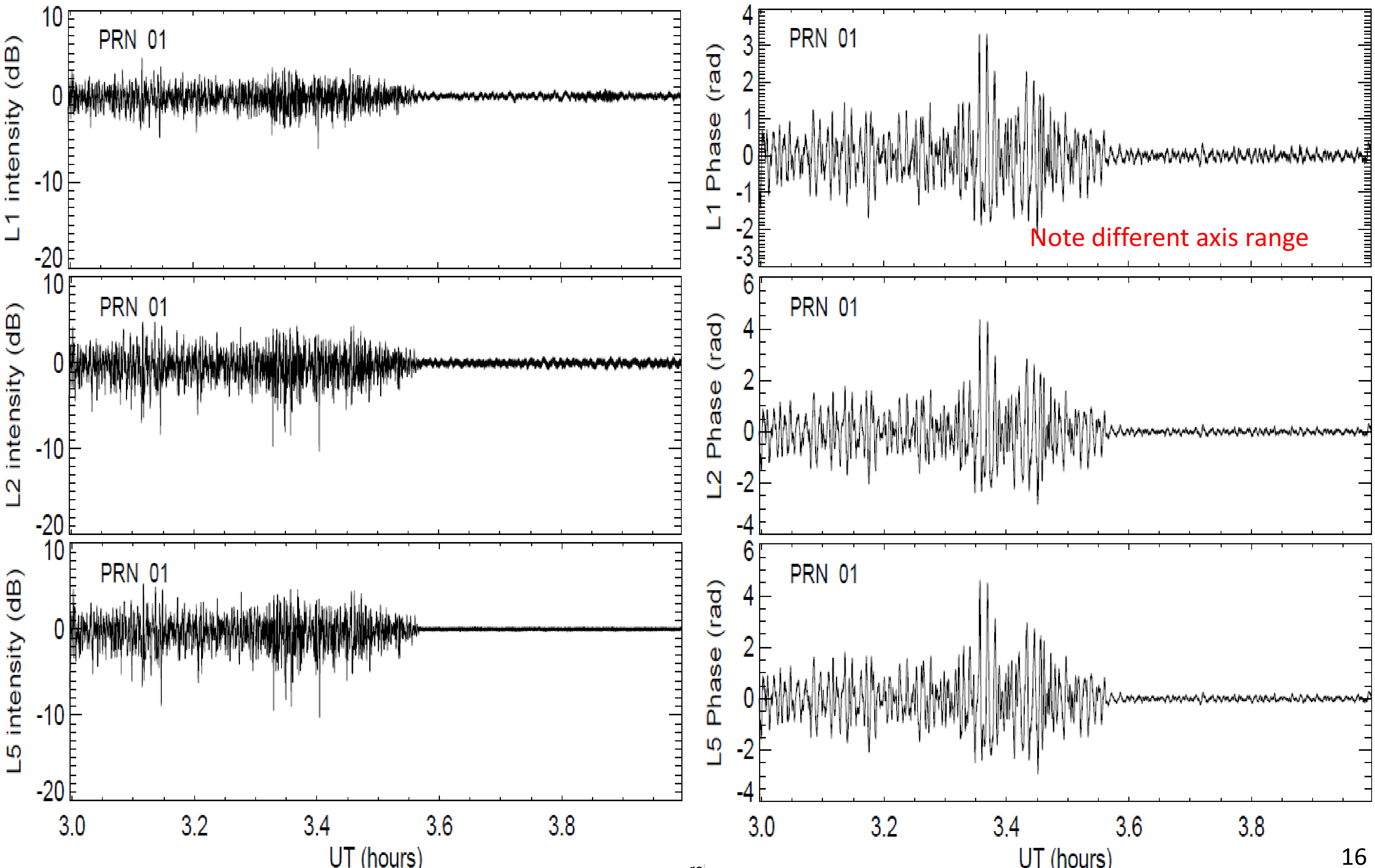
Inverse Diffraction Method: Back Propagation



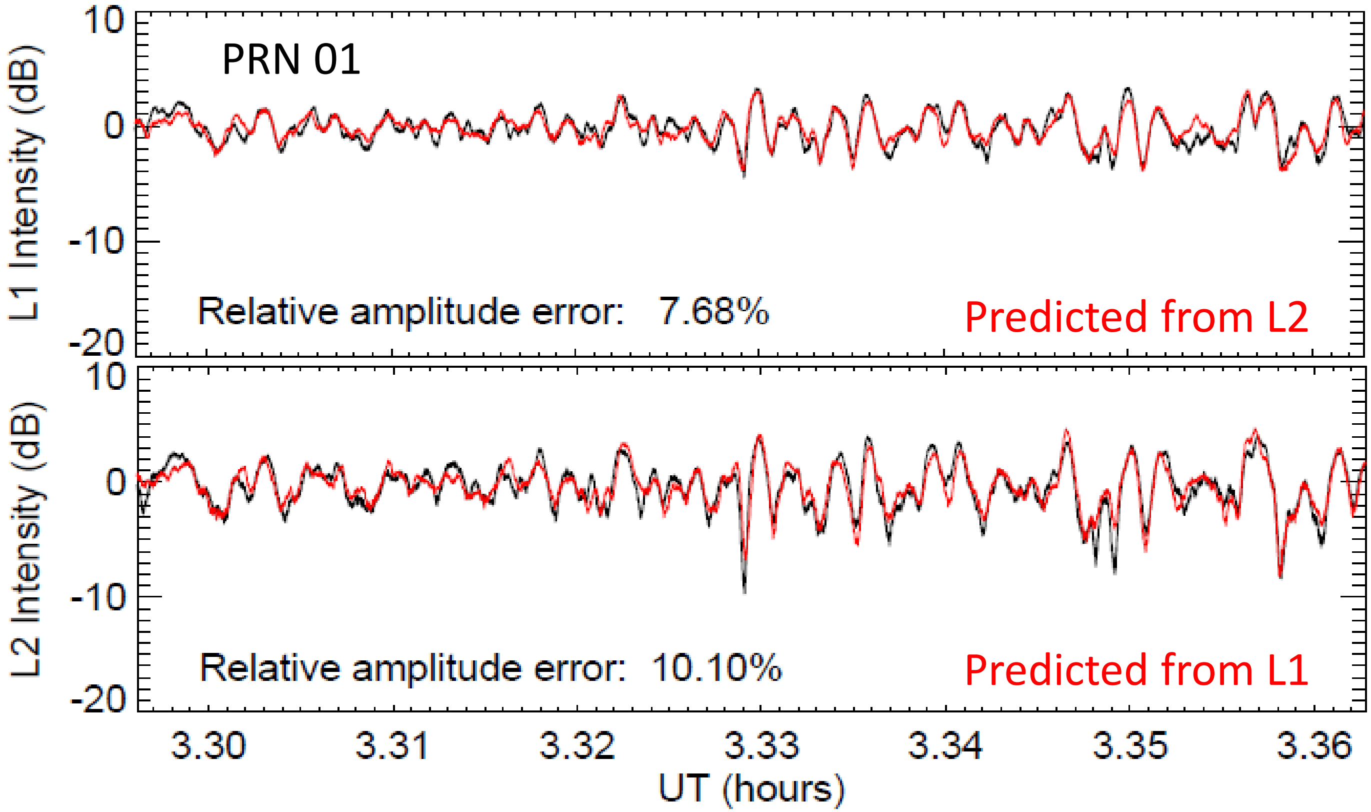
2013 Day 052 – PRN 01

Example using actual GPS data



2013 Day 052 – PRN 01

Black – measured, Red - Predicted



Technique can be applied to GPS RO

Questions

In the next paper, *McNeil et al.* will expand on the use of the PCA toward the development of an ALL-CLEAR forecasting tool