The use of an HF data assimilative optimization of a physics based model of TIDS

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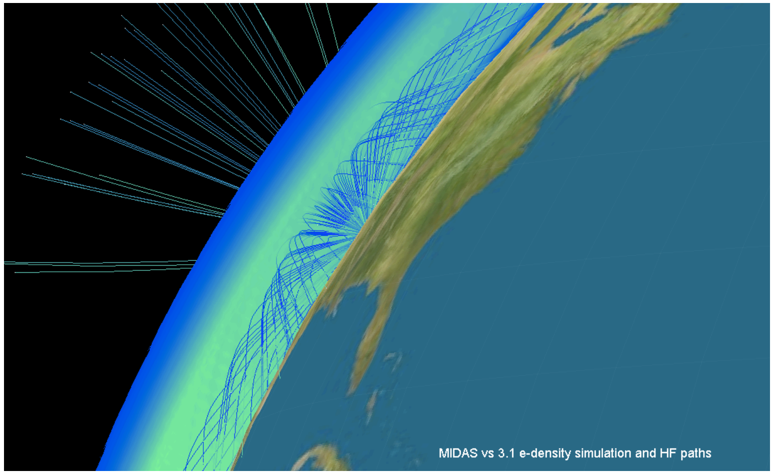
Introduction

What is HF geolocation?



When is HF geolocation difficult?

When the ionosphere departs from the 'norm' which happens:

- *Most of the time in the auroral and polar regions* where the concept of normal behavior is inappropriate
- *Some of the time in the equatorial regions* where the ionosphere can be very structured particularly in the post-sunset hours
- *Some of the time in the mid-latitudes* where storm events or waves or sporadic E are not well characterized in real-time models

Introduction

Why not just use an empirical model of the ionosphere?

Because you don't always have a long time to average and empirical models are excellent for *climate* but not for *weather* – i.e. they are not great at what is happening right now

So:

<u>All of the problems are amplified as you move to shorter timescales (i.e. seconds to minutes) and cannot average the ionosphere out</u>

Can ionospheric data assimilation help?

Yes but it is not as straightforward as conventional data assimilation, particularly in the case of TIDs, and that is what this talk is about

Approach

- Build upon the extensive knowledge of what works and what does not work in ionospheric tomography and data assimilation
- Use all available observations over any time period to specify the ionosphere at the time-resolution required by the geolocation
- Keep focused on the problem – the best possible electron density specification for HF

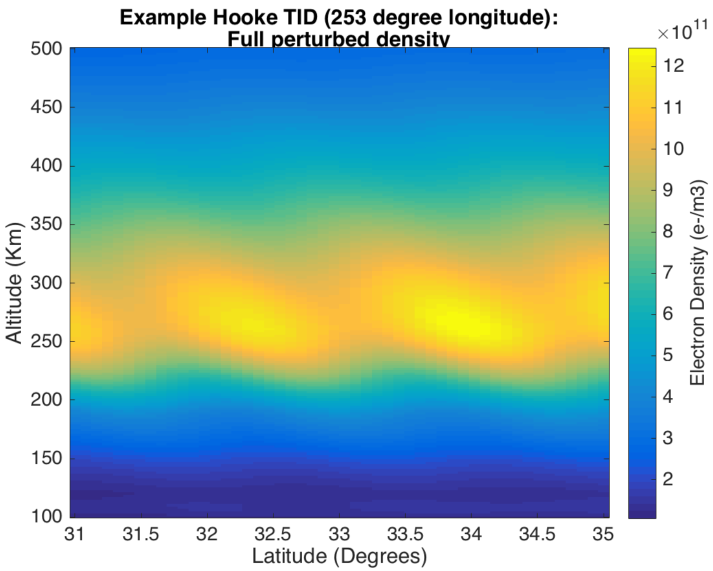
- Assimilative model: Hooke TIDs
- Use state-of-the-art US-developed ionospheric ray-tracer ***Strider***
- Optimization data: HF signals of opportunity
- Evaluation of success: compare to empirical model alone and to SSL

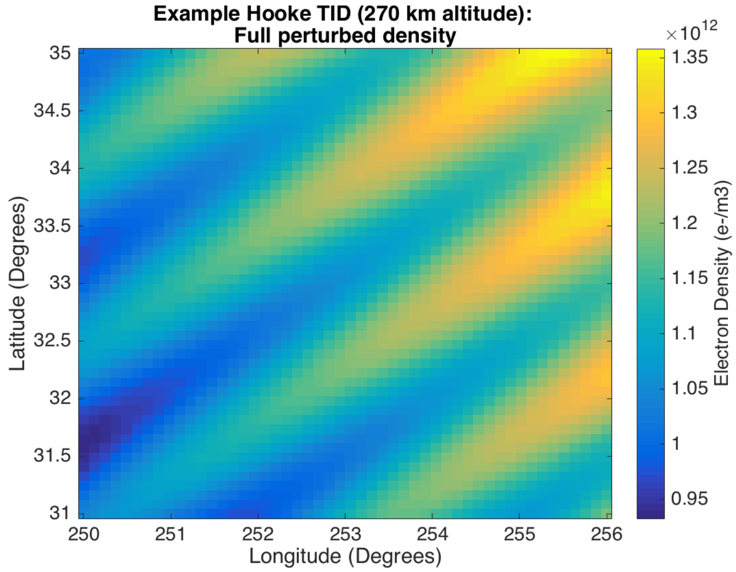
Approach

Hooke TID model example:
- Horizontal wavelength 160 km
- Wave direction (horizontal) southeast
- Vertical wavelength 200 km
- Amplitude 7 m/s along magnetic field

Why use a model of the TIDs rather than simple tomography?
- Physical model of TID
- Extends in space and time
- Only adjust a few model parameters

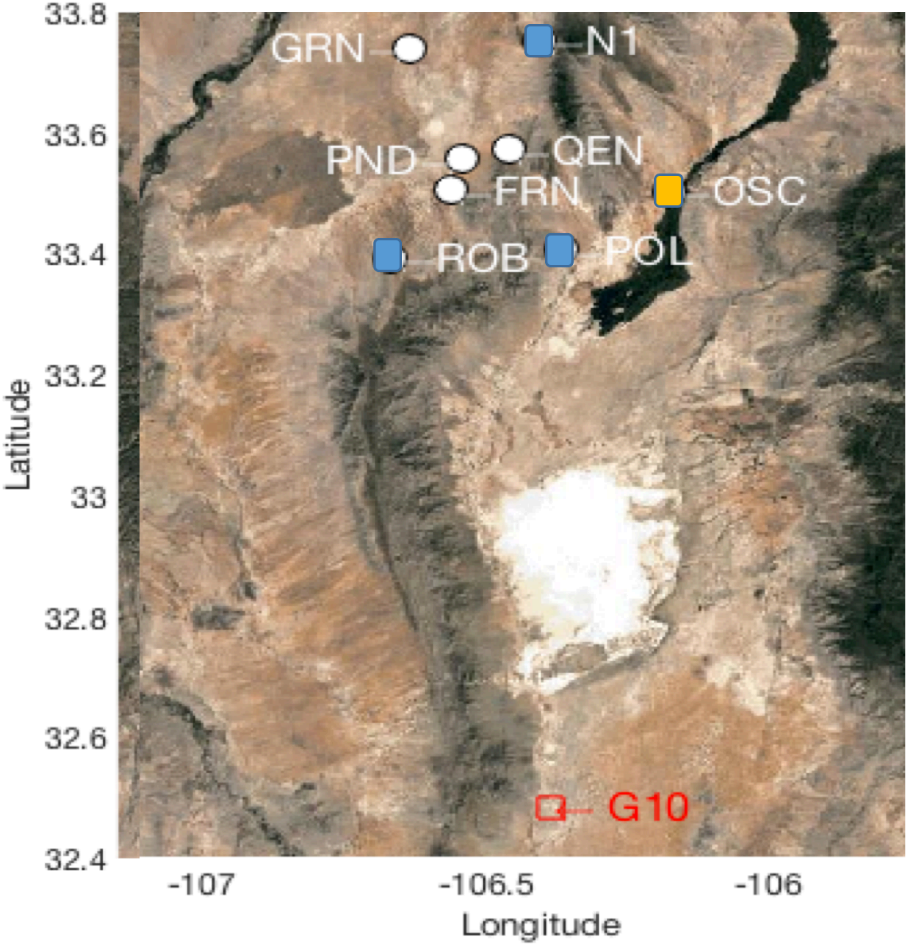
When is it expected to help?
- Extrapolation outside of observation space
- Other altitudes and frequencies
- Different spatial ranges
- Different directions
- Future times





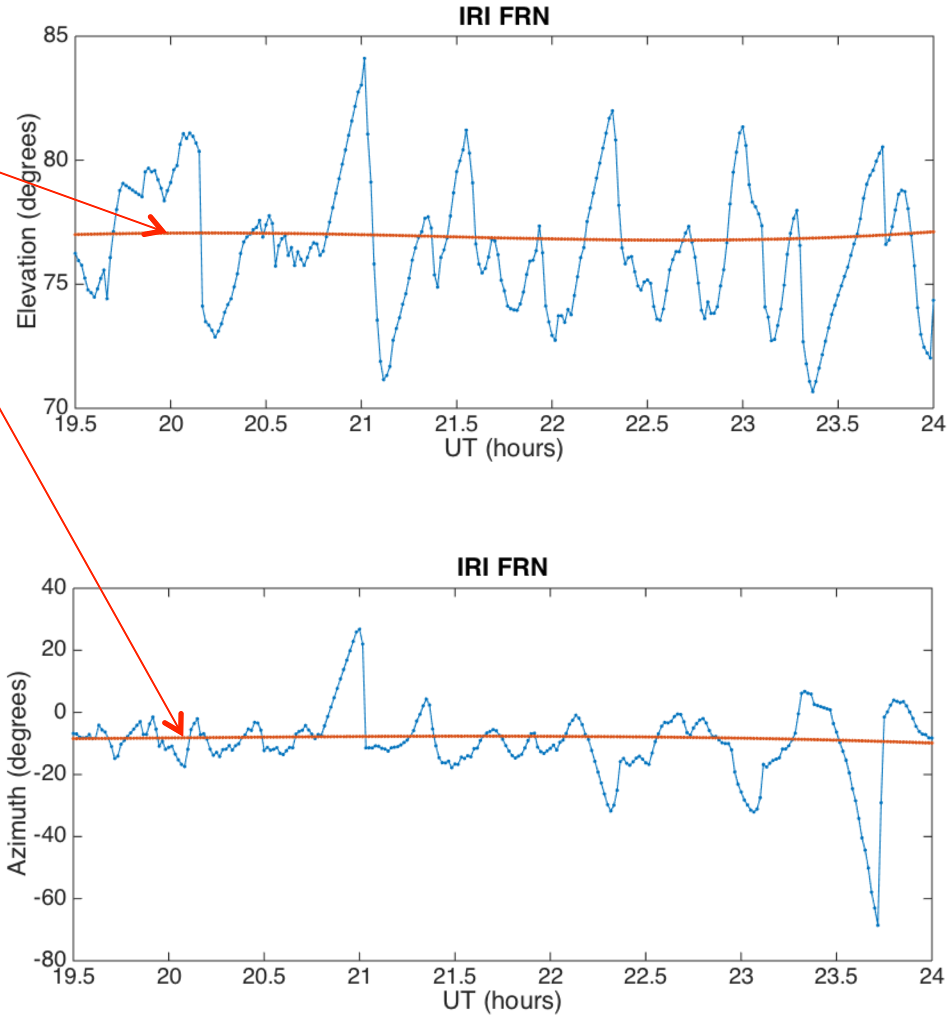
Results

- Assimilate: N1, POL, ROB
- Predict: GRN, PND, FRN, QEN
- OSC in sounder mode



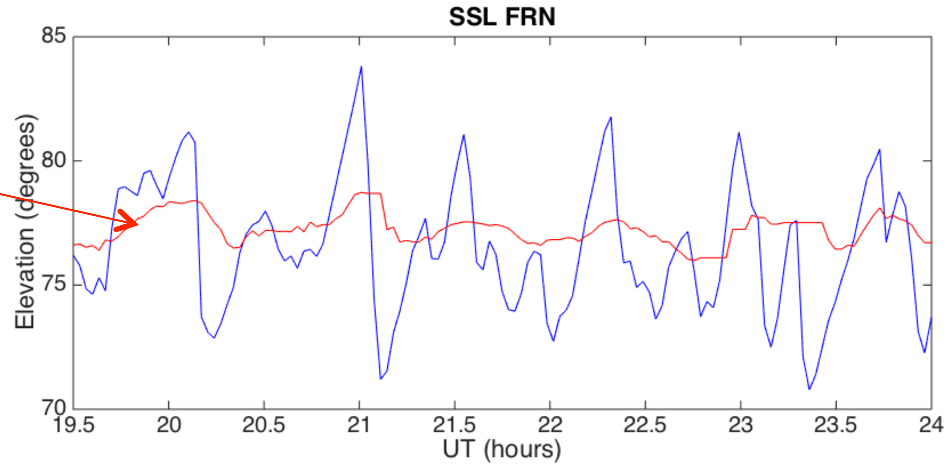
Results

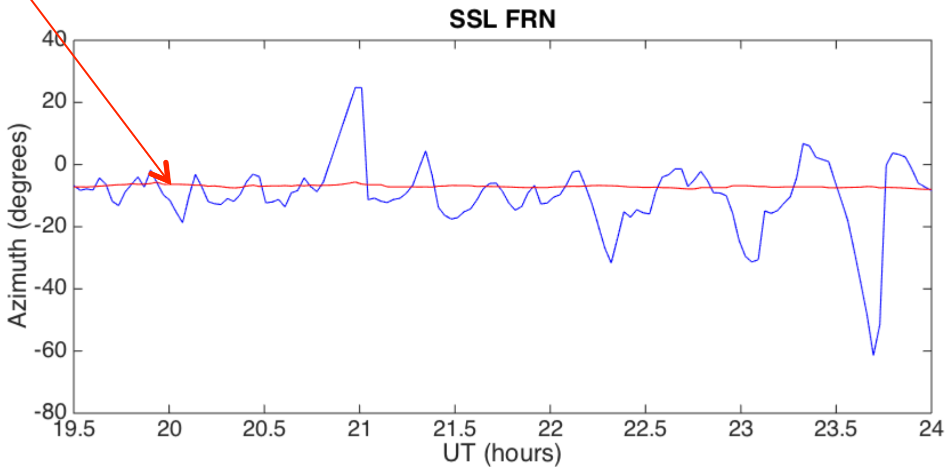
- 26 January 2014
- IRI red
  - Driven with relevant space weather parameters from date/ time.
- Observed angles from FRN in blue



Results

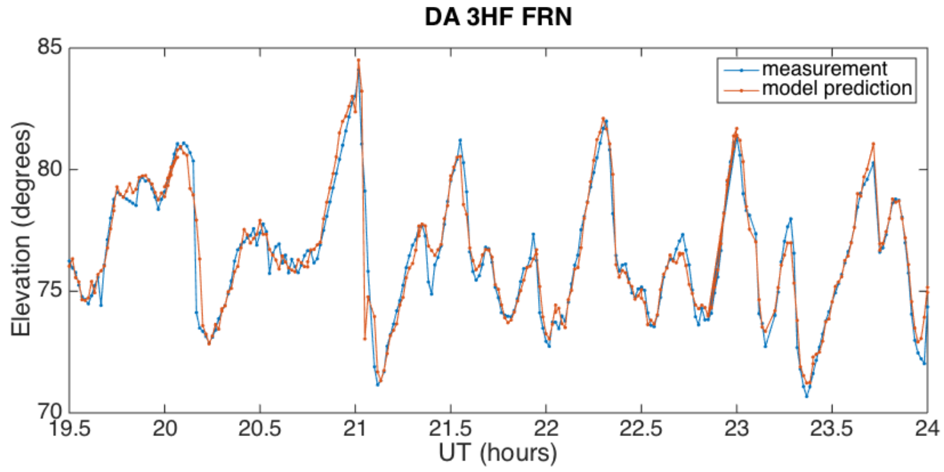
- 26 January 2014
- Ionosonde red
  - Ionosphere derived from POL ionograms at 2-minute cadence.
- Observed angles from FRN in blue

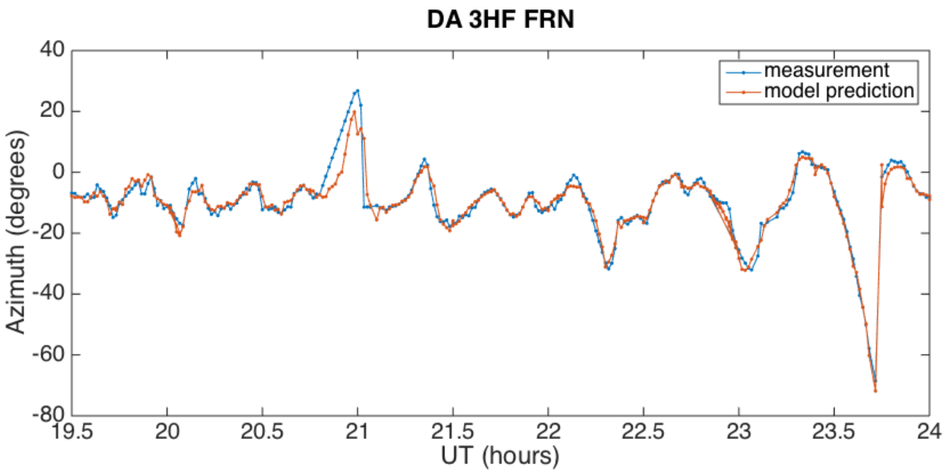




Results

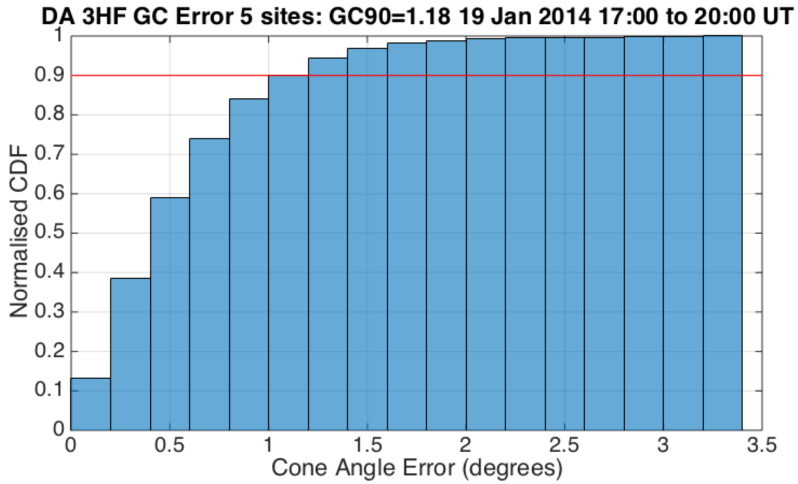
- 26 January 2014
- HF-Lynx data assimilation using N1, POL, and ROB, in red
- Observed angles from FRN in blue

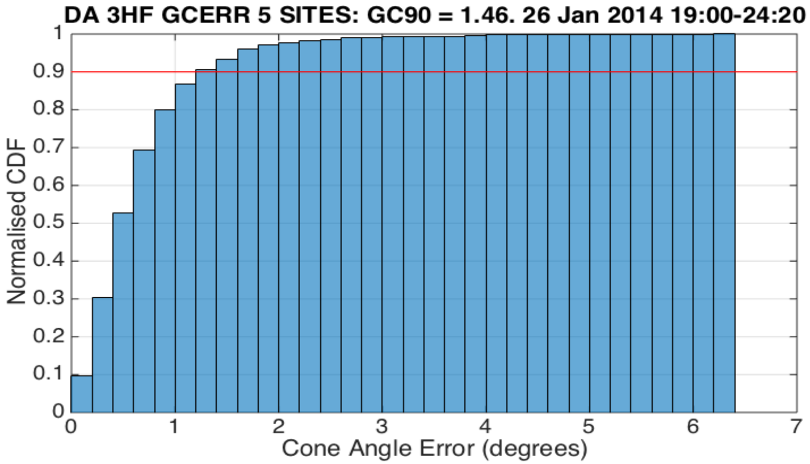




Results

90% cone angle (all in degrees)	IRI	Iono	DA HF-Lynx
Easy day	2.82	2.27	1.18
Difficult day	4.43	5.35	1.46





Summary: HF-Lynx Angles of Arrival Prediction

- **Assimilation of angles into a TID model gives great results in predicting angles at new locations**

- **But … all of the predictions were at the same radio frequency as the observations (5.3 MHz)**

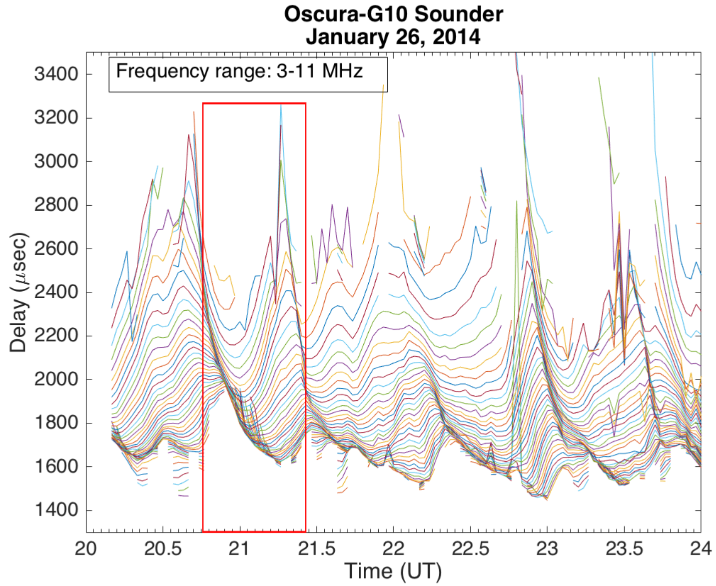
- **What happens when you try to predict to a new location on a different radio frequency?**
  - **We do not have extensive observations of AoA's simultaneously at multiple frequencies**
  - **However we do have observations of Group Delay at multiple frequencies (Oscura in sounder mode)**
  - **Warning: Keep in mind results from Group Delay do not necessarily translate to AoAs**

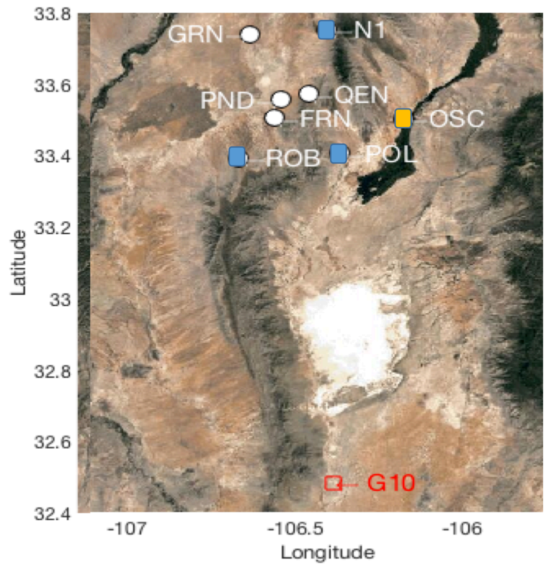
Comparison to Oscura Sounder: Group Delay at Other Frequencies

- **First: IRI – sets a baseline**
  - **How well does IRI predict Group Delay at wide range of frequencies?**
- **Second: ionosonde every 2 minutes**
  - **Expect to work since *ionosondes measure Group Delay***
  - **But: we already know that ionosonde-derived ionosphere DOES NOT predict variable AoA's very well (earlier result)**
- **Third: combine ionosonde with HF-Lynx wave optimization**
  - **Get good AoA predictions at 5.3 MHz**
  - **AND good predictions of GD across a wide range of frequencies?**

Oscura Sounder: January 26, 2014

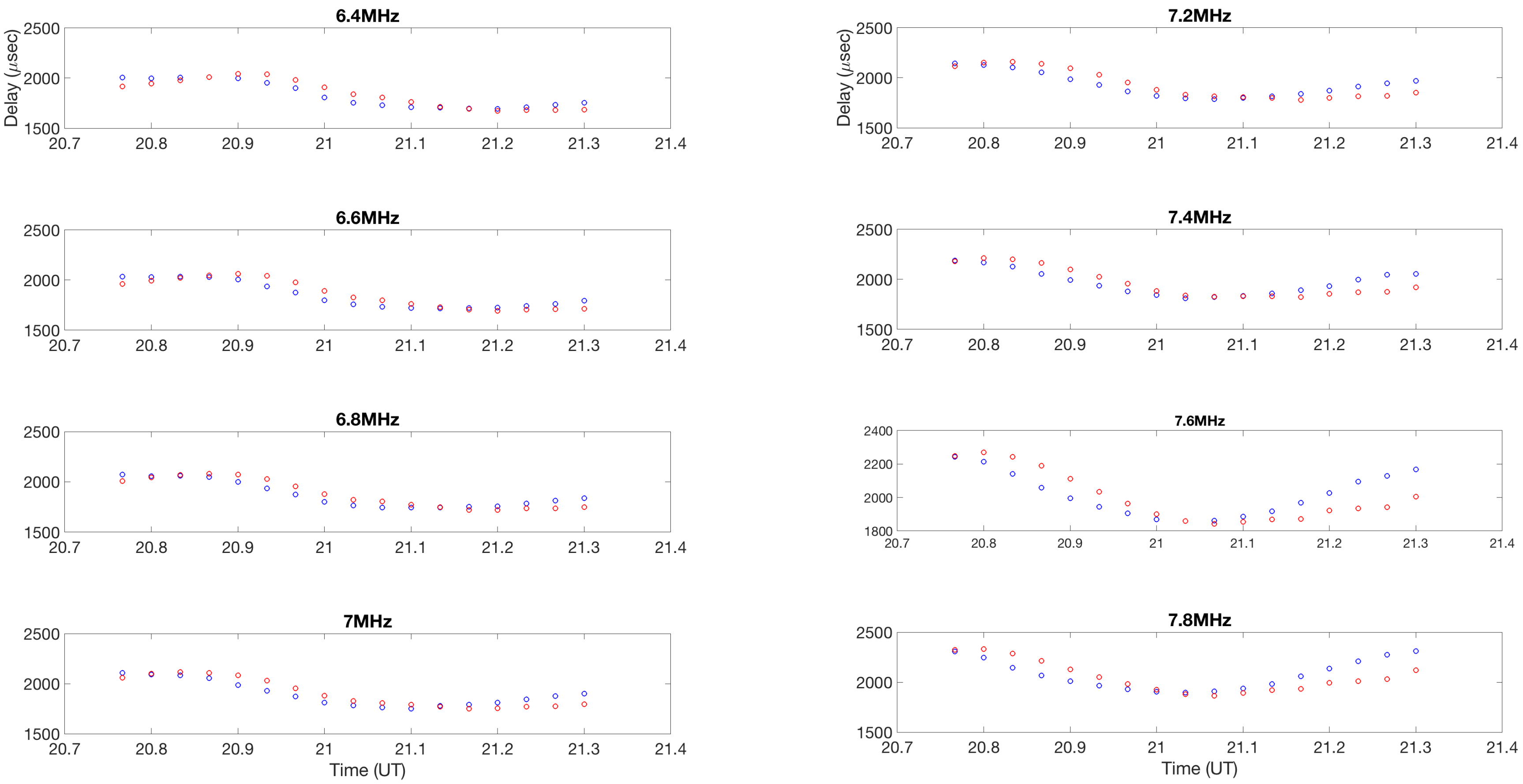
- **Oscura Sounder:**
  - **Oscura was in "sounder" mode on 26 January 2014**
  - **Linear frequency sweep 3-11 MHz every 2 minutes (125 kHz/ sec)**
  - **The sounder signal was observed at G10, which is *115 km away***
  - **Oscura sounder delays versus frequency and time over ~4-hour test period (upper right) and over study period 20:45 – 21:20 (red box)**





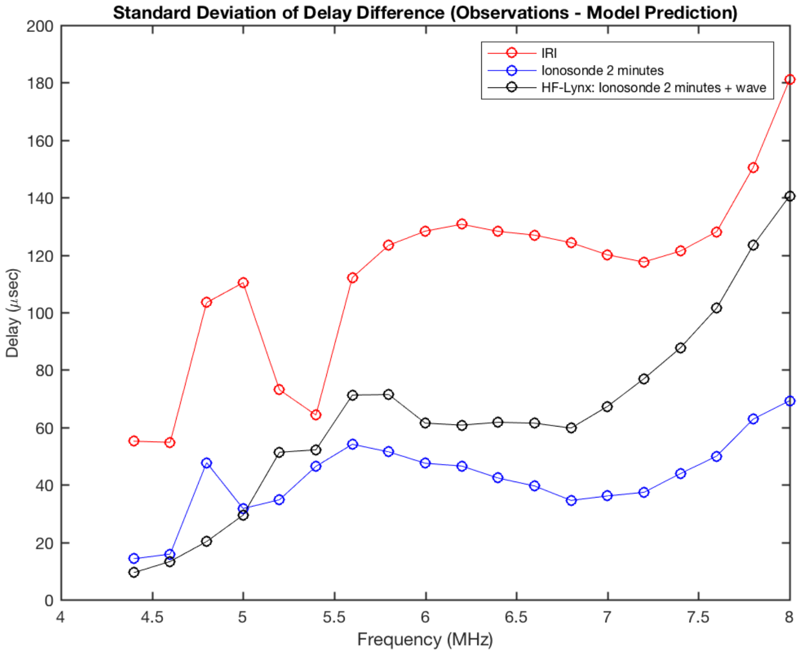
Results: Comparison to Oscura – Delays versus time and frequency

HF-Lynx: Ionosonde 2 minute + wave prediction (Red)
Oscura observations (Blue)

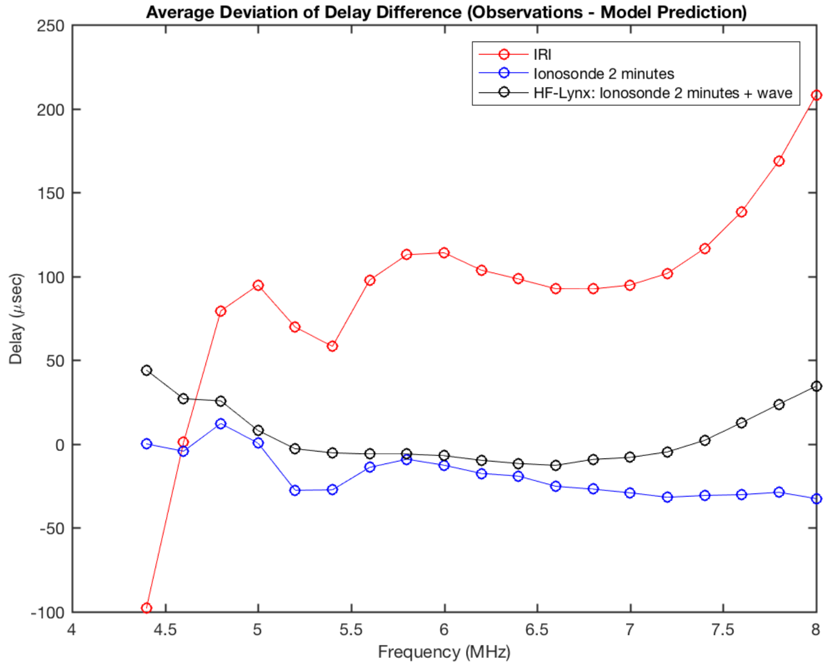


Results: Comparisons to Oscura – Standard deviation and mean difference of delay

Standard Deviation of Delay: Oscura - Prediction

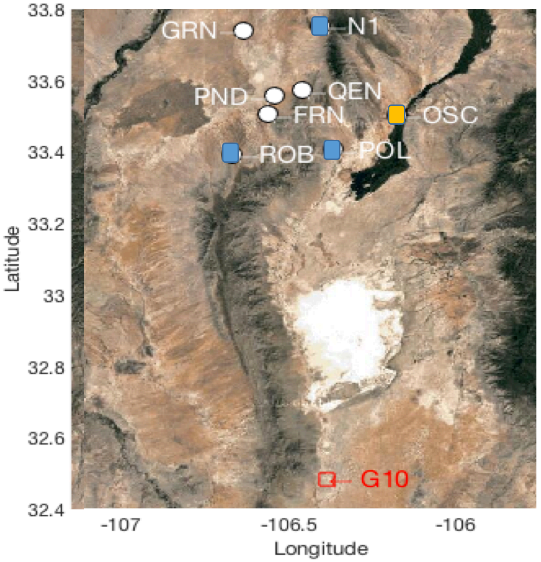


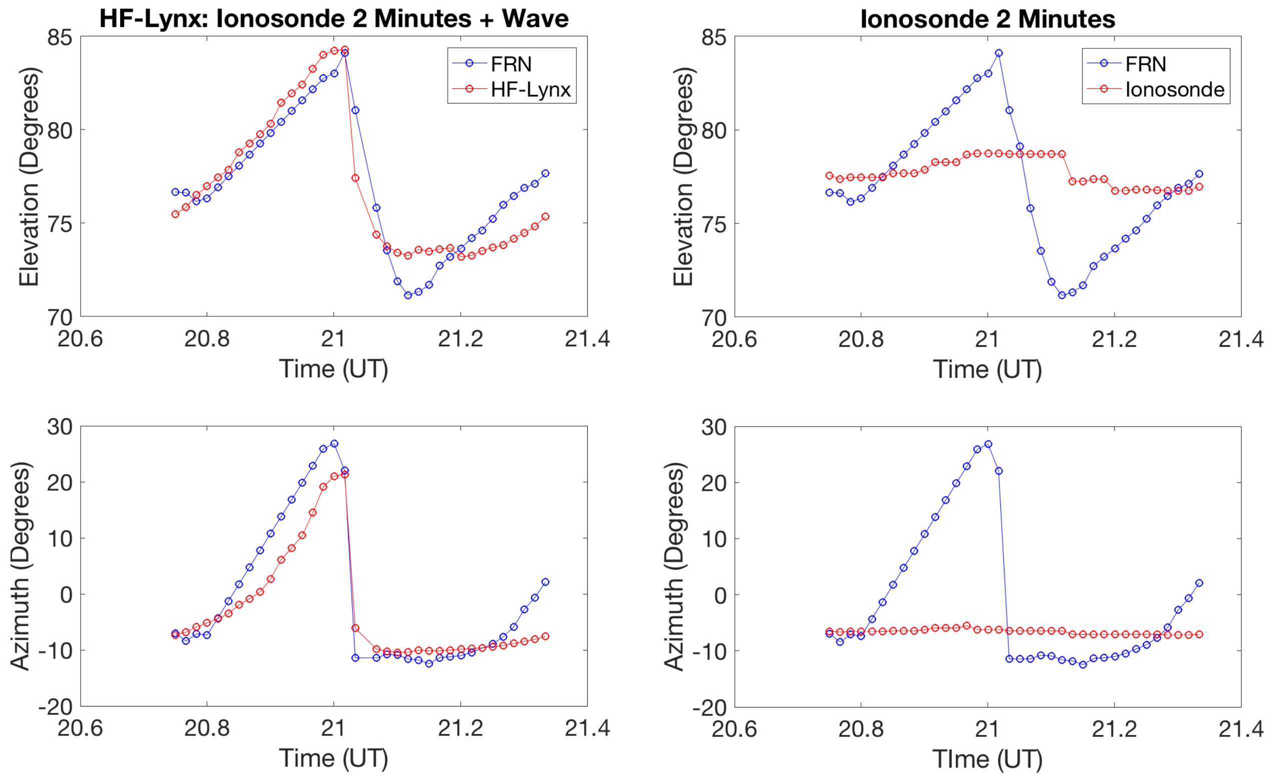
Mean difference of Delay: Oscura - Prediction



- **Ionosonde every two minutes (blue circles) provides the best results**
- **IRI (red circles) sets the empirical model baseline**
- **Ionosonde every 2 minutes + HF-Lynx wave optimization (black circles) provides a good result**

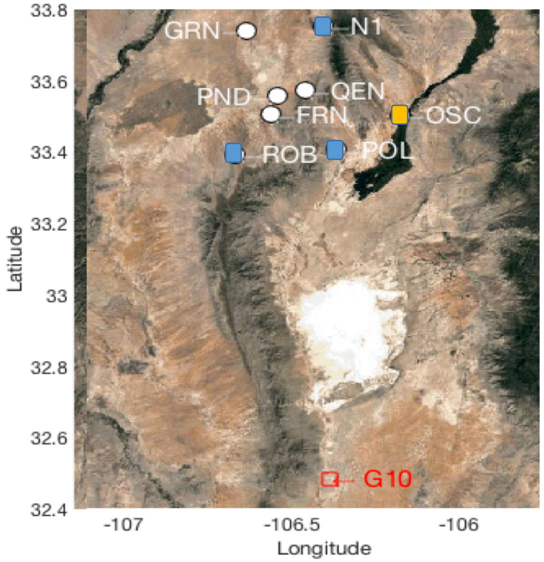
Results: Comparison of Ionosonde and HF-Lynx Prediction of FRN AoAs

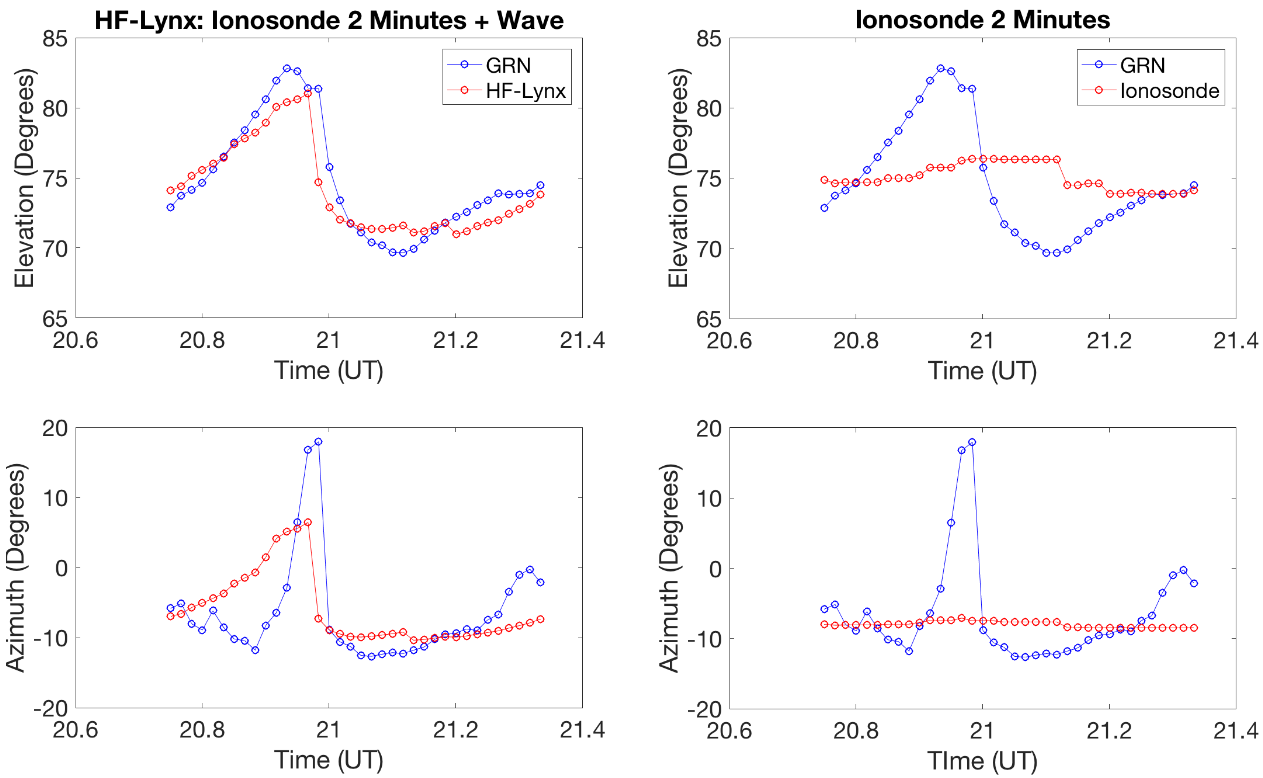




- **HF-Lynx: statistics for FRN:**
  - **Great Circle Error STD: 1.6**
  - **Great Circle Error AVE: 0.36**
- **Ionosonde: statistics for FRN:**
  - **Great Circle Error STD: 3.7**
  - **Great Circle Error AVE: 1.5**

Results: Comparison of Ionosonde and HF-Lynx Prediction of GRN AoAs





- **HF-Lynx: statistics for GRN:**
  - **Great Circle Error STD: 2.1**
  - **Great Circle Error AVE: 0.48**
- **Ionosonde: statistics for GRN:**
  - **Great Circle Error STD: 4.1**
  - **Great Circle Error AVE: 0.58**

Summary

- HF signals of opportunity at a single frequency can be used in TID data assimilation to assimilate angles from some locations and predict angles at other locations.
- We only had angles at that one frequency so to test other frequencies we had to move to using time delays
- The ionosonde at POL did a good job of predicting the delays at OSC over all frequencies.
- The data assimilation did a good job of predicting the delays at OSC over a limited range of frequencies - in order to get a good data assimilative results that can predict the time delays over all radio frequencies you need to accommodate this aspect by having diversity in the assimilated signals of opportunity.
- If you want to match *angles* assimilate *angles*. If you want to match *group delay* assimilate *group delay*. If you want to match *both* assimilate *both.*

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