A Regional Optimum Assimilative Model for Improved HF Geolocation Accuracy

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Overview

- We introduce a data assimilation system called the Regional Optimum Assimilative Model (ROAM) to specify the ionospheric bottomside for geolocation applications.
- The ionospheric model consists of a parameterized background with superimposed gradient (tilt) to represent the effects of traveling ionospheric disturbances (TIDs).
- All or a subset of the model parameters are estimated via nonlinear least-squares using “in-the-loop” 3D magneto-ionic ray tracing (Cervera and Harris, JGR, 2014).
- ROAM can assimilate density profiles or profile parameters from sounders, AoAs from sounders (Paznukhov, et al.) or known HF emitters, and TID velocity from a sounder or passive GNSS receivers (Groves, et al.).
- TID dynamics are accounted for during the assimilation and prediction stages. Provides benefit if the distance between midpoints of assimilated and geolocated links is less than distance over which the TID structure is coherent.
- We demonstrate the approach using HF AoA data collected by the IARPA HFGeo Program Government team at White Sands Missile Range.

Model Parameterization

Parameterized Background ionosphere

Modified IRI convention: $\mathbf{I} = [\,foF2,\ foF1,\ foE,\ hmF2,\ B0,\ B1]$

- Layer plasma frequencies, *F2* height, bottomside thickness and shape
- *F1* height inferred from bottomside shape and *FoF1*; E region height ≈ 110 km

Parameterized Tilt model

$$\mathbf{G} = [\beta_{lat}, \beta_{lon}]$$

- Gradient factors in latitude and longitude, with modulation in altitude

$$f_p(h, lat, lon) = f_p^0(h, lat_0, lon_0)A(h)\left[1+\beta_{lat}(lat - lat_0)\right]\left[1+\beta_{lon}(lon - lon_0)\right]$$

TID Dynamics

$$\delta t = \mathbf{R}\cdot\mathbf{V}/\left|\mathbf{V}\right|^2$$

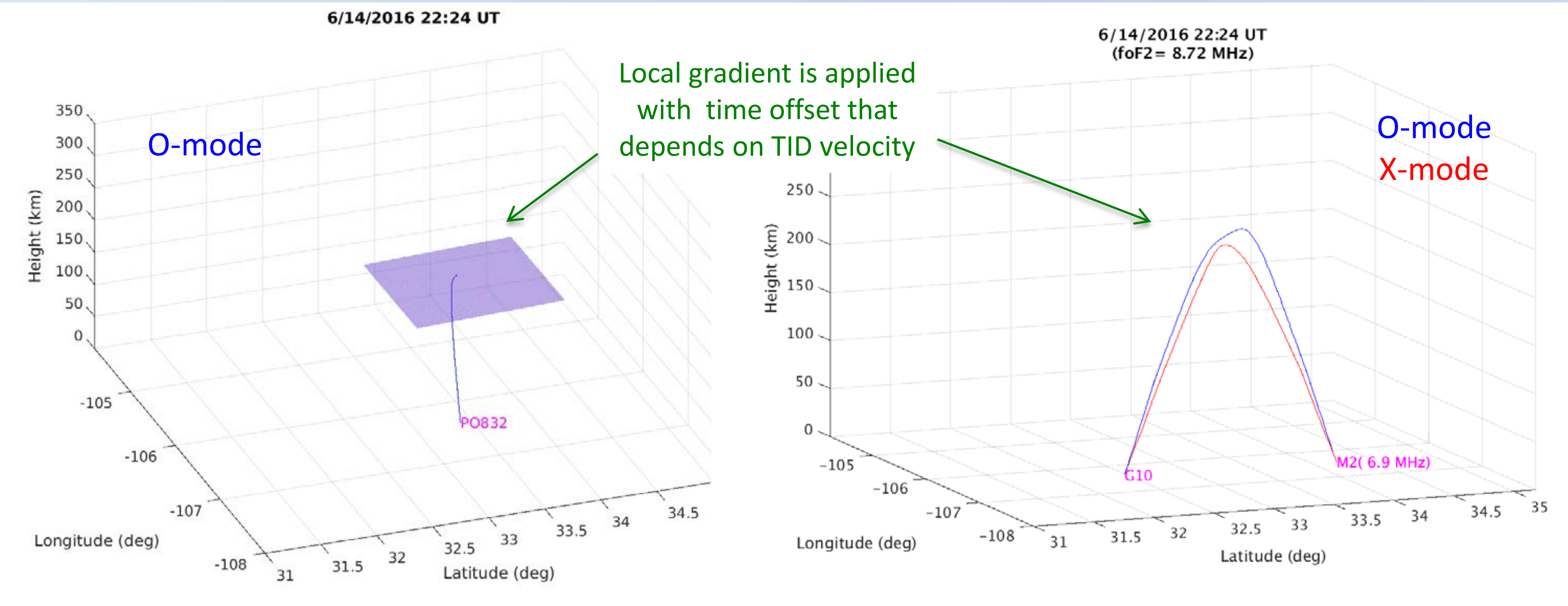
- Tilts are "propagated" to reflection point of TOI by time-shifting the ionospheric state
- Time shift δt is the distance between assimilation and reflection points (**R**) projected onto direction of TID motion, divided by the TID speed (**V**)

Assimilating and Predicting Angle of Arrival

ROAM assimilates AoA (sounder or CxT) and estimates local density gradients due to TIDs. Gradients are ‘propagated’ to midpoint location when responding to iono-model queries.

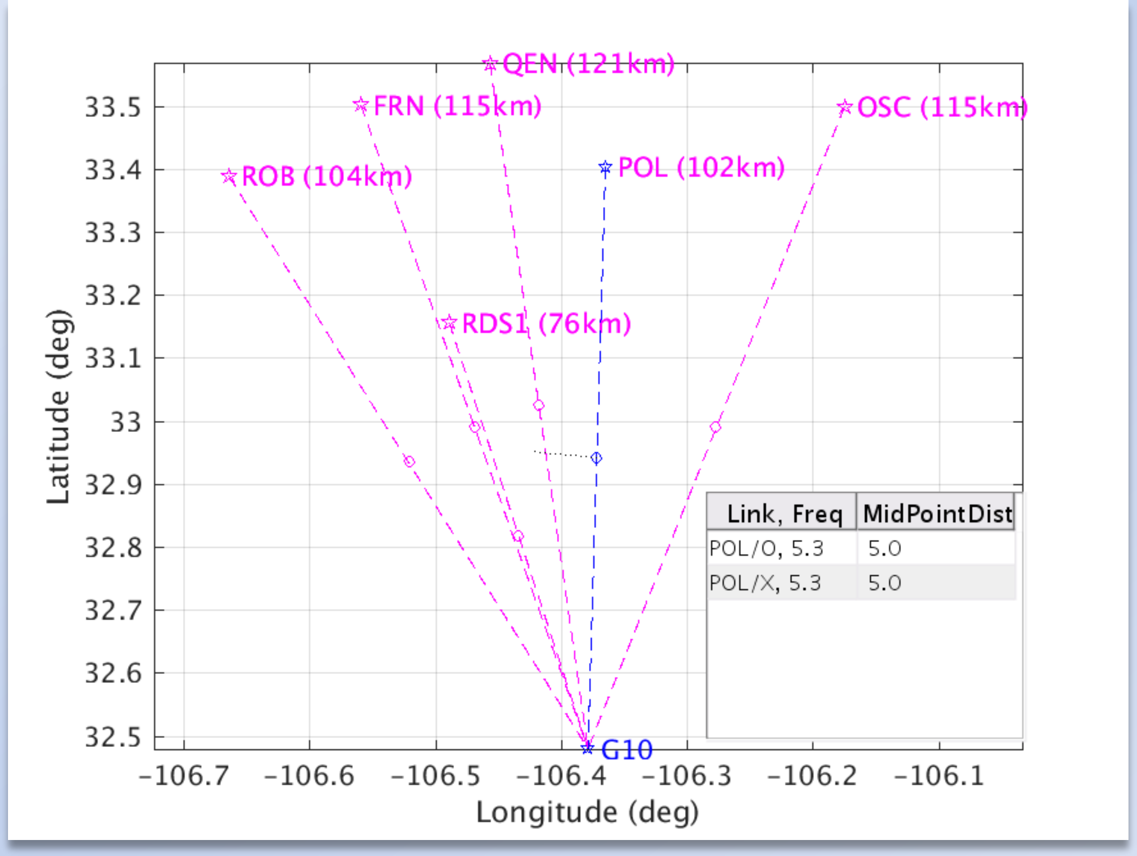
Data Assimilation (tilt)

Prediction (ray-homing)



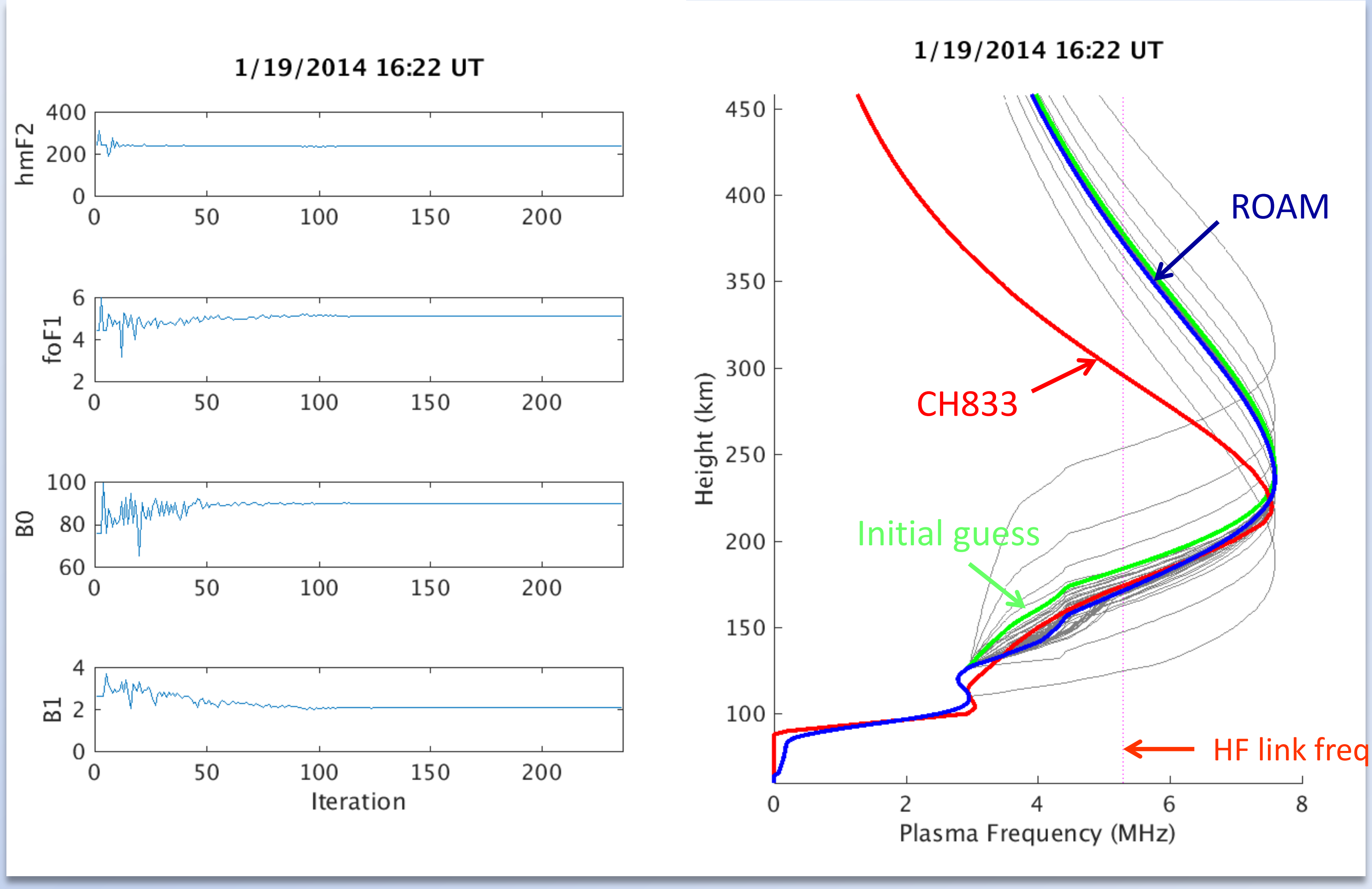
Example 1 – Assimilated AoAs from Oblique HF Links

Assimilate AoAs from several (5) oblique HF links; Validate with additional HF link



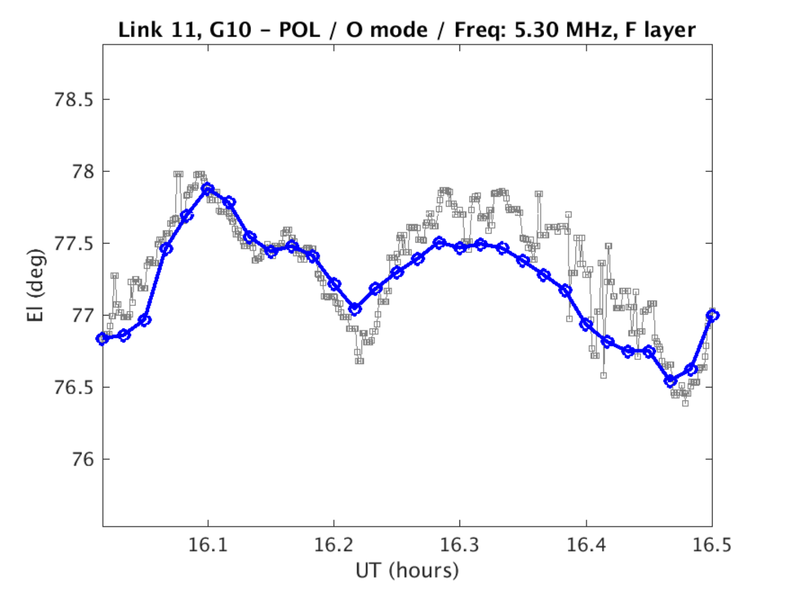
Data collected by HFGeo government team at WSMR

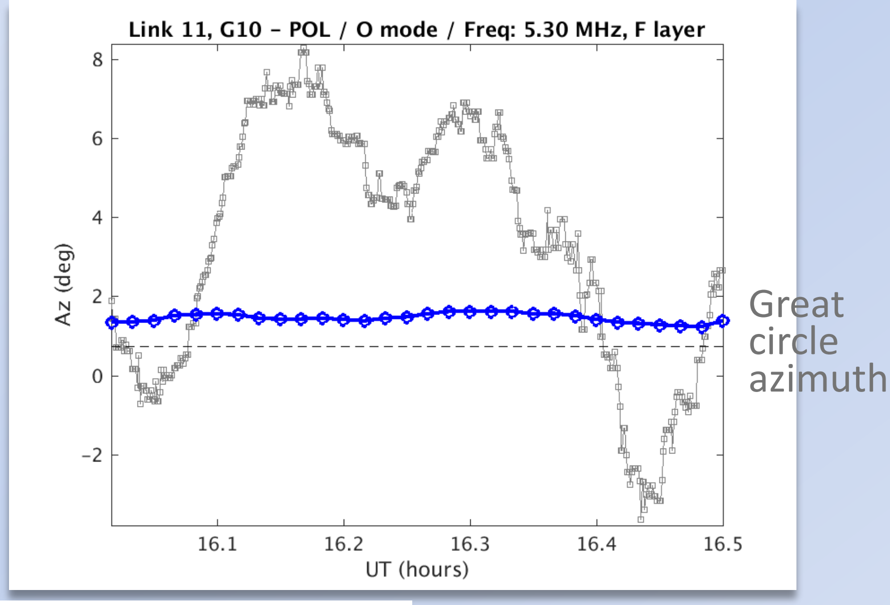
Example 1 – Estimated Profile Parameters

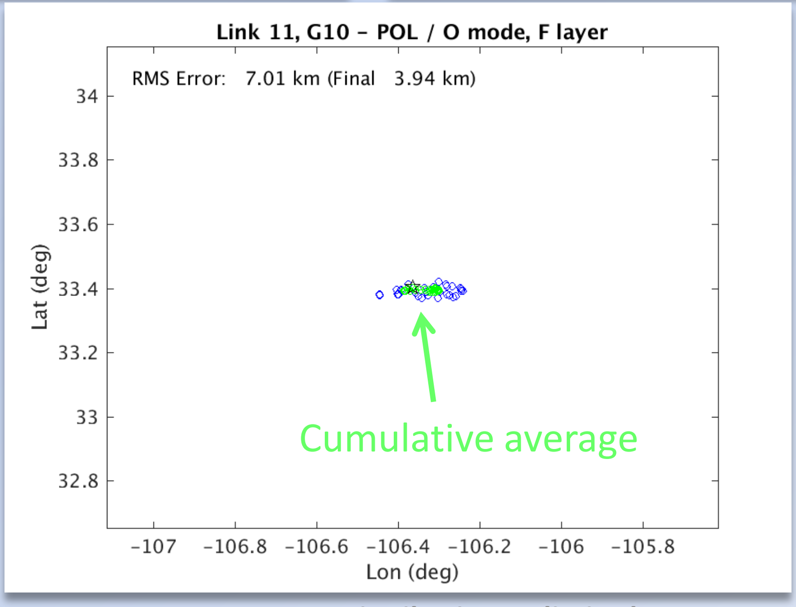


This problem has non-unique solutions (metric has several local minima)

Example 1 – Predicted AoAs and Geolocation Error





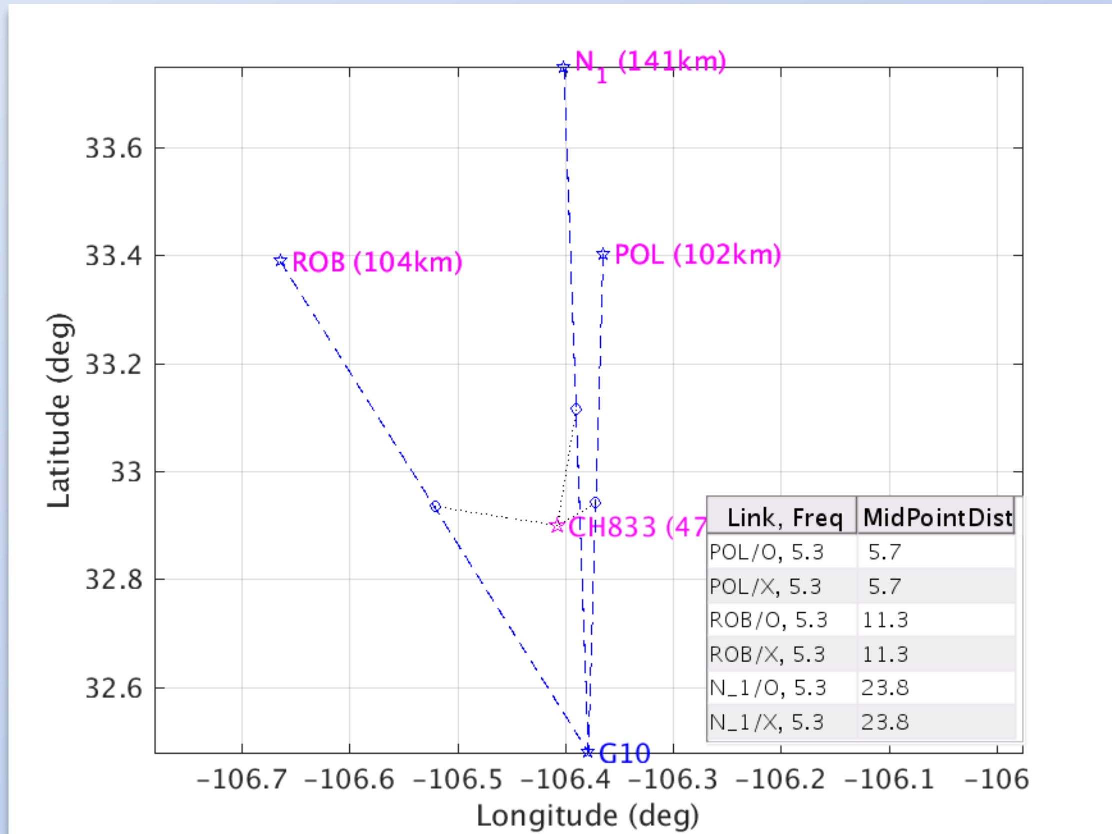


Captures variations in elevation but not azimuth since we have neglected tilt

East-west errors due to inability to model azimuth variations

Example 2 – Assimilated Digisonde AoA (skymap tilt)

Assimilate data from a single Digisonde close to midpoints of validation links

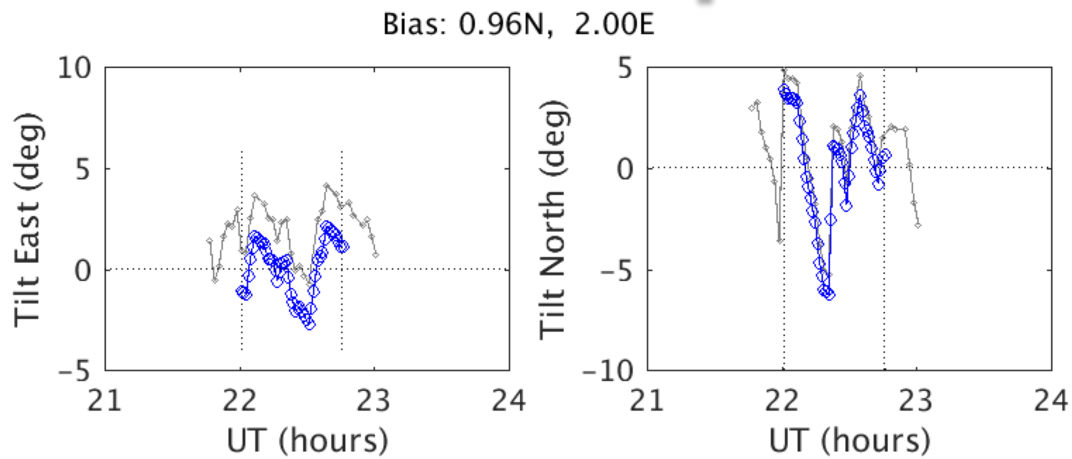


Data collected by HFGeo government team at WSMR

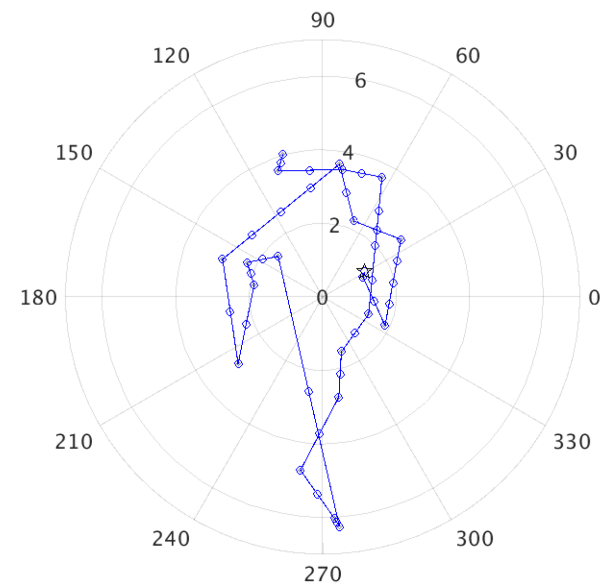
Example 2 – Assimilated Digisonde Tilt and TID Velocity

Digisonde tilt

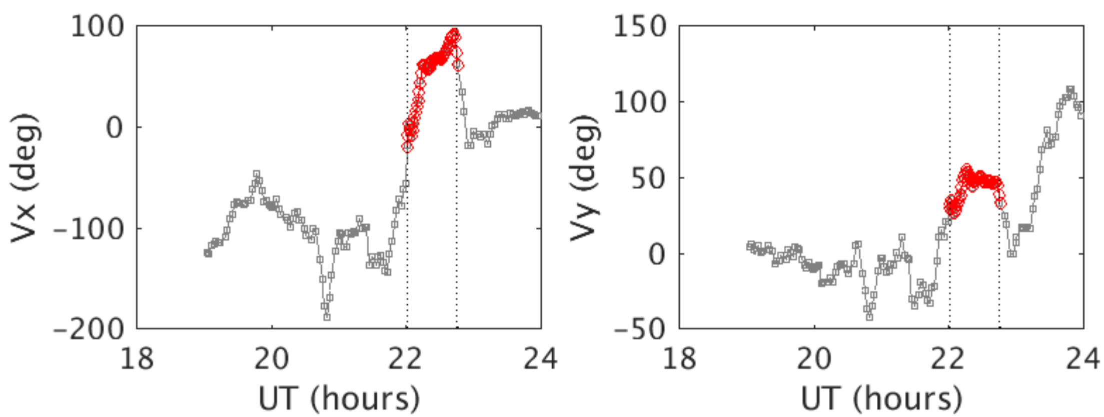
Remove Bias



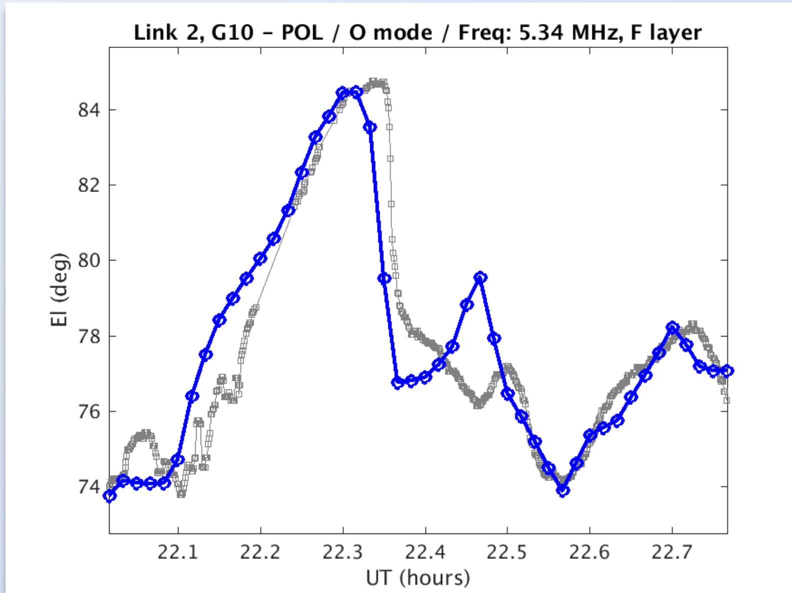
Digisonde AoA

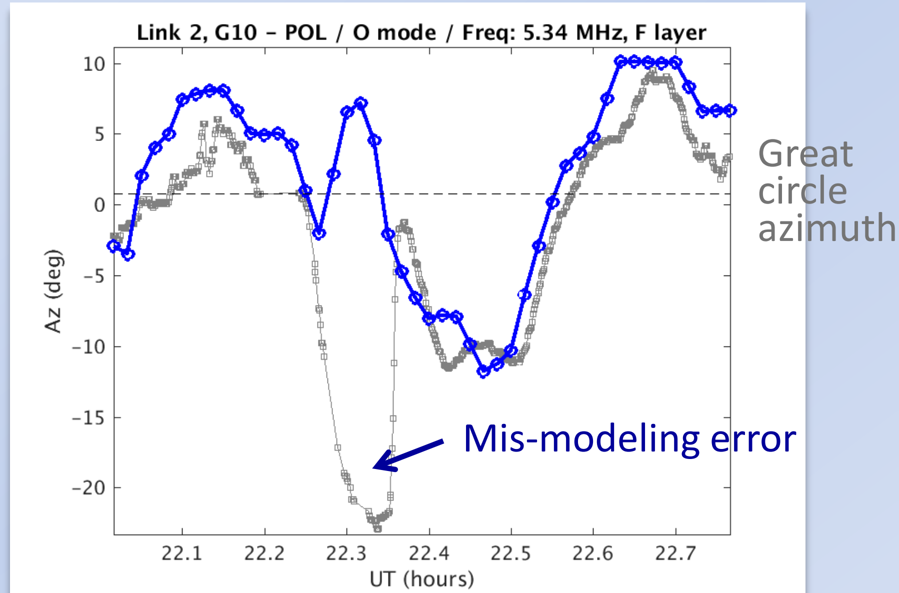


Digisonde velocity

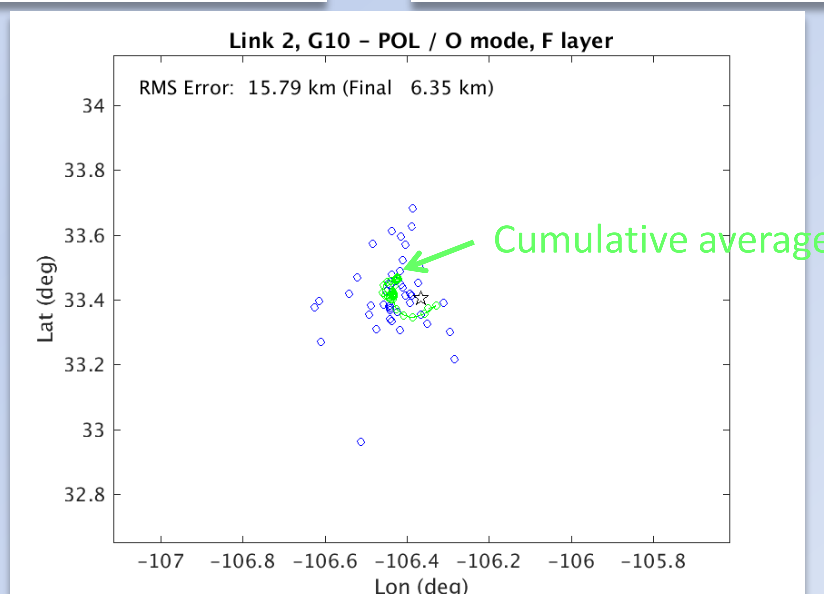


Example 2 – Predicted AoAs and Geolocation Error



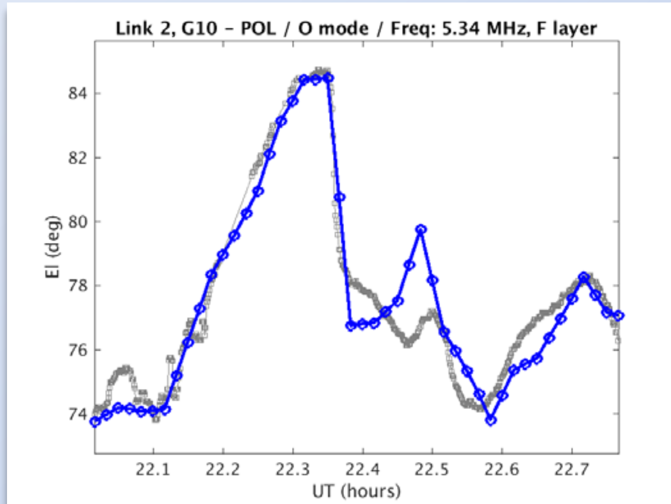


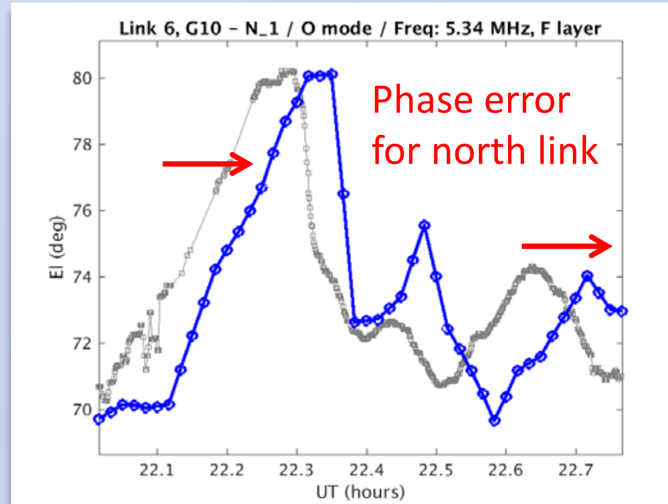
Model with tilt captures most AoA variations, even in this strong TID environment



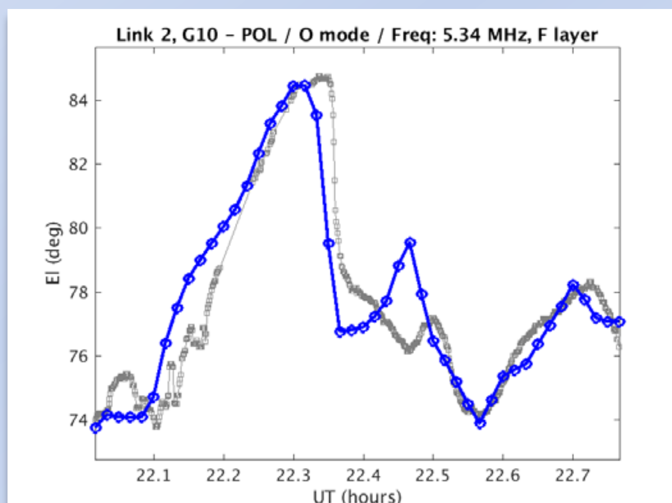
Benefits of Dynamic TID Modeling

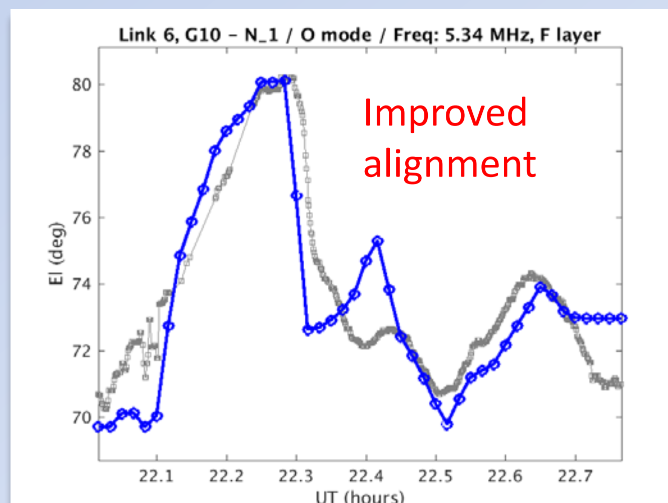
No TID Velocity Assimilation





With TID Velocity Assimilation





Conclusions

- ROAM's parametric model with 8 parameters (6 background, 2 gradient) has proven useful given limited data to constrain the bottomside ionosphere.
- Nonlinear least squares provides accurate ionospheric parameter estimates, provided they can be constrained by the data assimilated (e.g. an HF link provides no information at altitudes greater than its reflection point).
- Using a Digisonde to constrain background and either Digisonde or CxT to constrain tilt associated with TIDs appears to be a robust mode of operation for geolocation applications.
- To be effective, distance between assimilation and prediction link midpoints must be less than distance over which the TID structure is correlated.
- Dynamically accounting for TID propagation during data assimilation and prediction steps helps to mitigate phase errors.