

Assimilative Modeling of Ionospheric Dynamics for Now-casting of HF Propagation Channels in the Presence of TIDs

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Background

- **IARPA HFGeo program seeks improvements in ionospheric modeling and to mitigate the effects of traveling ionospheric disturbances on geolocating HF emitters**
- **Our approach is to use the GPSII ionospheric data assimilation model, assimilating information from known reference point (KRP) emitters in the region of interest**
 - **Delay/Doppler/Angle-of-Arrival measurements of KRPs**
- **Theory for delay-Doppler-AoA assimilation presented in a companion paper (Fridman, et al., IES 2015)**
- **Here we present results from the IARPA HFGeo WSMR collection campaign of January 2014**

The Ionospheric Reconstruction Problem: Tikhonov Method

$$N(\mathbf{r}, t) = N_0(\mathbf{r}, t)e^{u(\mathbf{r}, t)}$$

$$U = \{ \{u(\mathbf{r}, t)\}, \text{Biases} \}$$

$$Y \approx M[U]$$

Y is the set of measured absolute/relative TEC values and data points from other types of ionospheric measurements.

The solution must fit the data within errors of measurements.

$$(Y - M[U])^T S^{-1} (Y - M[U]) / \dim(Y) \leq 1$$

Error covariance matrix

There are infinitely many such solutions:

The smoothest solution is selected by minimizing the stabilizing functional

$$U^T P^{-1} U \rightarrow \min$$

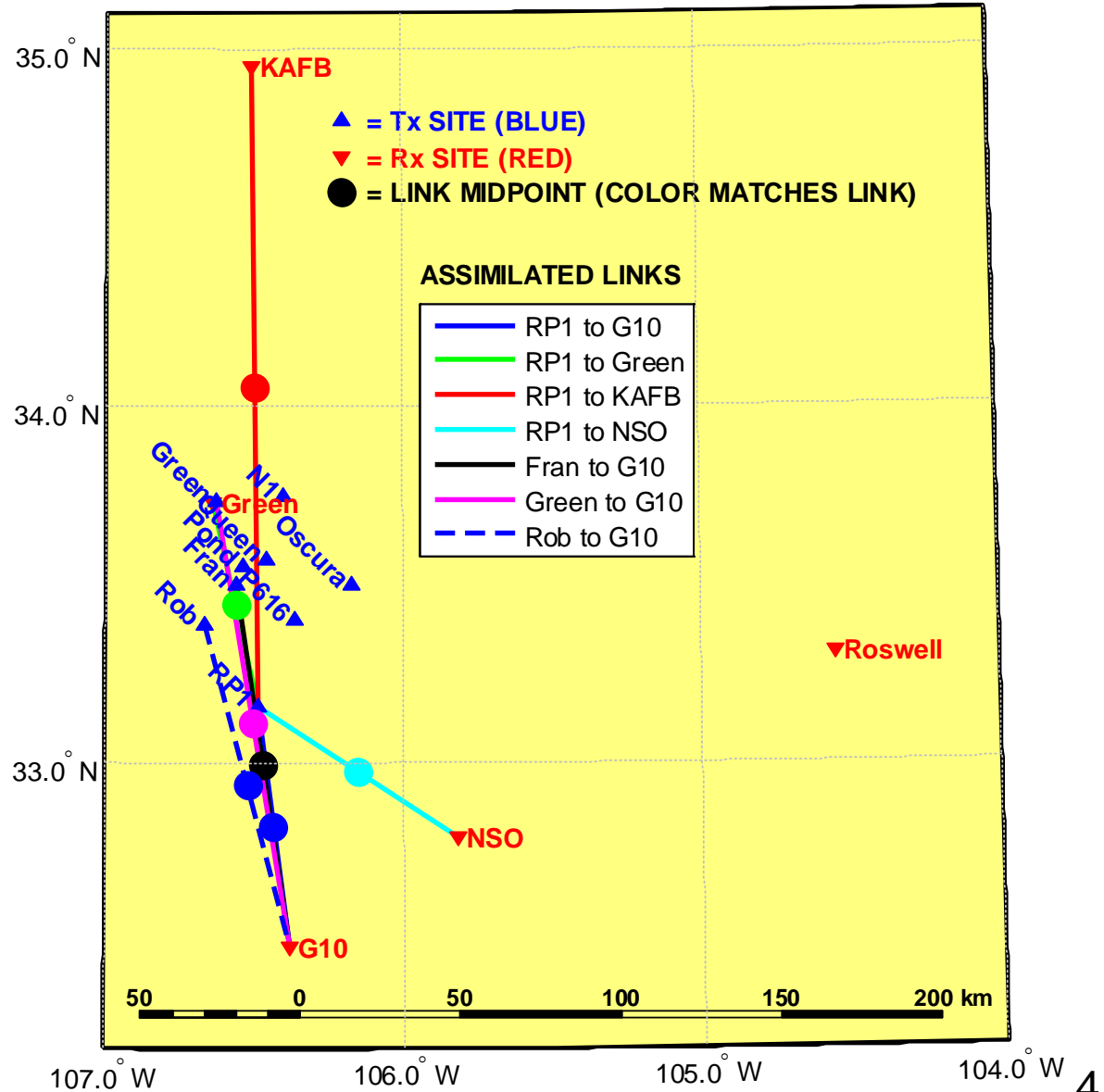
Pseudo-covariance matrix

-The pseudo-covariance P matrix is defined in such a way that the stabilizing functional tends to take on larger values for unreasonably behaving solutions (“reasonable” \Leftrightarrow “smooth”).

-The nonlinear optimization problem is solved iteratively (Newton-Kontorovich).

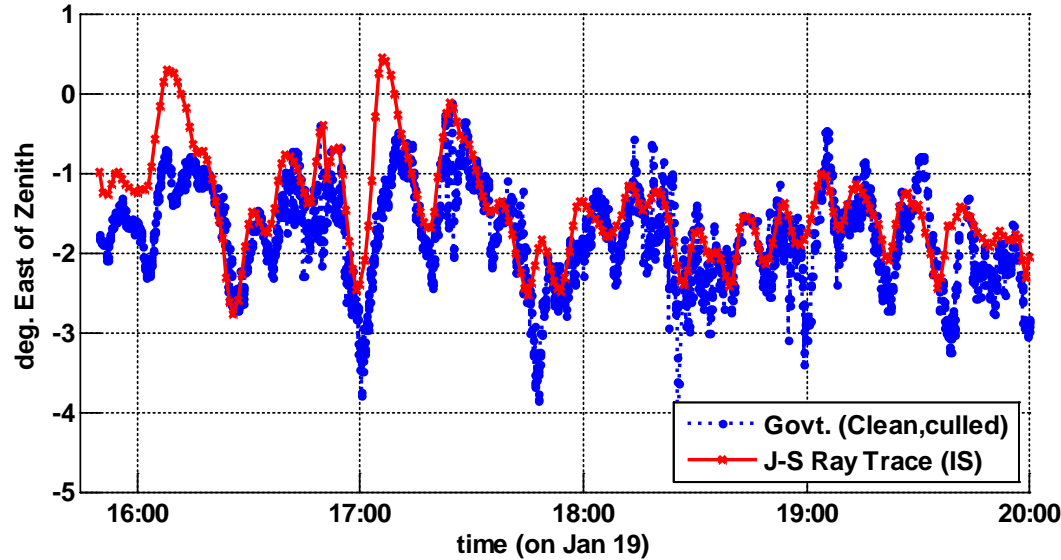
Delay-Doppler Assimilation

- Good results on TID modeling can be attained by assimilating only delay-Doppler data of receptions from Known Reference Point (KRP) emitters
- Links used in the following results are shown here

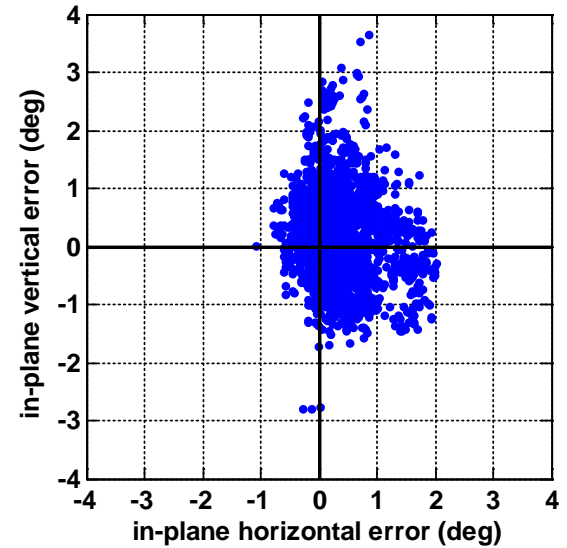


Results on an assimilated link

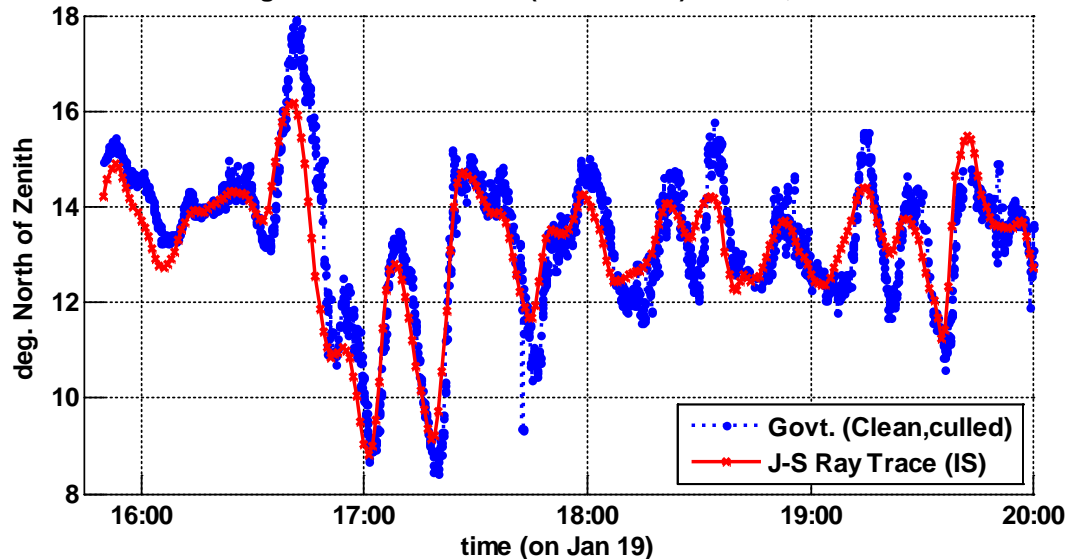
Degrees East of Zenith (Fran to G10): train O, trace O



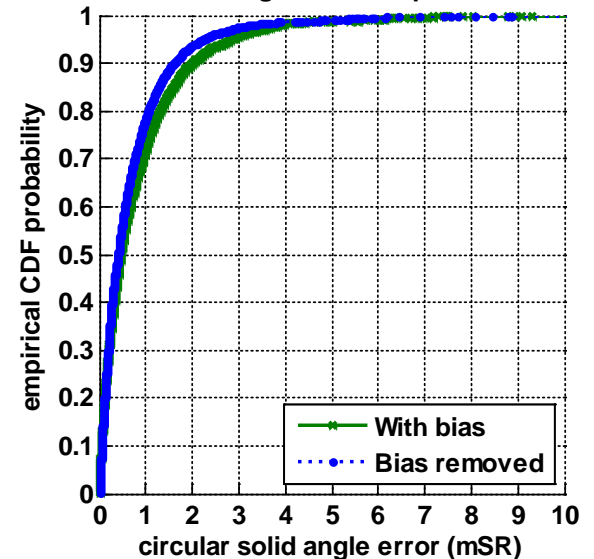
In-plane Err. w.r.t. Array Est.



Degrees North of Zenith (Fran to G10): train O, trace O

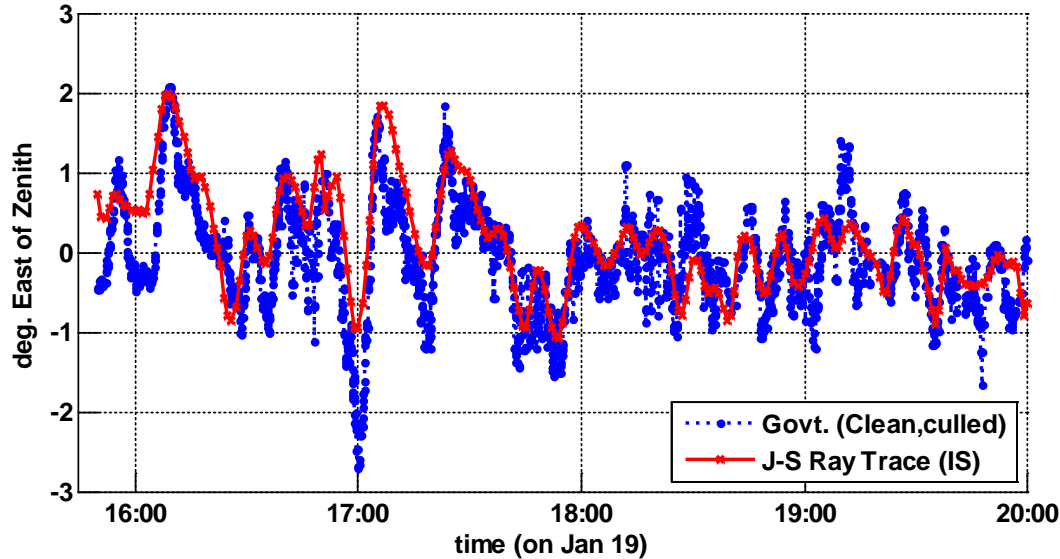


Solid Angle Error Emp. CDF

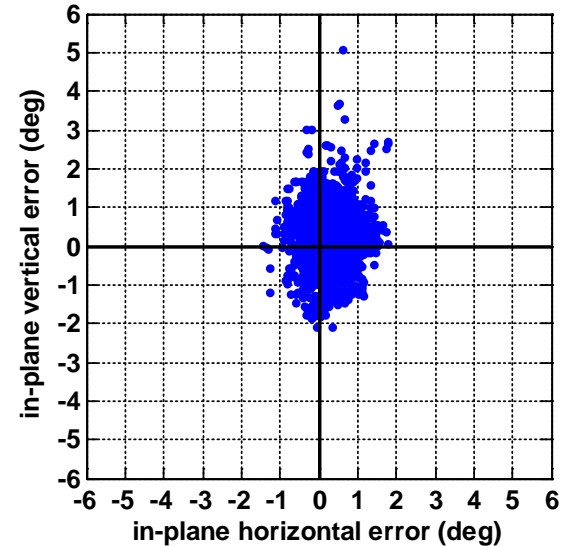


Results on a non-assimilated link

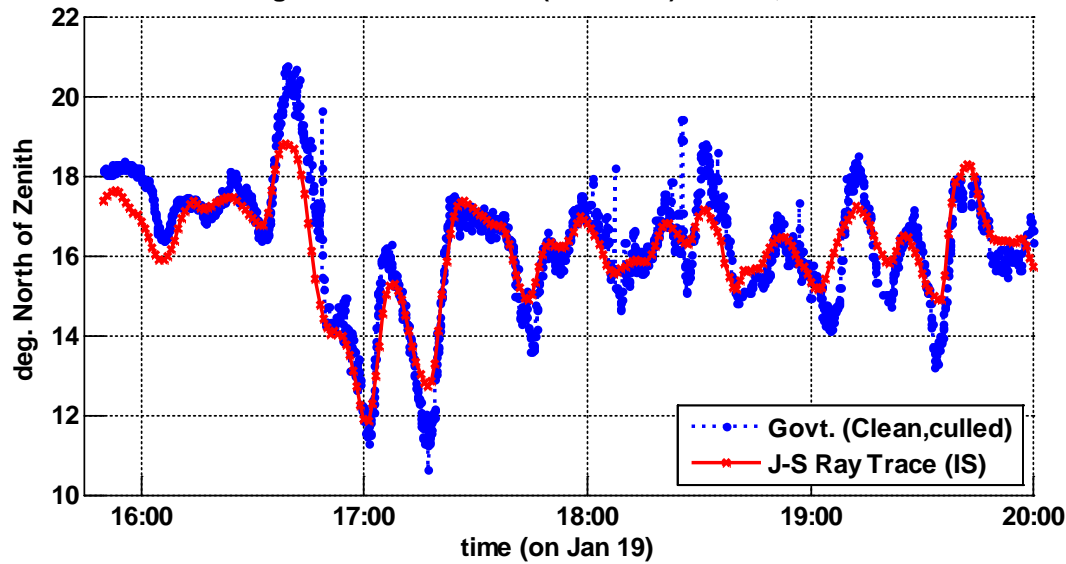
Degrees East of Zenith (N1 to G10): train O, trace O



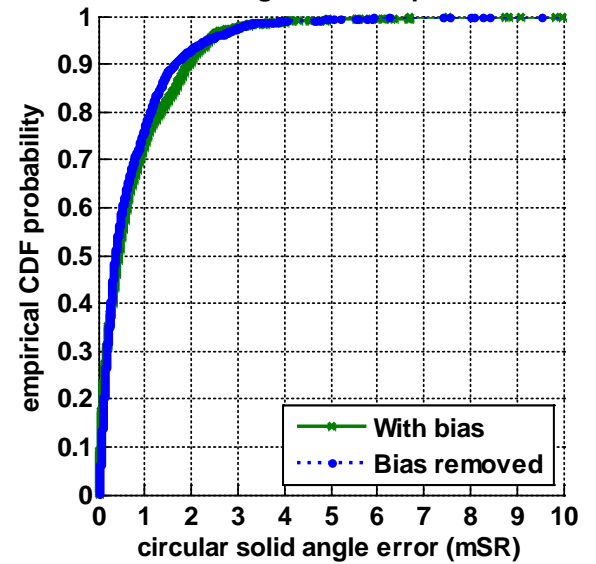
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Degrees North of Zenith (N1 to G10): train O, trace O

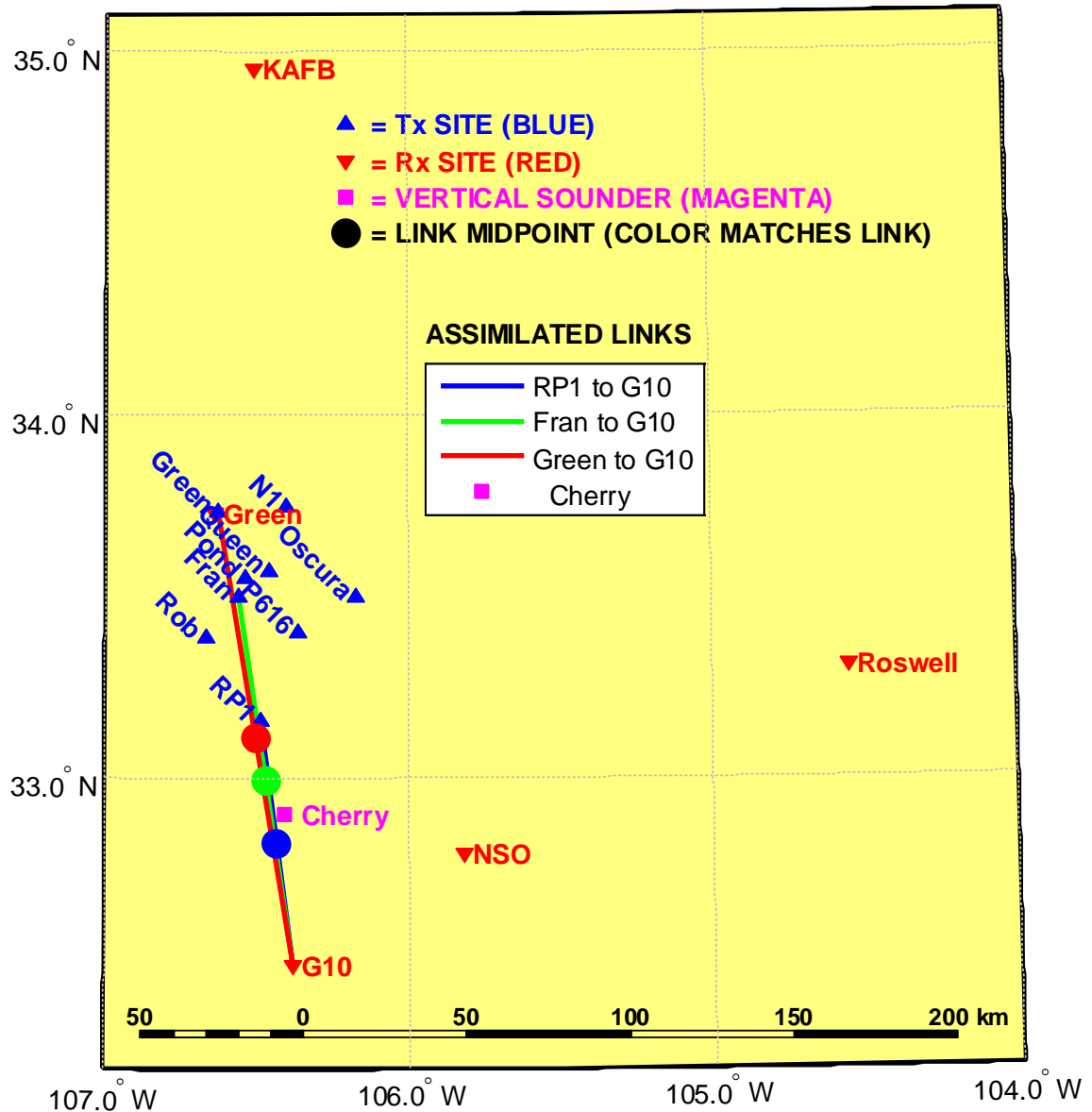


Solid Angle Error Emp. CDF



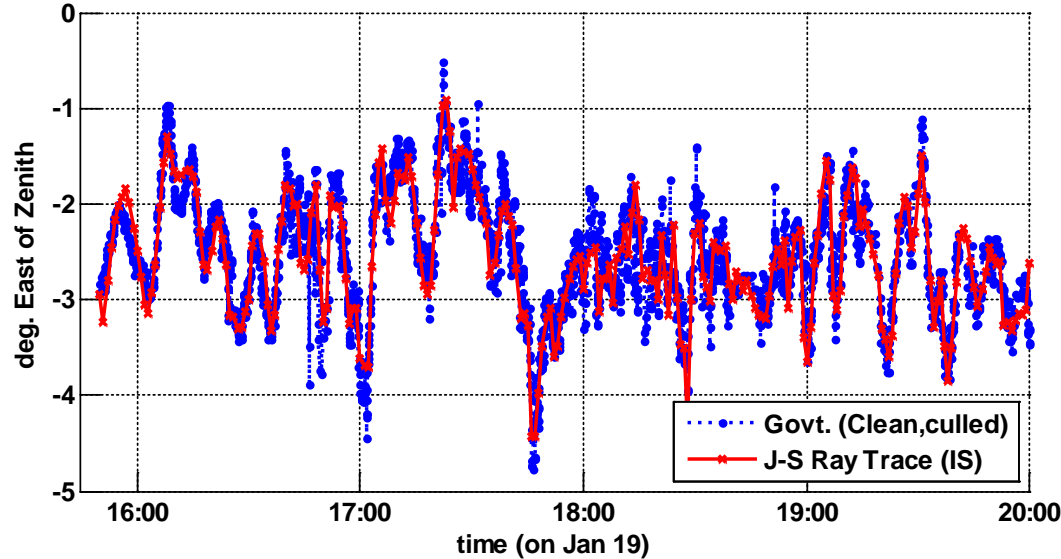
Delay-Doppler-AoA Assimilation

- Better results on TID modeling can be attained by also assimilating Angle-of-Arrival (AoA) data in addition to delay-Doppler data of receptions from Known Reference Point (KRP) emitters
- Links used in the following results are shown here

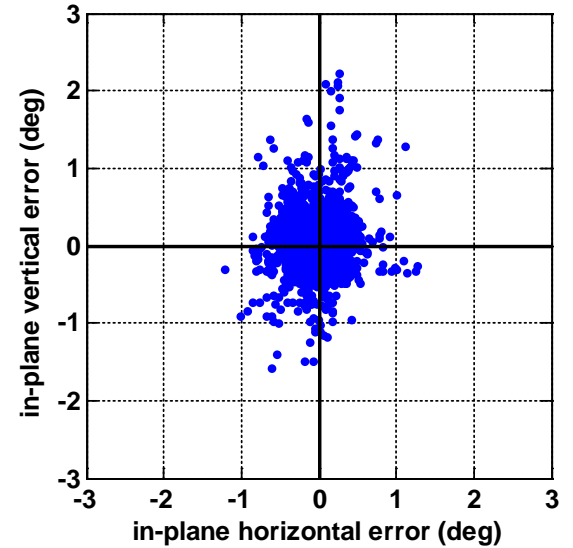


Results on an assimilated link

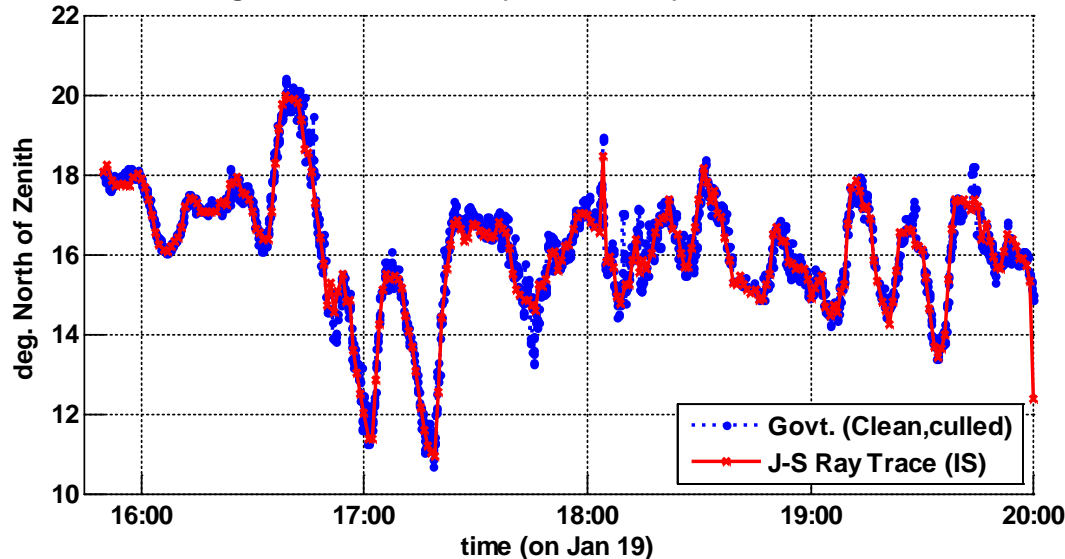
Degrees East of Zenith (Green to G10): train O+VI, trace O



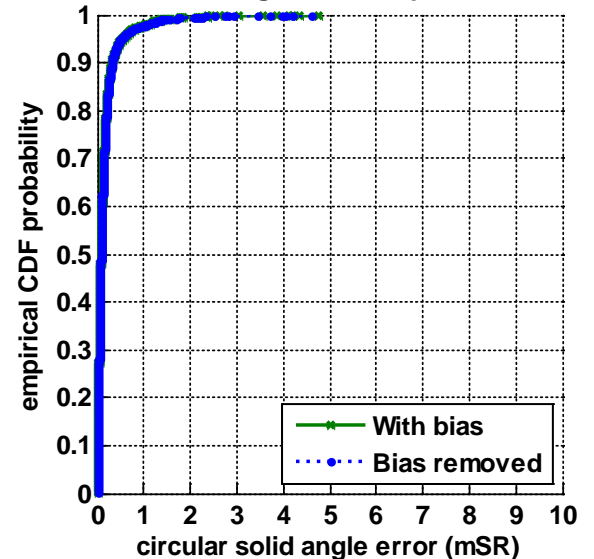
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Degrees North of Zenith (Green to G10): train O+VI, trace O

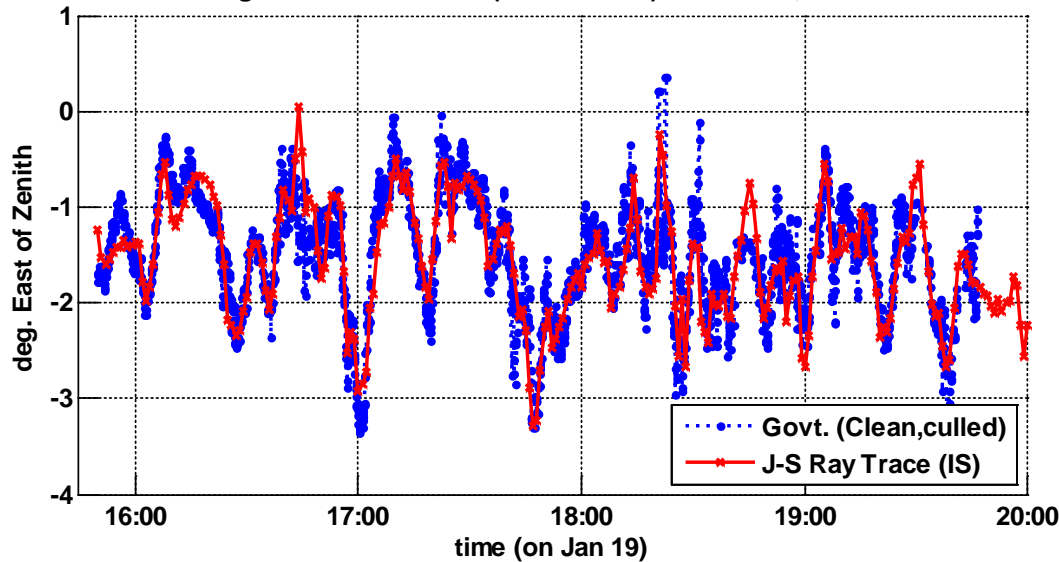


Solid Angle Error Emp. CDF

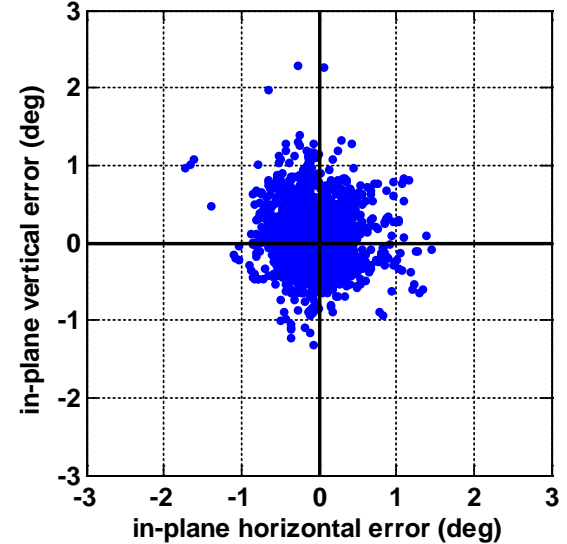


Results on a non-assimilated link

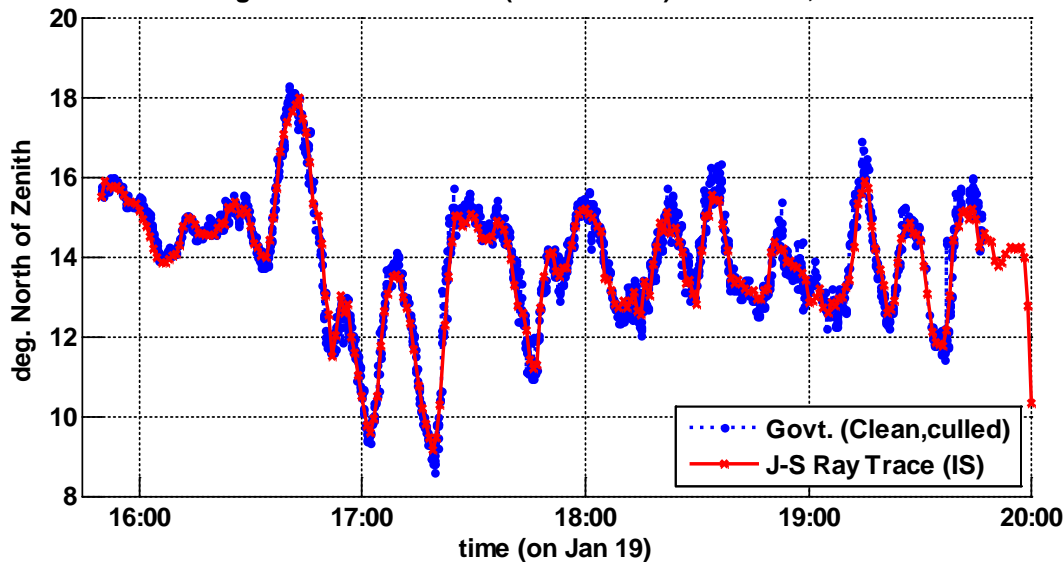
Degrees East of Zenith (Pond to G10): train O+VI, trace O



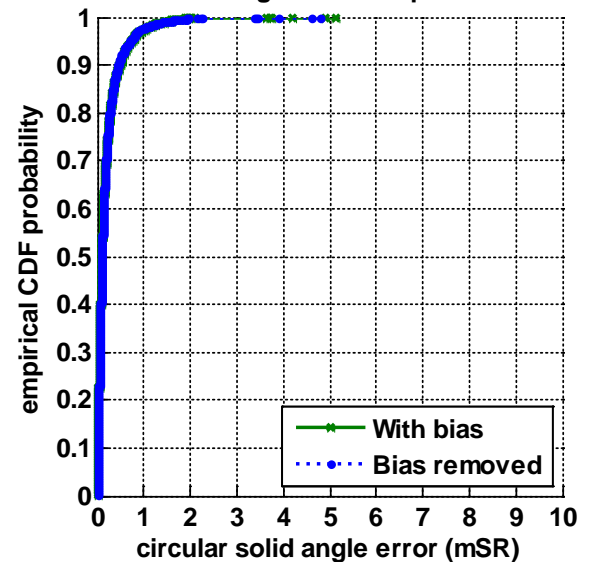
In-plane Err. w.r.t. Array Est.



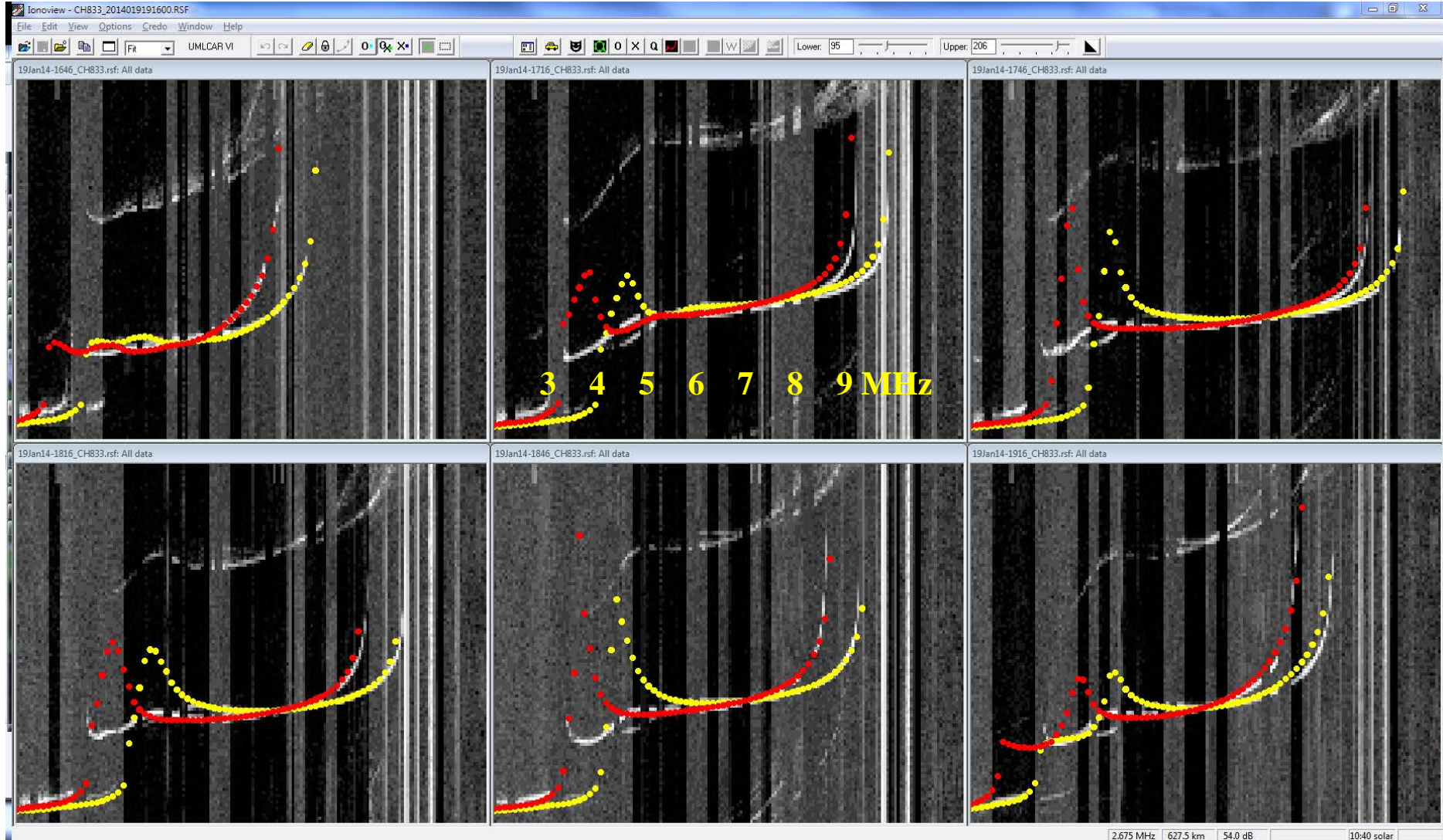
Degrees North of Zenith (Pond to G10): train O+VI, trace O



Solid Angle Error Emp. CDF



Ionogram comparison



Lessons

- **Notably, delay-Doppler assimilation of KRP data is sufficient to define TIDs in the ionosphere model and track AoA deviations**
- **Delay-Doppler-AoA assimilation of KRPs works a bit better (not surprisingly)**