Estimating Causes of Ionospheric Threats to GNSS-based Navigation Service with Data Assimilation

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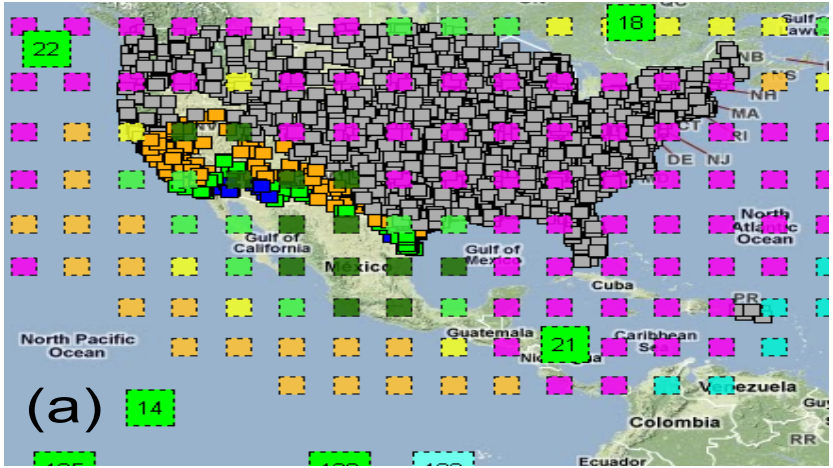
Outline

- Motivation
- Estimating Model Parameters from Ionospheric Reverse Engineering (EMPIRE)
  - Overview
  - Run configurations
- Results
- Conclusion

Motivation



Datta-Barua et al., (2014)

- Large error bounds on this ionospheric estimate
- Nominal ionosphere, ok to use
- Airport with precision approach unavailable
- Airport with precision approach available

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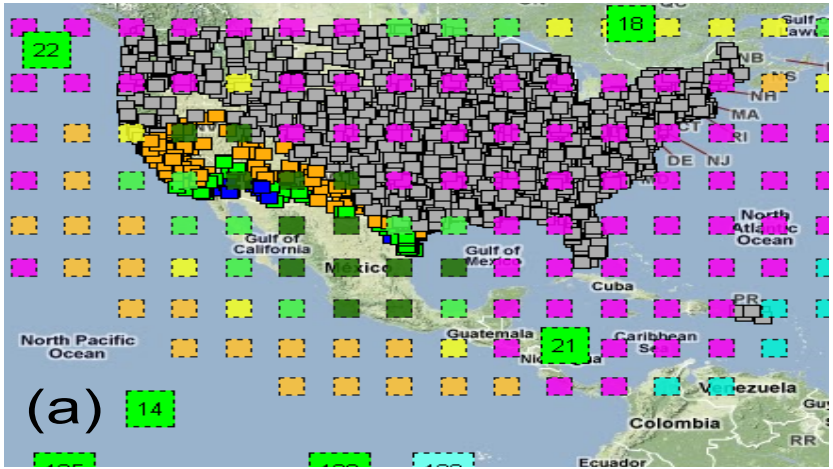

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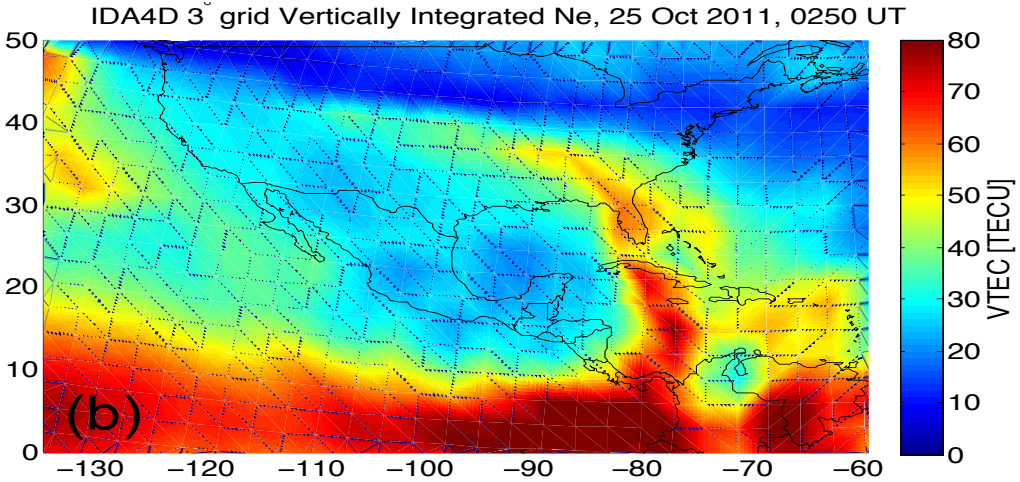

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Nighttime ionospheric localized enhancement (NILE) imaged using Ionospheric Data Assimilation 4-Dimensional (IDA4D)

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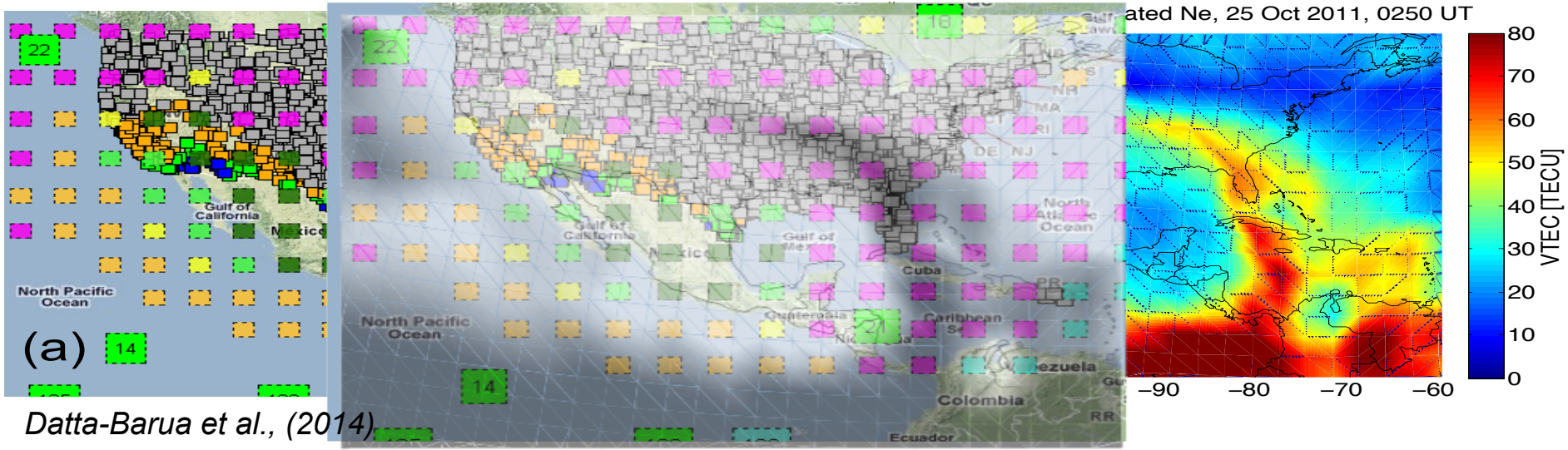
Motivation



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EMPIRE Overview

- Estimating Model Parameters from Ionospheric Reverse Engineering
  - Kalman filter assimilating global density rates and line-of-sight (LOS) Fabry-Perot interferometer (FPI) neutral wind data (*Miladinovich et al., 2016*)
  - Global electric potential (*Miladinovich et al.,2020*)
  - New: global neutral winds via vector spherical harmonics

$$\frac{dN}{dt} = P - L - \vec{\nabla}\cdot(N\vec{v})$$

$$\approx -\vec{\nabla}\cdot\left(N\left(\vec{u}_{\parallel} + \frac{-\vec{\nabla}V\times\vec{B}}{B^2}\right)\right)$$

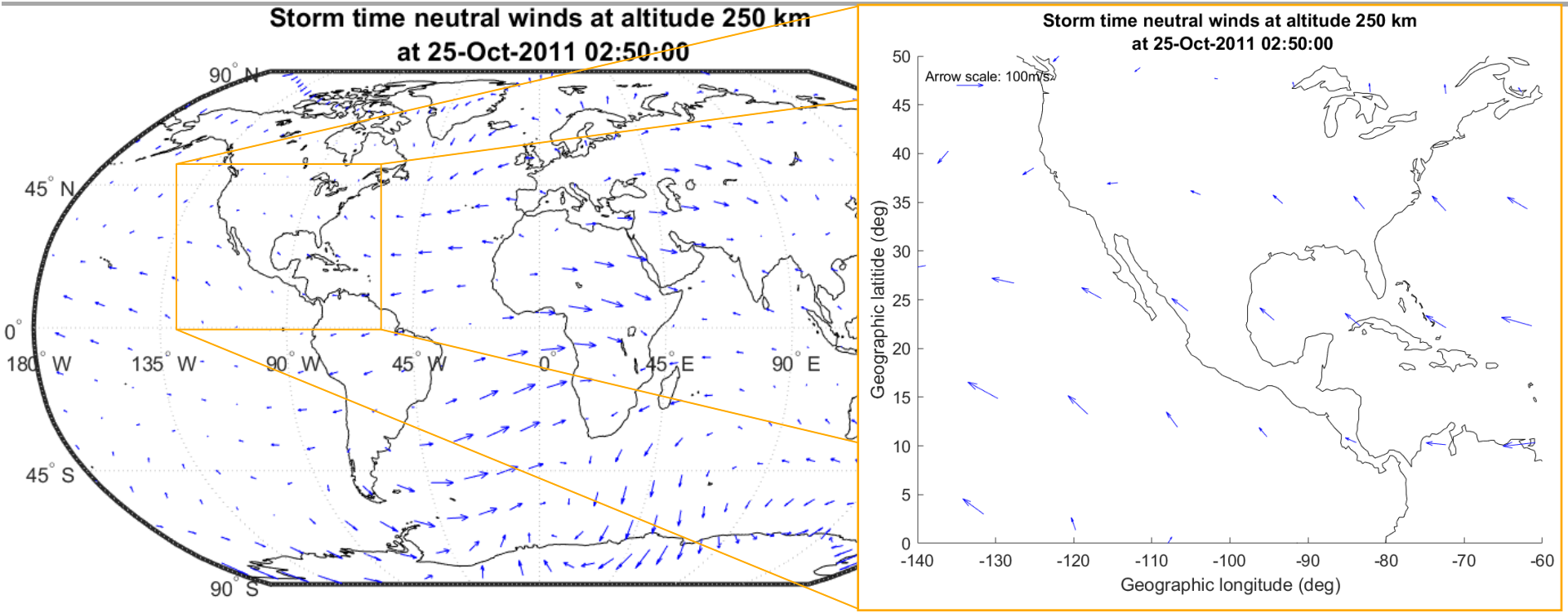
$$\begin{bmatrix} \frac{dN}{dt} \\ u_{LOS} \end{bmatrix} = \begin{bmatrix} [H_{u_m} + H_{u_z}] & [H_{exb}] \\ LOS & 0 \end{bmatrix} \begin{bmatrix} x_u \\ x_{exb} \end{bmatrix}$$

$$\mathbf{z} = \mathbf{Hx}$$

Run configurations

- Domain
  - +/-80 deg magnetic lat, 360 lon, at 12 deg spacing
  - height 200-650 km, 50 km intervals
  - 20-minute epochs
  - October 25, 2011 00:00 – 09:00 UT
- Cases
  - Case 1: use only plasma density rates dN/dt from IDA4D
  - Case 2: use line-of-sight (LOS) winds at 250 km at U.S. site
- Compare to FPI

Case 1 dN/dt only: winds at 250 km



Case 1 dN/dt only: validating with FPI wind measurements

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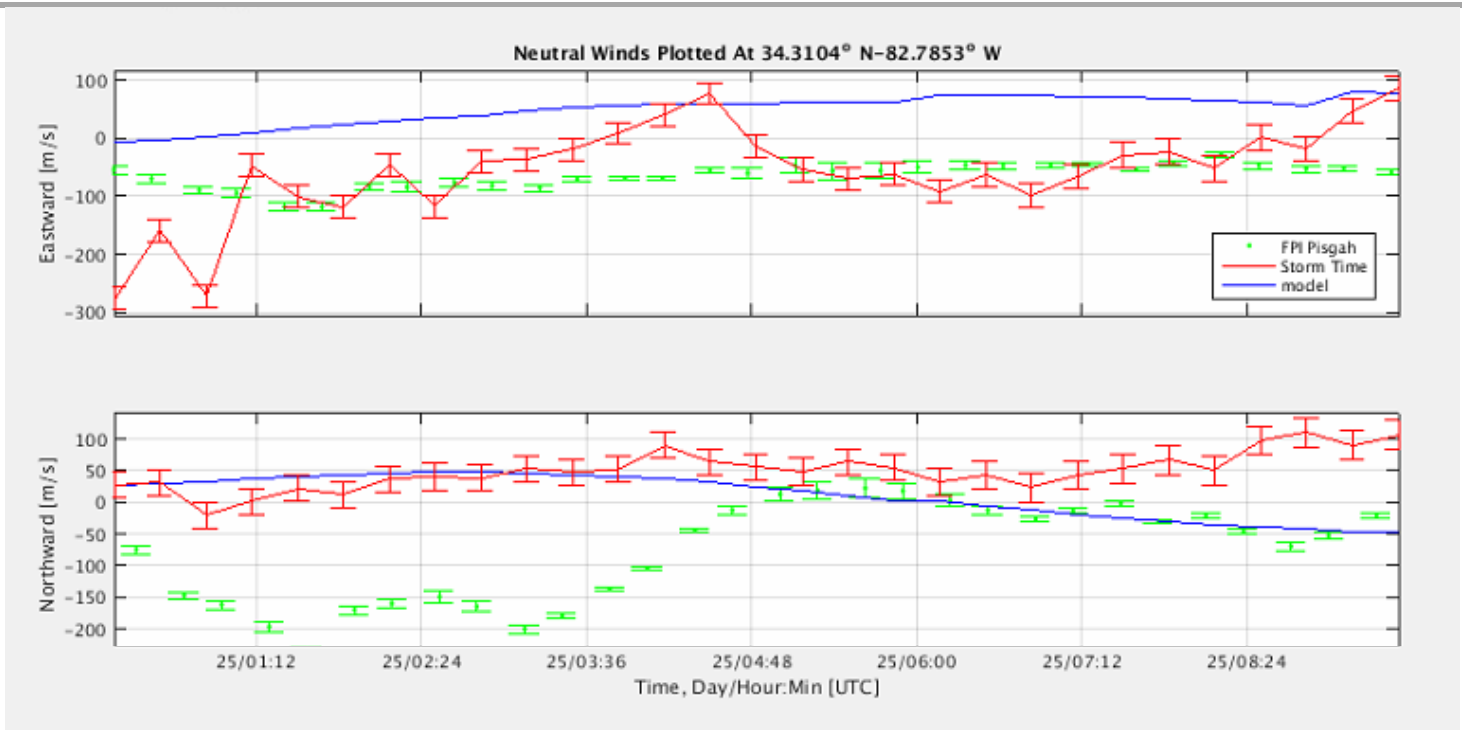
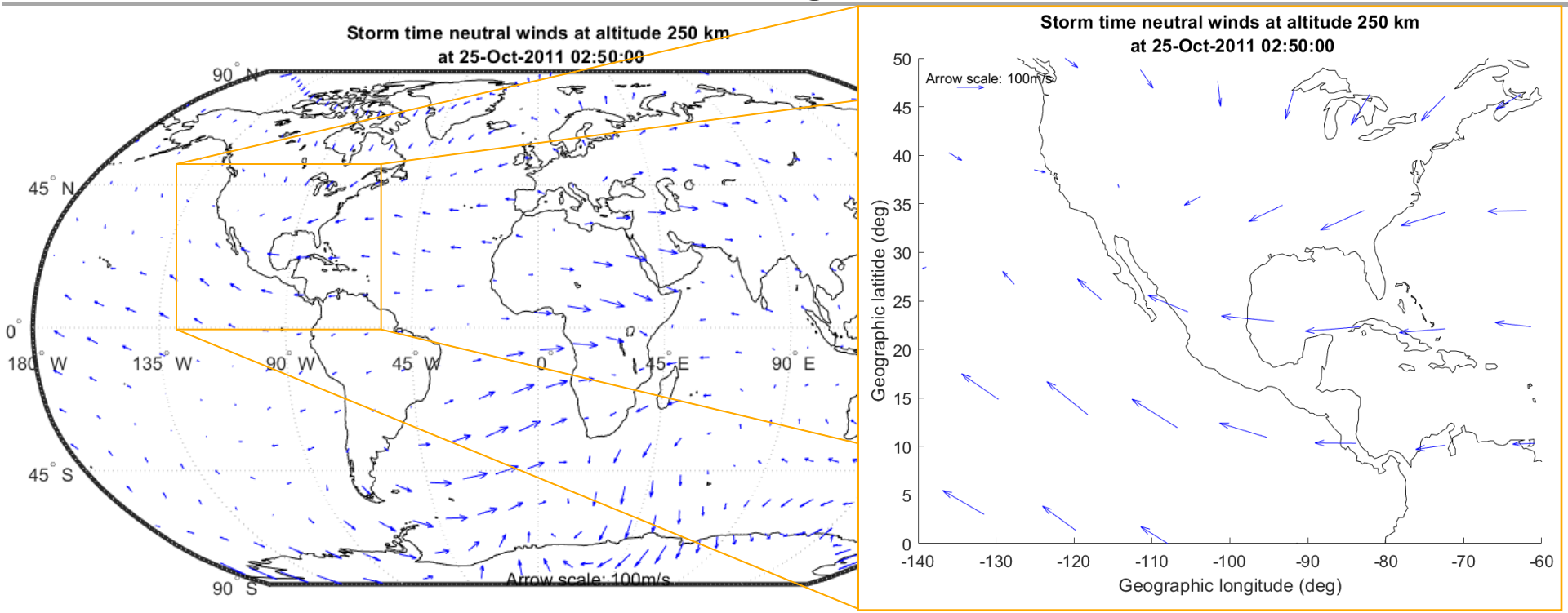
Horizontal wind model 2014

EMPIRE estimate

FPI measurement projected to horizontal



Case 2: assimilating dN/dt and FPI line of sight winds



Case 2 dN/dt + FPI: confirming FPI winds are assimilated

Horizontal wind model 2014

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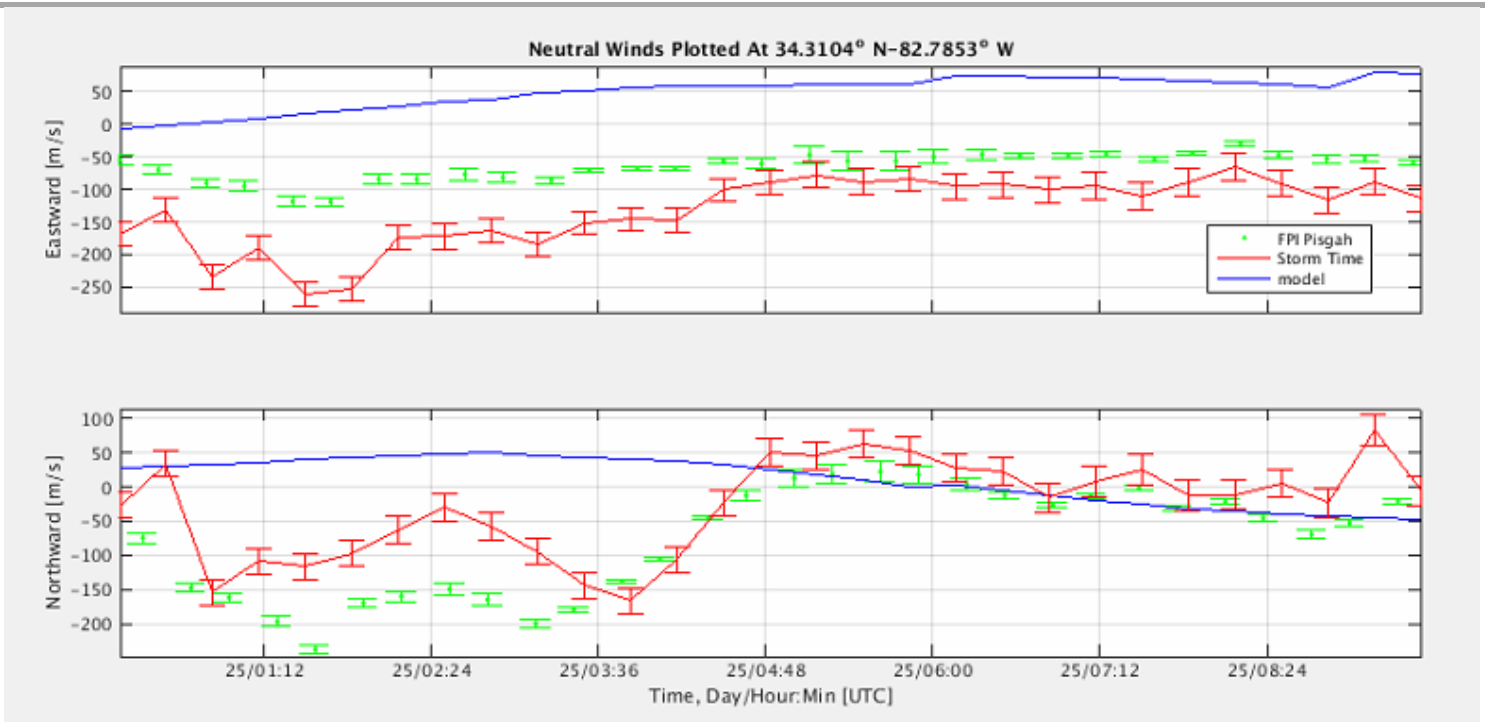
FPI measurement projected to horizontal



Conclusion

- Plasma density rates, augmented with FPI neutral wind measurements enable global neutral wind estimation.
  - Global vector spherical harmonic basis for neutral winds
- Preliminary results will be used to analyze the neutral winds during a nighttime ionospheric localized enhancement over the southeastern U.S. (*Chartier et al., under review*)

References

Datta-Barua, S., T. Walter, G. S. Bust, and W. Wanner (2014), Effects of solar cycle 24 activity on WAAS navigation, Space Weather, 12, 4663, doi10.1002/2013SW000982

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Chartier, A., Datta-Barua, S., McDonald, S., Tate, J., Bust, G. S., Romeo, G., Schaefer, R., & Goncharenko, L., Night-time Ionospheric Localized Enhancements (NILE) Observed in North America Following Geomagnetic Disturbances, under review

EMPIRE

- Estimating Model Parameters from Ionospheric Reverse Engineering (EMPIRE)
  - Via Kalman filter, estimates global electric potential, assimilates global density rates and neutral wind data (Miladinovich et al., 2020)
  - New: estimates global neutral winds

$$Y_{lm}(\theta,\phi) = P_l^m(\cos\theta)\Phi_l^m(\phi)$$

$$u_\theta = (r\vec{\nabla}Y_{lm} + \vec{r}\times\vec{\nabla}Y_{lm})\cdot\hat{\theta}$$

$$u_\phi = (r\vec{\nabla}Y_{lm} + \vec{r}\times\vec{\nabla}Y_{lm})\cdot\hat{\phi}$$

Measurement update:

$$\mathbf{x}_a = \mathbf{x}_f + (\mathbf{P}_a\mathbf{H}^T\mathbf{W})(\mathbf{z} - \mathbf{H}\mathbf{x}_f)$$

$$\mathbf{P}_a = (\mathbf{H}^T\mathbf{W}\mathbf{H} + \mathbf{P}_f^{-1})^{-1}$$

Time update:

$$\mathbf{x}_f = \mathbf{x}_b + (\mathbf{x}_a - \mathbf{x}_b)\Phi$$

$$\mathbf{P}_f = \mathbf{P}_a\Phi^2 + \mathbf{P}_b(1-\Phi)^2$$