ATMOSPHERIC & SPACE TECHNOLOGY RESEARCH ASSOCIATES

SCIENCE + TECHNOLOGY + APPLICATIONS // *Bringing it all together*

Modeling and Multi-Instrumented Observations of Traveling Ionospheric Disturbances

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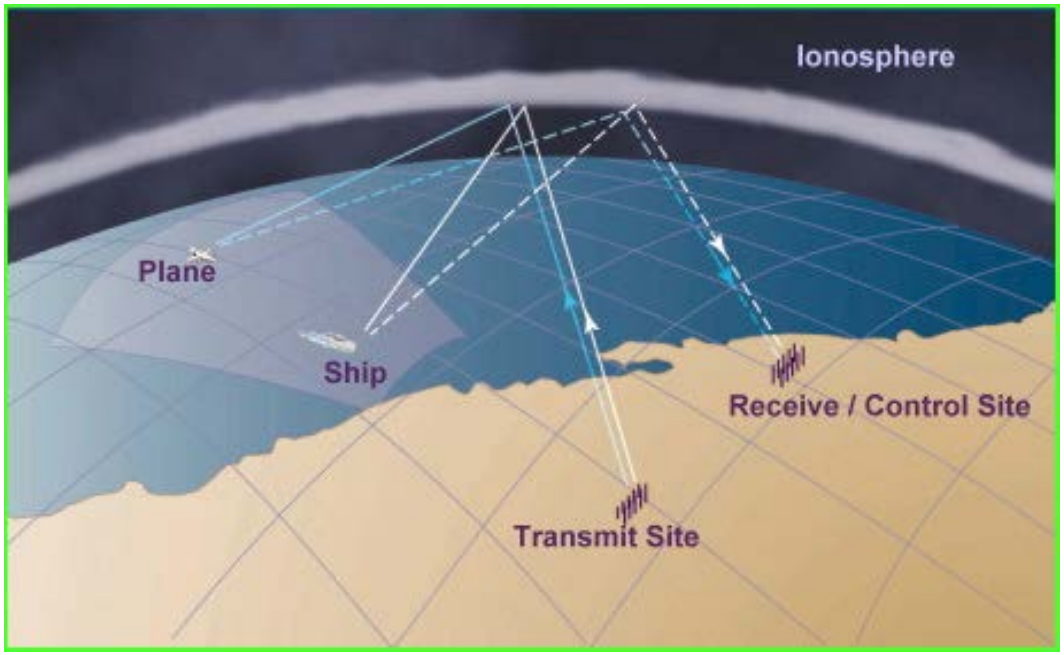
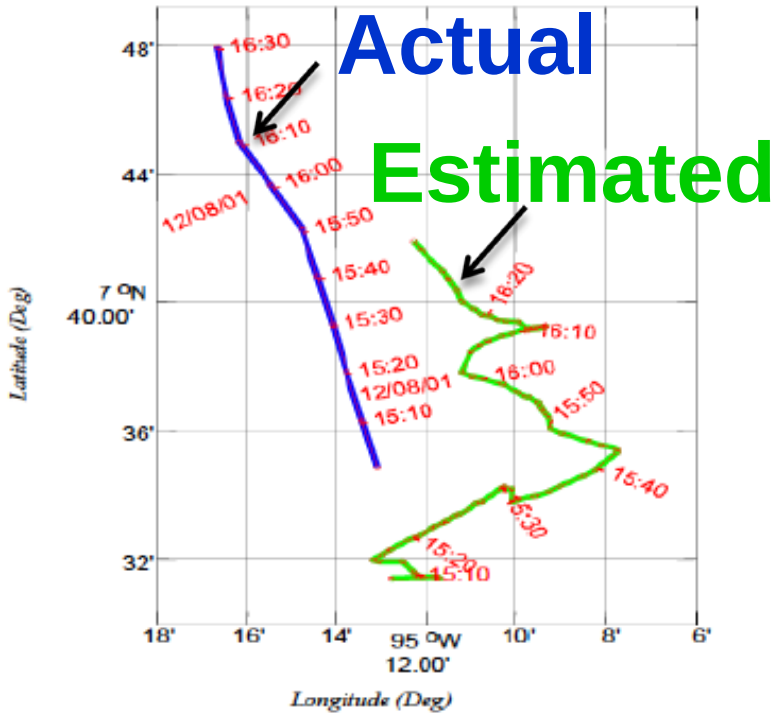
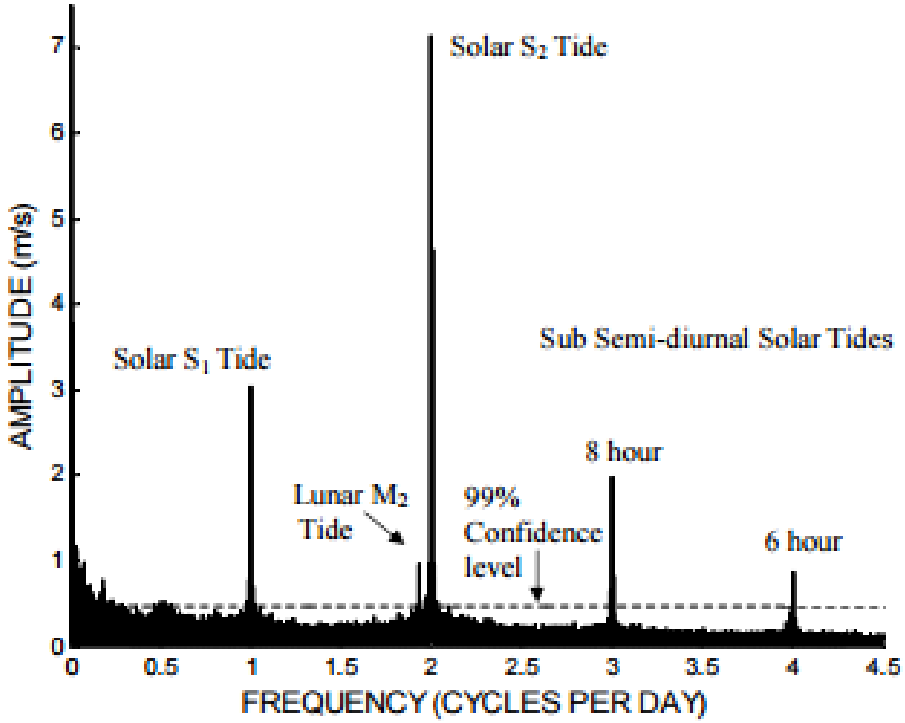
Motivation

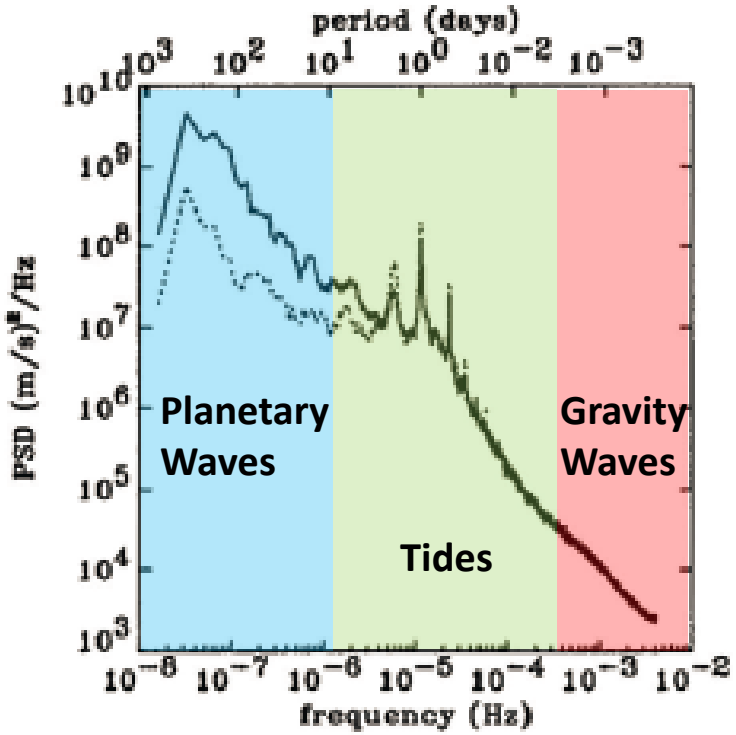
- Large-scale TIDs cause corrugations in the bottomside ionosphere, which are a source of tip and tilt errors in OTHR target location
- Improvement in Coordinate Registration (CR) requires improved characterization (and prediction) of ionosphere tilts.





Wave Spectrum

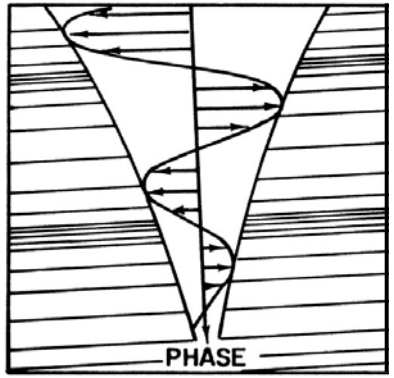




Sanford et al., **Atmos. Chem. Phys., 2006**

Introduction

- Traveling Ionospheric Disturbances (TIDs) are perturbations in the ionosphere caused by atmospheric gravity waves (AGW)
- The motion of the neutral gas in the AGW sets the ionosphere into motion through ion-neutral collisions.
- The signature of the AGW is imposed as variations of electron density in the ionosphere, resulting in a TID.



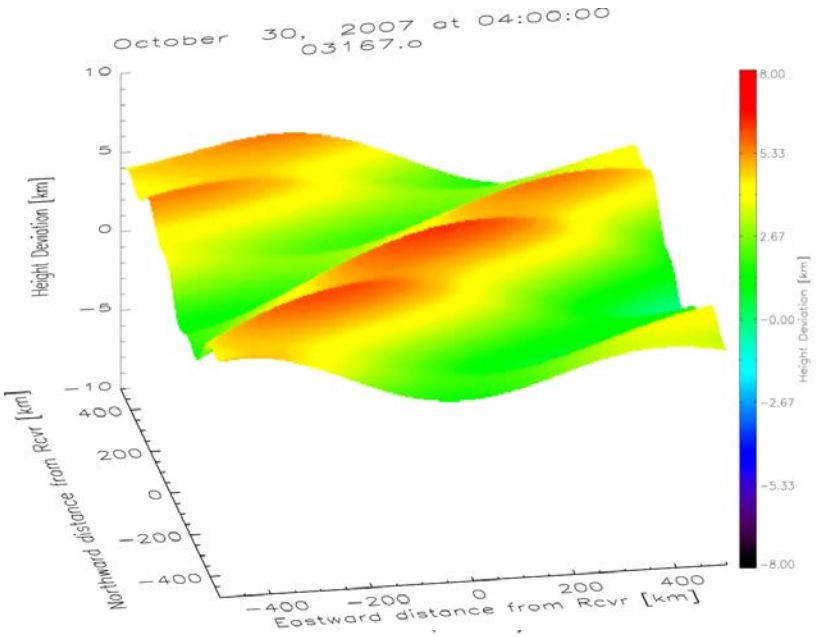
Growth with Altitude

ρV^2

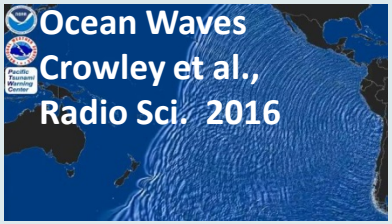
Restoring Force

AWs - Pressure

GWs - Gravity



AGW Sources

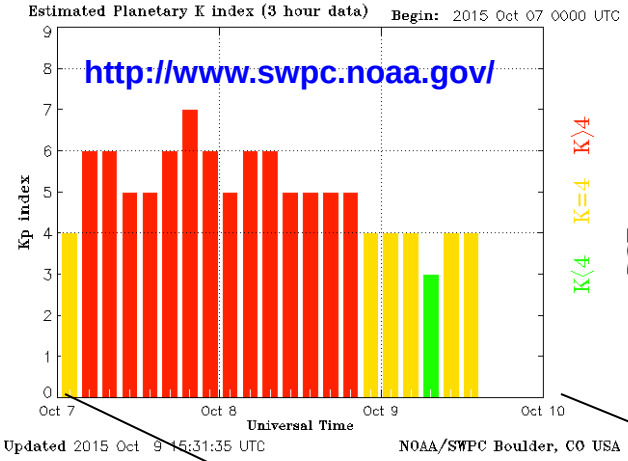


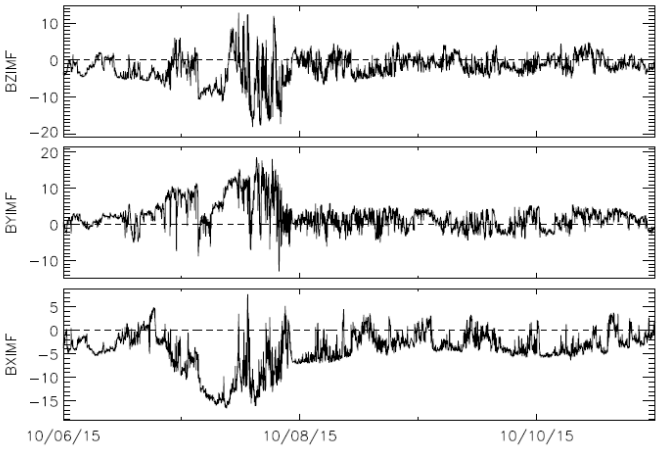
Objectives

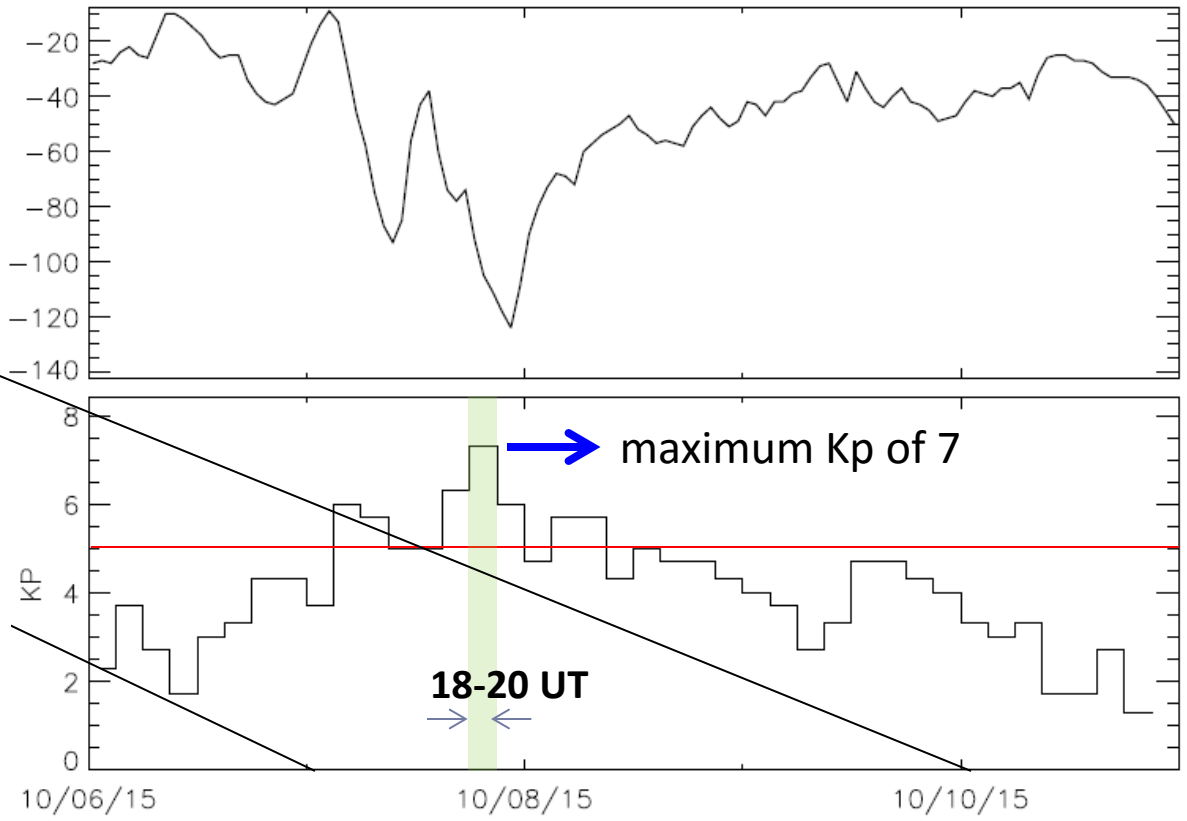
- Use an HF Doppler system (called TIDDBIT) and ground-based Global Positioning System (GPS) receivers to study TIDs
  - This study focuses on an LSTID event that occurred during a geomagnetically active period during October 7-8, 2015.
- Quantify wave parameters of the observed LSTIDs
- Use a numerical model (AMIE) to investigate the auroral source of the LSTIDs.
- Use TIME-GCM to simulate the LSTID and investigate the underlying physical process

October 7, 2015 Geomagnetic Storm

- A coronal hole high speed solar wind stream generated a G3-level geomagnetic storm







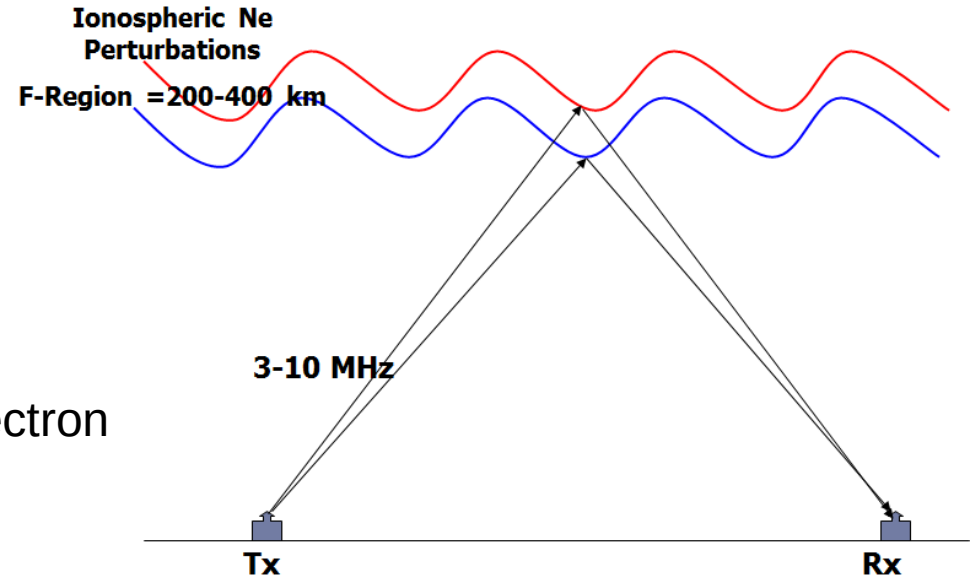
TIDDBIT HF Doppler System

- The TIDDBIT HF Sounder records HF Doppler shifts of the ionospheric layer, typically with three transmitters and one receiver in a spatial array
- Two frequencies are transmitted, corresponding to reflections from two different altitudes.
- The measurements are processed to calculate horizontal and vertical velocities, azimuths and amplitudes ranging from the acoustic (1-min periods) to the gravity wave (10-90 min periods) regime.

Radar Principle

$\Delta f = -1/\lambda(d\phi/dt)$

$d\phi$ can be caused by:
a) changes in reflection height
b) changes in refractive index (electron density profile)



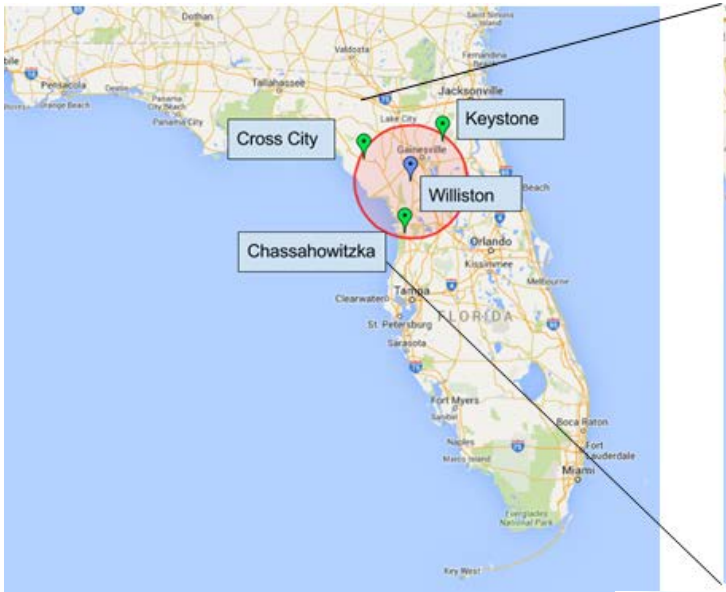
Florida TIDDBIT

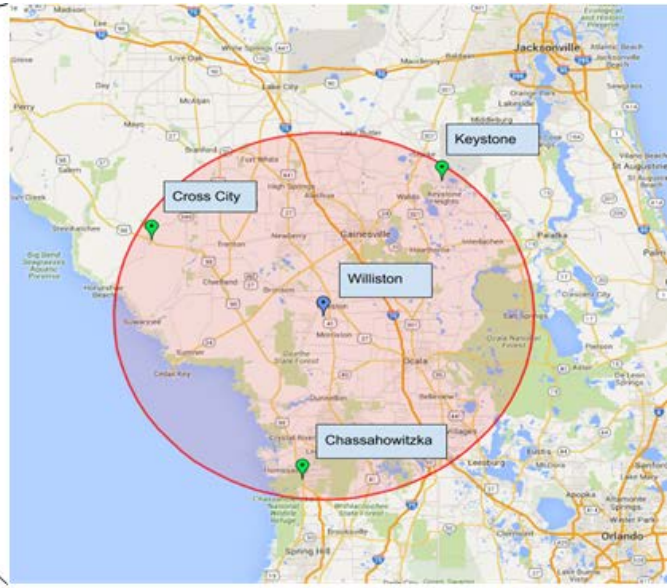
- The Florida TIDDBIT was deployed in September 2015 to study TIDs at a mid-latitude site.

Spacing: 50 – 300 km

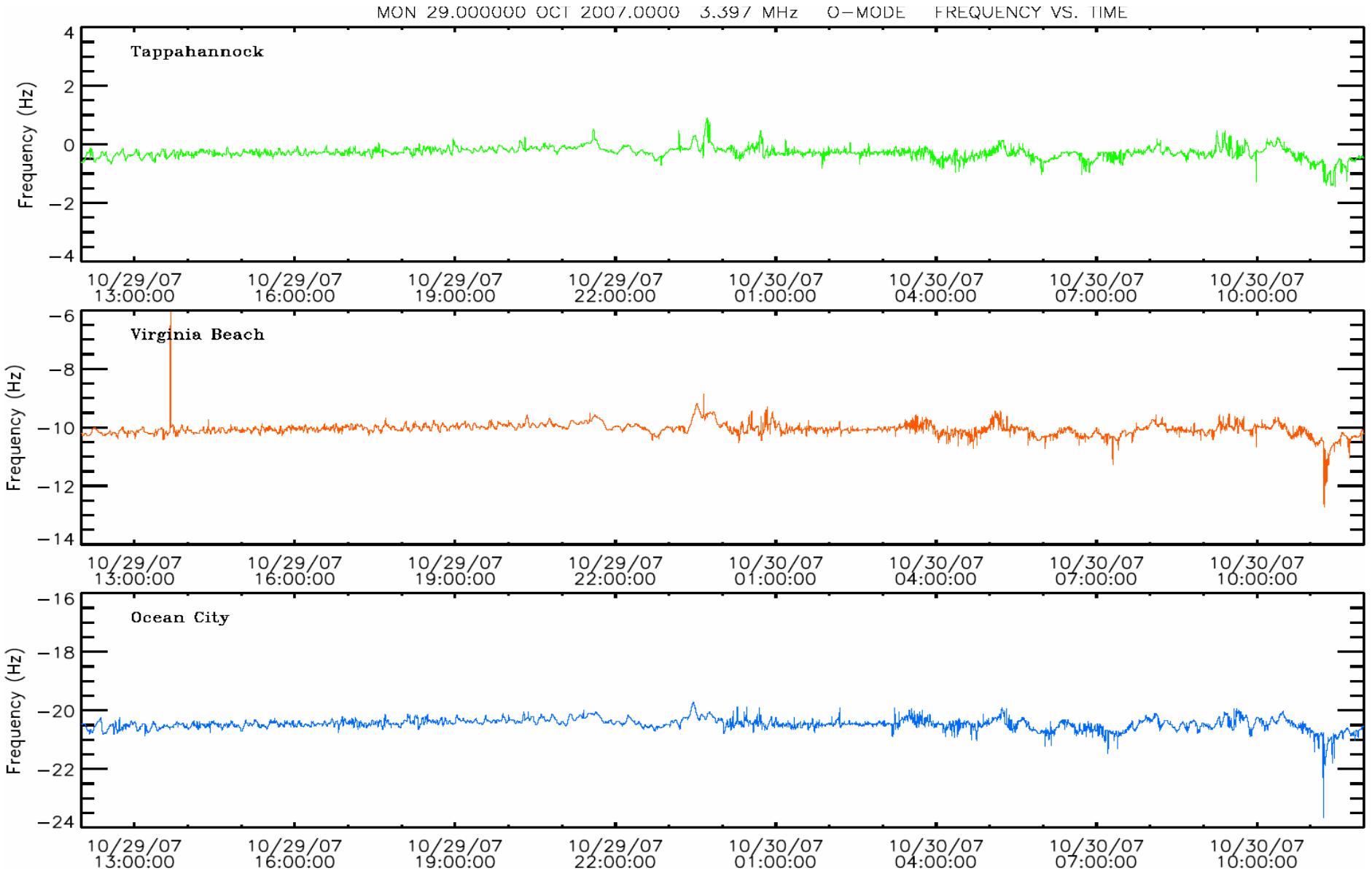
Dual Frequency

CW system



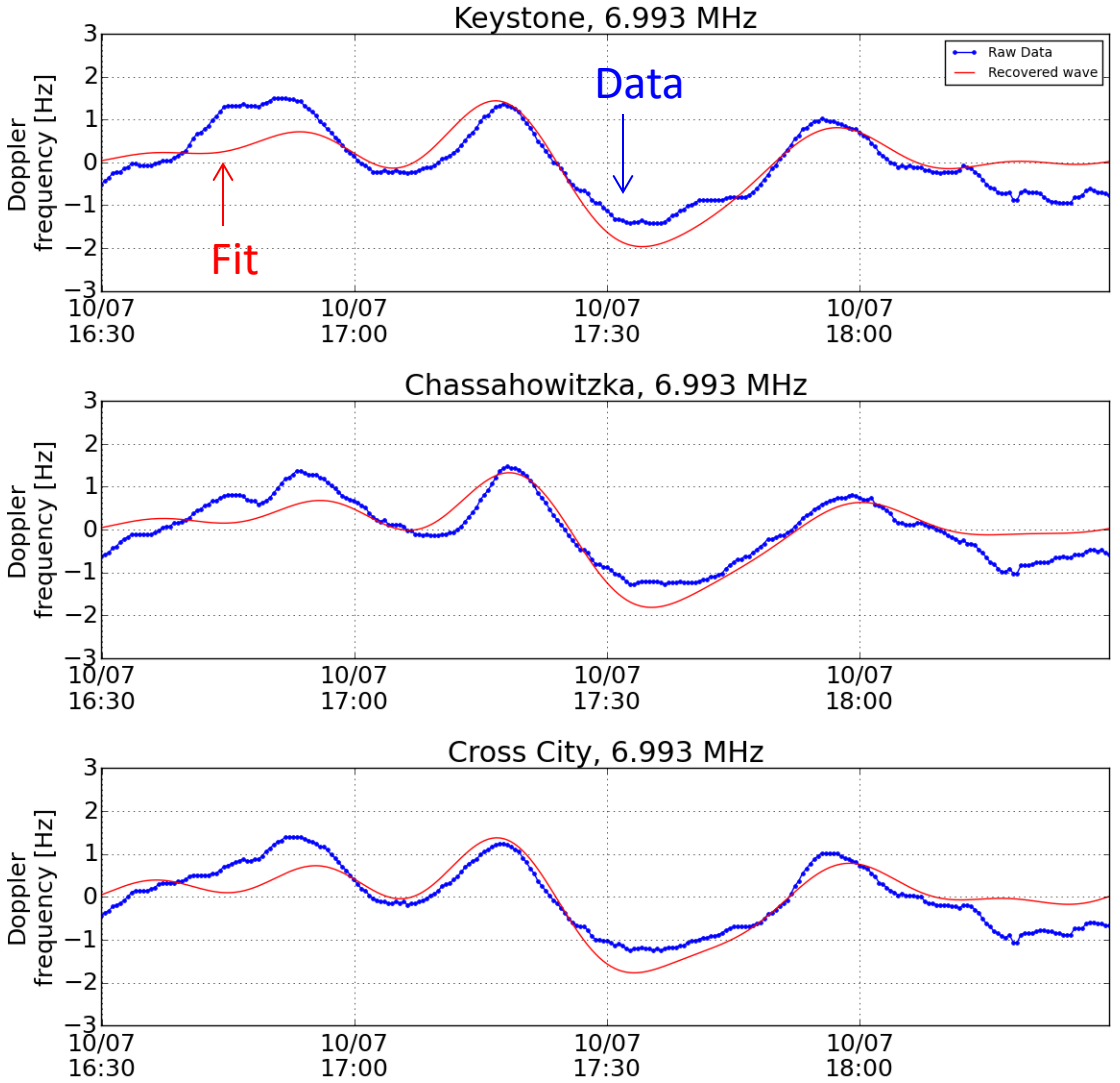


TIDDBIT Raw Data: Example



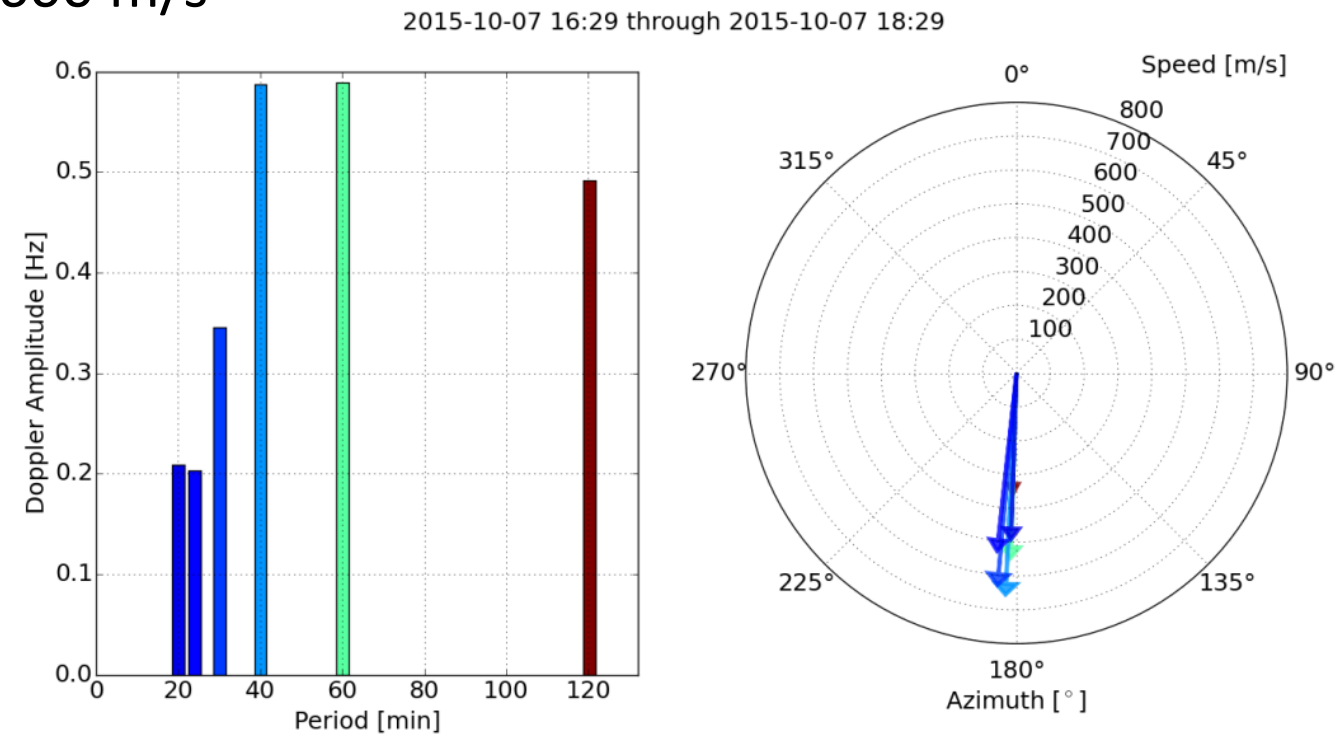
FL TIDDBIT DATA

- TIDDBIT data from a 2-hour duration on October 7, 2015
- Quasi-periodic variation in the Doppler frequency
- Visible signatures of LSTIDs in the measured Doppler shifts



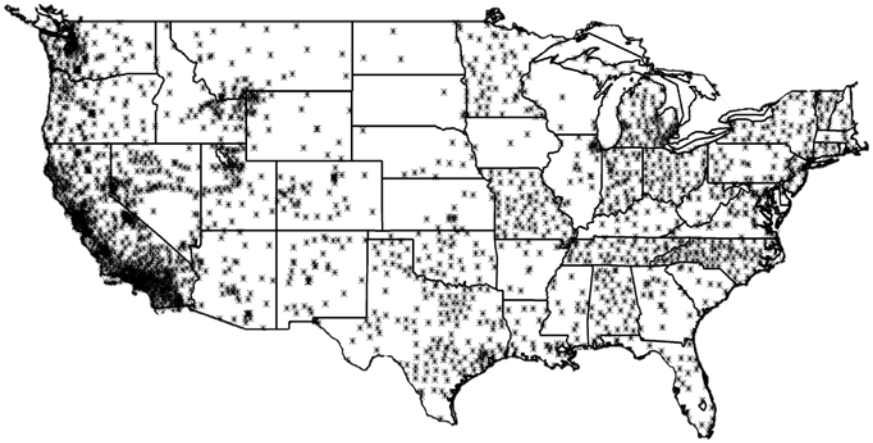
LSTID Characterization from TIDDBIT Data

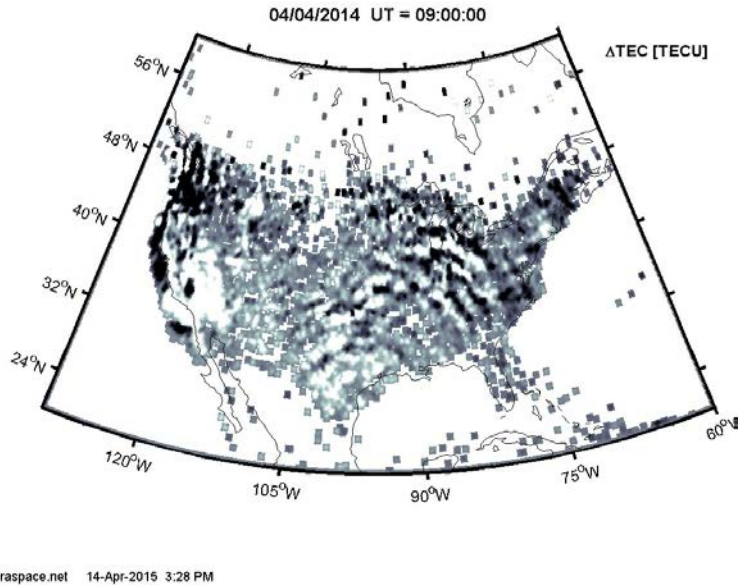
- Based on the FFT analysis we find dominant LSTID periods near 20-, 30-, 40- and 120-minutes.
- *Azimuth:* ~-180°
- *Phase speeds:*
- 350-600 m/s



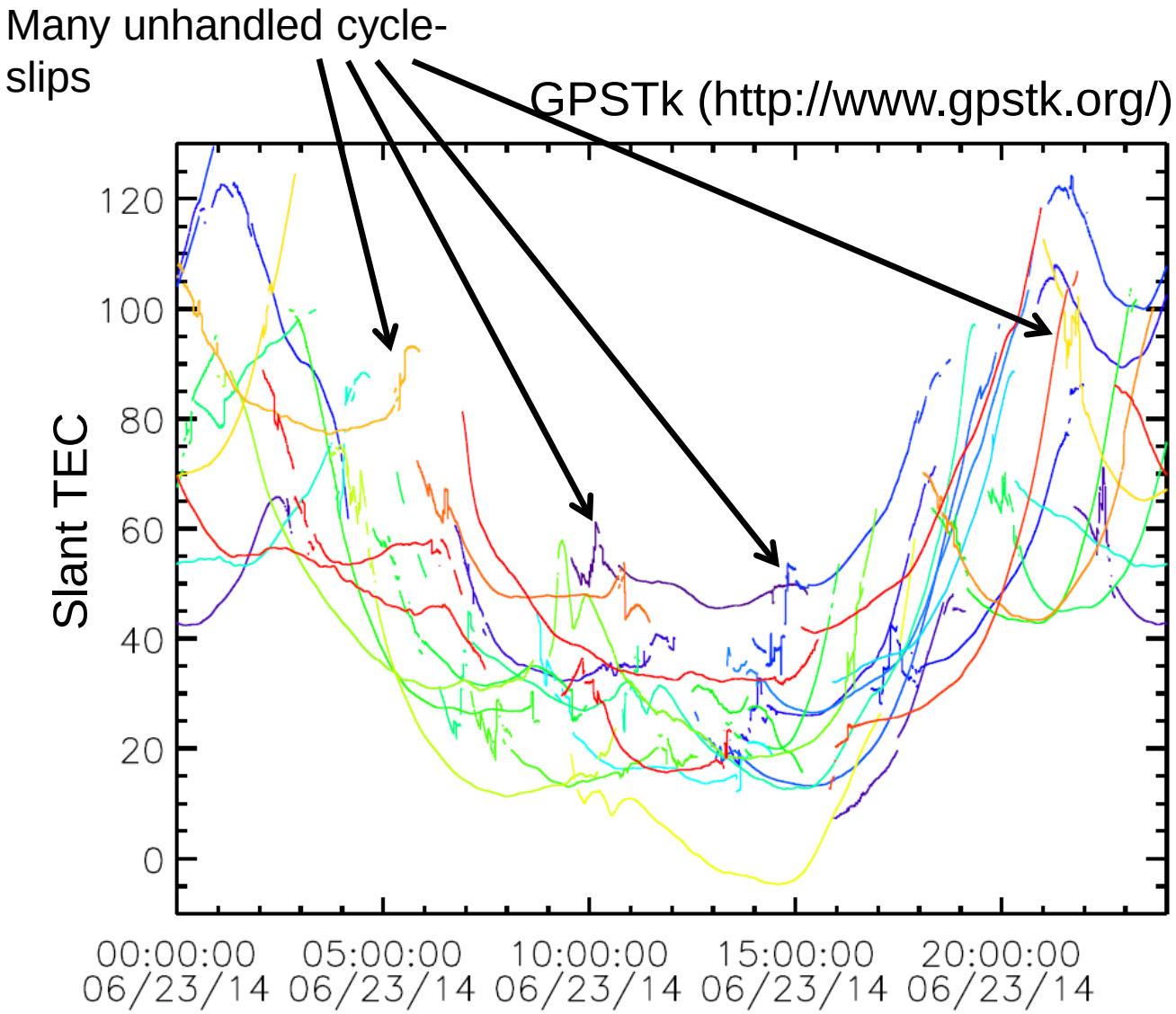
GPS TEC Data

- We use dual-frequency GPS receivers in the United States to calculate the total electron content (TEC).
- Data from ~4000 receivers are combined to create 2D spatial maps of TEC perturbations caused by TIDs [e.g., Tsugawa 2007; Nishioka et al., 2013; Azeem et al., 2015].
  - Important to consider cycle clips
- ***Spatial Resolution*** **(lat × lon):** 0.15 ° × 0.15 °
- ***Time Resolution:*** 30 sec

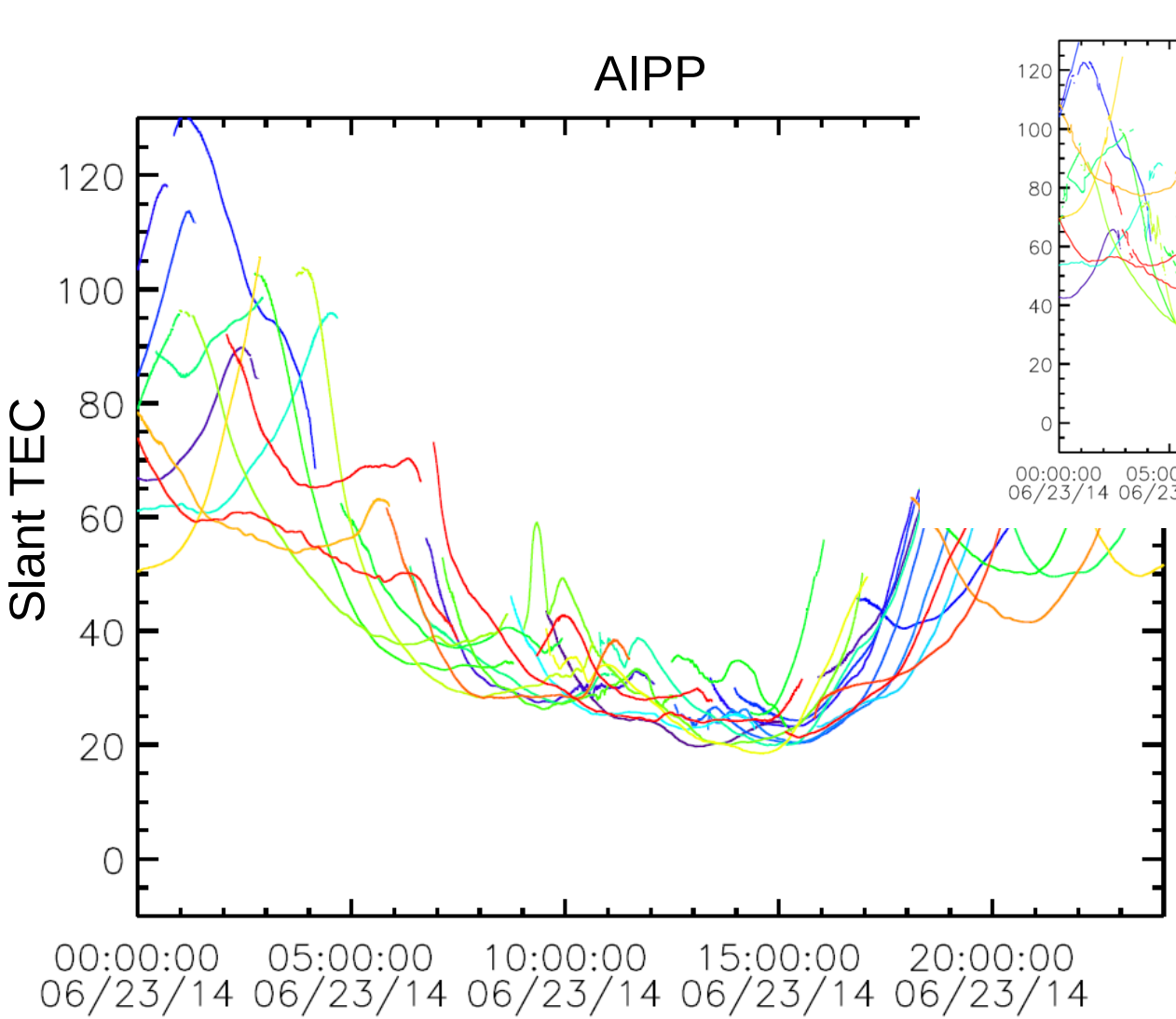


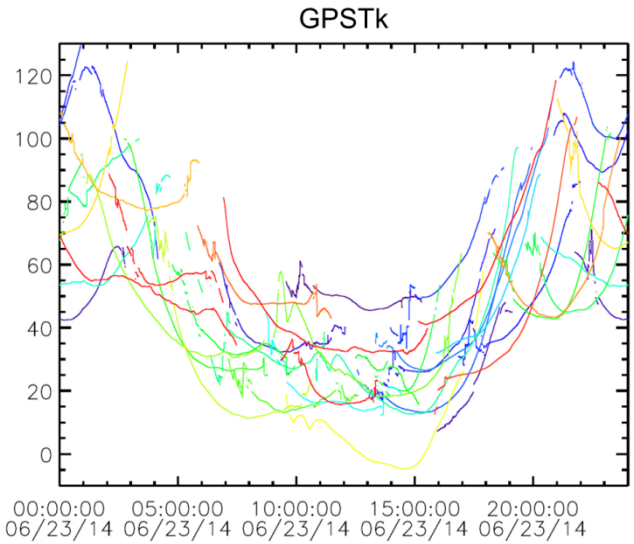


24 Hours of 1-second GPS Slant TEC Data Processed by GPSTk

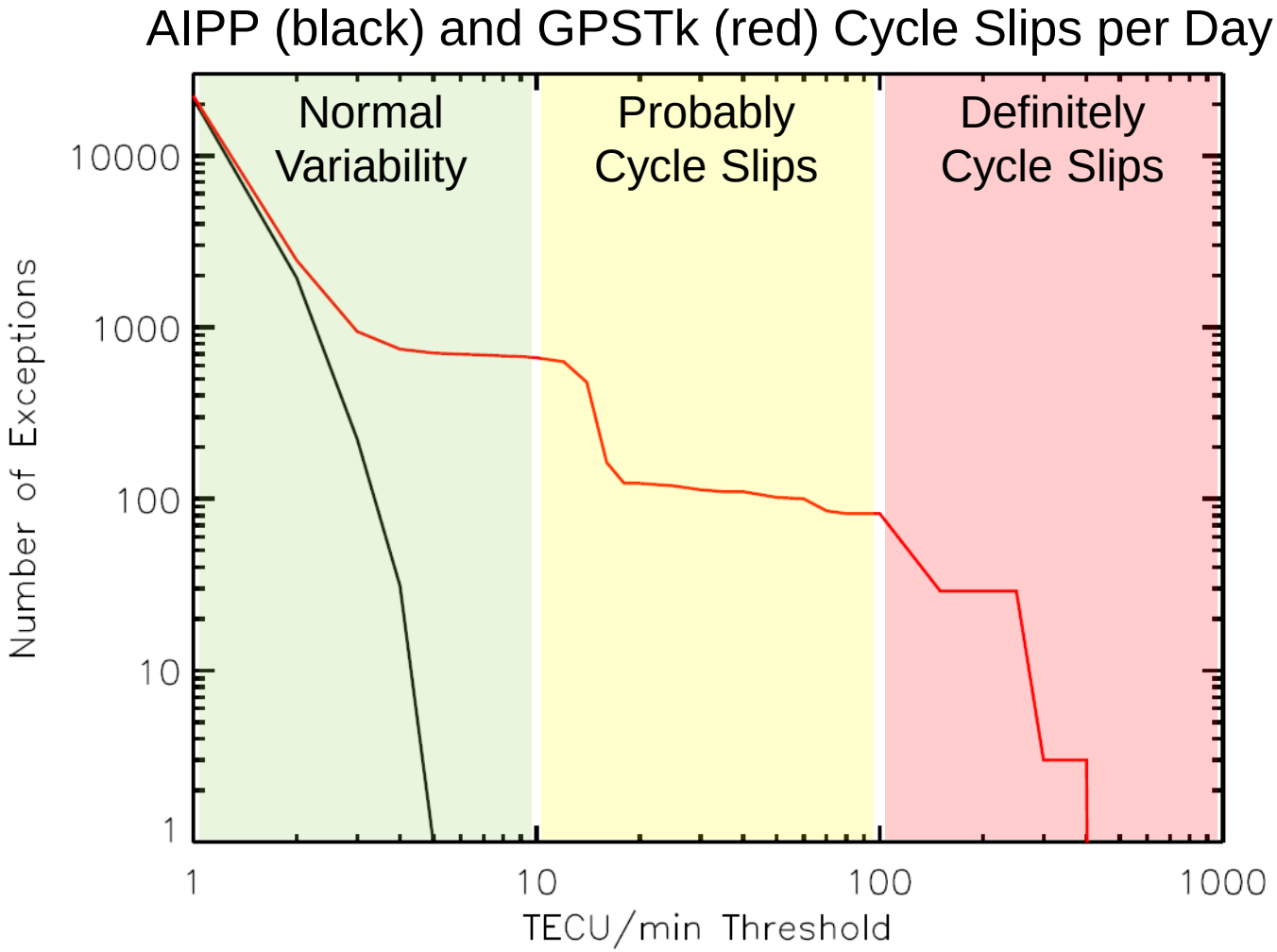


24 Hours of 1-second GPS Slant TEC Data Processed by AIPP



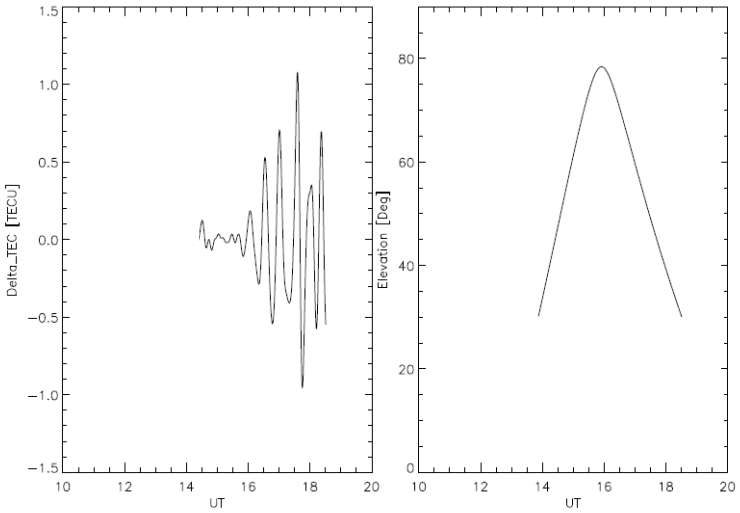


Comparison of Cycle-Slips Remaining in Data After Processing

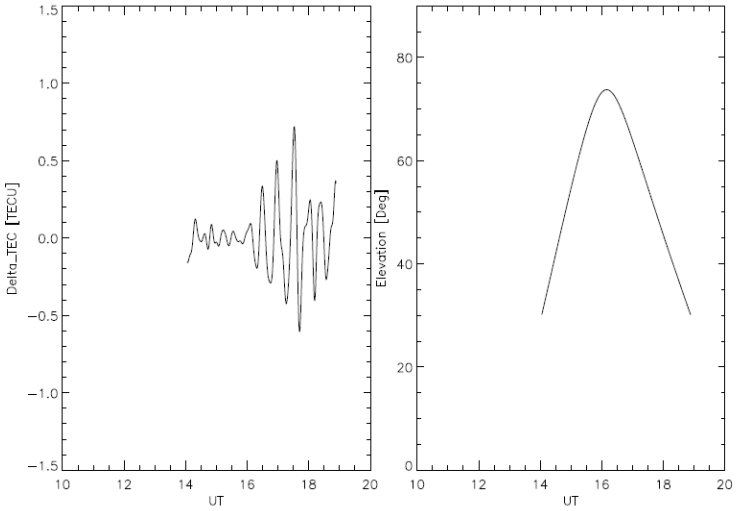


TEC Variations

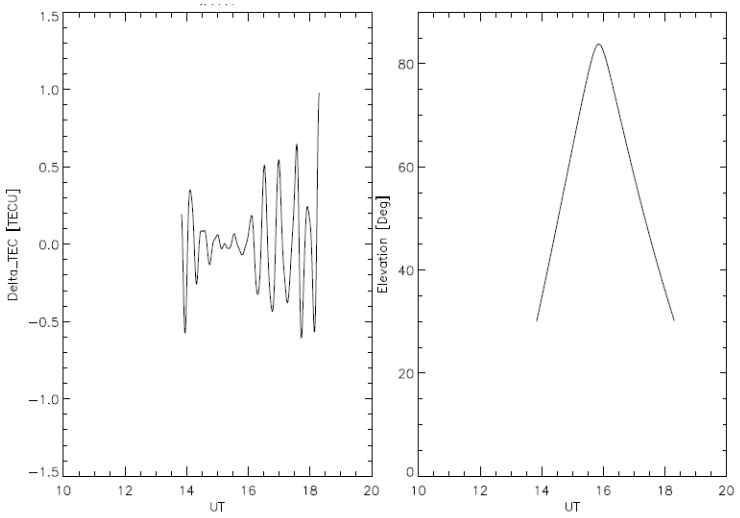
ALJA: Jasper, AL **PRN = 6**



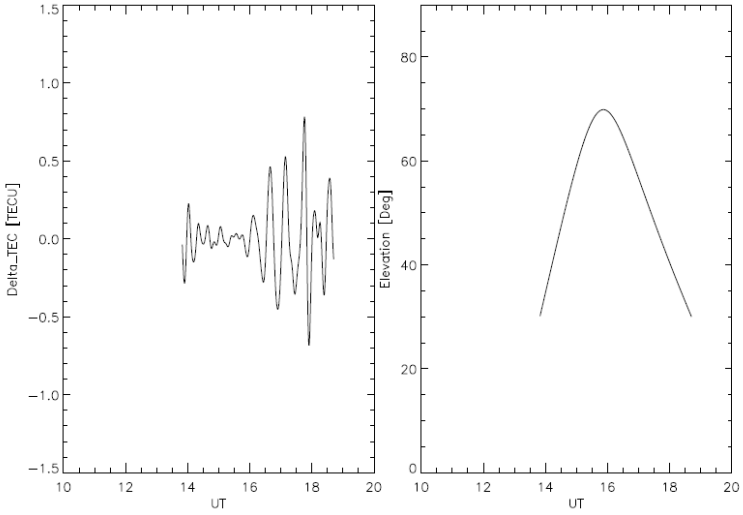
NCCO: Concord, NC **PRN = 6**



ARLR: Little Rock, AR **PRN = 6**



FLBN: Bunnell, FL **PRN = 6**

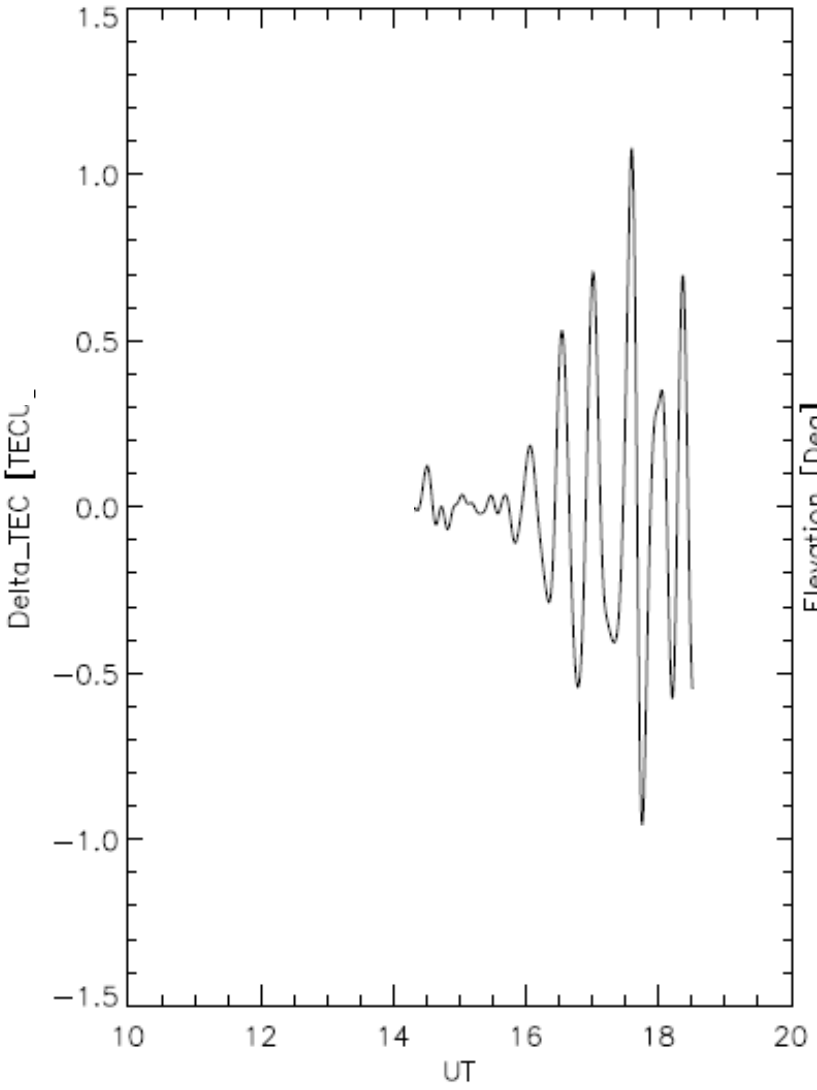


TEC Variations

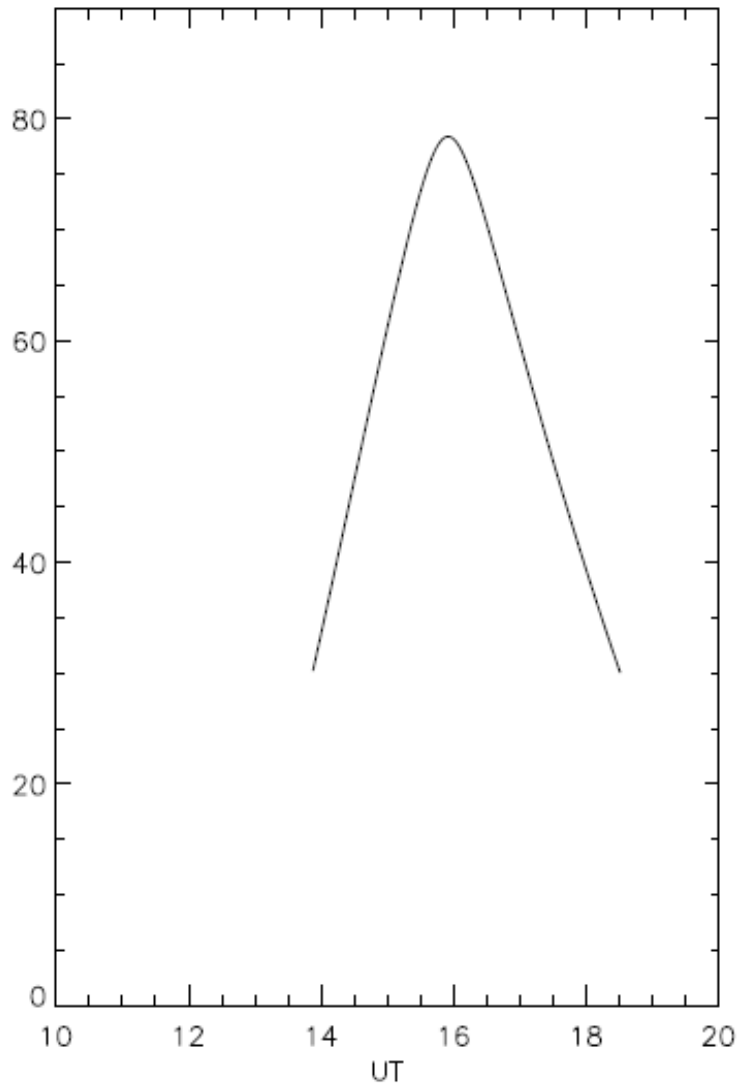
❖Science
❖ Technology
❖ Applications
Bringing It All Together

ASTRA

ALJA: Jasper, AL

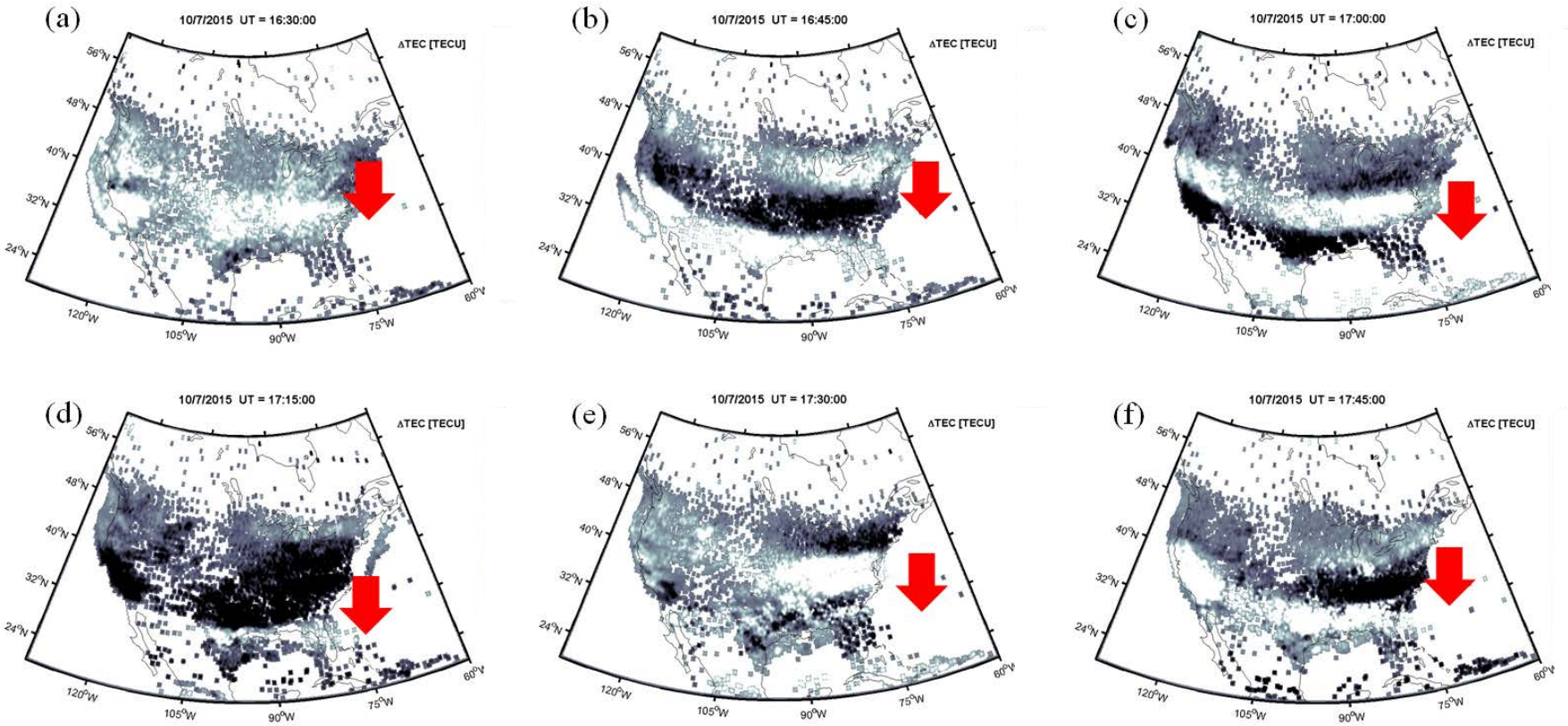


PRN = 6



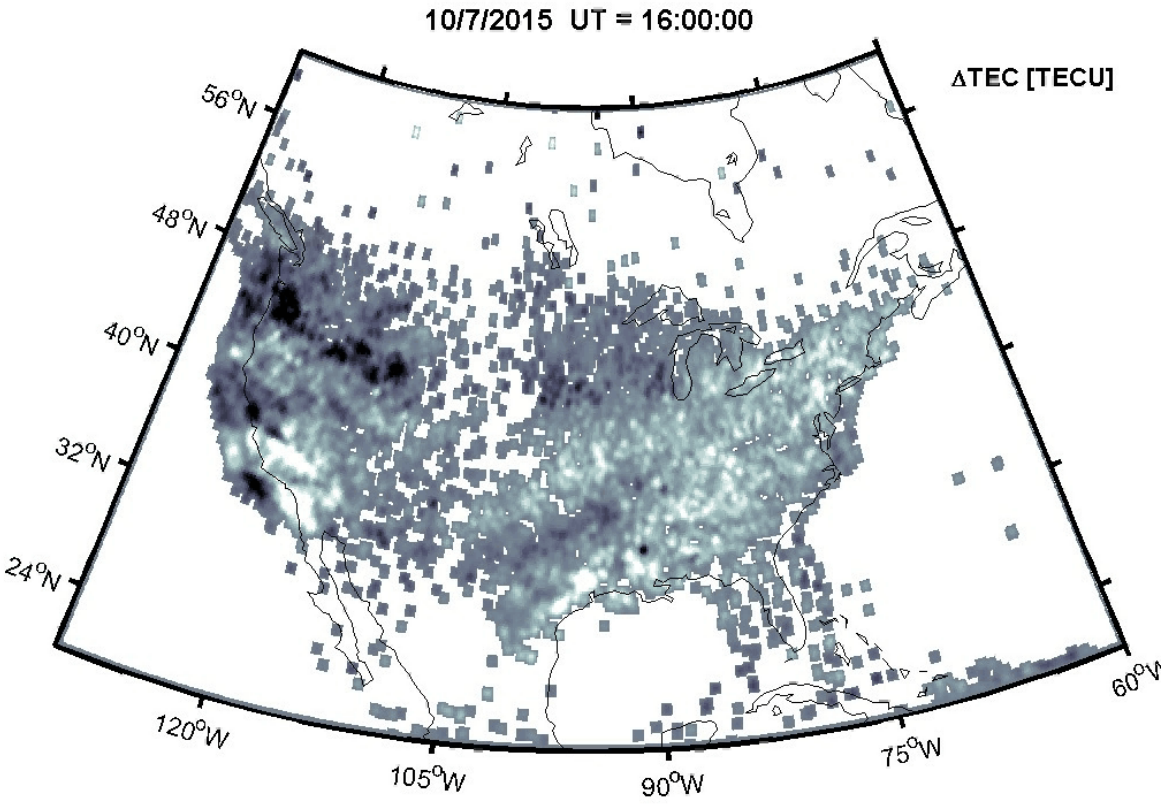
LSTID in GPS TEC Data

- 2D maps of TEC perturbations from 16:30 UT to 17:45 UT at 15 min cadence on Oct. 7, 2015.
- These maps show LSTID wavefronts propagating southward throughout the US.



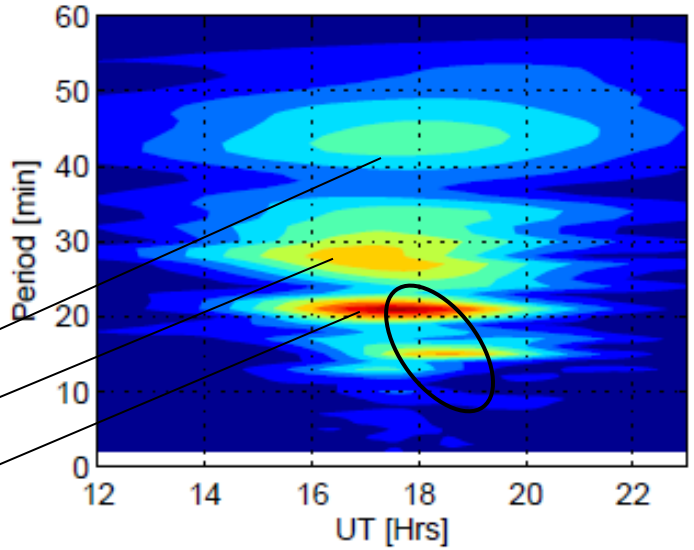
LSTID in GPS TEC Data

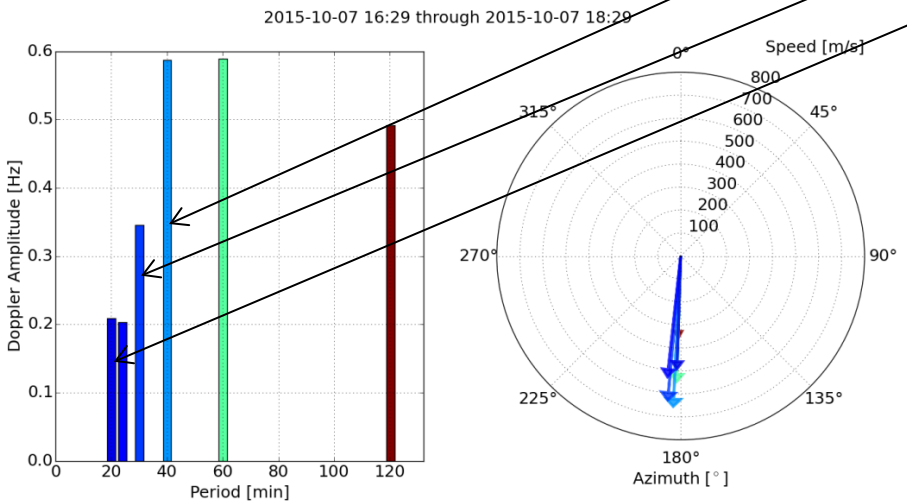
- 2D map of TEC perturbations at 1 min cadence.
- The animation shows LSTID wavefronts propagating southward throughout the US.

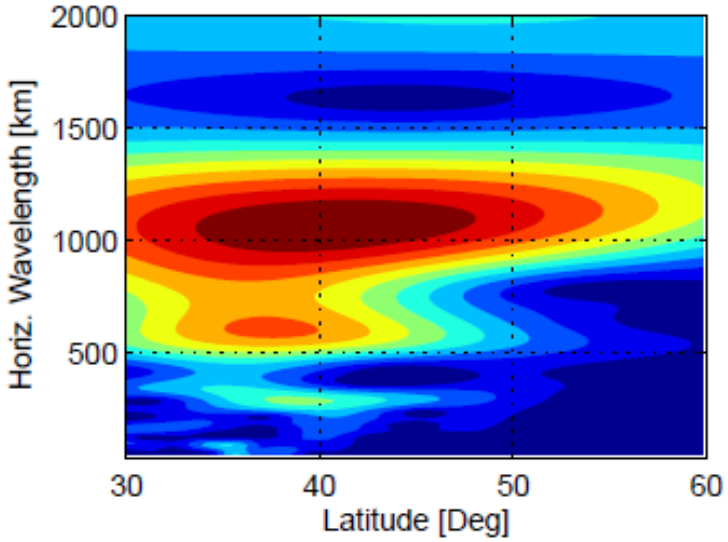


LSTID in GPS TEC Data

- GPS TEC maps illustrate the spatial extent and propagation of the TIDs.
- The amplitude of the LSTID in raw TEC data is about ±0.8 TECU.

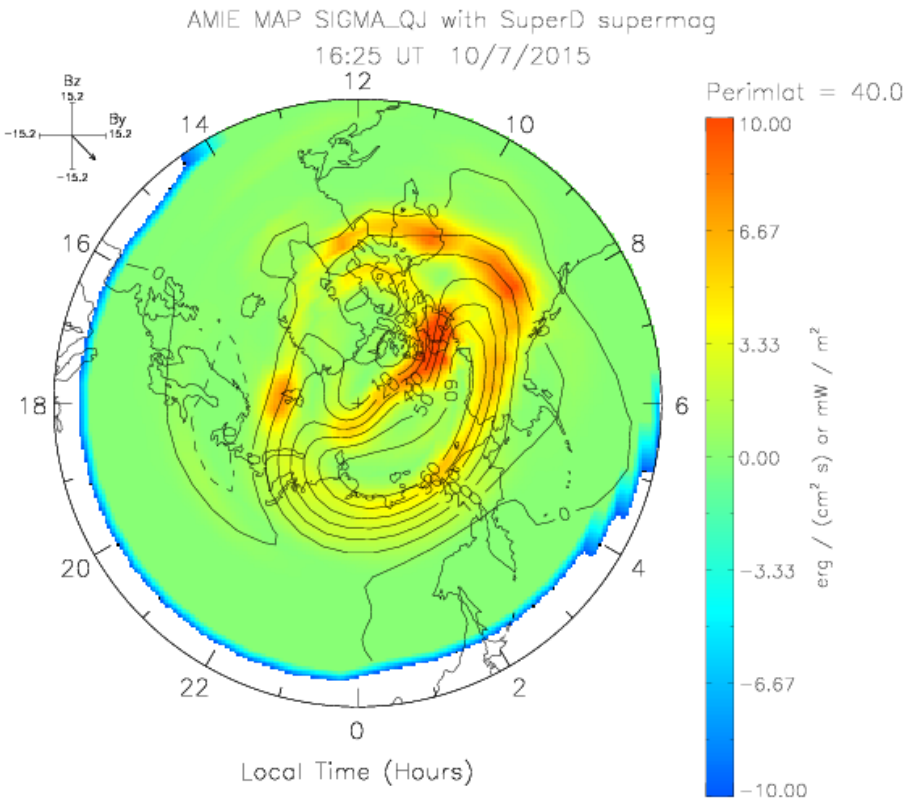




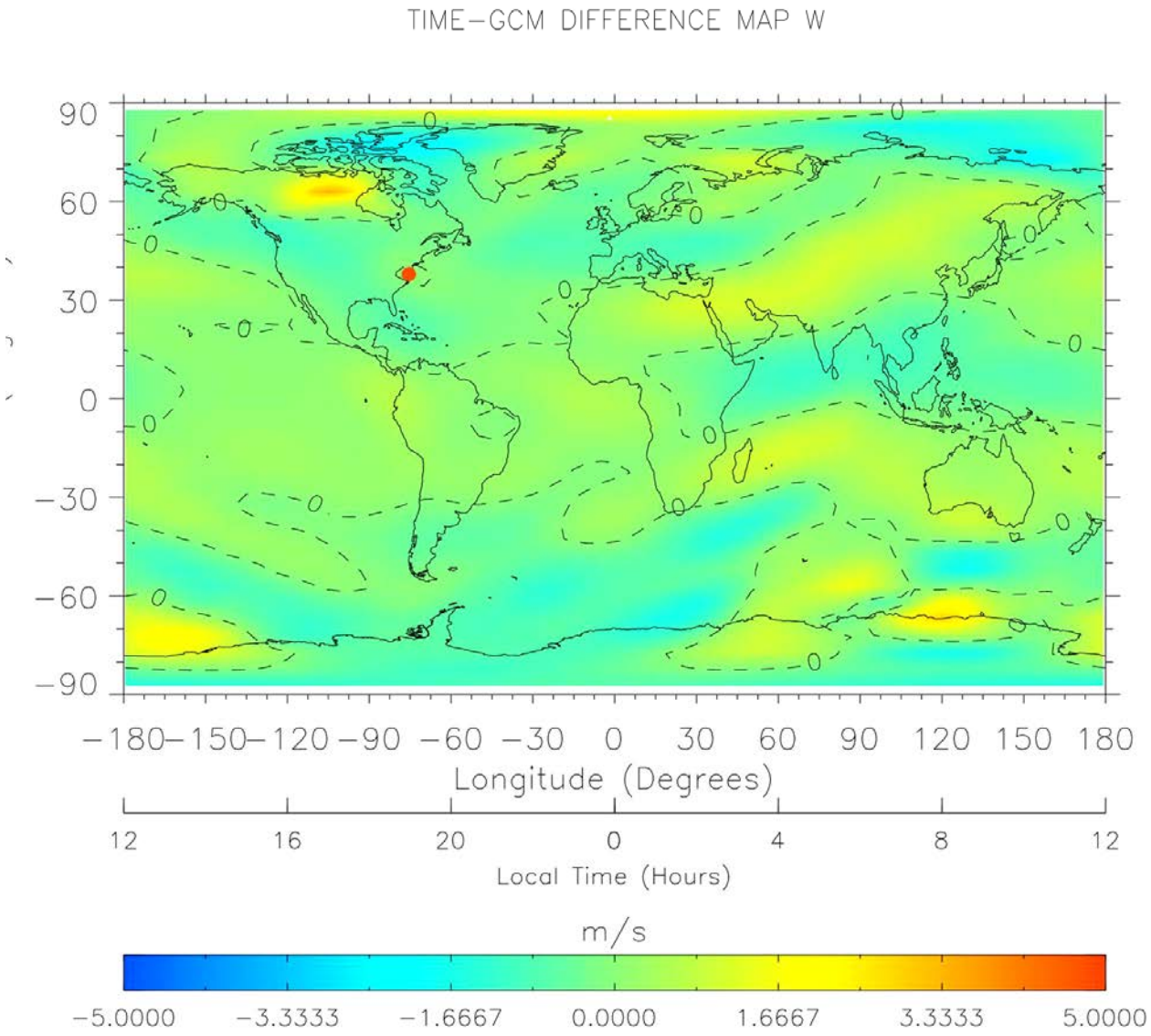


Joule Heating as the Source of LSTIDs

- Joule heating rates obtained by the AMIE assimilation code show impulsive heating situated poleward of the observed LSTIDs.
- Drive TIMEGCM with AMIE inputs at high latitudes



TIMEGCM Simulations



Conclusions

- The phenomenon of TID is an important manifestation of atmosphere-ionosphere coupling.
- We report on the LSTIDs generated by the October 7, 2015 storm.
- LSTID characteristics were successfully obtained from the *F*-region reflections of the HF Doppler system. The system provided a complete description of LSTID characteristics from Florida.
- We compared TIDDBIT-derived estimates of LSTIDs with those from the GPS TEC analysis.
- Both systems indicated that the LSTID wave packet consisted of periods ranging from 20-minute to 45-minute, all propagating roughly southward with horizontal phase speeds of ~300-600 m/s and horizontal wavelength of ~1200 km.
- Using the dense network of GPS measurements over the US, we have demonstrated that the LSTIDs persisted for about three hours over North America.
- Joule heating rates obtained by the AMIE assimilation code show impulsive heating situated poleward of the observed LSTIDs.