The Impact of Traveling Ionospheric Disturbances on Global Navigation Satellite Systems

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Overview

- Introduction to TIDs
- “Historical” TID Observations with GPS
- GPS maps of MSTIDs and LSTIDs
- TID measurements with other instruments

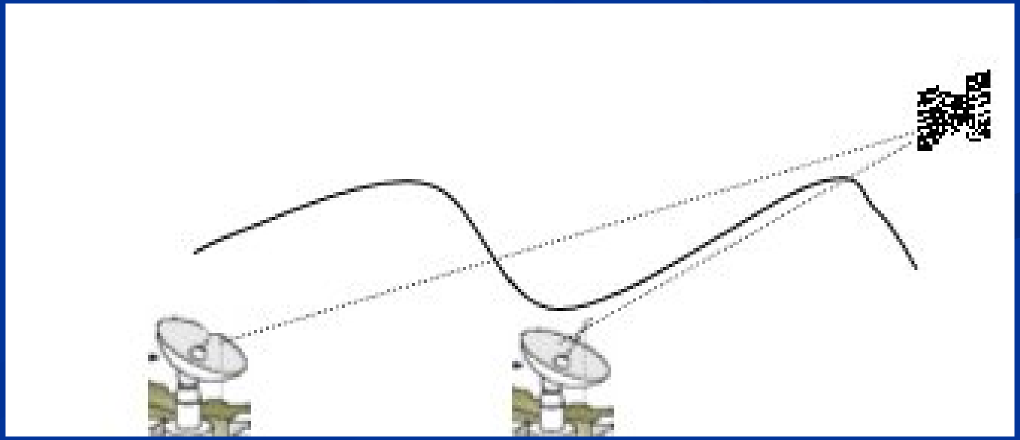
Traveling Ionospheric Disturbances (TIDs)

Differential Ionospheric Errors greater than 34 cm (2 TEC units) are problematic

TIDS are short-term variations in the TEC, covering a large range of periods and amplitudes.

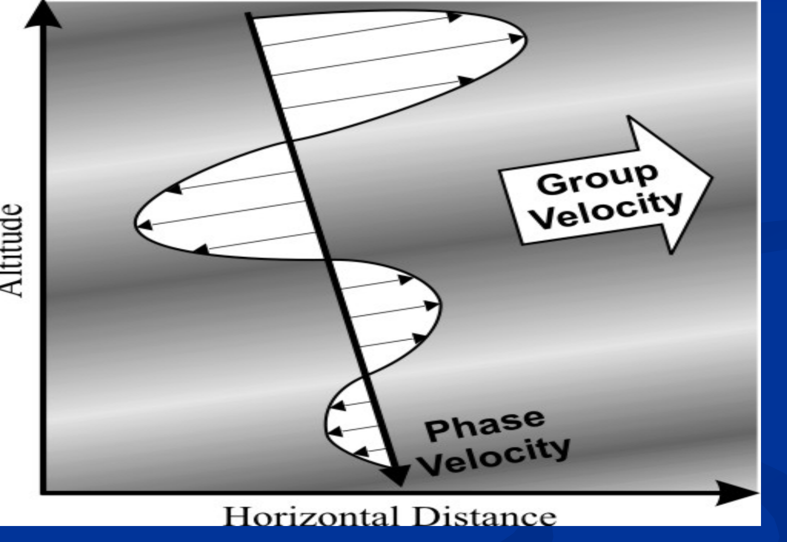
Mid-Latitude TIDs can originate:

- in the auroral regions (associated with geomagnetic disturbances - high Kp).
- Atmospheric Gravity Waves associated with
  - atmospheric tides, tropospheric weather, volcanic explosions, earthquakes, rocket launches.
- Electrodynamic Forces



Dissipation altitudes for "white noise" GWs
Vadas, JGR, 2007

- Dissipative filtering causes λz (for the gravity waves remaining in the spectrum) to increase nearly exponentially with altitude
- λ_H also increases rapidly with altitude, and the wave periods asymptote to 10 - 60 minutes

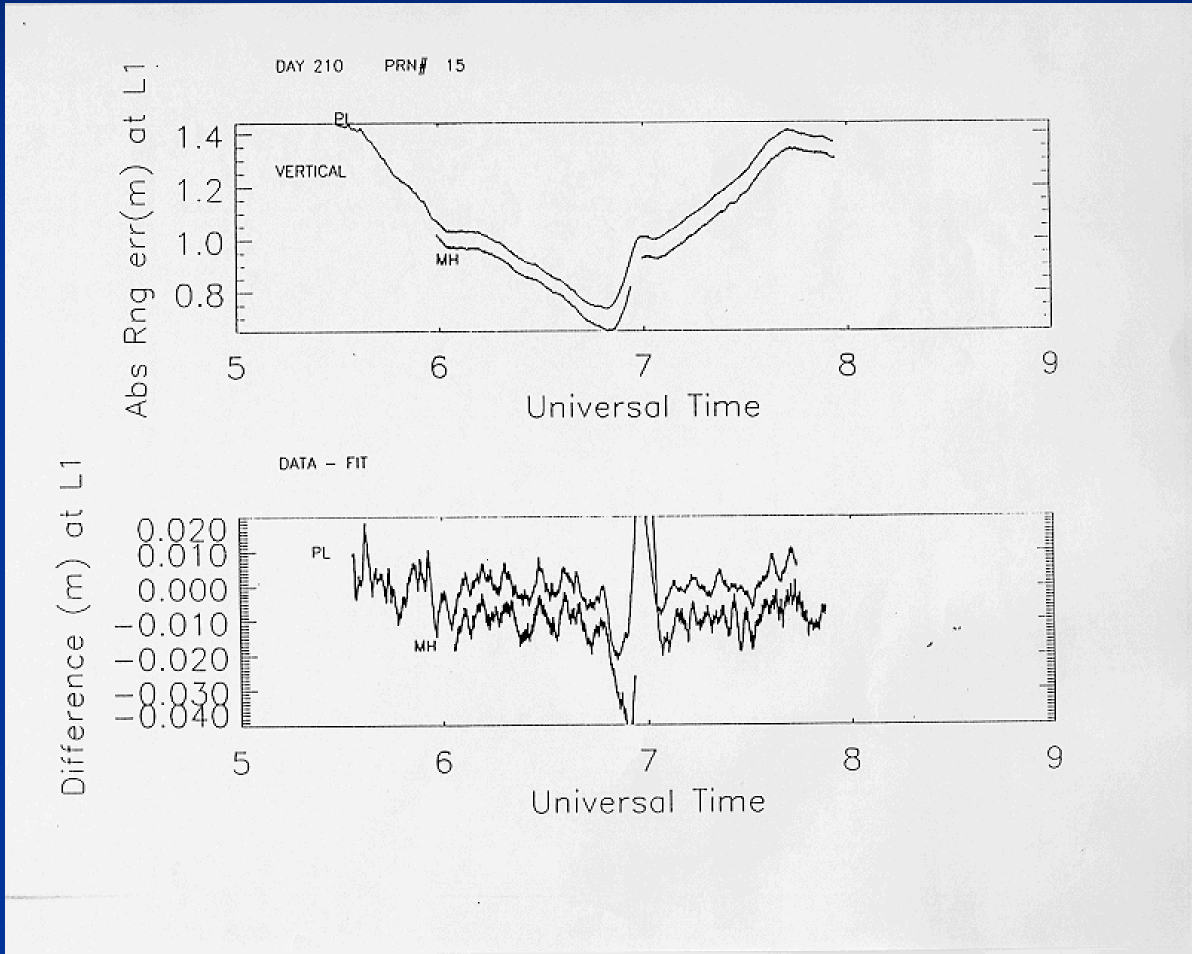


- GWs with λ_H ~100-600 km, λz~100-125 km and τ ~20-60 minutes propagate well into the F region to z~250 km before dissipating

Historical TID Data 29 July 1991

Near Solar Maximum   Geomagnetically Quiet   Local Night

Characteristics of Nighttime MSTID with a 3% TECP



Two TI 4100 receivers separated ~ 25 km in MA P. Doherty and A. Coster

Statistics of Ionospheric Error over 25 km Baseline

- Data collected from Nov 97 - Nov 98 over 25 km baseline
- Vast majority of the data measures less than 0.15 m of ionospheric error.
- On 15 % of the days examined, ionospheric errors were measured that were greater than 35 cm (~2 TECU).
- Absolute maximums greater than 1 m were observed
  - A single value of 1.75 m was observed during the 08 Nov 1998 magnetic storm, Kp=8.

Two Classes of TIDs

- Medium-Scale Traveling Ionospheric Disturbances (MSTID)

  Wavelength: 100 - 300 km

  Propagation Velocity: ~100 m/s)

- Large-Scale Traveling Ionospheric Disturbances (LSTID)

  Wavelength: 1,000 - 3,000 km

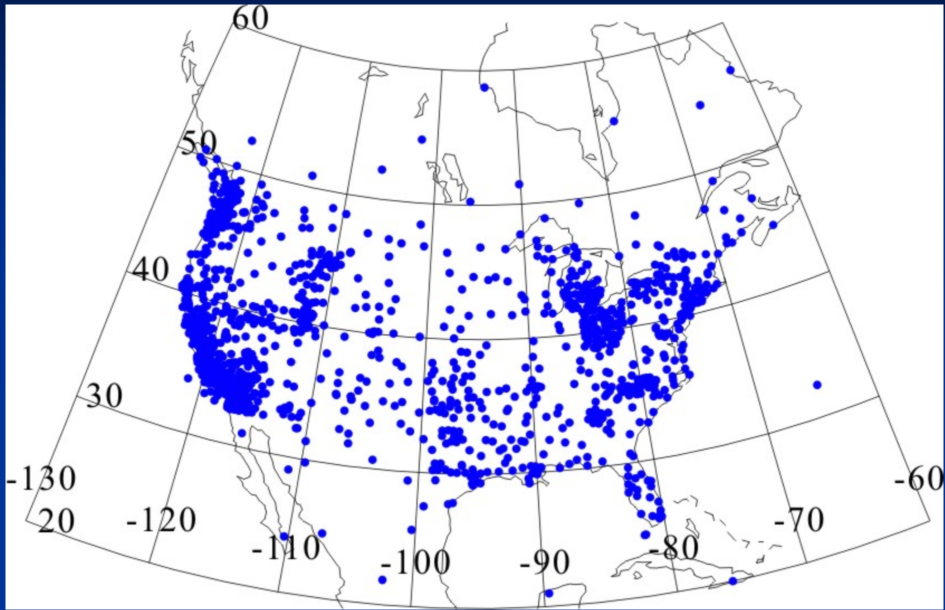
  Propagation Velocity: 300 – 1,000 m/s)

Typical amplitudes of a TID

1% above the background TEC is common

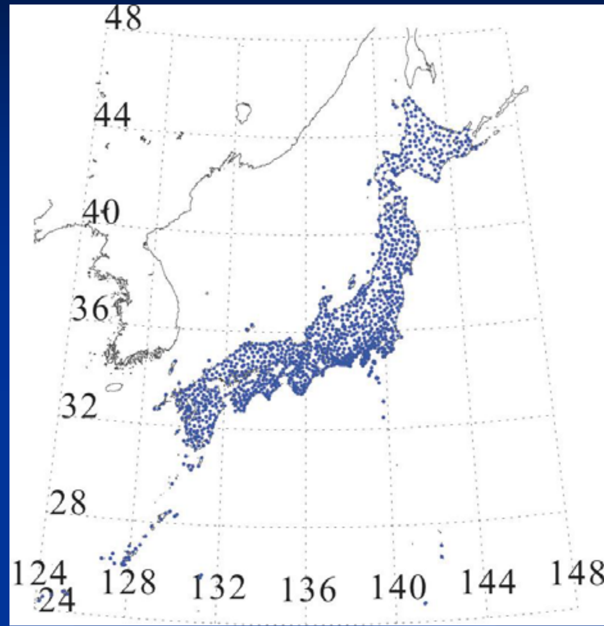
10% above the background TEC is uncommon

GPS Receiver Network in North America



GPS network in North America

- ~1,600 GPS receivers
- 10 - 200 km spatial interval
- 30 - 50° N, 70 - 130° W
  (40 - 60° N in geomag. lat.)
- 30-sec sampling

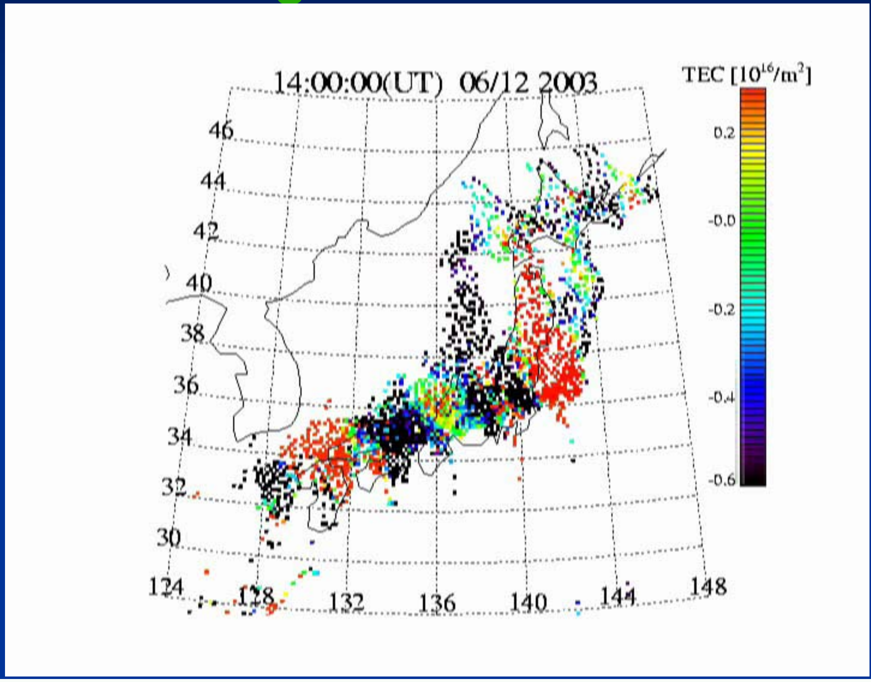


GPS network in Japan
(the densest in the world)

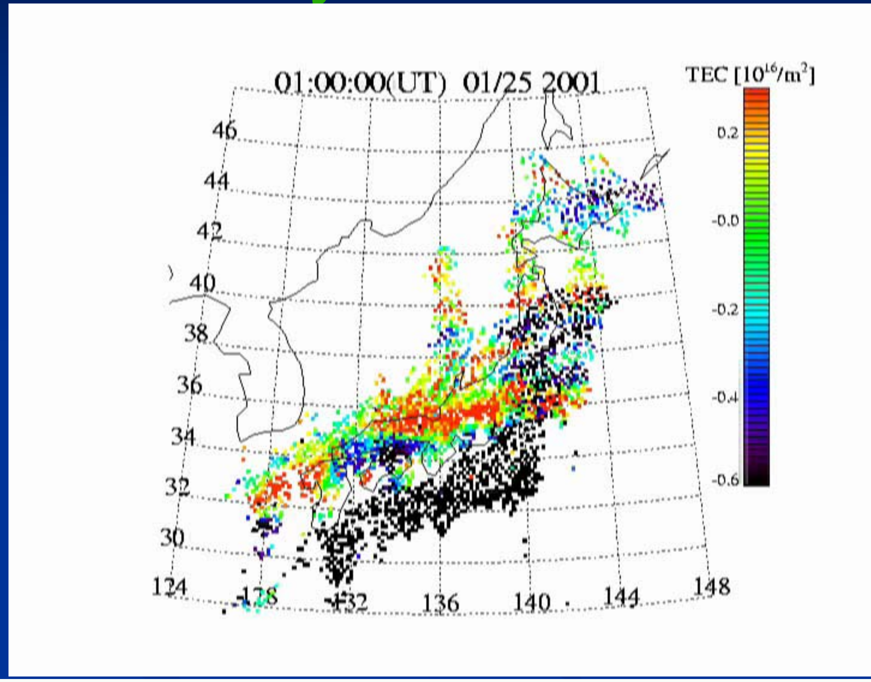
- ~1,200 GPS receivers
- ~20 km spatial interval
- 30 - 46° N, 128 - 148° E
  (20 - 36° N in geomag. lat.)
- 30-sec sampling

Medium-Scale Traveling Ionospheric Disturbances (MSTID) over Japan

Nighttime MSTID



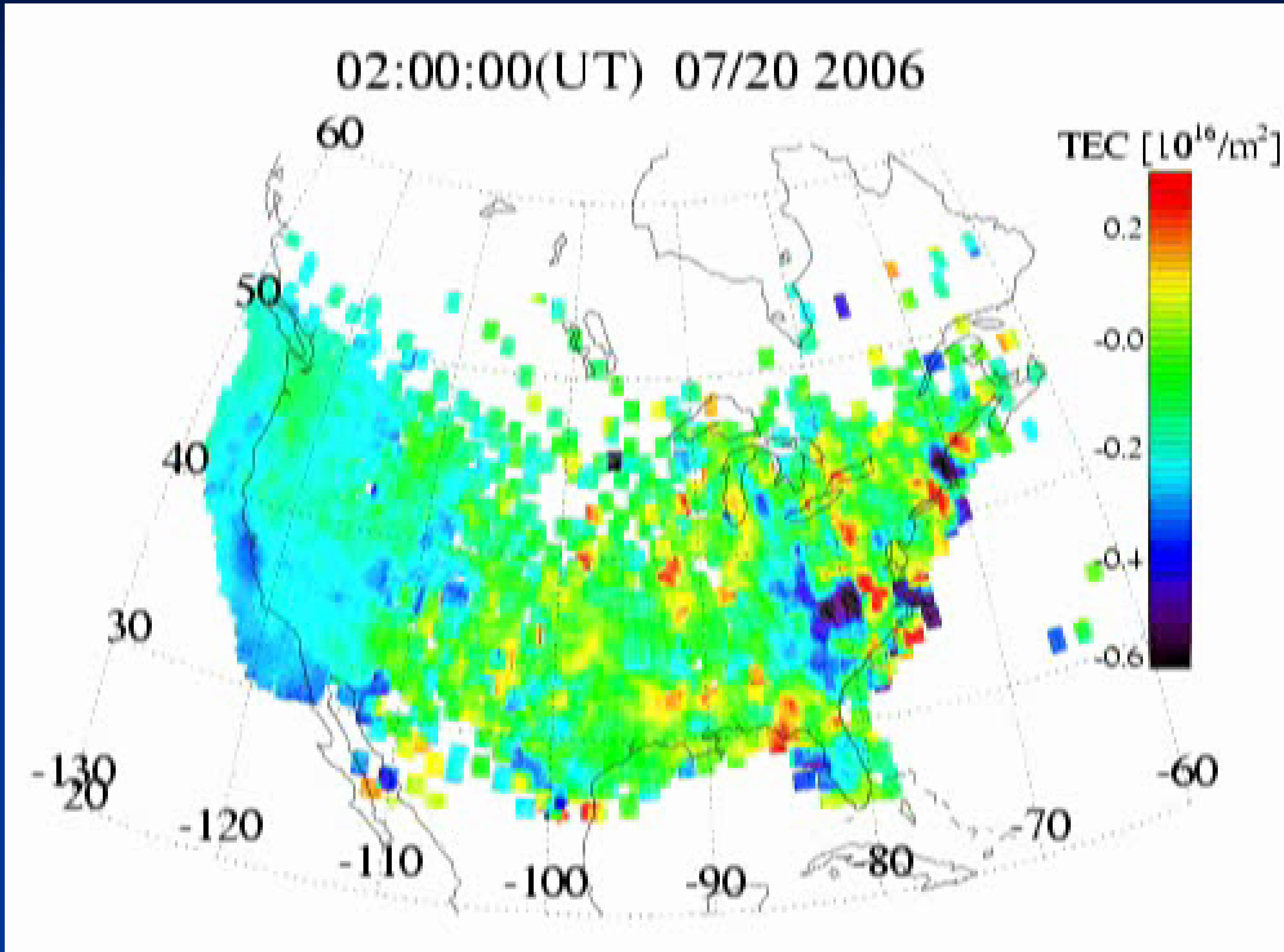
Daytime MSTID



	Nighttime MSTID	Daytime MSTID
Wavelength	150–500 km	100–350 km
Velocity	50–150 m/s	100–200 m/s
Direction	Southwestward	South-southeastward
Activity ($\Delta TEC/TEC_0$)	1–5%	1–2%
Seasonal dependence	Summer (1st max), winter (2nd max)	Winter
Geomagnetic activity dependence	No	–
Solar activity dependence	Negative	Not clear
Remarks	Electrodynamic forces play important role in their generation	Atmospheric gravity waves would be responsible for their generation

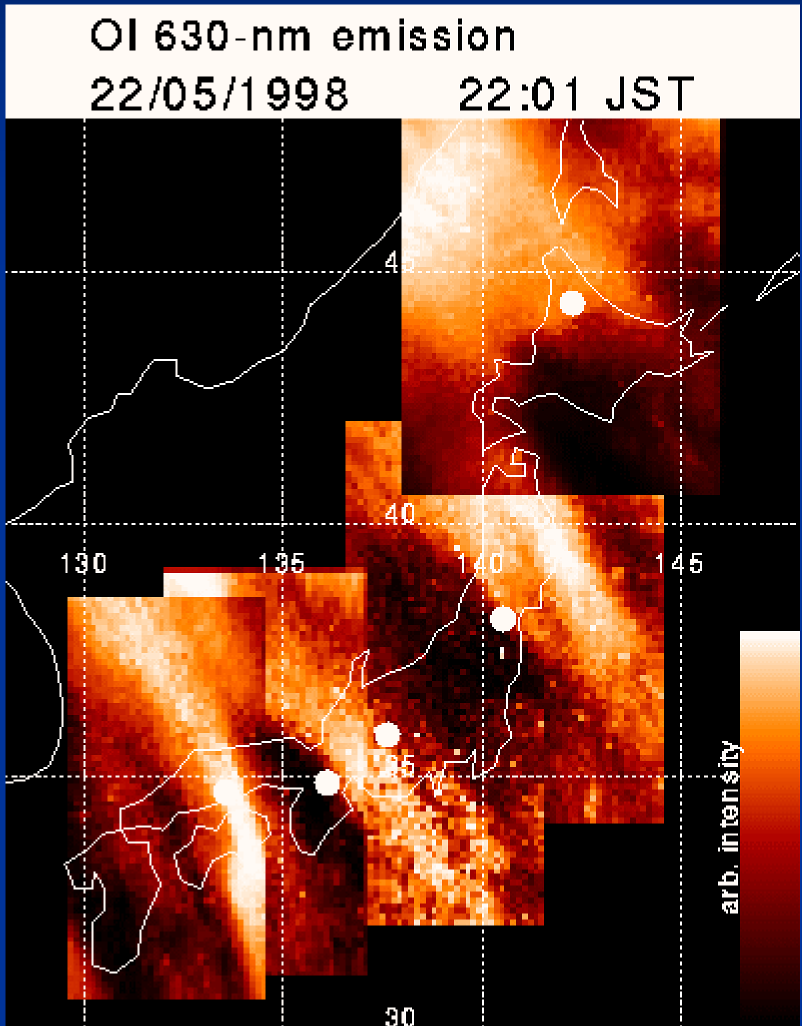
[Tsugawa et al., GPS solut., 2006]

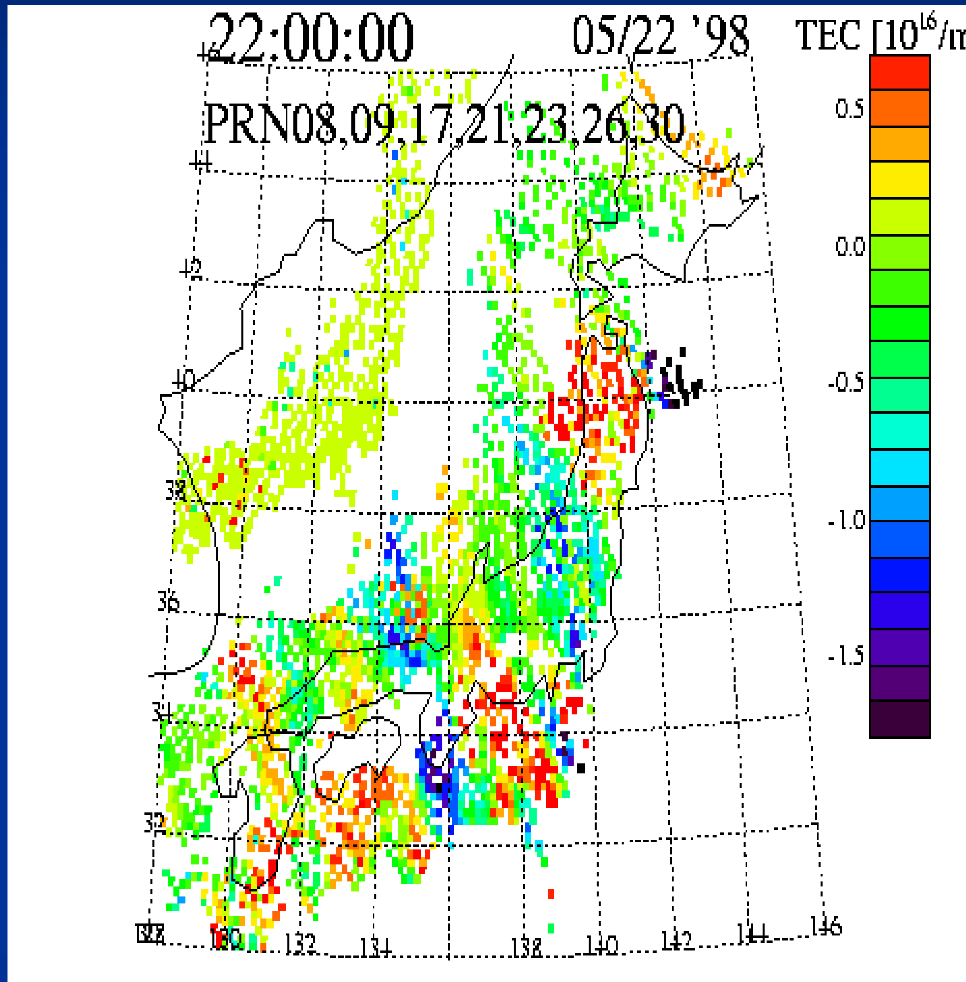
Nighttime MSTID on Jul 20, 2006 (Kp_{max} = 1)



- Detrended TEC map (60-min window)
- 0.15°x0.15° with 7x7 smoothing (running average)

Nighttime MSTID Observations (TEC, Airglow) [*Saito et al.*, 2001]





Nighttime MSTID : Summary

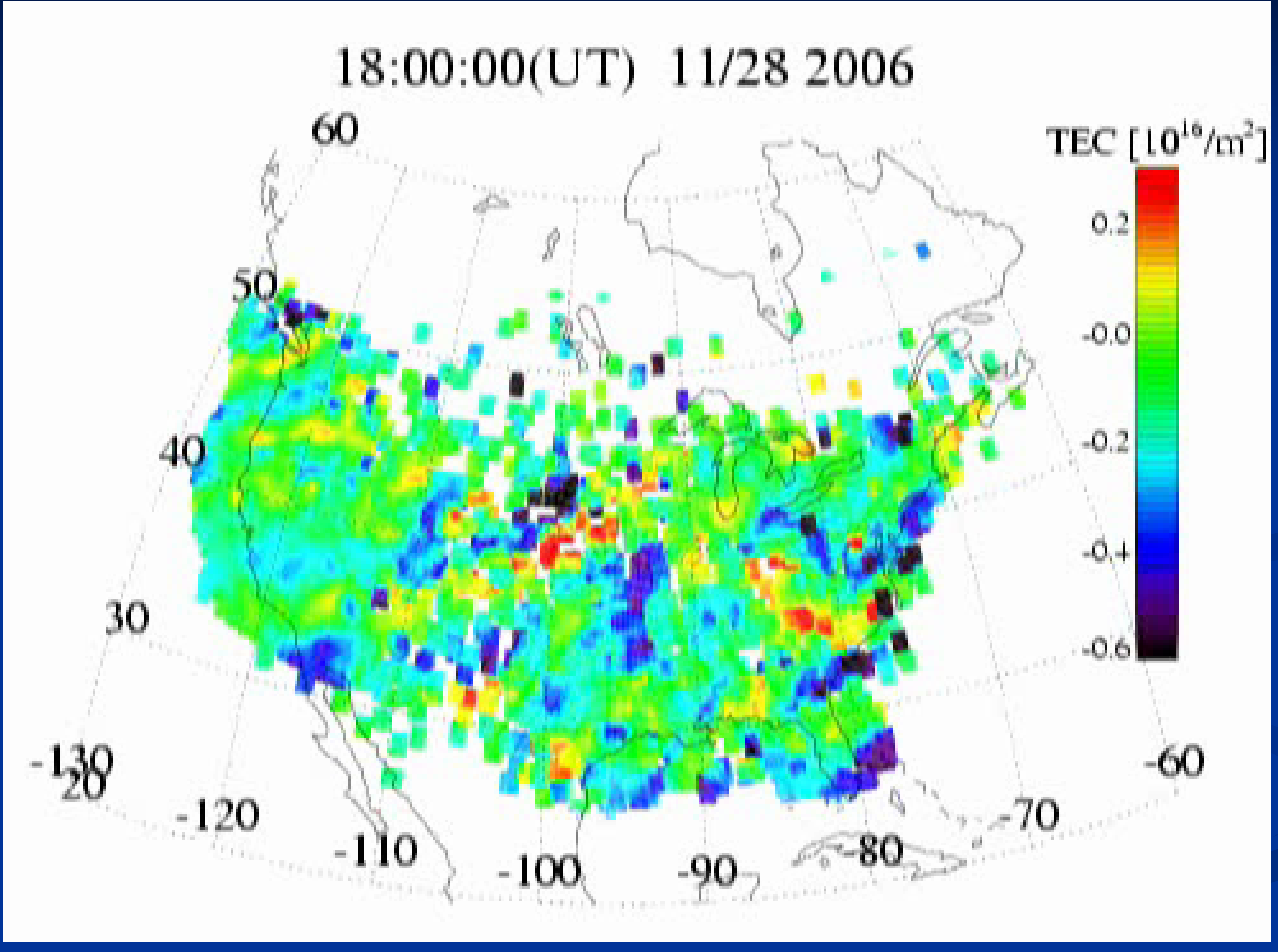
- Wavelength of 200-500 km
- Propagation velocity of 50-150 m/s
- Southwestward propagation
- High occurrence rate in summer and winter
- No clear correlation with geomagnetic activity

→ Consistent characteristics with the nighttime MSTIDs previously observed over Japan.

New findings

- Their wavefront can be extended from 35° to 55° N in MLAT.
- Their wavefront is long since their appearance.
- Each TEC enhancement seems to decay in 2-4 hours.

Daytime MSTID on Nov 28, 2006 (Kp_{max} = 2)



- Detrended TEC map (60-min window)
- 0.15°x0.15° with 7x7 smoothing (running average)

Daytime MSTID : Summary

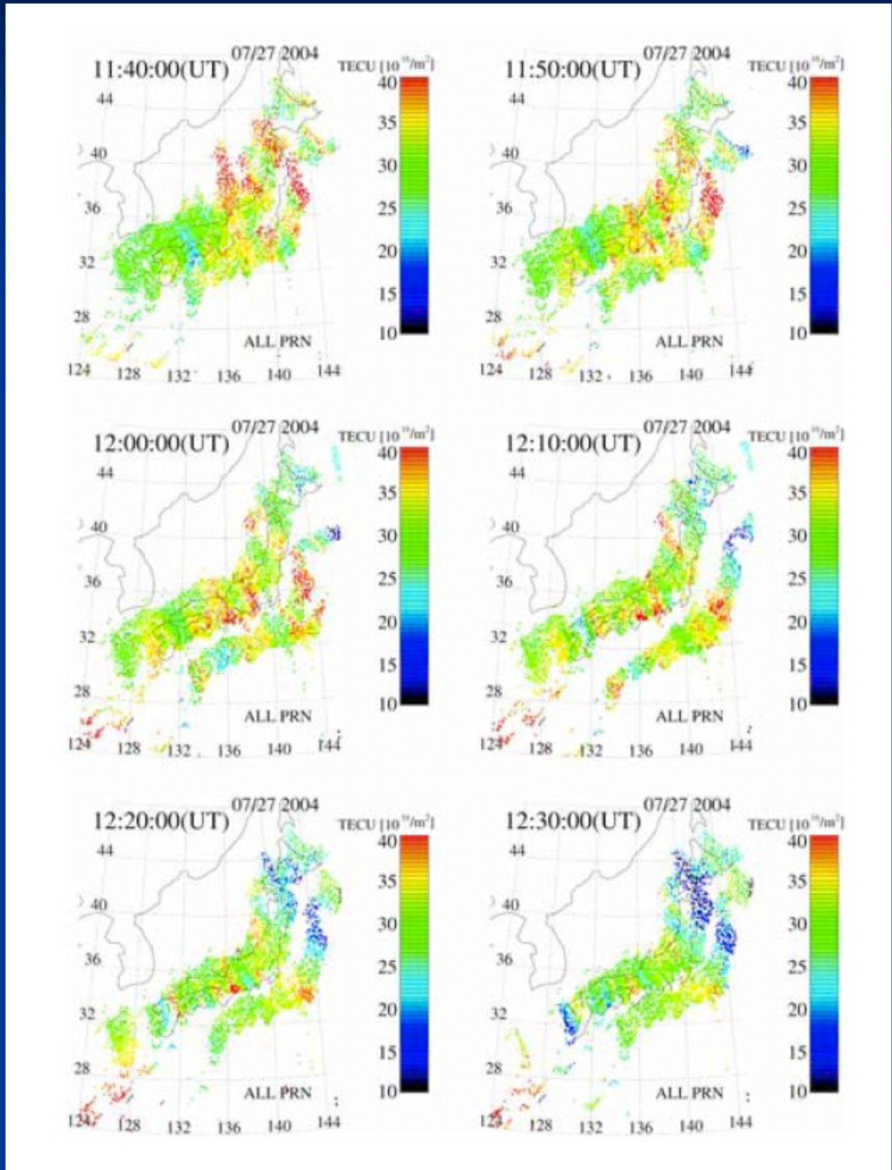
- Wavelength of 300-1,000 km
- Propagation velocity of 100-200 m/s
- Propagation direction:
  - morning: southeastward
  - post-noon: superimposition of southeast and southwestward
  - afternoon: southwestward
- High occurrence rate in winter
- No correlation with geomagnetic activity

→ These characteristics are consistent with daytime MSTIDs previously observed over Japan and South California.

New findings

- Their wavefronts extend zonally more than 2,000 km.
- The two MSTIDs propagating southeastward and southwestward are superimposed on each other around mid- to late afternoon.

“Super MSTIDs” observed in Japan on Jul 27, 2004



- Their wavelength and propagation direction are similar to those of typical MSTIDs.
- Their amplitudes can be larger than 10 TECU.

Two Classes of TIDs

- Medium-Scale Traveling Ionospheric Disturbances (MSTID)

  Wavelength: 100 - 300 km

  Propagation Velocity: ~100 m/s)

- Large-Scale Traveling Ionospheric Disturbances (LSTID)

  Wavelength: 1,000 - 3,000 km

  Propagation Velocity: 300 – 1,000 m/s)

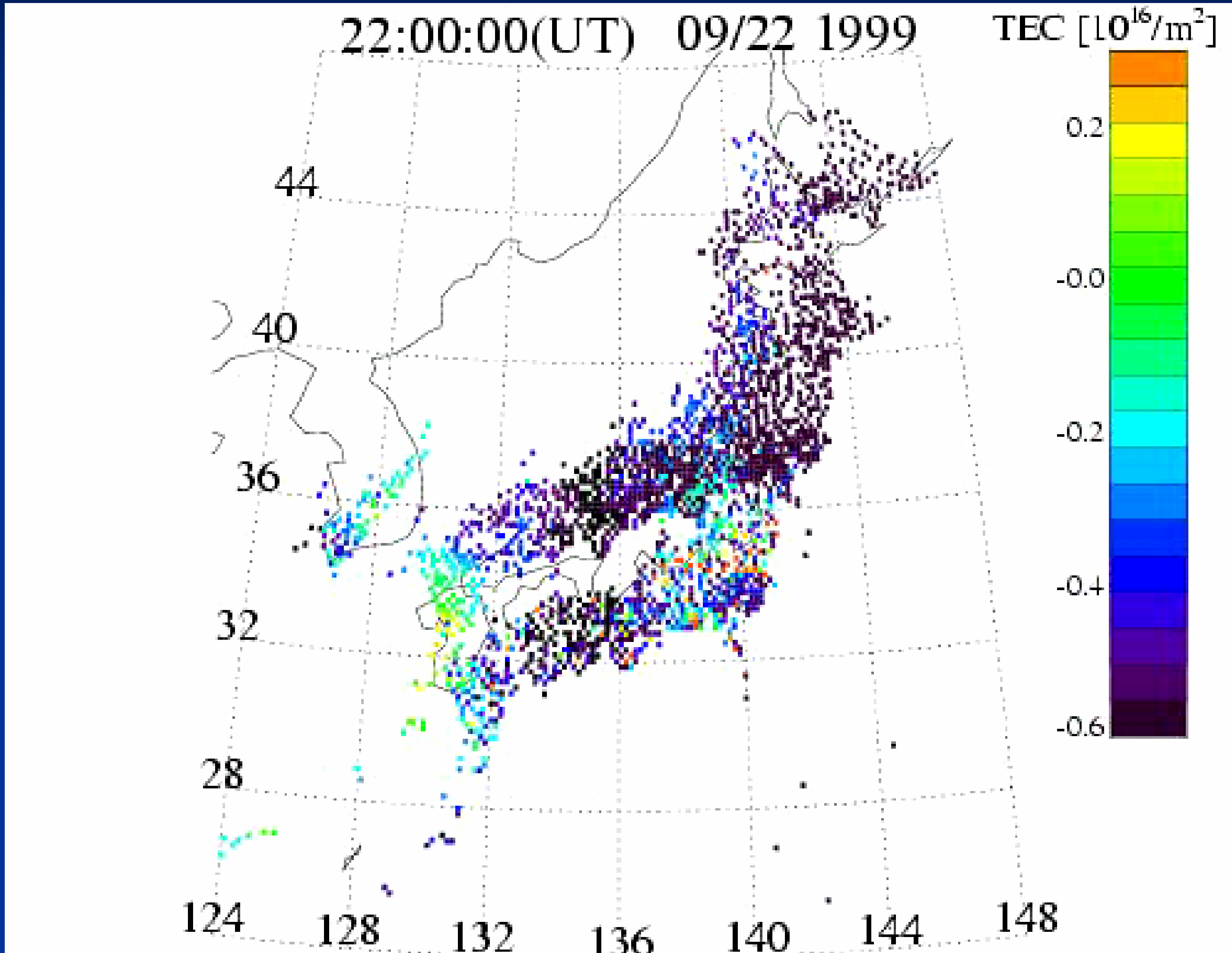
Typical amplitudes of a TID

1% above the background TEC is common

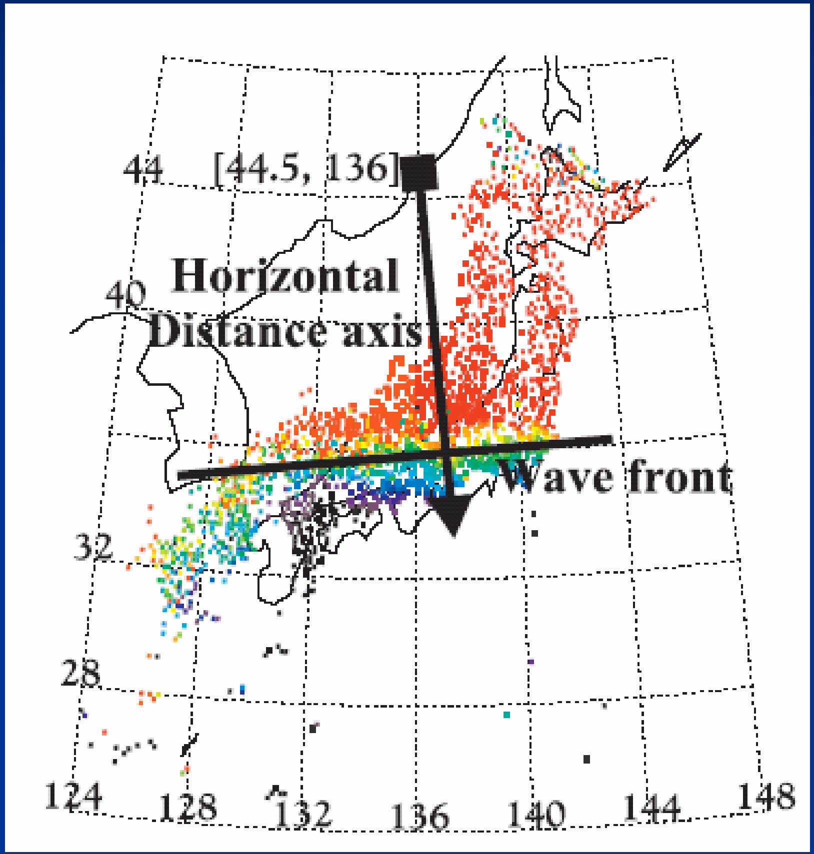
10% above the background TEC is uncommon

Typical Large-Scale TIDs after geomagnetic storms

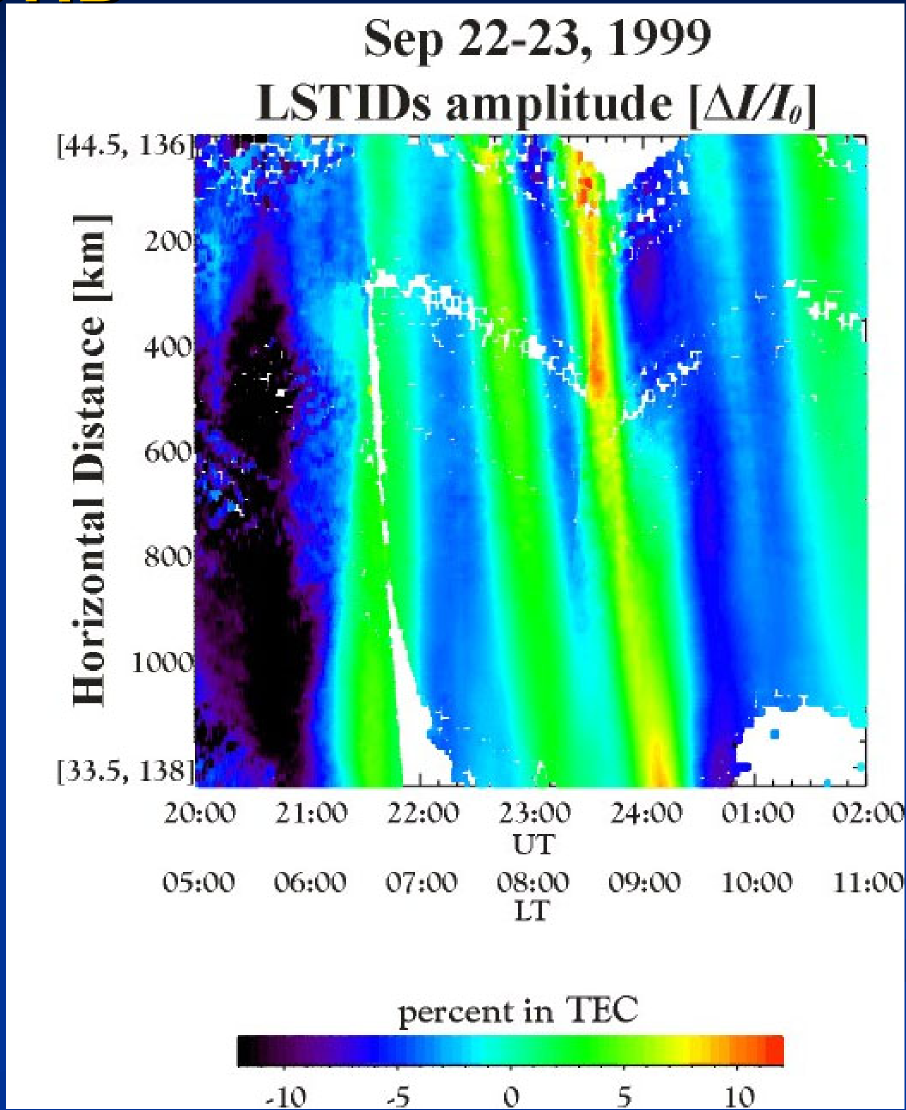
LSTID



Wave Parameters of LSTID



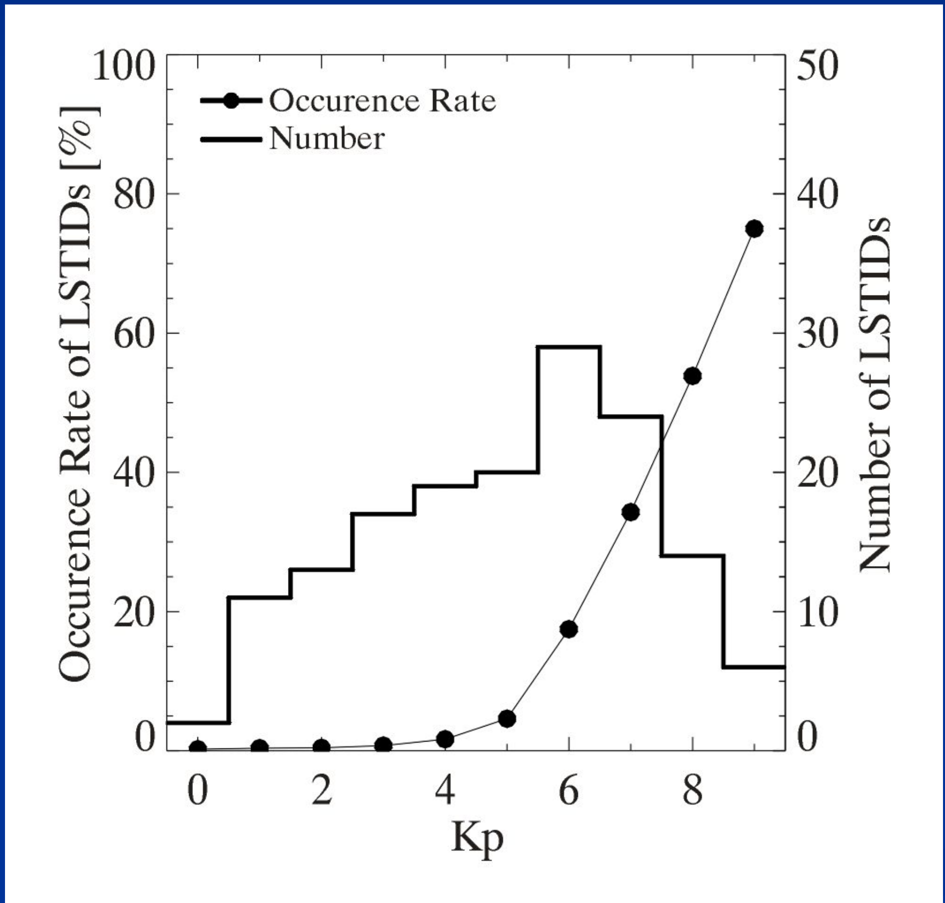
[*Tsugawa et al*., 2003]

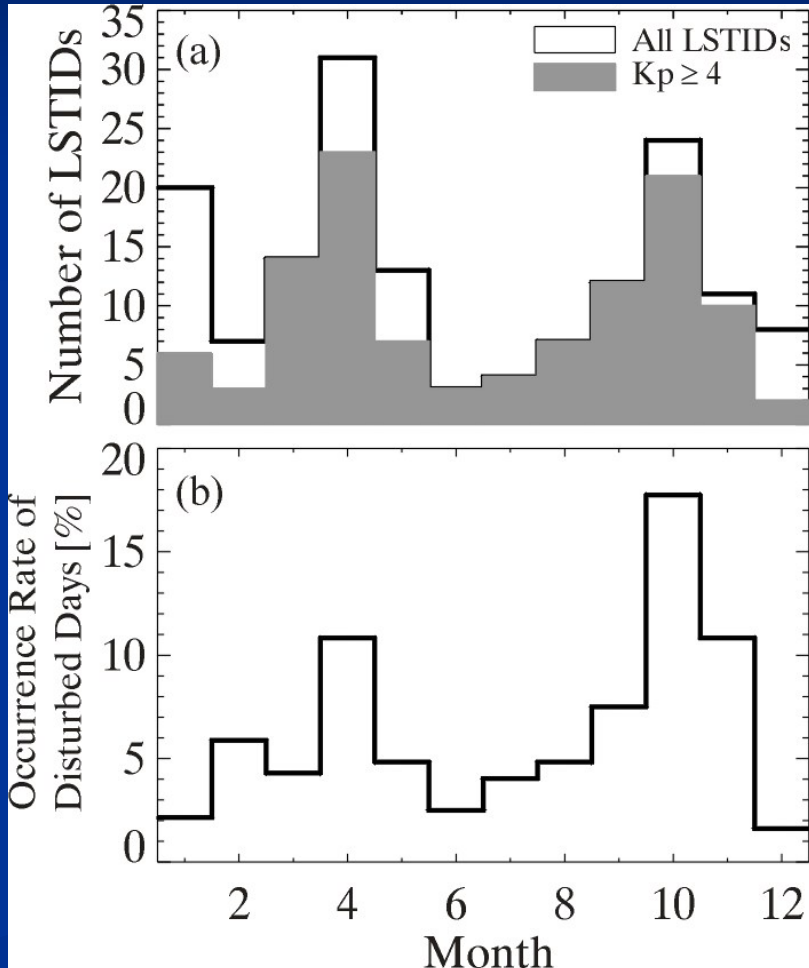


- The amplitudes of LSTIDs are often larger than 10 %.

Occurrence of LSTID

- Statistical analysis (Apr. 1999 – Dec. 2002) [*Tsugawa et al.*, 2004]





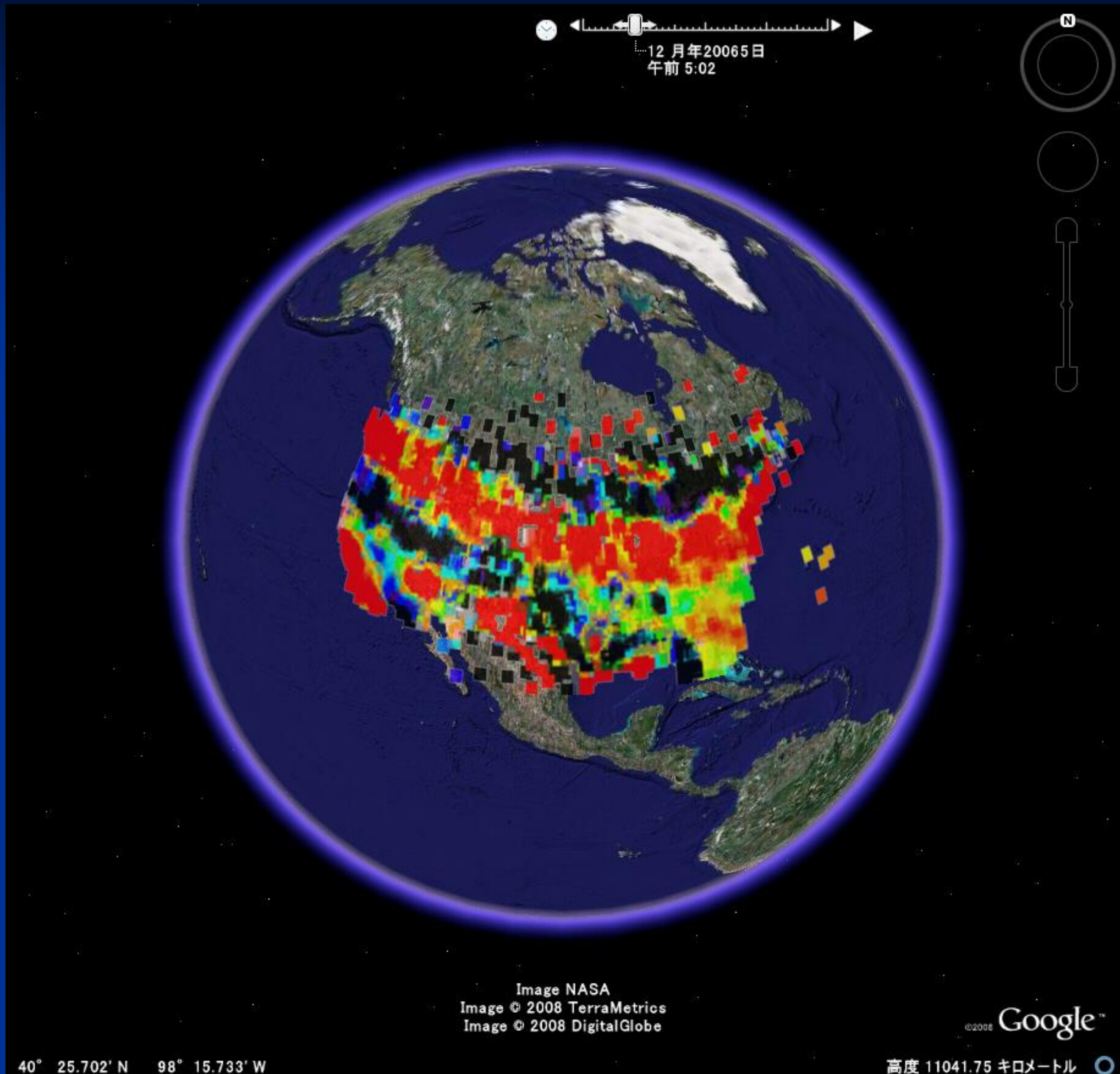


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Image NASA
Image © 2008 TerraMetrics
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40° 25.702' N 98° 15.733' W
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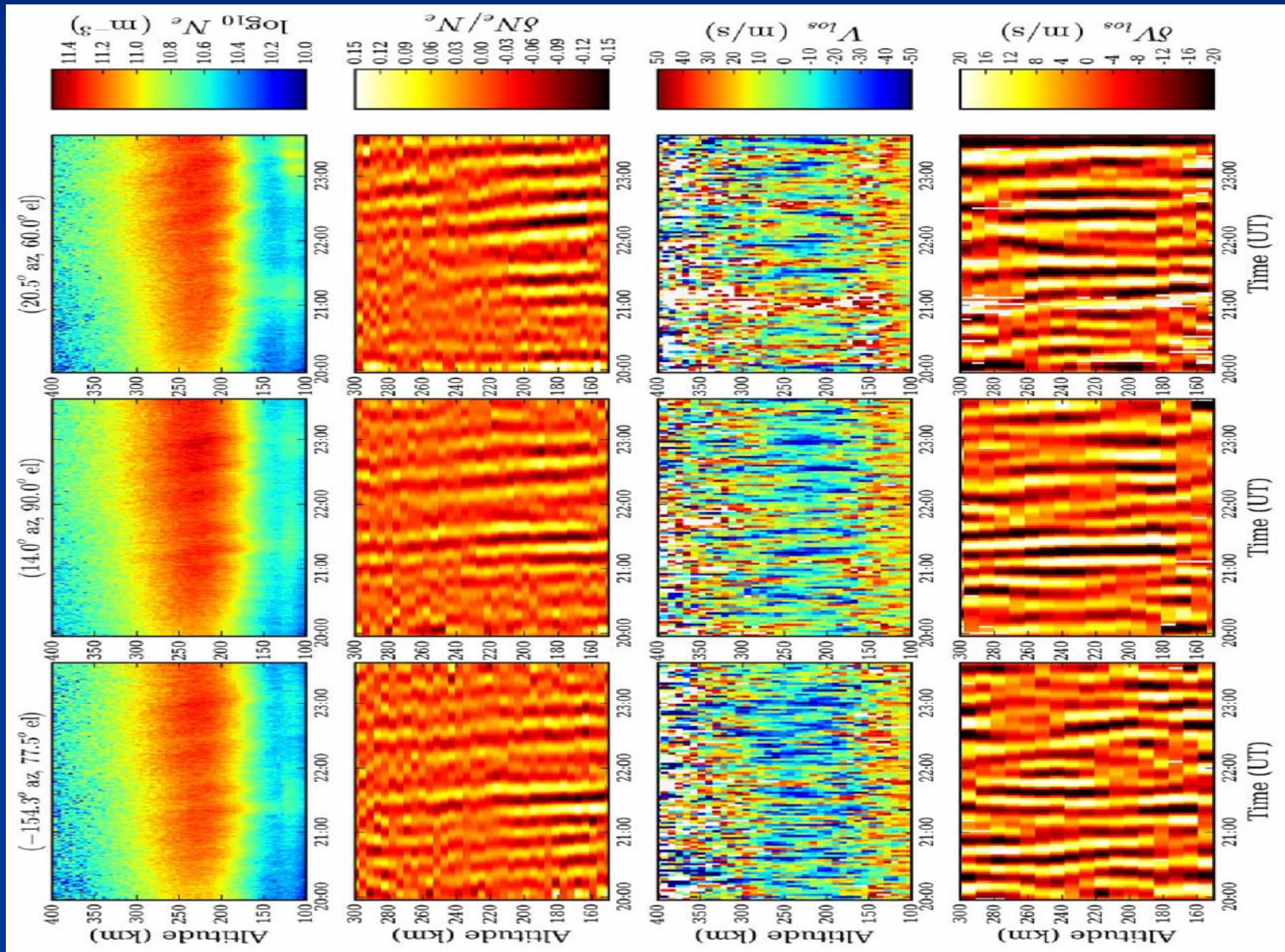
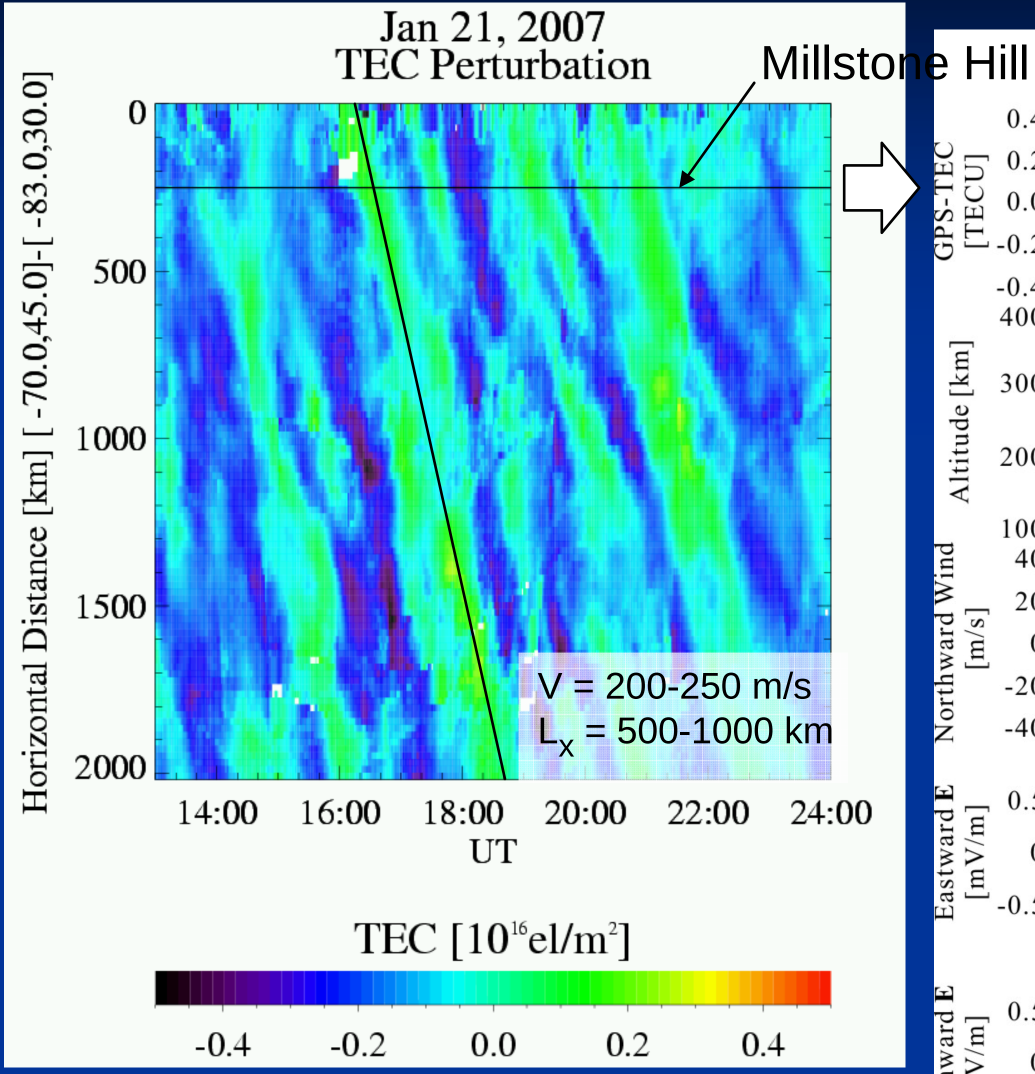
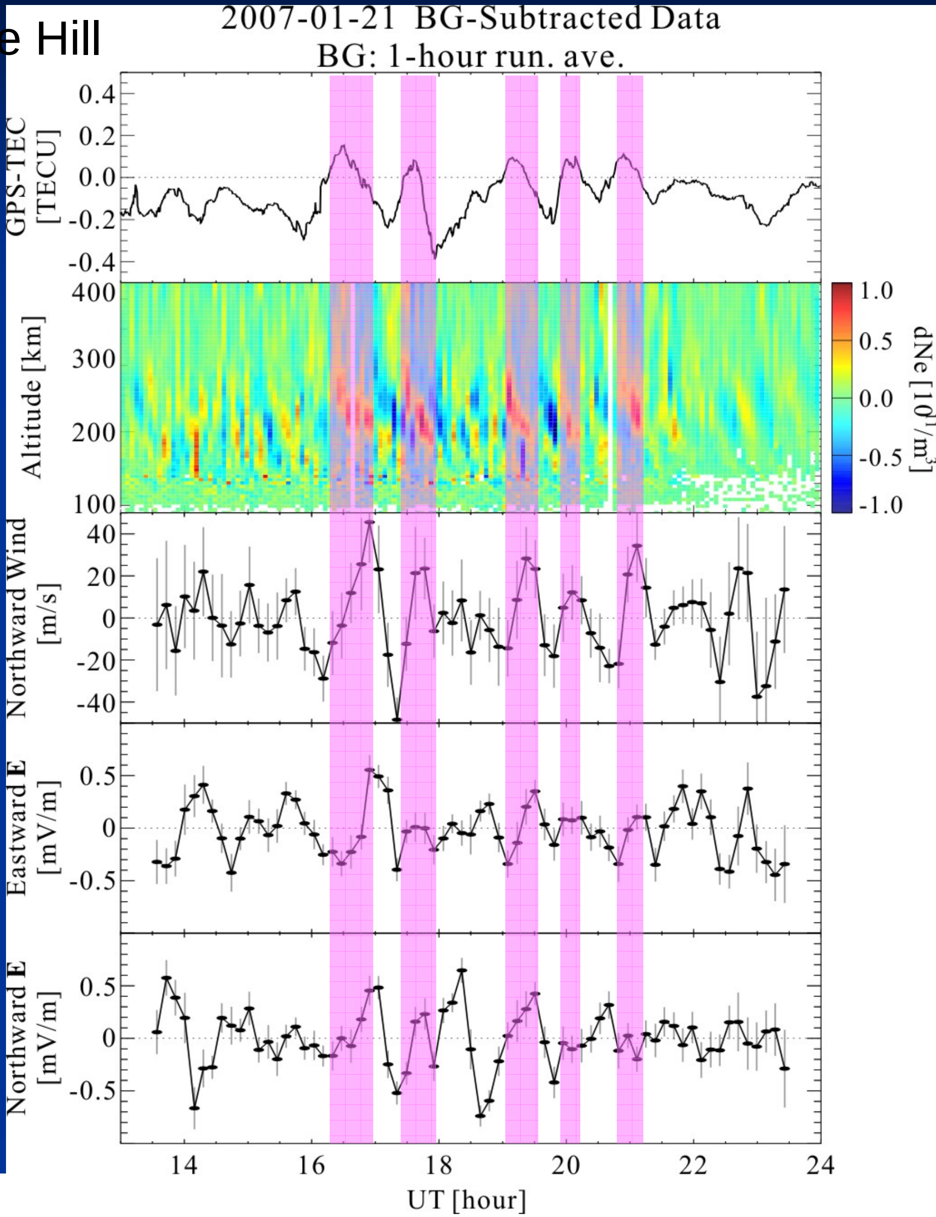
Observed Gravity Waves in Thermosphere using AMISR) system in Poker Flat, Alaska (Dec. 13, 2006)

(Vadas and Nicolls, GRL, 2008)



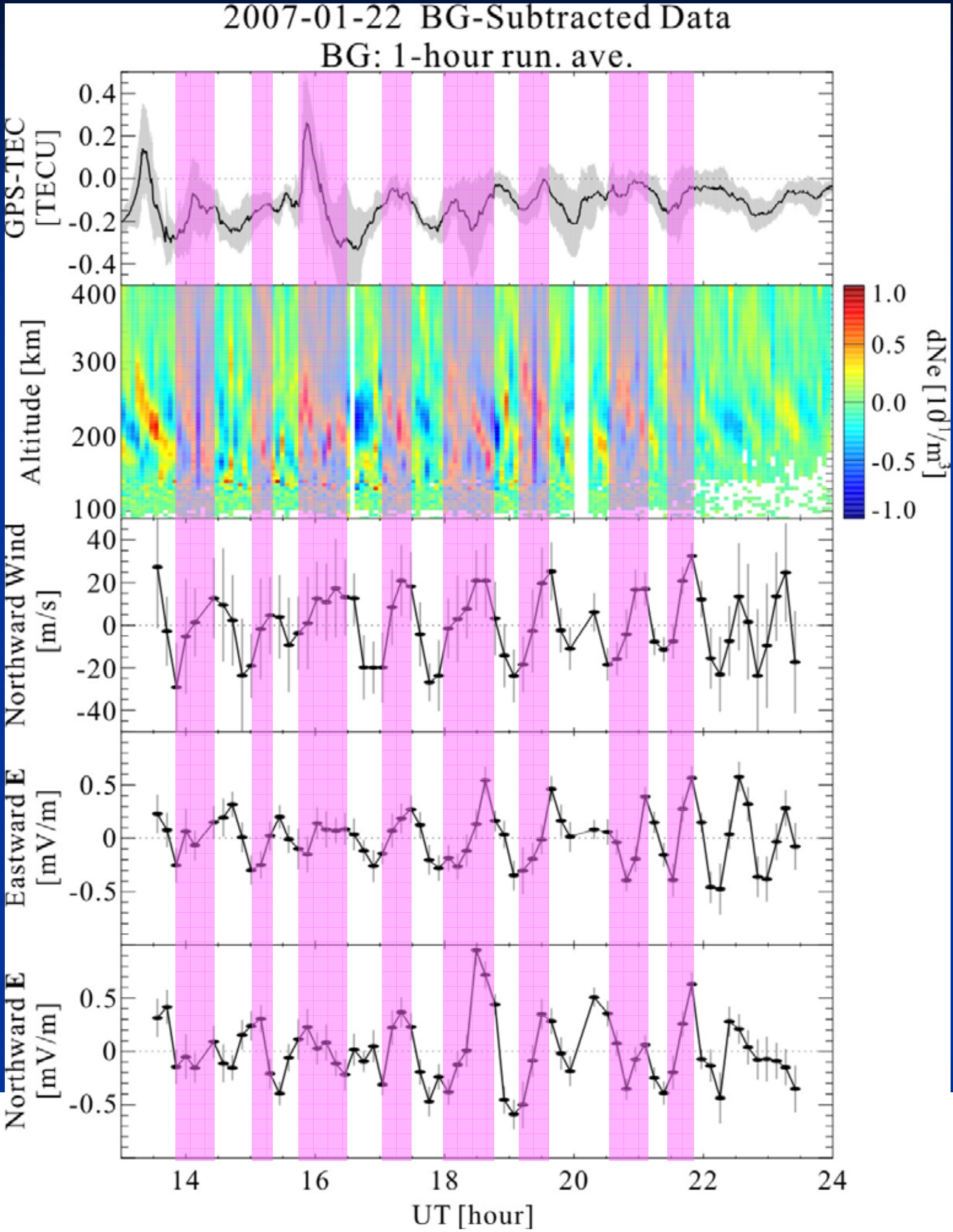
1h BG-Subtracted Data : Jan 21, 2007





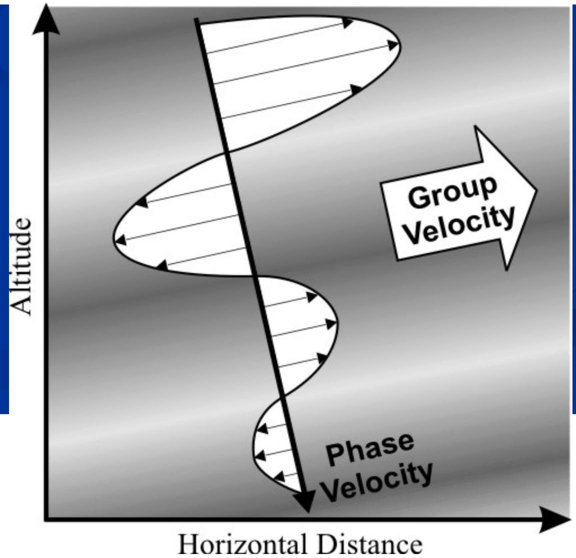
- GPS-TEC along the horizontal distance axis.

1h BG-Subtracted Data : Jan 22, 2007

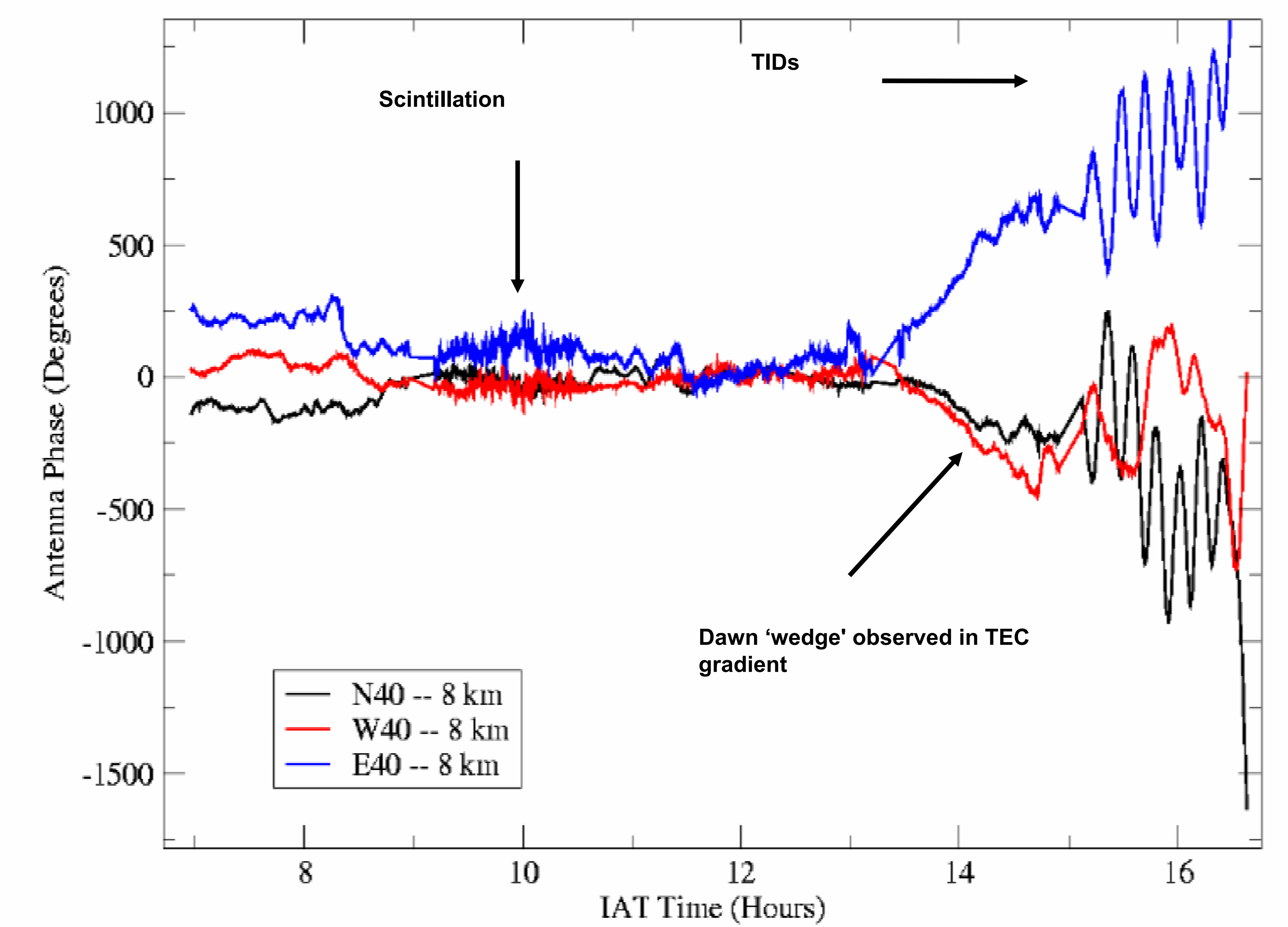


- ISR-Ne perturbations have downward phase propagations.
- Enhancements of ISR-Ne and GPS-TEC are seen during the transition from southward to northward wind perturbation.

→ These characteristics are consistent with those of the atmospheric gravity waves (AGWs).



Observations collected at VLA (Perley and Bust, URSI) GA,



Summary

- Differential Ionospheric Errors greater than 34 cm (2 TEC units) are problematic for high precision differential GPS applications.
- MSTIDs are observed almost constantly in the mid-latitudes, but the vast majority have amplitudes of less than 1 TEC unit.
  - Super MSTIDS are occasionally observed with amplitudes of 10 TEC units.
- LSTIDs frequently have amplitudes greater than 5-10 TEC units.
  - Associated with major magnetic storms.
- TID Issues for GNSS users will become more significant as we approach solar maximum

http://stdb2.stelab.nagoya-u.ac.jp/GPS/TEC-DAWN/

Hernandez-Pajares, M., J. M. Juan, and J. Sanz (2006), Medium-scale traveling ionospheric disturbances affecting GPS measurements: Spatial and temporal analysis, J. Geophys. Res., 111, A07S11, doi:10.1029/2005JA011474, 2006.