Ionospheric Storm Effects in GPS Total Electron Content

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Geomagnetic Storms

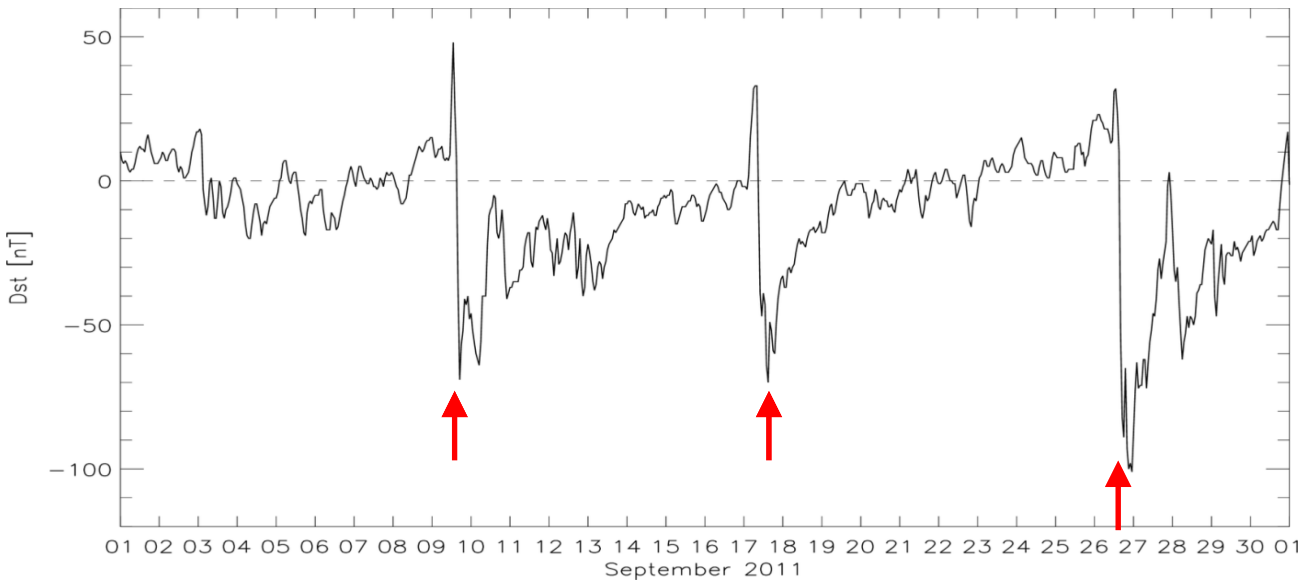

Figure: Hourly *Dst* index values for the month of September 2011.

- A geomagnetic storm is characterized by a disturbance in the horizontal (*H*) component of the Earth's magnetic field at the equator due to the changing intensity of the ring current [*Gonzalez et al.*, 1994].

- The Disturbance storm time (*Dst*) index is an hourly measure of the average global *H* variation obtained from low-latitude ground stations and is often used to indicate the occurrence of geomagnetic storms.

Ionospheric Storm Effects

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• The ionospheric electron density response to a geomagnetic storm is traditionally classified as either a positive (increase) or negative (decrease) storm effect [*Prölss*, 1995; *Buonsanto*, 1999].

• Initial positive storm effects are generally attributed to an uplift in the ionospheric *F* layer to regions of decreased recombination.

• Longer lived negative storm effects are attributed to neutral composition changes, specifically an increase in molecular gas (O_2, N_2) and decrease in atomic oxygen density.

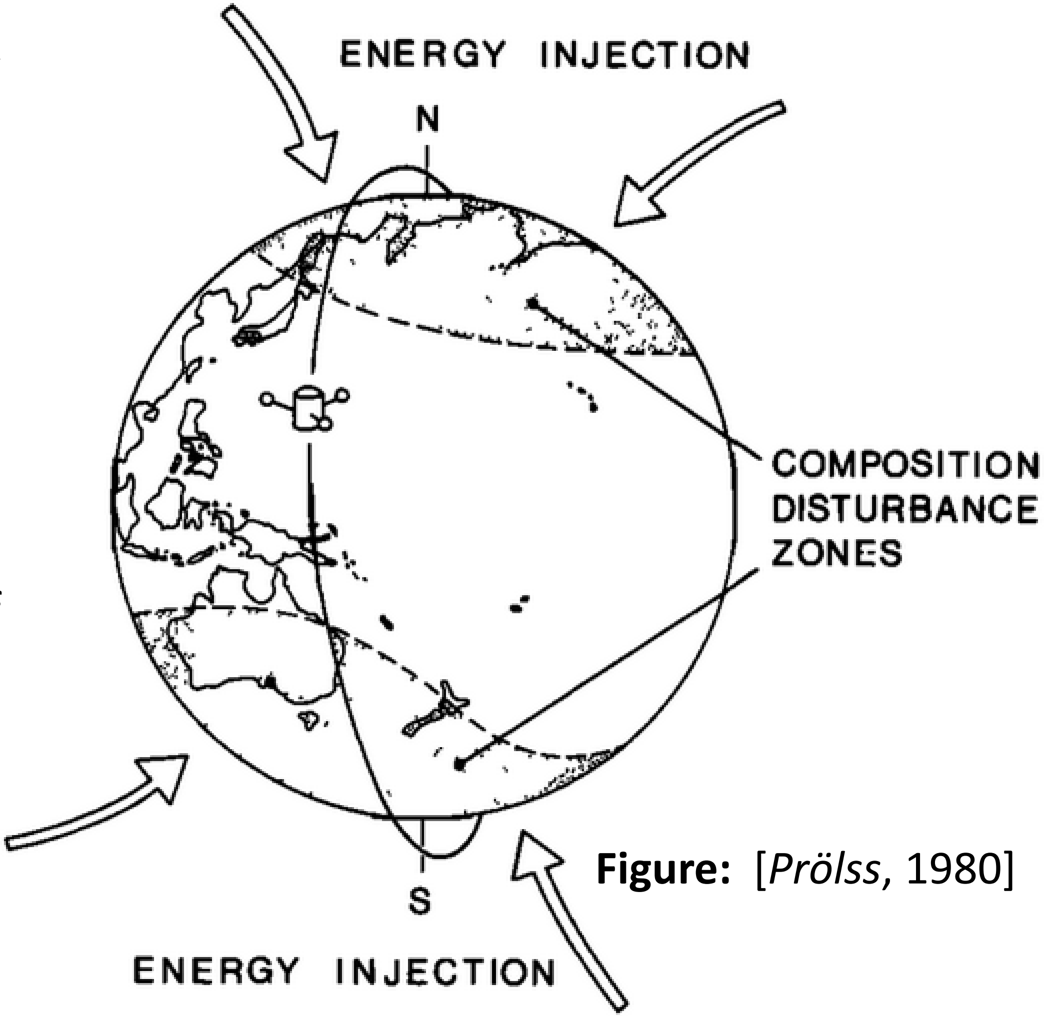
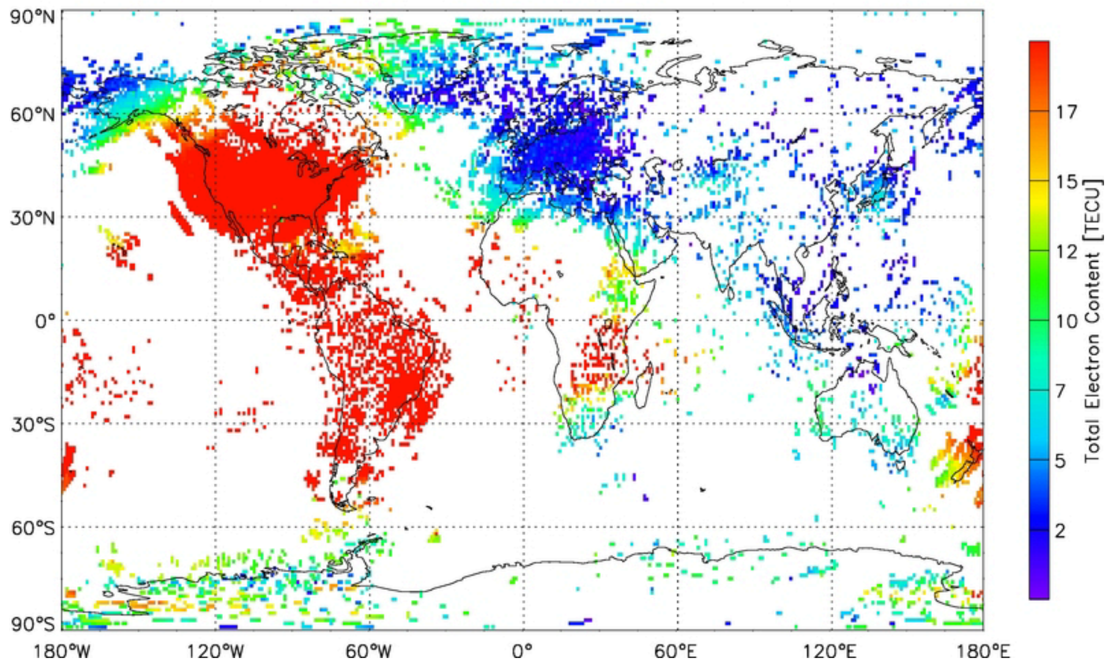


Figure: [*Prölss*, 1980]

Motivation



- One increasingly popular approach for describing ionospheric behavior is by using measurements of vertically-integrated total electron content (TEC) from ground-based GPS receivers [*Mendillo*, 2006].
- The goal of this study is to statistically examine positive and negative storm effects at high spatial and temporal resolution using the densely-populated network of GPS receivers in North America to develop predictive capabilities.

Motivation – WAAS

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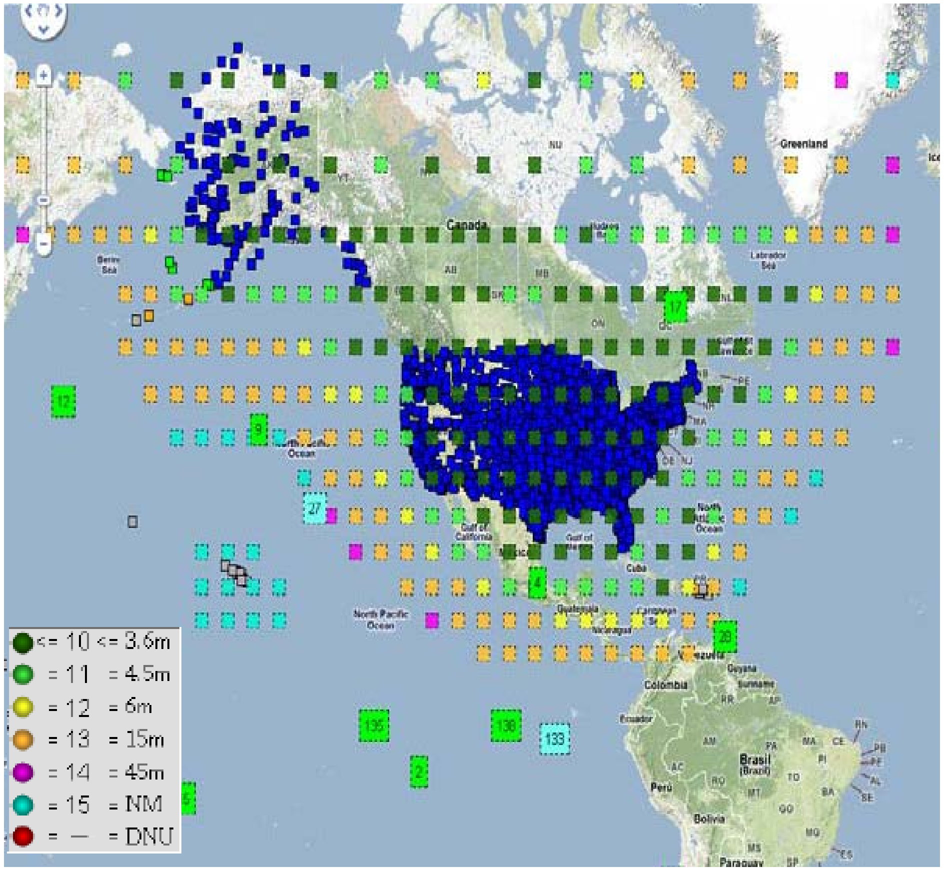

September 25th, 2011
19:51:57 UT

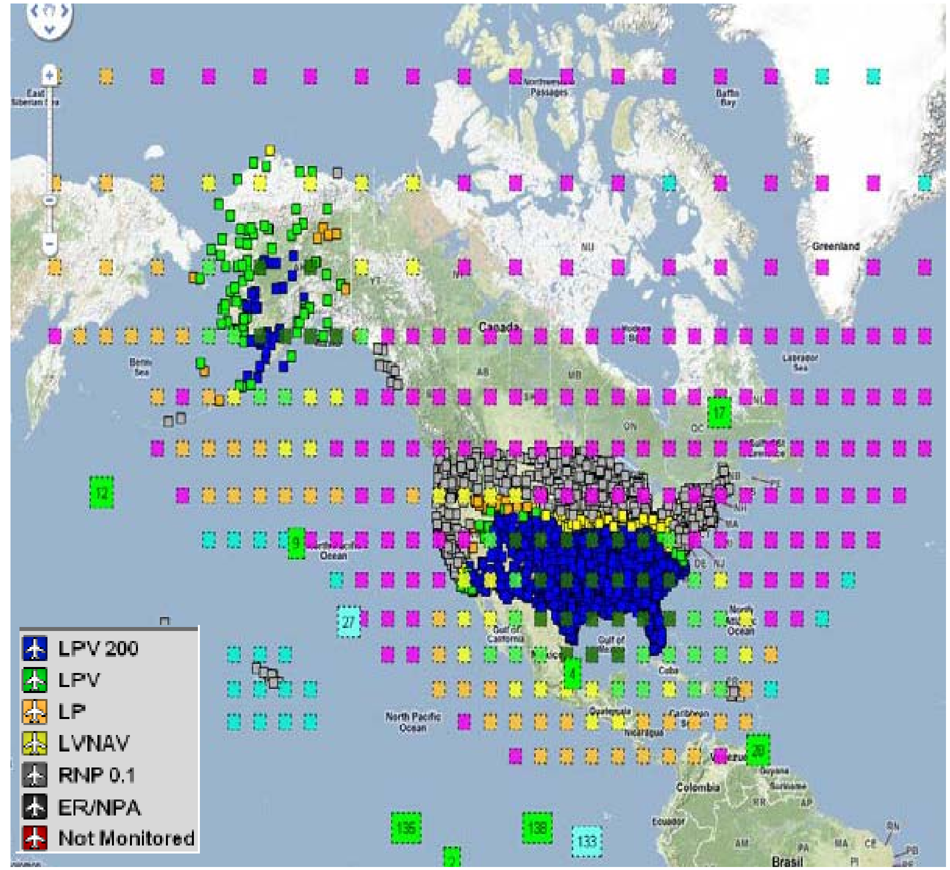

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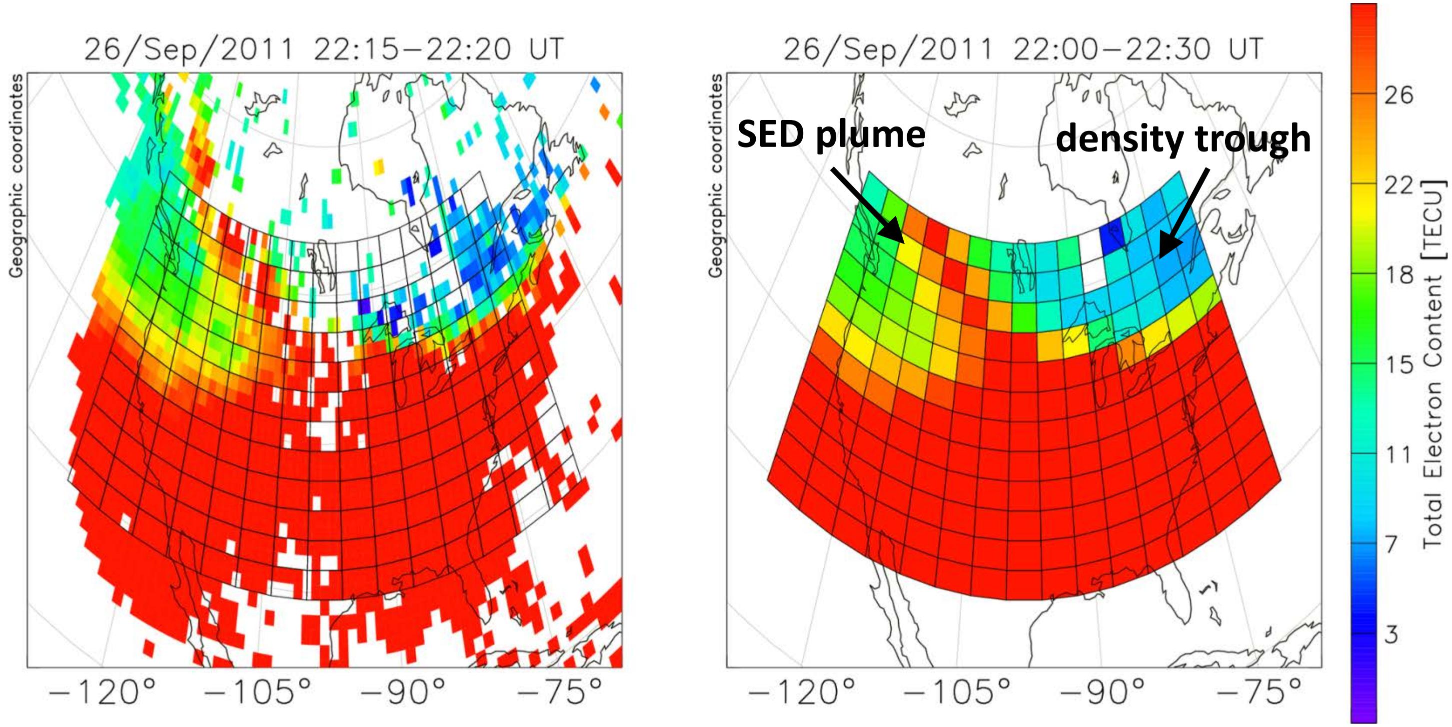
Figure: Wide Area Augmentation System (WAAS) availability over the U.S. before/after storm; small squares denote individual airport status; large squares denote grid ionosphere vertical error [*Wanner*, 2011].

GPS Total Electron Content

• Original 5 min GPS TEC values are re-binned from 1°×1° geographic lat/lon cells to 30 min averages in a new 2°×4° geographic lat/lon grid over North America.



• These values are then compiled into a database spanning 13 years (2001-2013), comprising a total of 41,022,720 TEC measurements.

Storm Identification

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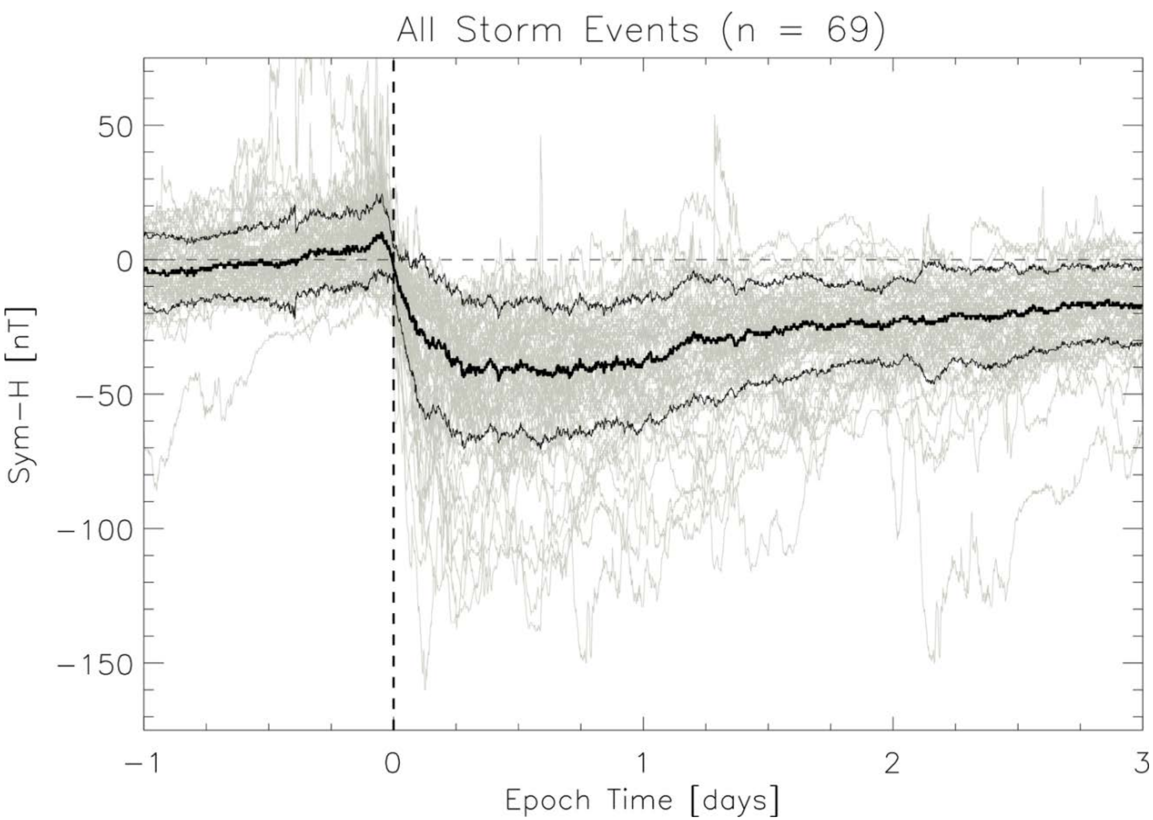


Season:

Winter: 9 Summer: 19
Spring: 24 Fall: 17

Magnitude:

-40 ≥ *Dst* > -80 nT : 50
Dst ≤ -80 nT : 19

- Using *Dst* values from the World Data Center for Geomagnetism in Kyoto, we have identified all geomagnetic storms during the current solar cycle maximum (2010-2013) reaching a magnitude of at least -40 nT (total of 69 events).

- In this study, we use the time of storm main phase onset (sharp decrease to negative values) rather than the storm sudden commencement (initial storm signature).

Superposed Epoch Analysis

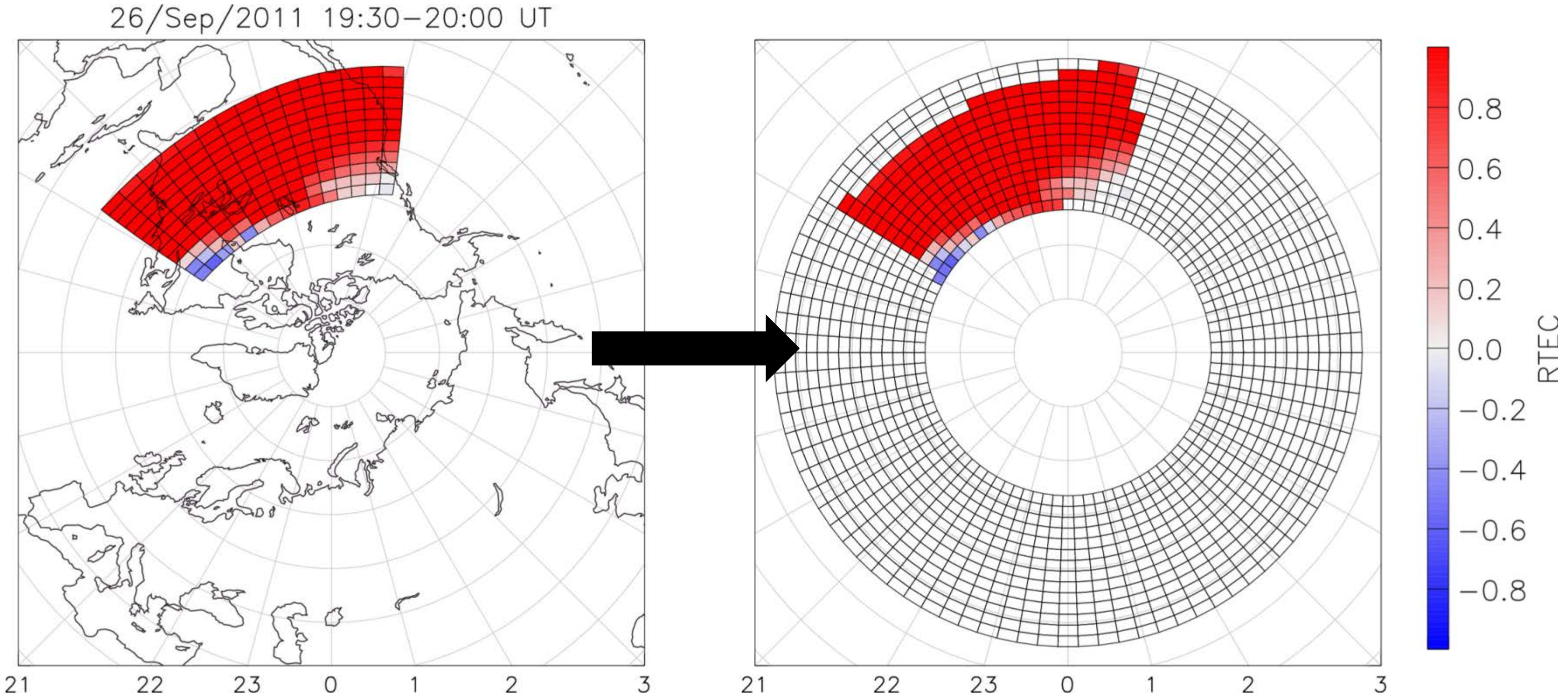
- Instantaneous (TEC) and 27-day median (TECq) values were recorded in each geographic latitude/longitude bin for the interval ranging from 1 day before to 3 days after storm onset.

- The storm time change in total electron content (RTEC) defined as

$$RTEC = (TEC - TECq)/TECq$$

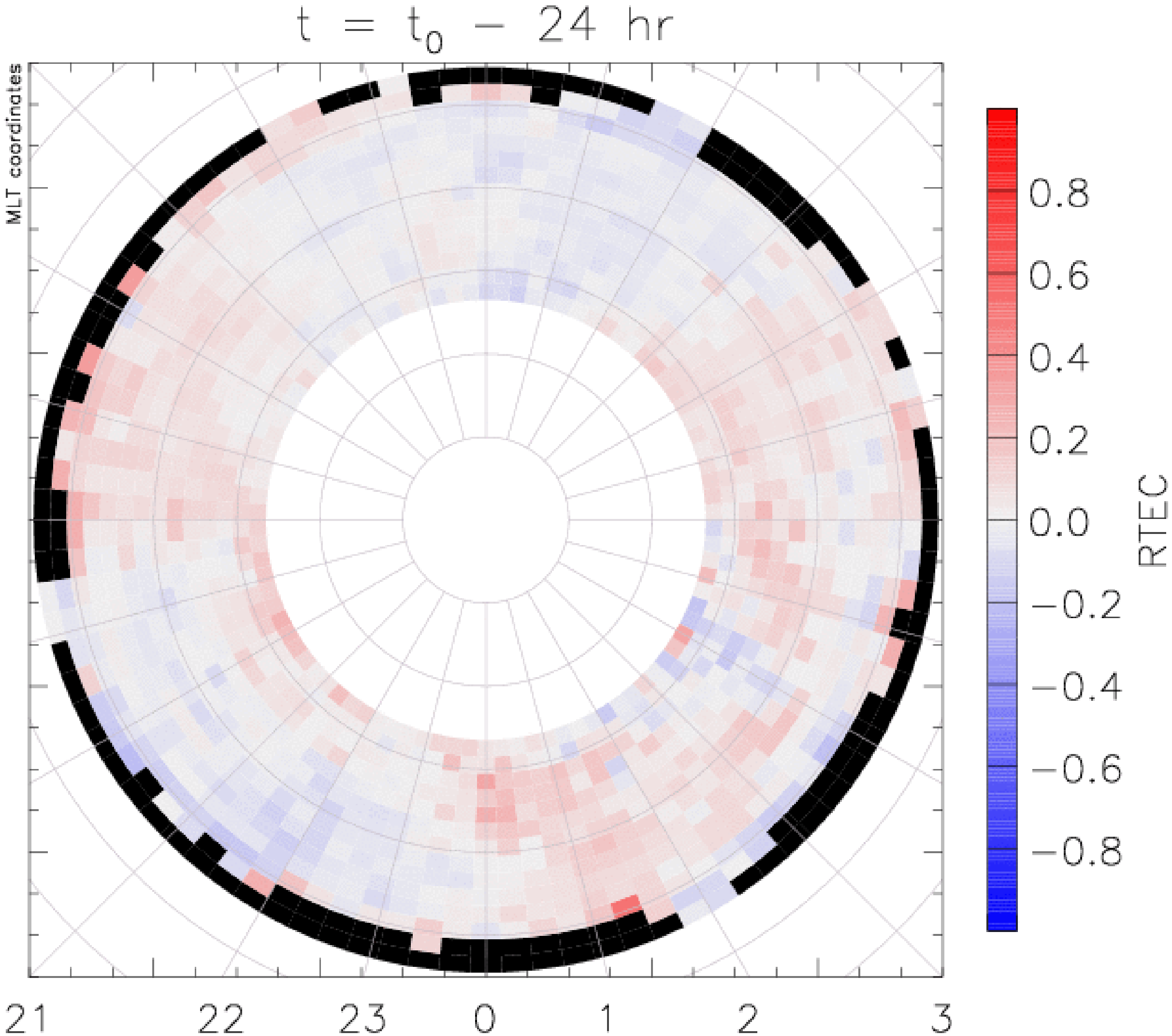
was calculated for each bin and then organized by magnetic latitude (MLAT) and magnetic local time (MLT) [e.g. *Biqiang et al.*, 2007].

Superposed Epoch Analysis



- Finally, median values of RTEC within each MLAT/MLT bin were then calculated using data from all storm events.
- Here we use a relative change (RTEC) rather than an absolute difference because of dependence of the background TEC magnitude on solar cycle variability.

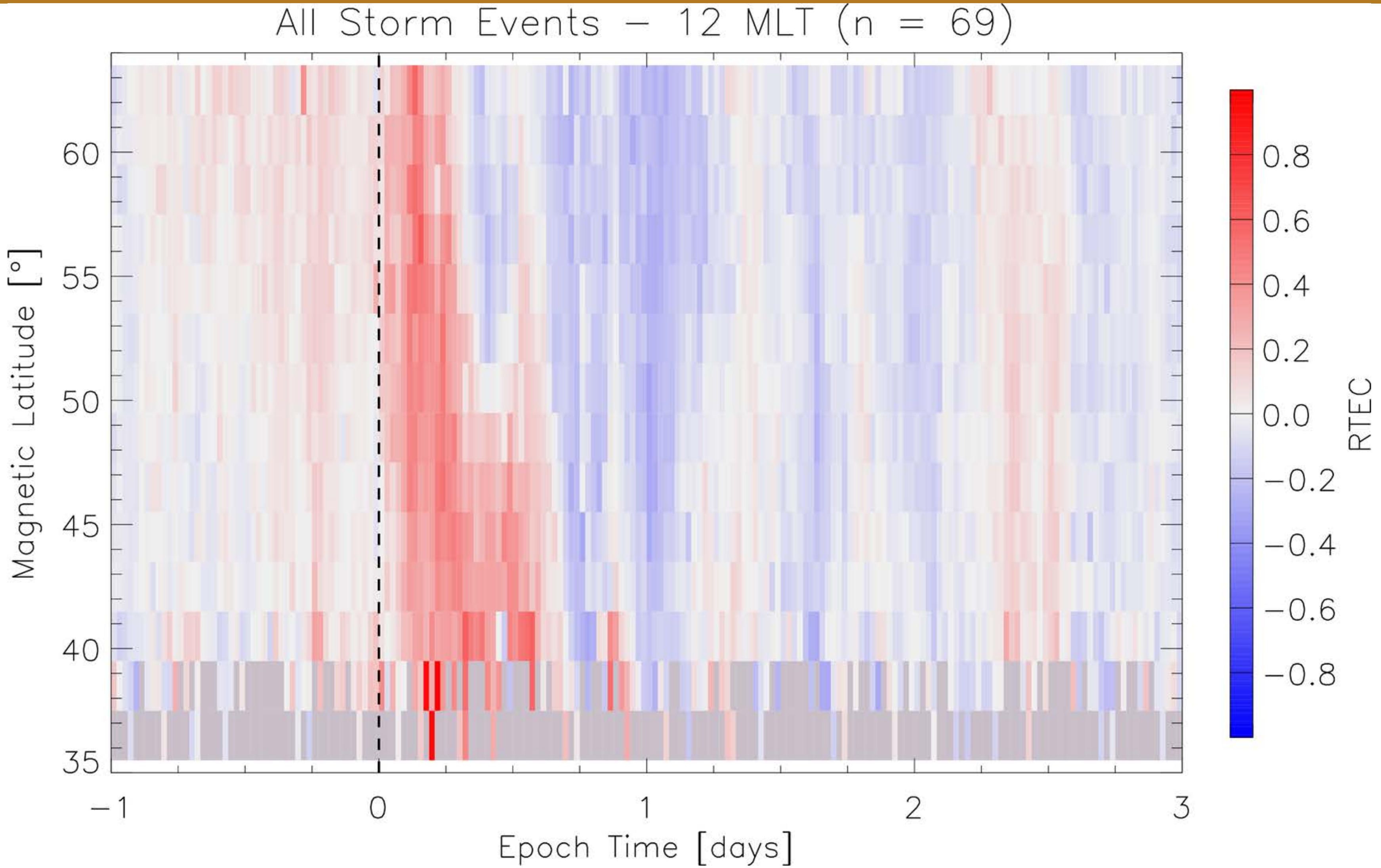
Results – Global RTEC



Key Features:

- Positive phase spanning 06-24 MLT observed at all latitudes at storm onset
- Negative phase starts in dawn sector within 6 hours
- Complete change from positive to negative phase at all MLTs within 24 hours
- Auroral oval seen as early positive response from 24-06 MLT at high latitudes
- Trough seen as negative response from 18-24 MLT about 4-24 hours after onset

Results – RTEC at 12 MLT



Future Work – Storm List

Sometimes simple…

Future Work – Storm List

Sometimes not.

Future Work – EOF Model

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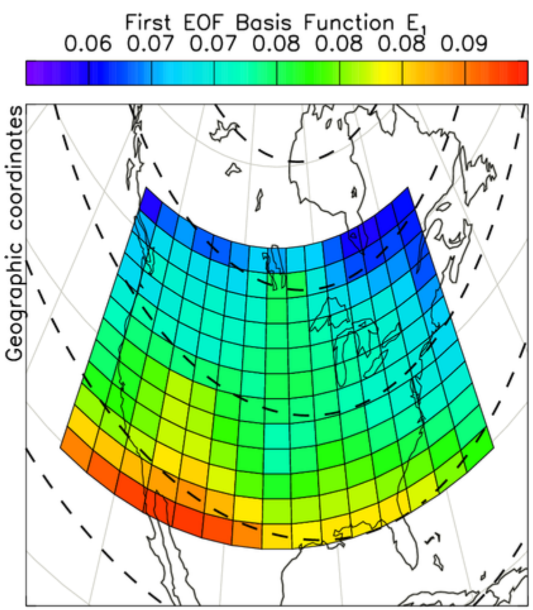
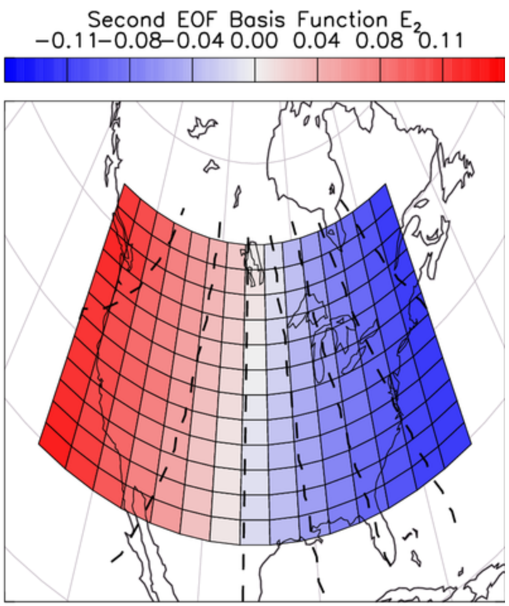


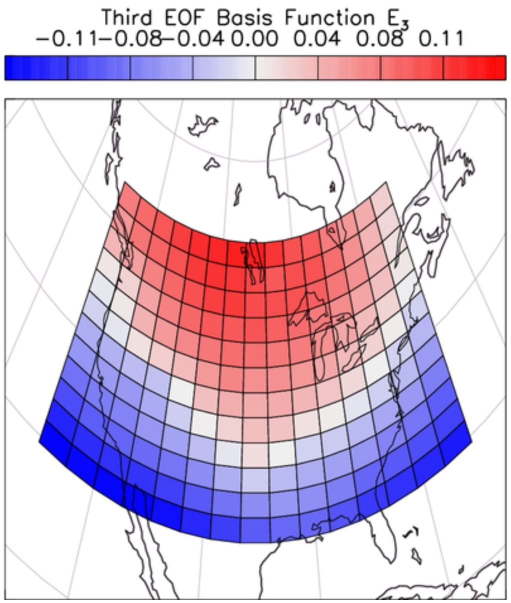
1st Basis Function: variation with geomagnetic latitude and solar EUV

$E_1 \times P_1 = 94.28\%$ of variance



2nd Basis Function: variation with declination (neutral winds)

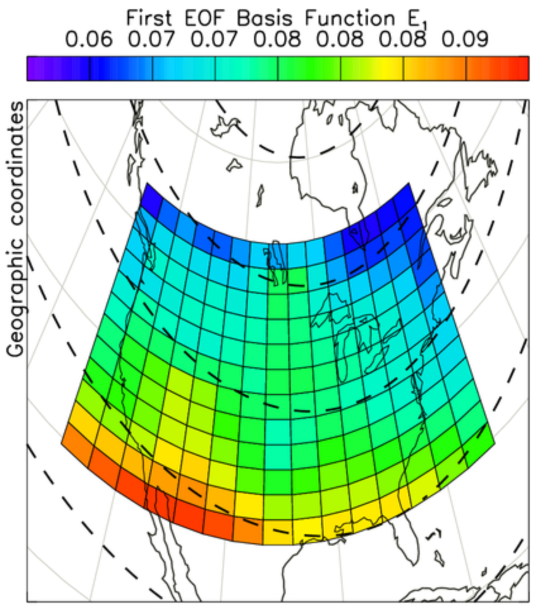
$E_2 \times P_2 = 3.90\%$ of variance



3rd Basis Function: variation with dipole tilt offset + geomagnetic latitude?

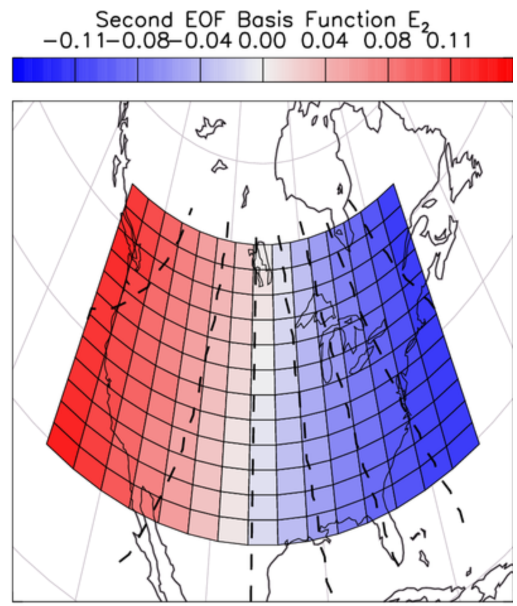
$E_3 \times P_3 = 0.61\%$ of variance

Future Work – EOF Model



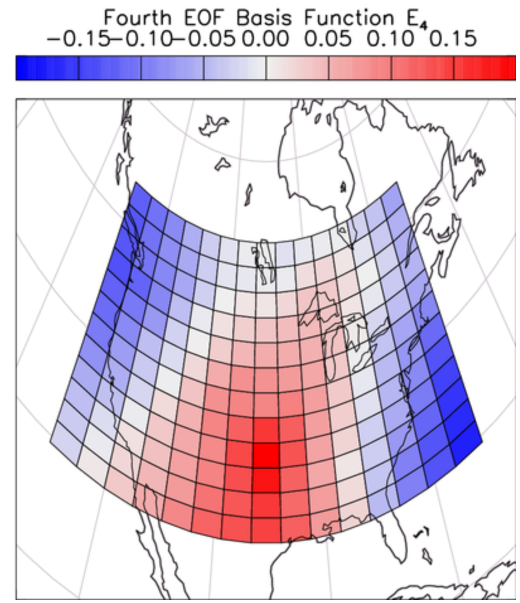
1st Basis Function: variation with geomagnetic latitude and solar EUV

$E_1 \times P_1 = 94.28\%$ of variance



2nd Basis Function: variation with declination (neutral winds)

$E_2 \times P_2 = 3.90\%$ of variance



4th Basis Function: “Kansas Anomaly” (bad GPS receiver biases in MIT data processing)

$E_4 \times P_4 = 0.36\%$ of variance
(cumulative variance = 99.15%)

Summary

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- We have performed a superposed epoch analysis of 69 geomagnetic storms from the recent solar cycle maximum period (2010-2013) to gain a better understanding of the average GPS TEC response in the North American sector.

- A new effort is underway to automatically identify geomagnetic storm onset times and durations for the full 2001-2013 period to improve statistics of seasonal / local time / etc. effects.

- Future work will also include modeling of TEC storm effects using Empirical Orthogonal Function (EOF) techniques for potential predictive or operational capabilities.

References

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Thank You!