Characterizing Extreme Ionospheric Storms

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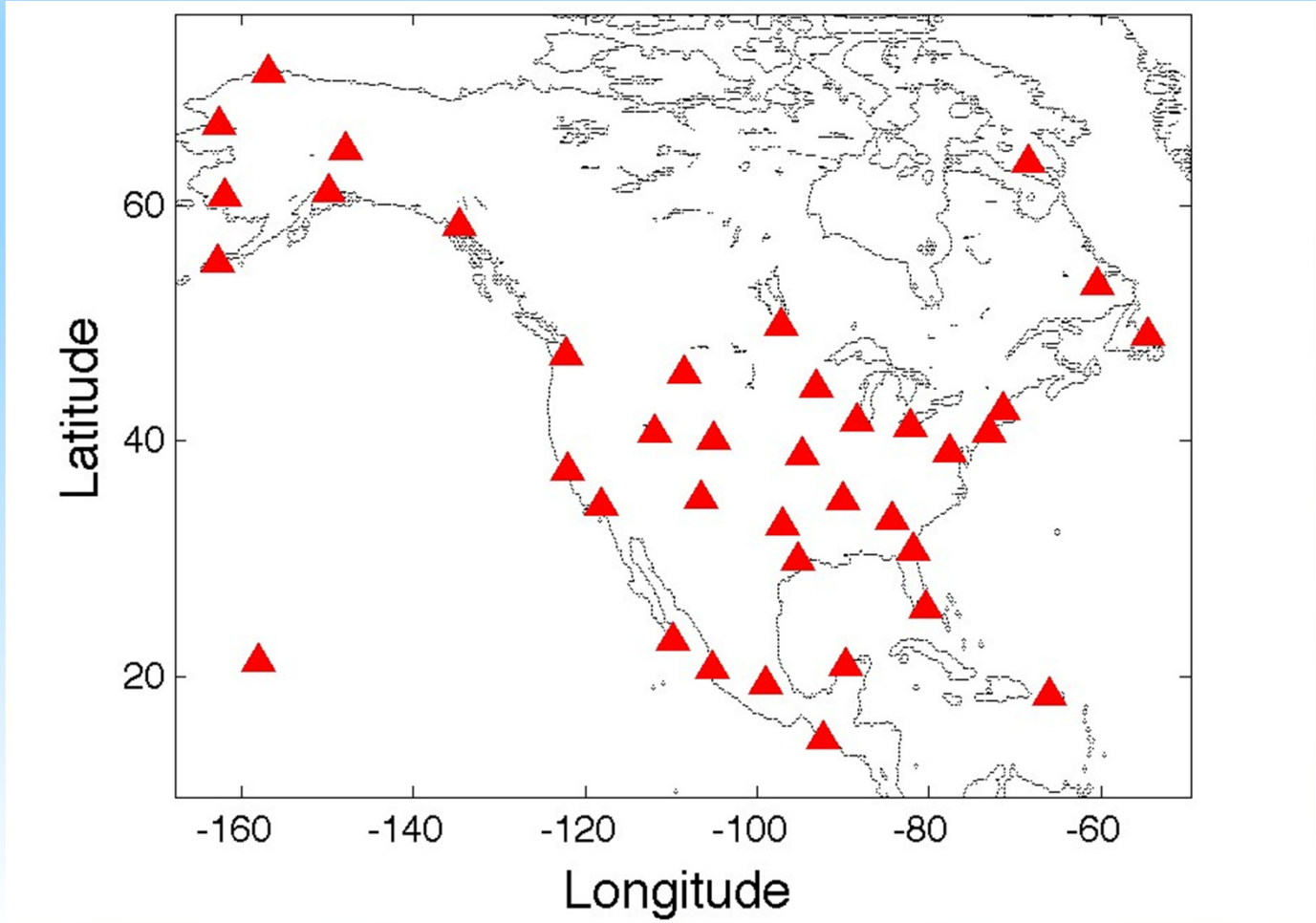
Outline

Objective:
to develop a method of characterizing ionospheric storm strength in terms of scalar metrics

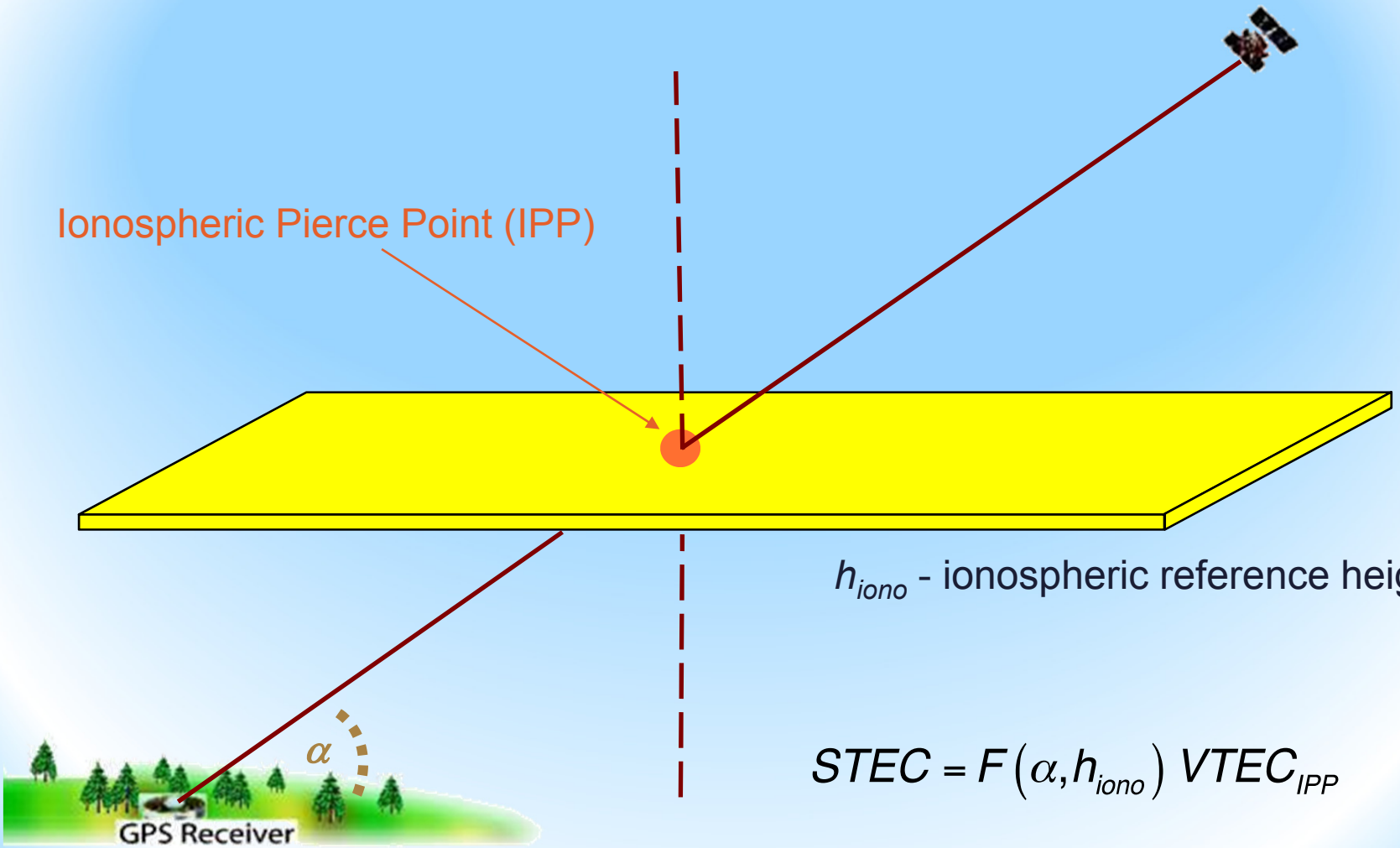
- Motivation
- Methodology
- Results
- Future work

WAAS receiver sites



WAAS receiver network currently consists of 38 sites in North America.

Thin-shell model of ionosphere

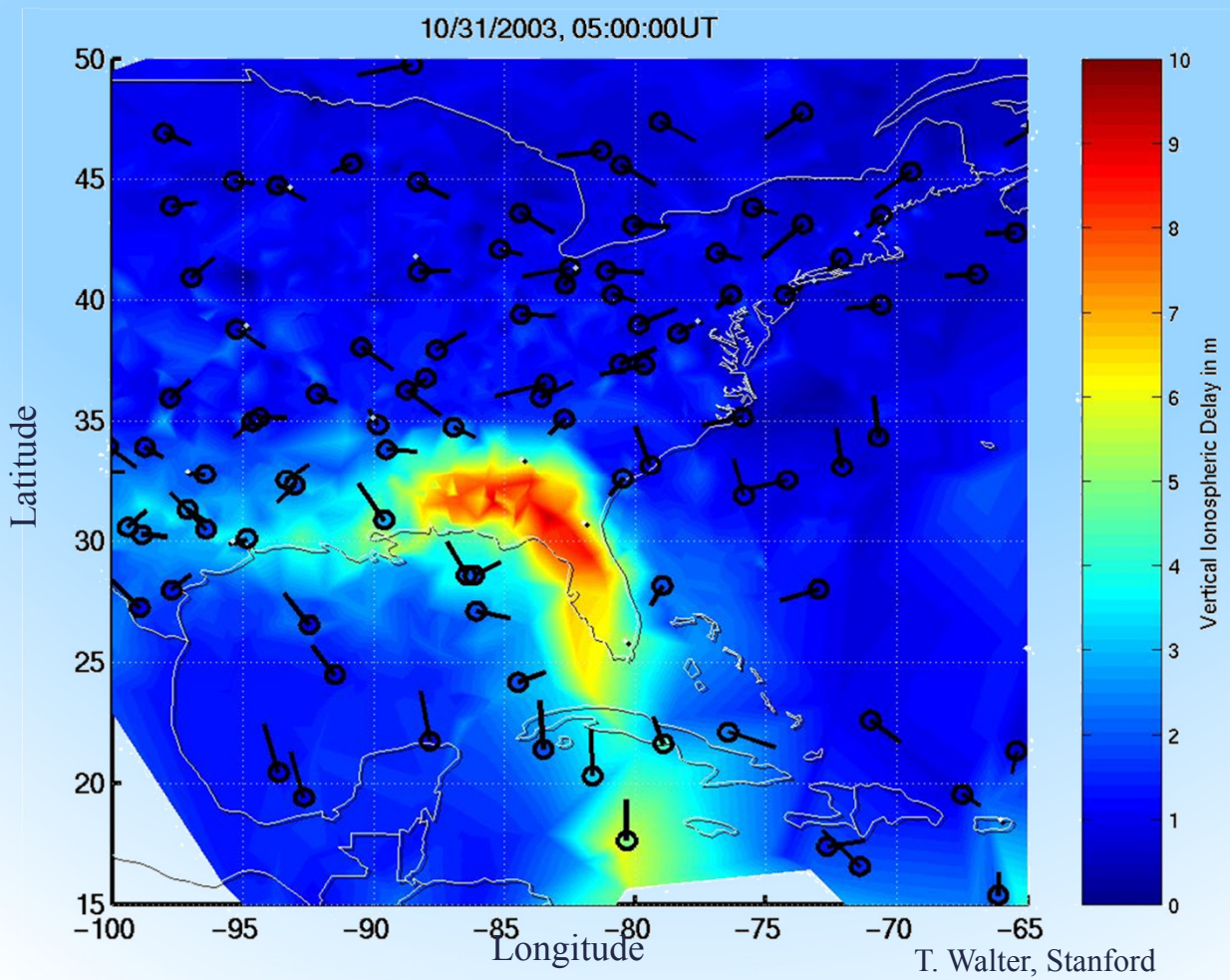


h_{iono} - ionospheric reference height

$$STEC = F\left(\alpha, h_{iono}\right) VTEC_{IPP}$$

Mapping slant TEC to vertical TEC assumes the ionosphere occupies a thin shell.

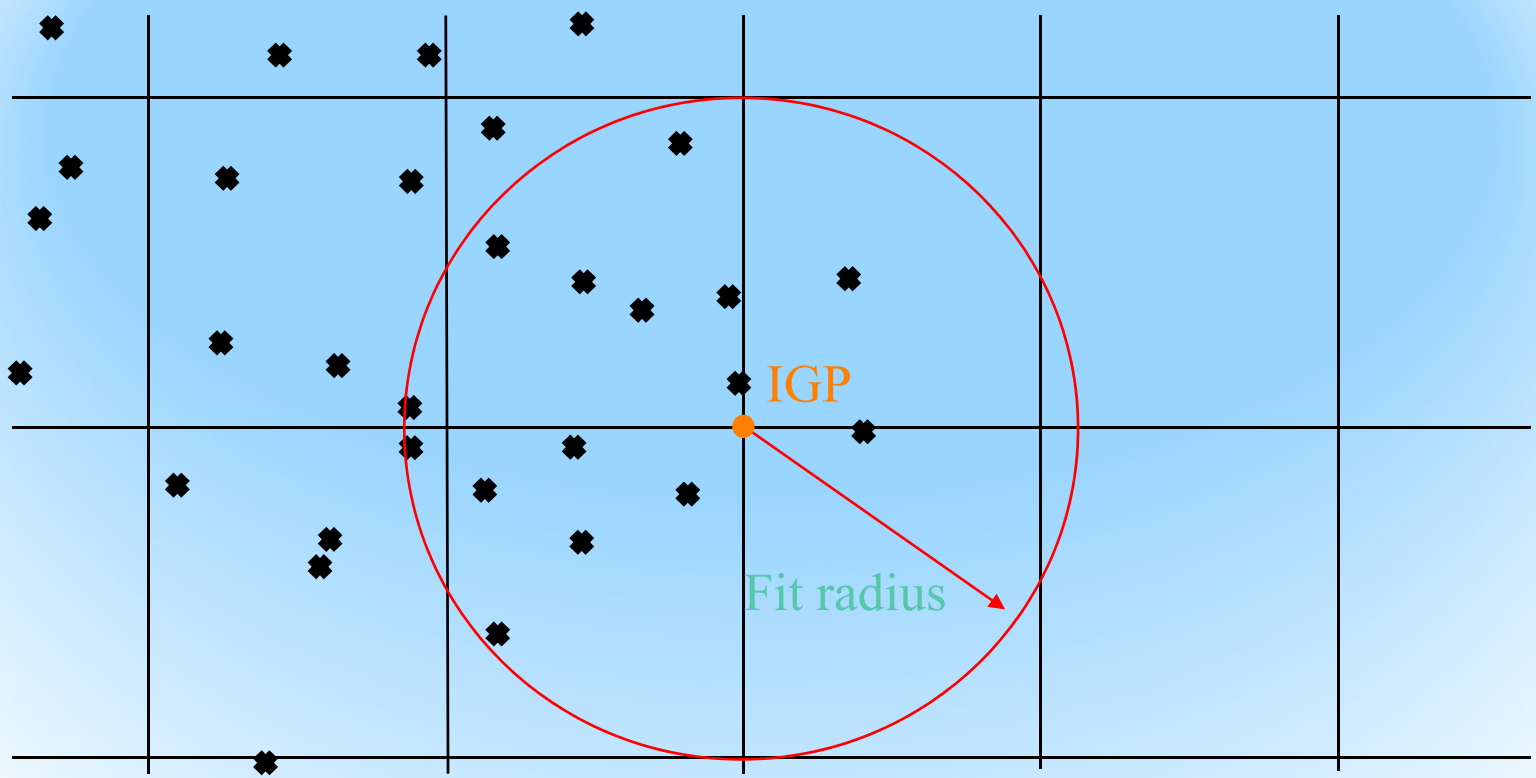
Ionospheric threat to WAAS user due to undersampling



T. Walter, Stanford

Highly localized irregularities in ionospheric TEC represent an integrity threat. (Note: 5 measurements that sample the irregularity have been removed.)

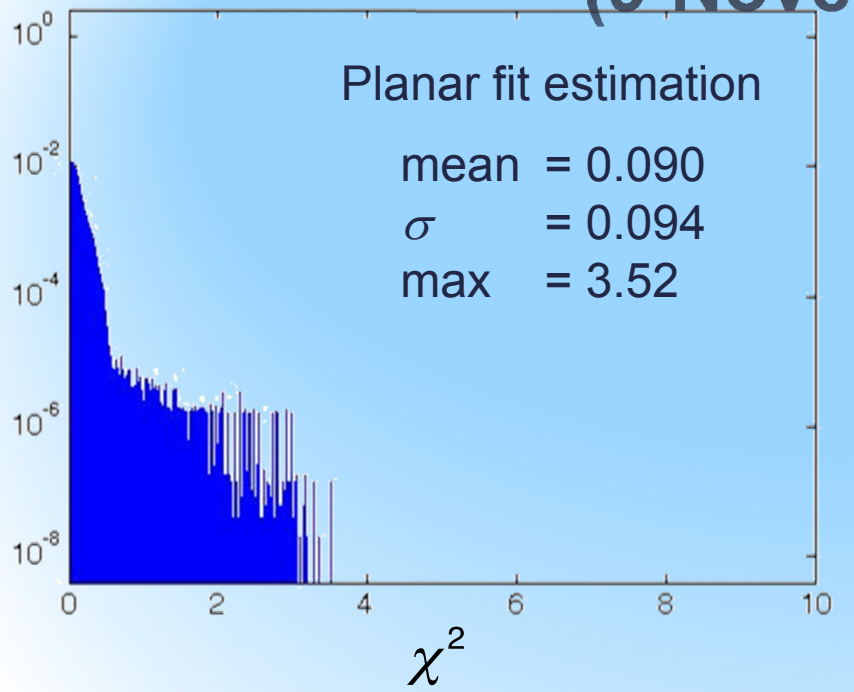
Estimating vertical TEC at a specified location

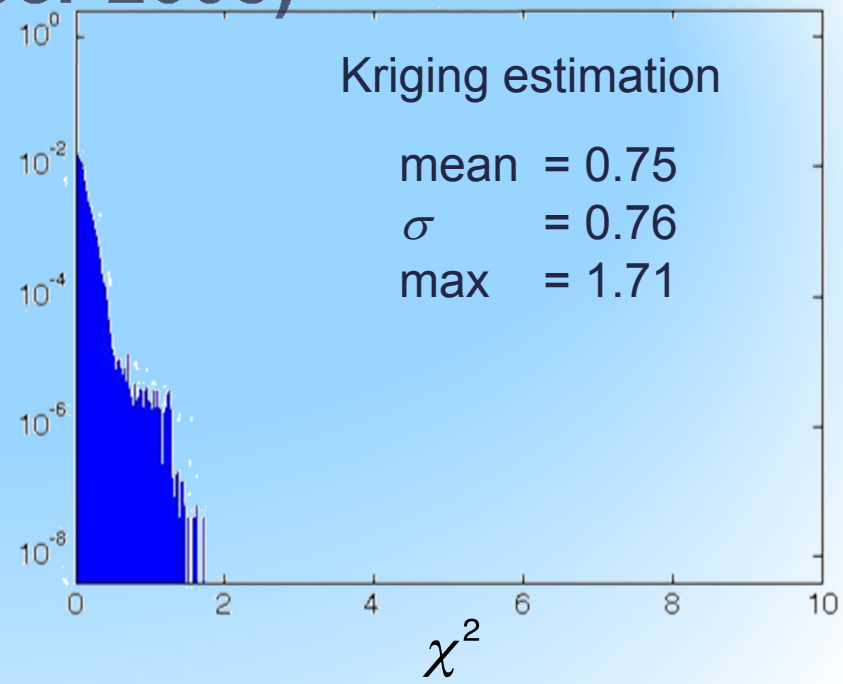


$$Model: \quad VTEC_{true}\left(\Delta\mathbf{x}\right) = a_0 + a_{east}\,\Delta\mathbf{x}^T \cdot \hat{e}_{east} + a_{north}\,\Delta\mathbf{x}^T \cdot \hat{e}_{north} + r\left(\Delta\mathbf{x}\right)$$

Estimated TEC values and error bounds are based upon fits of vertical TEC measurements near the ionospheric grid point (IGP).

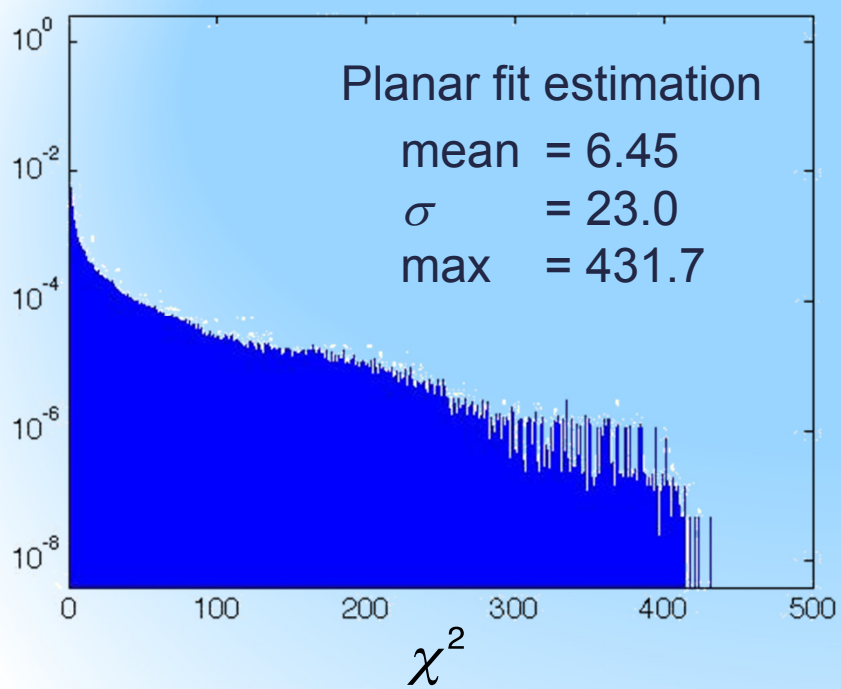
χ^2 under quiet ionospheric conditions (9 November 2005)

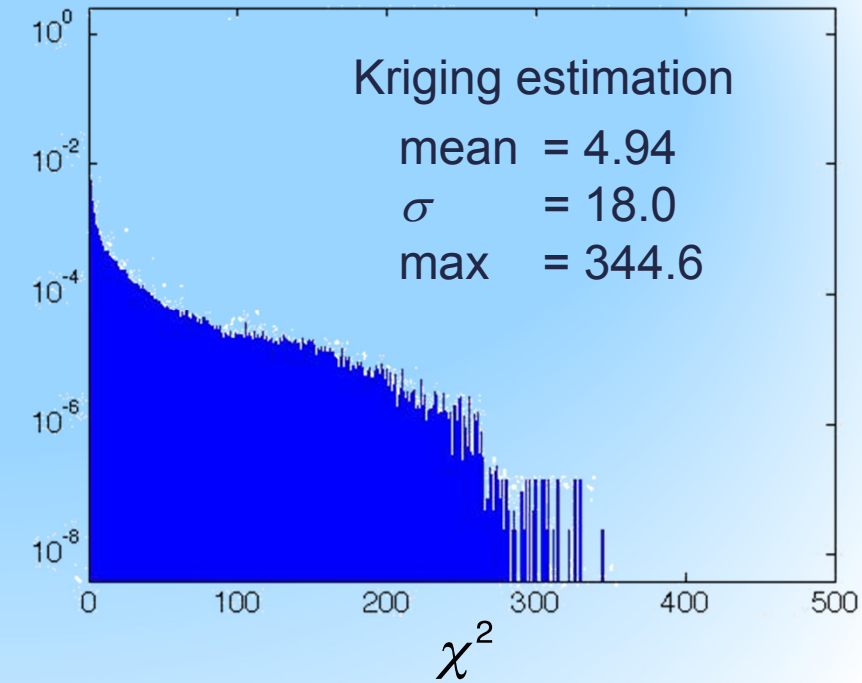




The distribution *of* χ^2 depends upon the type of estimation used.
WAAS has used both planar fit estimation and kriging.

χ^2 under highly disturbed ionospheric conditions (30 October 2003)





χ^2 reflects the local level of ionospheric disturbance.

Note: the horizontal scale maximum has increased from 10 to 500.

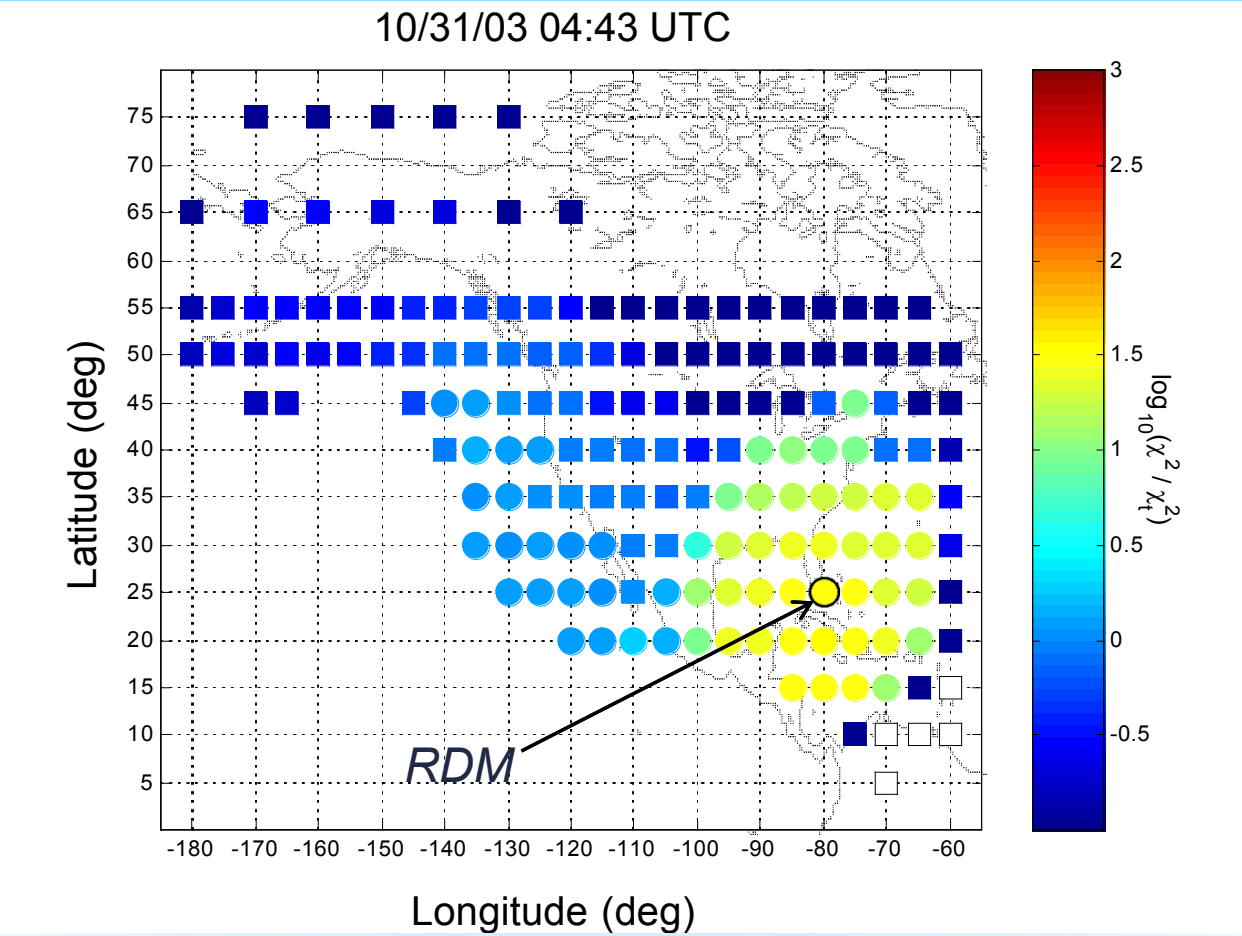
WAAS metrics that characterize the level of ionospheric disturbance

- $\chi^2_{irreg}(\theta, \phi, t)$ - *local disturbance metric*:
derived from the goodness-of-fit at an IGP, a function of space and time

- *RDM*(*t*) - *regional disturbance* metric:
derived from $\chi^2_{irreg}(\theta, \phi, t)$ over the region of interest, a function of time (monitored by the WAAS *extreme storm detector*)

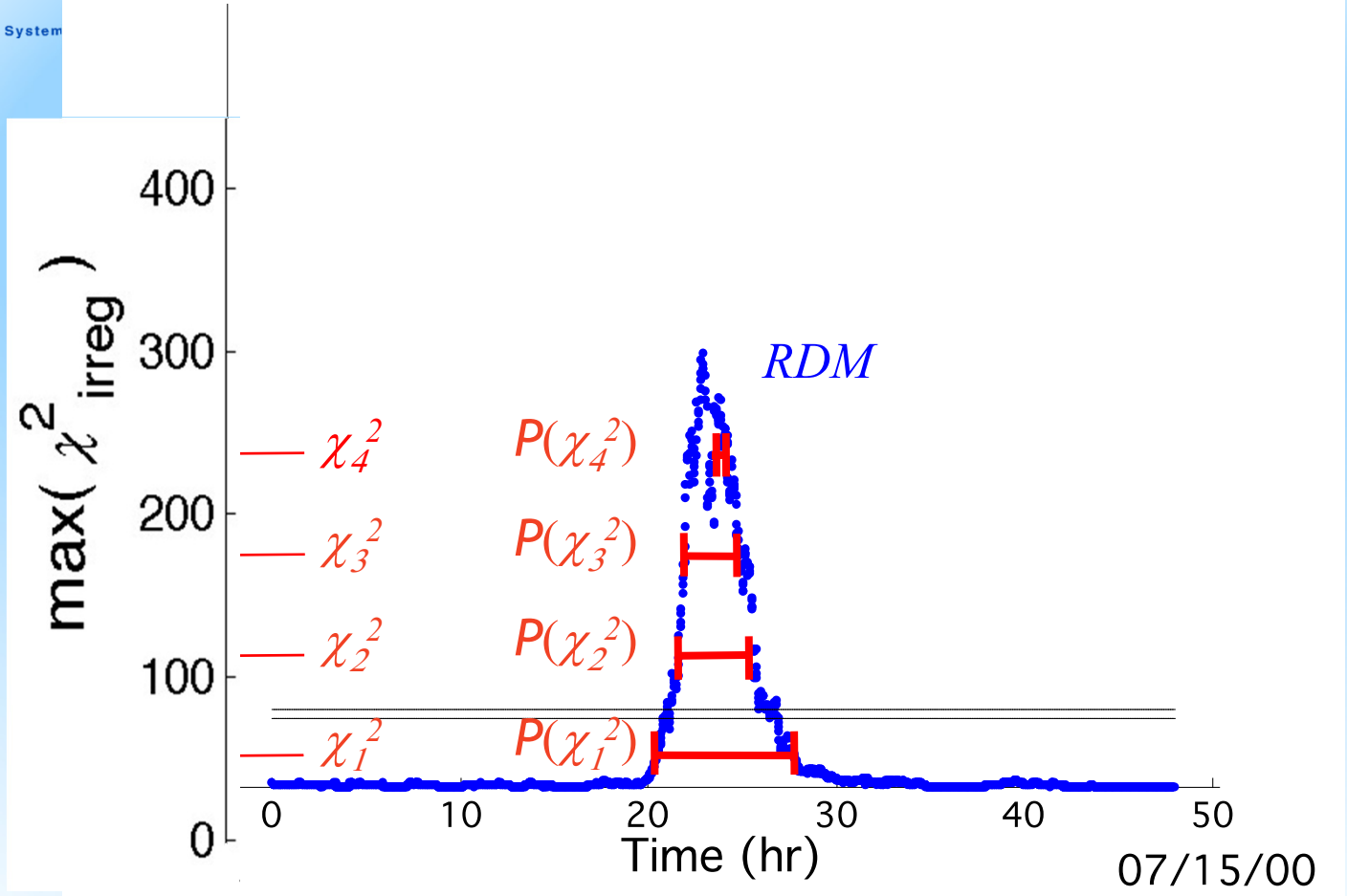
- *SSM* - *storm magnitude metric*:
derived from the *RDM*(*t*), used to rank the size of an ionospheric storm

Regional disturbance metric



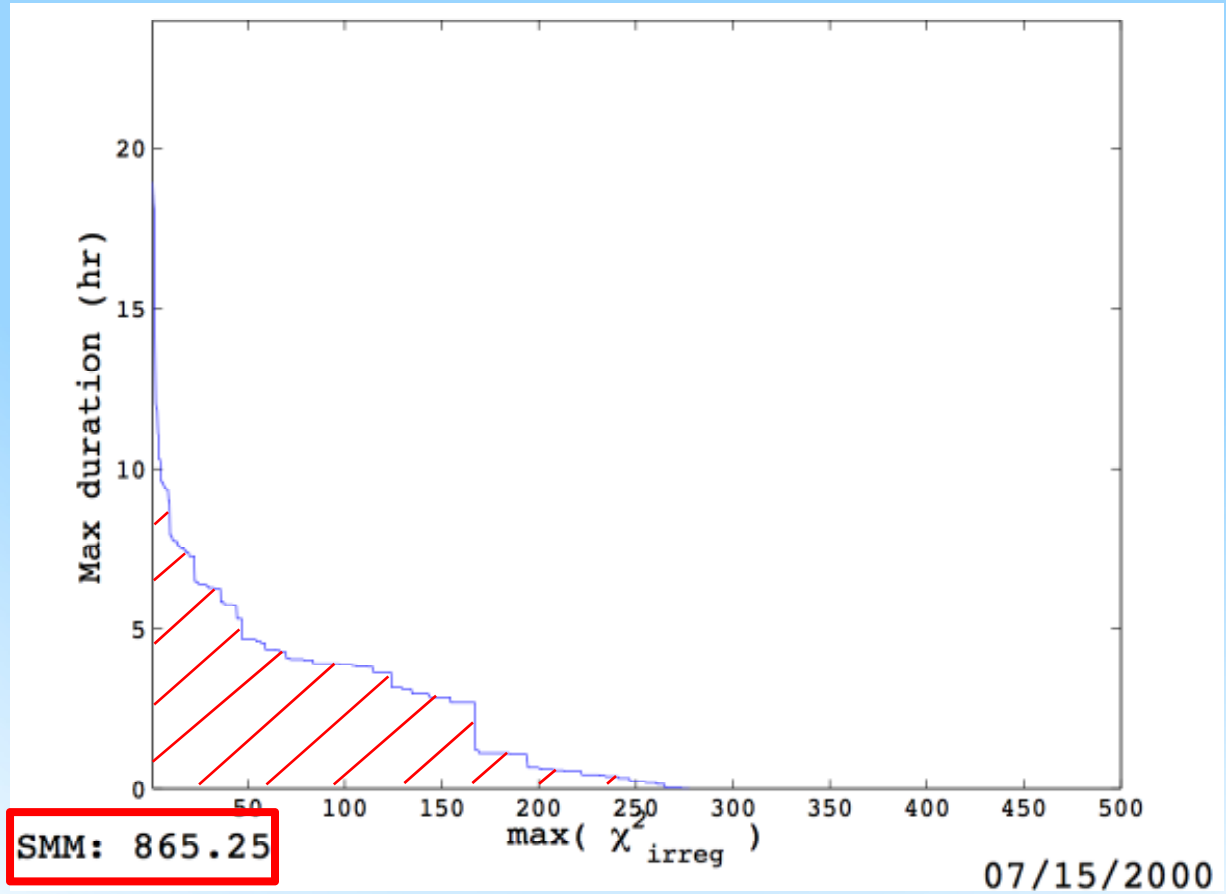
RDM(t) is defined to be the *maximum* of $\chi^2_{irreg}(\theta, \phi, t)$ over the region of interest.

Regional disturbance metric vs. time



A storm profile is $P(\chi^2)$ such that, for a given value χ^2, $P(\chi^2)$ is the maximum duration over which $RDM(t) = \max[\chi^2_{irreg}(\theta, \phi, t)]$ remains *continuously* above χ^2.

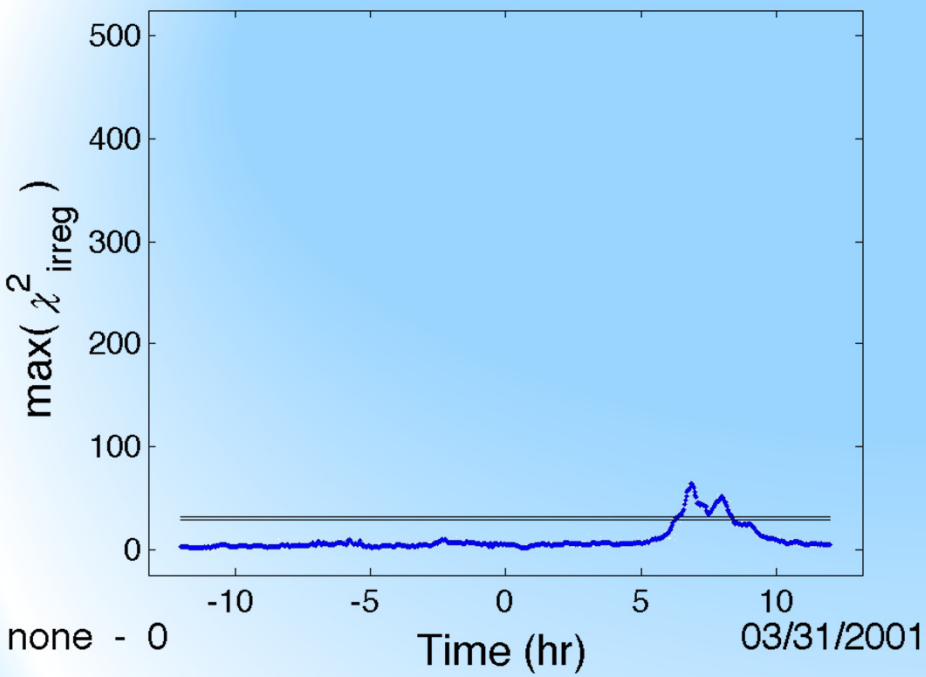
Storm profile for July 15-16, 2000

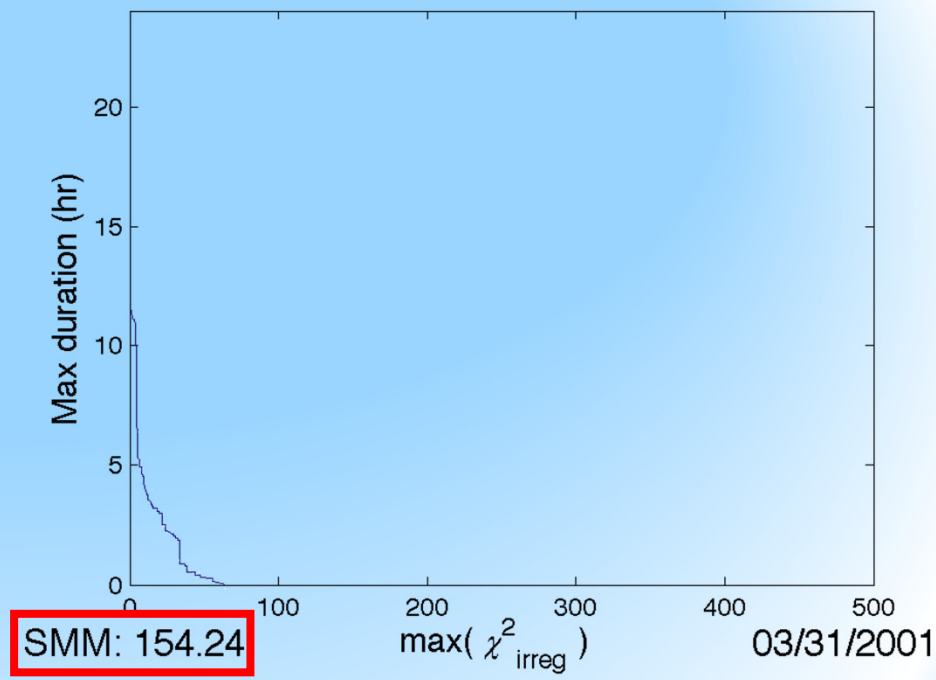


Define the *storm magnitude metric* (*SMM*) to be the area under the curve.

This metric takes into account both the maximum instantaneous level of disturbance and the temporal duration of the storm.

Metrics for a moderate storm



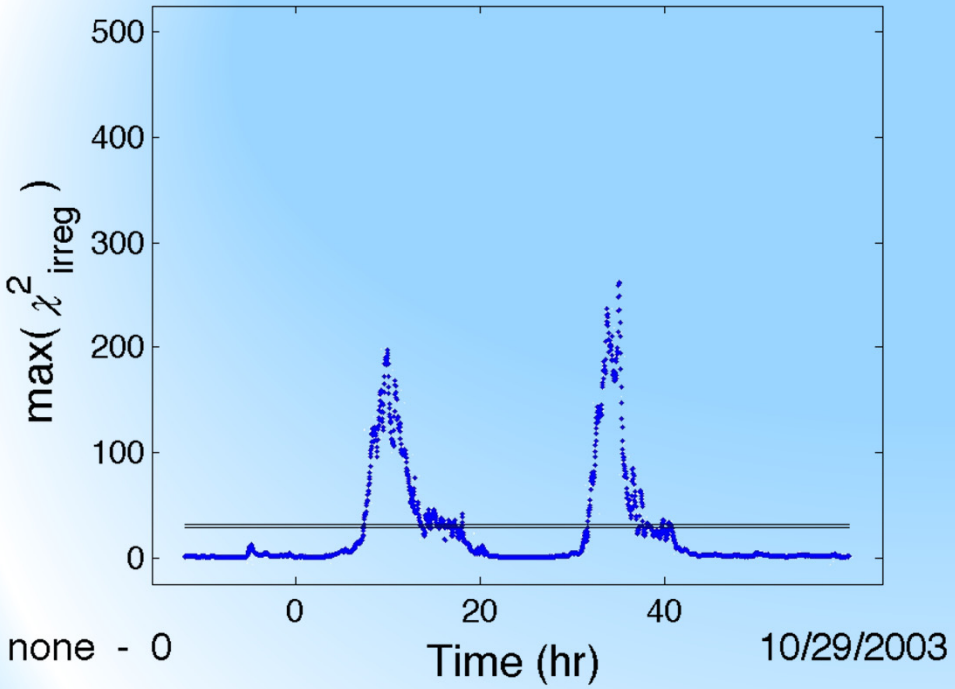


RDM vs. time

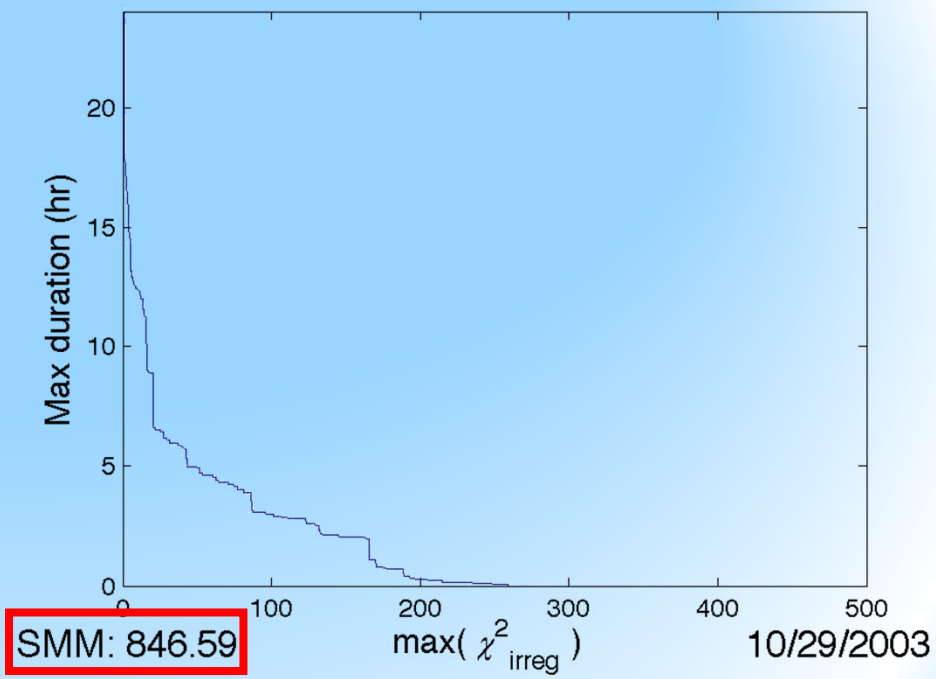
Maximum duration above *RDM* vs. *RDM*

Regional disturbance metric history and storm profile for March 31, 2001.

Metrics for an extreme storm



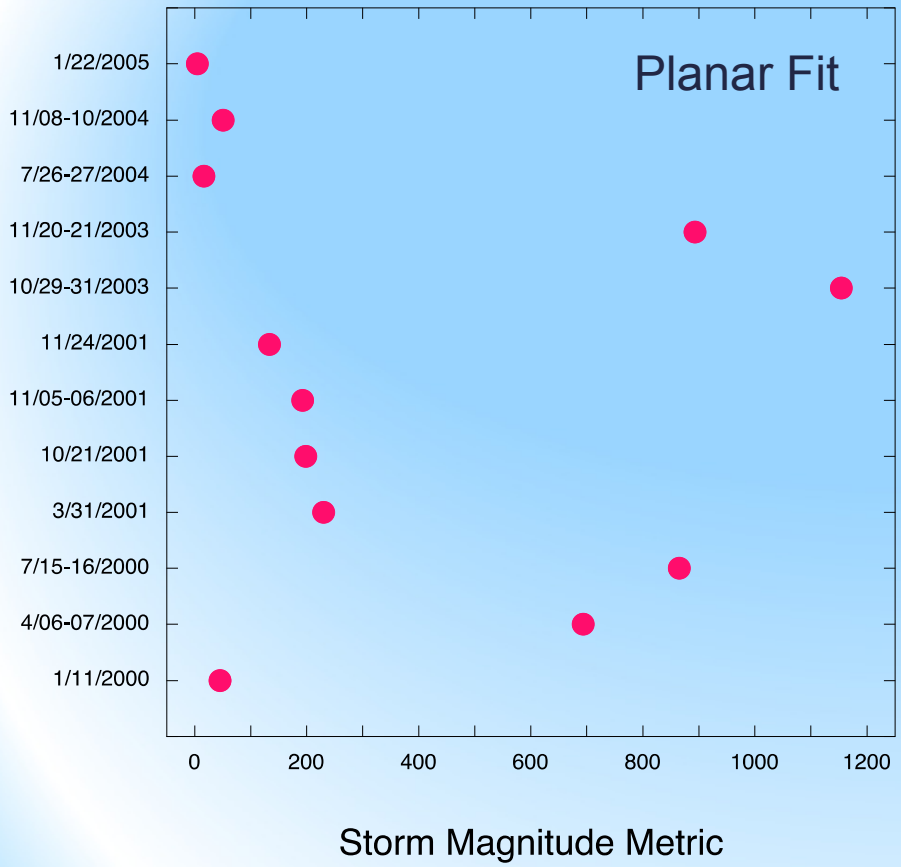
RDM vs. time

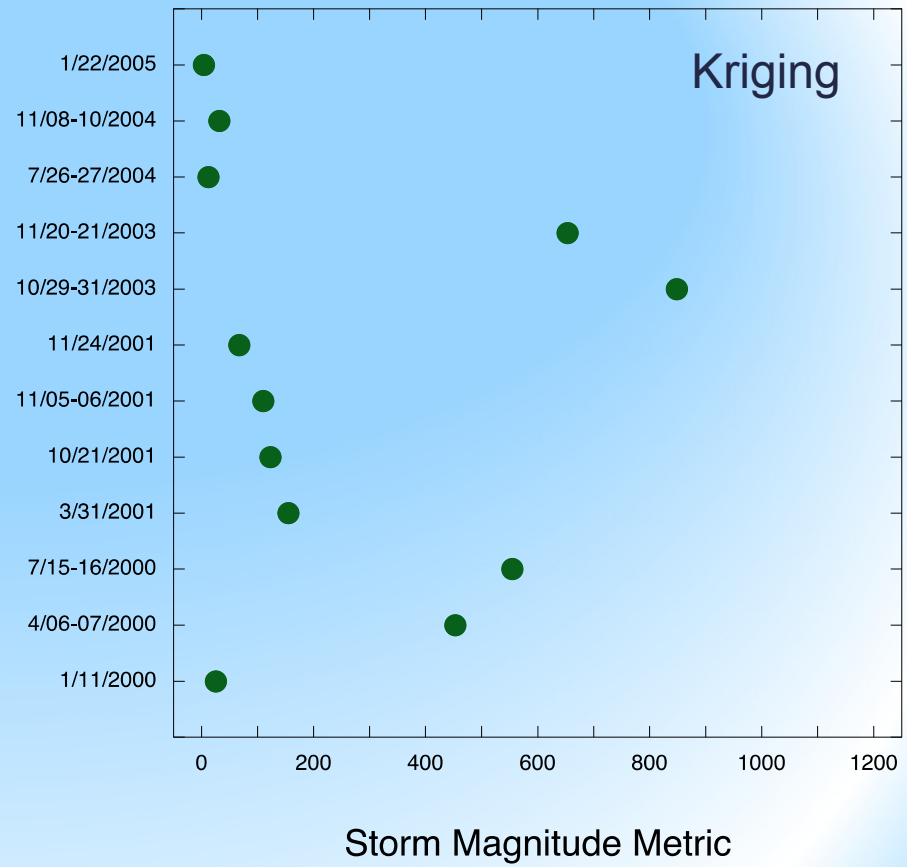


Maximum duration above *RDM* vs. *RDM*

Regional disturbance metric history and storm profile for October 29-31, 2003.

Ranking major storms over the last solar cycle





The planar fit *SMM* and the kriging *SMM* yield similar storm rankings!

Future work

To establish a database of ionospheric disturbance metrics, various issues must be agreed upon:

- geographic region of interest
- TEC estimation model
- TEC estimation algorithm
- definition of $\chi^2_{irreg}(\theta, \phi, t)$
- definition of *RDM* [*e.g.*, sum, product, or median of $\chi^2_{irreg}(\theta, \phi, t)$]
- definition of storm profile (*e.g.*, continuity requirement?)
- storm profile time interval

Conclusions

- We have presented an approach for defining :

a *regional disturbance metric* that quantifies the level ionospheric disruption as a function of time;

a *storm magnitude metric* that provides a robust means of ranking the magnitudes of ionospheric storms over specified geographic regions.

- Both metrics have been adopted by the FFA's Wide Area Augmentation System as means of protecting users from positioning errors due to ionospheric storms.

For more details on estimation methods, see

Sparks, L., J. Blanch, and N. Pandya, "Estimating Ionospheric Delay Using Kriging: 1. Methodology", *Radio Science* 46, RS0D21, doi:10.1029/2011RS004667.

Acknowledgment:

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