An Investigation of Rate of Change of Hourly Receiver Interfrequency Bias Estimates for Quiet and Storm Days

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Action Item and Additional Questions to Answer

- JPL action item 18: to investigate receiver bias ramping using GPS measurements for multiple receivers and for quiet and disturbed ionospheric conditions
- Questions to Answer:
  - How does the unmodeled ionospheric effect propagate into the receiver interfrequency bias solution for
    - quiet and disturbed days;
    - and nearby receivers?
  - How does the geographic distribution of GPS sites affect the receiver bias estimation?
  - Characterize the ramping of receiver bias estimates for quiet and storm days and geographic regions. Compute mean, standard deviation and maximum value of ramping under the conditions discussed above.

Outline

- We modified our routine GIM receiver bias estimation scheme to solve for biases on an hourly basis instead of solving for daily bias estimates. The hourly biases are solved for in a random walk process using a Kalman filter.
- Data set used for quiet and storm days: October 27-31, 2003.
- We used 98 globally distributed IGS stations to solve for GIM coefficients, satellite biases and hourly receiver biases. We decided to use high quality IGS stations to minimize the effect of multipath error and measurement noise on data leveling.
- We present case studies for multiple receivers in a small geographic region.
- We also present results using the 98 globally distributed IGS stations.

Results Presented

- Slant TEC, slant residuals, hourly and daily GIM bias estimates for
  - Quiet (Oct 27-28) and storm days (Oct 29-31) at JPLM
  - Quiet (Oct 27-28) and storm days (Oct 29-31) at MDO1
- Comparison of hourly and daily GIM receiver bias estimates for
  - Nearby receivers JPLM and CASA during Quiet Days (Oct 27-28)
  - Nearby receivers JPLM and CASA during Storm Days (Oct 29-30)
- Computing statistics for hourly changes in receiver bias estimates (separately for Oct 27,28,29,30,31): mean, standard deviation and maximum value of hourly receiver bias changes as a function of receiver geographic latitude using all 98 globally distributed IGS receivers

GIM and WAAS Ionospheric Correction Algorithm

For single shell, our **GIM** is

$$TEC = M\,(h,E)\sum_i C_i B_i(lat, lon) + b_r + b_s$$

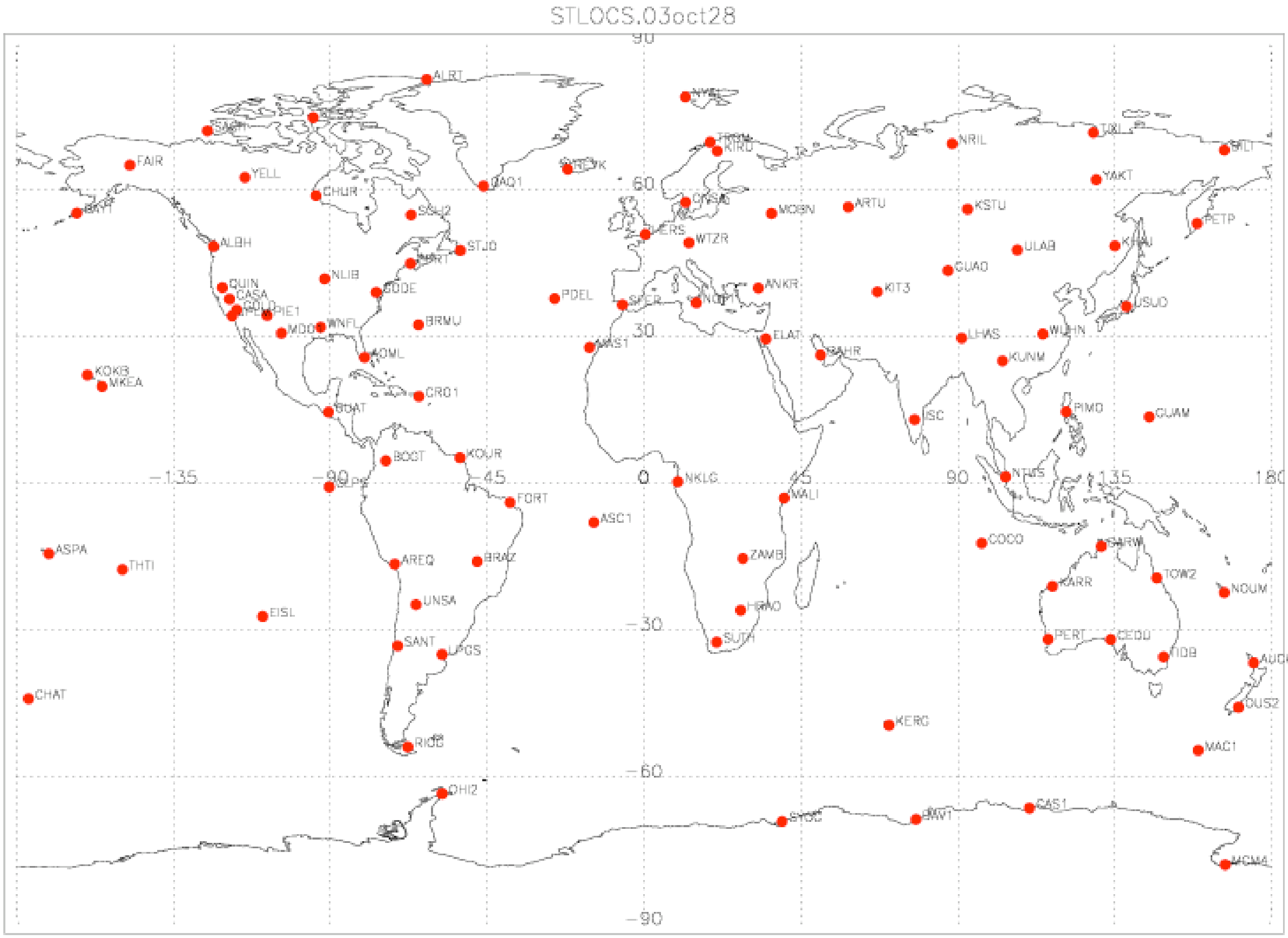
For **WAAS** the ionospheric model is

$$TEC = M(h,E)\left[a_0 + a_1 d_E + a_2 d_N\right]$$

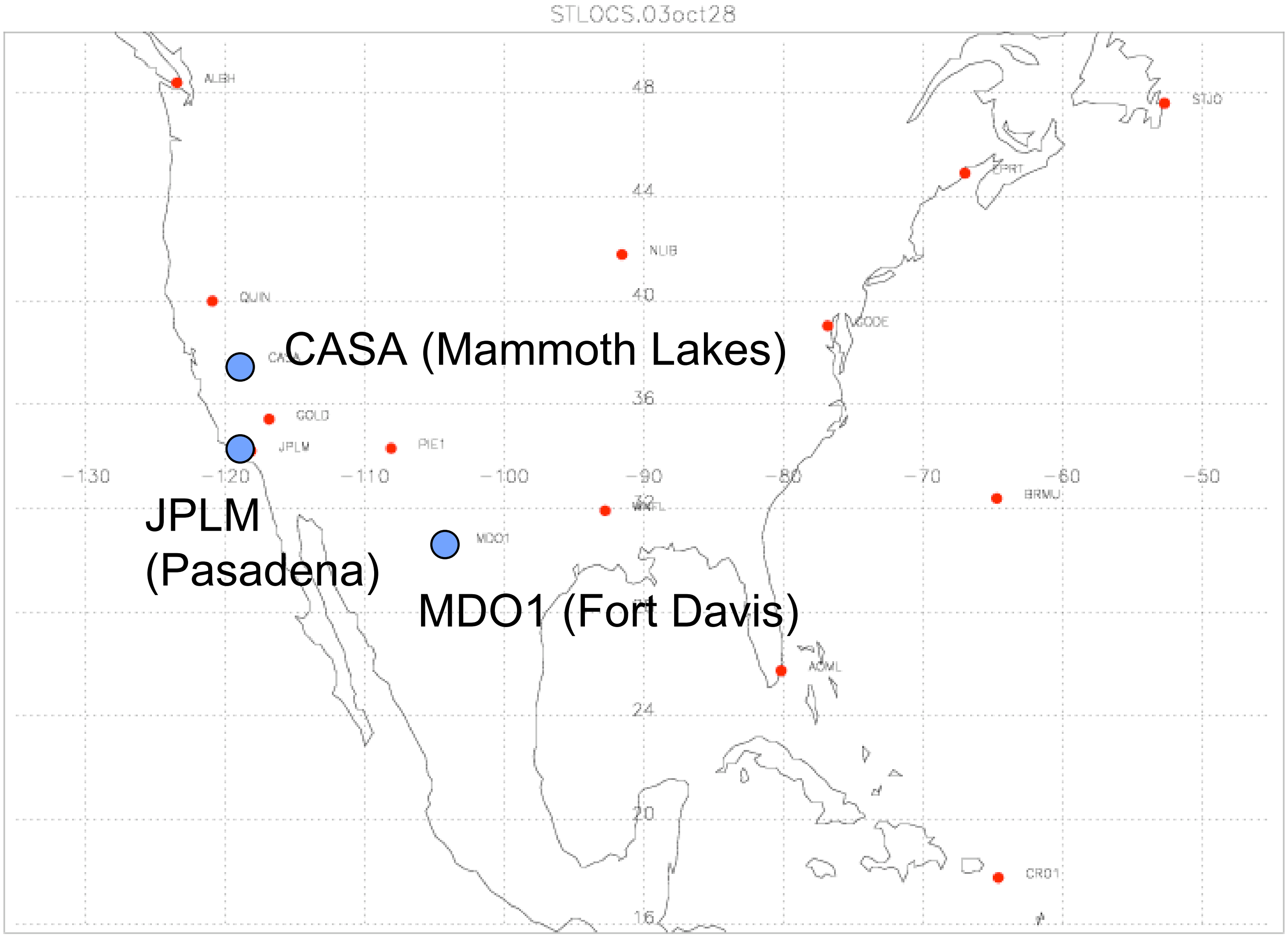
where

TEC	is the slant TEC
$M(h_1,E)$	is the thin shell mapping function
$B_i(lat,lon)$	is the horizontal basis function (C^2, TRIN, etc);
C_{1i}	are the basis function coefficients
b_r, b_s	are the satellite and receiver instrumental biases
a_0, a_1, a_2	are the planar fit parameters
d_E, d_N	distances from IGP to IPP

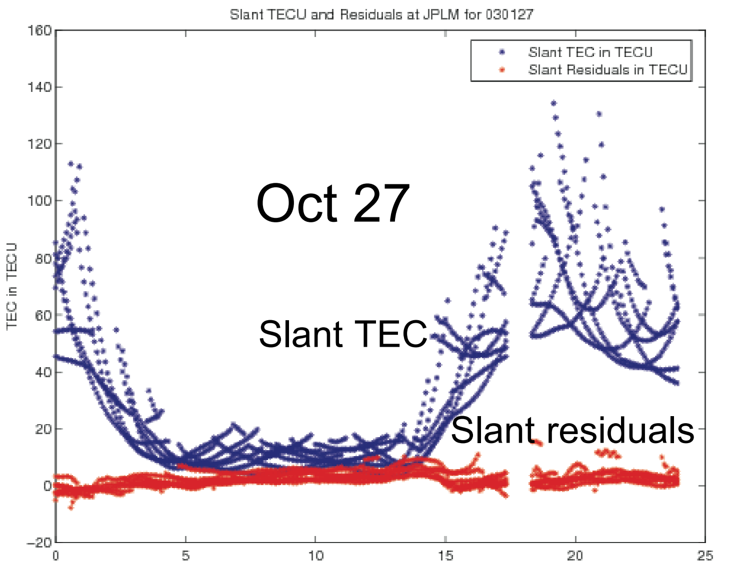
98 Globally Distributed Sites for Oct 28, 2003

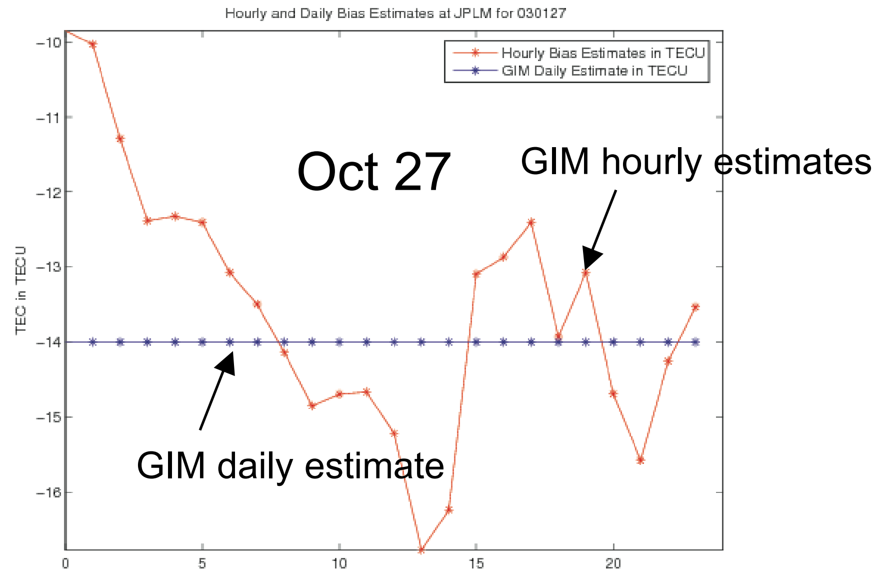


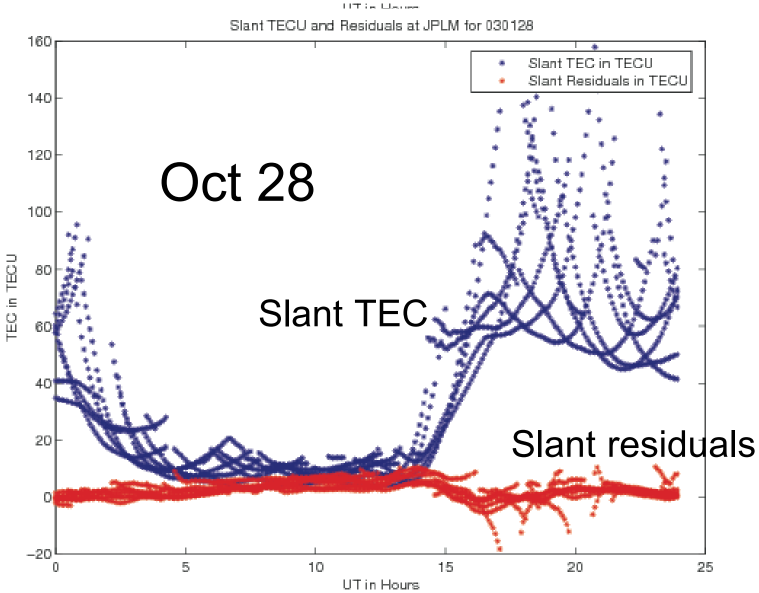
Case Studies: JPLM, CASA and MDO1

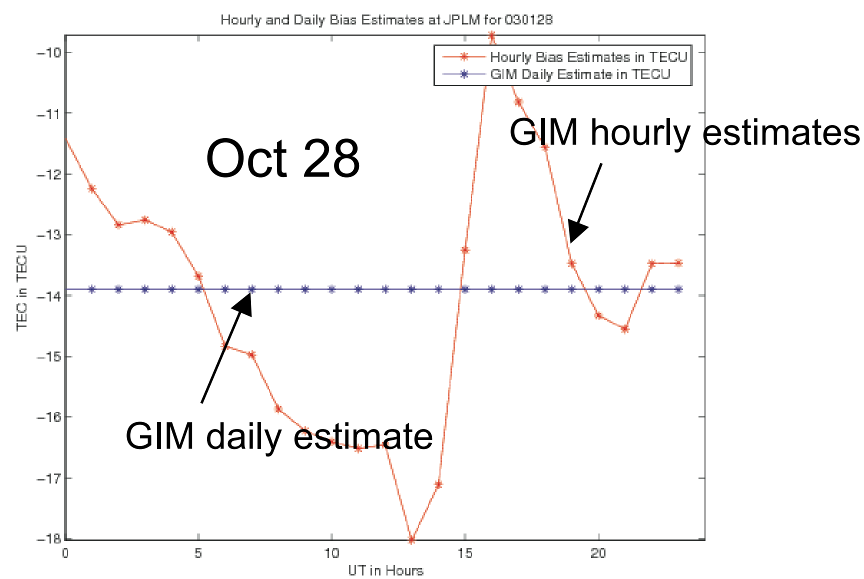


Quiet Days at JPLM for Oct 27-28, 2003

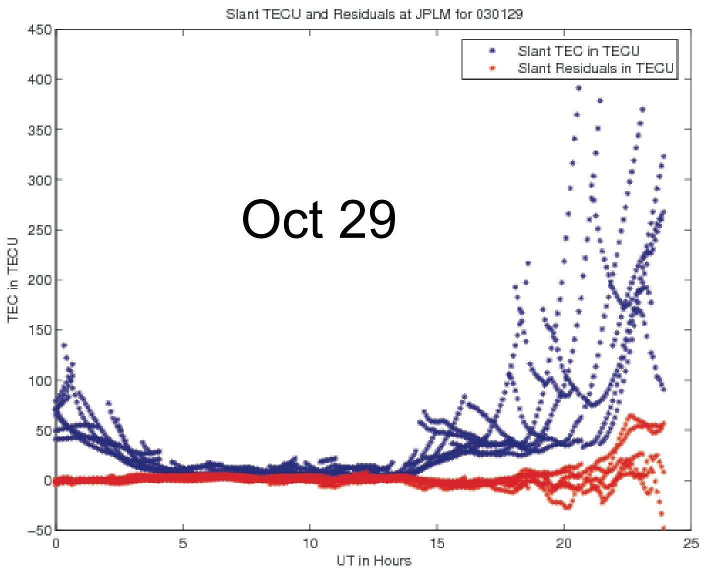


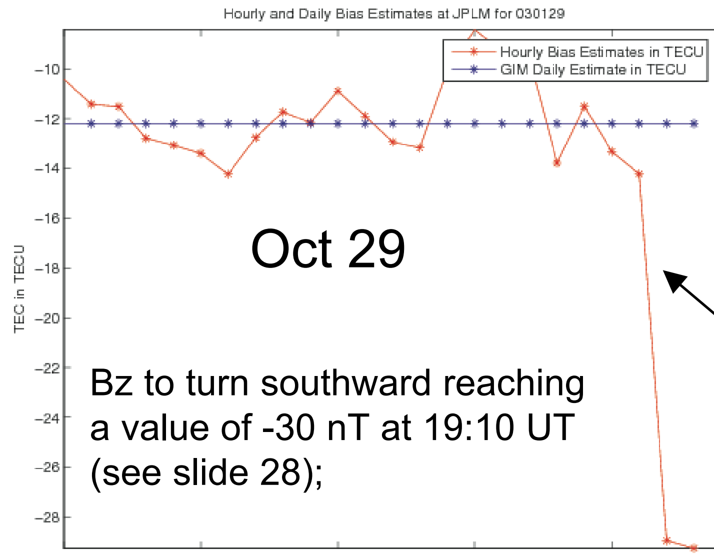


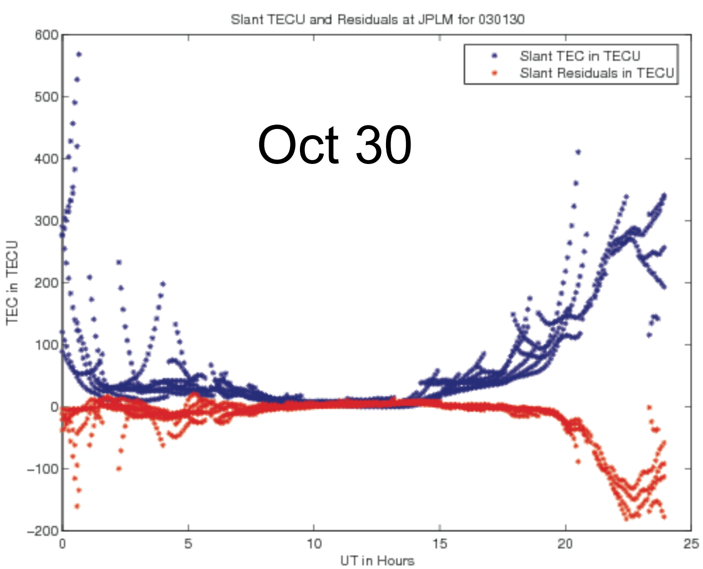


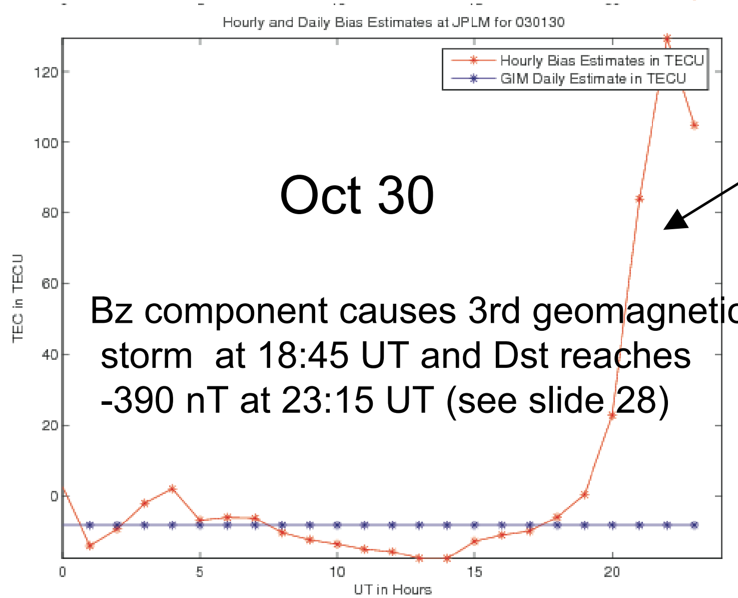


Storm Days at JPLM for Oct 29-30, 2003



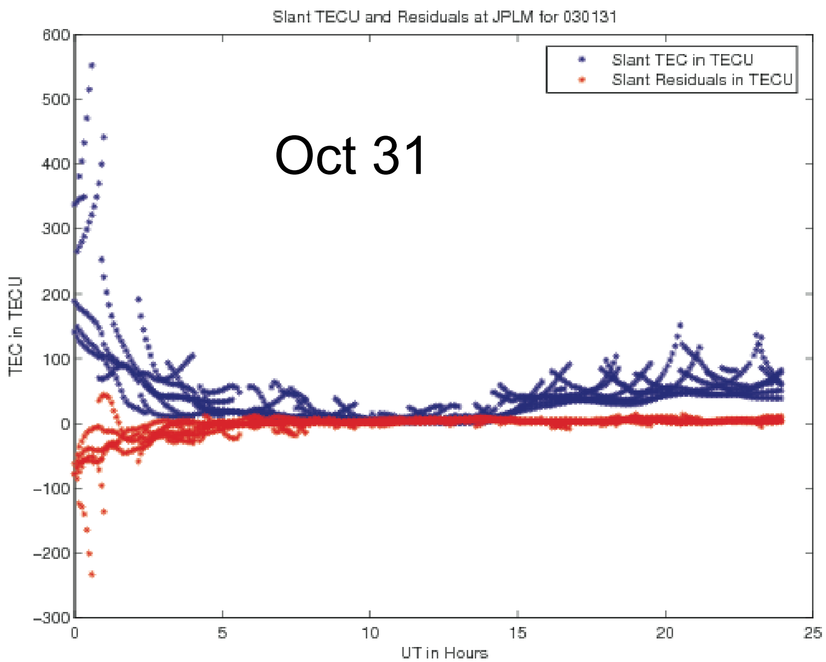


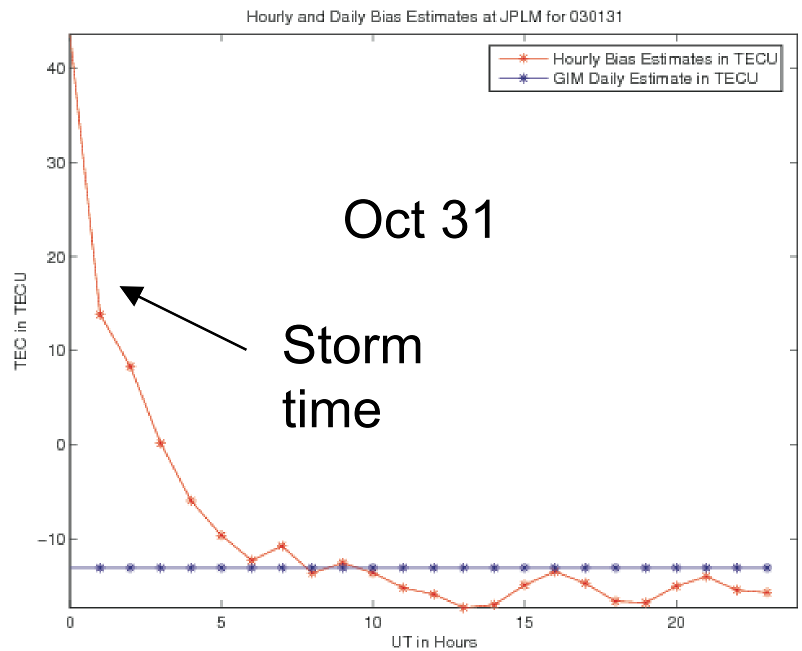




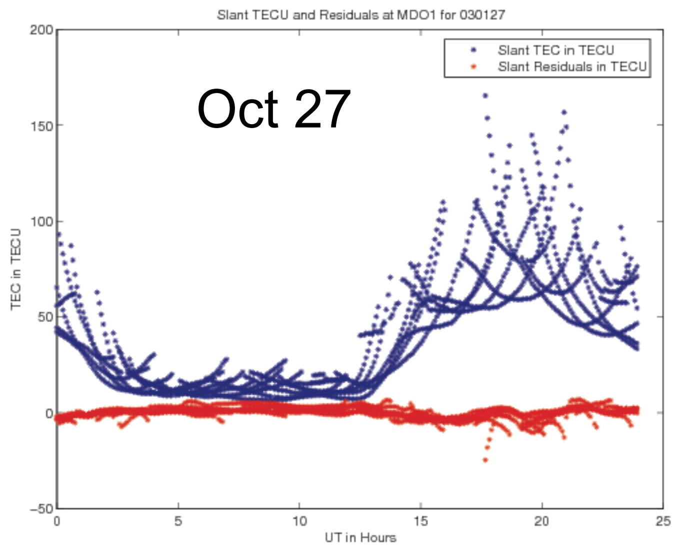
Storm time

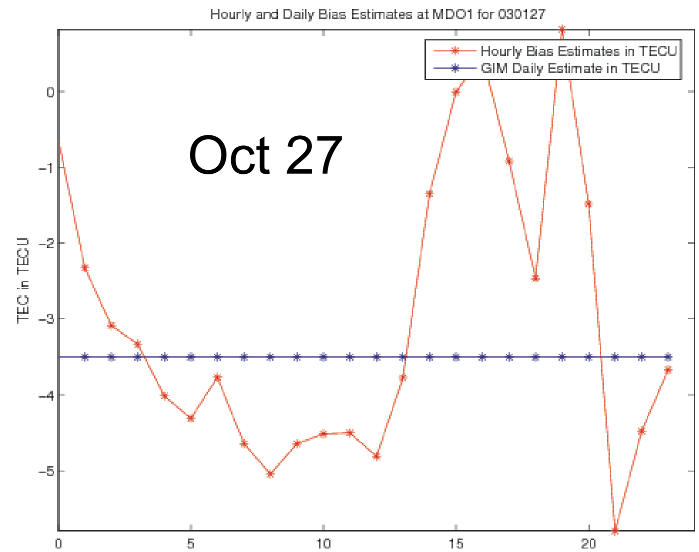
Last Storm Day of October 31, 2003 at JPLM

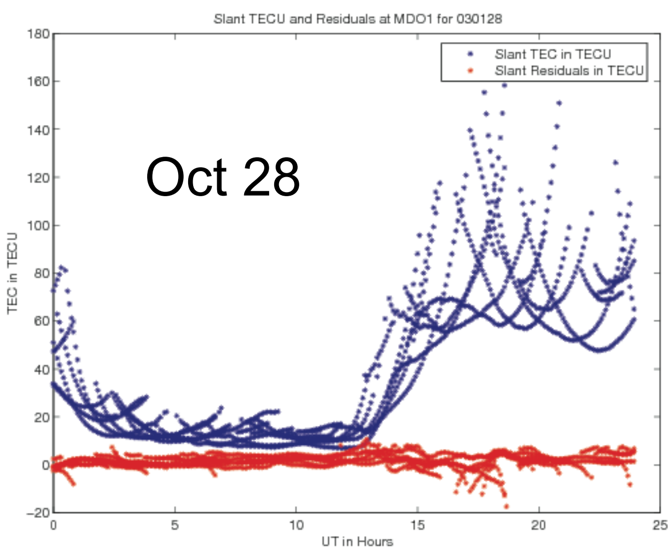


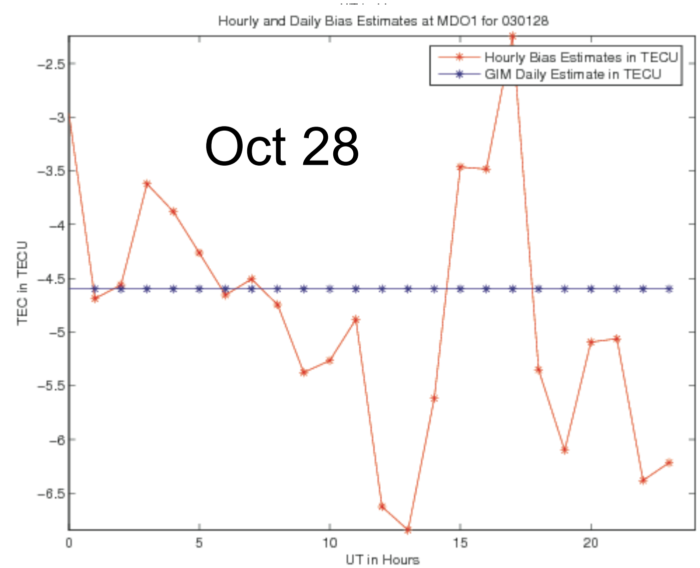


Quiet Days at MDO1 for Oct 27-28, 2003

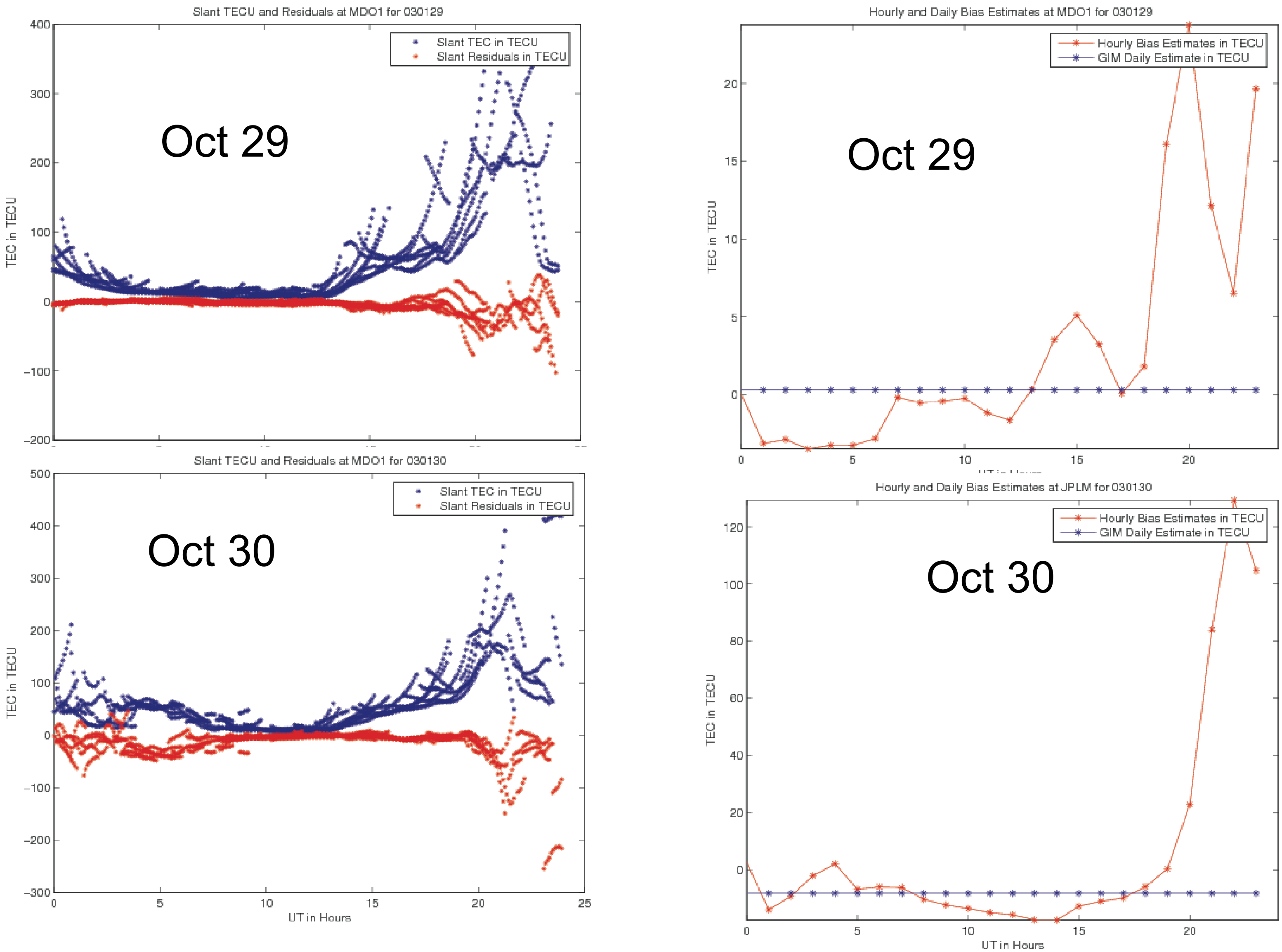




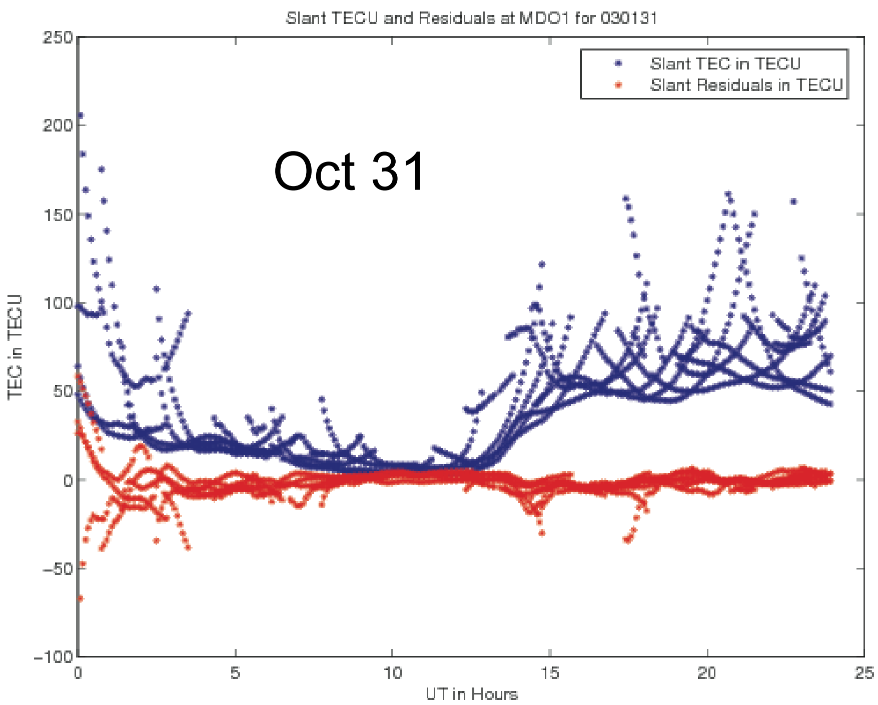


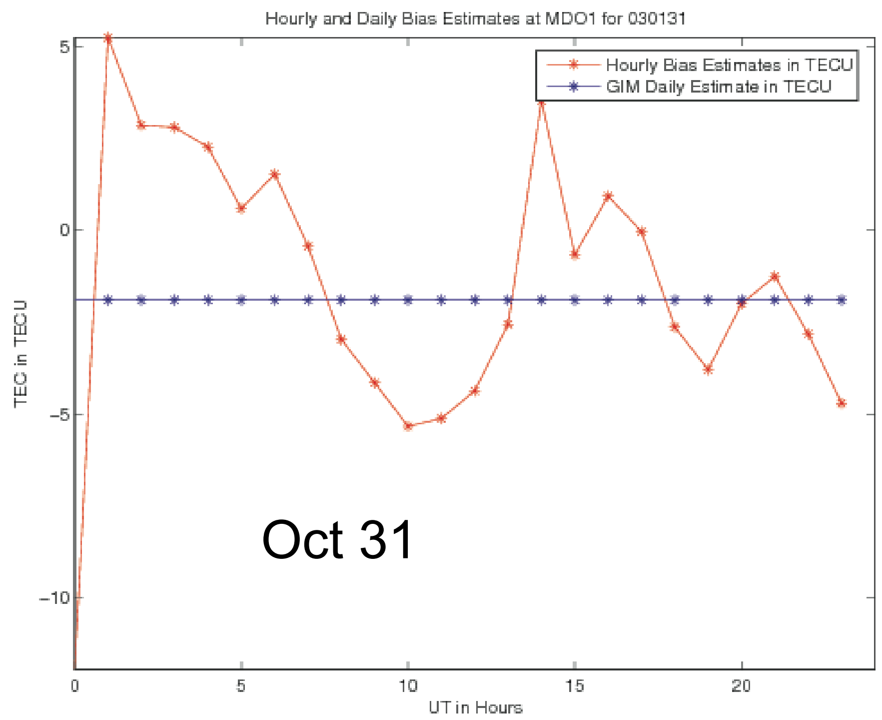


Storm Days at MDO1 for Oct 29-30, 2003

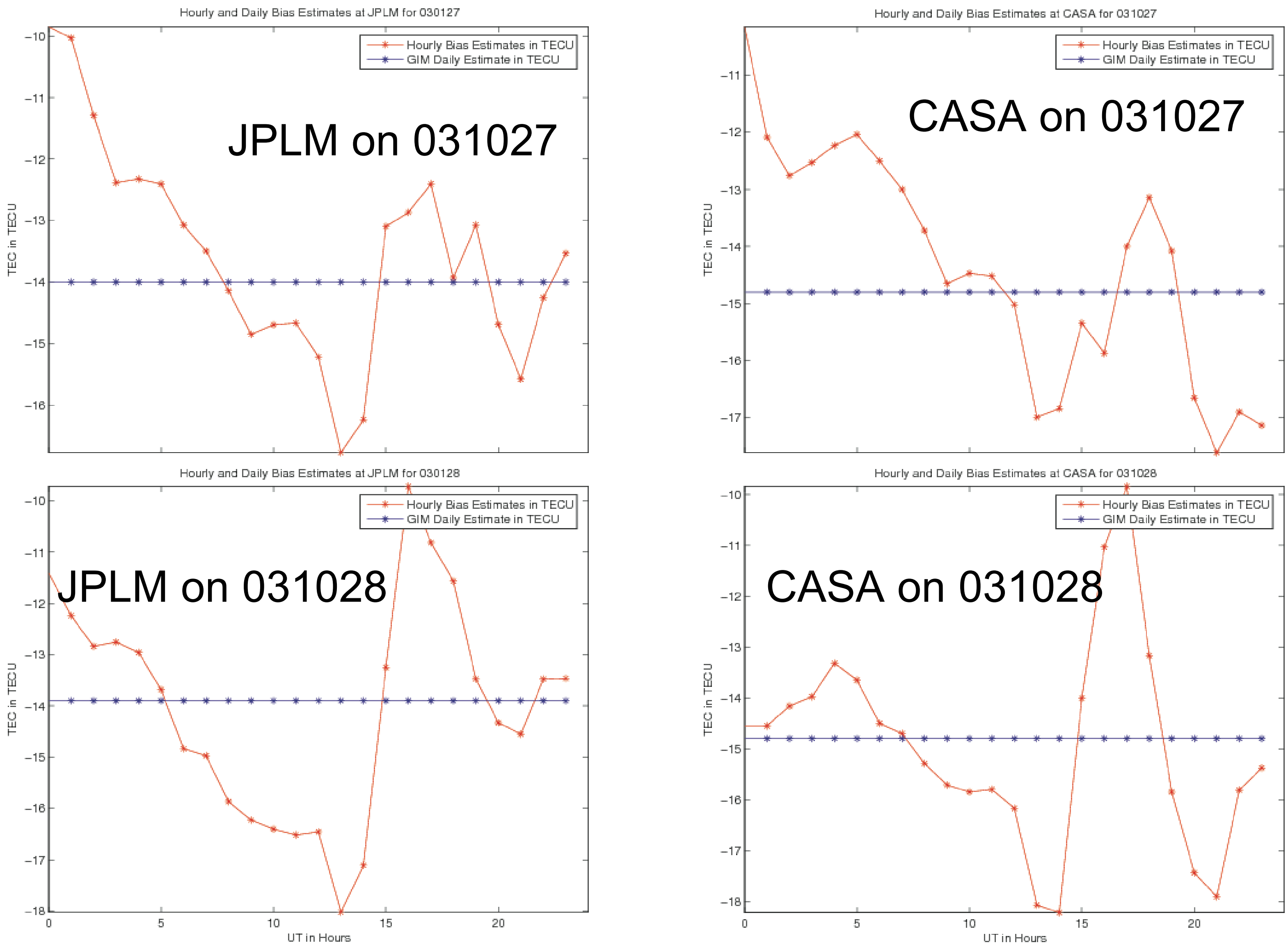


October 31, 2003 at MDO1

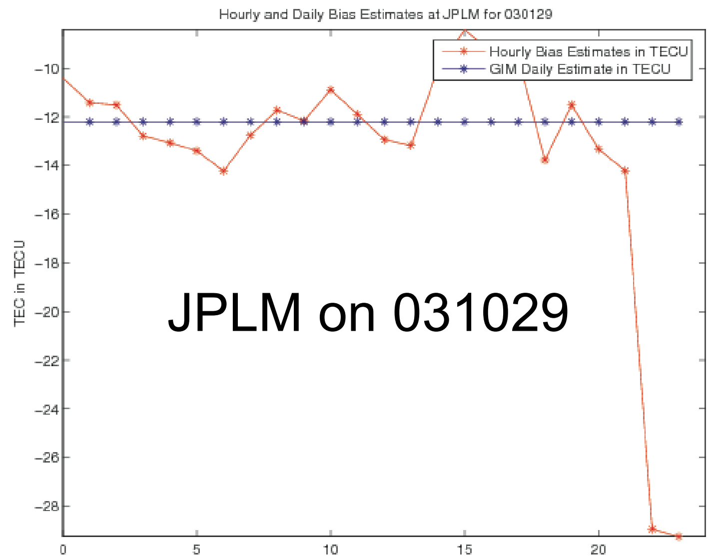


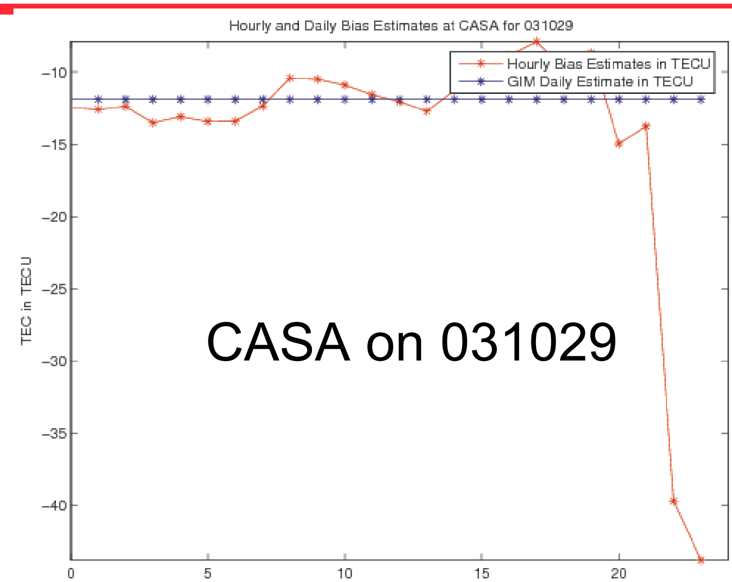


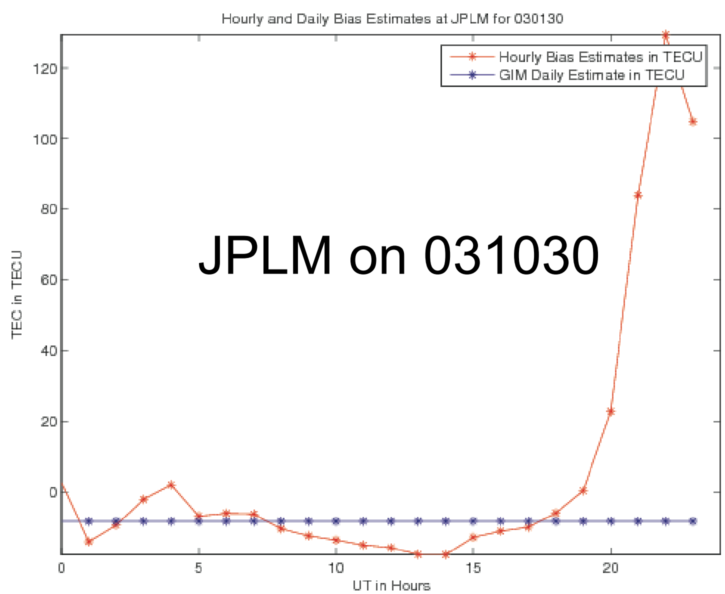
Nearby Receivers JPLM and CASA for Quiet Days

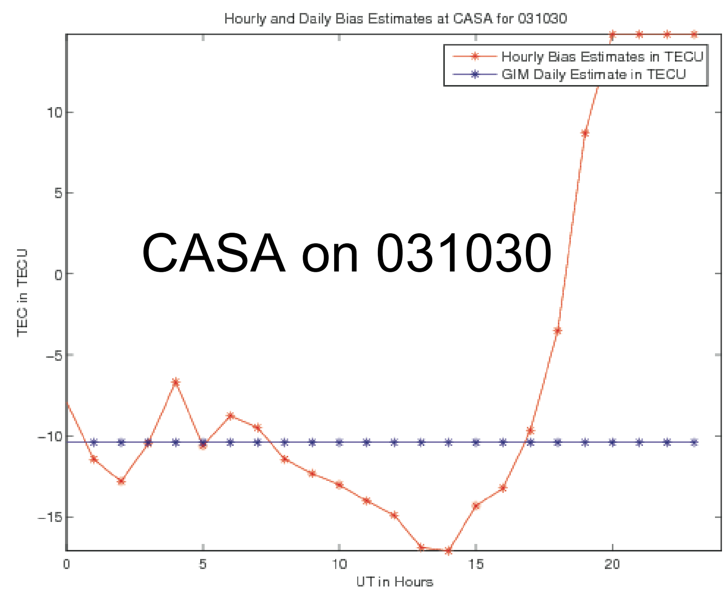


Nearby Receivers JPLM and CASA for Storm Days



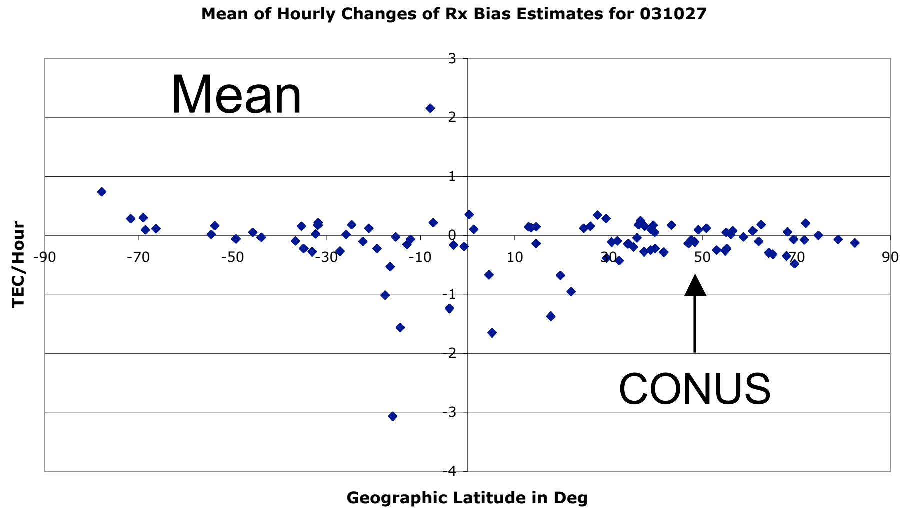


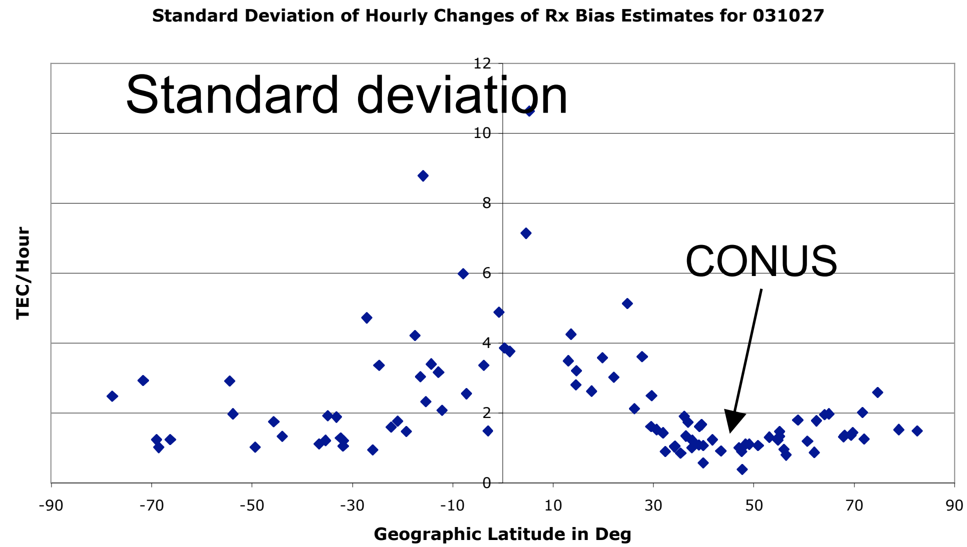


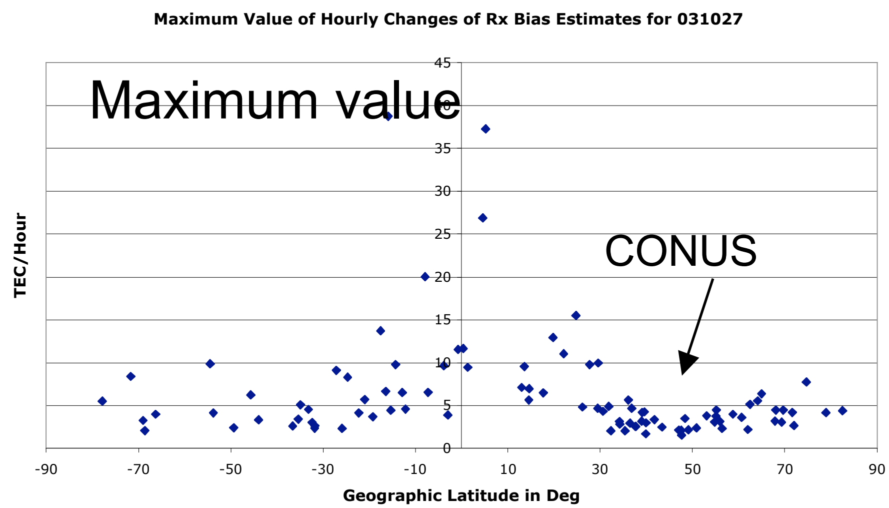


Hourly Changes in Bias Estimates for 031027 Using All 98 Stations

Geographic dependence of hourly changes of bias estimates in TECU/hour

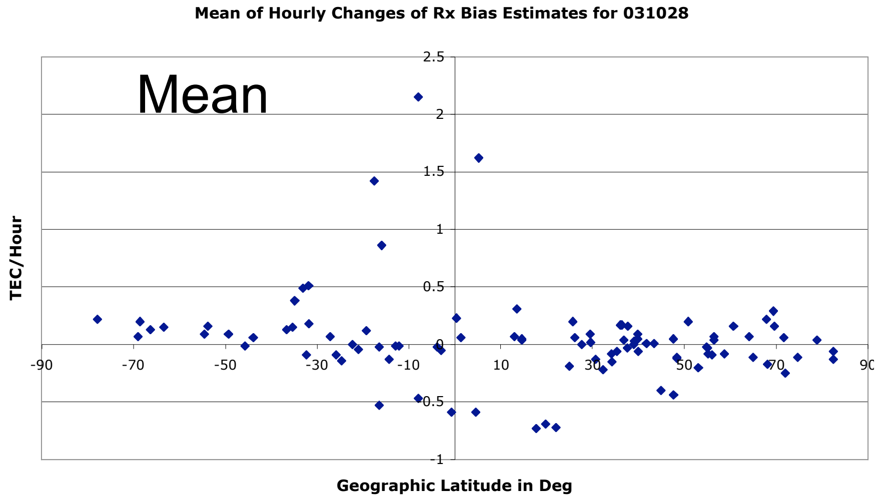


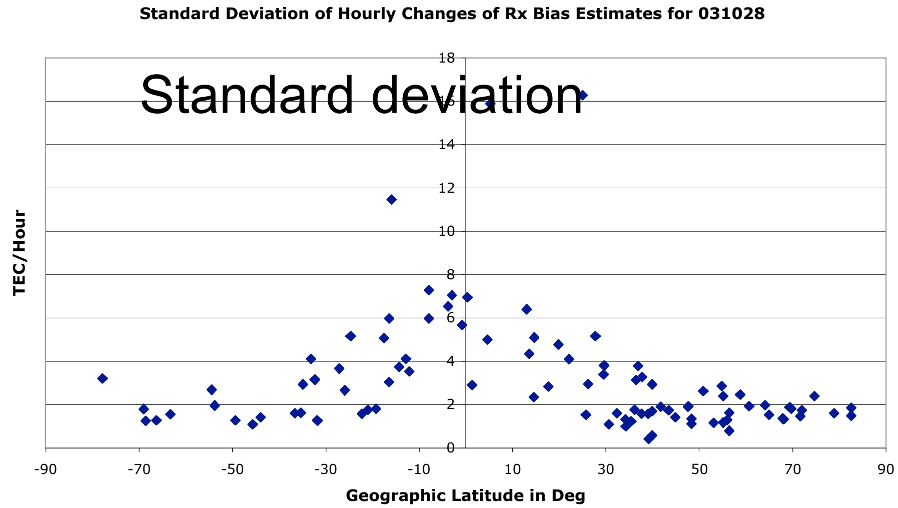


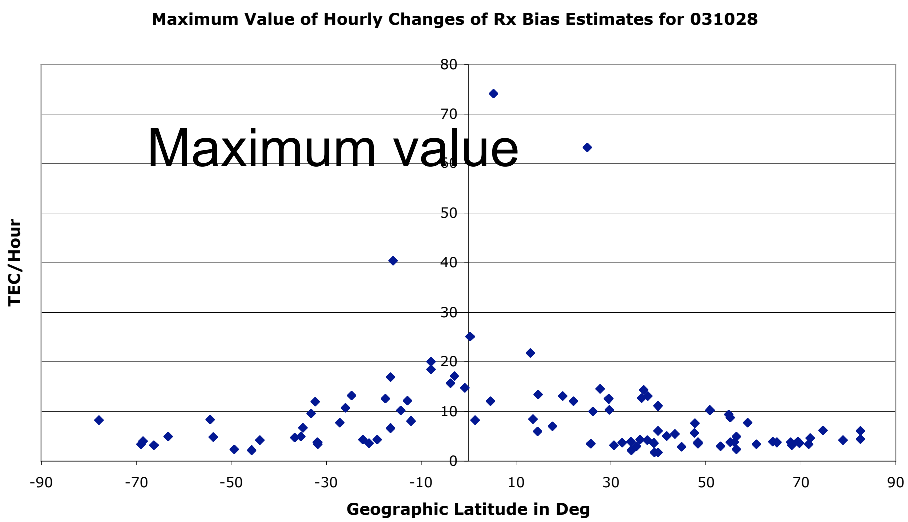


Hourly Changes in Bias Estimates for 031028 Using All Stations

Geographic dependence of hourly changes of bias estimates in TECU/hour

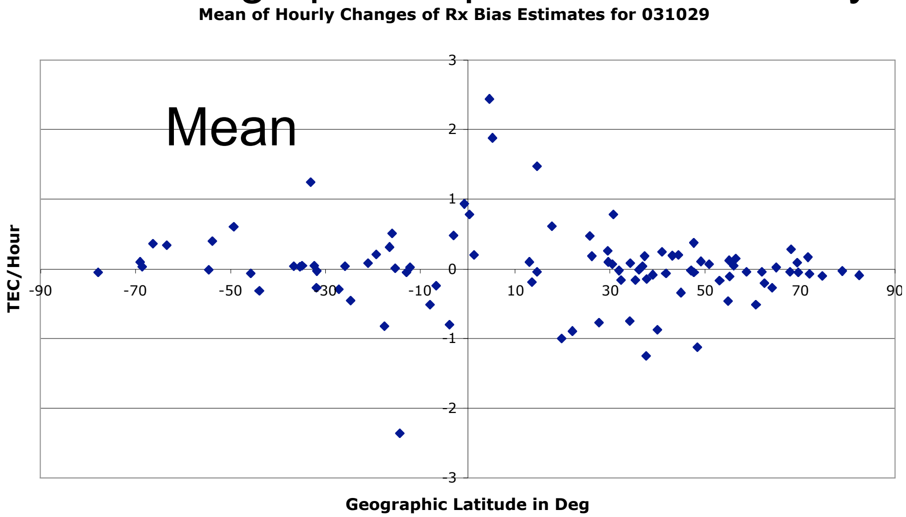


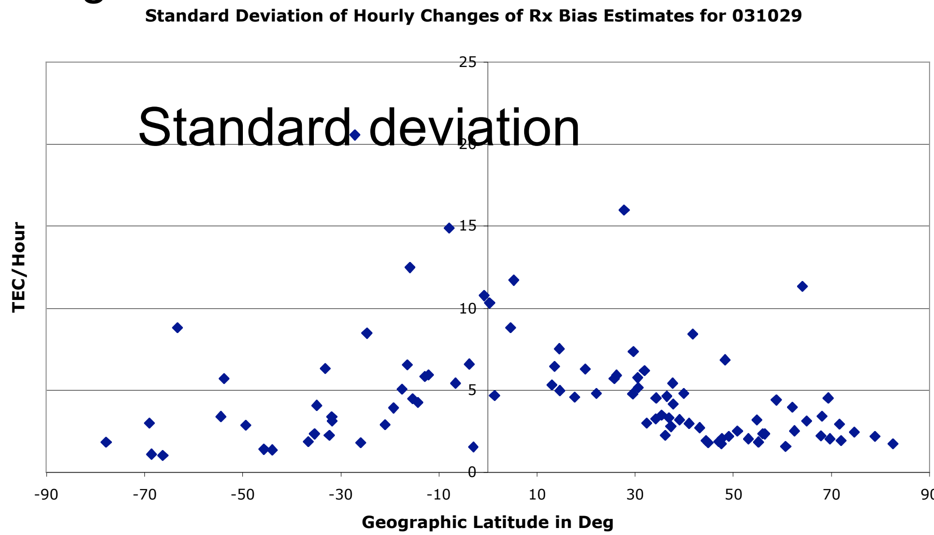


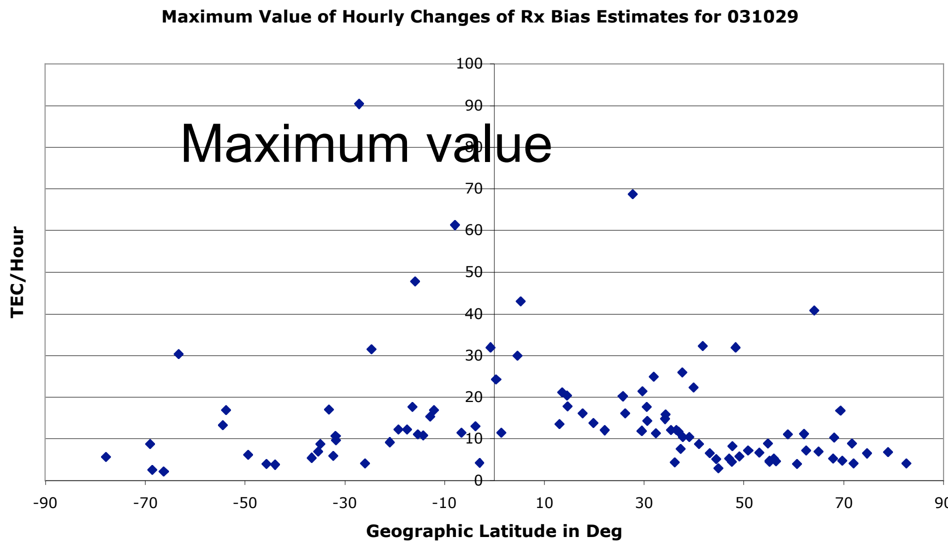


Hourly Changes in Bias Estimates for 031029 Using All Stations

Geographic dependence of hourly changes of bias estimates in TECU/hour

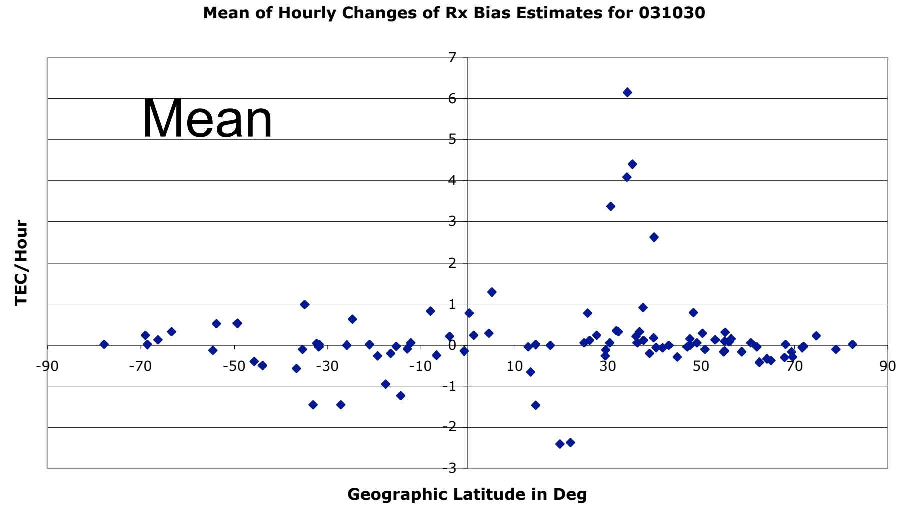


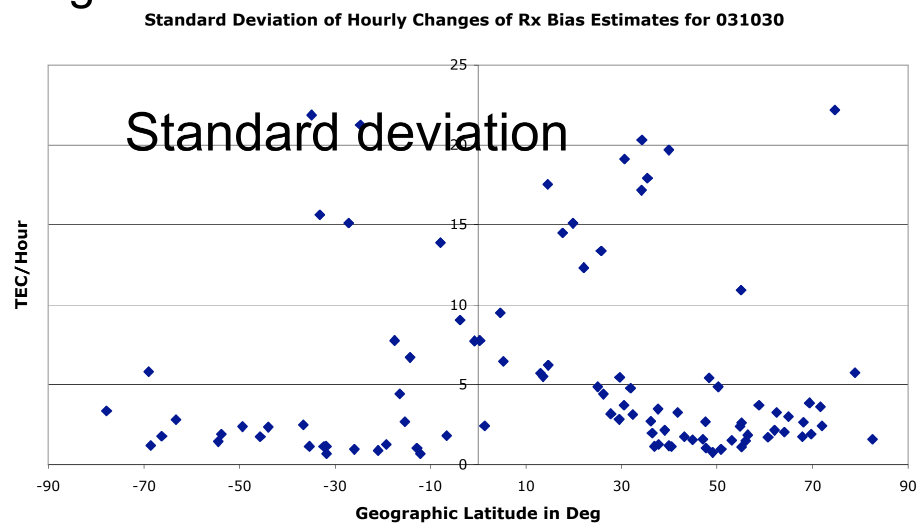


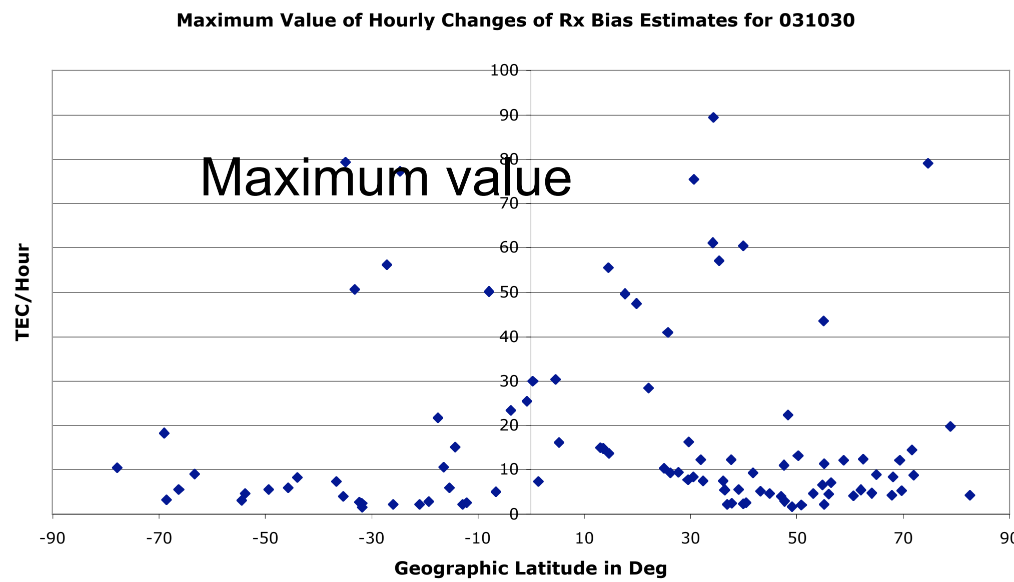


Hourly Changes in Bias Estimates for 031030 Using All Stations

Geographic dependence of hourly changes of bias estimates in TECU/hour

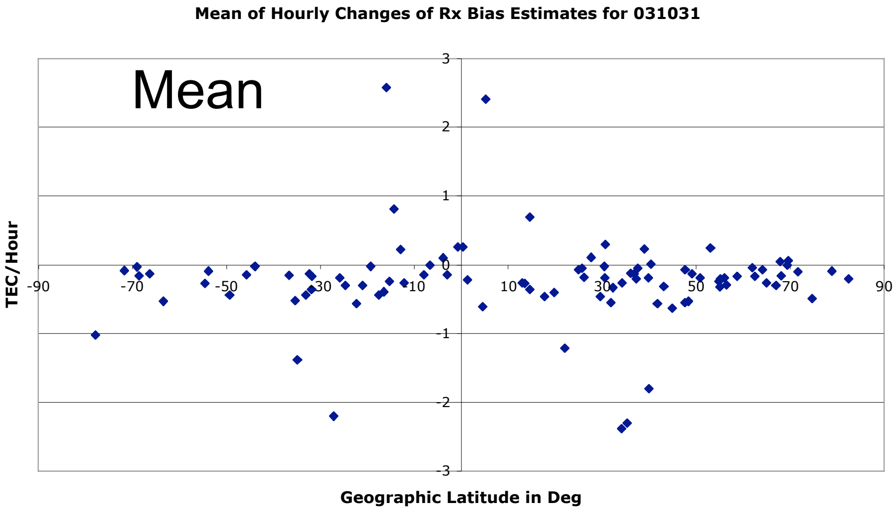


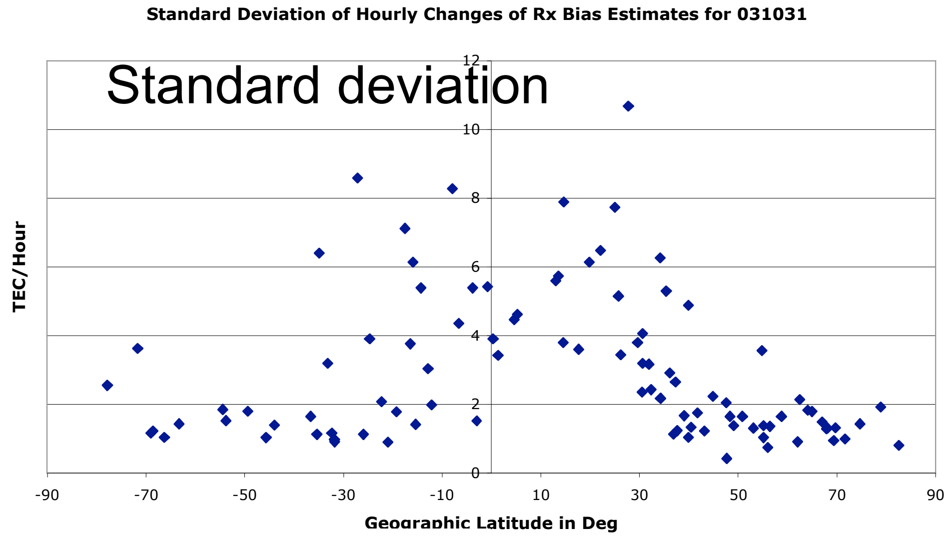


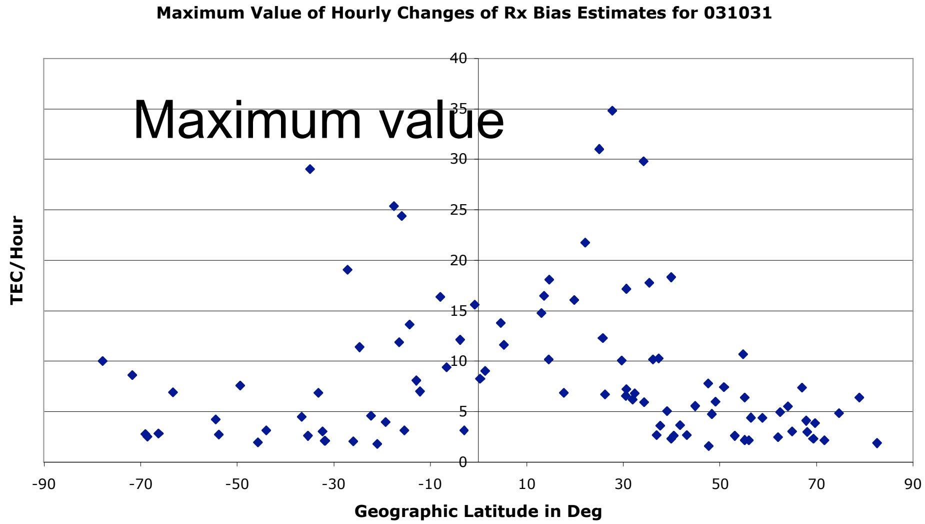


Hourly Changes in Bias Estimates for 031031 Using All Stations

Geographic dependence of hourly changes of bias estimates in TECU/hour





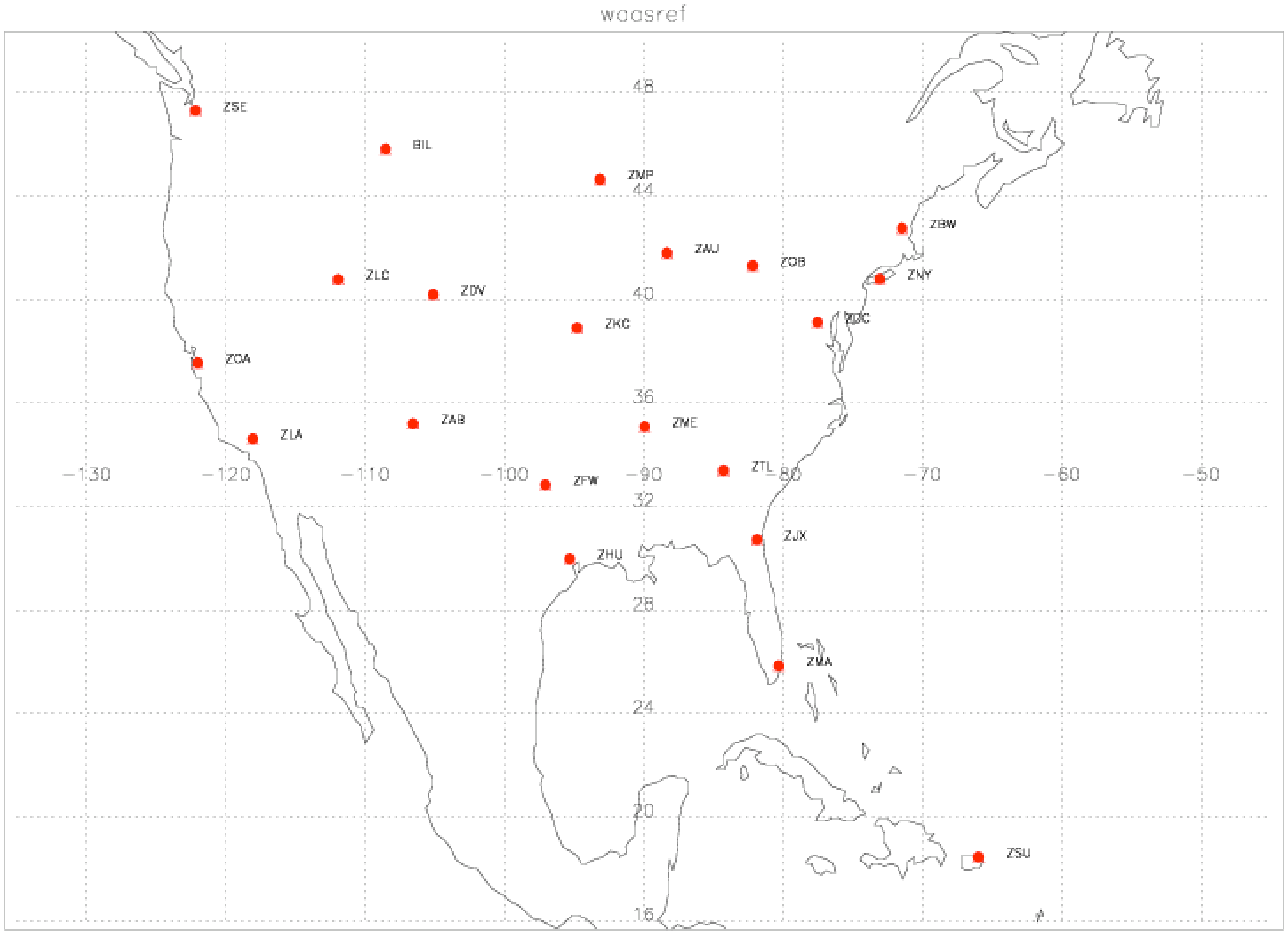


Summary

- Distinct diurnal changes of receiver bias estimates for quiet days. This is mainly due to the 450 km ionospheric shell height uniformly used for daytime and nighttime data. The optimal approach would be to use local time and geographic latitude dependent ionospheric shell heights to minimize the diurnal effect.
- Large changes in hourly receiver bias estimates during storm conditions. These changes are no longer of diurnal nature. They are a result of unmodeled iono effect absorbed by the bias estimates.
- Correlation of diurnal variation of hourly receiver estimates for nearby receivers both for quiet and storm-time conditions.
- As expected, we observe a geographic dependence of mean, standard deviation and maximum value of hourly changes of receiver bias estimates.

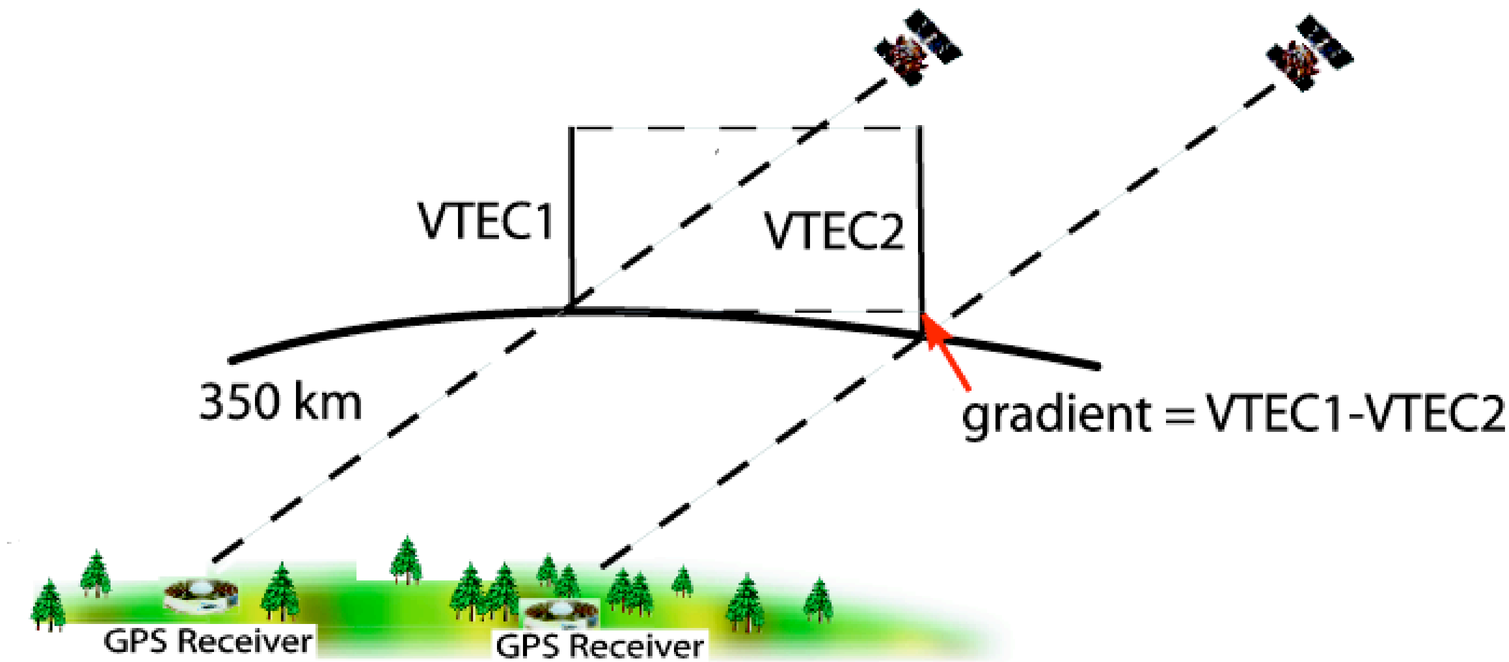
Backup

WRS Locations



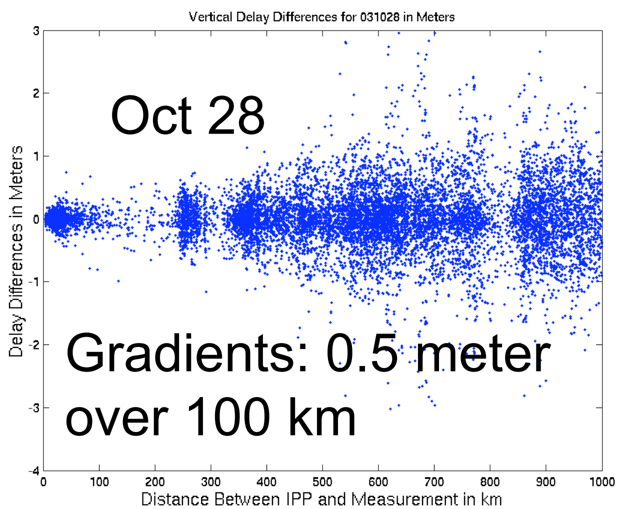
WRS locations each equipped with three WREs

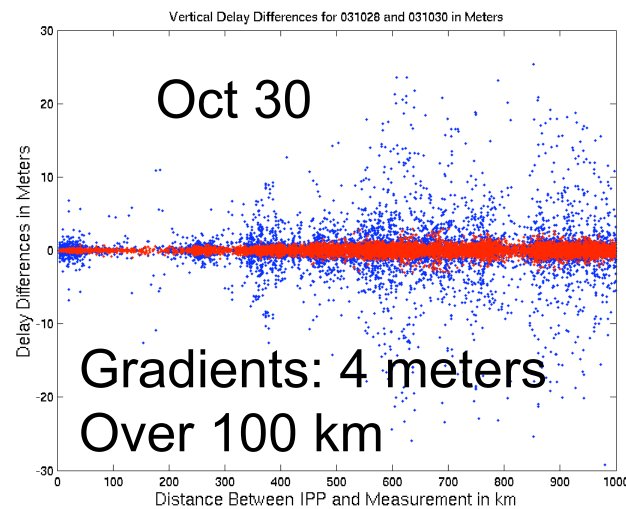
Characterizing WAAS Ionospheric Gradients

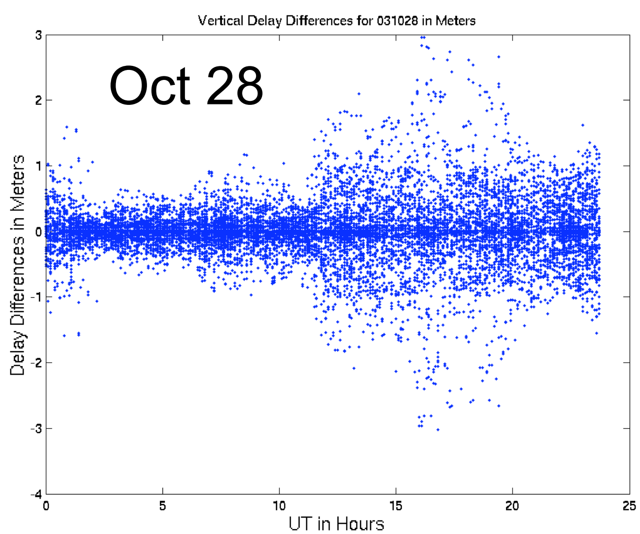


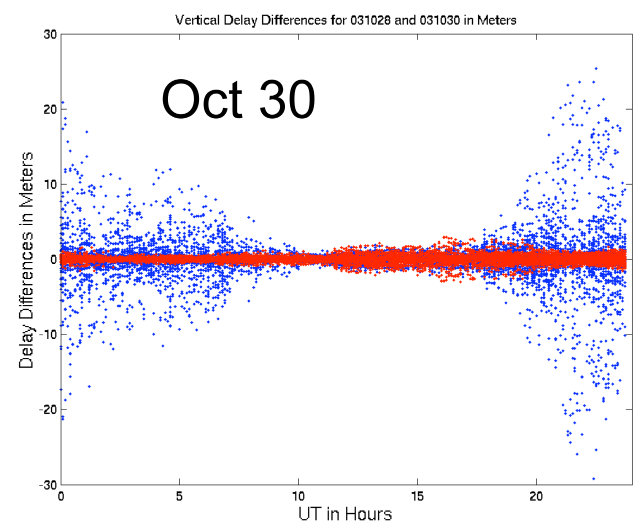
- To investigate gradients, we looked at pairs of GPS receivers observing the same satellites at nearly identical elevation and azimuth angles.
- Vertical delay differences were computed by projecting the differenced slant ionospheric range delay into the vertical.

Measured Vertical Delay Differences

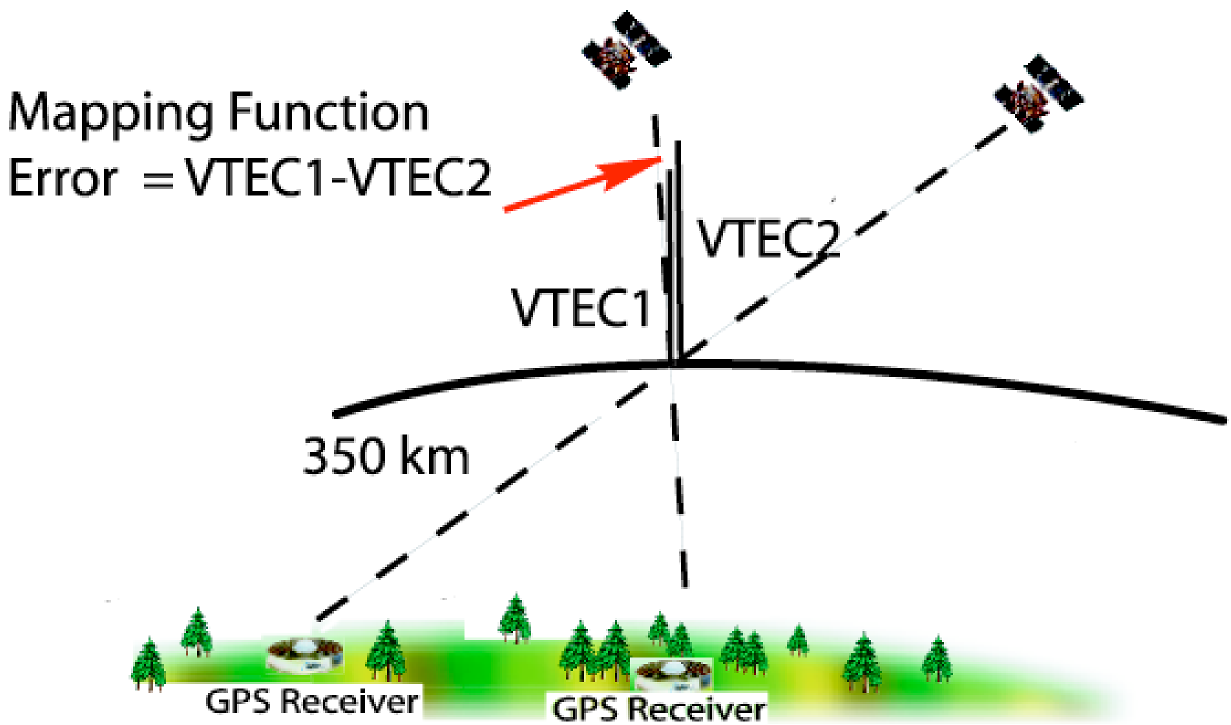








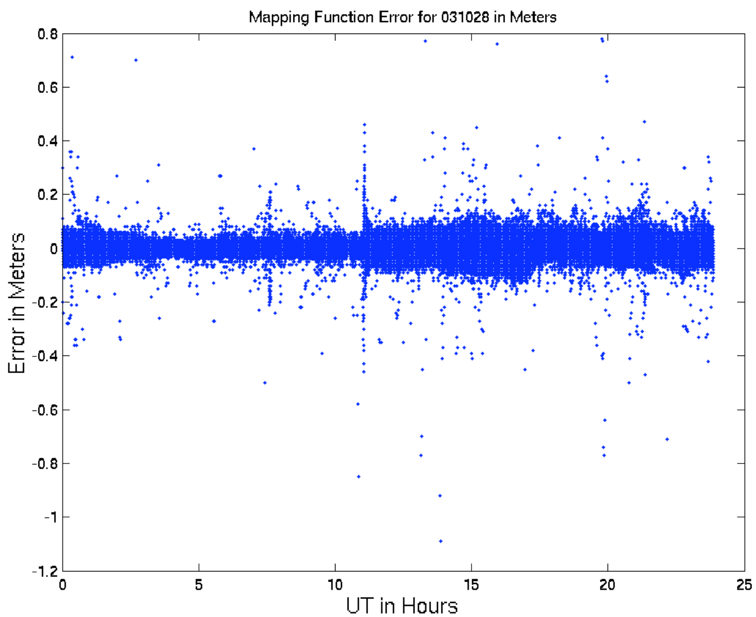
Mapping Function Error



- We only included measurements where IPPs were nearly co-located but differing elevation angles.
- Mapping function errors were computed by taking the difference between the two slant ionospheric measurements, each projected to the vertical using the WAAS thin-shell mapping function.

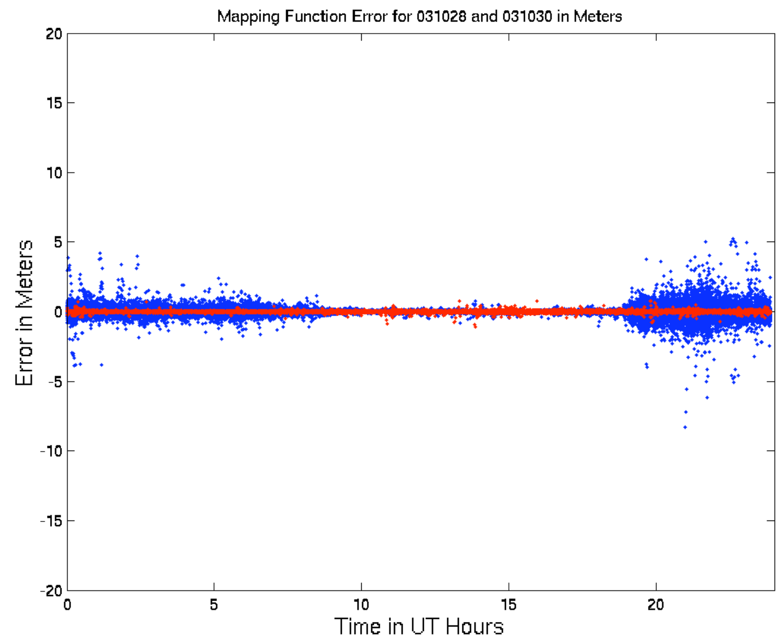
Mapping Function Errors

Quiet Day of Oct 28



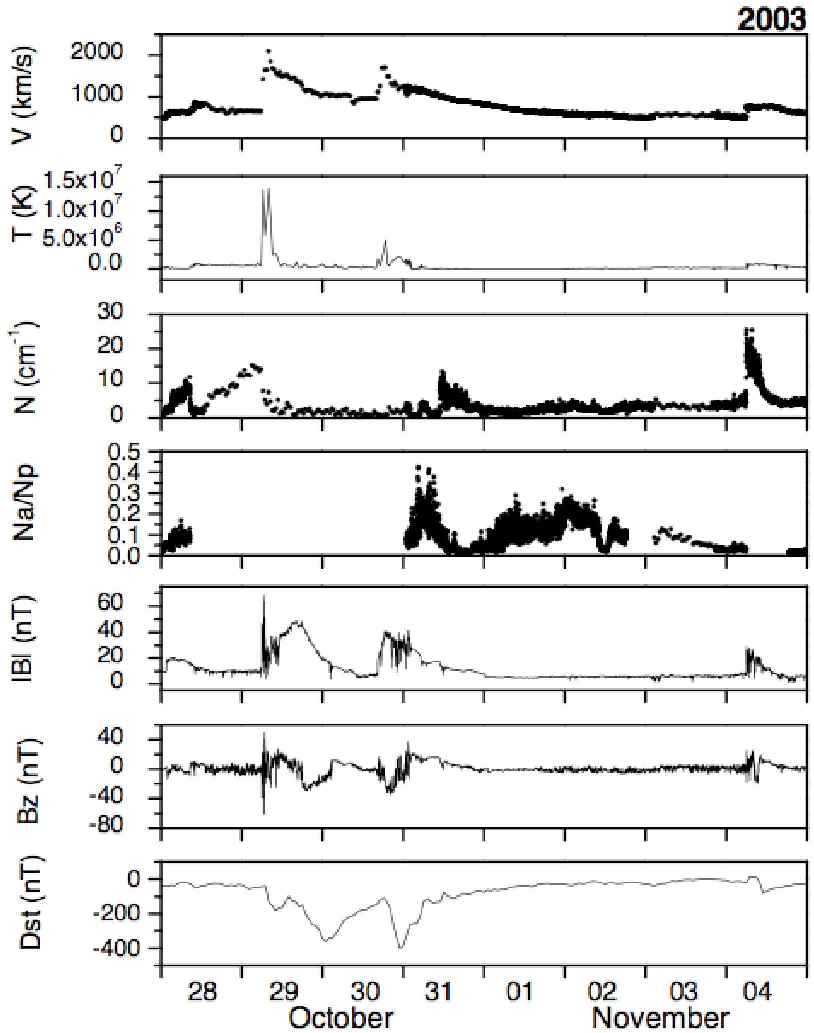
Error < 0.8 meter
4 cm RMS

Storm day of Oct 30



Error < 10 meters
35 cm RMS

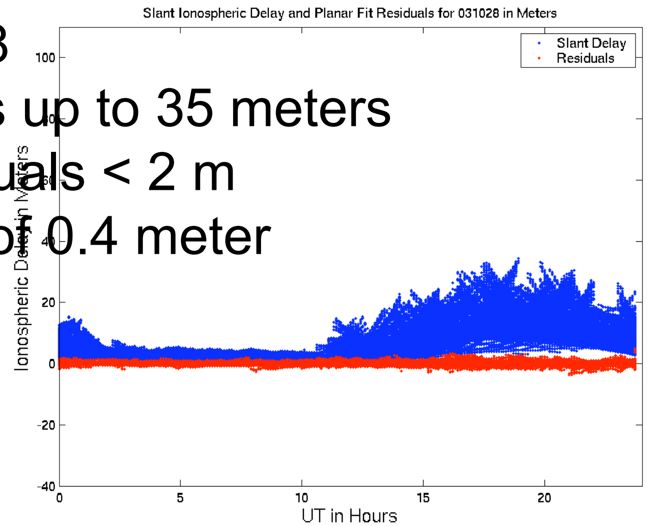
Geomagnetic Field Components during Halloween Event

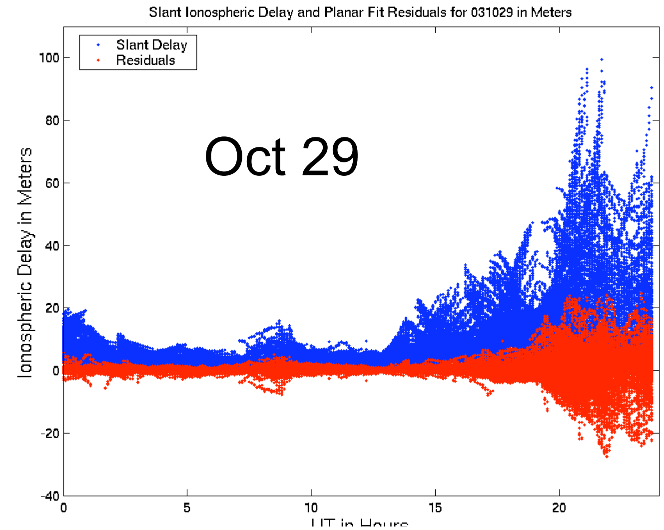


- X-class solar flares on Oct 28 and 29;
- Interplanetary coronal mass ejections (ICMEs) detected by ACE on Oct 29 and 30;
- First shock reaches ACE at 5:45 UT, Oct 29
- Sharp rise in velocity, temperature and magnetic field strength;
- 1st geomagnetic storm peak Dst at -159 nT;
- Dst index begins to recover at 13:45 UT;
- 2nd geomagnetic storm begins during recovery phase of first one; sudden Dst decrease;
- Bz continues to turn southward reaching a value of -30 nT at 19:10 UT;
- Combined with solar wind velocities of 1200 km/s causes a major geomagnetic storm with Dst of -350 nT at 01:25 UT on Oct 30;
- Shock of 2nd ICME at 16:50 UT on Oct 30;
- Bz component causes 3rd geomagnetic storm at 18:45 UT and Dst reaches -390 nT at 23:15 UT on Oct 30.

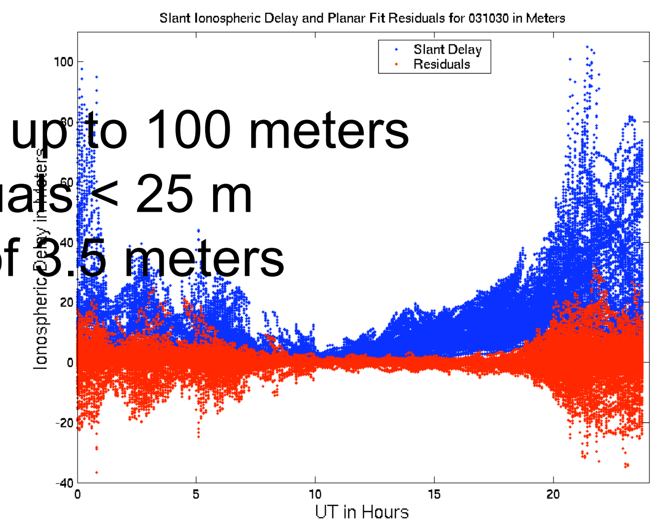
Slant Delay and WAAS Planar Fit Residuals

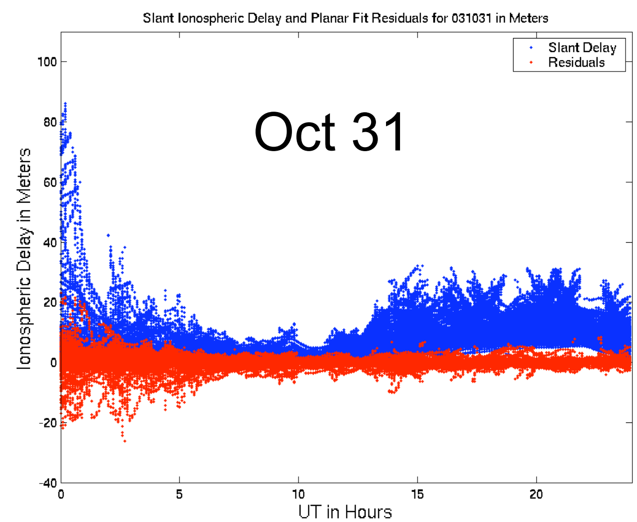
Oct 28
delays up to 35 meters
Residuals < 2 m
RMS of 0.4 meter



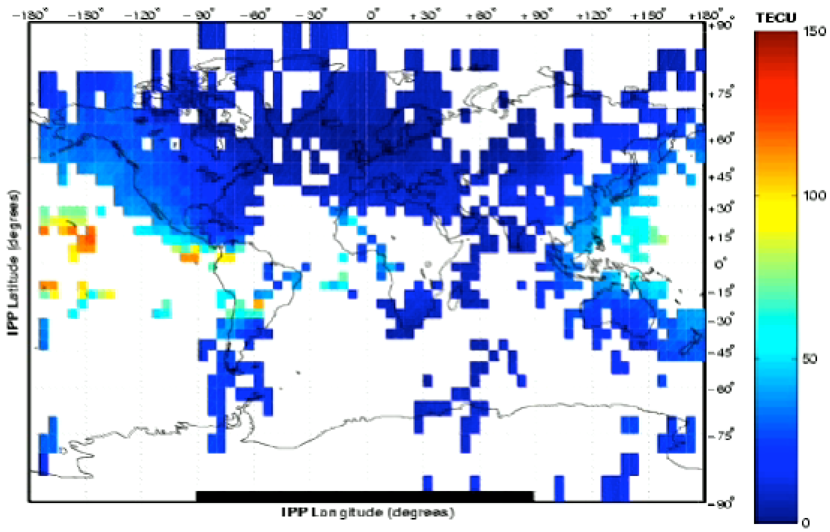


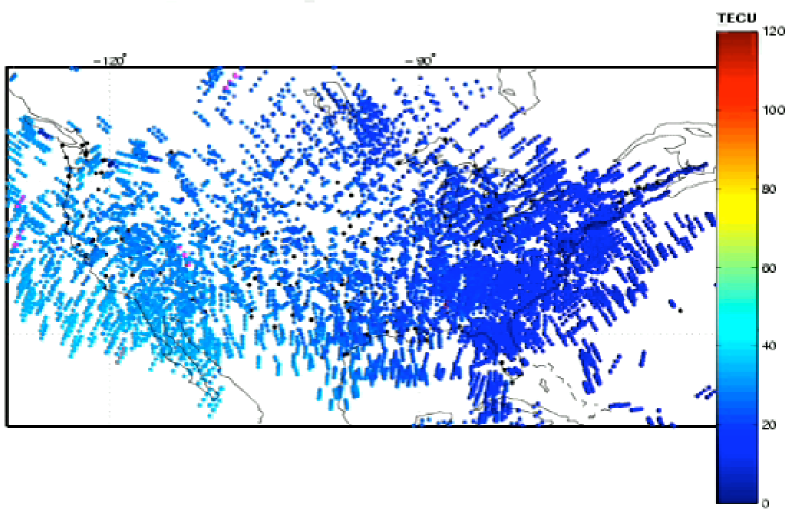
Oct 30
delays up to 100 meters
Residuals < 25 m
RMS of 3.5 meters



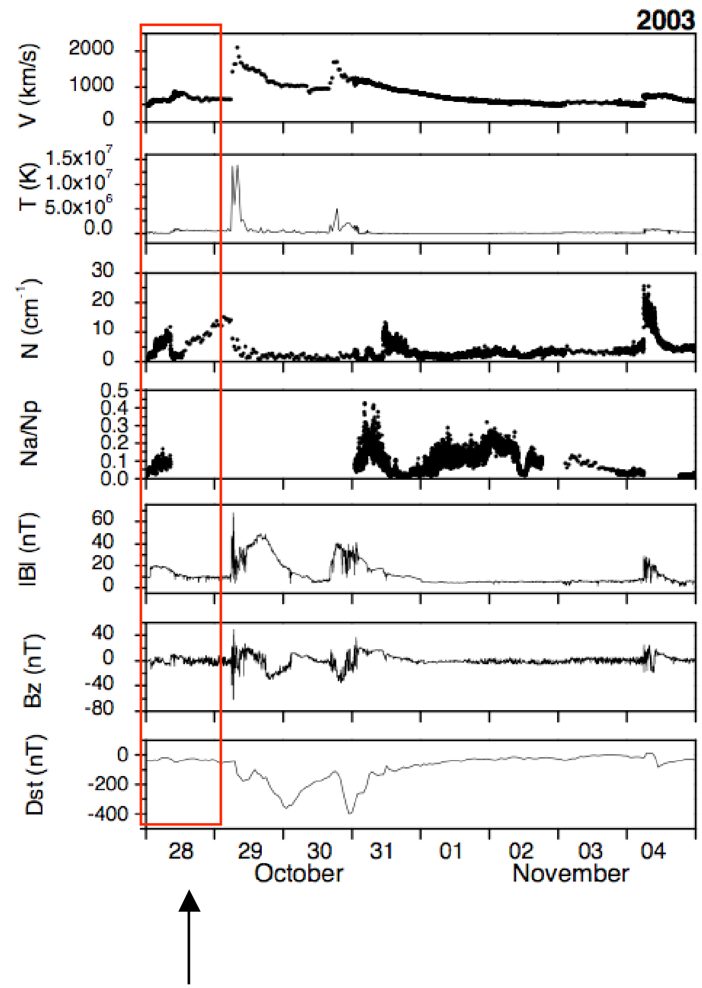


October 28, 2003

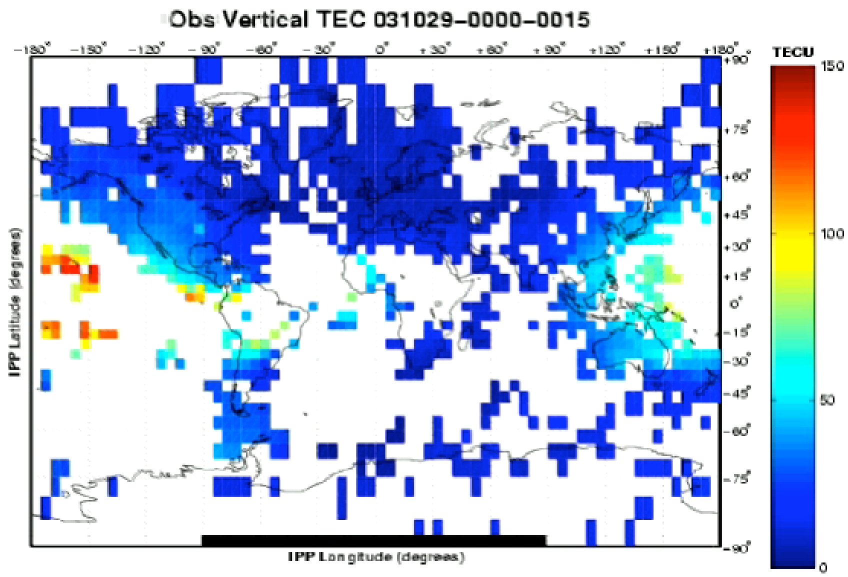


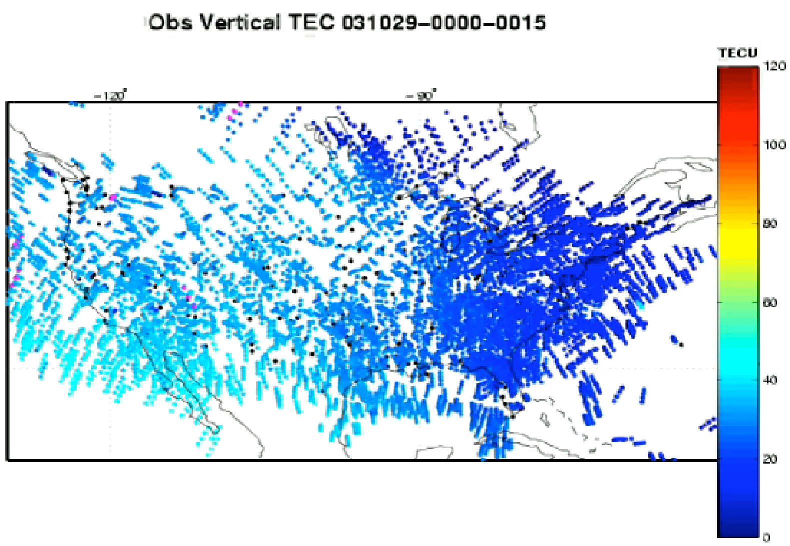


X-class Solar Flares on Oct 28 and 29

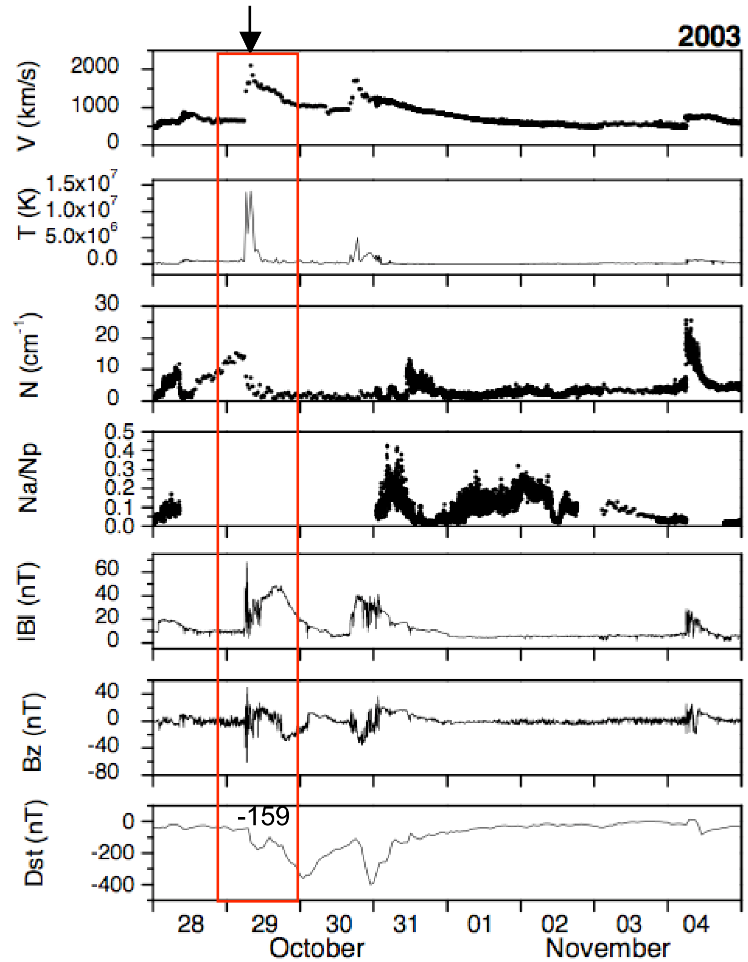


October 29, 2003



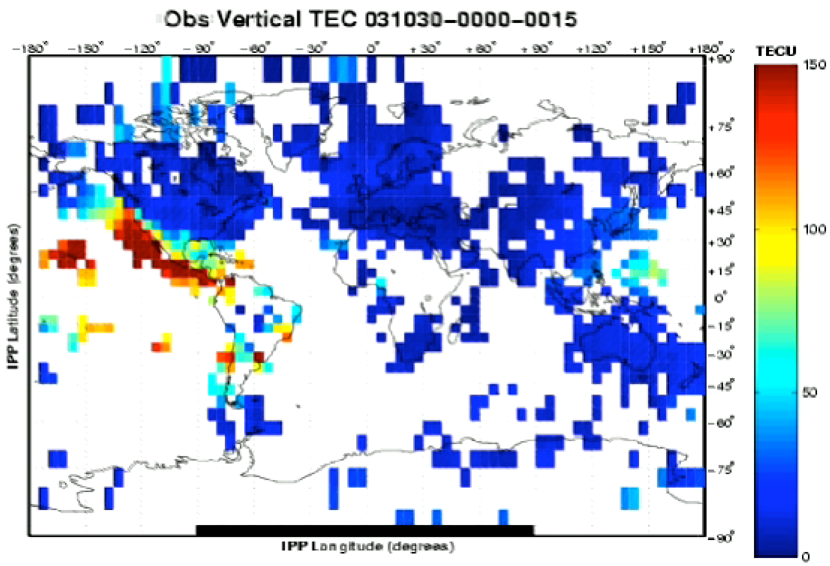


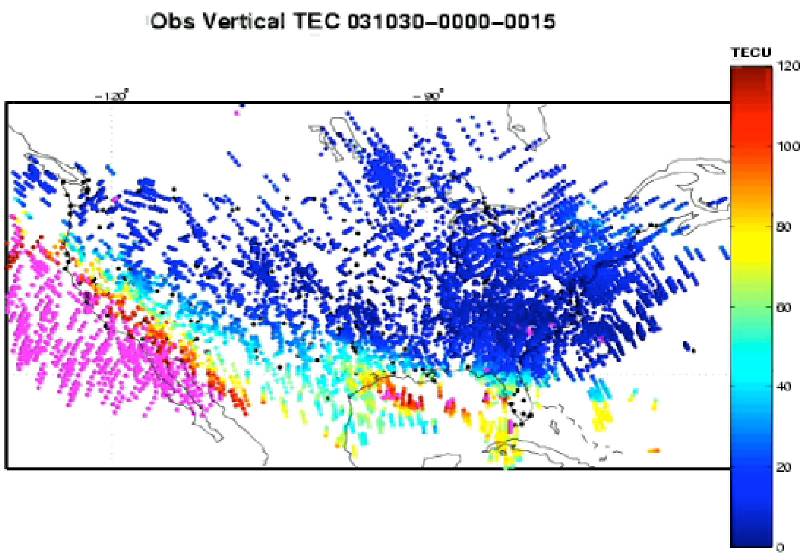
1st Interplanetary Coronal Mass Ejection

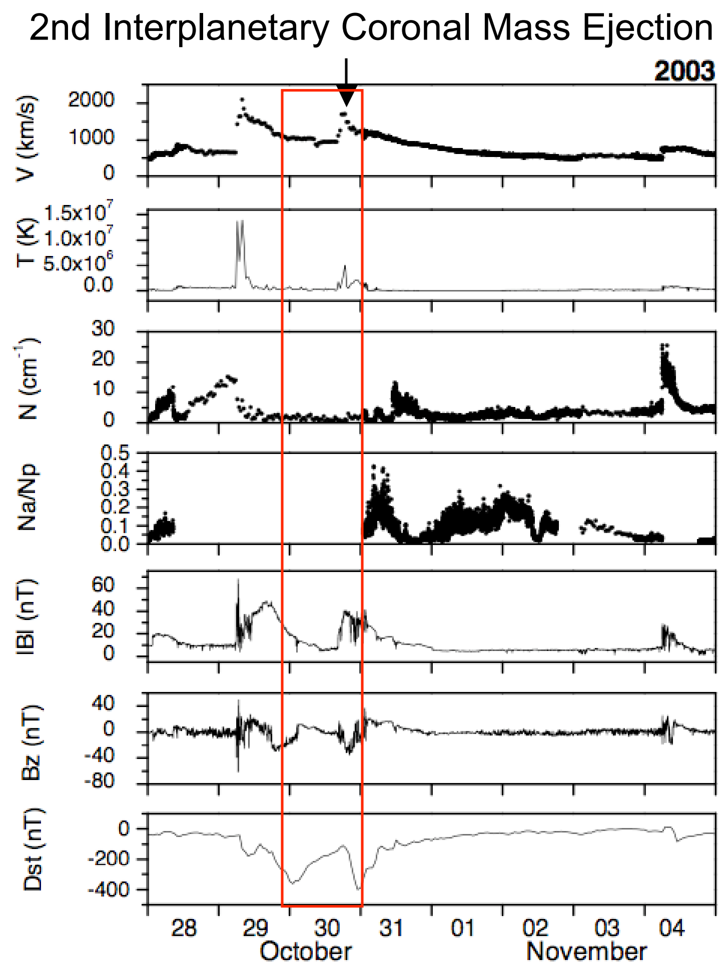


DST -350 nT at 0125 UT on October 30

October 30, 2003







DST -390 nT at 2315 UT on October 30

October 31, 2003