Validation of modeled plasma density changes during geomagnetic storms

Parameters: TEC, NmF2, hmF2

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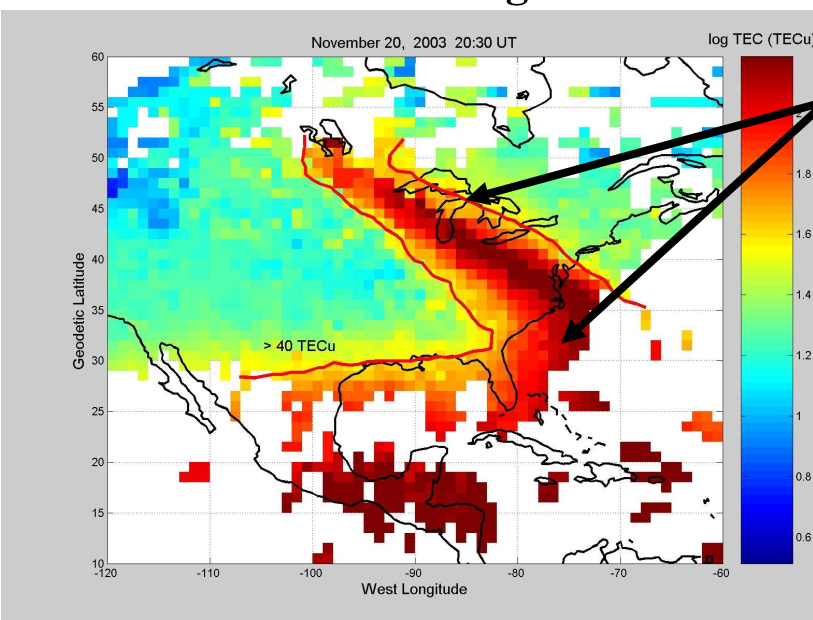
NOAA Space Weather Prediction Center and
CIRES University of Colorado

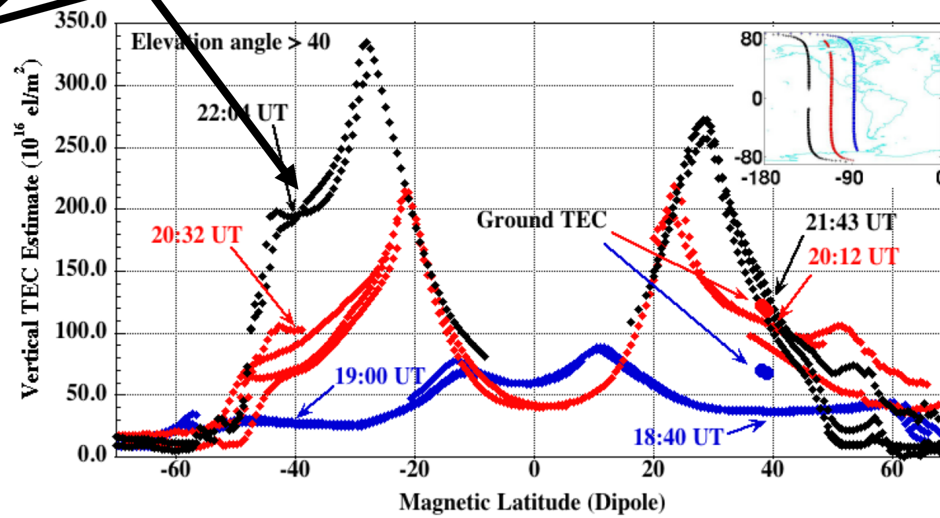
Examples: Build-up of plasma and structure at mid-latitudes

- TEC maps from GPS available in some regions and longitude sectors
- RO and in-situ satellite observations
- Point locations with ionosondes

Large increases in TEC (bulge) and structure (SED)

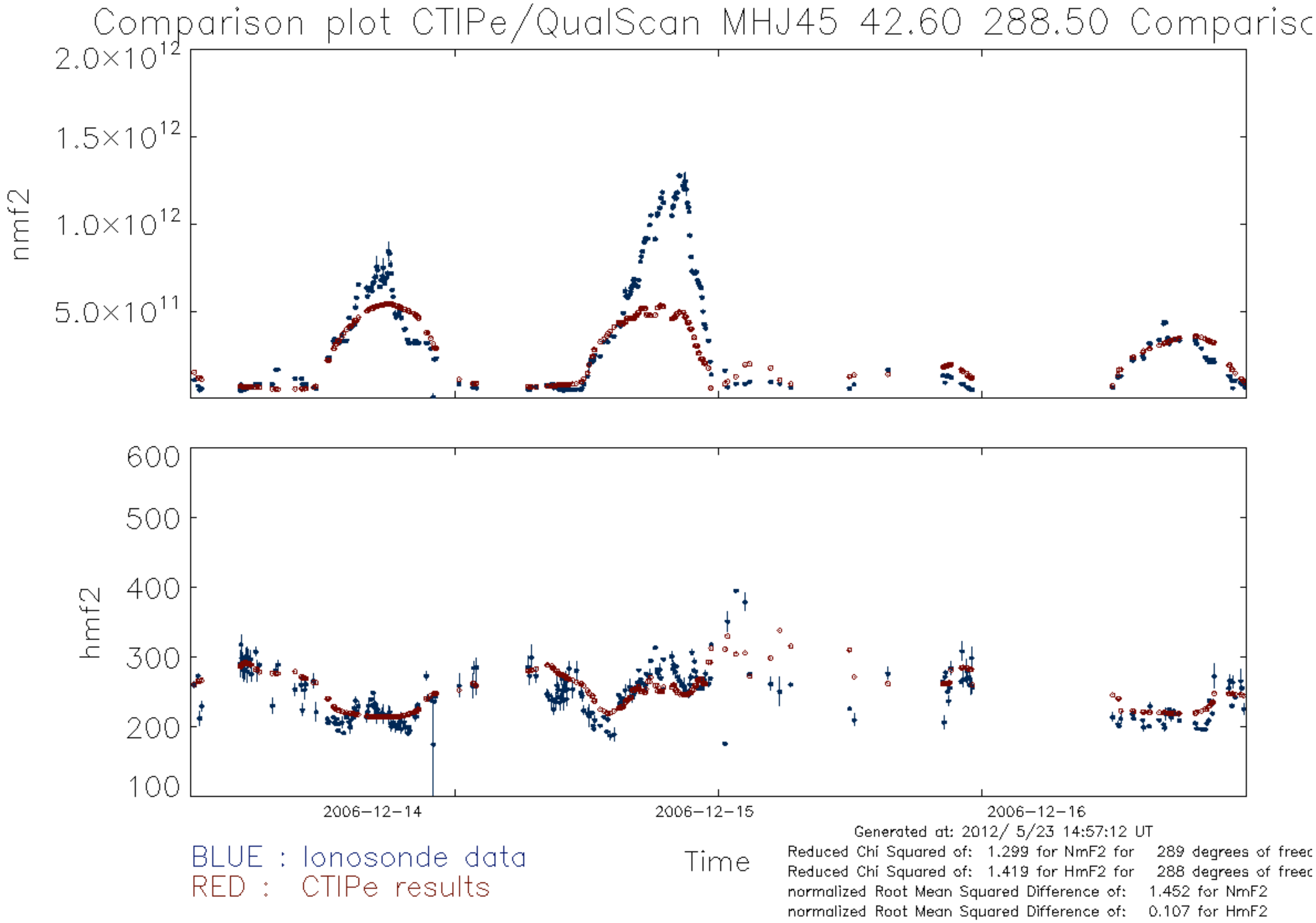


Foster and Coster



Mannucci et al 2005

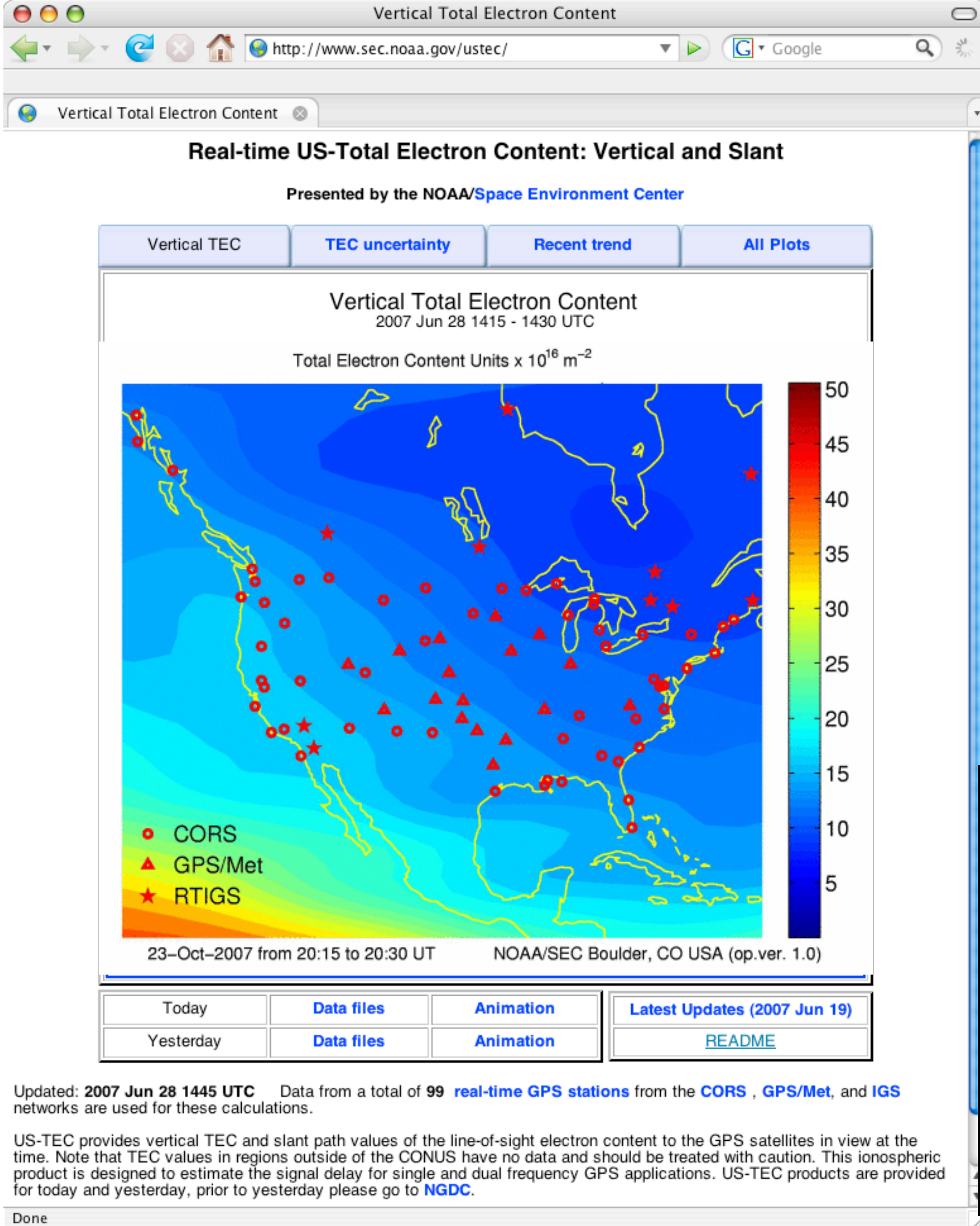
Ionosonde NmF2, hmF2 at Millstone Hill (positive and negative response)



Suggested metrics for model validation of storm response

- Challenges
    - Bias in TEC measurements and map - use storm-quiet response
    - hmF2 from ionosondes is an indirect measure
    - Predicting the magnitude of a feature in the wrong place (high RMSE)

- Possible methodologies and metrics
    - Differential validation – used to validate TEC maps from GPS
    - RMSE comparison with regional TEC maps (or difference from normal)
    - RMSE with N/S cuts through TEC maps in well-observed sectors
    - RMSE with ionosonde NmF2 and hmF2 (or +/- phases, divide into low, mid, and high latitude response)
    - RMSE with in-situ satellite N_e

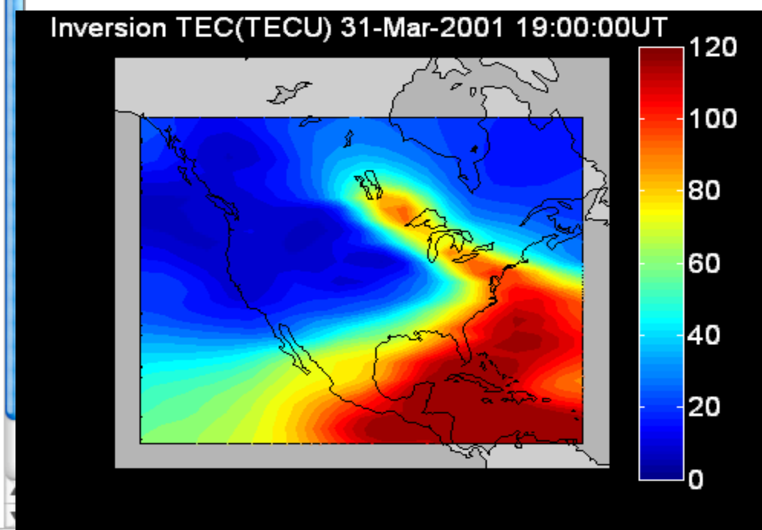


Example of regional TEC map

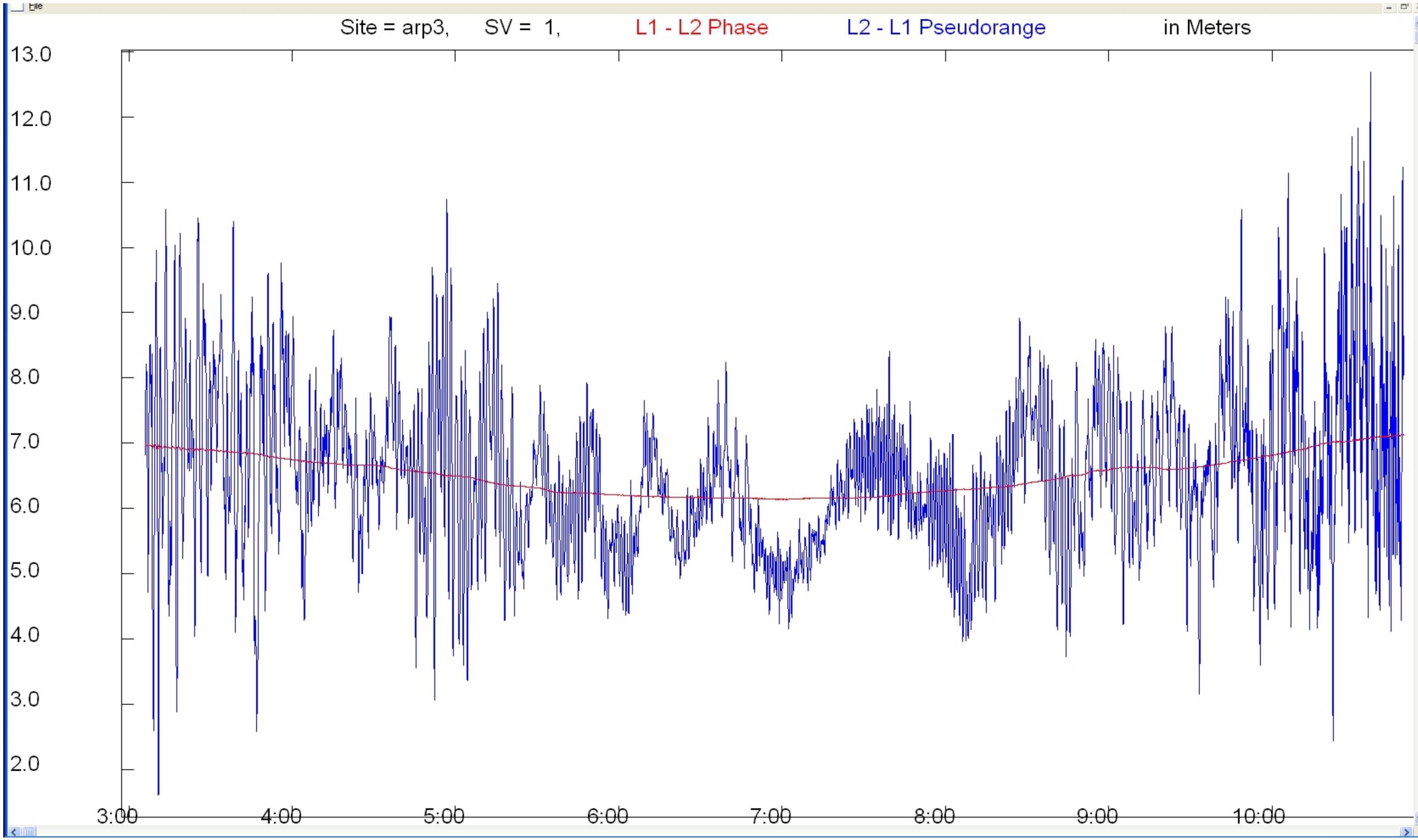
Target Users: Positioning and Navigation community

- Kalman filter over CONUS + ground-based GPS data, IRI background model, solve for receiver biases, 15-minute cadence, 15 to 30 minute latency

- What is accuracy of storm response



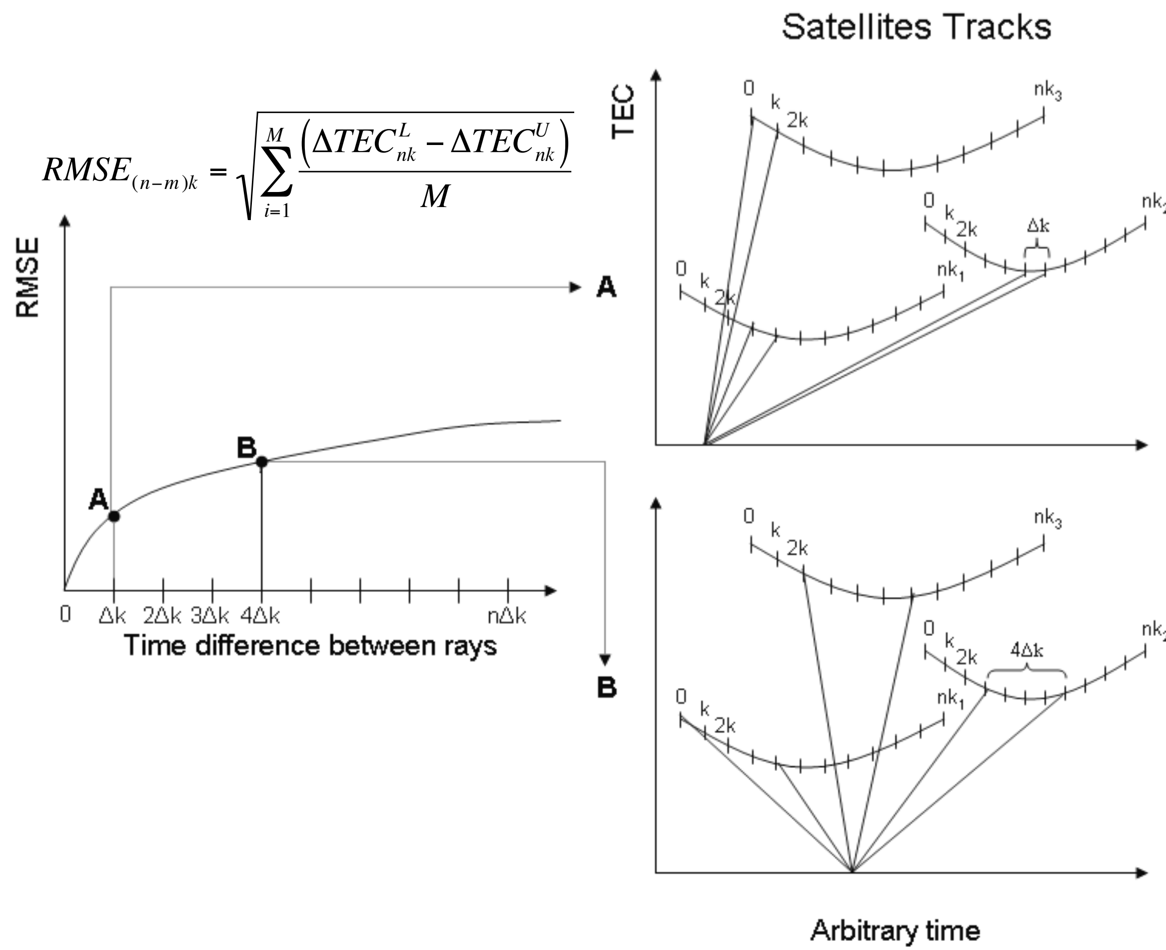
Differential Code and Phase



“Differential” Validation

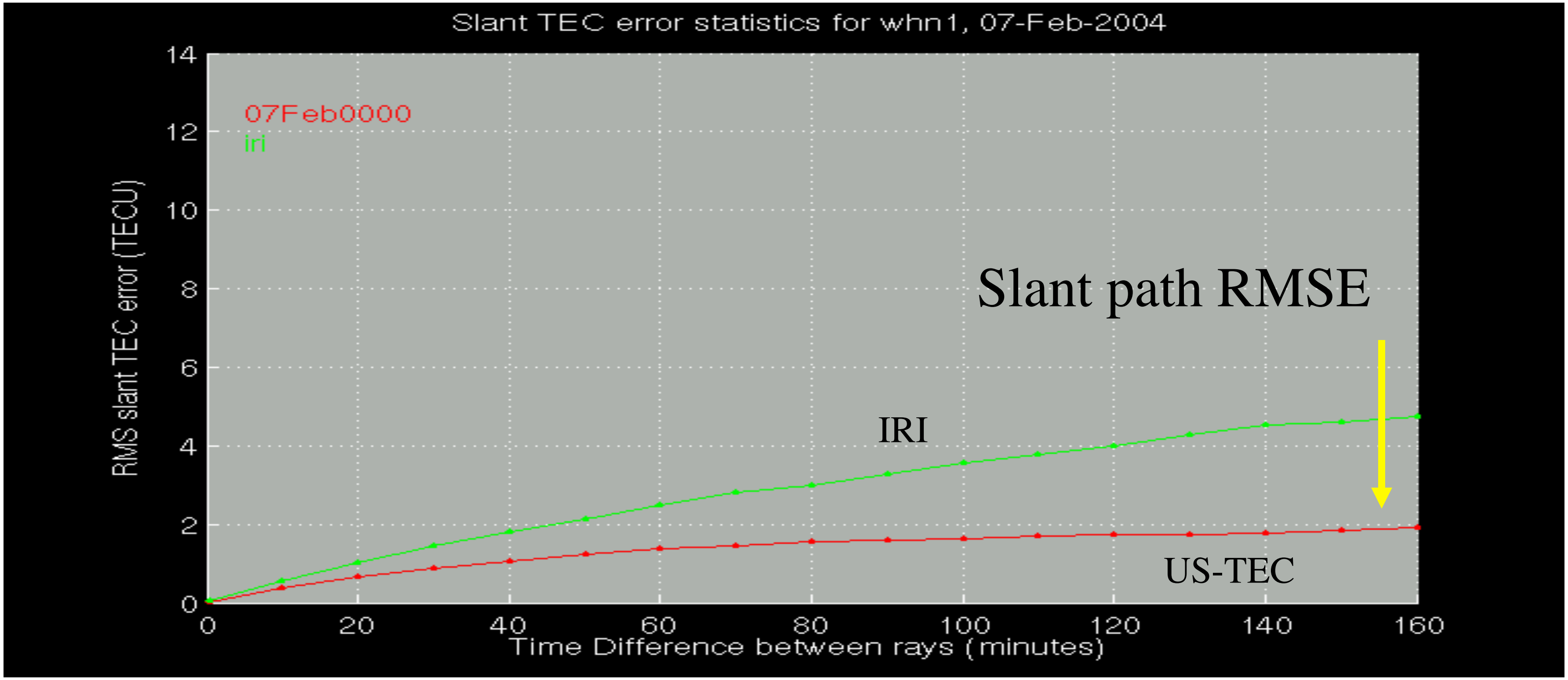
- Integrate through US-TEC model at two different times.
- Compare directly to the phase difference in the original RINEX data file.
- As time separation increases, errors in US-TEC map become uncorrelated and approach true uncertainty.

$$RMSE_{(n-m)k} = \sqrt{\sum_{i=1}^{M} \frac{\left(\Delta TEC_{nk}^{L} - \Delta TEC_{nk}^{U}\right)}{M}}$$



Araujo-Pradere et al. 2006

US-TEC “Differential” Validation



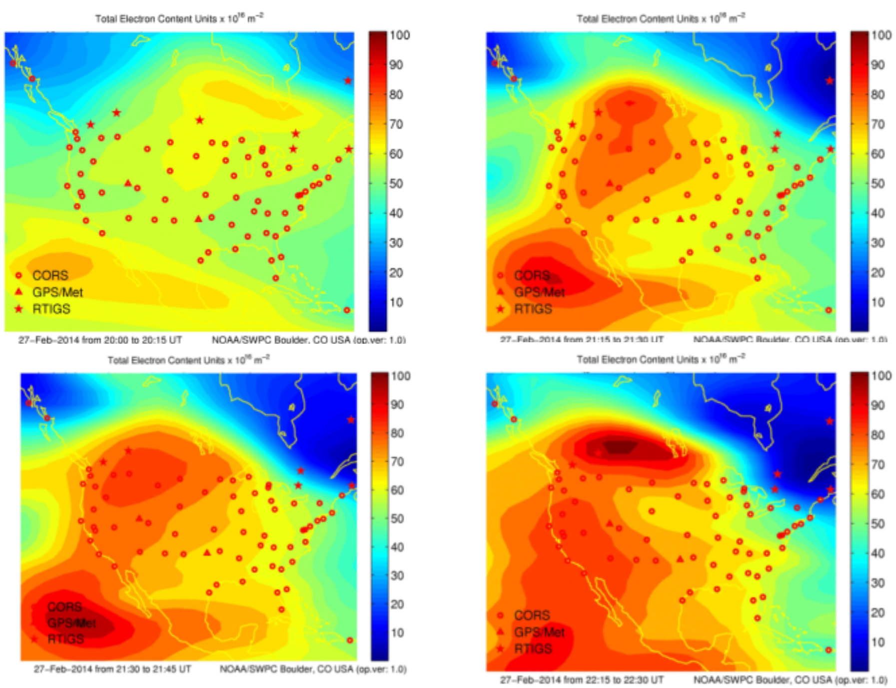
- **Validation stations not included in assimilation process**
- **Build up statistics every 5th day over 6 months**
- **Daily average RMSE for each site**

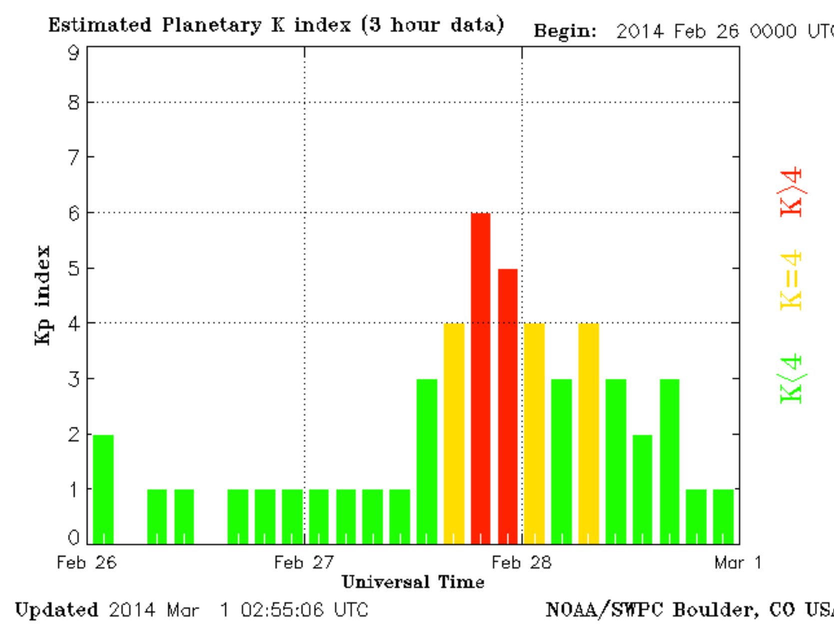
Validate models against regional TEC maps

- RMSE
- departures from normal

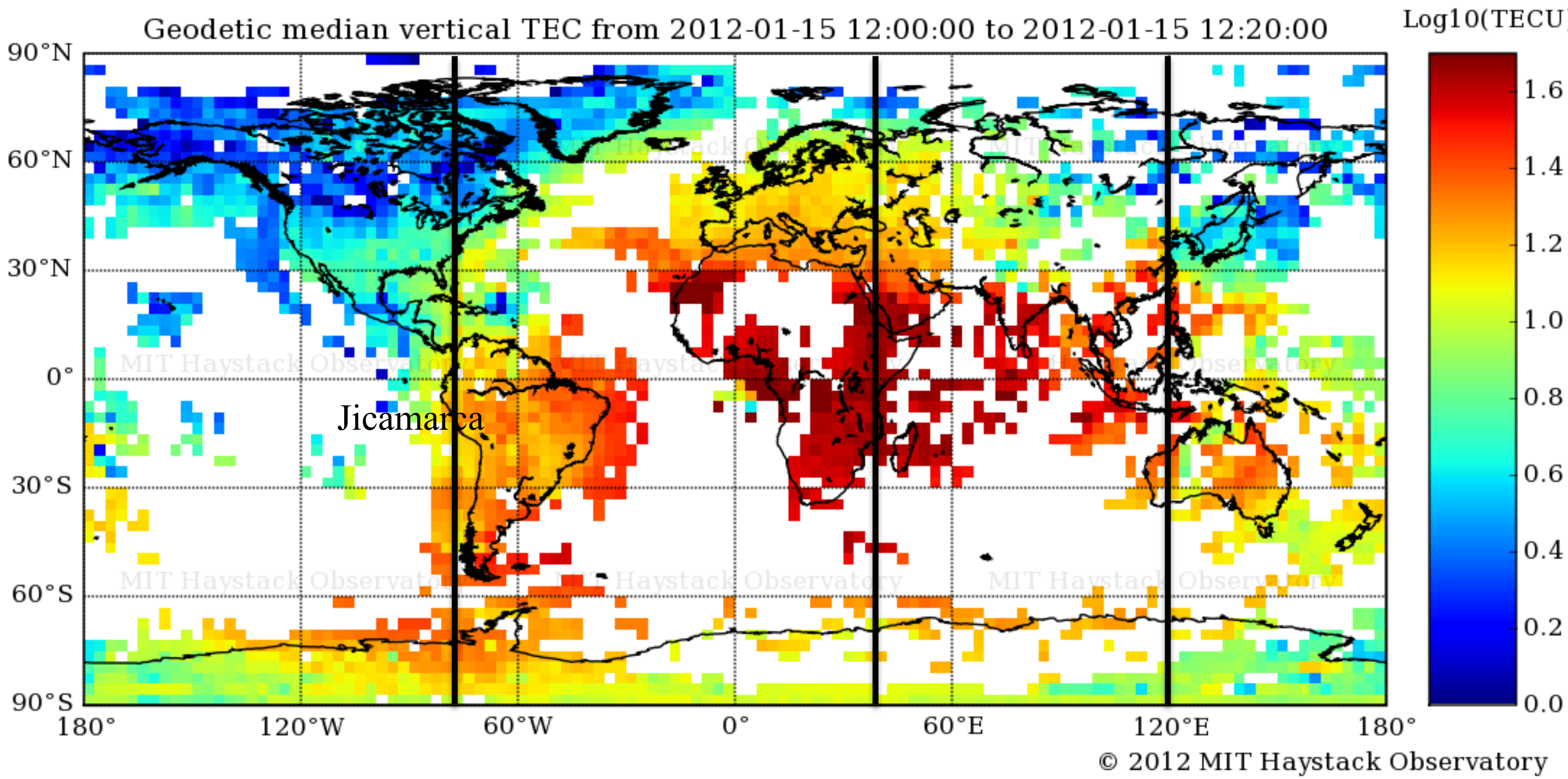
Observational TEC map accuracy:

Slant = 2.4 TEC units
Vertical = 1.7 TEC units



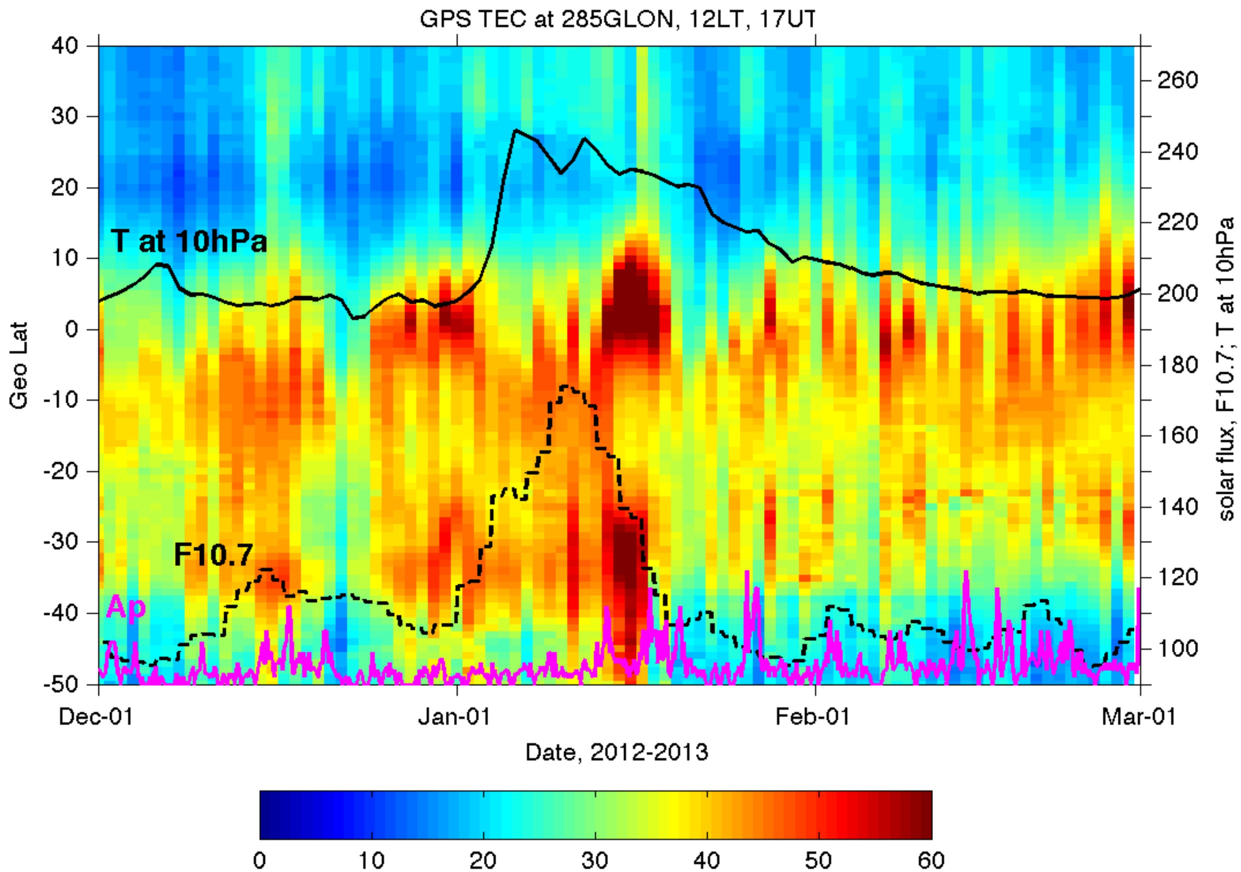


Global TEC data (Goncharenko, Coster)



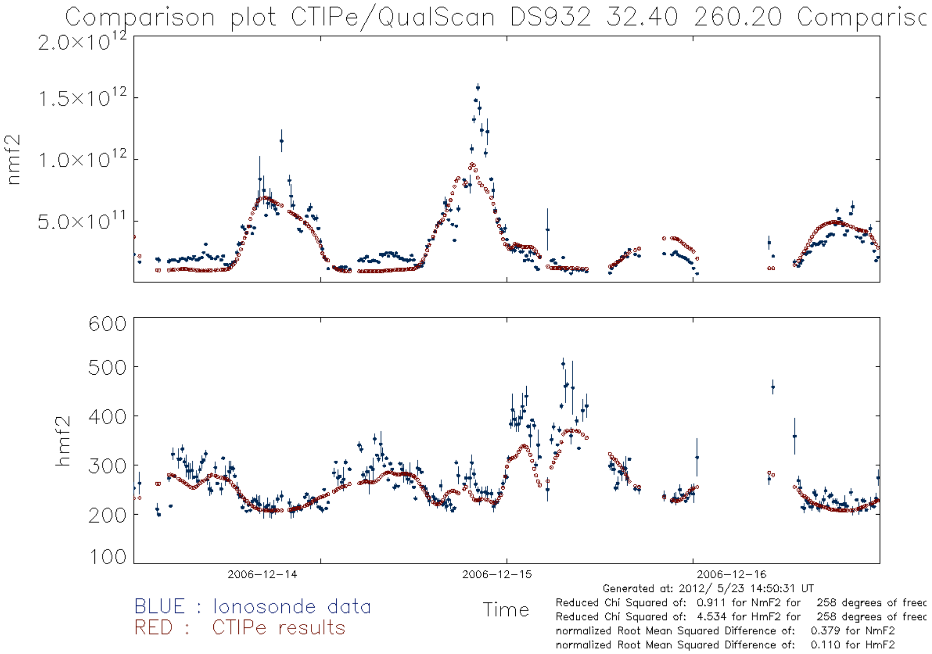
- GPS TEC, MIT Haystack Observatory:
  - ~2000 GPS receivers, 5 min, 1°x1° resolution
  - Longitudes selected: 75°W, 40°E, 120°E
- Too many gaps for a global RMSE

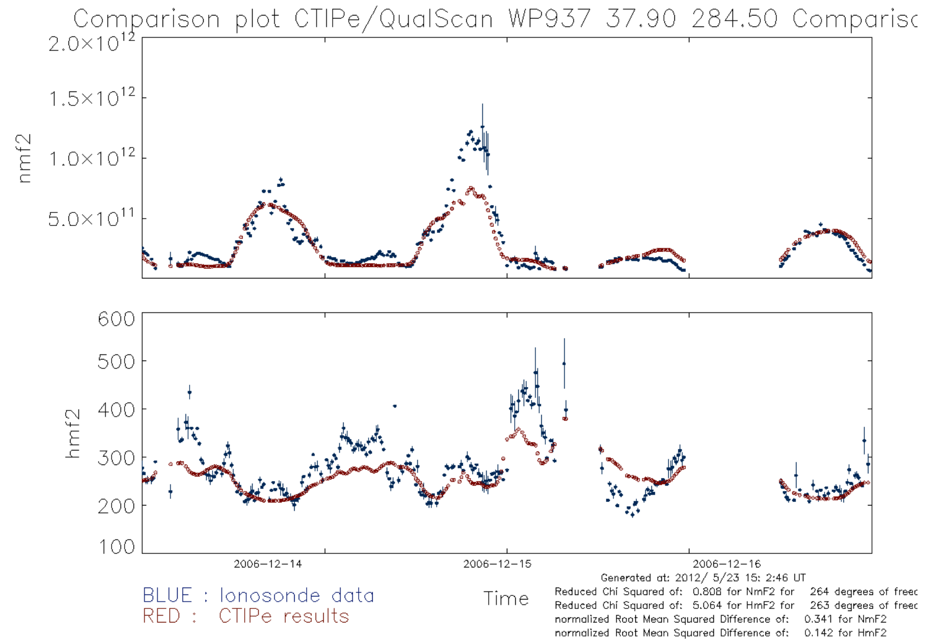
GPS TEC cut through 75°W, 12LT



- Hourly or daily RMSE along three longitude sectors
- Departures from normal

Ionosondes at low, mid, and high latitude NmF2, hmF2, RMSE, difference from average





Station map and examples of real-time validation:
Mihail Codrescu, http://helios.swpc.noaa.gov/ctipe/CTIP.html

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Validation Statistics: "differential" TEC

	Jul						Aug						Sep						
IRI	5	10	15	20	25	30	5	10	15	20	25	30	5	10	15	20	25	30	AVE
pabh	2.6	4.1	4.4	3.2	6.1	1.6	2.6	2.0	4.5	3.9	4.0	2.8		4.2	2.1	2.0	3.0	2.9	3.4
ybhb	3.4	4.5	4.6	4.0	7.3	2.8	2.9	3.8	4.5	4.5	3.9	4.2		4.4	3.3	3.0	4.1	4.1	4.0
bill	5.0	5.0	5.4	5.2	7.8	3.3	4.0	5.2	4.5	4.0	4.2	4.6		3.5	3.8	9.7	4.9	6.4	5.1
clk1	2.3	2.4	5.5	4.3	6.9	2.6	3.0	2.9	4.1	3.9	4.2	4.5		5.0	4.7	2.1	2.5	3.1	3.8
hbrk	3.7	3.6	6.0	4.7	9.5	3.5	3.6	3.1	5.3	3.4	3.2	3.5		4.7	4.9	2.8	4.0	3.4	4.4
arp3	4.9	5.1	5.1	5.3	8.1	3.3	3.6	4.6	4.9	4.1	3.2	6.9		4.2	4.7	3.7	5.7	5.0	5.0
wes2	2.9	4.0	4.9	5.0	6.7	3.0	3.0	3.4	5.8	3.7	2.9	4.8		4.8	4.2	2.7	2.3	2.5	3.8
vims	3.5	4.9	5.8	4.8	8.6	4.0	2.9	3.5	6.0	2.6	3.3	4.7		3.1	5.3	2.8	3.6	2.9	4.3
ccv3		5.9	6.2	5.1	7.6	3.6	3.2	3.2	6.3	3.4		4.3		3.1	4.3	2.8	4.2	3.1	4.5
AVE	3.5	4.4	5.3	4.6	7.6	3.1	3.2	3.5	5.1	3.7	3.6	4.5		4.1	4.2	3.5	3.8	3.7	4.2
USTEC																			
pabh	1.9	1.9	1.8	1.6	3.2	1.1	1.6	1.2	2.0	2.0	1.9	1.8							1.9
ybhb	2.0	2.8	2.3	2.1	2.9	1.7	1.9	1.6	2.5	2.6	2.5	2.3							2.3
bill	3.1	3.5	3.4	3.5	3.7	2.1	2.5	2.4	3.0	2.8	2.3	2.9							3.2
clk1	1.6	1.5	2.1	2.5	3.2	1.3	1.6	1.9	1.8	2.1	2.4	2.9		2.2	2.4	1.2	1.3	1.5	1.9
hbrk	1.9	1.6	2.2	2.6	3.9	1.5	1.7	1.7	2.1	2.1	2.3	2.0		2.0	2.3	1.3	1.6	1.9	2.1
arp3	3.4	2.8	2.8	3.9	2.8	1.9	2.7	2.6	3.0	3.5	1.8	4.7		3.3	3.3	2.3	[illegible]	3.3	3.2
wes2	1.7	1.9	2.2	1.8	2.9	1.4	1.6	1.9	2.6	1.3	1.8	2.4		2.3	2.3	1.5	1.4	1.6	2.0
vims	1.9	1.7	2.1	2.0	4.0	1.5	1.8	1.9	2.4	1.6	2.3	2.3		2.0	2.5	1.7	1.5	1.4	2.0
ccv3		2.8	2.4	3.0	3.1	1.6	2.0	2.2	2.8	2.4		2.4		2.4	2.6	2.1	2.3	2.3	2.7
AVE	2.2	2.3	2.4	2.5	3.3	1.6	1.9	1.9	2.5	2.3	2.2	2.6		2.3	2.4	2.5	2.0	2.2	2.4
USTEC - IRI																			
pabh	-0.8	-2.2	-2.5	-1.5	-2.9	-0.4	-1.1	-0.8	-2.5	-1.9	-2.1	-1.0		-2.5	-0.8	-0.4	-1.3	-1.2	-1.5
ybhb	-1.4	-1.7	-2.4	-1.9	-4.4	-1.1	-1.0	-2.2	-2.0	-1.9	-1.3	-1.9		-2.1	-1.3	-1.2	-2.0	-1.6	-1.7
bill	-1.9	-1.6	-2.0	-1.7	-4.0	-1.2	-1.5	-2.8	-1.5	-1.2	-1.9	-1.7		-0.9	-1.2	-0.8	-2.3	-3.0	-1.9
clk1	-0.7	-0.9	-3.4	-1.8	-3.7	-1.3	-1.4	-1.0	-2.4	-1.8	-1.8	-1.5		-2.8	-2.3	-0.9	-1.2	-1.7	-1.9
hbrk	-1.9	-2.0	-3.8	-2.1	-5.6	-2.0	-1.9	-1.3	-3.2	-1.4	-0.8	-1.5		-2.7	-2.6	-1.5	-2.4	-1.5	-2.3
arp3	-1.5	-2.3	-2.3	-1.5	-5.3	-1.4	-1.0	-2.0	-1.8	-0.6	-1.4	-2.2		-1.0	-1.4	-1.4	-2.8	-1.7	-1.8
wes2	-1.2	-2.1	-2.7	-3.2	-3.7	-1.6	-1.4	-1.5	-3.2	-2.3	-1.0	-2.3		-2.6	-1.9	-1.1	-0.9	-1.0	-1.9
vims	-1.6	-3.3	-3.7	-2.8	-4.5	-2.5	-1.1	-1.6	-3.6	-1.1	-1.0	-2.4		-1.2	-2.8	-1.1	-2.1	-1.5	-2.2
ccv3		-3.0	-3.8	-2.1	-4.5	-2.0	-1.2	-0.9	-3.5	-1.0		-1.9		-0.7	-1.7	-0.7	-1.8	-0.8	-1.8
AVE DIF	-1.4	-2.1	-3.0	-2.1	-4.3	-1.5	-1.3	-1.6	-2.6	-1.4	-1.4	-1.8		-1.8	-1.8	-1.0	-1.9	-1.5	-1.9
ap index	7	8	9	9	122	7	7	14	7	14	7	34	7	5	14	13	5	4	
# stations	58	59	59	58	58	57	58	57	57	53	49	58	3	58	59	58	57	57	50

2.4 TEC units

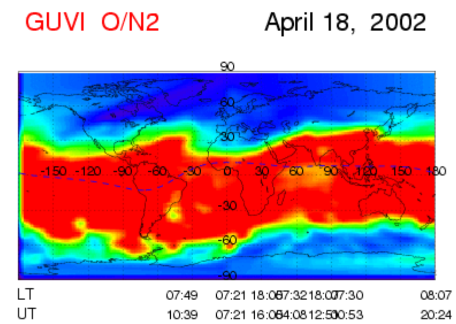
Process 6

Evolution of neutral composition change

Response and recovery of O/N_2

Movement of boundaries in O/N_2

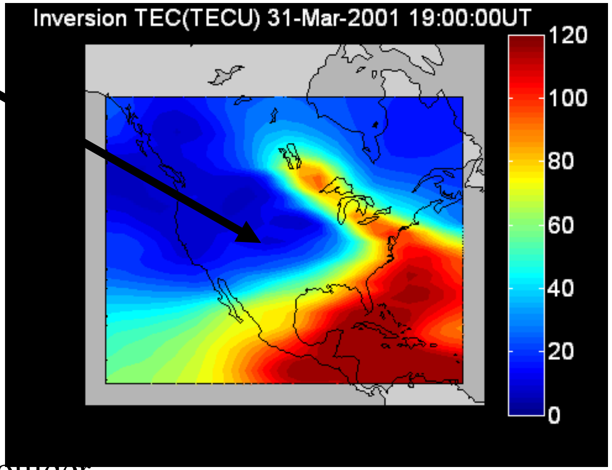
Observations: TIMED/GUVI, SSUSI, GOLD,….



Process 7

Ionospheric negative storm phase at mid latitude

- Validate TEC from GPS maps
- Validate in-situ from satellite
- Validation point with ionosondes



Process 8

Disturbance dynamo

Difficult to validate.

Confused by penetration electric field and its time constants.

Process 2 and 8

- Possibility: Combine penetration and disturbance dynamo at low latitudes

Time series of electric field (e.g., Jicamarca, magnetometers).

Validation of total E at low latitudes, penetration + dynamo + time constants

Validate total EIA response

Suggested **process-orientated** storm metrics for model validation

Process 1: Quantifying the geomagnetic storm energy dissipation

Process 3: Build-up of plasma and structure at mid-latitudes

Process 4: Gravity wave propagation from high to low latitude

Process 6: Evolution of neutral composition change

Process 7: Ionospheric negative storm phase at mid latitude

Process 2 and 8: Combined penetration and dynamo electric fields