IT Model Validation Studies for TEC prediction

performed by CCMC

via CEDAR/GEM-CEDAR Modeling Challenges

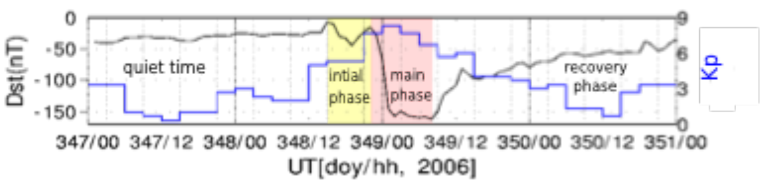
- Global TEC study
  - Eight longitude sectors
  - 2006 AGU storm
  - CEDAR-GEM Challenge for Systematic Assessment of Ionosphere/Thermosphere Models in Predicting TEC during the 2006 December Storm Event, to be submitted to *Space Weather*, 2017.

- Regional TEC study
  - North American sector
  - 2006 AGU storm, 2013 March storm

Global TEC Study

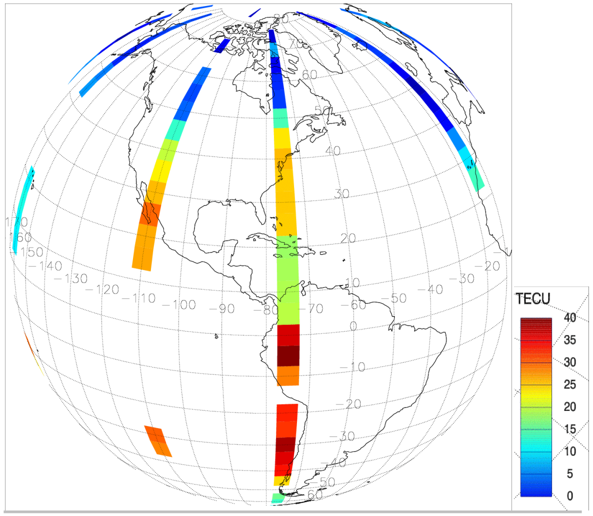
- Eight longitude sectors:
  25-30, 90-95, 140-145, 175-180°E,
  200-205, 250-255, 285-290, 345-350°E

- Time intervals (including one quiet day):
  2006/12/13 -12/16 (Dst_min = - 162 nT)



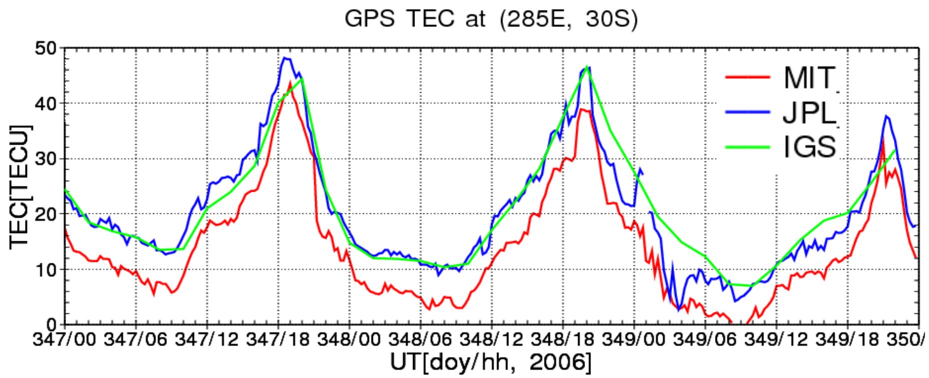
- Observations : GPS vertical TEC
  - MIT and JPL vTEC
    - data bin : 5° lat × 5° lon × 15 min
  - IGS (International GNSS service) vertical TEC
    - data bin : 2.5° lat × 5° lon × 2 hrs

- 15 model simulations (using 8 models)

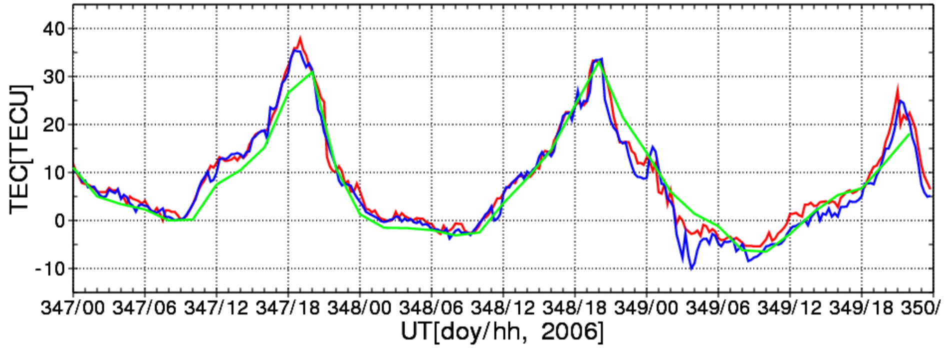


Biases/Baselines in TEC Measurements

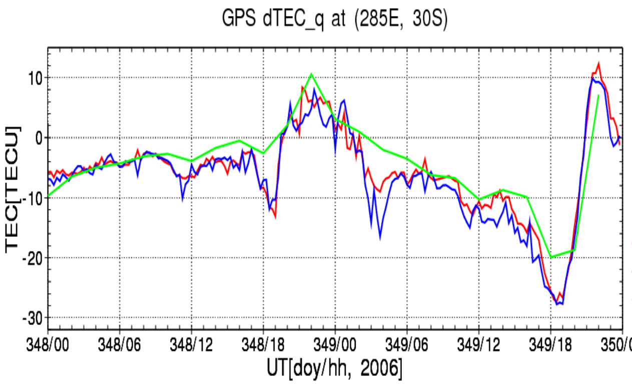
- Difference between GPS TEC data sets



- TEC – TEC_min(pre-storm period)



- TEC – TEC_quiet:
  - TEC of one day prior to the storm event



What would be the best quiet time reference?

Model Simulations used for the study

Model Setting ID		Upper boundary
1_IRI*	IRI-2007, empirical ionospheric model	~2,000 km
2_IRI*	IRI-2012 using IRI-corr for topside Ne and CCIR F-peak	
1_SAMI3_HWM93*	SAMI3 with the neutral wind model HWM93	~2,000 km
1_USU-IFM*	IFM driven by F10.7, Kp and empirical inputs for the thermosphere parameters	~1,600 km
1_CTIPE*	CTIPe driven by Weimer electric potential model, $2^\circ \times 18^\circ$, 15 levels in logarithm of pressure	~2000 km
2_CTIPE	CTIPe runs at NOAA/SWPC with Weimer 2005 using 1-minute solar wind and IMF from ACE; (f10.7+f81)/2	
4_GITM*	GITM 2.0 driven by Weimer electric potential model	~600 km
1_TIE-GCM*	TIE-GCM1.93 driven by Heelis electric potential model with constant critical co-latitudes	~600 km
2_TIE-GCM	TIE-GCM1.94 driven by Weimer electric potential model with dynamic critical co-latitudes	
3_TIE-GCM	TIE-GCM1.94 driven by Weimer electric potential model with dynamic critical co-latitudes and with double resolution	
4_TIE-GCM	TIE-GCM1.94 with Weimer 2005 and SABER/TIDI lower boundary conditions in double resolution	
1_UAM	Upper Atmosphere Model (UAM), A.A. Namgaladze et al., FAC as external driver	~2,000 km
2_UAM	UAM with AMIE electric potentials as external drivers	
3_UAM	UAM with Weimer-2005 (and/or Weimer-96) electric potentials	
1_USU-GAIM*	USU-GAIM23 with GPS TEC observations from up to 400 ground stations	~1,400 km

*Runs performed at the CCMC

Physical Quantities

- Differential TEC:
  dTEC_m = TEC – TEC_min(pre-storm period) => TEC
  dTEC_q = TEC – TEC_quiet => TEC change

  - remove biases in observations and models
  - reduce model performance dependence on ground truth
  - reduce impact of difference in upper boundary among models

- **What else would be better? (e.g., spatial gradient)**

Metrics

- RMSE
- NRMSE : normalized by the mean absolute value of the observed dTEC

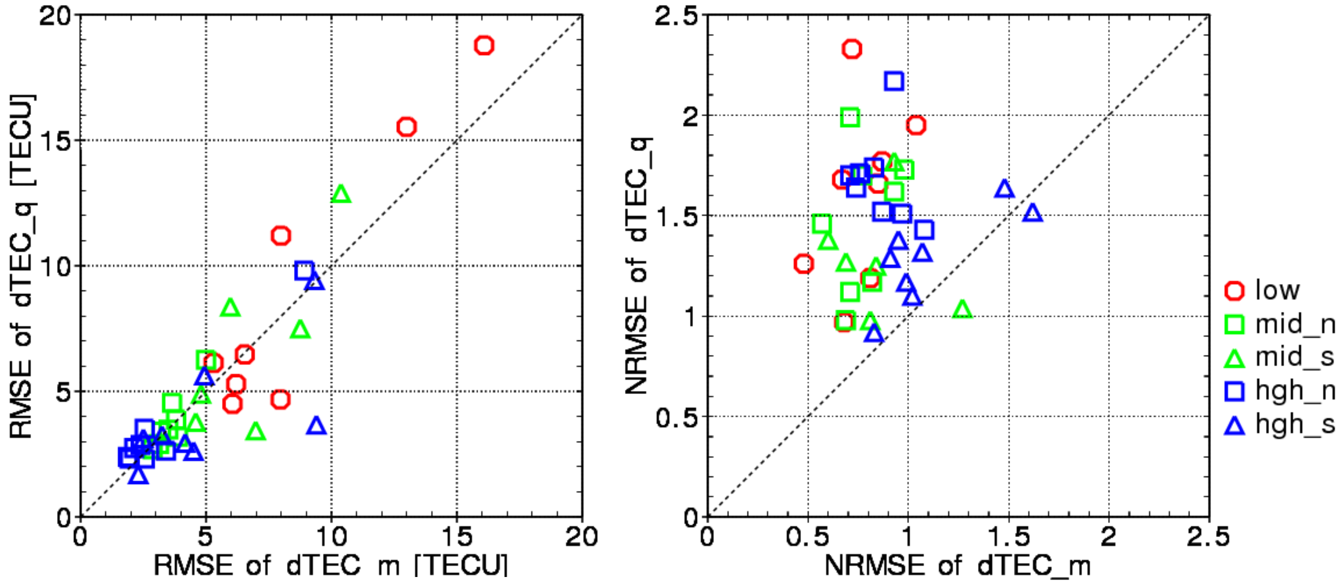
- Yield: ratio of the maximum modeled to the observed TEC during the storm
- Time difference: between the modeled peak time and observed peak time

- Focus on ionospheric positive storm effects

RMS and NRMSE for all 8 longitude sectors

Low (|lat| < 25°) Mid_s (-50° < lat < -25°) Mid_n (25° < lat < 50°) High_s (lat < -50°) High_n(lat > 50°)

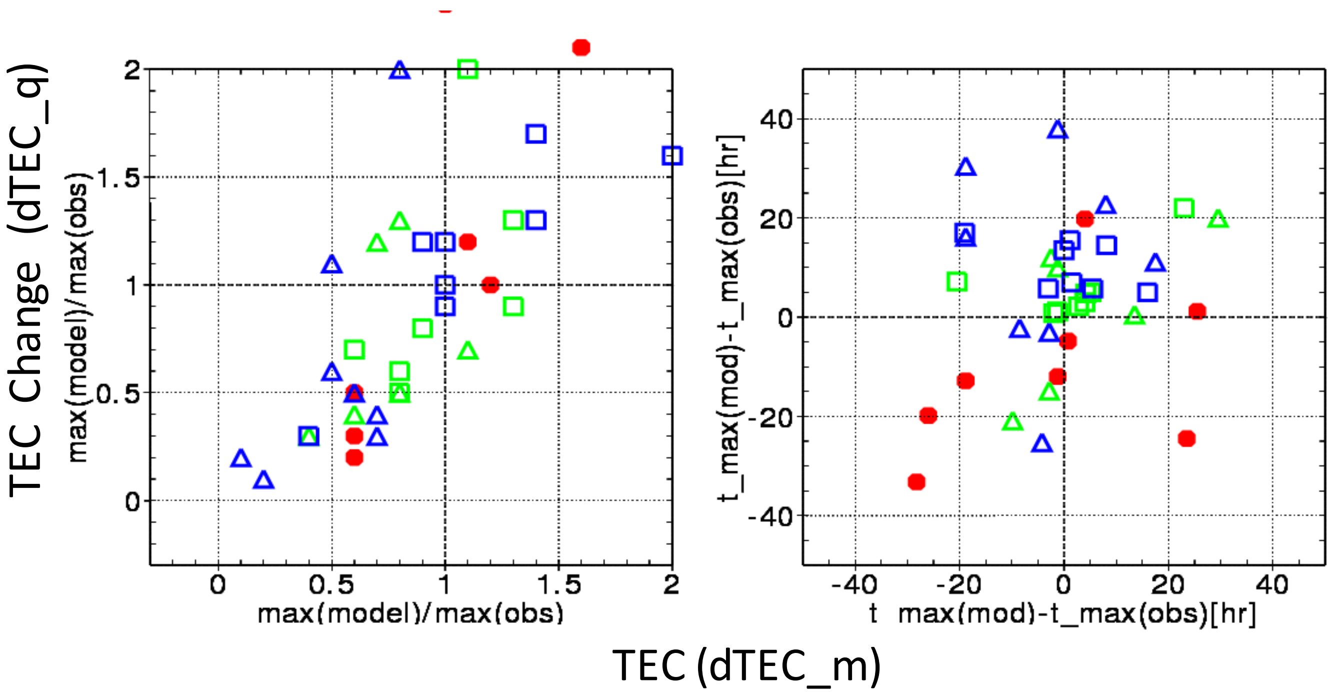
TEC Change (dTEC_q)



TEC (dTEC_m)

- RMSE appears to have latitudinal dependence of TEC
- red: low, green: middle, blue: high latitudes

Yield and dt_max for all 8 longitude sectors

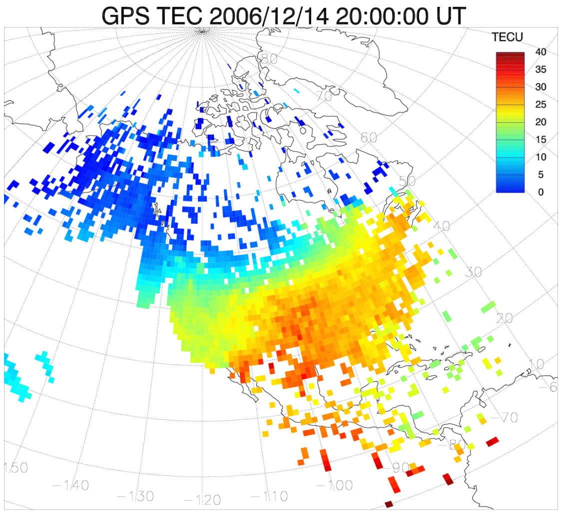


- x and y axes correspond to TEC (dTEC_m) and TEC changes (dTEC_q).
- Yield= modeled dTEC_max/observed dTEC_max)
- dt_max = t_max_model – t_max_obs
- better Yields, but worse dt_max
- red: low, green: middle, blue: high latitudes

Regional TEC study

- North American sector (North and South America, and European sector)

- Time intervals:
  - 2006/12/13 – 12/16 (Dst_min = - 162 nT)
  - 2013/03/16 – 03/20 (Dst_min = -132 nT)



- Observations :
  - MIT GPS TEC (provided by A. Coster and L. Goncharenko)
    - data bin : 1° lat × 1° lon × 5 min

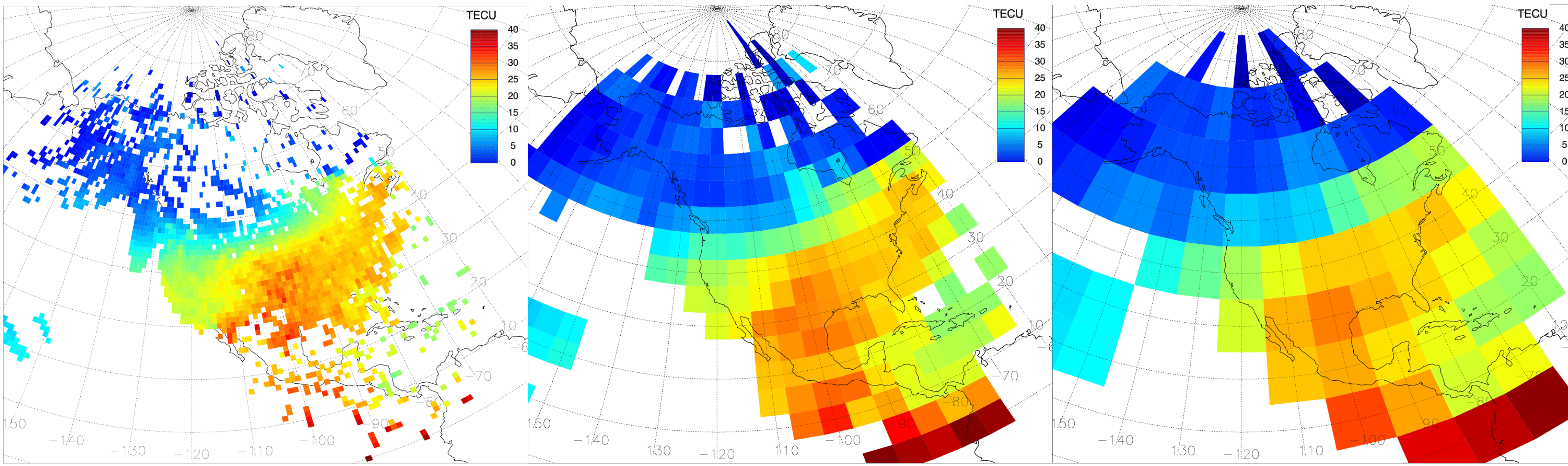
- 3 model simulations are compared with measurements

- Work in progress

Regional TEC Study

- Preparation of observed data (with three different bin size)

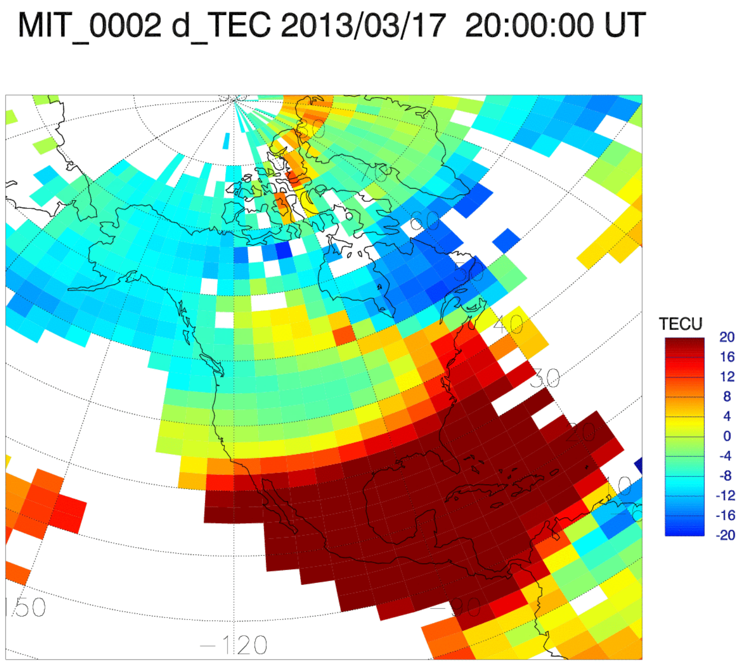
GPS TEC during 2006 AGU Storm (2006/12/14 20:00:00 UT)

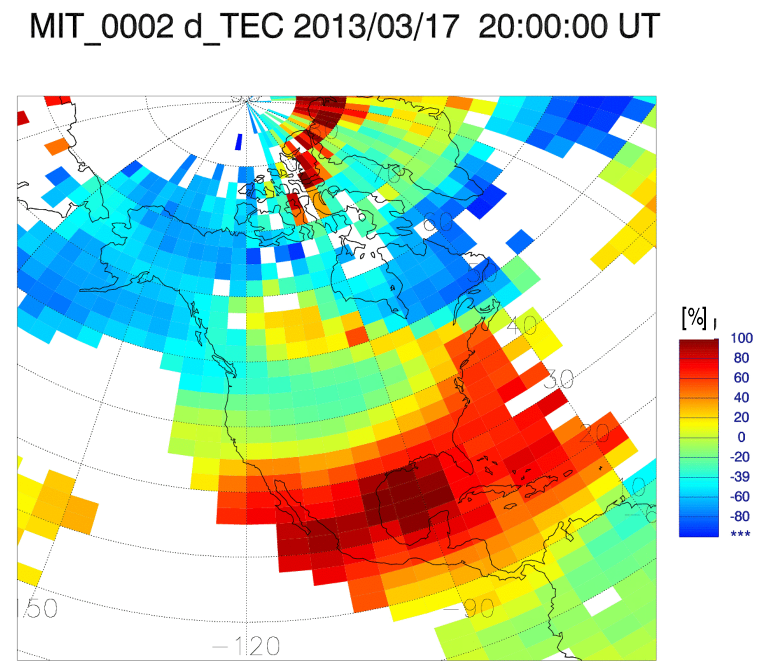


1° lat × 1° lon | 5° lat × 5° lon | 10° lat × 10° lon

- What is the optimal spatial and temporal scales?
- Need understanding of the users' needs for different spatial and temporal scales

TEC Changes vs Percentage Changes



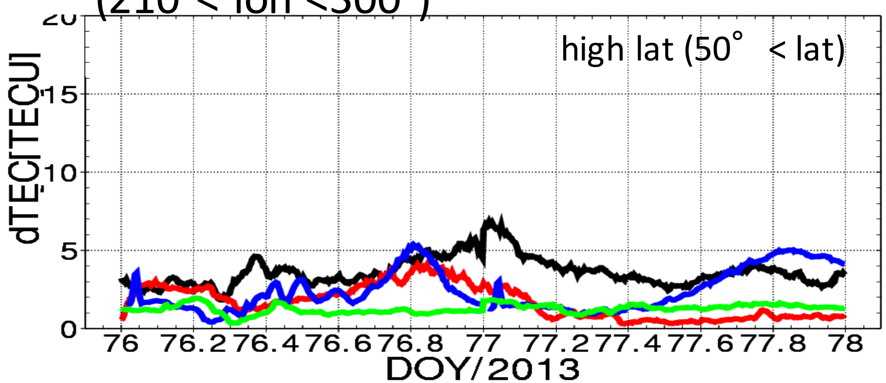


GPS TEC (5° lat × 5° lon)

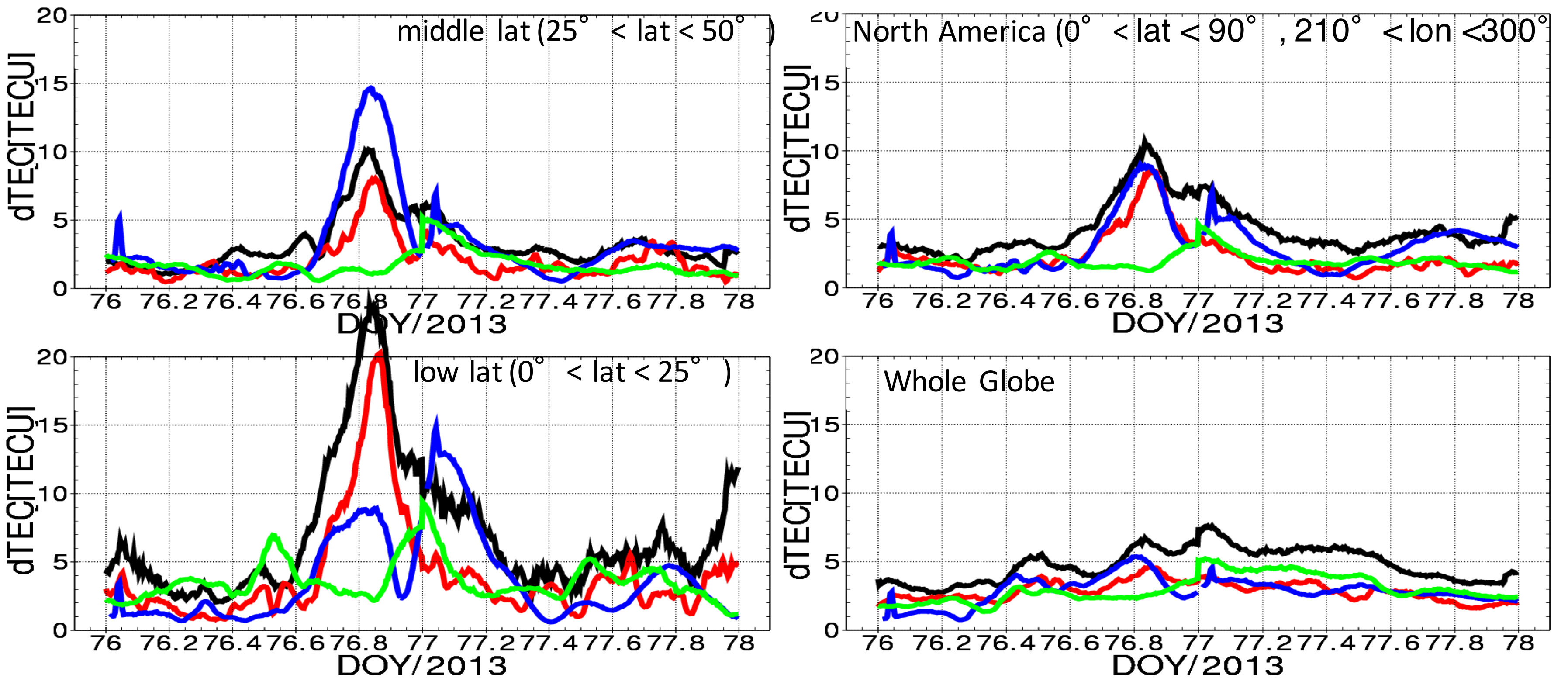
- TEC Change: dTEC_q = TEC – TEC_quiet
- Percentage Change = 100*dTEC_q/TEC_quiet

Average |TEC Changes|

(210°< lon <300°)

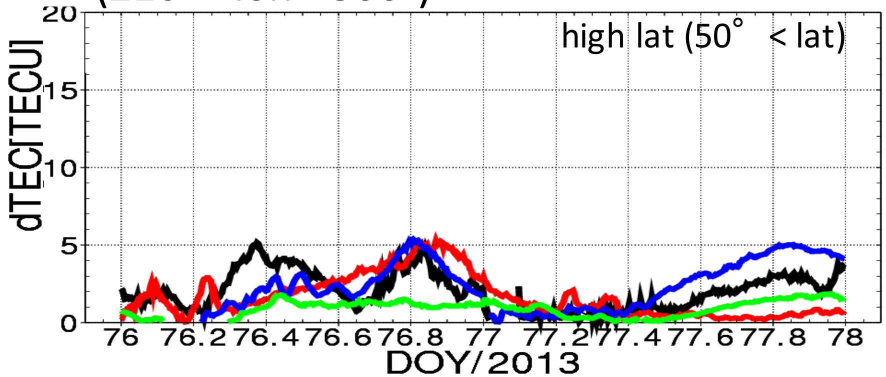


- Latitudinal
- Regional
- Over the whole globe
- Averages can be misleading

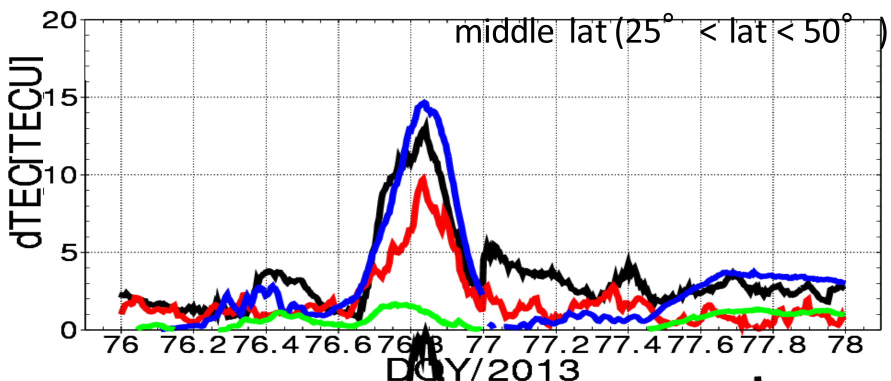


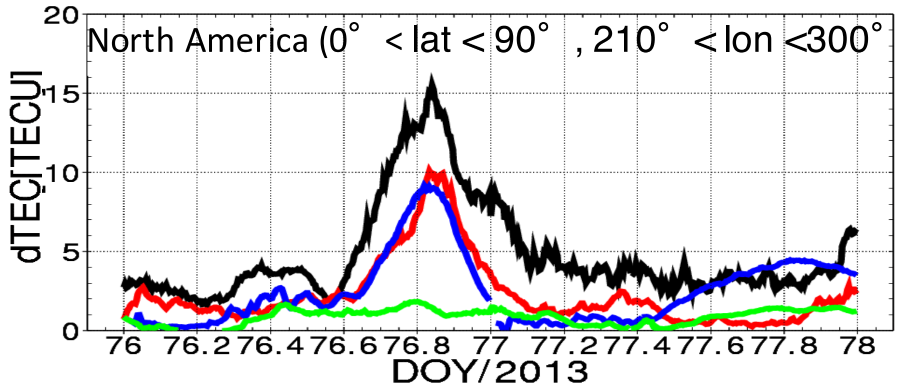
Average Positive TEC Changes

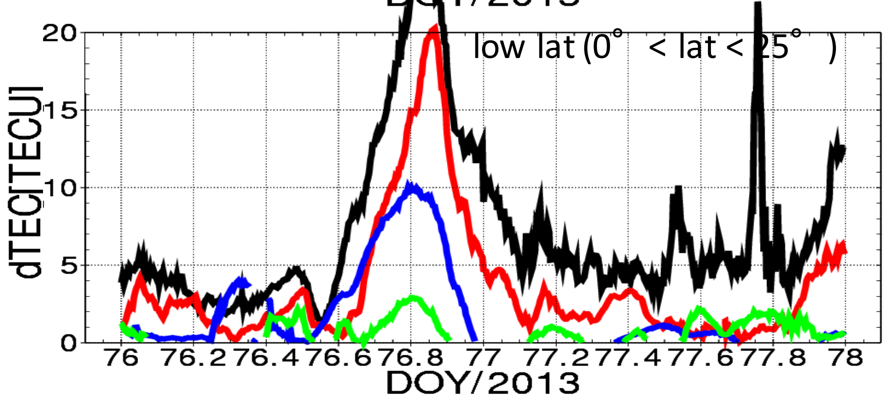
(210°< lon <300°)

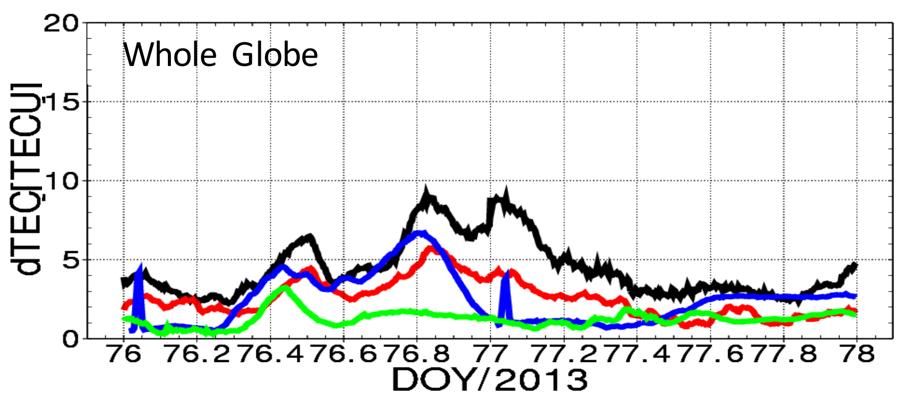


- Latitudinal
- Regional
- Over the whole globe



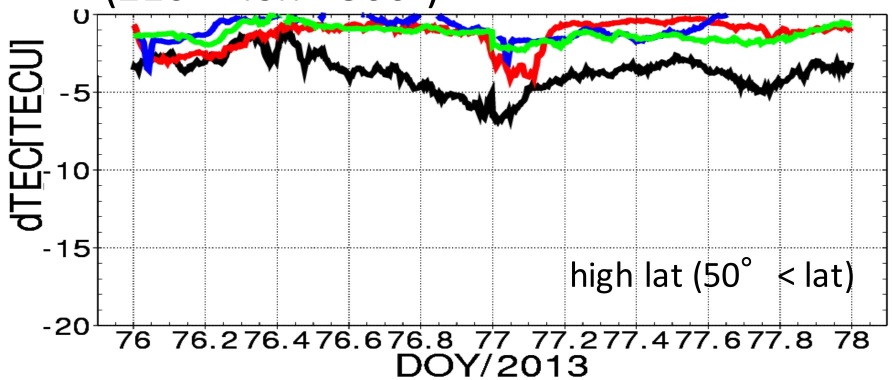






Average Negative TEC Changes

(210°< lon <300°)



- Latitudinal
- Regional
- Over the whole globe