Defining Metrics and Tracking Progress for Ionosphere Disturbances Modeling:

Highlights from the International Forum on Space Weather Capabilities Assessment

Ionosphere Working Group

Goals of the Ionosphere Working Group

- Establish metrics agreed upon by the community
- Evaluate where we stand with ionosphere/thermosphere prediction
- Provide a benchmark against which future models can be assessed

Four Working Teams

Team	Primary Lead and co-leads	Linkage to LWS SSA	Example of Applications
Neutral Density and Orbit Determination at LEO	**S. Bruinsma**, S. Solomon, T. Fuller-Rowell, E. Sutton	SSA-2: Satellite Drag	space object orbital elements
Global & Regional TEC	**L. Scherliess**, R. Calfas	SSA-4:TEC	HF communication, GPS positioning and navigation
Ionosphere Plasma Density: NmF2/foF2, hmF2	**I. Tsagouri,** M. Angling, J. Shim	SSA-5: Scintillation	
Ionosphere Scintillation	**E. Yizengaw**		

Selection of Time Intervals

- Mainly based on data availability
- Proposed Storm Events:

Date	Min. Dst (nT)
29 March – 3 April 2001	-387
18 - 31 July 2004	-170
14 - 16 May 2005	-247
8 - 11 March2012	-131
16 - 20 March 2013	-132
31 May – 4 June 2013	-119
16 - 20 March 2015	-222
21 - 24 June 2015	-204

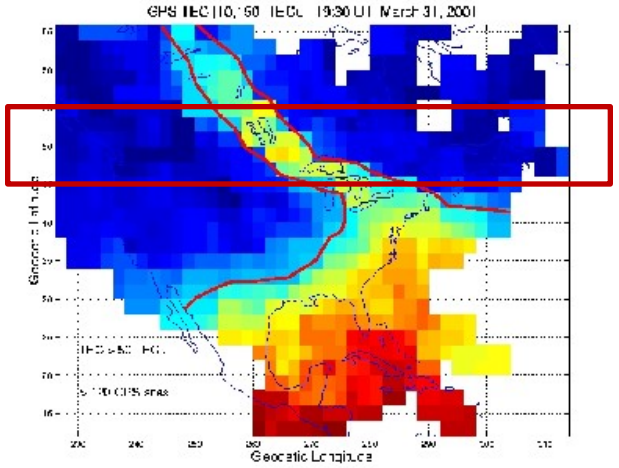
more new events will be added

- Proposed to study entire year 2012:
  - Understand quiet times
  - Understand importance of background conditions

Proposed Metrics

Global TEC Modeling Validation:
SSA-4, TEC Forecasting Capability

- **TEC gradient :**
  - For example, **new index G45-55** will be calculated **as the maximum absolute longitudinal TEC gradient** in the mid-high latitudes (45° < geo. lat. < 55°) in North American and European Sectors.

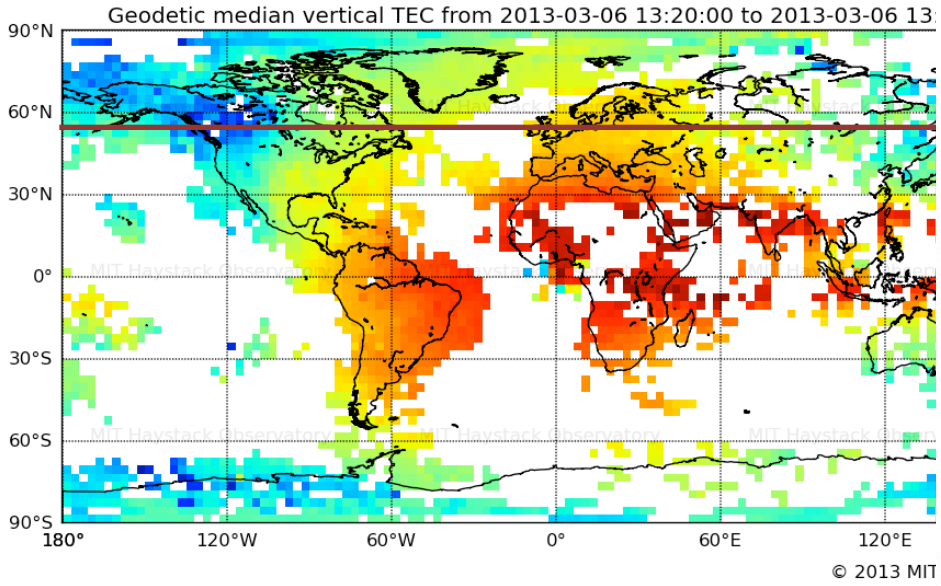


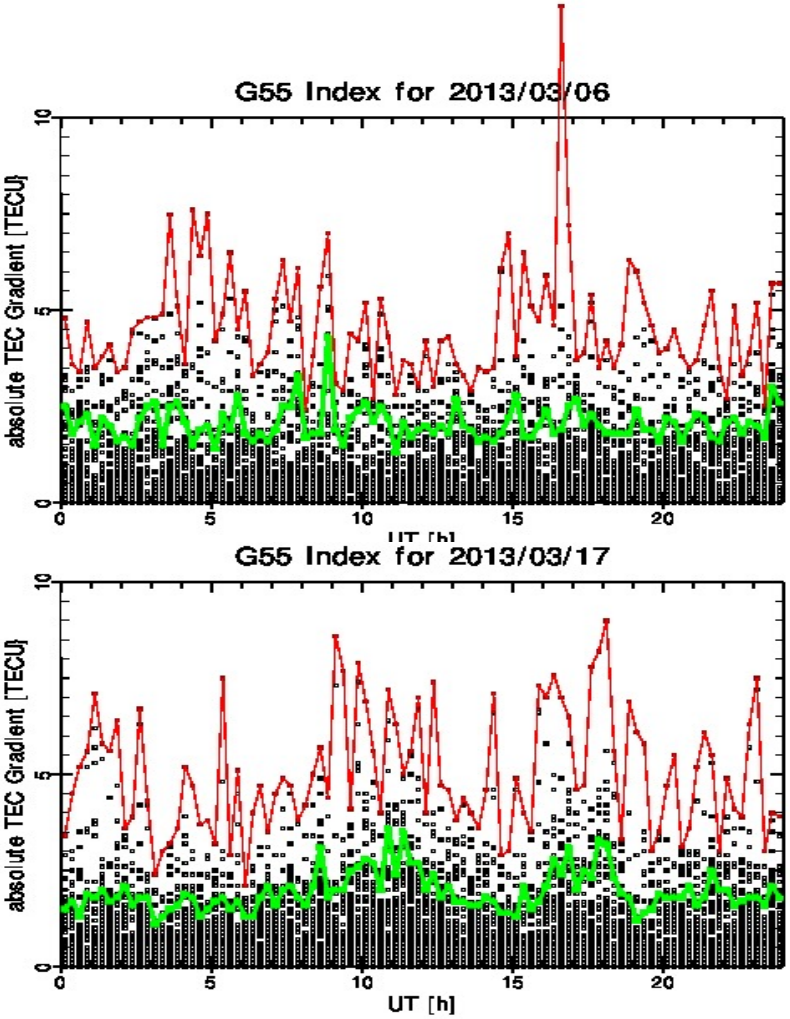
- 1D quantity for time-series model/data comparison
- Advantage of this index is that it is largely ignorant of biases but captures dynamical response due to storms!

Example of G55 Index

G55 was calculated every 15 minutes on a 1° grid as the maximum absolute longitudinal TEC gradient at 55° geographic latitude.

Vertical TEC from Madrigal Database



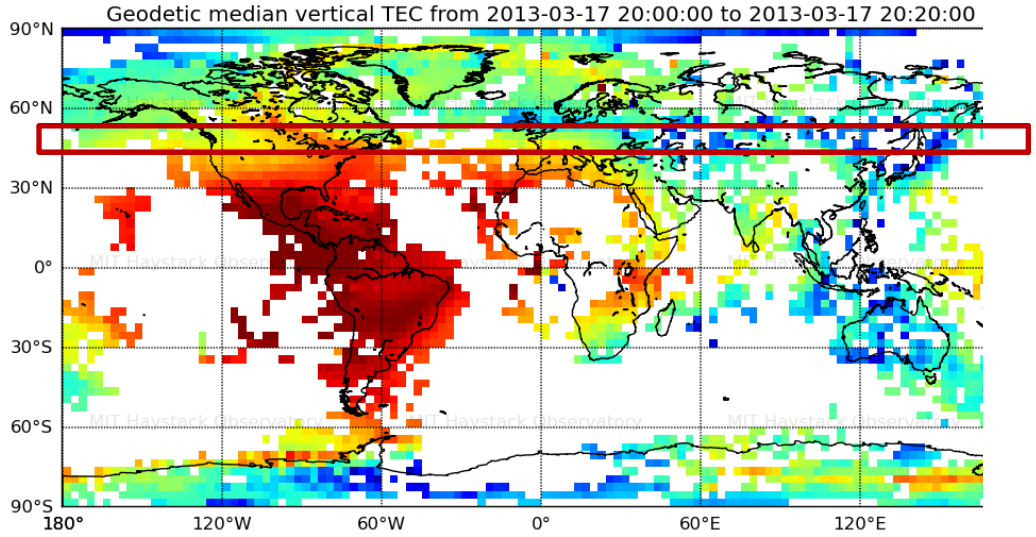


With this resolution gradients are very noisy and lead to unreliable estimates of G55!

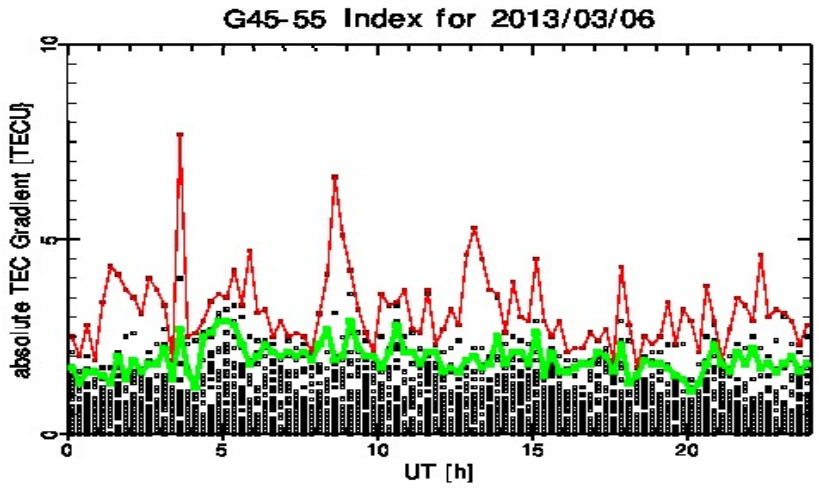
Example of G45-55 Index

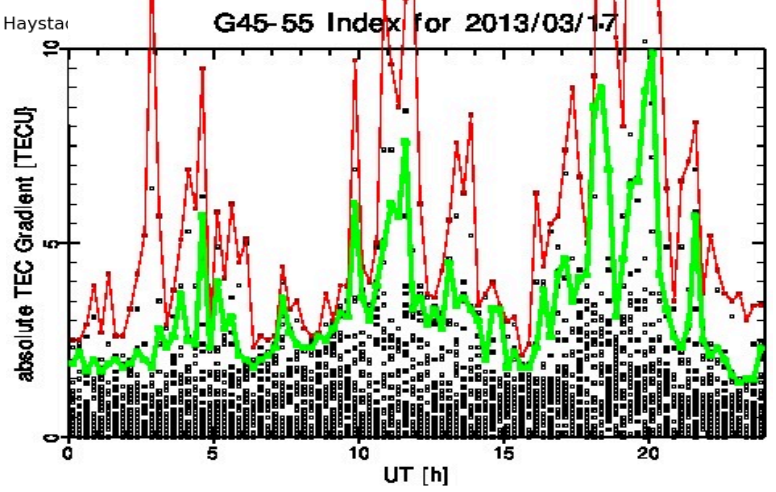
Extend latitude range (45 ° ~ 55 °) **and longitude resolution** (5 °): **considering only American and European sectors**

Vertical TEC from Madrigal Database



- Storm features are now much clearer
- Large peak in the G45-55 index corresponds to the SED that occurred around 20:00 UT in 03/17 .





Proposed Metrics

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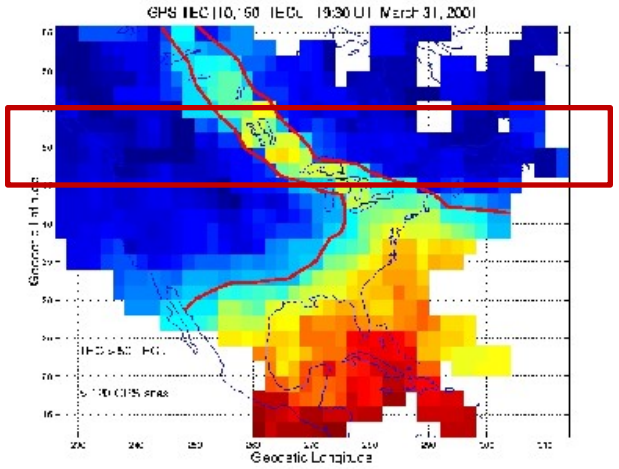
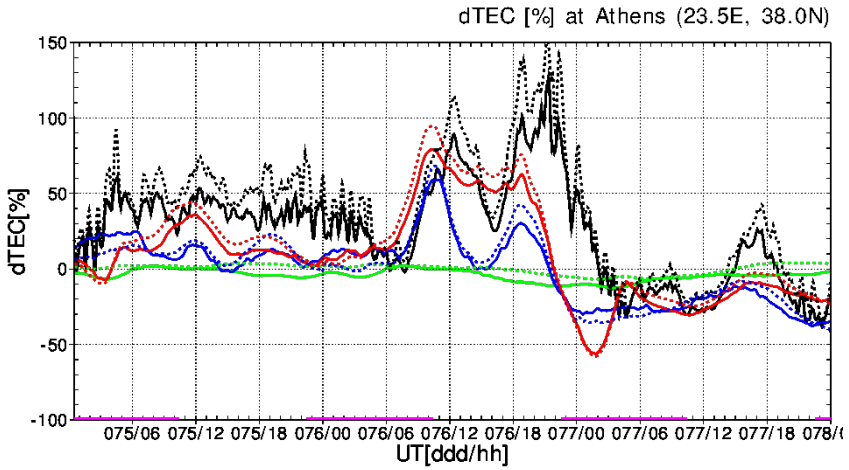


- **Normalized percentage change from baseline**:

  n_dTEC= [dTEC[%] -ave_dTEC[%]]/std_dTEC[%]

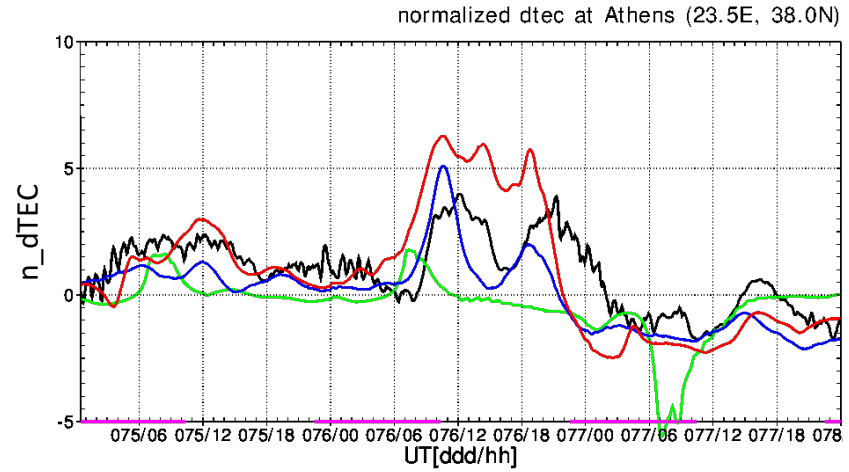
  - max. of n_dTEC
  - (max. of n_dTEC + max. of |n_dTEC|)/2

Example: dTEC[%] vs Normalized dTEC[%]



GPS_TEC
CTIPE
TIEGCM
IRI2016

solid lines: dTEC with median,
dotted: dTEC with average of 5 quietest days



- Larger nighttime dTEC[%] due to smaller TEC_median
- To remove local time dependence, dTEC[%] is normalized using average and standard deviation of dTEC[%] over 30 days:

n_dTEC=

[dTEC[%] -ave_dTEC[%]]/std_dTEC[%]

(*Nishioka, M., T. Tsugawa, H. Jin, and M. Ishii, 2017*)

Proposed Metrics

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SSA-4, TEC Forecasting Capability

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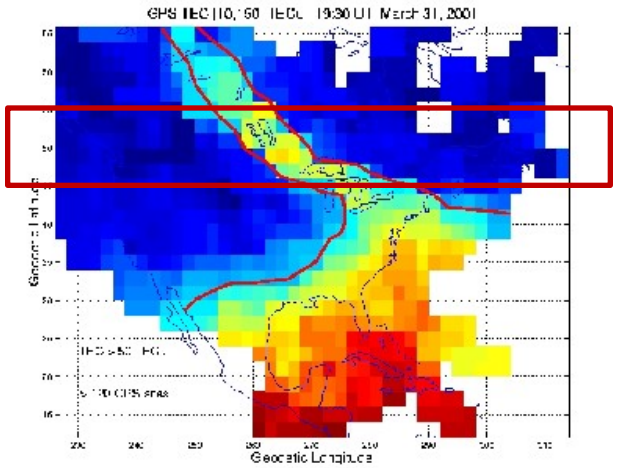


- **Normalized percentage change from baseline**:

  n_dTEC= [dTEC[%] -ave_dTEC[%]]/std_dTEC[%]
  - max. of n_dTEC
  - (max. of n_dTEC + max. of |n_dTEC|)/2

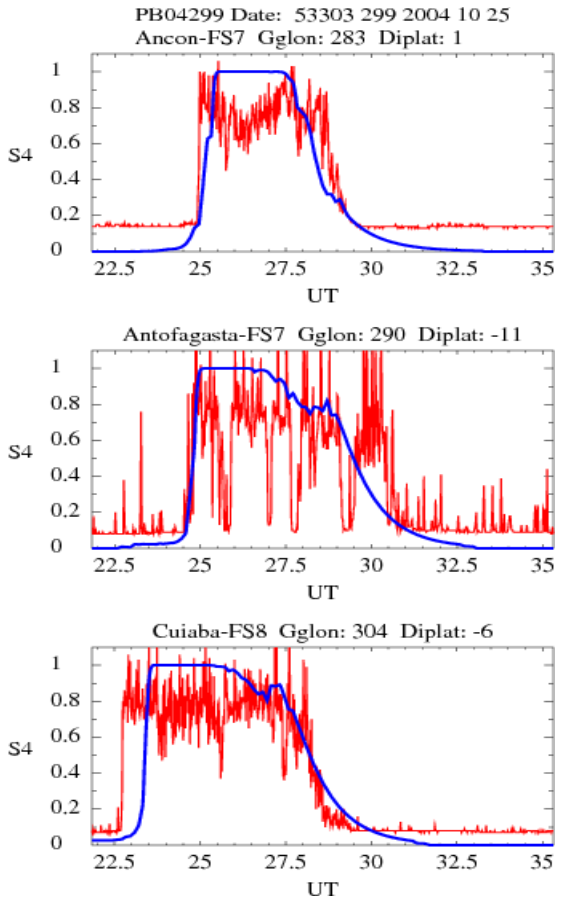
- **TEC difference/average among several stations (~12) strategically selected**

Proposed Metrics

Ionospheric Scintillation Modeling Validation:
SSA-5, Scintillation Forecasting Capability

- S4 index
- ROTI (Rate of TEC index:

  STD of the ratio of change of TEC)
- Onset time at a particular level
- Peak value
- Duration above a certain level
- Average value
- Time integral



Proposed Metrics

Ionosphere Plasma Density Modeling Validation: SSA-5, Scintillation Forecasting Capability

- foF2/NmF2, hmF2, vTEC, MUF
- In different latitude and local time sectors
- Complementary analysis of a set of metrics (e.g., RMSE, MAE, and Correlation Coefficient)
- For each physical quantity, the metrics will be calculated to measure ability to model
  - Climatological variations
  - Day-to-day variability
  - Storm impact (deviation from climatological estimates over storm events)

Proposed Metrics

Neutral Density Modeling Validation:
SSA-2, Satellite Drag Forecasting Capability

- Neutral density in the altitude range 200 ~800 km
- For comparison with accelerometer data:
  - Daily mean
  - Orbit averaged for satellite orbits
  - Model sampled at satellite locations, binned 5° along track
- For comparison with Emmert global mean daily data
  - global-mean daily mean
- Compute ratios of Observed/Modeled

2013 March Storm Event (03/16-03/20) Study

- Global/Regional TEC: North American and European Sectors
- foF2/TEC:
  - 12 ionosonde locations in the mid-latitudes
  - 14 simulations using 8 models
  - GIRO foF2 and GPS TEC
- Characterizing the Low-latitude Scintillation
- Neutral Density at LEO (e.g., GOCE, GRACE, Stella)

Climatology Study for Year 2012

- foF2/hmF2
  - monthly median (1 hr resolution)
  - 7 ionosonde locations in the mid-high latitudes
  - 4 model simulations
- Neutral Density at LEO (e.g., GOCE, GRACE, Stella)

Papers to be submitted for Space Weather Special Issue

1. "The iCCMC Ionosphere Validation Study: Overview and Initial Results", Ludger Scherliess et al.

2. "Assessment of Current Capabilities in Modeling the Ionospheric Climatology: foF2 and hmF2", Ioanna Tsagouri et al.

3. "Systematic assessment of Ionsophere/Thermosphere Models for Prediction of TEC and foF2 during the 2013 March Storm Event", Ja Soon Shim et al.

4. "Validation of Ionospheric Specifications During Geomagnetic Storms: Global and Regional TEC", Ludger Scherliess et al.

5. "Characterizing the Low-latitude Scintillation", Endawoke Yizengaw et al.

6. "Benchmark density data and metrics for thermosphere model evaluation 1: Semi-empirical models", Sean Bruinsma et al.