Implications of Forecasting Thermosphere-Ionosphere Conditions After Initiation of an Eruptive Solar Event

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Overview

- Detection of a CME at the sun can be used to initiate forecasts of solar wind conditions at Earth and then the response of the global thermosphere-ionosphere (TI) storm, using first-principles models
- We assessed custom forecastable-mode simulations of three models running at CCMC: TIE-GCM, GITM and CTIPe
- Forecastable-mode simulations are driven by the measured solar wind parameters and short-term (~few day) F10.7 index forecasts
- We developed forecast metrics that define positive phase (*increased TEC*) and negative phase (*decreased TEC*) storm features – relative to quiet background
- We compared data-driven TEC maps to simulations using *binary evaluation criteria*: are "observed" storm-time *features* matching simulations?
- What factors limit TI forecasts initiated after CME detection?

Approach: Metrics for Global Ionospheric Storms Based on Total Electron Content (TEC)

TEC metric definition

- For GIM (GPS TEC data)

$$dTEC_{GIM}(UT,lon,lat) = \frac{TEC_{GIM}(UT,lon,lat) - TEC_{GIM,pre-storm}(UT,lon,lat)}{variability\ of\ TEC_{GIM,quiet}(UT,lon,lat)}$$

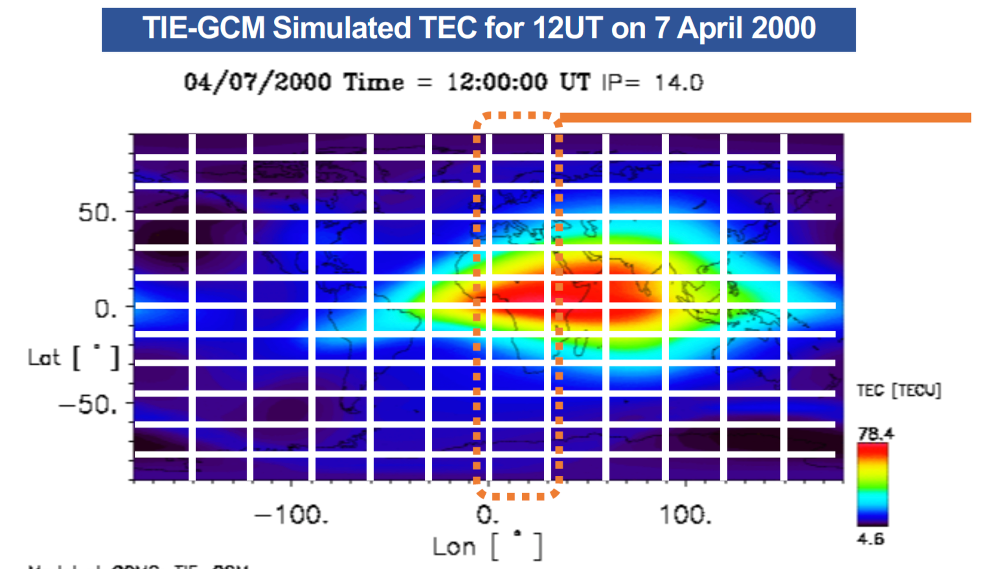
- For Model (TIE-GCM, GITM, CTIPe)

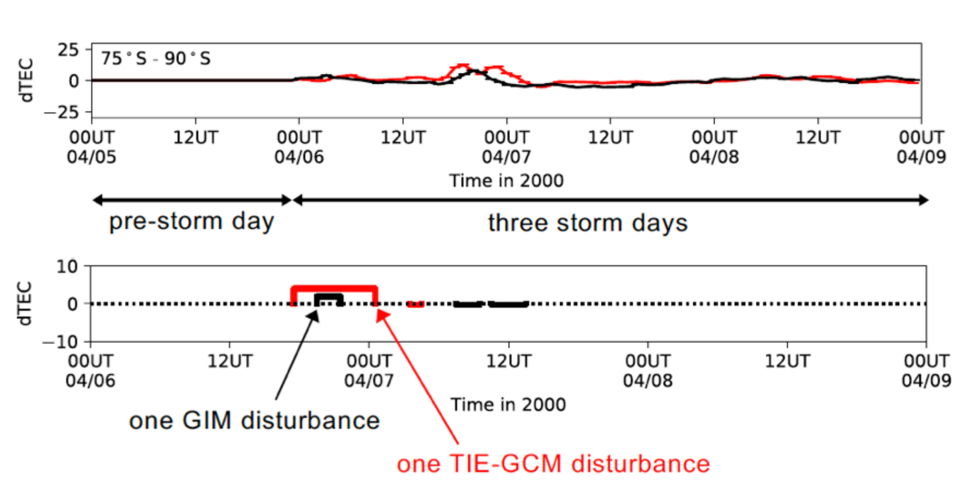
$$dTEC_{Model}(UT,lon,lat) = \frac{TEC_{Model}(UT,lon,lat) - TEC_{Model,pre-storm}(UT,lon,lat)}{variability\ of\ TEC_{GIM,quiet}(UT,lon,lat)}\ Scale\ (UT)$$

$$Scale(UT) = \frac{median\left(TEC_{GIM,pre-storm}(UT,lon,lat)\right)}{median\left(TEC_{Model,pre-storm}(UT,lon,lat)\right)}$$

- $TEC(UT,lon,lat)$: the mean TEC within a **30° x 15°** grid box centered at (lon,lat) and at a given **UT hour** for either GIM or Model

TIE-GCM Simulated TEC for 12UT on 7 April 2000





Simulated Forecast: Success Rate and False Alarm Rate

Forecast Success: for a given GIM disturbance, Model predicts a disturbance that starts +/- 3 hours of the GIM disturbance starting time and ends +/- 3 hours of the GIM disturbance ending time

(see previous panel for definition of "disturbance")

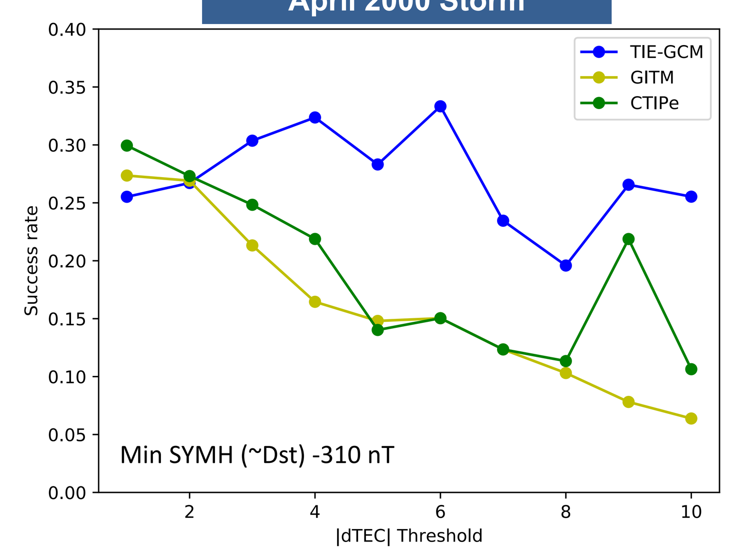
Forecast Success Rate

$$= \frac{number\ of\ disturbances\ that\ are\ \text{"}Forecast\ Successes\text{"}}{number\ of\ GIM\ disturbances\ (over\ the\ globe\ and\ across\ three\ storm\ days)}$$

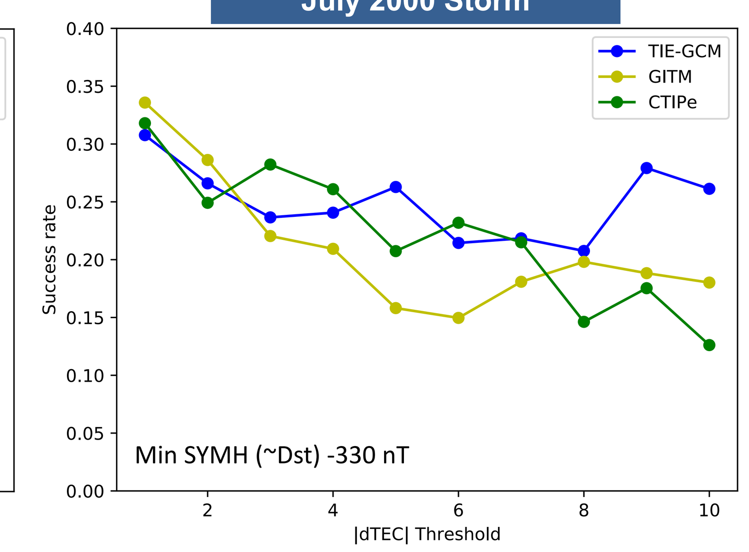
Forecast False Alarm Rate

$$= \frac{number\ of\ disturbances\ that\ are\ not\ \text{"}Forecast\ Successes\text{"}}{number\ of\ Model\ disturbances\ (over\ the\ globe\ and\ across\ three\ storm\ days)}$$

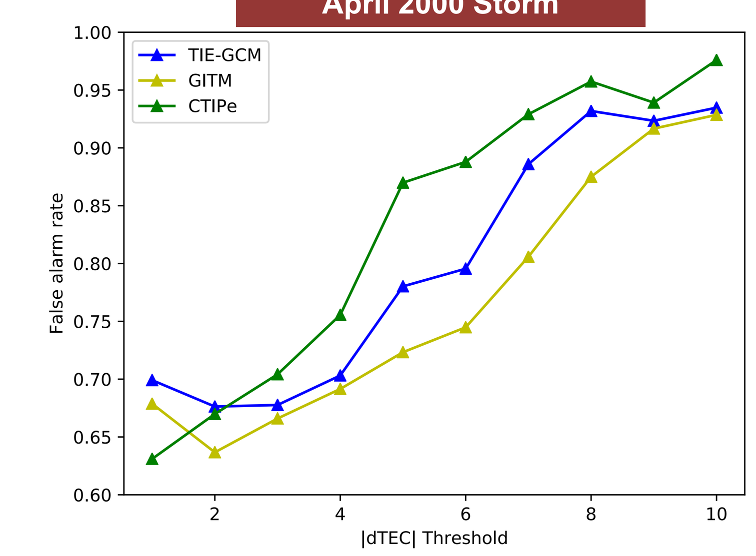
Forecast Success Rate April 2000 Storm



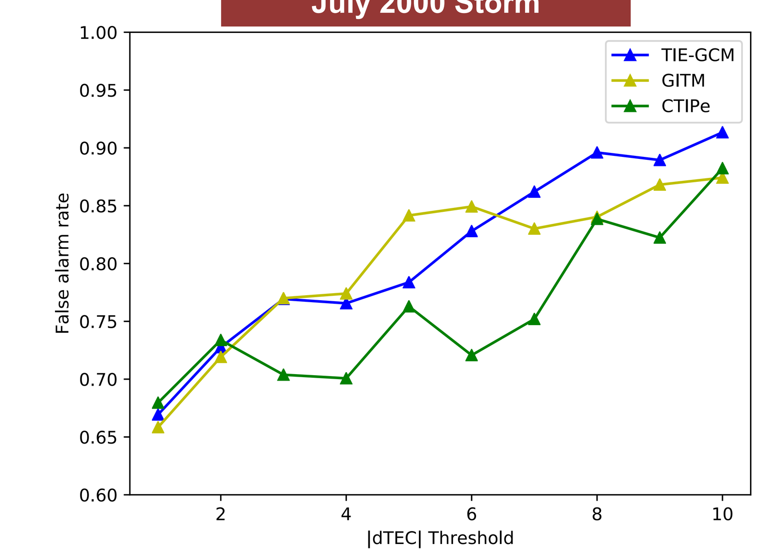
Forecast Success Rate July 2000 Storm



Forecast False Alarm Rate April 2000 Storm



Forecast False Alarm Rate July 2000 Storm



All three models are coupled thermosphere-ionosphere (TI) first-principles models

X. Meng, A. J. Mannucci, O. P. Verkhoglyadova, B. T. Tsurutani, "Assessing an Approach to Ionospheric Total Electron Content Forecasting using Physics-based Models" No. MT-401, Session PSW.1, 42nd General Assembly COSPAR Pasadena CA July 2018

Key points

- Rates are threshold dependent
- Models below 35% success rate
- One model has clearly higher success rate in April 2000
- False alarm rate increases with threshold – models can overestimate increasingly larger (and fewer) features
- Forecasting the complex TI response using only solar wind and F10.7 inputs is very challenging
- What are the factors determining forecast success rates and false alarm rates?

Simulated Forecast: Skill Scores

Model Output

Observation	Contingency Table	Feature is reproduced by the model	Feature is not reproduced by the model
	Feature is observed	True Positive (TP)	False Negative (FN)
	Feature is not observed	False Positive (FP)	True Negative (TN)

True Skill Statistic (TSS) approach to TEC-based metric

$$TSS = \frac{TP}{TP+FN} - \frac{FP}{FP+TN}$$

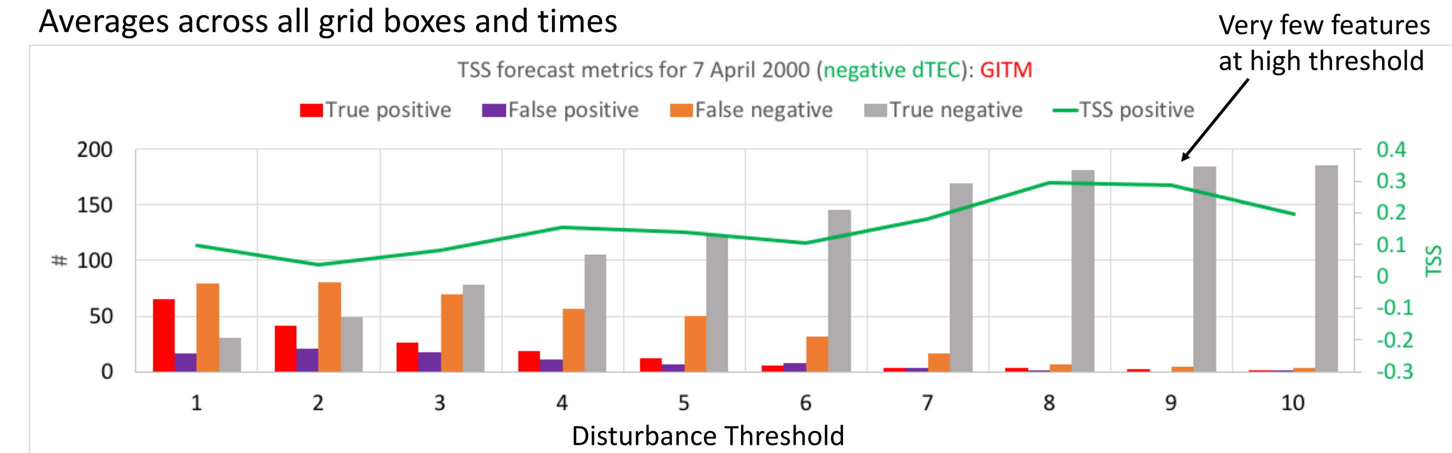
Steps to calculate the metric:

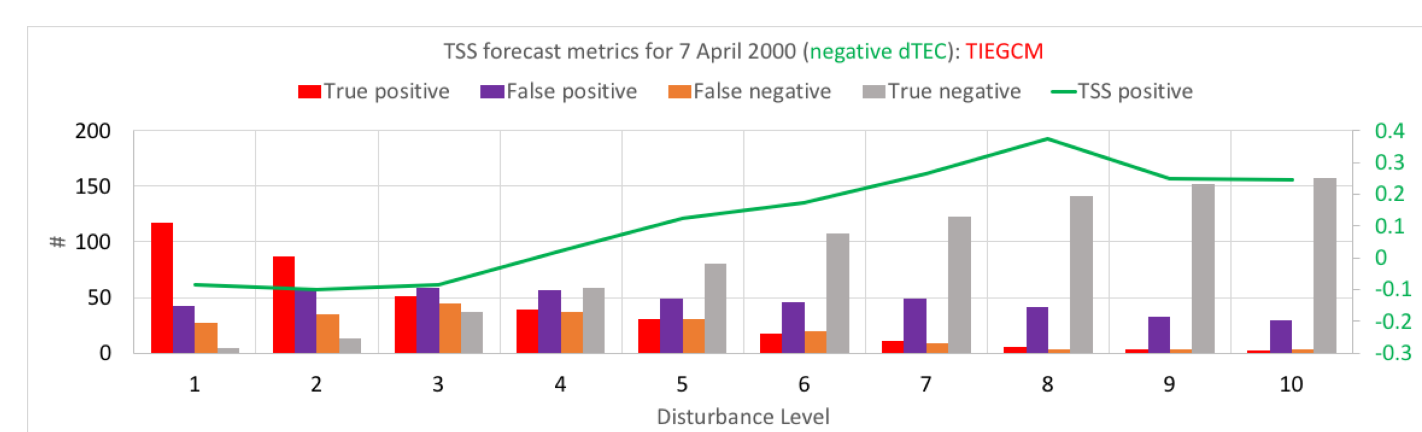
- Find occurrences when dTEC reaches a threshold (level) for each grid box within successive 3 hour windows
- Do separately for observation (GIM) and simulation within each time window
- Define TP, FP, FN and TN based on if threshold is reached at any time within each time window
- Compute separately for positive (+) and negative (-) dTEC

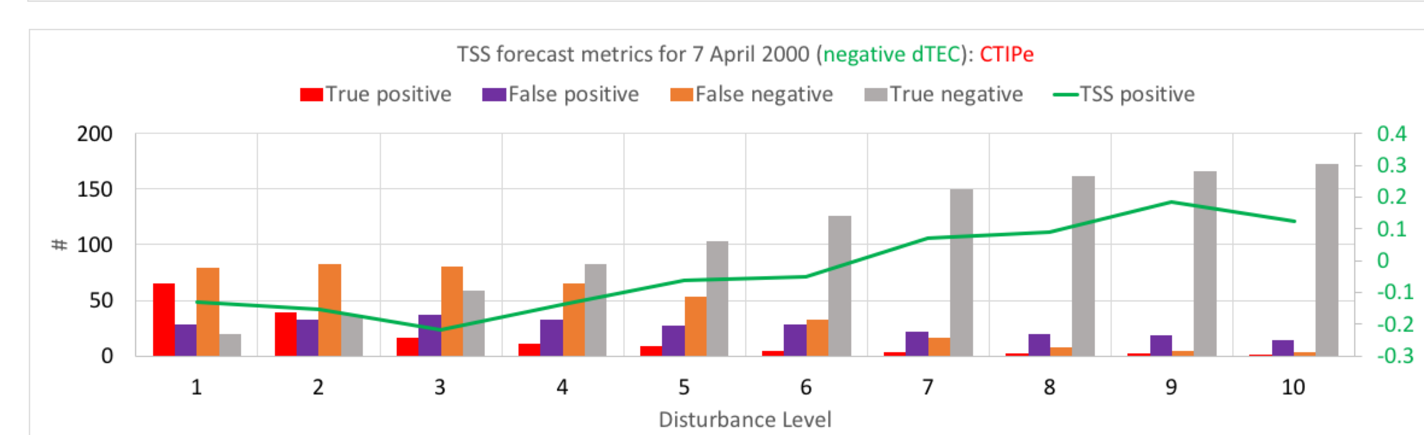
TSS: Bloomfield et al., 2012

Averages across all grid boxes and times

Very few features at high threshold







Negative storm features analyzed (*TEC decreases*)

Not to be confused with T/F Negative!

Key points

- All models show some skill
- One model is most consistently positive TSS
- Another model reaches a higher peak TSS
- A particular TSS value weakly represents underlying contingency table
- Recommend analyzing all four contingency table values according to location, time and local time

See McGranaghan et al., 2018

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Conclusions and Future Work

- We have developed ionospheric storm metrics that are valuable to assess how first-principles simulations may perform for forecasts initiated after CME eruption (1-4 day lead time)
- Storm-feature based metrics can be further refined to understand how simulations capture basic features of the storm (positive and negative phases), not necessarily exact details of the TEC behavior
- The forecast scenario – driving by solar wind conditions alone – is challenging given the complexities of storms
- These simulated forecasts are "optimistic" and do not account for errors in a solar wind ensemble forecast
- Approximately 40 storm periods have been run at CCMC with three models, available for further statistical analysis
- The community needs improved tools to determine factors limiting such forecasts