

# CCMC ITMAP-Ionosphere Model Assessment & Validation Platform



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## Introduction

### Introduction:

- The CCMC houses many empirical, data assimilation, and physics based ionospheric models.
- Observation data taken from ground-based GNSS Total Electron Content (TEC) and FORMOSAT-7/COSMIC-2 satellites data during storms in 2013 and 2021 was used to evaluate and compare the performance of 16 ionospheric models.
- 14 models were evaluated based off their performance predicting TEC, and 12 based on their performance predicting foF2 and hmF2.
- The web application houses the results of this evaluation, giving easy access to model performance and enabling researchers to further improve them for future research and eventual space weather forecasting.

## Model Validation

### Models Used:

- Empirical and Data Assimilation
  - IRI-2016
  - IRI-2020
  - NASA JPL GIM
  - NOAA SWPC GloTEC
  - WAM-IPE
  - GIS-NCKU
- Physics Based
  - SAMI3 (3.22, RCM, ICON, and TIEGCM)
  - TIEGCM (Weigmer and Heelis)
  - CTIpe
  - GITM SWMF
  - WACCM-X
  - PBMOD

### Model Data Comparison Page:

- DST/KP indexes are shown for the chosen storm event (top left)
- TEC versus time is shown for any selected models (top right)
- TEC change versus time for any selected models (bottom left)
- Model to observation data comparison (bottom right)

## Statistical Analysis

### Skill Score Page:

- Accuracy: Root Mean Square Error

$$\text{RMSE} = \sqrt{\frac{1}{N} \sum_{i=1}^N (M_i - O_i)^2}$$

- Bias: Mean Error
  - $\text{ME} = \bar{M} - \bar{O}$
- Association: Pearson Linear Correlation Coefficient

$$R = \frac{\sum_{i=1}^N (O_i - \bar{O})(M_i - \bar{M})}{\sqrt{\sum_{i=1}^N (O_i - \bar{O})^2 \sum_{i=1}^N (M_i - \bar{M})^2}}$$

- Precision: Difference in standard deviations between the model and observation
  - $P_{\sigma, \text{diff}} = \sigma_M - \sigma_O, P_{\sigma, \text{diff}}$
- By combining these metrics into a normalized Skill Score, the overall performance of each model can be evaluated and compared

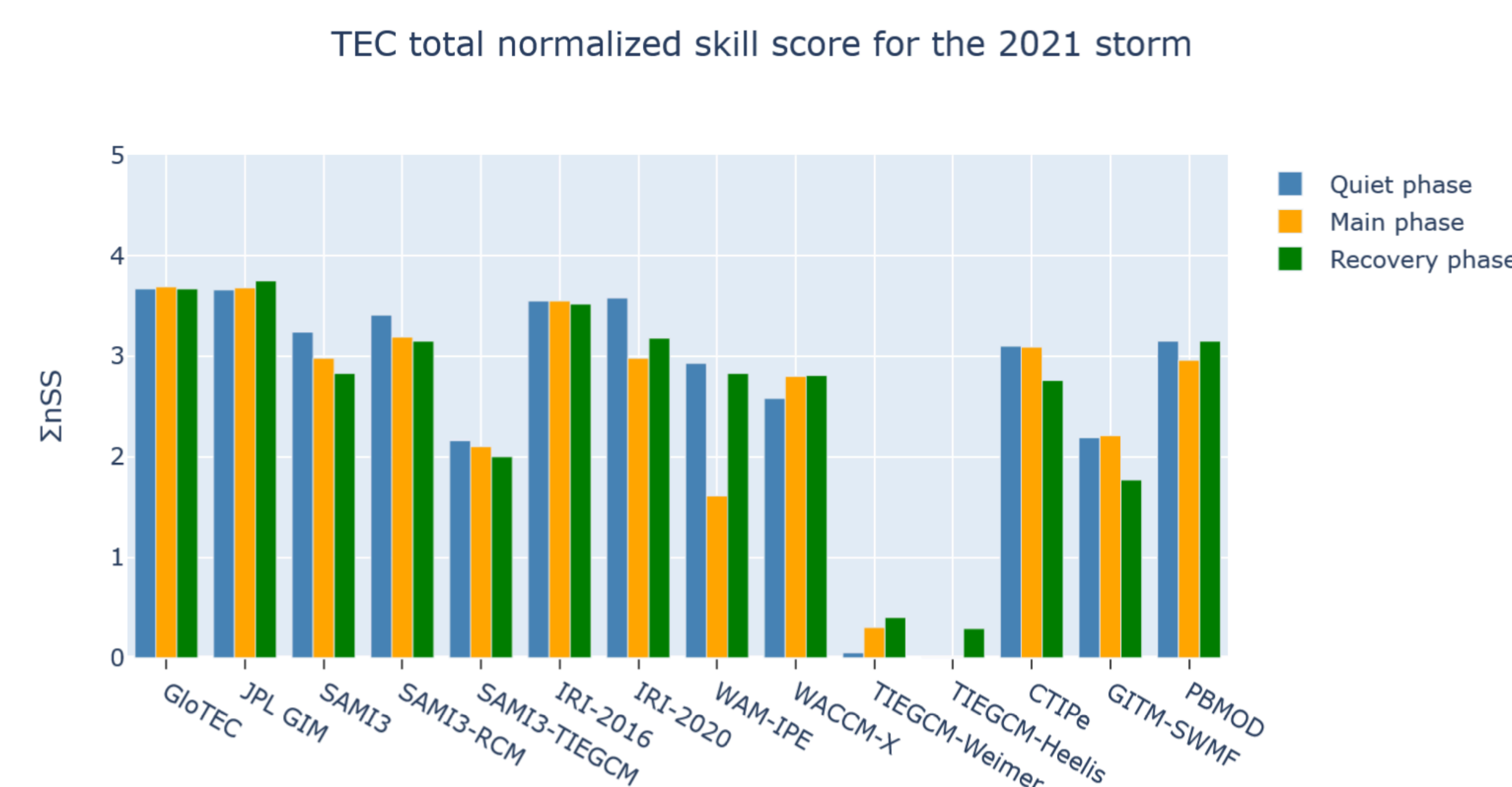


Figure 2: The normalized skill score for the 2021 storm. The maximum possible skill score is 4, as there are four metrics used.

### TEC Change:

- To evaluate a models ionospheric storm anomalies, three metrics are used
  - TEC change Model and TEC change Observation Ratio 80<sup>th</sup> percentile
  - TEC change Model and TEC change Observation ratio taking the difference between the 80<sup>th</sup> and the 20<sup>th</sup> percentiles
  - TEC change Model and TEC change Observation Correlation Coefficient

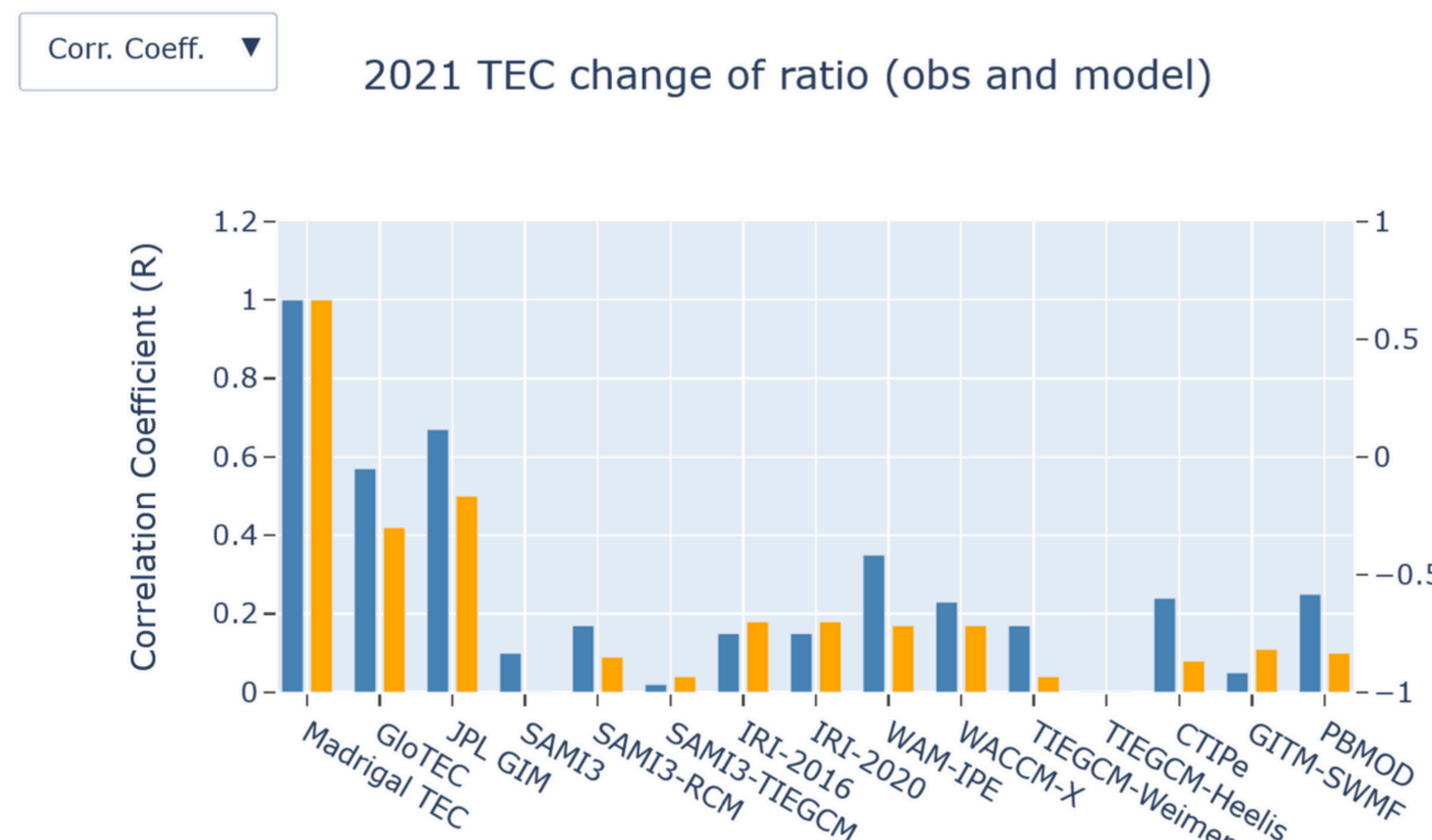


Figure 3: TEC Change plots with the Correlation Coefficient graph selected for the 2021 storm.

## User Inputs

### Project:

- Selects the current ITMAP project. These include Ionosphere Model Validation, Thermosphere Neutral Density Assessment, and GPS Position.

### Storm ID:

- Selects the 2021 storm, the 2013, or both for side by side comparisons.

### Observation:

- Selects Madrigal TEC, foF2, or hmF2 Observations

### Model Type:

- Selects between 14 different models plus the observation data for Madrigal, or 12 different model plus the observation data for foF2 and hmF2

### Task:

- Selects between Model Data Comparison and Skill Score pages

### Plot:

- Selects which plots are displayed

The sidebar contains several dropdown menus and checkboxes. The 'Project' dropdown is set to 'Ionosphere Model Validation'. The 'Storm ID' dropdown is set to '2021-11-TP-01'. The 'Observation' dropdown is set to 'Madrigal TEC'. The 'Model Type' dropdown is set to 'Madrigal TEC'. The 'Task' dropdown is set to 'Model-Data Comparison'. The 'Plot' section has checkboxes for 'TEC', 'Model Comparison', 'TEC Change', and 'Dst\_kp', all of which are checked.

Figure 4: The sidebar on the ITMAP website, used for selecting what data to display.

## Future Work

### More storm data:

- Later updates will work to expand the catalog of storms currently being validated for TEC, foF2, and hmF2.

### Single Frequency GNSS Positioning:

- Ionosphere is major error source of GNSS positioning.
- Application based validation technique to evaluate ionosphere model performance.

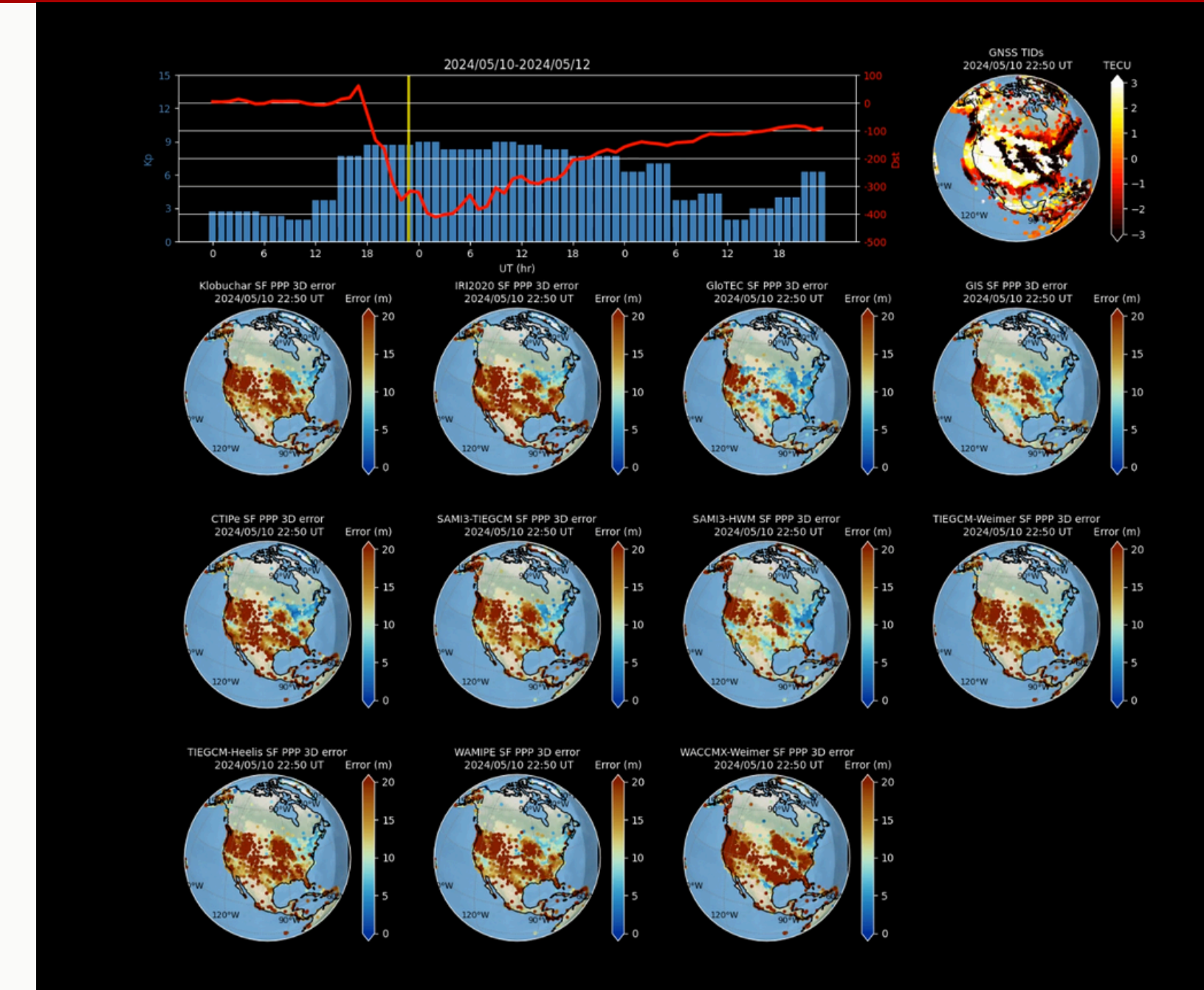


Figure 5: Error for various models during the 2024/05/10 solar storm.

## References

Chou, M.-Y., Yue, J., Wang, J., Huba, J. D., El Alaoui, M., Kuznetsova, M. M., et al. (2023). Validation of ionospheric modeled TEC in the equatorial ionosphere during the 2013 March and 2021 November geomagnetic storms. *Space Weather*, 21, e2023SW003480. <https://doi.org/10.1029/2023SW003480>.

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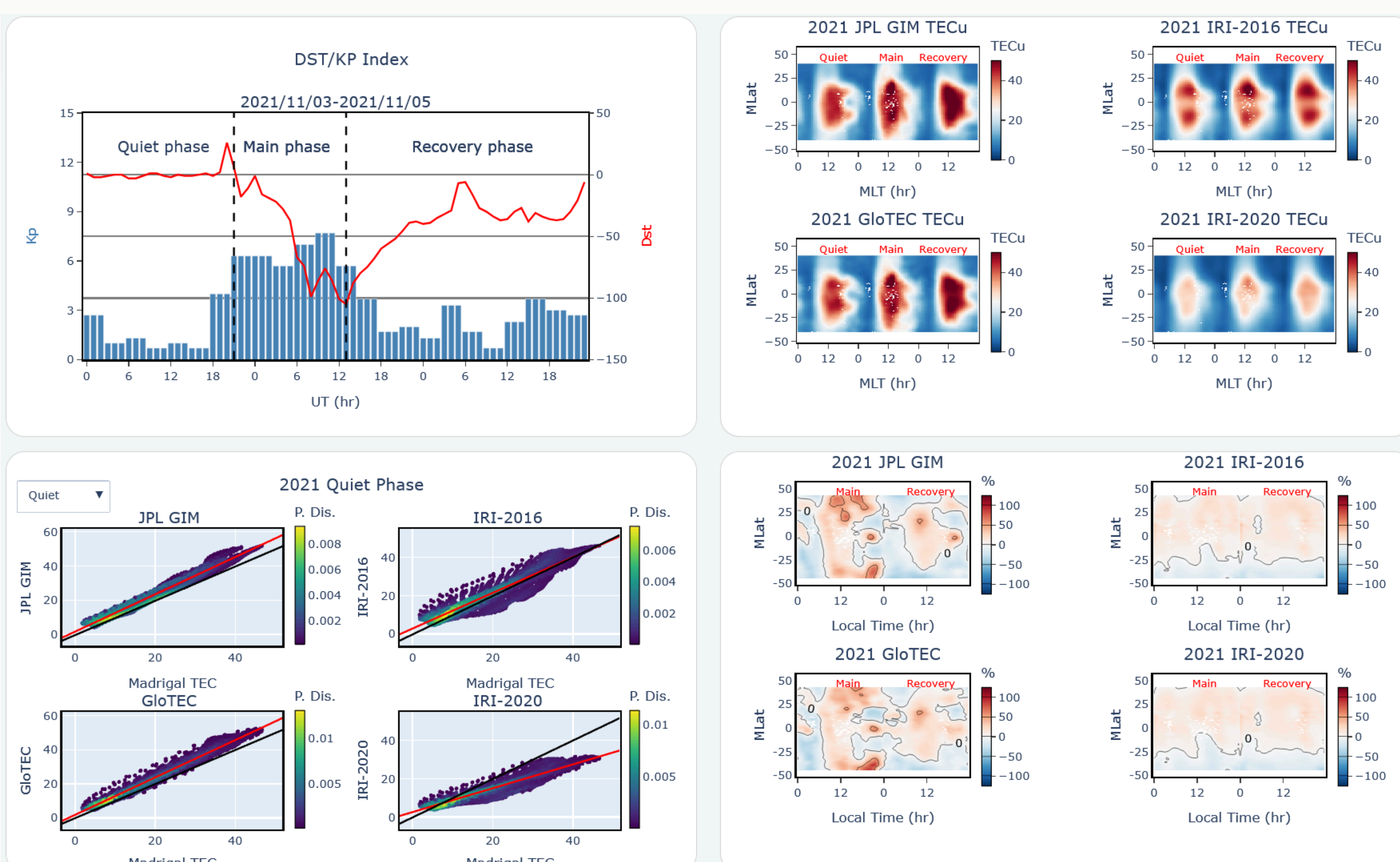


Figure 1: The Model Data Comparison Page on the ITMAP Website, displaying results for four models during the 2021 storm.