STORM TIME EMPIRICAL IONOSPHERIC CORRECTION MODEL

Modeling and Nowcasting Ionospheric Storms

OPERATIONS GUIDE

(E.A. Araujo-Pradere and M. Husler. August 22, 2003)

SPACE ENVIRONMENT CENTER

I - MODEL DESIGN

***STORM* TIME EMPIRICAL IONOSPHERIC CORRECTION MODEL**

I - MODEL DESIGN

1.1 Introduction

The ***STORM* *Time Empirical Ionospheric Correction Model*** is the first empirical model of the response of the ionosphere to a geomagnetic storm that has demonstrated a consistent and measurable improvement over climatology. The first characterization of ***STORM*** has been designed to adjust the F-region peak critical frequency (foF2) as function of geomagnetic latitude, season, and intensity of the storm. The model is purely empirical, being based solely on an analysis of an extensive database of ionosonde observations, but the algorithms and data sorting procedure has been guided by numerical simulations from a coupled thermosphere ionosphere model. The intensity of the storm is characterized by a new index derived from filtering the previous 33 hours of ap.

STORM provides an estimate of the expected change in the ionosphere during periods of increased geomagnetic activity. The model estimates the departure from normal of the F-region critical frequency (foF2) every hour of the day for the current and previous day. Values are given in six separate geomagnetic latitude bands, 20° wide, from 20° geomagnetic latitude to the North and South magnetic poles. The corrections are given in terms of a scaling factor, which can be used to adjust the climatological mean. An estimate of the error in the prediction is also shown based on an average of the geophysical variability and the standard error of the mean. The empirical model provides a useful, yet simple tool for estimating the changes to ionosphere in response to geomagnetic activity.

1.2 Model background

The ***STORM*** model was developed from ionospheric observations during many storms that were analyzed as a function of season and latitude. Within each season and latitude sector, the magnitude of the ionospheric response was determined as a function of an index parameterizing the storm.

1.3 Known limitations

The ionospheric response to all of the physical processes are very difficult to capture and understand even with a complex physical model, and are even more difficult to capture in a simple empirical model as is attempted with ***STORM***. The details of the ionospheric response to a particular storm therefore are unique due to the many physical processes involved and due to the complexity of the driving processes from the magnetosphere. However, there are underlying trends in the response that can be captured, and provide a useful first step in characterizing the ionosphere response to storms in a relatively simple way.

Specifically, there are three known areas where the model has limitations:

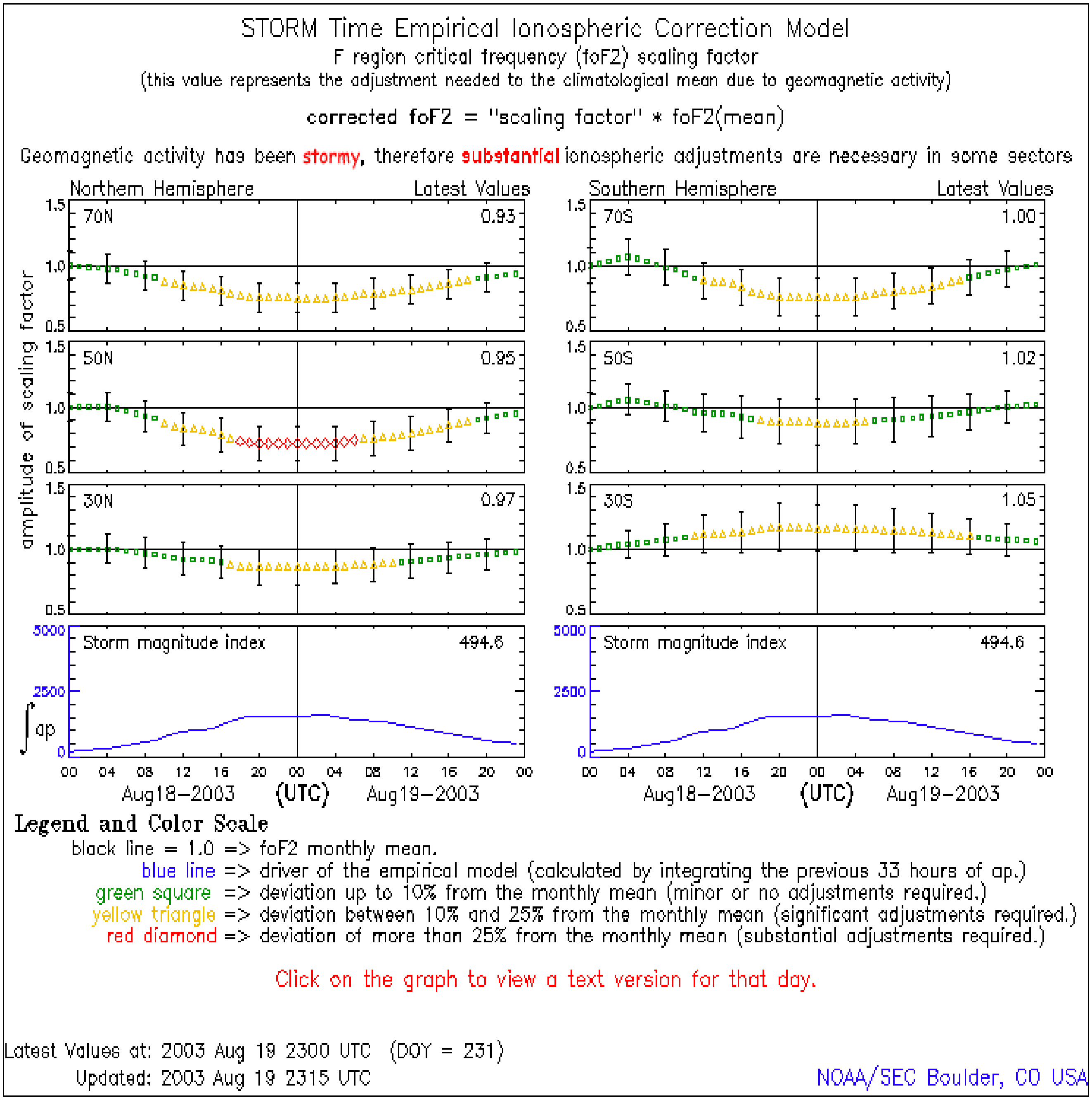
Ø The complexity of the processes intervening in the equatorial zone makes it difficult to capture the ionospheric response for perturbed conditions within an empirical model. No storm-time ionospheric corrections are offered within 20^0 of the magnetic equator.

- Capturing the storm response in the winter hemisphere is also less reliable than at equinox or summer due to the higher level of variability during this season.
- During the early phase of a storm (< 6 hrs) strong dynamic changes in the upper atmosphere cause rapid variations that are difficult to predict in an empirical model.

1.4 User Guidance

The storm-time correction of the F2-region critical frequency (or maximum concentration) is primarily of benefit for high frequency (HF, 3-30MHz) communication users. During a geomagnetic storm the F-region ionosphere can be either depleted or enhanced. When the ionosphere is enhanced, higher communication frequencies can be used, enabling a reduction in absorption and an increase in received signal strength. If the ionosphere is depleted; the maximum usable communication frequencies must be reduced to assure reflection of the radio signal by the ionosphere to the receiver. To change the frequencies, the correction factor offered by the ***STORM*** model can be used, in real time, to adjust the monthly mean values (independently from what source they were obtained).

Values of the output are given in six separate geomagnetic latitude bands, 20° wide, from 20° geomagnetic latitude to the North and South magnetic poles. The latitude label on each panel corresponds to the mid-point of each latitude band. The bottom plots in both sides correspond to the storm magnitude index (integral of ap over the previous 33 hours).



Because of the difficulty to capture the ionospheric response for perturbed conditions in the equatorial zone within an empirical model, ***STORM*** does not offer a correction for this latitudinal band.

Results of the model calculations are displayed in an eight-panel plot. As the ionosphere departs further from normal (monthly mean), the color and shapes of the trace changes from green squares, to yellow triangles, to red diamonds; where green represents variations within 10% of normal, yellow corresponds to changes between 10% and 25%, and red indicates departures in excess of 25%. For each condition a corresponding message will appear at the top of the plot:

For variations within 10% of normal: "Geomagnetic activity has been **nominal**, therefore **minor or no** ionospheric adjustments are necessary"

For variations between 10% and 25%: "Geomagnetic activity has been **disturbed**, therefore **significant** ionospheric adjustments are necessary in some sectors"

For variations in excess of 25%: "Geomagnetic activity has been **stormy**, therefore **substantial** ionospheric adjustments are necessary in some sectors"

Users can access the numerical output of the model for each day, including the hourly ap, the storm magnitude index, and the correction factor, just by clicking in the corresponding graph. Interpolated values will be mark in the last column of the text file. The values in the "interpolated" column will either be 0 for no interpolation or 1 for data that are missing and consequently interpolated.

An explanation and the values of the error bars for each day, an estimate of the accuracy of the prediction, can be accessed following the link "Estimated Errors".

1.5 Error Messages

Several messages regarding the flow of input data (*i.e.*, missing or interpolated points) will appear in the lower right-hand corner in red of the plot:

"No data for today or yesterday" – means there has been missing data since the start time of the plot.

"xxx data point(s) interpolated" – means there is missing data in the last 48 hours and xxx points had to be linearly interpolated.

"Input data are missing for the last xxx hours" – means that the ap index has not been updated in the database for xxx hours.

This message will be in the text file (RTST-today.txt) if there has been no data processed for the current day: "**No Data for today at the moment**".

1.6 Future Enhancements

We have received several requests from users to extend the scope of the model from real time (nowcast) to, at least, one-week forecast, but at the present this has not been incorporated into the model calculations. Due to the relatively slow response and recovery of the ionosphere, a forecast driven by SWO geomagnetic activity forecast would likely be of some value.

There is an on-going effort to add a permanent verification of the ***STORM*** model through a third party. In this case, the International Reference Ionosphere (IRI) task force is coordinating with the staff of a digisonde station to establish a real-time verification of IRI2000, which includes ***STORM*** as the correction for perturbed conditions. Once the system is in place, a link will be added to the ***STORM*** web page.

1.7 Additional Information

Description about the model, methodology, and validation statistics are available from the links on the model's web page. The references below provide more detailed information regarding the development of the model:

1. Araujo-Pradere, E. A., T. J. Fuller-Rowell, and D. Bilitza, Validation of the STORM response in IRI2000, *J. Geophys. Res.*, *108*(A3), 1120, doi:10.1029/2002JA009720, 2003.

2. Araujo-Pradere, E. A., and T. J. Fuller-Rowell, STORM: An empirical storm-time ionospheric correction model, 2, Validation, *Radio Sci.*, *37*(5), 1071, doi:10.1029/2002RS002620, 2002.

3. Araujo-Pradere, E. A., T. J. Fuller-Rowell, and M. V. Codrescu, STORM: An empirical storm-time ionospheric correction model, 1, Model description, *Radio Sci.*, *37*(5), 1070, doi:10.1029/2001RS002467, 2002.

4. Fuller-Rowell, T.J., M.V. Codrescu, and E.A. Araujo-Pradere; Capturing the Storm-Time Ionospheric Response in an Empirical Model. *Space Weather, AGU Geophysical Monograph*, **125**, 393 – 401, 2001.

II - OPERATIONS CONCEPT

II - OPERATIONS CONCEPT

2.1 General Information

The ***STORM Time Empirical Ionospheric Correction Model*** provides an estimate of the expected change in the F-region ionosphere during periods of increased geomagnetic activity. The model prediction is a straightforward statistical technique based on the selection of appropriate empirical relationship from historical data, and the application of these to real-time data in order to predict the departure of the ionosphere from normal (monthly mean) conditions.

2.2 Computer resources

The ***STORM*** model has been implemented on the SEC Outside User System (OUS) operational computers, and runs automatically every 15 minutes.

2.3 Output Distribution

The output of the ***STORM*** model is available in two formats, graphical (that offer, at a glance, an idea of the state of the ionosphere), and text files with the numerical output of the model, which can be directly used to correct the monthly mean values. The values of the error bars for each day, an estimate of the accuracy of the prediction, can be accessed following the link “Estimated Errors”.

2.4 Operational Procedures

The ***STORM*** model requires no direct intervention during routine operations. Model runs, output updates, and error conditions are handled automatically. In the case of several missing input values, the model will "catch-up" once they arrive, and a corresponding message will appear on the web site.

2.5 Known Limitations

The error bar represents an estimate of the accuracy of the ***STORM*** prediction. The estimated error is based on the mathematical average of two estimates of errors: the geophysical variability (standard deviation) and the standard error of the mean. The geophysical variability is a measure of the scatter of the data used to produce the model. This represents the standard deviation, or scatter, about the mean, which is the error on the model prediction when applied to a given location for a particular storm. The standard error of the mean is the error of the fit to the data, and represents how well the prediction matches the **average** ionospheric storm response for a given location. The tables of estimated errors show all three: the geophysical variability, the standard error of the mean, and their mathematical average. The latter is the value used on the ionospheric prediction display.

The ***STORM*** model is based in an extensive database of ionosonde observations for perturbed conditions. These values were then binned as a function of season and latitude and as a function of a new index derived from filtering the previous 33 hours of the ap index. The model development used the final validated ap index which is not available in real-time. The operational, real-time version of the model uses the estimated hourly ap that is part of the USAF Magnetometer Analysis message. The difference between the real-time and final validated ap has not be fully assessed.

2.6 Validation

A comprehensive validation of the ***STORM*** model has been performed. The model has been tested on five significant geomagnetic storms during the year 2000. For each storm, data from 15 ionosonde stations were obtained. Visually, the prediction from the storm model follows the observed changes for many of the cases, but does particularly well in the summer hemisphere. The accuracy of the model has been quantified by evaluating the daily RMSE between the model and observations and compared with the prediction using the monthly mean. The values calculated using this metric show the model is on average 33% improved over the monthly mean. The results indicate that the STORM model captures more than half of the increase in variability due to the storms.