Assessment and validation of ionospheric forecasting techniques during extreme space weather events

Ioanna Tsagouri, Kostas Koutroumbas and Anna Belehaki

National Observatory of Athens, Institute for Space Applications and Remote Sensing, Greece

Second European Space Weather Week

ESTEC (Noordwijk, The Netherlands)
14—18 November 2005

Session 3: Ionosphere/positioning and telecommunications

Abstract

The development of validated ionospheric prediction services is a high priority task especially concerning operational purposes, increasing the demand for ionospheric prediction models suitable for real time applications. A well-established approach comes from tools from the time series prediction framework, where the problem considered is the estimation of the value of the foF2 parameter some time-steps ahead, based on its current and its previous observations. Alternatively, empirical ionospheric storm-time correction models are imposed to quiet-time ionospheric empirical models in order to predict the ionospheric parameters under all possible ionospheric conditions. Such a model was recently developed to introduce a storm time correction factor to the monthly median pattern of foF2, based on IMF conditions observed from ACE spacecraft. The model performance was tested during several storm events, and the validation tests showed significant improvement on the monthly median values during storm days. Moreover, the new model was proved able to capture the physical processes that governs the ionospheric storms onset and their temporal evolution during the first 24-hour. In this paper, the predictions of this model are compared to the predictions from the time series prediction framework in conjunction with real observations from Athens Digisonde under storm conditions. The investigation of the relative performance of two different in technique models reveals significant results concerning both the development of ionospheric forecasting services and the deeper understanding of the ionospheric storm dynamics during the first 24-hour of the storm.

Time series forecasting technique

In this framework, it is assumed that the current value *x(n)* of the quantity under estimation depends on its *d* previous values. In other words, *x(n)* depends on the vector $\mathbf{y}(n) = [x(n-1),\ldots,x(n-d)]^T$. For the present problem of the estimation of the *foF2* value and based upon the current data set $X=\{x_1, x_2,\ldots,x_p\}$ of hourly values of *foF2* for the time period from February 2002 to August 2005, the *false nearest neighbor method* estimates that $d=6$. The tool we use for the estimation of *foF2* is a two-layer feedforward neural network with 6 input nodes (as the dimension of $\mathbf{y}(n)$ indicates), 5 nodes in the hidden layer and one node in the output layer (here the estimate of the estimated value of *foF2* will be formed).

For the training and the evaluation of the performance of the above network, we work as follows. We split the data set *X* into to halves X_1 and X_2. From those we create the sets Y_1 and Y_2 such that each Y_i contains pairs of the form $(\mathbf{y}(n),x(n))$. Then, we use X_1 to train the network using the *Levenberg-Marquardt* method and X_2 to assess the quality of learning. The *Mean Square Error (MSE)* on the test set equals to *0.7775*.

New empirical Storm Time Ionospheric Model (STIM)

Tsagouri and Belehaki, Advances in Space Research, 2005 (in press)

The empirical ionospheric storm time model is designed to scale quiet daily ionospheric variation taking into account the **storm onset time in UT** and the **local time of the observation point**.

The modeling technique is established on:

i) the determination of the "storm onset" based on IMF disturbances in order to use it as a triggering point. The "storm onset" is determined to be the onset in Bt disturbances.

The range in the rate of change in Bt variations is estimated to be: 3.9 nT/h – 5.4 nT/h

ii) the estimation of the time delay of the ionospheric disturbance onset in respect to the storm onset in each LT sector,

LT of the observation point at storm onset	**Prenoon (0600-1200)**	**Afternoon (1200-1800)**	**Evening/midnight (1800-0100)**	**Morning (0100-0600)**
Time Delay (hours)	14	7	3	20

iii) the empirical formulation of the ionospheric response in each LT sector.

LT at storm onset	**y=foF2obs/foF2med**
Prenoon	y = -5E-06x4 + 0.0003x3 - 0.004x2 - 0.0044x + 1.0867
Afternoon	y = -7E-06x4 + 0.0004x3 - 0.0074x2 + 0.0134x + 1.0022
Evening	y = -2E-07x4 - 2E-05x3 + 0.0023x2 - 0.0473x + 0.9514
Midnight	y = 6E-07x4 - 4E-05x3 + 0.0017x2 - 0.032x + 1.0241

Known Limitations

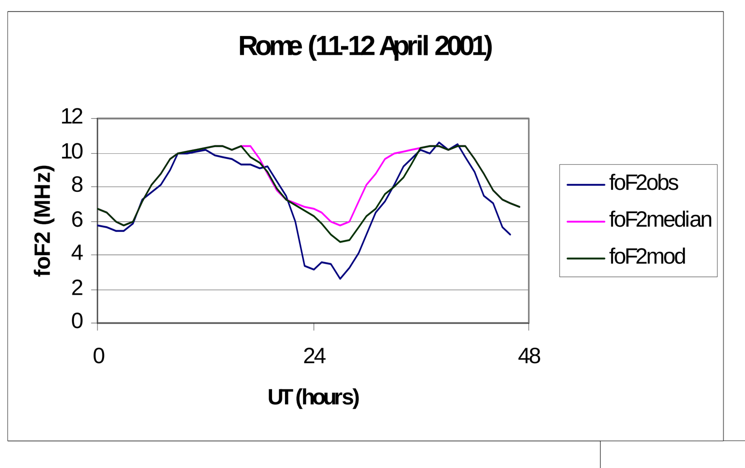
In its current version, the model

- Doesn't include seasonal and latitudinal dependence.
- Distinguishes four LT sectors. Further analysis will enable the model effectiveness for predictions in specific locations.

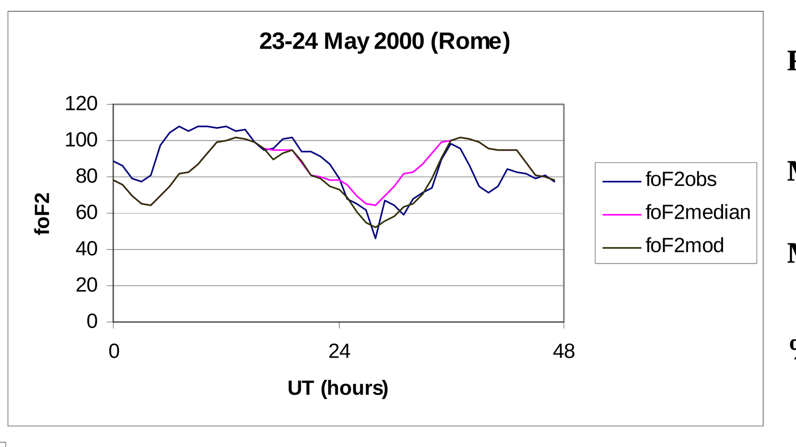
Validation of STIM

- Substantial improvement during the second day of each storm period for both stations, which corresponds to the main storm days. The average over all days is a 44% improvement over the monthly median values.
- Success in the prediction of the ionospheric storm disturbances onset at both stations

Onset: 1300 UT

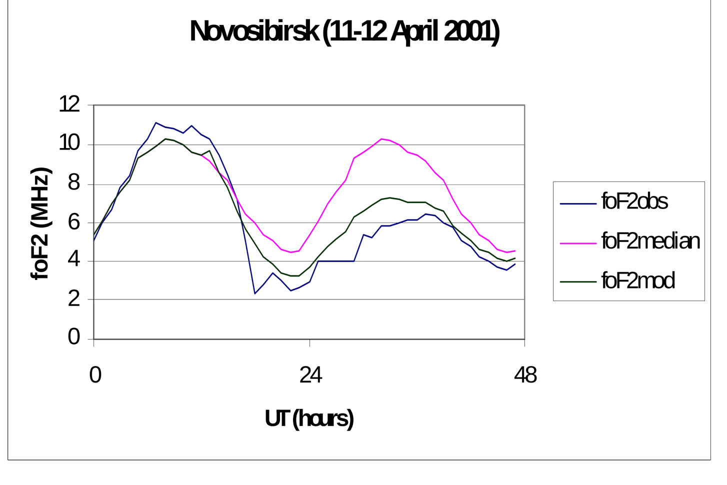


RMSE	1st Day	2nd Day
MODEL	0.84	1.23
MM	0.91	1.92
% Improvement	7.95%	32.4%

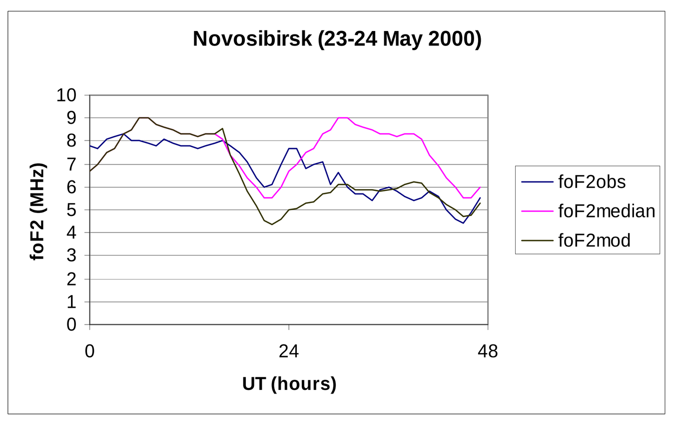


RMSE	1st Day	2nd Day
MODEL	1.41	1.03
MM	1.43	1.32
% Improvement	~1.4%	22.0%

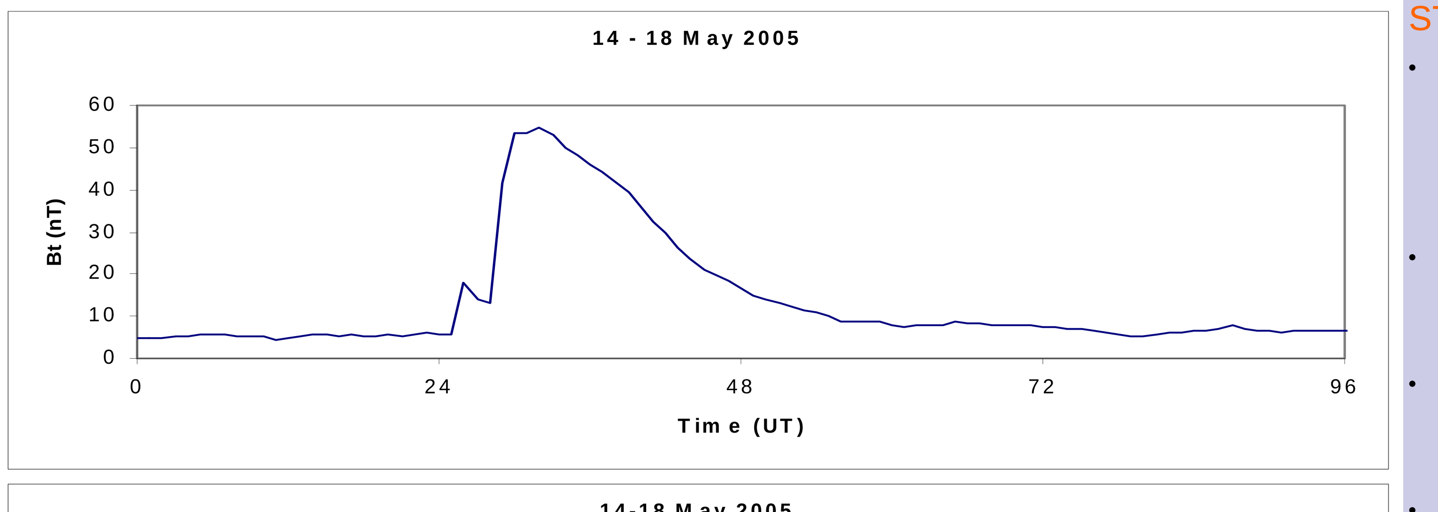
RMSE	1st Day	2nd Day
MODEL	0.89	0.99
MM	1.32	3.05
% Improvement	33.2%	67.7%

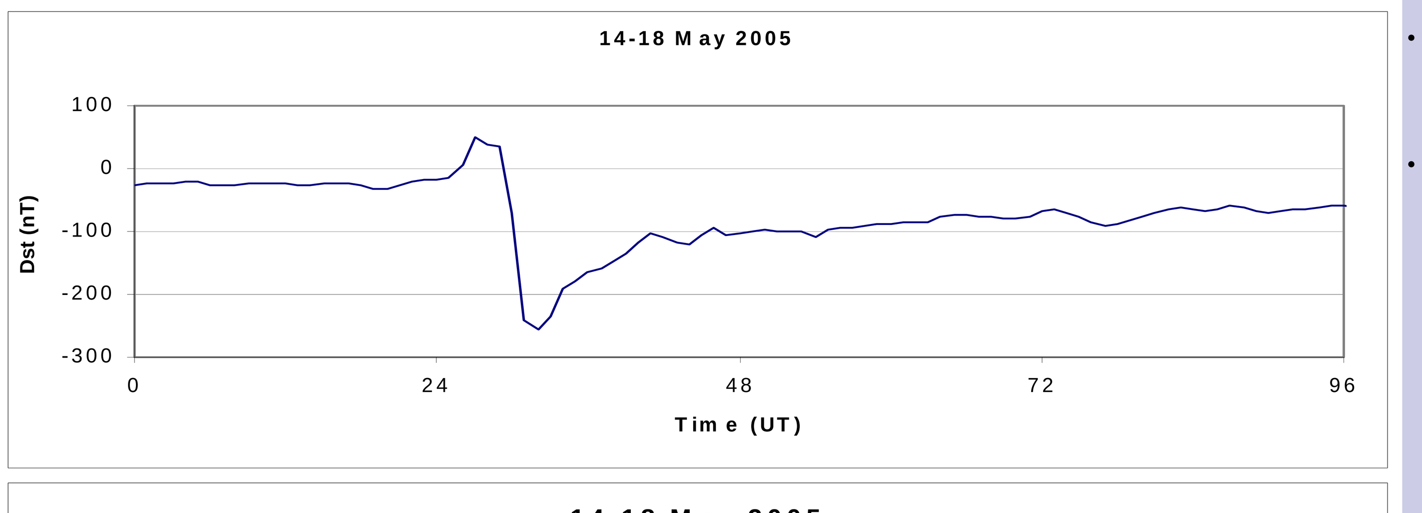


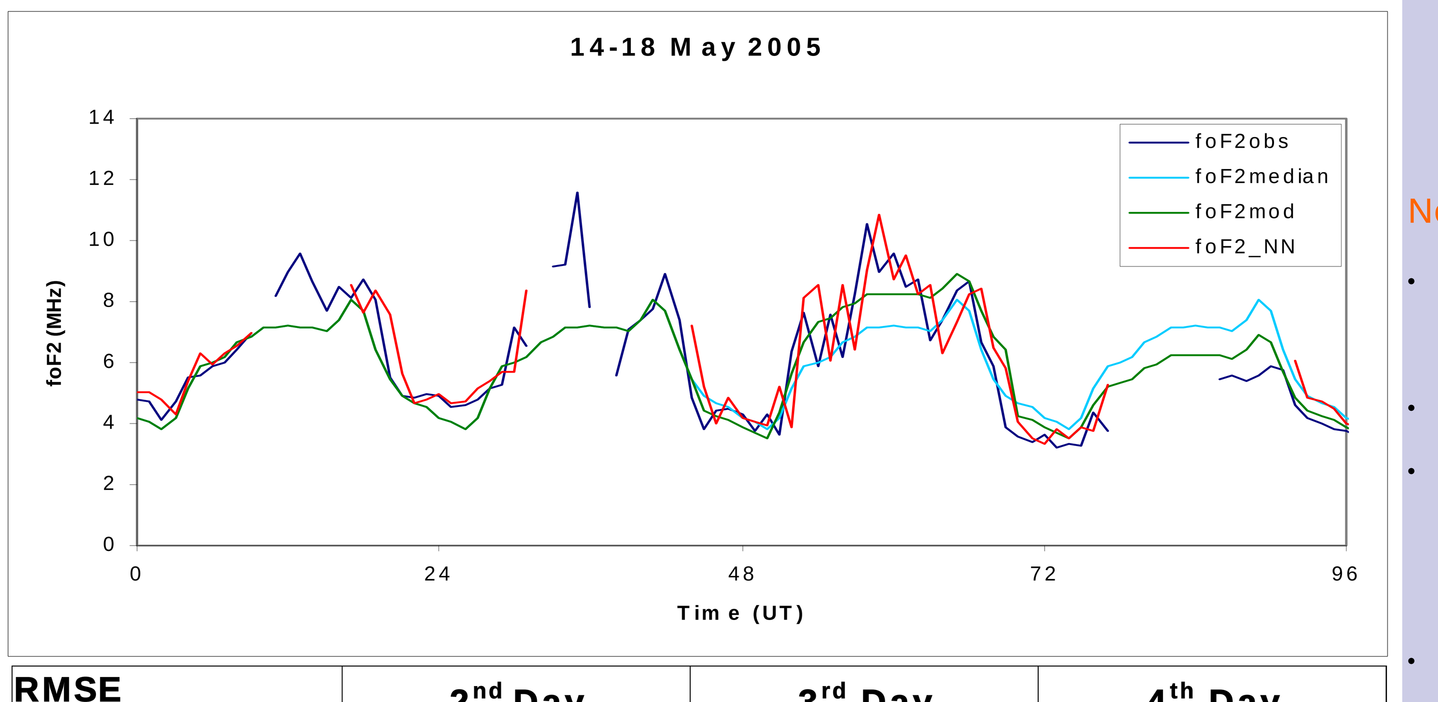
RMSE	1st Day	2nd Day
MODEL	0.98	0.99
MM	0.97	2.05
% Improvement	~0%	51.8%



Comparative Study







RMSE	2^{nd} Day	3^{rd} Day	4^{th} Day
STIM	2.370	1.818	3.482
Neural Network Tool	1.070	2.614	0.837

Discussion

STIM

- The new empirical model can capture the physical processes that governs the ionospheric storms onset and their temporal evolution during the first 24-hour.
- In general, it yields the large scale ionospheric disturbances (e.g. positive effects of long duration and long lasting negative phases).
- By using the ACE measurements, the model gives ionospheric storm time predictions at least 3 hours ahead.
- However, it has been proved inadequate to follow the localized effects of small scale (e.g. TADs effects).
- Future improvements should be based on:
  - Reformulation of the model's expressions in order to enable more localized predictions (e.g. for Athens).
  - Analysis of the observations during a significant number of storm event cases in order to include the seasonal and the latitudinal dependence into the model formulation.
  - Introduction of more accurate criteria for the on line determination of the storm onset from the ACE's observations.

Neural Network forecasting tool

- In general, it follows the ionospheric response in terms of both large and small scale effects but shifted in time.
- However, it gives the safer ionospheric predictions just one hour ahead.
- Its performance depends strongly on real time measurements, reproducing gaps in the prediction for data gaps. Moreover, model predictions are sensitive in automatic scaling errors.
- Future improvements should be based on:
  - ⇒ Dealing with data gaps
  - ⇒ Possible collaboration of the two methods especially at the triggering point.