ASSESSMENT OF UPC MODEL FOR IONOSPHERE VTEC PREDICTION

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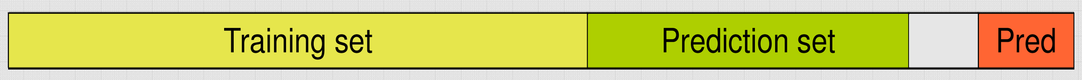
Abstract

The UPC approach for short-term prediction of Global Ionospheric Maps (GIMs) has been tested for several periods including different solar/geomatic conditions. Then, three weeks in 2004, 2006 and 2009 years have been selected for preliminary performance evaluation. In this context, the results will be compared with an independent source of vertical Total Electron Content (TEC) provided by dual frequency altimeter on-board JASON satellite. In brief, the prediction method is based on taking long time series of International GNSS Service (GNSS) GIMs as input data (in this work, from UPC or CODE IAAC centers) and on both the use of the Discrete Cosinus Tranform (DCT) and a Linear Regression algorithm.

Forecasting of ionospheric TEC is becoming important to improve a wide variety of scientific and technological applications. In fact, IGS ionospheric Working Group received a request from ESA's SMOS mission (launch scheduled on November, 2009) to use two days ahead prediction products. At the moment, UPC prediction product is automatically generated on a daily basis and in IONEX format as well. Also, it is about to be available through IGS distribution server at cddis.gsfc.nasa.gov FTP site. Although this product is still under test, the results seem promising.

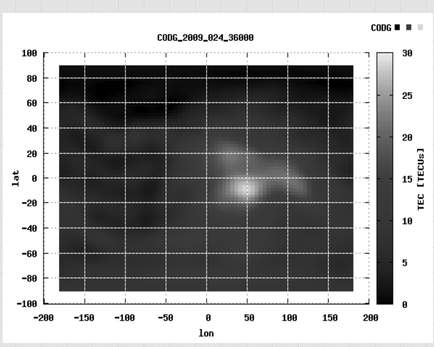
Technical description

The model is trained using one year of final IGS products as input data, such as UPCG or CODG. Afterwards, the model is applied to a prediction set including the corresponding rapid IGS products from the last seven days (if available). Being on day T, the last available rapid IONEX file is on T-1 and prediction is performed for day T+1:

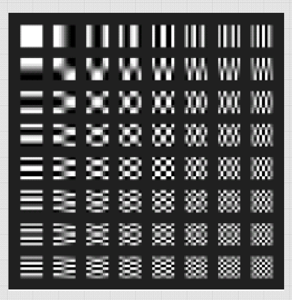


T - (7+366) T - 7 T T+1

Every IONEX map in the training set and in the prediction set is transformed using the DCT as can be seen in the following diagram. Therefore, we express the IONEX map as an expansion of cosinus functions with certain amplitudes defined by the so-called *CoefDCT* coefficients.



$$= \Sigma\, \mathrm{CoefDCT}_{i,j} \;\cdot$$



IONEX map
(grid 71x72 elements)

DCT basis functions
(ex. with 64 elements)

More in detail, UPC prediction model is based on applying a Linear Regression to each DCT coefficient (i.e. the prediction is applied to the coefficients that are used to reconstruct the predicted map). Then, information of all the IONEX map is present in each DCT coefficient. Moreover, the DCT transform is windowed, in the sense that we use only the low frequency coefficients. The effect of using only a triangular subset of coefficients, is smoothing the image in the space domain. For instance and in order to obtain the predicted value of the DCT coefficient at **i**=13 and **j**=4 :

$$\mathrm{CoefDCT}_{13,4}\,[T_{\mathrm{maps}}+m]=\omega_0+\Sigma\,\omega_n.\mathrm{CoefDCT}_{13,4}\,[T_{\mathrm{maps}}-n]$$

where ω_0 and ω_n are the regression coefficients and **n** can take values from last map on T-1 to first map on T-7 (i.e. 85 maps after mixing 00UT maps), and **m** can take values from 12 to 24 in case of two days ahead forecasting (as a complete IONEX file contains 13 maps).

Finally, the obtained regression coefficients are applied to the prediction set. It is remarkable that, differently as in Autoregressive (AR) modelling, it is not necessary to use consecutive samples, the prediction may not be of the following sample, and additional information can also be used in the model (ex. Kp, Sunspots number, GEC, values of the grid points in the neighbourhood).

See also

Hernández-Pajares, J.M. Juan, J. Sanz, R. Orús, A. García-Rigo, J. Feltens, A. Komjathy, S.C. Schaer and A. Krankowski (2009): '**The IGS VTEC maps: A reliable source of ionospheric information since 1998**', Journal of Geodesy, 83:263–275, doi:10.1007/s00190-008-0266-1.

Schaer, S. (1999): '**Mapping and Predicting the Earth's Ionosphere Using the Global Positioning System**', *Dissertation*, Astronomical Institute, University of Berne, Berne, Switzerland, 25 March 1999.

Acknowledgements

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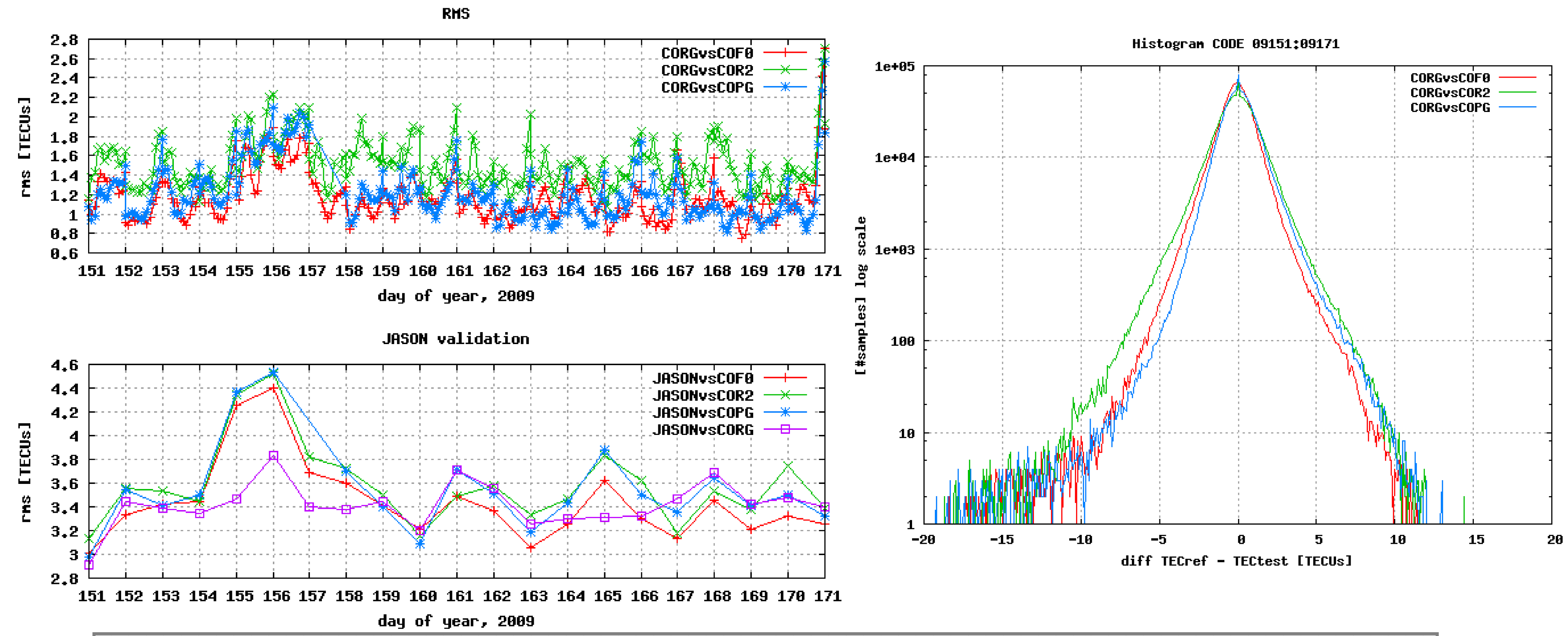

Figure 1: First test corresponding to doy 151 to 171, 2009. Plots on RMS (Fig. 1a; top left) and histogram in logarithmic scale (Fig. 1b; right) of the difference between the reference (CORG) and the predicted values (COF0, COPG and COR2), and also RMS (Fig. 1c; bottom left) when considering JASON TEC data as reference.

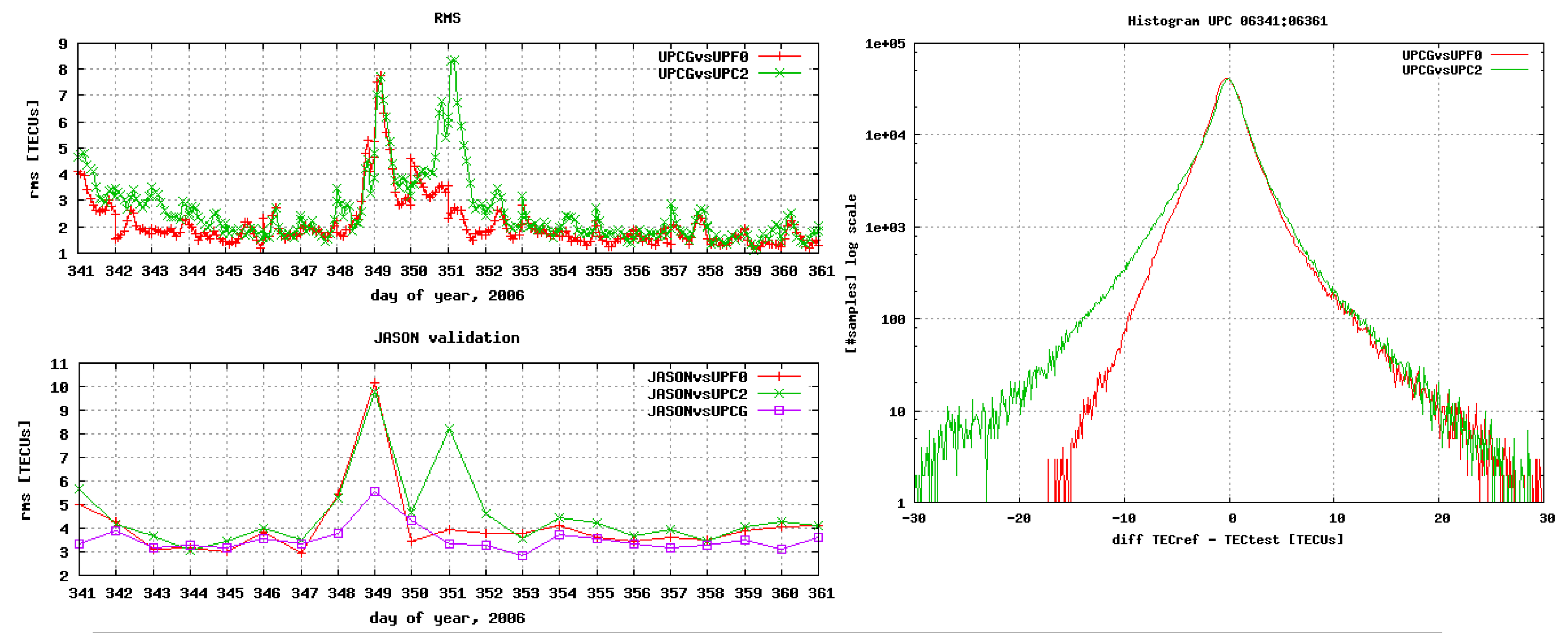

Figure 2: Second test corresponding to doy 341 to 361, 2006 (0 ≤ Kp ≥ 8.3; meanKp = 2.9). Plots on RMS (Fig. 2a; top left) and histogram in logarithmic scale (Fig. 2b; right) of the difference between the reference (UPCG) and the predicted values (UPF0 and UPC2), and also RMS (Fig. 2c; bottom left) when considering JASON TEC data as reference.

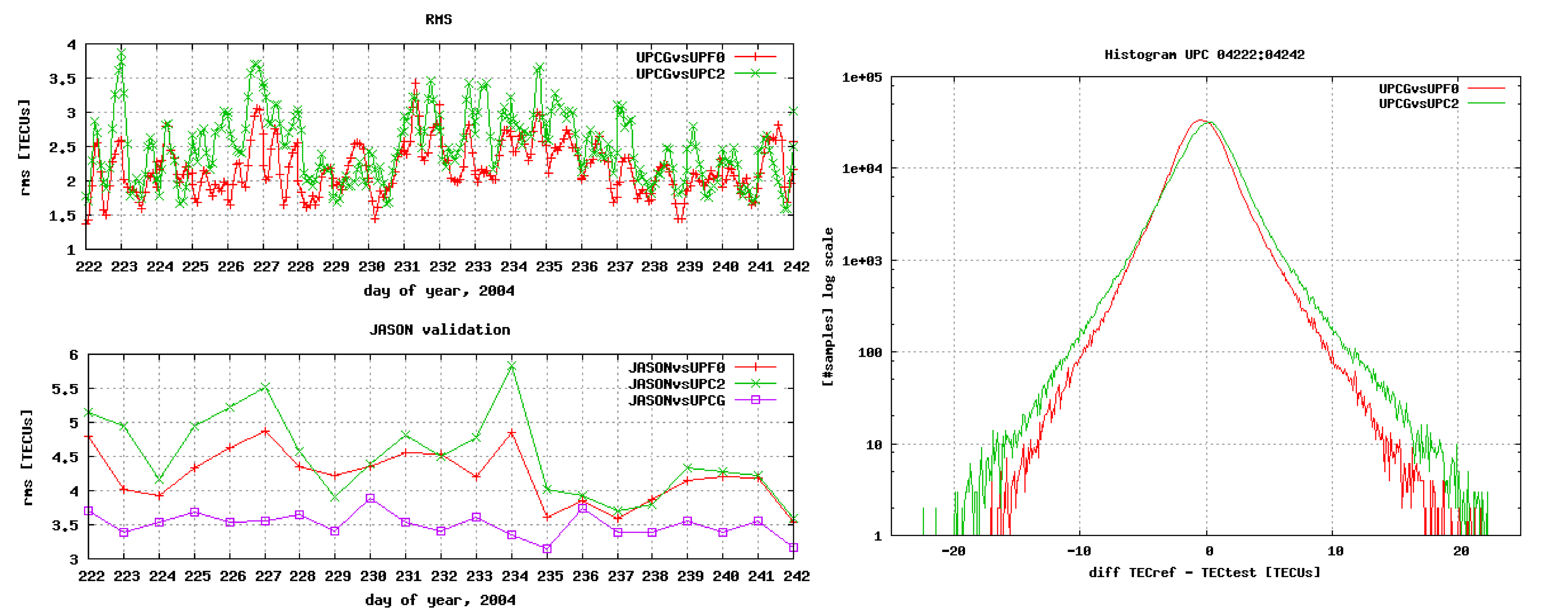

Figure 3: Third test corresponding to doy 222 to 242, 2004 (0 ≤ Kp ≥ 4.3; meanKp = 1.8). Plots on RMS (Fig. 3a; top left) and histogram in logarithmic scale (Fig. 3b; right) of the difference between the reference (UPCG) and the predicted values (UPF0 and UPC2), and also RMS (Fig. 3c; bottom left) when considering JASON TEC data as reference.

Results & Conclusions

Three tests have been carried out to assess the performance of the model under different geomagnetic/solar conditions. The periods are from doy (day of year) 151 to 171 on 2009 using CODE official IGS products, 341 to 361 on 2006 and 222 to 242 on 2004 using UPC official IGS products. The prediction results (UPF0 and COF0 in this work) have been compared to the corresponding official IGS rapid products as reference (i.e. on day T+1) or the final products if not available. The prediction product is also compared to considering that ionosphere has not changed in 48 hours (prediction file on T+1 is equal to last available IONEX file on day T-1; called UPC2 and COR2). In the first test, the application of the UPC method to CODE IGS products is of great interest as they are providing a non-official prediction product called COPG that can be used as well for comparisons.

First of all, results are compared to TEC values derived from CORG files. In Fig. 1a, COF0 overall results show an RMS improvement of 3.3% with respect to COPG case and of 26.4% with respect to COR2 case. In the case of 2006 and 2004 tests (Figs. 2a and 3a), the UPF0 overall results show RMS improvements of 24.7 % and 14.6 % with respect to UPC2 case, respectively.

Also, results are compared to TEC values derived from JASON altimeter as an external source for validation. Then, prediction results should be as close as possible to CORG/UPCG results. In Fig. 1c, COF0 overall results are only 1.0 % worse than CORG ones while COPG and COR2 results are 4.3 % and 5.2 % worse. In Fig. 2c, UPF0 overall results are 22.2 % worse than UPCG ones and UPR2 are 35.1 % worse. In this context, two solar flares were recorded by GOES on doys 347 (X3.4) and 348 (X1.5), 2006. As a consequence, there was a TEC sudden increase due to overionization that was not predicted. That can be seen not only in the RMS plots (Figures 2a and 2c) but also in the asymmetry of the corresponding histogram (Fig. 2b). Finally in Fig. 3c, UPF0 overall results are 20.9 % worse than UPCG ones and UPR2 are 29.6 % worse.

Then, applying a prediction model shows better performance than considering non-variant ionosphere in the tested periods. Moreover, applying the UPC approach to CODE input data leads to slightly better results than with CODE prediction model. It is also concluded that results are promising enough to think on providing an IGS official product in the near future to be used in SMOS mission.

It is also remarkable that future tests should be done to evaluate the model under solar maximum conditions. This is important as we are facing another maximum in the years to come and the prediction model must cope with the situation as well.