Testing regional vTEC maps over Europe during the 17-21 January 2005 sudden space weather event

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ABSTRACT

The intense level of solar activity recorded from 16 to 23 January 2005 led to the series of events with different signatures at the Ionosphere. Measurements of the critical frequency of the F_2 layer $foF2$ and the vertical total electron content vTEC are used to describe the temporal and spatial electron density distributions during this space weather event. It is found that the ionospheric storm morphology was dominated by positive disturbances during the first two days and by overall negative disturbances as storms develop. Although a good agreement between the two independent measurements was detected by comparing the storm-time behaviour of foF2 and vTEC during the event, some spatial irregularities have been recognized in both foF2 and vTEC variations at different latitudes. This gave an excellent opportunity to test regional vTEC maps over Europe under such disturb solar-terrestrial conditions.
In this context, the tests used to validate the International GNSS Service (IGS) vTEC maps have been applied to assess the accuracy of the European RAL vTEC maps in such stormy conditions. Thus, the self-consistency test (that employs GPS data) and the JASON altimeter test (that employs the JASON-1 altimeter ionospheric data) have been used in order to compare such performances with the IGS and UPC Global Ionospheric Maps (GIMs). The results show discrepancies between the RAL vTEC maps and the IGS ones which lead to significant RMS and bias values, regarding to the self-consistency and altimeter test respectively, of several TECUs on such stormy conditions. Moreover in this work a kriging technique to impove the accuracy of any regional vTEC map is also presented, with relative improvements up to 26% in the highest stormy conditions.

1. The 20th January 2005 sudden event

The whole week from 16 January 2005 was dominated by one single big sunspot group, that it was clearly visible on the solar disk (http://sidc.oma.be). The group marked an M and X-flaring period with a wide impact on both solar-terrestrial physical system and human technology. Together with the flares and associated interplanetary coronal mass ejections (ICMEs), several proton events occurred. On 16 January around 09:30UT, ACE data showed a changing in several physical quantities: higher density, decreasing temperature, high solar wind speed, increased total interplanetary magnetic field. A clear shock was seen in ACE-data on 17 January at 07:00UT when the solar wind speed changed from slightly beneath 600 up to 650 km/s. Then at 10:30 UT the speed rose more smoothly to 800 km/s. The total interplanetary magnetic field Bt went up to 40nT, while its Bz component reached the level up till -20nT. This was the onset of a severe geomagnetic storm with Kp up to 7 on 17 January. The night between 17 and 18 January saw several changes in Bt and Bz and the solar wind speed of 1000 km/s at the beginning of 19 January, resulting in two days of severe geomagnetic disturbances on 18 and 19 January. Although the next day ACE showed some evidence for another CME passing through, it was until the solar wind speed made a sudden jump from 600 up to 1000 km/s and the Bz went up to more than -20nT around 16:50UT on 21 January that a sudden severe geomagnetic storm with Kp equal 8 appeared. See the table below to see th Ap and Kp values for the whole week.

Date	Ap / Kp (each 3 hours)
2005 01 15	22 / 3 6 4 3 3 3 3 2
2005 01 16	12 / 2 2 2 2 3 3 2 3
2005 01 17	63 / 5 4 3 7 7 7 5 3
2005 01 18	72 / 6 5 7 5 6 6 4 5
2005 01 19	62 / 6 6 6 7 6 4 3 4
2005 01 20	12 / 2 1 1 2 4 4 3 3
2005 01 21	61 / 3 1 3 2 2 8 8 6

2. Testing the vTEC regionals maps

The methods used to test vTEC regional maps are those used for IGS ionospheric working group to validate its global GIMs. Thus, the self-consistency test, that uses the GPS carrier phase data, and the JASON altimeter test, that employs the derived JASON-1 dual frequency altimeter ionospheric data, are adapted, as will be explained below, to perform the regional validation. The Rutherford Appleton Laboratory (RAL) provides an interactive 24/7 service for short-term ionospheric forecasting (STIF) at http://ionosphere.rcru.rl.ac.uk/ (Cander, 2003). Part of this service are regional TEC maps, which are tested in this work. The GIMs provided by IGS (ftp://cddis.gsfc.nasa.gov/gps/produtcs/ionex) are also tested in this work in order to compare with a standard reference for the vTEC Ionospheric estimations.

References:
Lj.R. Cander: "Toward forecasting and mapping ionospheric space weather under the COST actions", Advances in Space Research, Vol. 31, No. 4, pp. 957-964, 2003.

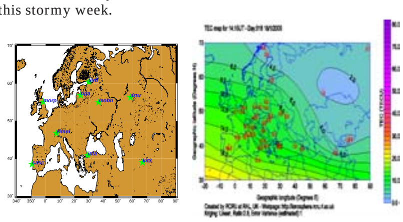
R. Orus, M. Hernandez-Pajares, J.M. Juan and J. Sanz: "Improvement of global ionospheric VTEC maps by using kriging interpolation technique" Journal of Atmospheric and Solar-Terrestrial Physics, In Press, 2005.

Self-consistency test

This test measures the capability of a certain model to reproduce the differences of the ionospheric carrier phase observable (L_I) over a single station as a function of the elevation (ϵ_{ti})of the satellites in view, which is a direct measurement with a typical error below 0.02 TECU. In fact, it is a measure of difference of Slant TEC ($STEC$) at two different epochs. Thus, the RMS (RMS_{self}) of this test is computed as follows:

$$RMS_{self} = RMS[L_I(\epsilon_{t1}) - STEC_{Model}(\epsilon_{t1}) - (L_I(\epsilon_{t2}) - STEC_{Model}(\epsilon_{t2})]$$

Thus, the test used in this work is based on the estimation of the different RMS_{self} over 9 European stations widely distributed, for this stormy week.

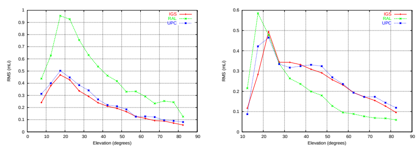


Self-consistency test.Results

Thus, the spatial distribution of the RMS_{self} is obatined from each receiver. This is useful in order to determine if the interpolation method is accurate in regions with low density of GPS observations. Moreover, this network is representative enough in order to compute the mean value of the $RMS_{self}(inTECU)$ for the whole zone and day:

day	15	16	17	18	19	20	21
IGS	2.79	2.73	4.35	4.66	2.94	2.61	4.19
UPC	3.04	3.06	4.97	6.04	3.38	2.91	4.59
RAL	3.68	4.34	4.79	4.93	3.53	3.36	5.85

It can be seen in the above table that the RAL average RMS_{self} results for the week of this study are a typically 10% (somtimes up to 50%) higher than the corresponding to the IGS and UPC ones. Thus, a receiver study has been done finding that there are several stations with significant high RMS_{self}. These receivers are mostly the receivers located at edge of the map, and mostly in high latitudes. These errors could indicate that the interpolation method is not accurate enough to get the local features, see the example below correspondig to the 19th of January.

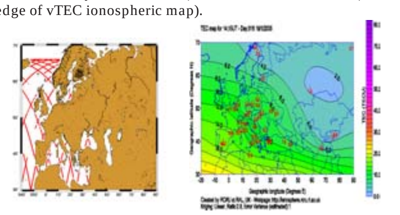


JASON altimeter test

This test is employed to test the different ionospheric maps with an external source of ionospheric data derived from the dual altimeter transmitter-receiver on-board the JASON-1 satellite (mean height orbit: 1330 km over the Earth's surface). The performance has been computed as follows:

$$Bias_{JASON} = < TEC_{JASON} - TEC_{vTECmap} >$$
$$RMS_{JASON} = \sqrt{< (TEC_{JASON} - TEC_{vTECmap})^2 >}$$
$$\sigma_{JASON} = \sqrt{RMS^2_{JASON} - Bias^2_{JASON}}$$

One of the main features of this data is that is gathered over the oceans and seas, see figure below for the JASON footprints over the European region for the days 15th, 16th and 17th of January. This fact causes the interpolation method be tested in that zones because there are few available close GPS stations. Then, in the European region this data is mostly taken oven the Mediterranean Sea (zone surrounded by GPS receivers) and the Atlantic Ocean (zone in the edge of vTEC ionospheric map).



JASON altimeter test. Results

The daily results for the Bias and standard deviation (σ_{JASON}) regarding to the JASON data are showed in the following table:

	15	16	17	18	19	20	21
IGS_{Bias}	0.74	1.11	2.71	0.71	2.87	2.43	1.02
σ_{JASON}	1.67	2.05	3.99	3.39	2.26	2.53	2.71
UPC_{Bias}	0.90	1.36	2.83	0.39	2.93	2.43	0.96
σ_{JASON}	1.73	2.25	4.24	3.24	2.24	2.42	2.39
RAL_{Bias}	2.03	1.92	5.08	3.71	4.37	3.57	2.22
σ_{JASON}	2.44	2.46	4.87	2.70	2.65	2.61	3.02

As can be seen in the previous table there is a bias of about 2 TECUs between the IGS GIMs and the RAL vTEC maps. However, the standard deviation is slightly higher than the IGS GIMs ones but in general, it is quite compatible with them.

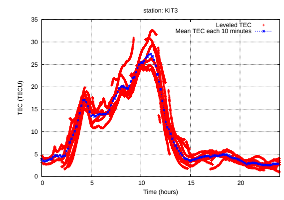
3. Recomputing vTEC regional maps

In order to get high sample time TEC, for instance 30 seconds as in the RINEX files, the vTEC maps jointly with the carrier phase observables can be used. In this context, the vTEC maps are employed to align the geometry free or Ionospheric combination L_I by means of computing the ambiguity term (B_I) for each satellite - receiver arch.

$$< B_I > = < L_I - STEC_{vTEC;MAP} > \qquad TEC_{align} = F_{IPP}(L_I - < B_I >)$$

Where F_{IPP} can be the thin layer mapping function.

Therefore, a levelled vTEC, with the same bias as the vTEC map used, is obtained over each IPP each 30 seconds. Then, the following step is to compute the mean values over the station each 10 minutes in order to get the input data that will be used to generate the vTEC maps.



Thus, the final step is to compute the RAL vTEC map by means of employing the kriging techinque (Orus et al, 2005). Thus, a vTEC map is obtained with the same temporal and spatial resolution, (for instance 10^{min} x 5.5^o x 2.5^o; UT x longitude x latitude).

Recomputing vTEC maps. Results

Self-consistency test (RMS_{self})

	15	16	17	18	19	20	21
RAL	3.68	4.34	4.79	4.93	3.53	3.36	5.85
RAL Kr.	3.37	3.40	4.56	4.15	3.14	2.93	4.90
Improvement	8%	22%	5%	16%	11%	13%	16%

JASON test (σ_{JASON})

	15	16	17	18	19	20	21
RAL	2.44	2.46	4.87	2.70	2.65	2.61	3.02
RAL Kr.	2.30	2.23	3.59	2.12	2.63	2.25	2.30
Improvement	6%	9%	26%	21%	1%	14%	24%

As can be seen in the previous tables the recomputed RAL maps has always better performance reaching up to 21% and 26% for the self-consistemcy and JASON tests.

Conclusions

It has been shown in this work the feasability of using the IGS global tests in order to calibrate regional vTEC ionospheric maps in stormy conditions. In this context the RAL vTEC maps has been tested showing significant discrepances, of about several TECU, when it is compared with the official IGS Global Ionospheric Maps (GIM). Moreover, a kriging techique jointly with a *levelled TEC* has been used in order to improve the RAL estimations, which has introduced improvements up to 26 %, showing performances sometimes better than the official IGS GIMs.

Acknowledgements

This work has been partially supported by AGAUR (Agència de Gestió d'Ajuts Universitaris i de Recerca de la Generalitat de Catalunya) amd by ESP-2004-05682-C02-01