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PRESENT AND FUTURE IGS VTEC MAPS AS A RELIABLE SOURCE OF IONOSPHERIC INFORMATION SINCE 1998

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Abstract. The purpose of this paper is to show the present performance of the combined final and rapid IGS global ionosphere maps (GIMs) and, on the other hand, to inform the geophysics and geodetic communities on the new IGS product predicted GIMs.

1 INTRODUCTION

The International GNSS Service (IGS) Ionosphere Working Group (Iono WG) started the routine generation of Ionosphere Vertical Total Electron Content (TEC) maps in June 1998. This has been the main activity so far performed by the four IGS Ionosphere Associate Analysis Centers (IAACs): CODE (Center for Orbit Determination in Europe, Astronomical Institute, University of Berne, Switzerland), ESOC (European Space Operations Center of ESA, Darmstadt, Germany), JPL (Jet Propulsion Laboratory, Pasadena, California, U.S.A), and UPC (Technical University of Catalonia, Barcelona, Spain). This has been done under the direct responsibility of the Iono-WG chairman.

2 FROM RAW DATA TO IONOSPHERIC MAPS

In order to generate the combined VTEC maps (called GIMs Global Ionosphere Maps) several steps are needed. Raw GNSS data are provided by the IGS ground network. Presently IGS manages a network of as much as 384 stations. Figure 1 shows the data flow from IGS ground network trough IAACs, IGS Ionosphere Combination Center and IGS Ionosphere Validation Centers finally providing the final and rapid IGS ionosperic products. Currently four IAACs contribute with their rapid and final VTEC maps to the IGS products: CODE, ESA, JPL, and UPC. They compute the global distribution of TEC independently using independent approaches and methodology.

The IGS ionosphere product is a result of the combination of different Analysis Centers TEC maps by using weights computed from GPS data by Validation Centers, in order to get the most accurate product. During a period of about 10 years of continuous IGS ionosphere operation, the techniques applied by the IAACs and the strategies of combination have both improved in such a way that the combined IGS Ionosphere TEC maps are now significantly more accurate and robust. As a matter of example, one can see in Figure 2 the layout of a typical approach to compute global VTEC maps from GNSS data. In order to make feasible the generation of a combined IGS ionospheric product, the IAACs agreed on providing their maps in IONEX format, with temporal resolution of 2 hours and spatial resolution of 5 degrees by 2.5 degrees in longitude and latitude respectively.

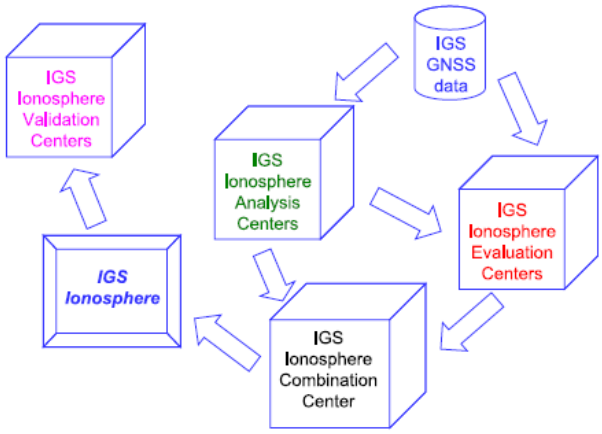

Figure 1: Diagram showing the data flow required to generate IGS GIMs

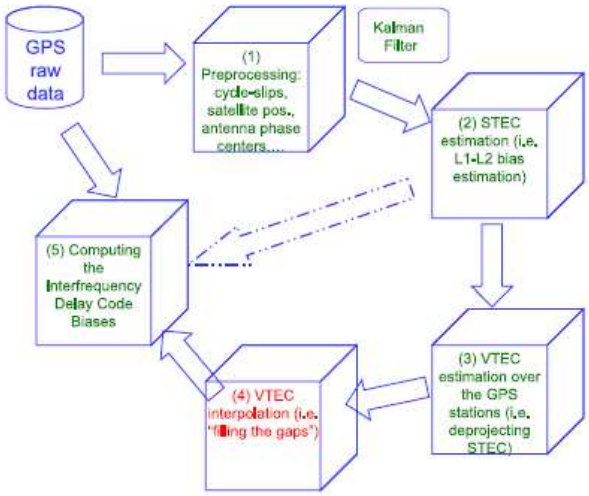

Figure 2: Diagram showing the main typical steps on computing IGS GIMs

The combined IGS maps are obtained as a weighted mean of the available IAAC VTEC maps, by using the values provided by the Evaluation Center in previous step. Figure 3 shows an example of IGS VTEC and RMS snapshots, after combining maps and taking into account the evaluation involving. A similar process is performed for combining the differential code bias (DCB) estimates for transmitters (GPS satellites) and receivers.

Validation of the GIMs is performed by comparing them to an independent source of VTEC. The reference VTEC values are provided by dual frequency altimeters on board of TOPEX satellite (up to 2003) and JASON satellite (from 2003), and ENVISAT (from 2003). Because the altimeters are working over Oceans, this comparison can be considered as a pessimistic determination of the global VTEC map actual errors. Indeed, in such regions there are few ground based GNSS receivers, and as a consequence, most part of the provided information by the VTEC global maps is based on interpolation. Presently there are two IAVCs: JPL and ESA, providing JASON and ENVISAT validations. As a matter of example, in Figure 4 some comparisons with JASON data and IGS final VTEC maps are shown (with very good agreement between TEC data).

Nowadays the IGS IonoWG generates three types of ionospheric products: the final, rapid and predicted. Latency of the final and rapid GIMs is of 10 days and 1 day, respectively. The maps of IAACs are uploaded to IGS Ionosphere Product Coordinator, who computes official IGS combined products. Since January 2008, this coordination is carried out by the GRL/UWM (Geodynamics Research Laboratory of the University of Warmia and Mazury in Olsztyn, Poland).

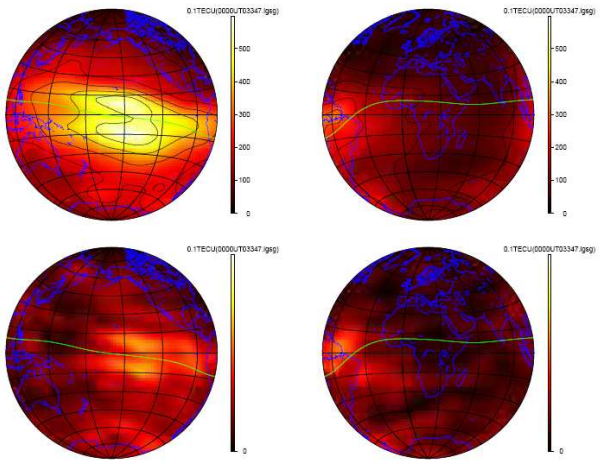

Figure 3: Example of IGS VTEC final maps snapshots for day 347 of 2003 (Dec 13th), at 00UT. Every row, from top to bottom, correspond to combined VTEC and RMS maps, the units are 0.1 TECU. The scale ranges from 0 to 60 TECU in VTEC maps, and from 0 to 6 TECU units in RMS map.

In November 2009, the IGS Iono WG started to generate predicted ionospheric products 1 and 2 days in advance (requested for ESA's SMOS mission). These new IGS products are currently based on predicted ionosphere maps prepared by UPC and ESA.

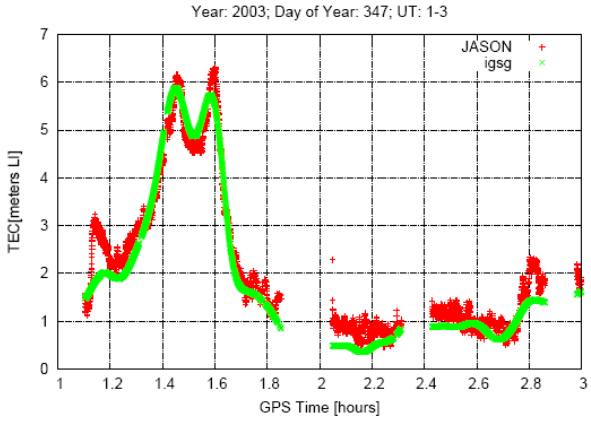

Figure 4: Example of validation of IGS VTEC map using dual frequency JASON Altimeter footprint during 01-03UT, day 347 of 2003: Directly measured altimeter VTEC (red crosses) vs. VTEC deduced from IGS global maps (green Xs). Note: the altimeter measurements are just slightly smoothed before being compared (in this case by an sliding window containing 16 consecutive observations, during a time span of about 16 seconds). from 0 to 6 TECU units in RMS map.

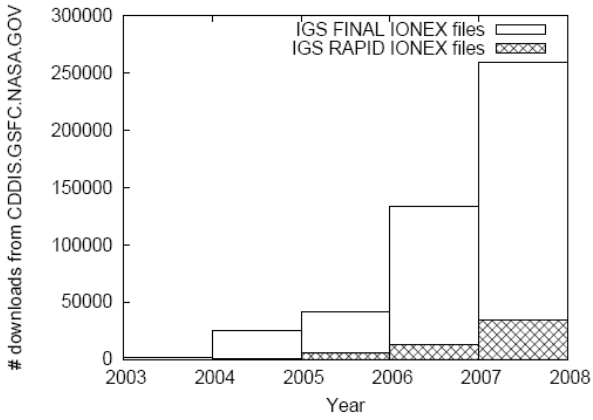

Figure 5: IGS IONEX usage statistics for both final (IGSG) and rapid (IGRG) VTEC maps: downloads from main server only (cddis.gsfc.nasa.gov).

It has to be pointed out that the evolution of usage has maintained a continuous growth (see for example Figure 5 considering only CDDIS server statistics).

3 OVERALL VALIDATION OF VTEC MAPS DURING MORE THAN 9 YEARS OF IGS FINAL VTEC MAPS

In order to provide significant performance numbers of IGS GIMs, the comparison between the interpolated VTEC value from IGS final maps and the direct altimeter (TOPEX or JASON) measurements is shown in Figure 6. This detailed comparison presents results for each of IAACs (CODE, JPL, ESA and UPC) and combined IGS products since day 349/2002 up to end 2007 (after improvement of several IAAC VTEC mapping techniques). The IGS performance is in general equal or better than the best performance of

each individual IAAC.

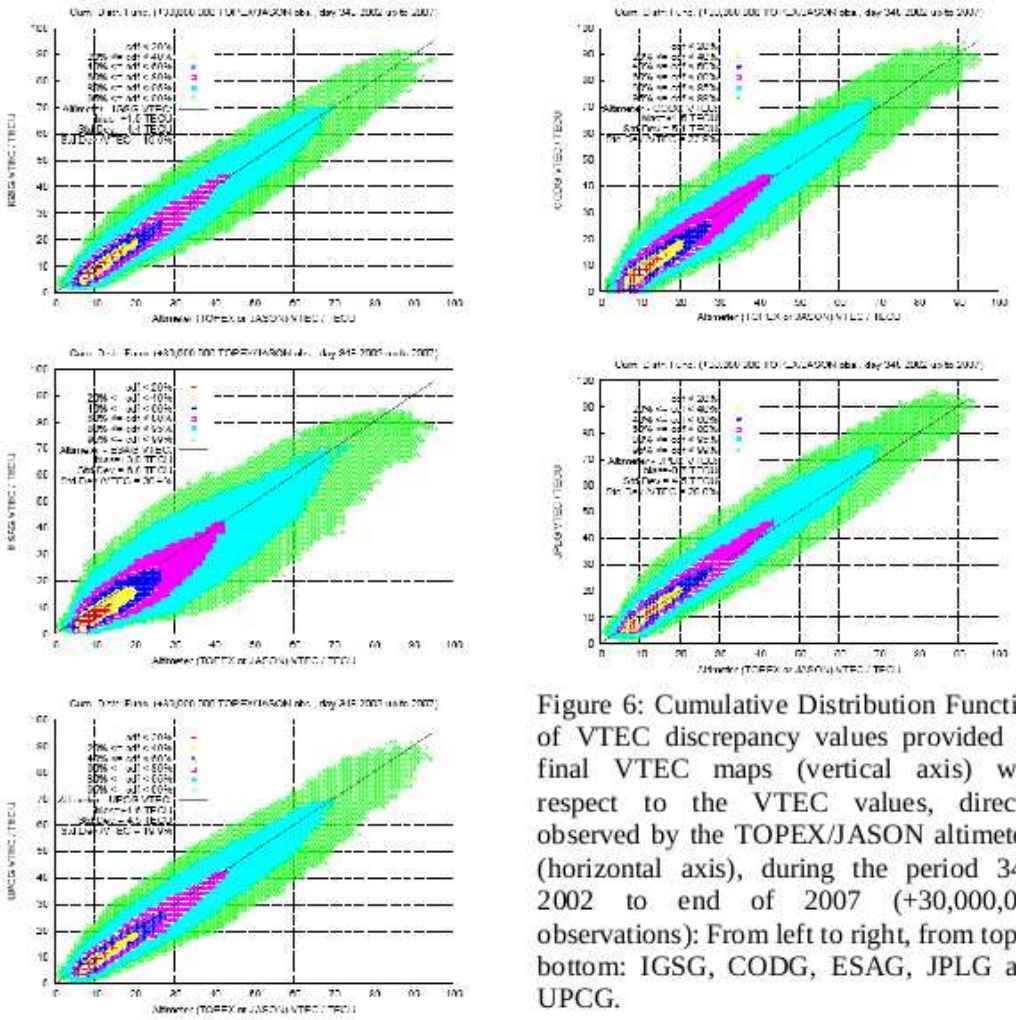

Figure 6: Cumulative Distribution Function of VTEC discrepancy values provided by final VTEC maps (vertical axis) with respect to the VTEC values, directly observed by the TOPEX/JASON altimeters (horizontal axis), during the period 349/ 2002 to end of 2007 (+30,000,000 observations): From left to right, from top to bottom: IGSG, CODG, ESAG, JPLG and UPCG.

4 CONCLUSIONS

Long series of IGS VTEC maps offers a very good source of information about ionosphere with high spatial and temporal resolutions. Future improvements are determined by users requirements. A good example is recent interest of ESA SMOS mission in using the IGS VTEC maps, including the predicted ones.

A long time series of accurate global VTEC values are available since 1998, which are freely available for scientific or technical usage. Thanks to the cooperative effort developed within the IGS framework and the international scientific community this open service will hopefully continue its evolution during the next years, sensitive to both new user needs and scientific achievements.

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