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COMBINING SPACE GEODETIC TECHNIQUES FOR GLOBAL VTEC MODELING

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Abstract.

1 INTRODUCTION

For space geodetic techniques, operating in microwave band, ionosphere is a dispersive medium; therefore signals traveling through this medium are affected proportional their frequencies. This effect allows gaining information about the parameters of the ionosphere in terms of Total Electron Content (TEC). The classical input data for development of Global Ionosphere Maps (GIM) is obtained from dual-frequency Global Navigation Satellite System (GNSS) observations. However, the GNSS stations are in-homogeneously distributed, with large gaps particularly over the sea surface, which lowers the precision of the GIM over these areas. On the other hand, dual-frequency satellite altimetry missions such as Jason-1 provide information about the ionosphere precisely above the sea surface. And furthermore Low Earth Orbiting (LEO) satellites, such as FORMOSAT-3/COSMIC (F-3/C) provide well-distributed information of ionosphere around the world. This study aims at developing combined global models of VTEC from different space geodetic techniques. The combined GIMs provide a more homogeneous global coverage and higher reliability than results of each single method.

2 TEC FROM GNSS

In the last decade the Global Navigation Satellite System (GNSS) including GPS and GLONASS have turned into a classical tool for monitoring the ionosphere. Dual-frequency observations of these techniques can be used to determine the slant total electron content. By subtracting the observation equations of the L1 and L2 frequency the so-called geometry-free linear combination is formed. In this combination all frequency-independent effects such as clock errors, tropospheric delay, etc. are removed and the new observable which contains only the ionosphere refraction and the inter-frequency hardware biases remain:

$$P_{i,4}^{k} = P_{i,1}^{k} - P_{i,2}^{k} = \xi_4 \xi_E (F(z) E_\nu(\beta, s))_i^k + c(\Delta b^k - \Delta b_i) \tag{1}$$

Where $E_\nu(\beta, s)_i^k$ is the VTEC at ionospheric pierce point; $\Delta b^k = b^{k,1} - b^{k,2}$ is the satellite differential code biases (DCB); $\Delta b_i = b_{i,1} - b_{i,2}$ is the receiver DCB; $F(z)$ is the mapping function, and ξ_4 and ξ_E are constants.

3 TEC FROM OTHER SPACE GEODETIC TECHNIQUES

Ionosphere parameters can also be derived from other space geodetic techniques such as satellite altimetry and Low Earth Orbiting (LEO) satellites. Satellite altimetry is a particular way of ranging which measures the vertical distance between a satellite and the ocean surface. The signals are transmitted permanently in the high frequency domain (about 14 GHz) and the echo from the sea surface received by the satellite is used for deriving the round-trip time between the satellite and the sea. The two widely separated frequencies allow TEC to be detected directly from nadir altimetry sampling data along the satellite track (Imel, 1994). LEO satellites are also capable of providing information about the ionosphere. Multi- channel GPS carrier phase signals received by the FormoSat-3/COSMIC (F-3/C) satellites are used to undertake active limb sounding of the Earths atmosphere and ionosphere via radio occultation (RO). By using different techniques such as the Abel inversion transform, its possible to retrieve TEC from these RO measurements.

4 GIM MODELING THEORY

The GNSS-derived STEC values are extracted from the geometry-free linear combination applied on dual-frequency carrier-phase smoothed code observations. Within the geometry- free linear combination the unknown parameters in the observation equation are the absolute TEC information $E_n u(\beta, s)_i^k$, satellite and receiver code biases (DCBs) $\Delta b_i, \Delta b^k$ and in the case of phase pseudo-range the ambiguity parameter. There are different approaches in order to parameterize the distribution of TEC; here we consider a global representation using Spherical Harmonic expansion (SH) up to degree and order 15. In our study data from around 180 IGS stations were used with sampling rate of 30 sec. In the case of satellite altimetry, the original ionosphere correction from T/P and Jason-1 was adopted and converted into Vertical Total Electron Content (VTEC) by a factor depending on the operational frequency of the altimeter. In the case of F-3/C, VTEC were deduced from the Abel inversion transform of the RO measurements, assuming a constant unknown bias for each F-3/C satellite with respect to GPS. The VTEC can be expressed by $E_n u$:

$$E_\nu(\beta, s) = \sum_{n=0}^{n_{max}} \sum_{m=0}^{n} P_{nm}(\sin\beta)(C_{nm}\cos(ms) + S_{nm}\sin(ms)) \quad (2)$$

where β is the geomagnetic latitude of the ionospheric pierce point, $s = \lambda_G + UT - \pi$ (with λ_G geographical longitude) is the sun-fixed longitude of the ionospheric pierce point,P_{nm} is the normalized Legendre function of degree n and order m, and C nm and S nm are the unknown coefficients of the spherical expansion. Using the SH expansion, VTEC can be represented in form of Global Ionosphere Maps (GIM) with specified spatial and temporal resolution.

5 COMBINATION TECHNIQUE

For the combination of GNSS, satellite altimetry and F-3/C data, least-squares adjustment is applied on each set of observations and then the normal equations are combined. This is done by adding the relevant normal matrices obtained from the three types of observations:

$$N_{COMB} = N_{GNSS} + N_{ALT} + N_{F3/C} = A^T_{GNSS} . p_{GNS} . A_{GNSS} + A^T_{ALT} . p_{ALT} . A_{ALT} + A^T_{F3/C} . p_{F3/C} \quad (3)$$

For the relative weighting of the altimetry and F3/C data, different strategies are possible. Due to the much higher number of GNSS measurements compared to satellite altimetry and the F3/C these data should be up-weighted, in order to increase its impact on the combined GIM. Within this study the adopted weight is $p_{ALT} = (1/4)^2$, and $p_{F3/C} = (1/4)^2$ for satellite altimetry and F3/C, which corresponds to $\sigma_0^{ALT} = 4TECU$ and $\sigma_0^{F3/C} = 4TECU$ respectively.

6 COMBINED SOLUTION

A Matlab-based software was developed for computation of 12 GIM per day with temporal resolution of 2 hours and spatial resolution of 2.5° latitude and 5° longitude. The corresponding RMS maps and daily values of the DCB for all the GNSS satellites and receivers were also developed as a bi-product. The final outputs are in the IONEX format. Figure 1 depicts samples of the combined GIMs for day 202, 2007:

As it can be seen from the results, the RMS maps of the combined solution show an improvement of about 0.5 TECU in all 12 two-hourly maps. Thus it can be inferred that the precision of the combined maps are lower in areas where no GNSS sites are located. This is mainly above the sea surface and in the southern polar region, which is inadequately covered by GNSS observations but robustly covered by the satellite altimetry and F3/C measurements.

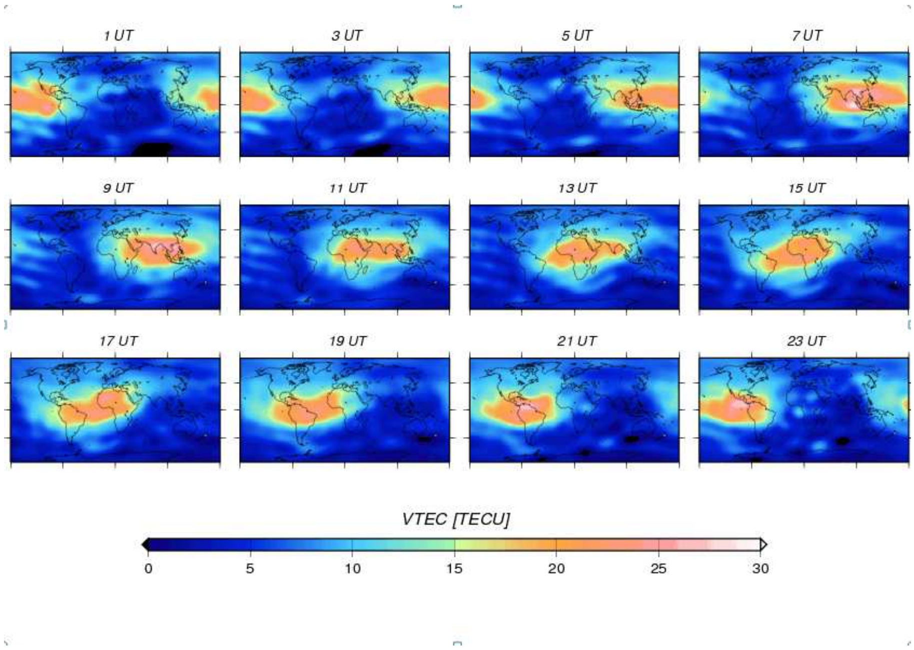

Figure 1: GNSS, satellite altimetry and F3/C Combined GIMs day 202, 2007

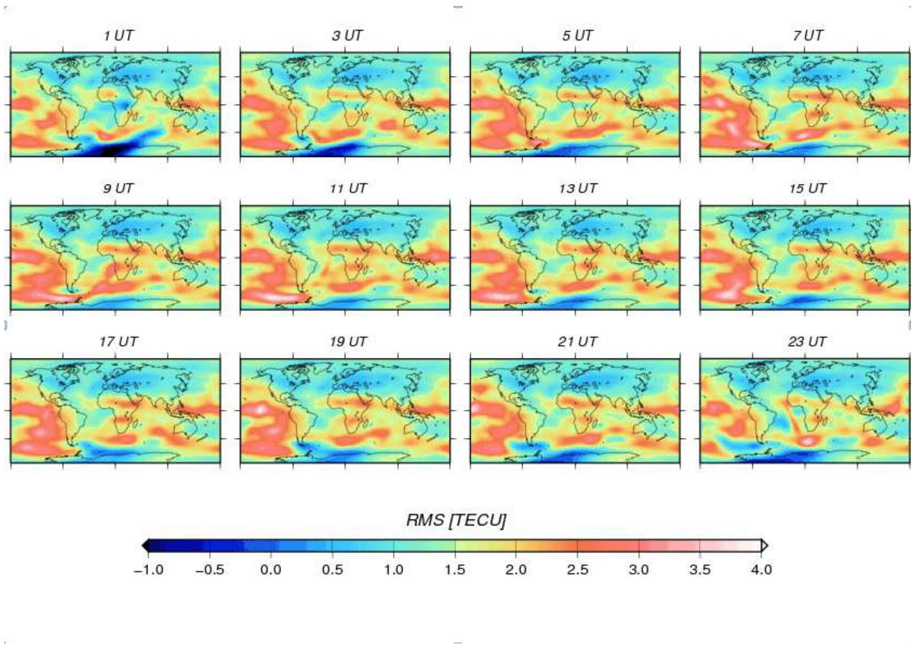

Figure 2: F3/C Combined minus GNSS/satellite altimetry only, RMS maps day 202, 2007

7 CONCLUSIONS

In this study we presented some results of combining GNSS and satellite altimetry data with data from FORMOSAT-3/COSMIC for developing global models of VTEC. As it was shown, COSMIC data have a great potential to improve the Global Ionosphere Maps when the number of occultation measurements in the whole day are considerable. Our further step is using mathematical approaches for weighting different techniques of this combination.

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