A Methodology to Assess Ionospheric Models for GNSS
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INTRODUCTION

Testing the accuracy of the ionospheric models used in the Global Navigation Satellite System (GNSS) is a longstanding issue. It is still a challenging problem due to the lack of accurate and reliable ionospheric delay measurements. The determination of the vertical electron content (TEC) is a long-standing issue. It is still an active area of research due to the uncertainty in the ionospheric models used in the Global Navigation Satellite Systems (GNSS).

In this work, we propose a methodology based on the comparison between the predictions of any ionospheric model with actual unambiguous carrier-phase measurements from a global distribution of permanent receivers. The main focus of this research is to evaluate the accuracy of the ionospheric models used in the GNSS, specifically the Global Ionospheric Models (GIMs), NeQuick, and Klobuchar.

METHOD DESCRIPTION

1. Transfer the centimeter-level modeling accuracy of the non-dispersive carrier-phase ambiguities: the wide-lane, and ionosphere-free combinations (BW and BC, respectively) to the carrier-phase ambiguity in the geometry-free combination (BI = B1 − B2) by:

   \[ BI = \left( \frac{f_1}{f_2} \right) (BW - BC) \]

2. Obtain the reference least determination by subtracting the BI ambiguity obtained without any ionospheric a priori to the geometry-free combination of carrier-phase measurements (LI = L1 − L2). After fixing the ambiguities, the combination of STEC and instrumental delays is known with few millimeters of accuracy between any satellite j and any receiver i:

   \[ LI = BI = STEC_i + DCB_j - DCB_i \]

3. Accumulate differences of the STEC predictions of the ionospheric model under test, STEC(modeli) with respect to the unambiguous geometry-free carrier-phase during 24 hours for the entire world-wide network of receivers every 5 minutes. Such differences shall differ only from the unambiguous (LI − BI), in the hardware delays (i.e., a receiver constant \( K_i \) and a satellite constant \( K_j \)).

   \[ STEC_i(model_j) - (LI - BI) = K_j - K_i \]

4. Estimate the \( K_j \) and \( K_i \) by a Least Squares (LS) adjustment on a global network: 0.35 million STECs (24 hours of data sampled every 5 minutes, 150 stations and ~8 satellites in view per station) are fit to 182 common parameters (150 K sat + 32 K rec).

5. Compute the post-diff residuals of the adjustment (5). Any mis-modelling present in the ionospheric prediction not being assimilated into the receiver and satellite constants degrades the user navigation.

GLOBAL IONOSPHERIC MAPS (GIMS)

IGS GIMs: The broadly-used GIMs from IGS [4] provide the VTEC IGP grid in a single layer at 450 km height, using a spatial resolution of 2° in latitude and 5° in longitude. Maps are updated every 2 hours together with 3 coefficients broadcast in the Ionosphere map EXchange format (IONEX) [6].

gAGE/UPC GIMs: The ionospheric model [6] with two layers at heights of 230 and 1600 km is used in the Fast Precise Point Positioning (Fast-PPP) technique [7] to provide high-accuracy navigation quickly. The real-time model is smoothed in post-processing to backward estimate the VTEC at the IGPs. Maps are stored every 15 minutes, with two interpolations: latitude (IONEX) and MODIP.

OPERATIONAL BROADCAST MODELS

Klobuchar model: This is the well-known ionospheric model [1] used by GPS. The ionospheric delays are assumed at a single height at a height of 350 km. The model predictions are driven by 8 parameters included in the navigation message updated once a day.

NeQuick Galileo model: The original ionospheric model [2] has been adapted for the implementation in Galileo. The effective ionisation level at the satellite Ionospheric Peculiar Point (IPP) MODified Dip latitude (MODIP) placed at 300 km height drive the model predictions together with 3 coefficients broadcast in the Galileo navigation message updated at least once a day.

Satellite-Based Augmentation System (SBAS) ionospheric corrections: Geostationary satellites broadcast the ionospheric model described in the Minimum Operational Performance Standards (MOPS) [3]. The Vertical TEC (VTEC) is provided on a single-layer distribution of Ionospheric Grid Points (IGPs) at a 350 km height, spaced by 5° both latitude and longitude at the equator, 10° north and south of 55° latitude, and 90° in longitude above 85°. The maximum update time is 5 minutes.

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REFERENCES


CONCLUSIONS AFTER ASSESSING THE ENTIRE 2014, I.E., THE LAST SOLAR MAXIMUM

Grid-based ionospheric corrections (IGS-GIMs or EGNOS) are several times more accurate than the previously mentioned models, specially if interpolation is MODIP-based.