

# AN ASSESSMENT OF THE GALILEO SINGLE-FREQUENCY IONOSPHERIC CORRECTION MODEL

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## Abstract:

This paper presents an independent assessment of the proposed single-frequency ionospheric correction model for the ESA Galileo satellite navigation system. The model provides an estimate of the component of pseudorange (PR) caused by group retardation of the radio signal in the ionosphere. The PR is proportional to the Total Electron Content (TEC) along the path. A comparison of model TEC values with calibrated dual-frequency measurements of TEC therefore provides the PR error expected on a single-frequency Galileo receiver. TEC is modelled by line integration through a global ionospheric electron density model (IEDM). The input to the IEDM includes a solar 10.7cm radio flux parameter (F10.7). In the proposed implementation, at least twenty ground "Monitoring" stations will be used to measure TEC over a 24-hour period. At each monitoring station an optimal value of F10.7 is then determined that minimises the IEDM TEC errors over this period. A second-order polynomial ( $Az(D)$ ) is fitted to the optimal F10.7 values, where the independent variable  $D$  is the geomagnetic field's modified dip angle. Over the following day, the three coefficients of  $Az$  are to be broadcast to all Galileo users' receivers, which can then determine their locally optimal F10.7 by evaluating  $Az(D)$  at the user's location. The user receiver then executes the IEDM with this parameter to estimate the TEC and the associated ionospheric PR component. To validate the technique, the proposed Monitoring stations have been simulated using 32 selected ground stations in the International GPS Service (IGS) network. Measurements of TEC have been obtained at each station from the dual-frequency transmissions from GPS satellites, which simulate the proposed Galileo satellites. The Differential Code Biases (DCB) used in calibrating the TEC measurements were downloaded from the Centre for Orbit Determination in Europe (CODE). Calibrated TEC has been recorded for all satellite elevations above  $30^\circ$ , for selected months across the solar cycle (1997-2004). Ephemeris data recording the precise location of the satellite is stored with each TEC measurement. An independent set of IGS stations was selected (covering high, mid, and low latitudes) to represent single-frequency user receiver sites. At these "User" stations the TEC was measured as for the simulated Monitoring stations, for all elevations above  $10^\circ$ , and model values of TEC were determined using  $Az$  coefficients determined from the Monitoring stations for the previous 24-hour period. An initial error analysis suggests that the vertical TEC values associated with "Mild" and "Worst Case" conditions used to determine range error budgets may be set too high since this has implications for the 'Position, Velocity, Time' error budget. An evaluation of the bias and standard error in the TEC predictions will be presented. An obliquity factor,  $F(E) = 1 + 16 (0.53 - E/180^\circ)^3$ , is used in the definition of ionospheric PR error budgets to describe the variation of TEC (and hence range error) with elevation angle,  $E$ .

Initial comparisons based on 1.4 million TEC measurements show excellent agreement at the 90th and 99th percentiles at all elevations. However, at the 10th and 50th percentiles and at the lowest elevations ( $\sim 15^\circ$ ), the obliquity factor,  $F(E)$  is about 20-30% too high. It should be noted that the IEDM does not use this obliquity factor, but instead calculates slant TEC by integration through a three-dimensional electron density distribution.

From our preliminary analysis, it may be stated that the ionospheric model calculates the ionospheric delay to within  $\pm 25\%$  of measured values for about two-thirds of the time, with higher percentage errors at low TEC values. A minimum slant TEC error is now assumed in the performance specification of the revised model. Tests are being conducted to determine whether the model predictions remain within specified error limits under ionospheric storm conditions. The analysis will determine the most appropriate thresholds for setting certain "ionospheric storm warning" flags. The impact of updating the  $A_z$  coefficients at 12 or 6 hour intervals (rather than 24 hours) is also being assessed with regard to slant TEC prediction accuracy.

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