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INTERCOMPARISON OF APPROACHES FOR MODELING SECOND ORDER IONOSPHERIC CORRECTIONS USING GNSS MEASUREMENTS

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Abstract

Correcting GNSS tracking data for the effects of second order ionospheric effects have been shown to cause a southward shift in GNSS-based precise point positioning solutions by as much as 10 mm, depending on the solar cycle conditions. The most commonly used approaches for modeling the higher order ionospheric effect include, (a) the use of global ionosphere maps to determine vertical total electron content (VTEC) and convert to slant TEC (STEC) assuming a thin shell ionosphere, and (b) using the dual-frequency measurements themselves to determine STEC. The latter approach benefits from not requiring ionospheric mapping functions between VTEC and STEC. However, this approach will require calibrations with receiver and transmitter Differential Code Biases (DCBs).

We present results from comparisons of the two approaches. For the first approach, we also compare the use of VTEC observations from IONEX maps compared to climatological model- derived VTEC as provided by the International Reference Ionosphere (IRI2012). We consider various metrics to evaluate the relative performance of the different approaches, including station repeatability, GNSS-based reference frame recovery, and post-fit measurement residuals. Overall, the GIM-based approaches tend to provide lower noise in second order ionosphere correction and positioning solutions. The use of IONEX and IRI2012 models of VTEC provide similar results in periods of low solar activity periods. The use of the IRI2012 model provides a convenient approach for operational scenarios by eliminating the dependence on routine updates of the GIMs, and also serves as a useful source of VTEC when IONEX maps may not be readily available.

Methodology

The **second order ionospheric effect** on GPS measurements ($\Delta I^{(2)}$) can be modeled using a **thin shell** assumption (e.g., Petrie, et al 2011):

$$\Delta I^{(2)} = f(\omega, B, STEC)$$

- ω = frequency
- B = magnetic field (International Geomagnetic Reference Field, IGRF)
- $STEC$ = Slant Total Electron Content.

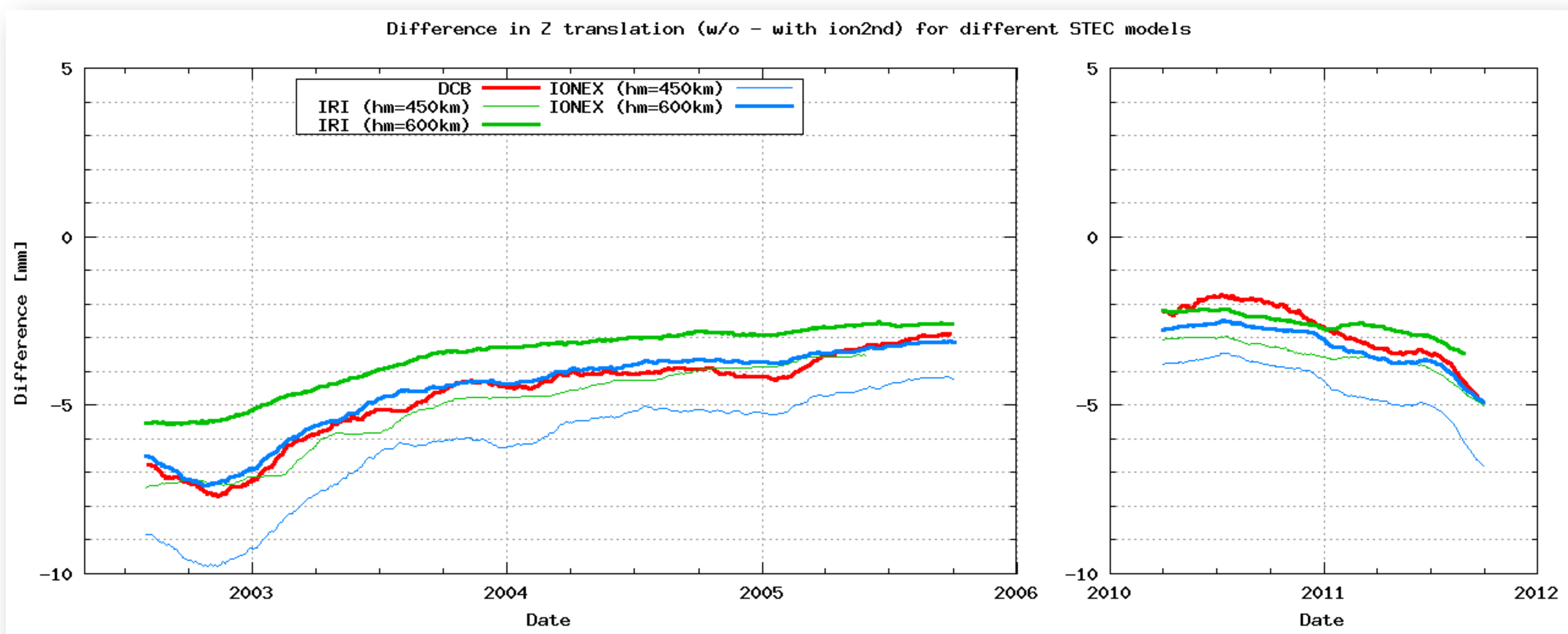
We use 3 possible models for STEC.

1. **DCB**: STEC computed using GPS measurements with receiver and satellite Differential Code Bias (DCB) calibrations. No mapping function is needed for this approach.
2. **International Reference Ionosphere (IRI)**: STEC computed by using geometric mapping function to map Vertical Total Electron Content (VTEC) from IRI2012 global ionosphere model at the ionospheric pierce point.
3. **IONEX**: Same as IRI, but VTEC is obtained using the Global Ionospheric Maps (from IGS).

Both magnetic field and VTEC are **computed at the pierce point location** at a selected **effective height** (h_m).Results from a fiducial free network solution using 40 stations. Time frame 2002-2005 (high solar activity) and 2010-2011 (low solar activity). **No elevation angle weighting** is applied to the data.

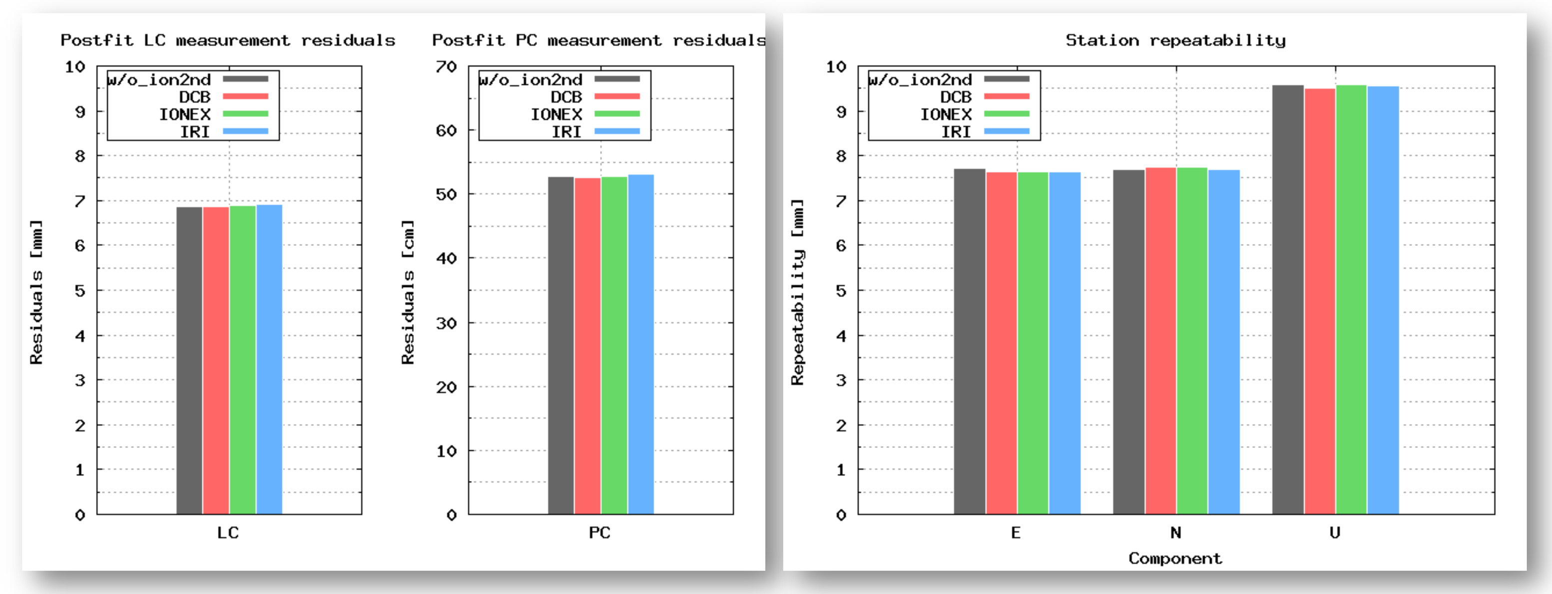
Difference in Z Translation of the Helmert Parameters

- The second order ionospheric correction causes a **southward (Z) translation** of the reference frame (see Petrie et al 2011) of 3-10mm.
- We show that the **choice of h_m impacts** the magnitude of **this translation.**
- If **h_m decreases**, **STEC increases** at low elevation angles (where most observations occur) and the **southward translation increase**.
- IONEX with 600 km provides similar results to DCB.
- IRI with 450km provides similar results to DCB. The VTEC provided by IRI is usually several TECU (~5 TECU) smaller than IONEX, therefore solutions with lower h_m (450km) are closer to DCB solution.



Other Performance Metrics

Post-fit measurement residuals and station repeatability among the 4 different approaches are shown to be **very similar**.



Ionospheric Effective Height

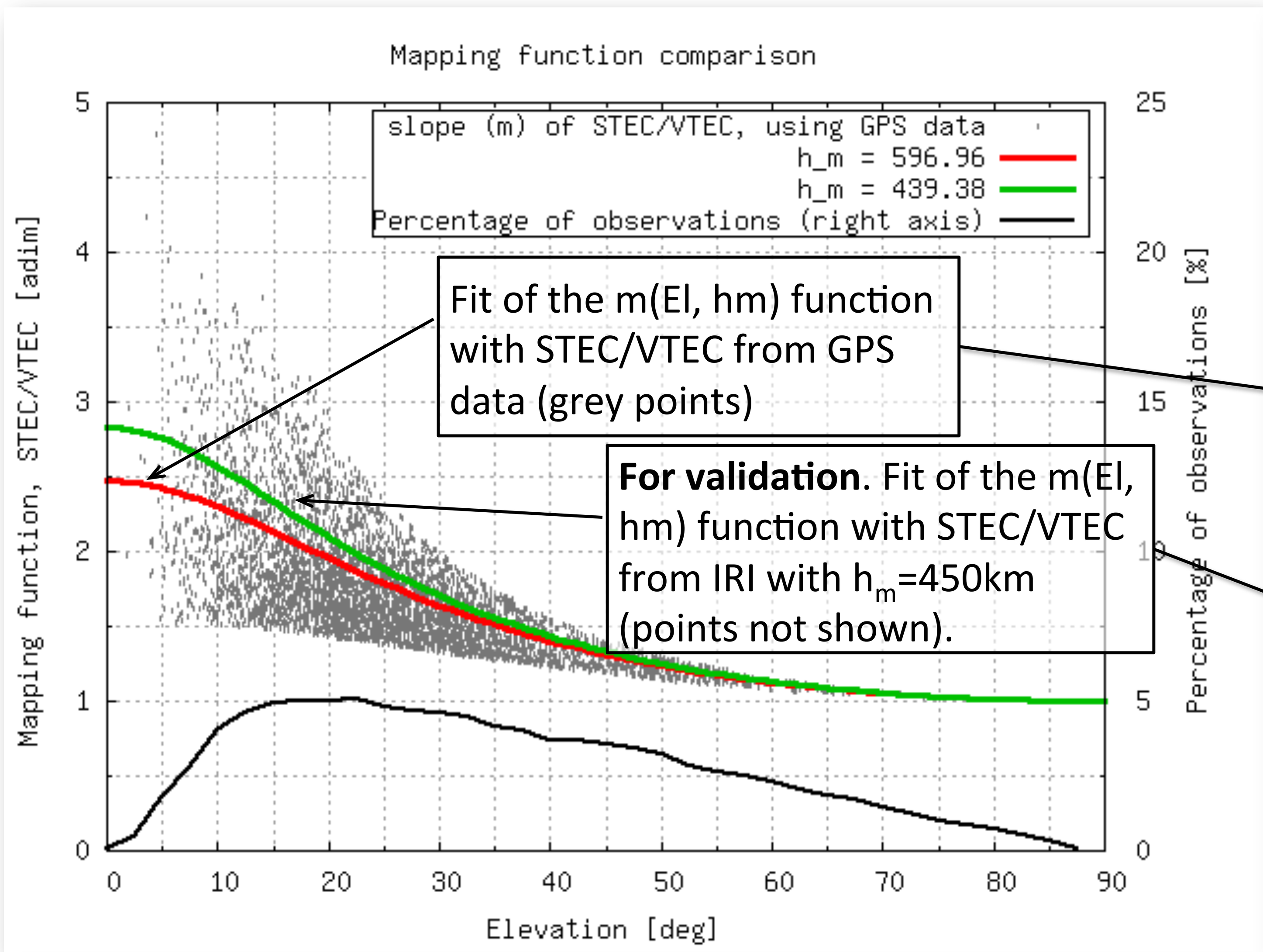
Estimation of h_m from Birch et al 2002:

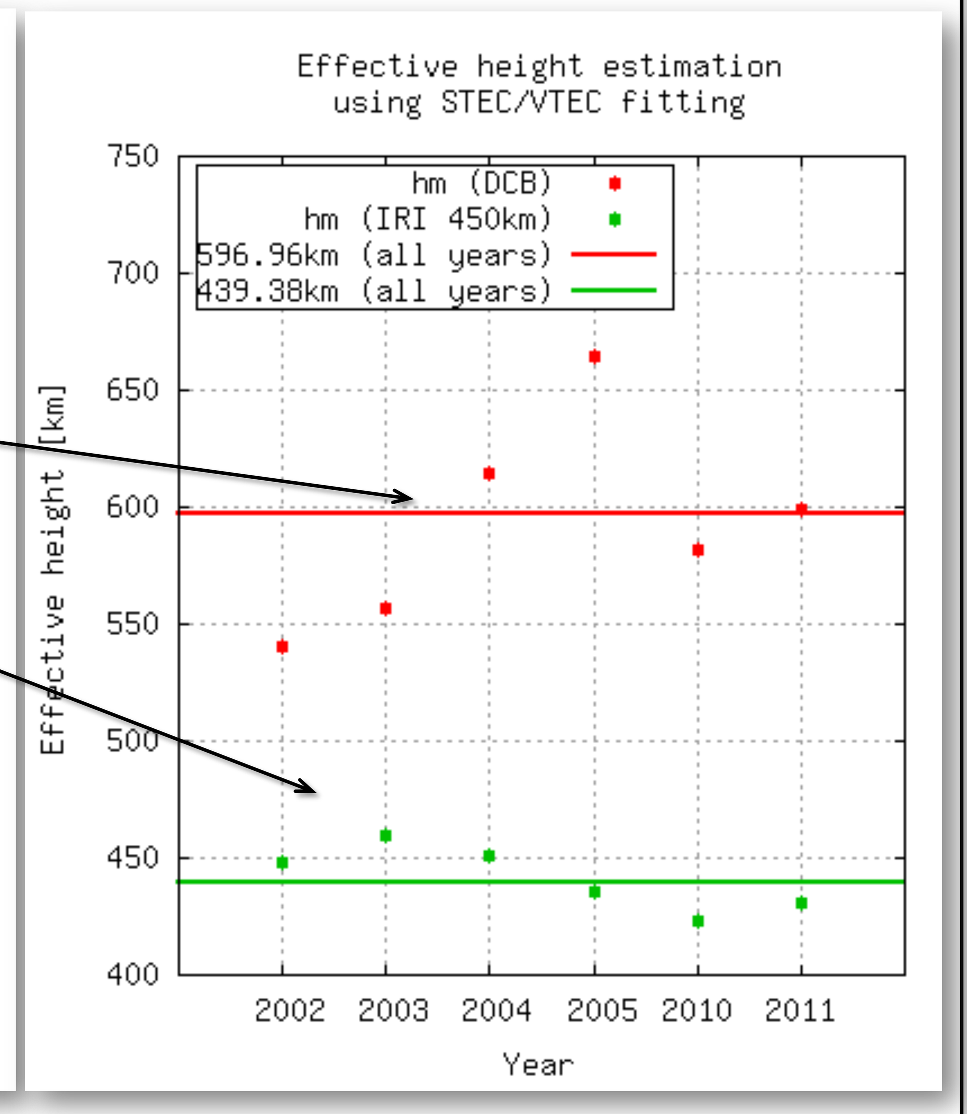
1. Linear fit of STEC vs VTEC: mapping function (m) is the slope of the fit. Independent of the DCB values.
2. Values of m used to obtain h_m through least square fitting of:

$$m(El, h_m) = \frac{1}{\sqrt{1-\left(R_E \frac{\cos(El)}{R_E + h_m}\right)^2}}$$

Typically, h_m is assumed to be **450km**. However, this height **overestimates the STEC** (i.e. mapping too large). A value of **600km** has been chosen for this work, based on the results of the method outlined above

Previous works (e.g. Birch et al 2002 or Hernandez-Pajares et al 2005) suggest that h_m=450km might be too low





Conclusions

- Correcting for the second order ionospheric effects primarily affects the **z translation of the reference frame**.
- The selection of the **effective height** noticeably **impacts** the magnitude of **the Z translation**. Results using 450km and 600km differ by 1-2 mm.
- Analysis of the GPS data (e.g., Birch et al. 2002) indicate that an **effective height of 450km appears to be low.** IONEX and DCB approaches have better agreement with an effective height of 600km.
- **Weighting observations based on elevation angles** (down-weighting low elevation angles) may mitigate the effects of effective height selection.
- The choice of STEC model **does not seem to impact other metrics** (e.g., residuals, station repeatability) noticeably.
- **DCB** approach avoids mismodeling from effective height selection, but is more challenging to routine implementation, e.g., DCB values are not always readily available for all stations and dates.
- IRI provides the least accurate results since it is a climatological model, but differences tend to diminish in low geomagnetic activity. However, IRI is useful when no VTEC or DCB values are available (e.g. mid 90s).

References

- Birch, et al 2002. *On the use of an effective ionospheric height in electron content measurement by GPS reception*. Radio Science 37(1), No 1.
- Hernandez-Pajares et al 2005. *Towards a more realistic ionospheric mapping function*. XXVIII URSI General Assembly, Delhi
- Petrie, et al 2011. A review of higher order ionospheric refraction effects on dual frequency GPS. Surv. Geophys. vol 32.