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CONVENIENT MODELING OF SECOND ORDER IONOSPHERIC EFFECTS ON GPS USING GIMs FOR OPERATIONAL NETWORK SOLUTIONS

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Abstract

The GPS signal was designed as a dual-frequency system so that the main source of error, the ionosphere, could be removed to first order. However, the contribution of **second (and higher) order effects** on the range and phase measurements amounts to several centimeters. These effects in particular impact the use of GPS data to realize the Earth's reference frame: they cause **a shift of up to 10mm** (in high solar activity periods) in the estimation of the origin of the **Earth's spin axis (Z axis)**. To remove this effect, a **model** based in the Earth's magnetic field and the Total Electron Content (**TEC**) along the line-of-sight is commonly employed. While the former is usually computed with the International Geomagnetic Reference Frame (IGRF), the latter can be obtained by (a) the ionospheric combination of GPS data calibrated by the differential code biases (DCB) or (b) by an external Global Ionospheric Model (GIM). The second method covers GIMs in the form of e.g. IONEX maps or climatological models such as the International Reference Ionosphere (IRI). We show that the agreement of these approaches, in terms of the Z-axis origin of the realized reference frame, is around 1mm. Among those methods to obtain the TEC, the DCB approach is considered to be the most accurate because, as opposed to the GIM methods, it does not need a mapping function to convert from Vertical TEC to Slant TEC. However, the **DCB approach poses a challenge for routine operations**: it requires the knowledge of the DCBs for all GPS stations that take part in the reference frame estimation. Given the fact that, in routine operations, the stations might vary from day to day, the DCB approach requires a database of time-dependent DCB values that needs to be regularly updated. We show that the **GIM approach is a more convenient** approach for operations because it does not require maintaining a database of time- and station-dependent DCBs. As such, the GIM approach allows for simpler operations while offering a similar level of accuracy as the DCB method. Recommendations on the processing details for the GIM models (e.g., shell height) to achieve the closest results relative to the DCB method are also given.

Methodology

The **second order ionospheric effect** on GPS measurements ($\Delta I^{(2)}$) can be modeled using a **thin shell** assumption:

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

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

Possible models for STEC:

	STEC source	Needs additional data?	Uses mapping function?
DCB	From GPS data (ionospheric combination)	Needs all DCB values for the stations in the network	No
GIM/IONEX	Derived from maps of VTEC	Daily IONEX files	Yes
GIM/IRI	Derived from modeled VTEC	Model coefficients (bi-annual updates)	Yes

Disadvantage Advantage

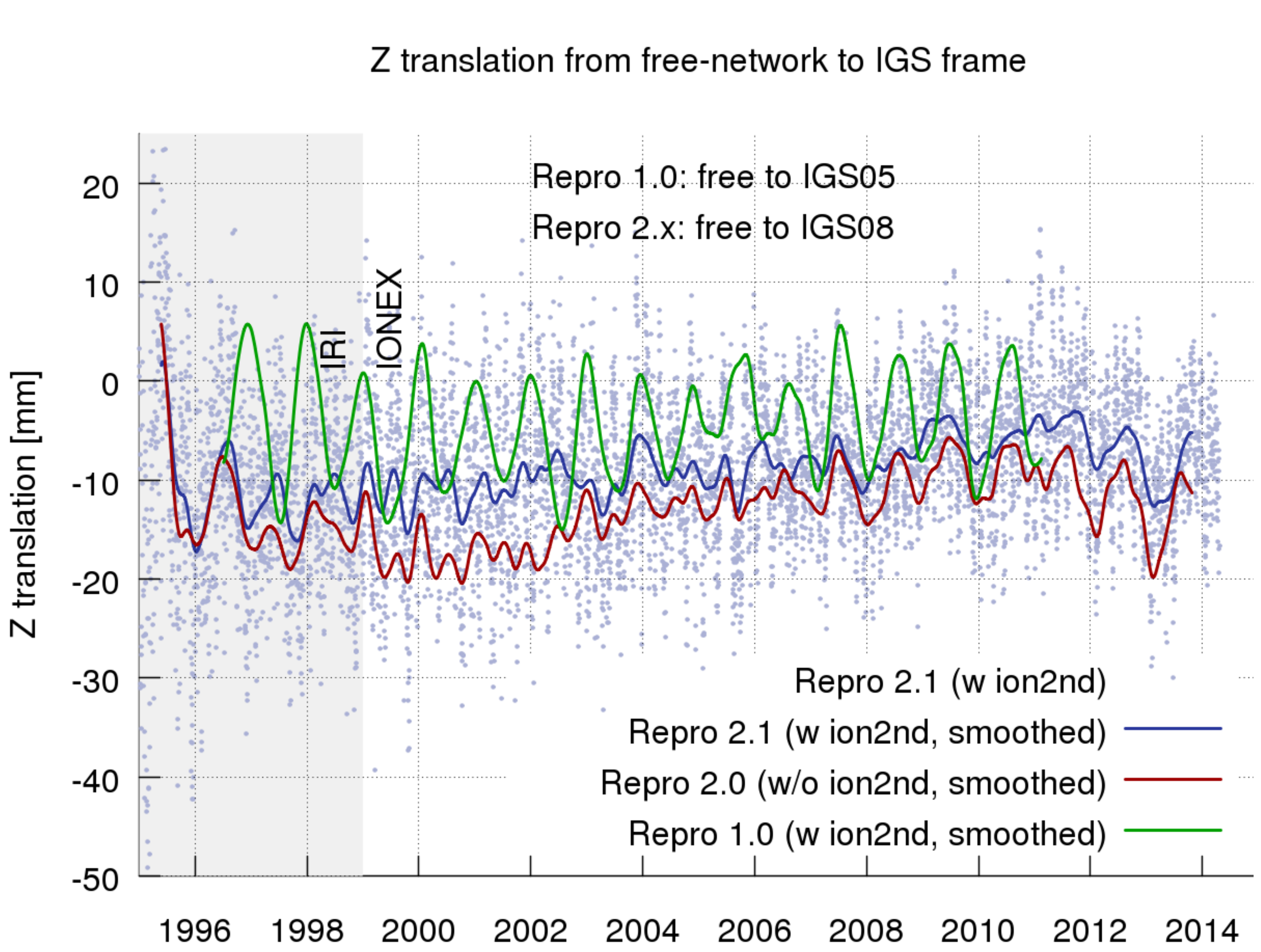
DCB is considered the most accurate (i.e. does not need a mapping function). However, for operational settings, the DCB approach requires the maintenance of a database of all DCBs of the receivers involved in the process. And these receivers might vary from day to day. This makes the **DCB approach challenging for operational implementation**. A simpler approach using GIM (IONEX or IRI) offers compatible results with much simpler maintenance for operations.

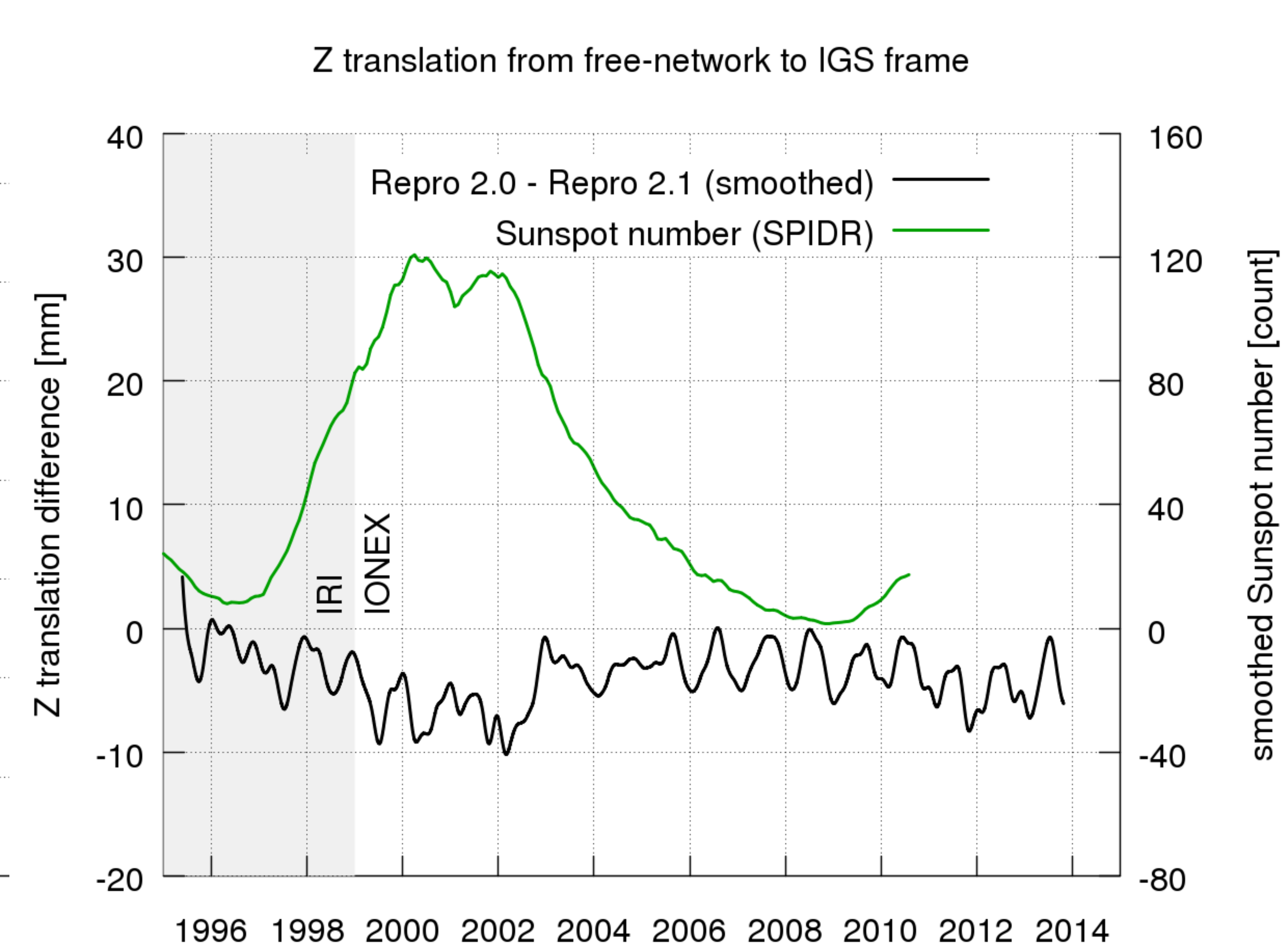
Settings of the second order ionospheric correction used in JPL's current reprocessing campaign (Repro 2.1) and comparison with previous campaigns:

Repro campaign	GIPSY version	Second order ionospheric correction	Model used	Effective height (mapping function)
1.0 (2009)	5	Yes	GPS data **NOT** calibrated with DCB	n/a
2.0 (2011)	6.0	No		
2.1 (2014)	6.3	Yes	IRI <= 1998(1) IONEX >= 1999(2)	600km

(1) IONEX maps not available before mid 1998
(2) JPL maps in IONEX format ("jplg") from CDDIS

Z Translation of the Earth's center (T_Z)

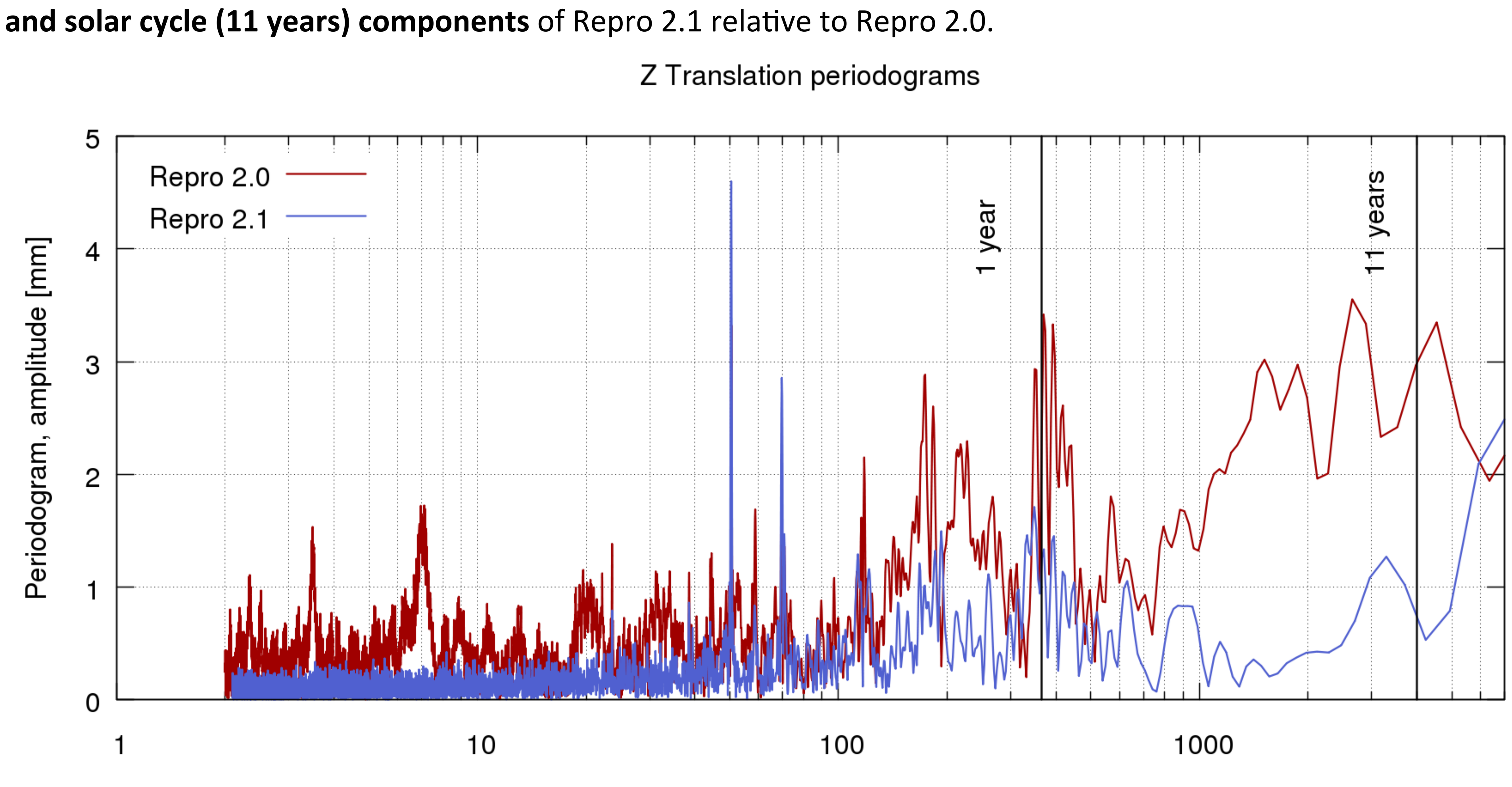




- The second order ionospheric correction causes a **southward (Z) translation** of the reference frame of 3-10mm in average, depending on solar cycle
- Z translation when using **GIM (IONEX or IRI) agrees to 1mm relative to the DCB** approach, when using an effective height of 600km in the mapping function.
- There is **no noticeable jump in the IRI to IONEX transition** (1999). The date of the switch was low solar activity, which implies small differences between the two GIM models.
- As expected, differences between Repro 2.0 and Repro 2.1 increase with solar activity, when the second order ionospheric effect is larger.
- The daily TZ values show a scatter with RMS of 6.5mm, 6.5mm and 7.0mm relative to its smoothed version for Repro 1.0, Repro 2.0 and Repro 2.1 respectively (smoothing method: Gaussian smoothing with a window of 180 days)

Periodogram of the Z translation

- A comparison of the periodograms for the Z translation indicates a noticeable **reduction of energy at annual (1 year) and solar cycle (11 years) components** of Repro 2.1 relative to Repro 2.0.



Conclusions

- **DCB approach is challenging** for operations where the network of receivers change from day to day. Instead, **GIM models are recommended**: use IONEX if possible, or IRI for older periods where IONEX maps were not available (before mid 1998)
- DCB versus GIM methods agree to ca. 1mm in the realization of the Z translation (TZ) of the reference frame, when an **effective height of 600km** is used. Lower effective heights (e.g. 450km) will create biases larger than 1mm between the DCB and GIM methods.
- Comparisons of TZ between Repro 2.0 and Repro 2.1 shows **reduction of annual and solar cycle (11 year) components**.
- IRI provides the least accurate results since it is a climatological model, but differences relative to other models tend to diminish in low geomagnetic activity. **IRI is useful when no VTEC or DCB values are available** (e.g. mid 90s and earlier).

References

Garcia-Fernandez, M., S. D. Desai, M. D. Butala, and A. Komjathy (2013), Evaluation of different approaches to modeling the second-order ionospheric delay on GPS measurements, J. Geophys. Res. Space Physics, 118, 7864–7873, doi: 10.1002/2013JA019356.