Construction of GPS-Based LEO Orbits Referenced to the Instantaneous Earth's Center of Mass

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NEED FOR A GEOCENTER MODEL

- *Non-tidal* geocenter motion mirrors major water mass transports occurring over large regions (not sensed by GRACE).
  - Effect of $1\ \mathrm{mm}$ geocenter error on GRACE's regional mass variation estimates : $65\ \mathrm{Gt}$ mass budget error for the Antartica (Wu and Heflin, 2015 ; Ries, 2016).

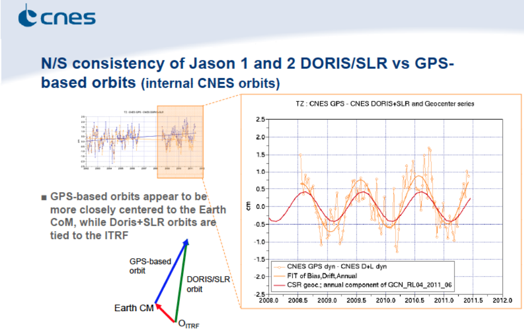
- Un/mis-modeled geocenter motion (especially its Z component) reflects in satellite orbit determination and thus affects global and regional MSL observations (asymmetric distribution of the oceans between the Northern and Southern Hemispheres).
  - Transfer function of Morel and Willis (2005) :

$$\textit{Global MSL error} = -0.16 \times \textit{DZ}, \tag{1}$$

where *DZ* is the mean orbit error in Z.

Historical Background

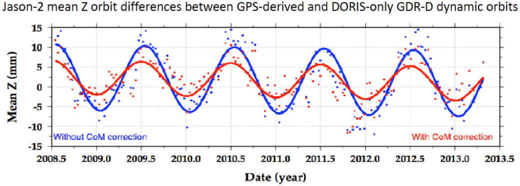
- Spurious *Z seasonal variations*, due to the omitted geocenter motion, exhibited between GPS-based and DORIS+SLR orbits.
  - Dependance on the tracking technique used : 100% for SLR-only (Altamimi et al., 2011), 75% for DORIS-only (Morel and Willis, 2005), 30% for GPS-derived orbits (Cerri et al., 2010).



Cerri et al. (2011), OSTST Meeting 2011, San Diego (CA)

SOLUTION FOR THE SLR/DORIS STATIONS

- Starting from the *GDR-E Standards*, a mean annual geocenter model was introduced to correct DORIS/SLR station positions.



The use of a **seasonal non-tidal geocenter correction** ("Climatological model" SLR-only; from J. Ries) **improves** DORIS-only (and DORIS+SLR) solutions **consistency** with GPS-based orbits, **but half of the signal (~4 mm) is still left…**

Couhert et al. (2014), OSTST Meeting 2014, Lake Constance, Germany

$\Rightarrow$ The seasonal variations in Z were reduced (also shown in Melachroinos et al. (2013)), but ~ 4 mm of the signal remains.

What About the GPS Satellites ?

- IGS recommendation : Analysis Centers (ACs) should align their GPS constellation solution to conform to the ITRF origin.
  $\Rightarrow$ Clock products are biased to fulfill the positioning need of users on the Earth's surface, i.e., GPS stations are referenced w.r.t. the center of figure (CF), not the center of mass (CM).

- Goal : To be consistent with the dynamic motion of LEO satellites (around CM) and the other measurement systems, where the geocenter motion is modeled, it is necessary to take into account the *miscentering effect* of the IGS GPS products.

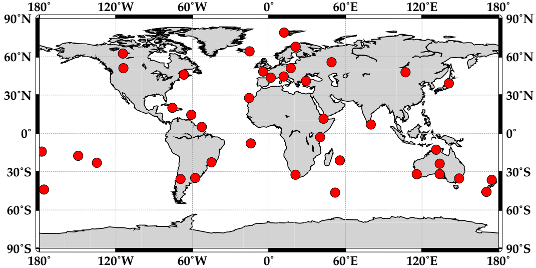
  $\Rightarrow$ Does the $\sim 4\ \mathrm{mm}$ remaining annual signal between GPS-only and DORIS-only (or DORIS+SLR) orbits has to do with this effect ?

APPROACH

- We use a *parametric model* for all the GPS satellite i clocks to represent the ground network translation motion (T_X, T_Y, T_Z) :

$$\textit{GPS satellite i clock correction}_X = T_X \times \frac{X_{GPS_i}}{r_{GPS_i}}, \text{same for Y,} \qquad (2)$$

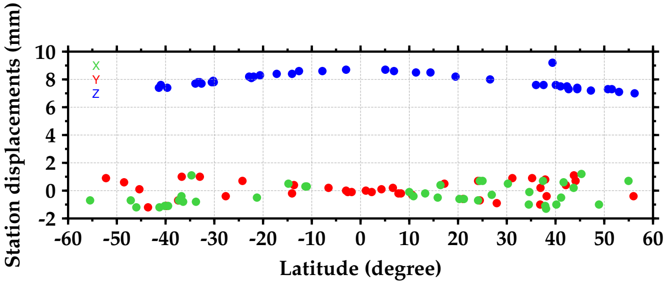
$$\textit{GPS satellite i clock correction}_Z = T_Z \times \frac{Z_{GPS_i}}{r_{GPS_i}} = T_Z \times \sin Lat_{GPS_i} \qquad (3)$$



GPS ground-based stations used in this study.

RESULTS

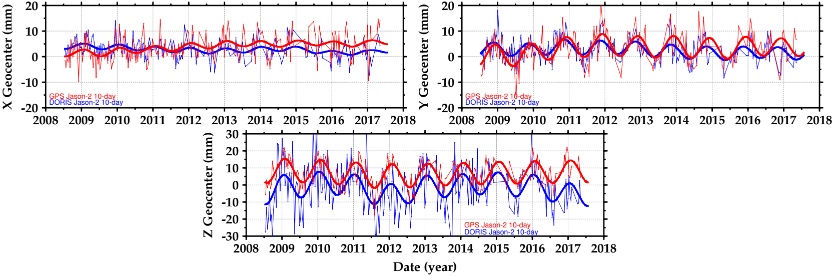
- The GPS network responds well ($\sim 80\ \%$) in all directions to the "translation correction" applied in the GPS satellite clocks.
  - This ratio may depend on the parameterization used in the GPS satellite orbit solutions.



GPS station displacements from a $T_Z = -1\ \mathrm{cm}$ translation in the GPS satellite clocks.

$\Rightarrow$ *Adjustment* in the Jason-2 LEO satellite orbit determination of this parametric correction in the GPS satellite clocks, to mitigate the miscentering effect of the GPS products (and estimate a GPS-based geocenter motion...).

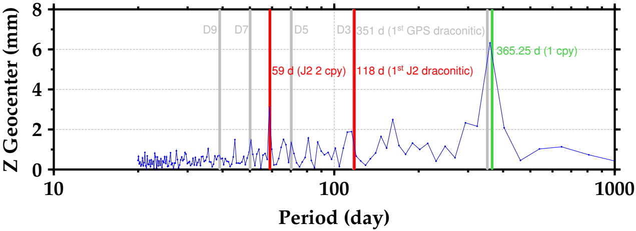
- Good consistency for the annual signal, but different equatorial drifts (IGS08 related ?) and a bias in the North–South direction (see Jason-3 GPS orbits with ambiguity fixing of F. Mercier).
  $\Rightarrow$ We only derive a *seasonal geocenter motion model* for GPS.
  - CM excursion in the Southern Hemisphere around 2012 related to the strong La Nina induced precipitation anomalies over Australia (Boening et al., 2012) ?



GPS and DORIS Jason-2 geocenter coordinate solutions.

DRACONITIC ERROR CONTAMINATION ?

- No significant aliasing of GPS or Jason-2 *draconitic* errors into the Z geocenter coordinate derived from GPS and the Jason-2 LEO satellite data.



Amplitude spectra of the GPS Jason-2 Z geocenter coordinate.

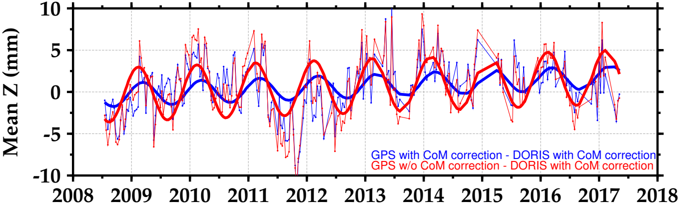
COMPARISON WITH INDEPENDENT MODELS

- 1 : GPS+GRACE (Haines et al. 2015), 3-day estimates (*the Z coordinate should be disregarded* because of spurious signals at draconitic periods)
- 2 : SLR L1+L2 (CN) (Ries 2016), 30-day estimates
- 3 : SLR L1+L2 ("CF") (Ries 2016), 30-day estimates
- 4 : DORIS Jason-2 (Couhert et al., 2017-*to be submitted*), 10-day estimates
- 5 : SLR Jason-2 (Couhert et al., 2017-*to be submitted*), 10-day estimates
- 6 : GPS Jason-2 this study, 10-day estimates

Solution	X		Y		Z	
	A (mm)	ϕ (day)	A (mm)	ϕ (day)	A (mm)	ϕ (day)
1	0.9	105	3.5	334	-	-
2	2.3	61	2.3	317	6.1	41
3	1.7	59	2.7	322	3.6	39
4	1.6	16	3.2	322	6.4	18
5	1.5	21	3.1	302	5.9	21
6	1.7	19	4.1	336	6.8	28

IMPROVED CONSISTENCY FOR GPS/DORIS

- Reduction of the ~ 4 mm annual signal to the $1-$ mm level, when correcting the GPS satellite clock solutions.



Jason-2 mean Z orbit differences between GPS-derived and DORIS-only dynamic orbits, before and after correcting the GPS satellite clocks.

- *Solved-for fixing ambiguities* would have reduced the differences further :
  - The shift induced on Jason GPS-only orbits would be of ~ 50 % of the geocenter signal (instead of ~ 30 %), reducing the annual signal of ~ 3 mm (instead of ~ 2 mm) and removing the $1-$ mm signal left.

CONCLUSION

- Even though the lack of a geocenter model is less dramatic for the GPS measurements compared to the DORIS and SLR techniques (more rigidly tied to the crust), we should expect to get consistent orbits regardless of the tracking system used.

- We tested in this study an approach that enables the GPS products to be referenced w.r.t. the CM of the Earth, instead of the CF (at least for the annual part).
  - The observation of the geocenter motion with GPS and the Jason-2 LEO satellite seems possible based on these results.

- Further progress could be performed using IGS14 orbit and clock products and fixing ambiguities with Jason-3, in order to also have access to the pluri-annual variations of the geocenter motion with GPS (not only the seasonal signal).