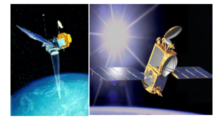

The effect of geocenter motion on Jason-2 orbits and the mean sea level

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OSTST 2012
Venice, IT

Abstract

We have investigated the impact of geocenter motion on Jason-2 orbits. This was accomplished by computing a series of Jason-2 GPS-based and SLR/DORIS-based orbits using ITRF2005 and the IGS05 framework based on the most recent GSFC 0905 standards. From these orbits, we extract the Jason-2 orbit frame translational parameters per cycle by the means of a Helmert transformation between a set of reference orbits and a set of test orbits. The fitted annual terms of these time-series are compared to two different geocenter motion models. Subsequently, we included the geocenter motion corrections in the POD process as a degree-1 loading displacement correction to the tracking network of the POD process. The analysis suggested that GSFC\'s Jason-2 std0905 GPS-based orbits are closely tied to the center of mass (CM) of the Earth whereas the SLR/DORIS std0905 orbits are tied to the center of figure (CF) of the ITRF2005 (Melachroinos et al., 2012).

We quantified the GPS and SLR/DORIS orbit centering and how this impacts the orbit radial error over the globe, which is assimilated into mean sea level (MSL) error, from the omission of the annual term of the geocenter correction. We find that for the SLR/DORIS std0905 orbits, currently used by the oceanographic community, only the negligence of the annual term of the geocenter motion correction results in a – 4.67 ± 3.40 mm error in the Z-component of the orbit frame which creates 1.06 ± 2.66 mm of systematic error in the MSL estimates, mainly due to the uneven distribution of the oceans between the North and South hemisphere.

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Introduction

The origin of the International Terrestrial Reference System (ITRS) is defined to be the center of mass of the Earth system, including oceans, atmosphere and continental water (McCarthy and Petit 2004). Ideally, the origin of the International Terrestrial Reference Frame (ITRF), realization of the ITRS, to which the Jason orbits are referenced, should coincide with the *mean center of mass* (CM) of the entire Earth system. Although, the realization of the reference frame, through the tracking stations, centered in the CM, and the separation from physical processes to which the stations are subject, is a coupled problem. For example, according to the principal of the conservation of momentum, the CM has to be a kinematic fixed point, invariant to terrestrial dynamic processes (Blewitt 2003). However, the redistribution of masses in the Earth system causes geocenter motion and as such seasonal, annual and trend variations between the CM and the center of figure - CF (geometric center of the outer surface of the solid Earth) to which the actual ITRF is referenced for sub-secular time scales (Dong et al., 2003; Blewitt et al., 2001). Métivier et al. (2010) have found that *global ice melting on the Earth can induce long-term displacements of the geocenter* particularly along the Z-axis, toward the North Pole. They have calculated that the geocenter velocity can reach 0.7-0.8 mm/yr and is today most probably between 0.3 and 0.8 mm/yr. As such, for the purpose of accurate geodetic observations, *having access to a nearly instantaneous geocenter* is extremely important for those missions that can sense geocenter motions to some extent but are not good enough to measure it well independently (Wu et al., 2012). Furthermore, the CM is directly related to satellite orbital motion and so is the most appropriate choice to model satellite geodetic measurements (Fritsche et al. 2010), such as altimetry.

From the above, and given the *required sea level infrastructure stability of 0.1 mm/yr (Cazenave et al. 2009)*, geocenter motion of the CM with respect to the CF, ideally, should also be included in the process of precise orbit determination (POD), which is based on the site crust-fixed coordinates of GPS, SLR, and DORIS stations. This movement can be thought of as a global degree-1 loading displacement correction to be applied to the crust-fixed coordinates of the tracking network in order to reference them to the CM of the whole Earth (Cerri et al. 2010). Hitherto, the lack of a community consensus on a geocenter model has not allowed the geocenter to be forward modeled as part of the Jason altimetry orbit standards (Cerri et al. 2010). Therefore, our motivation for this investigation arises from the fact that the realization of an orbital frame for altimetry centered in the CM plays a major role in the definition and accurate calculation of the rates of global MSL rise.

Table 1: Description of the Jason-2 orbit solutions used in this study

POD name used in the text	Description
gpsdyn	GSFC's GPS dynamic
gpsred	GSFC's GPS reduced dynamic
*gpsdyn_com_csr_*	GSFC's GPS dynamic + Cheng et al. 2010 CoM correction
*gpsdyn_com_swn_*	GSFC's GPS dynamic + Swenson et al. 2008 CoM correction
SLR/DORIS	GSFC's *SLR/DORIS* dynamic
SLR/DORIS_com_csr	GSFC's *SLR/DORIS* dynamic + Cheng et al. 2010 CoM correction
SLR/DORIS_com_swn	GSFC's *SLR/DORIS* dynamic + Swenson et al. 2008 CoM correction
jpl11a	JPL's release-11a GPS reduced dynamic

The north/south centering of the Z-component

We incorporated the 3-dimensionnal annual term from the geocenter motion models of Swenson et al. (2010) and Cheng et al. (2010) inside the Jason-2 POD process (trends and biases removed) as a correction to the a-priori position of the tracking stations according to Dong et al. (2003):

$$X^{CM}(t) = X^{CF}(t) + X^{CM}_{CF}(t) \quad (1)$$

Where

$$X^{CF}(t) = X^{CF}_0 + V^{CF}_0(t) + \sum_i \Delta X^{CF}_i(t) \quad (2)$$

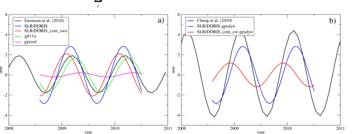

Fig. 2: Jason-2 fitted annual signal of the Z-component time-series from the 7-parameter transformation between the *gpsdyn* (reference orbit) and the test orbits: *SLR/DORIS*, *jpl11a* and *gpsred*. a) compared to the Swenson et al. (2010) applied only in the *SLR/DORIS* orbits, b) compared to the Cheng et al. (2010) applied only to the *SLR/DORIS* orbits

Spurious signals in the Jason-2 orbit origin

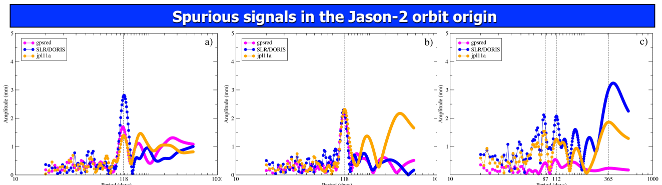

Fig.1 : Periodogram (in mm) of the orbit origins after a 7-parameter Helmert transformation between the NASA GSFC Jason-2 GPS-based dynamic orbits and the three test orbits: NASA GSFC Jason-2 GPS-based reduced-dynamic (*gpsred*), NASA GSFC Jason-2 *SLR/DORIS dynamic* and JPL Jason-2 GPS-based reduced-dynamic (*jpl11a*). a) X-component, b) Y-component, c) Z-component. In purple, blue and orange are the comparisons to GSFC's *gpsred*, *SLR/DORIS* dynamic orbits and *jpl11a* GPS-based reduced dynamic orbits respectively.

a) & b) 118-day signal is dominant in the X and Y components with the largest amplitudes of 2.8 mm and 2.3 mm respectively. The 118-day signal is the precise draconitic (beta-prime) period for the Jason satellites and this result supports the earlier discussion about the remaining orbit error due to solar radiation pressure (SRP) mis-modeling by Cerri et al. (2010) and Zelensky et al. (2010).
c) in the Z-component the annual signature has the largest amplitude .

Shift in the orbit frame

Geocenter model	Annual Amplitude	Geocenter model applied	Ratio of the reduction to the *SLR/DORIS – gpsdyn* signal	Ratio of the reduction to each model
Swenson et al. 2010	1.85			
Cheng et al. 2010	4.24			
Helmert transformation (ref. orbit *gpsdyn*)	Annual Amplitude			
SLR/DORIS	2.82			
*SLR/DORIS*_com_swn	2.10	Swenson et al. 2010	25 %	39 %
*SLR/DORIS*_com_csr	1.17	Cheng et al. 2010	58 %	39 %

Table 2: Z-component annual amplitudes (mm) from each geocenter motion model and orbit transformations compared to the ratios of reduction in the annual signature to each geocenter motion model and the *SLR/DORIS – gpsdyn* comparison

Amplitudes of the propagated signals in the Z-component

Helmert transformation	Ref. Orbit	Amplitude (mm)	Phase (degrees)	Ratio of the resulted signature to each model
gpsdyn_com_swn	*gpsdyn*	0.3	62.7	16 %
gpsdyn_com_csr	*gpsdyn*	0.8	4.9	19 %
*SLR/DORIS*_com_csr	*SLR/DORIS*	3.1	7.2	74 %
*SLR/DORIS*_com_swn	*SLR/DORIS*	1.5	64.3	81 %

Table 3: Z-component annual amplitudes (mm) and ratios from each orbit solution after the geocenter motion correction to each model

Geocenter motion and mean sea level

Geographical distribution of the amplitudes of the radial orbit differences

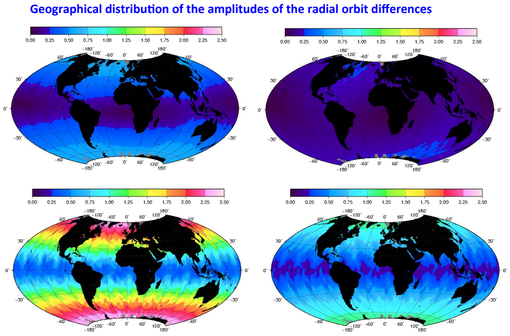

Fig. 3 Amplitude (in mm) of the geocenter motion correction as it maps into the radial orbit differences (DH) of the *gpsdyn* (up) and the *SLR/DORIS* (bottom) orbit frame. Left from Cheng et al. (2010) and right from Swenson et al. (2010).

Phases of the geocenter motion correction as this propagates over the globe into the orbit's radial component

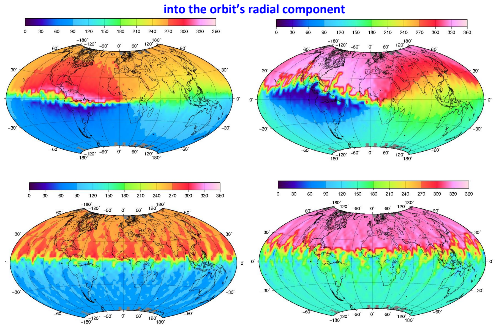

Fig. 4 Phase (in degrees) of the geocenter motion correction as it maps into the radial orbit differences (DH) of the *gpsdyn* (up) and the *SLR/DORIS* (bottom) orbit frame. Left from Cheng et al. (2010) and right from Swenson et al. (2010).

The systematic error from the modeled geocenter motion affects more the SLR/DORIS orbits. Propagates with the same transfer function in the GPS and SLR/DORIS orbits.

Orbit comparisons	Ref. Orbit	Tz (mm)	DH (mm)	DH/Tz
*SLR/DORIS*_com_csr	*SLR/DORIS*	-4.67 ± 3.40	1.06 ± 2.66	-0.22
gpsdyn_com_csr	*gpsdyn*	-0.82 ± 0.28	0.17 ± 0.37	-0.21

The geographical distribution of the MSL from the CoM omission error

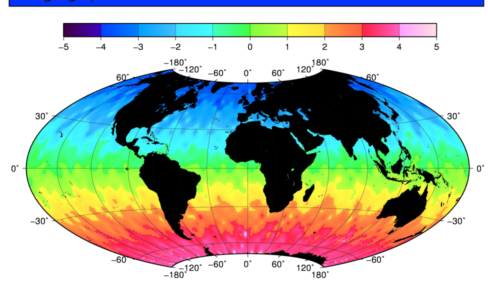

Fig. 5 Observed geographical MSL error (in mm) resulting from the geocenter motion model of the *SLR/DORIS* stations from Cheng et al. (2010) for Jason-2 cycle 058 (Jan 28-Feb 07, 2010)

Conclusions/Future work

- We've shown that the comparison of the *gpsdyn* to the *SLR/DORIS* orbits exhibits a large annual signal in the Z-component suggesting a motion of the origin between the two orbit sets.
- The *jpl11a* orbits (Bertiger et al. 2010) also exhibit an annual signature in Z when compared to the *gpsdyn* orbits but of smaller amplitude.
- The 7-parameter transformation between the *gpsred* and *gpsdyn* orbits, demonstrated that both orbits sets have a very consistent Z-origin. Based on these facts, we have concluded that our *gpsdyn* orbits closely follow the CM consistent with our conservative force modeling, while the *SLR/DORIS* are centered closer to the origin of the ITRF, which is the CF for sub-secular scales
- Future work could focus on the forward modeling of the seasonal displacements at the stations together with the complete geocenter model correction.
- Métivier et al. (2010) have calculated that the geocenter velocity can reach 0.7-0.8 mm/yr and is today most probably between 0.3 and 0.8 mm/yr. Especially in the last decade it seems that there's an increase in the geocenter velocity not superior to 0.5 mm/yr. Since one of the main objectives in the present development of altimetry MSL is stability at the 0.1 mm/yr level (Cazenave et al. 2009), it would be very interesting to extend the current study to the whole period of Jason-1 and Jason-2 with a complete geocenter motion correction.