Time Variable Gravity modeling for Precise Orbits across the TOPEX/Poseidon, Jason-1 and Jason-2 Missions

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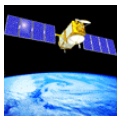


ABSTRACT

Modeling of the Time Variable Gravity (TVG) is believed to constitute one of the largest remaining sources of orbit error for altimeter satellite Precise Orbit Determination (POD). The GSFC operational TVG model consists of forward modeling the atmosphere gravity using ECMWF 6-hour pressure data, a GRACE derived 20x20 annual field to account for changes in the hydrology and ocean water mass, and linear rates for C_{20}, C_{30}, C_{40}, based on 17 years of SLR data analysis (IERS 2010), and linear rates for C_{21}, S_{21} (IERS 2003) using the EIGEN-GL04S1 (a GRACE+Lageos-based geopotential solution) Although the GSFC operational TVG model can be applied at anytime, there may be long-term variations not captured by these linear models, and more importantly the linear models may not be consistent with more recent surface mass trends due to global climate change We have evaluated the impact of TVG modeling on POD in two different ways: (1) by using the more recent EIGEN6S gravity model developed by the GFZ/GRGS team, which consists of annual, semi-annual and secular changes in the coefficients to 50x50 determined over 6.5 years of GRACE+Lageos data (2003-2009.5) and include GOCE data; (2) application of 4x4 time series developed from multi-satellite SLR+DORIS weekly solutions based on GGM03s that span the period from 1993 to 2011. POD tests were conducted for TOPEX/Poseidon (TP), Jason-1 (J1), and Jason-2 (J2) over 1993-2011. Although EIGEN6S shows significant improvement for J2 POD spanning 2008 – 2011, it also shows significant degradation for TP POD from 1992. The GSFC 4x4 SLR+DORIS-based time series which spans 1993 to mid 2011 shows promise for POD over this period. We evaluate the performance of the different TVG models based on analysis of tracking data residuals, use of independent data such as altimeter crossovers, and through analysis of differences with internally-generated and externally generated orbits.

TVG models and orbit sensitivity

Below the three plots illustrate: 1) error in current TVG modeling can affect orbits radially at the 1-cm or more, 2) gravity coefficients change over time as illustrated by the GSFC estimates of C_{20} and a TVG model developed over a limited time span may not capture these changes, 3) orbits are not sensitive to variation in individual TVG model coefficients, such as C_{20}, C_{21}, S_{21}. A 4x4 subset of the 50x50 EIGEN6S 50X50 TVG field accounts for 78% of the effect variance.

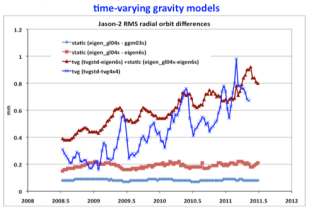
Time Varying Gravity (TVG) Modeling

TVG	Description (atmosphere gravity is forward modeled using ECMWF 6-hour pressure data)
tvgstd	Linear rates for C_{20}, C_{30}, C_{40}, C_{21}, S_{21}, (IERS 2010, 2003) based on 17 years of SLR data. 20x20 annual field derived from 4 years of GRACE data.
eigen6s	GFZ/GRGS 50x50 annual, semi-annual and linear terms estimated simultaneously with 240x240 static field determined over 6.5 years of GRACE+Lageos data (2003-2009.5), and including GOCE data.
tvg4x4	GSFC time series of smoothed gravity coefficients to degree/order 4x4 determined weekly from SLR tracking to Lageos1, Lageos2, Starlette, Ajisai, Stella, and SLR/DORIS tracking to TOPEX/Poseidon, and Envisat, with GGM03s (120x120) background model; from 1993.

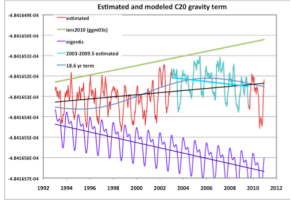
TVG POD Tests

TVG Test	Description
std1007	ITRF2008 SLR/DORIS dynamic orbits using eigen_gl04s
eigen6s	as std1007 using eigen6s (50x50 tvg coefficients)
eigen6s_4x4	as eigen6s but with only 4x4 eigen6s tvg coefficients
eigen6s_c20	as eigen6s but with C_{20} from tvgstd
eigen6s_cs21	as eigen6s but with C_{21}, S_{21}, from tvgstd
eigen6s_tvgstd	as eigen6s but with tvgstd
tvg4x4	as std1007 using GSFC tvg4x4 series
jpl11a	JPL Jason2 GPS reduced-dynamic rlse11a

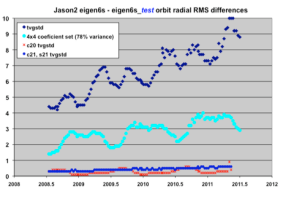
1a) orbit sensitivity to differences in current static and time-varying gravity models



2a) TVG model advantages/disadvantages - illustration



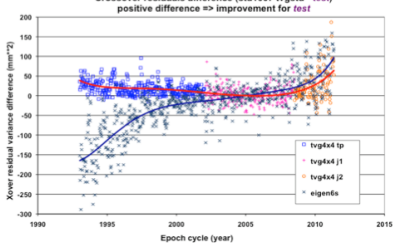
3a) orbit sensitivity to individual TVG coefficient terms



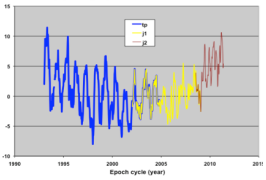
Performance across Missions

Below the five graphs illustrate: 1) tvg4x4 improves the orbit across the TP, J1, J2 missions; EIGEN6S improves the orbit only after about 2005, 2) radial orbit differences over specific regions such as the Indian Ocean show annual and other trends which would significantly impact regional Mean Sea Level (MSL) altimeter analysis and could be verified with tide gauge data, 3) mean radial differences over all water also show significant variation especially over the Jason-2 period, 4) the progressive and correlated improvement of tvg4x4 over the Jason-2 period suggests significant degradation of the tvgstd model, 5) eigen6s also improves the Jason-2 orbit, and jpl11a reduced-dynamic appears to accommodate TVG error as will be shown later.

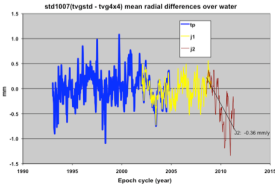
1b) tvg4x4 shows orbit improvement across TP, J1, J2, eigen6s after about 2005



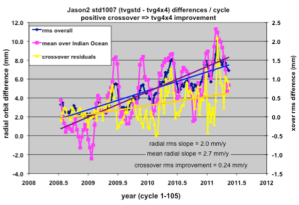
2b) std1007 (tvgstd –tvg4x4) mean radial differences / cycle over Indian Ocean (notice consistency for mission overlap)



3b) std1007 (tvgstd –tvg4x4) mean radial differences / cycle over water (notice apparent change for Jason-2)



4b) tvg4x4 shows progressive Jason2 orbit improvement



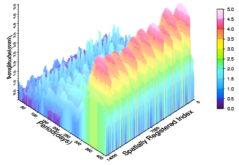
5b) Jason-2 orbit performance cycles 1-105

Test	residuals		
	doris (mm/s)	slr (cm)	xover (cm)
std1007	0.3704	1.148	5.449
tvg4x4	0.3704	1.133	5.424
eigen6s_4x4	0.3705	1.144	5.419
eigen6s	0.3704	1.128	5.407
jpl11a	0.3700	1.139	5.323

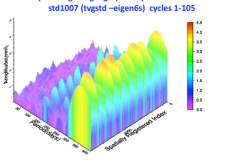
Jason-2 orbit differences between TVG modeling

Below the graphs illustrate: 1) tvgstd TVG error is largely represented with an annual and to a lesser degree semi-annual term, and 2) orbit rates separated by hemisphere. Although the two TVG models (tvg4x4, eigen6s) and the reduced-dynamic jpl11a approach improve the Jason-2 orbit (Table 5b), the orbit characteristics and especially orbit rates significantly differ and warrant further study.

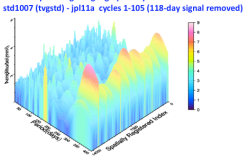
Jason2 periodogram geographically fixed radial differences std1007 (tvgstd –tvg4x4) cycles 1-105



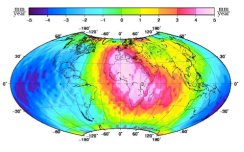
Jason2 periodogram geographically fixed radial differences std1007 (tvgstd –eigen6s) cycles 1-105



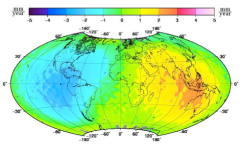
Jason2 periodogram geographically fixed radial differences std1007 (tvgstd) - jpl11a cycles 1-105 (118-day signal removed)



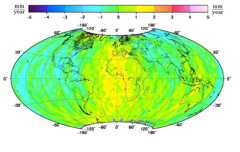
Jason2 std1007 (tvgstd–tvg4x4) radial orbit rates cycles 1-105 (annual and semi-annual terms removed)



Jason2 std1007 (tvgstd–eigen6s) radial orbit rates cycles 1-105 (annual and semi-annual terms removed)



Jason2 std1007 (tvgstd) - jpl11a radial orbit rates cycles 1-105 annual and semi-annual terms removed



Conclusions & Future Work

1) The differences between current static gravity models have a very small effect on 1-cm POD and are considered small, however error in current TVG models can have a significant effect on 1-cm POD. Three TVG models are evaluated: the standard TVG model (tvgstd), EIGEN6S, and tvg4x4. The jpl11a Jason-2 orbits are included in the tests.

2) Orbits are not sensitive to variations in individual low degree gravity coefficient rates, such as C_{20}, C_{21}, S_{21}. The set of 4x4 EIGEN6S TVG coefficients contribute 78% variance of the total EIGEN6S 50x50 TVG coefficient effect.

3) Compared to the tvgstd, tvg4x4 improves the orbits across the TP, J1, J2 missions. Eigens6s improves the orbits only after about 2005.

4) The tvgstd model shows significant and progressive degradation in accuracy from about 2008/2009. The reason for this degradation is not known. The TVG is much better modeled/accommodated since 2008/2009 using tvg4x4, EIGEN6S, and very possibly the reduced-dynamic approach with GPS. However, the radial orbits show systematic differences between these different modeling approaches.

5) Altimeter analysis of regional MSL will be significantly affected by the TVG model used for POD (see Beckley et al. poster)

6) Testing will continue using comparison with individual tide gauge data (see Beckley et al. poster), and direct comparison with other low degree/order gravity coefficient time series.

7) The GSFC tvg4x4 gravity coefficient time series will include Jason2 and will be recomputed.

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