Orbit error due to time variable gravity and impact on mean sea level trend estimates and tide gauge calibration

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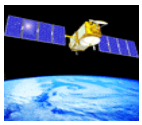

ABSTRACT

The stability and accuracy of the satellite orbit through time is essential to altimeter data analysis. Studies have shown the previously applied simple POD modeling of time variable gravity (TVG) has become increasingly less adequate since about 2005, and have suggested the recent increase in ice melt as one of the causes. Several new TVG models have emerged showing progressive improvement over the simple model as indicated by the Jason-1/2 and Envisat SLR and Crossover residuals. The new models include GRACE-derived 50x50 gravity coefficient 10-day snapshots, SLR+DORIS 4x4 7-day snapshots, and the application of the reduced-dynamic technique. Regardless of the improvement in SLR and Crossover residuals, the models differ considerably in their orbit projections affecting regional estimates of mean sea level (MSL) and changes in mean sea level. Such differences can also impact tide gauge calibration analysis. This study compares the Jason-2 SLR/Crossover residuals and projected Jason-2 orbit difference trends considering the GDRD, JPL Rlse11a, and several new orbits from GSFC. The new GSFC orbits include SLR+DORIS reduced-dynamic processing using the GRACE-derived 50x50 and SLR+DORIS 4x4 snapshot TVG models. The study also examines the sensitivity of the reduced-dynamic SLR+DORIS orbits to TVG, potential impact on tide gauge calibration using the various TVG models, and the question of identifying the best TVG model.

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TVG models and POD performance

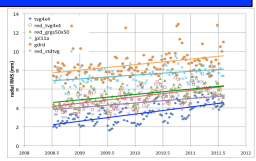
Orbits and Time Varying Gravity (TVG) Modeling

Orbit	TVG Description (atmosphere gravity is forward modeled using ECMWF / NCEP 6-hour pressure data)
GSFC stdtvg, std1007, red_stdtvg	**stdtvg:** Linear rates for C_{20}, C_{30}, C_{40}, C_{21}, S_{21}, (IERS 2010, 2003) based on 17 years of SLR data. Plus 20x20 annual field derived from GRACE data. EIGEN_GL04S / GGM03S static fields. GOT4.7 tides
GSFC std1204	**goco2s_fit2:** GSFC annual, semi-annual and linear terms estimated from the 19-year **tvg4x4** time series are applied depending on the coefficient. GOCO2S static field. GOT4.8 Ocean tides.
GSFC experimental tvg4x4, red_tvg4x4	**tvg4x4:** GSFC 4X4 7-day time series from 1993 re-estimated using SLR/ DORIS tracking to 11 satellites; GGM03S static field. Plus 20x20 annual field derived from GRACE data from degree/order 5x5
GSFC experimental grgs50x50, red_grgs50x50	**grgs50x50:** GRGS RL02 50x50 10-day time series estimated using GRACE +Lageos; GRGS RL02 mean is the reference field.
CNES gdrd	EIGEN-GRGS_RL02bis_mean, annual, semi-annual and linear terms up to degree/order 50 determined 2003-2011. FES2004 Ocean tides.
JPL jpl11a	GPS-based reduced-dynamic rlse11a, no TVG (including tides) or forward modeling of atmosphere gravity. GGM02C static field.

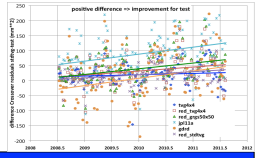
Jason-2 POD Performance

Jason-2 cycles 1-114 Jul 2008 – Aug 2011 external ephemeris test	average RMS residuals SLR (cm)	Crossover (cm)
std1007 (former Measures; slr, doris dynamic; gdr-c compatible)	**1.176**	**5.481**
std1204 (current Measures; slr, doris dynamic; gdr-d compatible)	**1.055**	**5.413**
stdtvg (as std1204 but stdtvg TVG)	**0.980**	**5.422**
tvg4x4 (slr, doris dynamic)	**1.019**	**5.405**
grgs50x50 (slr, doris dynamic)	**1.032**	**5.401**
red_stdtvg (reduced dynamic)	**1.067**	**5.405**
red_tvg4x4 (reduced dynamic)	**1.069**	**5.393**
red_grgs50x50 (reduced dynamic)	**1.081**	**5.386**
gdrd (slr, doris, gps dynamic)	**1.291**	**5.416**
jpl11a (gps reduced dynamic)	**1.184**	**5.341**

The old TVG (stdtvg) orbit progressively diverges from six orbits with recent TVG modeling

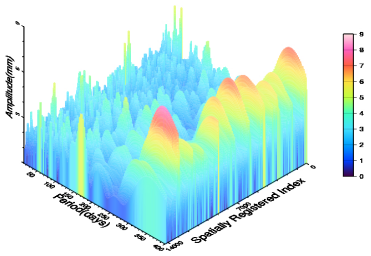


The old TVG (stdtvg) orbit accuracy progressively degrades compared to six orbits with recent TVG modeling

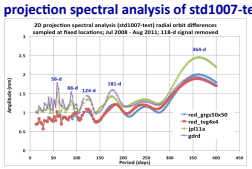


Jason-2 TVG orbit error impact on sea level – manifest as periodic signals and regional trends (mm/y)

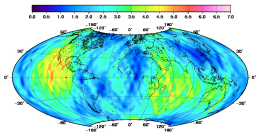
Spectral analysis of std1007-jpl11a radial differences over fixed geographic locations (118-day signal removed)



2-D projection spectral analysis of std1007-test

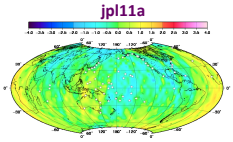


Annual amplitude projection std1007-jpl11a

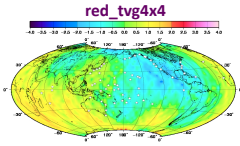


std1007-test orbit radial difference linear rates (mm/yr) estimated July 2008 – August 2011 after removing annual, semi-annual, and 118-day terms.

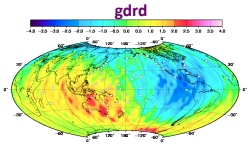
jpl11a



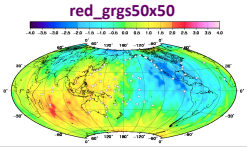
red_tvg4x4



gdrd



red_grgs50x50



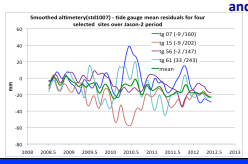
Tide gauge calibration sensitive to Jason-2 TVG regional trend orbit error

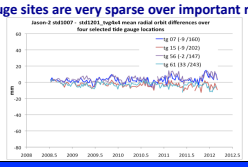
Altimetry-Tide Gauge Calibration Sensitivity to Jason-2 orbits cycles 1-114 (Jul 2008 – Aug 2011)

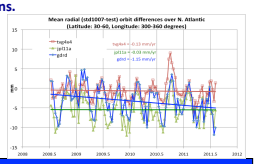
Estimated linear rate (mm/y)	Orbit std1007	tvg4x4	red_tvg4x4	grgs50x50	gdrd	jpl11a
weighted altimetry-tide gauge calibration estimate over 64 tide gauge sites (see Note below)	-1.00	-----	-----	-----	-----	-----
un-weighted mean orbit differences over 64 tide gauge sites (test-std1007)	0.00	0.33	0.48	-0.24	0.03	0.12
un-weighted altimetry-tide gauge calibration approximation	-1.00	-0.67	-0.52	-1.24	-0.97	-0.88

Note. Gary Mitchum's latest **weighted** altimetry-tide gauge residuals mean for the std1007orbits Jason-2 cycles 1-182 (see Beckley et al., 2013 poster, Global CAL-VAL session).

Direct use of tide gauge data to evaluate TVG models is questionable - tide gauge residuals are much larger than orbit differences and gauge sites are very sparse over important regions.



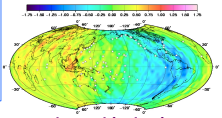




SLR+DORIS reduced-dynamic orbits sensitive to TVG regional trend error

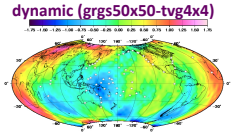
Periodic differences between dynamic / reduced-dynamic orbits largely show power at the 118-day period, followed by the annual and semi-annual periods depending on the gravity field. This suggests the reduced-dynamic largely removes solar radiation pressure (SRP) error followed by TVG orbit error. The linear trend estimates also suggests the reduced dynamic removes some TVG error depending on the gravity field. The largest differences are seen with **stdtvg** which is believed to be the least accurate model. All linear rate plots first have had the annual, semi-annual and 118-day signals removed.

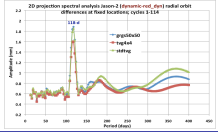
dyn-red (grgs50x50)



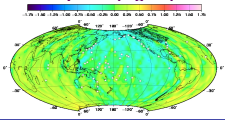
The reduced-dynamic improves the consistency between the grgs50x50 /tvg4x4 orbits as shown in the reduction of power in the periodic signals. However, the regional trend differences are even slightly increased! ***This suggests reduced-dynamic does not eliminate such TVG error at the level of differences seen between competing TVG models.***

dynamic (grgs50x50-tvg4x4)

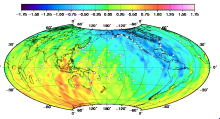


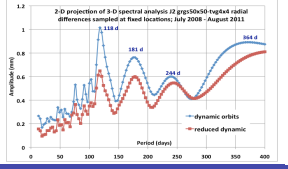


dyn-red (tvg4x4)

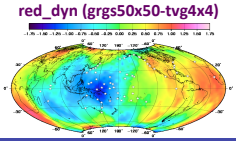


dyn-red (stdtvg)





red_dyn (grgs50x50-tvg4x4)



Conclusions

1) Recent Time Variable Gravity (TVG) models progressively improve Jason-2 orbits over the standard approach used for the previous Measures std1007 and GDRC orbits.
2) TVG orbit error manifests largely as an annual signal and in regional trends. All recent TVG models show significantly different regional trends which can impact sea level trend studies.
3) Tide gauge calibration is sensitive to TVG regional trend orbit error, however tide gauge data can probably not be directly used to evaluate TVG models.
4) SLR+DORIS reduced-dynamic approach does not eliminate TVG regional trend error at the level of differences seen between competing TVG models. There is some evidence the JPL GPS reduced-dynamic orbits are much less sensitive to TVG error and possibly can be used to help evaluate TVG model regional trend error.
5) Future work will try to improve gravity modeling over available GRACE/GOCE data , including the use of the GSFC mascon solutions, and will try to seamlessly extend improved solutions into the past.

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Acknowledgements: We acknowledge the NASA Physical Oceanography program and the MEaSURE's project for their support, as well as the International Laser Ranging Service (ILRS), the International DORIS Service (IDS) and IDS program in Mean Sea Level for their continued support.

OSTST 2013
POD
Boulder, Colorado