An Evaluation of Recent Gravity Models Wrt. Altimeter Satellite Missions

F. G. Lemoine[1], S. B. Luthcke[1], N. P. Zelensky[2,1], D. S. Chinn[2,1], T. A. Williams[2,1], C. M. Cox[2,1], B. D. Beckley[2,1]

[1] *Laboratory for Terrestrial Physics, NASA Goddard Space Flight Center, Greenbelt, Maryland, USA.*

[2] *Raytheon ITSS, Upper Marlboro, Maryland, USA.*

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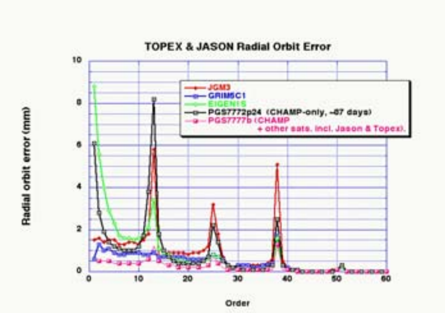
Overview

With the launch of CHAMP and GRACE, we have entered a new phase in the history of satellite geodesy. For the first time, geopotential models are now available based almost exclusively on satellite-satellite tracking either with GPS in the case of the CHAMP-based geopotential models, or co-orbital intersatellite ultra-precise ranging in the case of GRACE. Different groups have analyzed these data, and produced a series of geopotential models (e.g., EIGEN1S, EIGEN2, GGM01S, GGM01C) that incorporate the new data. We will compare the performance of these "newer" geopotential models with the standard models now used for computations, (e.g., JGM-3, EGM96, PGS7727, and GRIM5-C1) for TOPEX, JASON, Geosat-Follow-On (GFO), and Envisat using standard metrics such as SLR RMS of fit, altimeter crossovers, and orbit overlaps. Where covariances are available we can evaluate the predicted geographically correlated orbit error. These predicted results can be compared with the Earth-fixed differences between dynamic and reduced-dynamic orbits to test the predictive accuracy of the covariances, as well as to calibrate the error of the solutions.

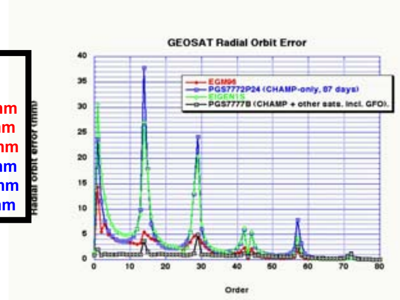
Gravity Model Summary

Gravity Model	Max. deg. & order	Description
JGM3 (1995)	70x70	Update to JGM-2 with TOPEX/GPS, Stella & other satellite data.
EGM96 (1996)	70x70 (360x360)	Model with new satellite-tracking data, altimetry and surface gravity.
DGME04 (1996)	70x70	EGM96 tuned for ERS (by TU Delft).
PGS7727 (2000)	70x70	EGM96 tuned for GFO (by GSFC).
GRIM5C1 (2000)	120x120	Pre-champ model from GRGS/GFZ.
EIGEN1S (2001)	115x115	~88 days of CHAMP + other satellites.
EIGEN2 (2002)	140x140	CHAMP-only model, ~6 months of data.
EIGEN3P (2003)	140x140	CHAMP-only model, ~3 years of data.
OSU03A (2003)	70x70	CHAMP-only model (energy method, OSU).
PGS7772P24 (2003)	99x99	CHAMP-only model, ~87 days of data.
PGS7777B (2003)	110x110	CHAMP (87 days) + other satellites, including SLR sats, GFO, Jason, Envisat.
GGM01S (2003)	120x120	Grace satellite-only model.
GGM01C (2003)	200x200	Grace combination model.

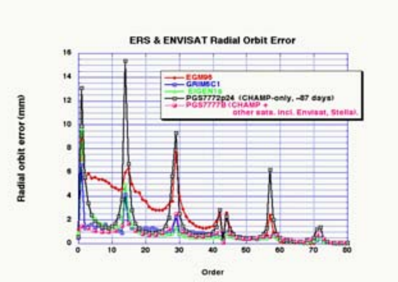
Radial Orbit Error Projections from Gravity Field Error Covariances For Altimeter Satellite Missions



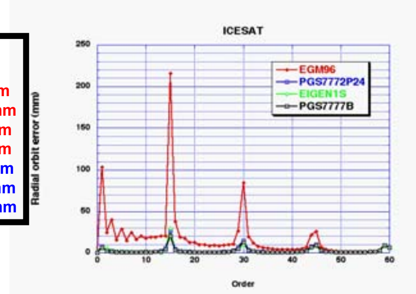
TP & JASON Radial Orbit Error:
- JGM3: 10.5 mm
- TEG3: 10.4 mm
- GRIM5C1: 4.6 mm
- EIGEN1S: 13.4 mm
- PGS7772p24: 12.8 mm
- PGS7777B: 2.8 mm



GEOSAT & GFO Radial Orbit Error:
- JGM2: 65.2 mm
- JGM3: 49.8 mm
- EGM96: 26.2 mm
- PGS7727: 13.2 mm
- GRIM5C1: 57.0 mm
- EIGEN1S: 61.9 mm
- PGS7772p24: 62.8 mm
- PGS7777B: 10.0 mm



ERS & ENVISAT Radial Orbit Error:
- JGM3: 35.5 mm
- TEG3: 27.8 mm
- EGM96: 27.9 mm
- GRIM5C1: 11.2 mm
- EIGEN1S: 14.7 mm
- PGS7772p24: 27.7 mm
- PGS7777B: 8.0 mm



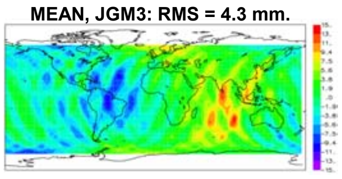
ICESAT Radial Orbit Error:
- JGM3: 679.5 mm
- EGM96: 277.5 mm
- GRIM5C1: 364.5 mm
- EIGEN1S: 36.6 mm
- PGS7772p24: 40.9 mm
- PGS7777B: 35.1 mm

We show the radial orbit error projections for various gravity models. The error projections are calculated via linear theory according to *Rosborough* [1986], and a ten day cutoff is used in the orbit element perturbations. In general, the CHAMP models that do not specifically include data for a satellite orbit still have errors in the resonance orders, and sometimes for the lower orders due to the influence of the m-daily perturbations. This is true for TOPEX/JASON, GEOSAT/GFO, ERS/ENVISAT and ICESAT. None of the CHAMP-only models do well on the GEOSAT/GFO orbit (108° inclination), and the introduction of actual GFO data (SLR & Crossovers) as in PGS7777B is necessary to further reduce the orbit error for this satellite. Of all the pre-CHAMP & GRACE models, GRIM5C1 performs particularly well on the ERS/Envisat orbit. ICESAT, being in a near-polar orbit (94° inclination) like CHAMP, benefits significantly from the addition of the CHAMP data, compared to the pre-CHAMP models such as EGM96 and GRIM5C1. We did not perform the error projections for the GRACE models, GGM01S and GGM01C, since the error covariances for these models have not been distributed.

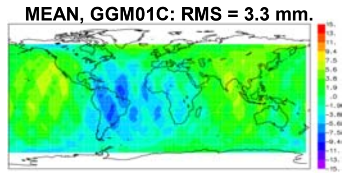
JASON Orbit Difference Analysis

Orbit differences between the dynamic and reduced dynamic orbits can reveal patterns in the geographically correlated and anti-correated error [*Marshall et al.*, 1995], with the caveat that the reduced-dynamic filter acts at frequencies less than about once cycle per revolution (see spectral plots below). We show below the reduced--dynamic (GPS +SLR) vs SLR/DORIS dynamic orbit differences for three gravity models: JGM-3, GGM01C, and GGM01S. With GGM01S, the ampliude of the geographically correlated error is reduced significantly. GGM01C retains the characteristic (C_{ss}/S_{22}) pattern, albeit at a lower amplitude and a different phase than JGM3. This degree two, order two pattern could originate directly due to the distribution of the tracking stations, or indirectly through errors in the reference frame.

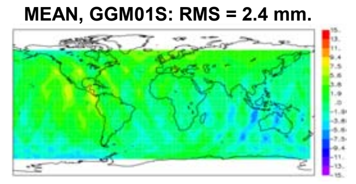
MEAN, JGM3: RMS = 4.3 mm.



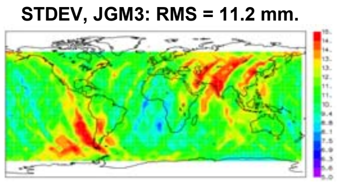
MEAN, GGM01C: RMS = 3.3 mm.



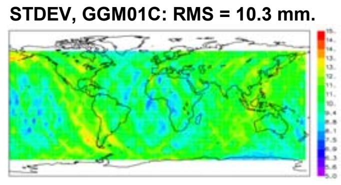
MEAN, GGM01S: RMS = 2.4 mm.



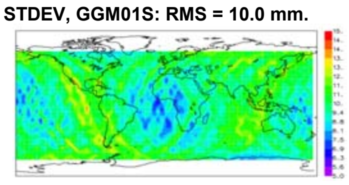
STDEV, JGM3: RMS = 11.2 mm.



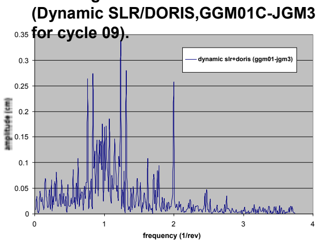
STDEV, GGM01C: RMS = 10.3 mm.



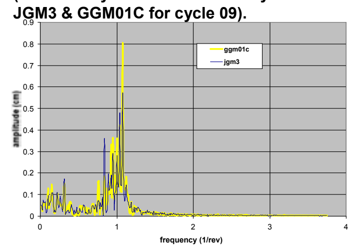
STDEV, GGM01S: RMS = 10.0 mm.



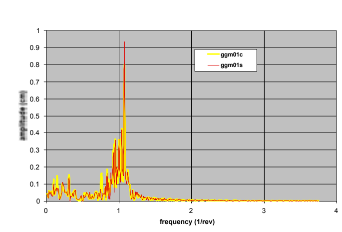
Periodogram: Jason radial orbit differences (Dynamic SLR/DORIS,GGM01C-JGM3 for cycle 09).



Periodogram: JASON radial orbit differences (Reduced dynamic GPS+SLR - Dynamic SLR/DORIS, JGM3 & GGM01C for cycle 09).



Periodogram: JASON radial orbit differences (Reduced dynamic GPS+SLR - Dynamic SLR/DORIS, GGM01C & GGM01S for cycle 09).



Orbit Determination Summary

JASON

GSFC SLR/DORIS Dynamic Orbits

Jason Cycles 8-24
Npts, Doris = 1,843,968.
Npts, SLR = 53,272.
Npts, Xovers = 64449.

Gravity	RMS, Doris (cm/s)	RMS SLR (cm)	RMS, Xovers, (cm)
JGM3	0.421	1.710	5.926
GGM01C	0.421	1.667	5.867
GGM01S	0.419	1.524	5.859
PGS7777B	0.420	1.580	5.922
EIGEN1S	0.427	3.355	6.058
EIGEN3p	0.426	3.379	6.024
EIGEN2	0.427	3.547	6.121
PGS7772p24	0.432	3.042	6.506

GSFC GPS & GPS+SLR Reduced-Dynamic Orbits

Jason Cycles 8-24
Npts, Doris = 1,839,118. Npts, SLR = 53,237.
Npts, Xovers = 64439.
NB: For GPS-only Red-dyn. Orbits, SLR, DORIS & Xovers are *Independent.*
For GPS+SLR Red-dyn Orbits, SLR is *Dependent,* and DORIS and Xovers are *Independent.*

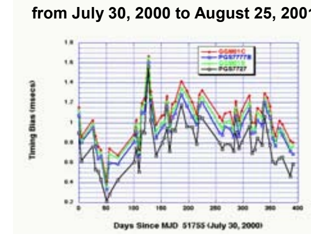
Gravity	RMS, Doris (cm/s)	RMS SLR (cm)	RMS, Xovers, (cm)
GPS, JGM3	0.419	1.698	5.766
GPS+SLR, JGM3	0.419	1.341	5.750
GPS, GGM01C	0.420	1.593	5.757
GPS+SLR,GGM01C	0.420	1.273	5.739
GPS, GGM01S	0.419	1.596	5.754
GPS+SLR,GGM01S	0.419	1.249	5.735

GEOSAT Follow-On (GFO)

RMS over 53 arcs from July 2000 to August 2001.

Gravity	SLR (cm)	Crossovers (cm)
PGS7727	5.07	7.00
PGS7777B	3.62	6.63
PGS7777B + New GFO macromodel	3.59	6.60
GGM01S	3.87	6.67
GGM01C	3.98	6.69
EIGEN1S	9.98	10.50
EIGEN2	5.98	7.87
EIGEN3p	5.36	6.92
GRIM5C1	7.14	10.49
OSU03A	7.70	11.19

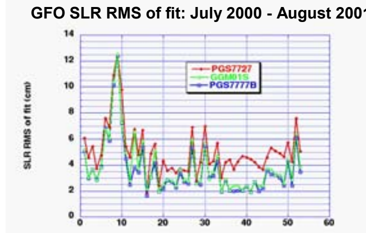
GFO Altimeter Time Biases for arcs from July 30, 2000 to August 25, 2001



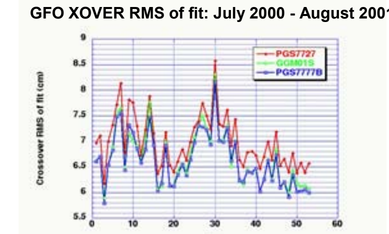
<u>GFO Mean altimeter time biases (msecs):</u>
PGS7727: 0.772 ± 0.032
PGS7777B: 0.945 ± 0.030
GGM01S: 0.999 ± 0.030
GGM01C: 1.059 ± 0.030

GFO arcs are 5-6 days in length, and include Doppler, SLR, and altimeter crossovers from GFO. The GFO Geophysical Data Records (GDR's) and associated corrections therein were used to form the streams of altimetry and derive the altimeter crossovers. The following crossover edit criteria were applied: (1) Reject all crossovers greater than 25 cm; (2) Reject crossovers where sea surface variability is greater than 20 cm; (3) Bathymetry: Edit crossovers where depth is less than 500 meters; (4) Reject crossovers where fit to polynominal around crossover is > 20 cm. In these arcs, empirical accelerations (opr's) were adjusted once/day along & cross track, and C_d 's were adjusted every eight hours.

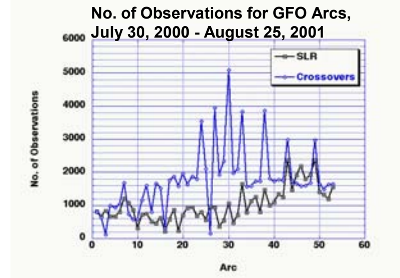
GFO SLR RMS of fit: July 2000 - August 2001



GFO XOVER RMS of fit: July 2000 - August 2001



No. of Observations for GFO Arcs, July 30, 2000 - August 25, 2001

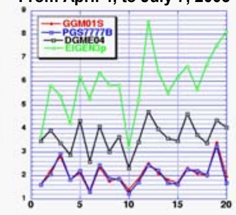


ENVISAT

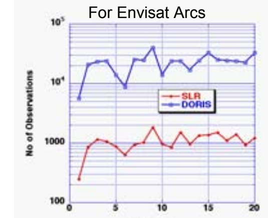
Gravity	SLR (cm)	DORIS (cm/s)
EGM96	4.75	0.587
PGS7727	4.81	0.590
DGME04	3.64	0.574
EIGEN1S	5.95	0.577
EIGEN3p	5.90	0.584
PGS7772P24	3.49	0.579
PGS7777B	2.02	0.561
GGM01S	2.04	0.561
GGM01C	2.05	0.562

The ENVISAT orbit tests used 20 arcs from April 4, 2003 to July 7, 2003. In these arcs, empirical accelerations were adjusted once/day along & cross-track, and C_d 's were adjusted every six hours, where the data permitted. Arcs stopped and started one hour before and after any orbital maneuvers. The CNES supplied macromodel was applied along with the associated ancillary information. The ERS attitude model was applied, with the corrections to the GEODYN ERSATT subroutine pointed out by Eelco Doornbos of TU/Delft.

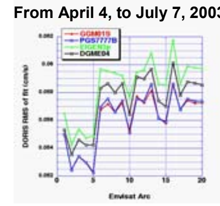
SLR RMS for ENVISAT Arcs From April 4, to July 7, 2003



No of Observations For Envisat Arcs



DORIS RMS for ENVISAT Arcs From April 4, to July 7, 2003



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