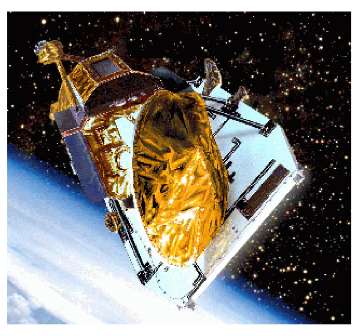
Evaluation of the GEOSAT and GEOSAT Follow-On Precise Orbit Ephemeris



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ABSTRACT

The U.S. Navy GEOSAT mission provided the first long-term altimetric record for studies of ocean circulation, marine gravity/bathymetry and continental ice, from early 1985 through 1989. The GEOSAT Follow-On spacecraft (GFO), launched in 1998, began continuous radar altimeter coverage of the oceans in 2000 and still returns data. By providing high quality altimeter data, GEOSAT delivered the first and only altimetric measurements over the 1980's. At the present, GFO supplements Jason, TOPEX/POSEIDON(T/P), and ENVISAT, providing a different synoptic sampling of the oceans with its 17-day ground track repeat cycle. Altimeter crossover analysis suggests GFO and GEOSAT are capable of POSEIDON class altimetry, both showing crossover residuals averaging below 7.5 cm, with 5-cm orbit error the largest contributor to the altimeter error budget. This study evaluates possible improvements to the recently released GEOSAT GGM02C GDR orbits and current GFO GDR orbits. POD model improvements include using model standards consistent with the latest generation of GSFC reprocessed TOPEX and Jason orbits as well as re-estimated coordinates of the GEOSAT Doppler stations. Here, we summarize the current status of our effort.

GEOSAT

Overview: The GEOSAT 20th anniversary brought about a major upgrade to the Geodetic Mission (GM) data, including the orbits. As described at the March 2006 SWT, the GEOSAT altimeter data have been re-tracked. In our work here we describe how Doppler data from the 53 TRANET and OPNET stations in combination with altimeter crossovers based on the new re-tracked altimeter data were used to compute the orbits based on up-to-date modeling standards.

The main improvement for the new orbits is from (1) the use of the GRACE-derived GGM02C gravity model, which is far superior to the JGM-3 gravity model used in the 1997 GDR release, (2) the inclusion of altimeter crossover with the Doppler data in the new orbit solution, and (3) the use of updated Doppler station coordinates based on a post-EGM96 gravity and station coordinate solution (Table 1). Previously in the 1997 GDR release, only Doppler tracking data were used. Several other aspects of the modeling have also been updated, as shown in Table 1.

Altimeter crossover POD fits of the 110 successive 6-day long orbital arcs during the Geodetic Mission, Fig. 1, yield an RMS height difference of 7.4 cm, consistent with a radial orbit error on the order of only 5 cm.

The mean crossover differences in the JGM-3 GDRs, Fig. 2, exhibited significant geographically correlated orbit error. The new GGM02C orbits have greatly reduced this error, as is particularly evident in areas of "quiet" mesoscale variability, Fig. 2.

In a recent analysis, the Doppler station positions have been re-estimated using data over the GM period (May 1985 – Sep 1986) and the latest POD strategy (Table 1). In this solution, the stations adjusted very little (Table 2), with only small effects on the orbit (Table 3). In the future, analysis of the ERM data should be added for the Doppler station adjustment. The current station velocity set relies on a plate model which could be updated using velocities from nearby current space geodetic sites (GPS, SLR, DORIS) where this is feasible.

GEOSAT Doppler Site Locations

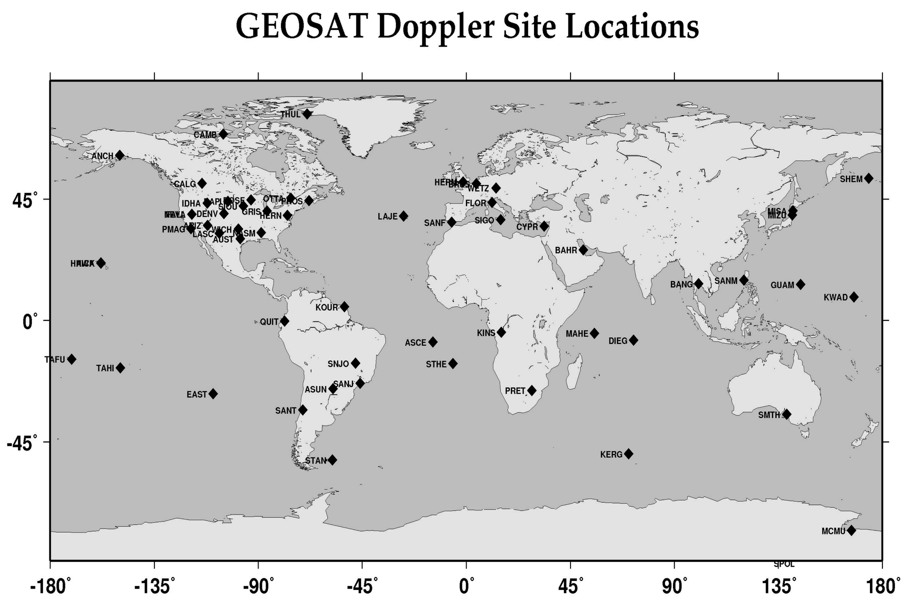


Table 1. GSFC GEOSAT POD modeling improvements

Version	JGM-3 GDR	20th Anniversary
Gravity (static)	JGM3 (70x70)	GGM02C (120x120)
Gravity (time-variable)	C20dot, C21dot, S21dot	C20dot, C21dot, S21dot + 20x20 annual terms from GRACE
Atmospheric gravity	Not applied	NCEP, 50x50 @6 hrs
Ocean Tides	Schwiderski + GEMT3X	(T/P-derived) GOT00.2 (20x20)
Solid Earth Tides	k_2= 0.300; k_3=0.093 + special handling for FCN	IERS2003
Albedo/IR	Knocke & Ries, 1988	Same
Atmospheric drag	MSIS86	MSIS86
Data	Doppler-only	Doppler + Altimeter Crossovers
Parameterization	C_d/day + C_r + once-per-rev/arc	C_d/8 hrs + once-per-rev along+cross-track/day
Doppler station coordinates	JGM2	pgs7727 (post-EGM96: used all ERM & GM Doppler data)

Figure 1. Altimeter crossover residuals (110 arcs)

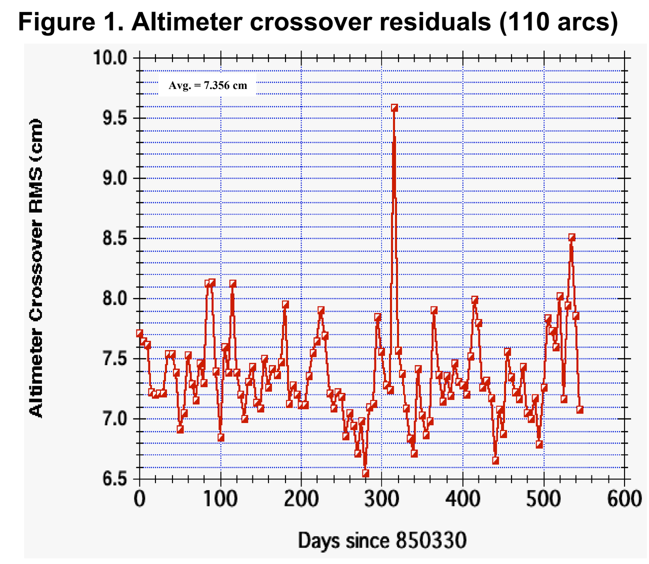


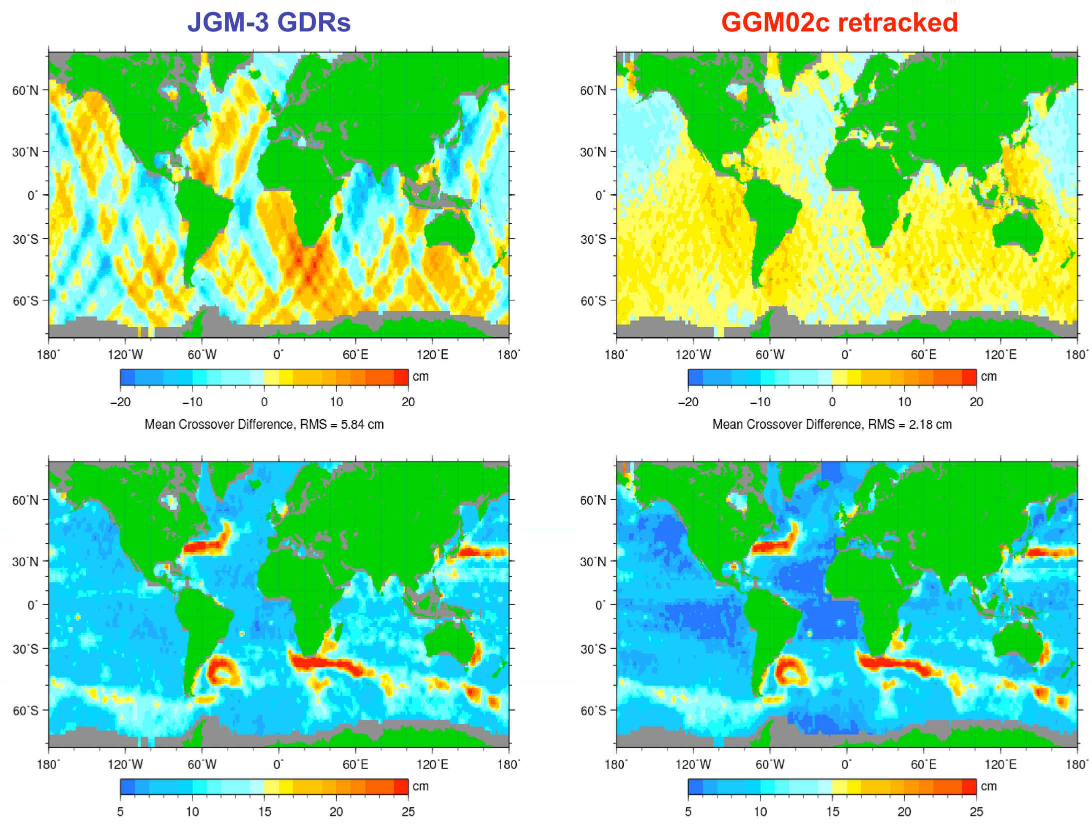
Table 2. Doppler station position differences: New – A-priori(pgs7727)

summary 53 stations	x (mm)	y (mm)	z (mm)
mean	-2.8	-13.1	7.7
standard deviation	37.0	37.0	52.9

Table 3. Orbit evaluation of new Doppler coordinates

station complement	Average RMS residuals (110 arcs)	
	Doppler (cm/s)	Crossover (cm)
A-priori(pgs7727)	0.3226	7.356
New	0.3224	7.356

Figure 2. Mean crossover differences (top) and rms sea level variability (bottom)



GFO

Overview: A progressive series of model improvements (Table 1) has achieved progressively improved orbits (Table 2). Even the early pgs7727 orbits show a 4-5 cm radial error relative to TOPEX (Figure 1). Figure 2 shows differences between the GDR and updated (*tvg, or updated orbits that include GGM02C, and Grace-derived annual terms of time-variable gravity to 20x20, and other improvements; See Table 1*) orbits, illustrating the need for consistency in a time series. Although GFO orbit error is driven by atmospheric drag over periods of high solar activity, the crossover residuals indicate radial error is below 4 cm over periods of solar quiescence (Figure 3). In recent analysis using the released GFO center of mass (COM) change history we have re-tuned the LRA (Laser Retroreflector Array) offset and Doppler station positions. In addition, the Doppler station velocities were assigned the ITRF2000 values of neighboring GPS sites. Previously the Doppler station positions were modeled without velocities. 14 6-day arcs spanning 2000-2006 were used to first re-tune the LRA offset, and using the new LRA value to re-tune the Doppler station positions. The LRA adjusted 1-cm in both body-fixed x and y (Table 3). Table 4 shows the progressive improvement over the GDR orbit by a) including DOPPLER station velocities and the GFO COM history, b) re-tuning the LRA, and c) re-tuning the Doppler station positions. In future analysis we plan to include more arcs for a better estimate of the Doppler station positions and velocities. **Spacecraft Status:** *The spacecraft was launched in 1998, and has been operational for seven years. The s/c batteries in particular are showing signs of age and at present the spacecraft only acquires altimeter data on ascending passes that are not in eclipse.*

Table 1. GFO Orbit Modeling Development (red is 'new')

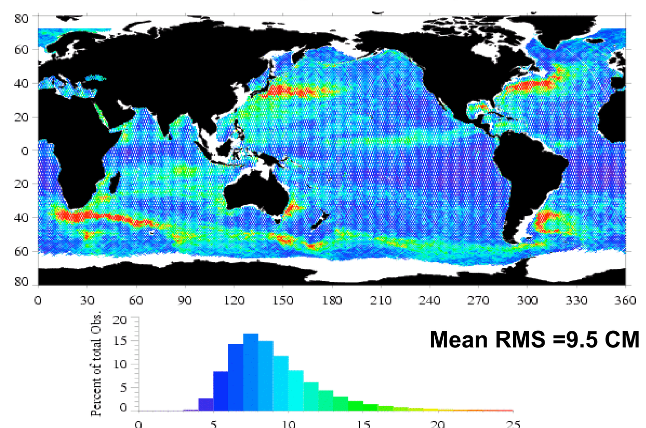
Orbit	pgs7727 (2001)	pgs7777b GDR (2004)	ggm02c (2005)	tvg (2006)
Gravity (static)	PGS7727 (70x70)	PGS7777b (110x110)	GGM02C (120x120)	GGM02C (120x120)
Gravity (time-variable)	C20dot, C21dot, S21dot	same	same	C20dot, C21dot, S21dot + 20x20 annual terms from GSFC GRACE solutions
Atmospheric gravity	Not applied	not applied	not applied	NCEP, 50x50 @6 hrs
Ocean Tides	Ray99 (T/P) + PGS7727 resonant	Ray99 (T/P) + PGS7777b resonant	same	(T/P-derived) GOT00.2 (20x20)
Solid Earth Tides	k_2= 0.300; k_3=0.093 + special handling for FCN.	same	same	IERS2003
Albedo/IR	Knocke & Ries, 1988	same	same	same
Atmospheric drag	MSIS86	same	same	same
surface force macromodel	tuned 8-panel model	re- tuned 8-panel model	same	same
Data	SLR + Altimeter Crossovers + Doppler	same	same	same
Parameterization and arc span	Cd/8 hrs + opr along+cross track/day; 6-day arc	same	same	same
SLR stations	ITRF2000 with ocean loading	same	same	same
Doppler stations	adjusted to the SLR CSR95L02 frame	same	same	same
LRA offset	tuned with 2-months SLR tracking data	same	same	same
precession	IAU1976	same	same	IAU2000
nutation	IAU1980+corrections	same	same	IAU2000

Table 2. Orbit Model Evaluation

Orbit Summary (06/24/05– 08/04/05)	RMS residuals	
	SLR (cm)	Crossovers (cm)
pgs7727	5.317	7.576
pgs7777b	4.127	7.440
ggm02c	4.047	7.472
tvg	4.001	7.421

Figure 1. 4-5 cm GFO orbit error relative to TOPEX inferred from the improvement in the mean rms of the Adjusted GFO SSH variability

GFO Sea Surface Height Variability



Adjusted GFO Sea Surface Height Variability

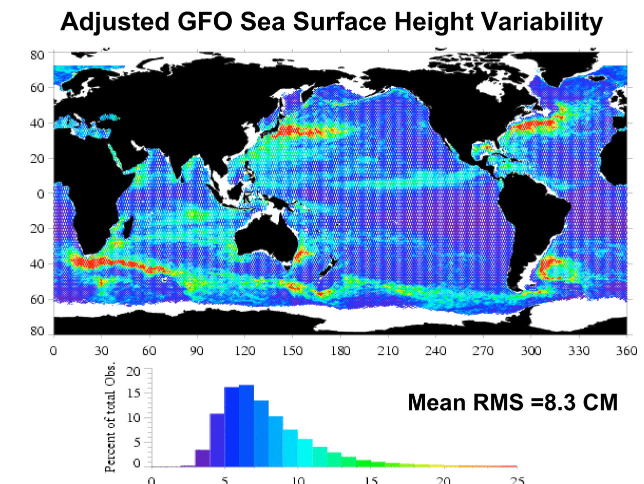


Figure 2. GDR-tvg orbit radial trends estimated over 5x5 degree bins

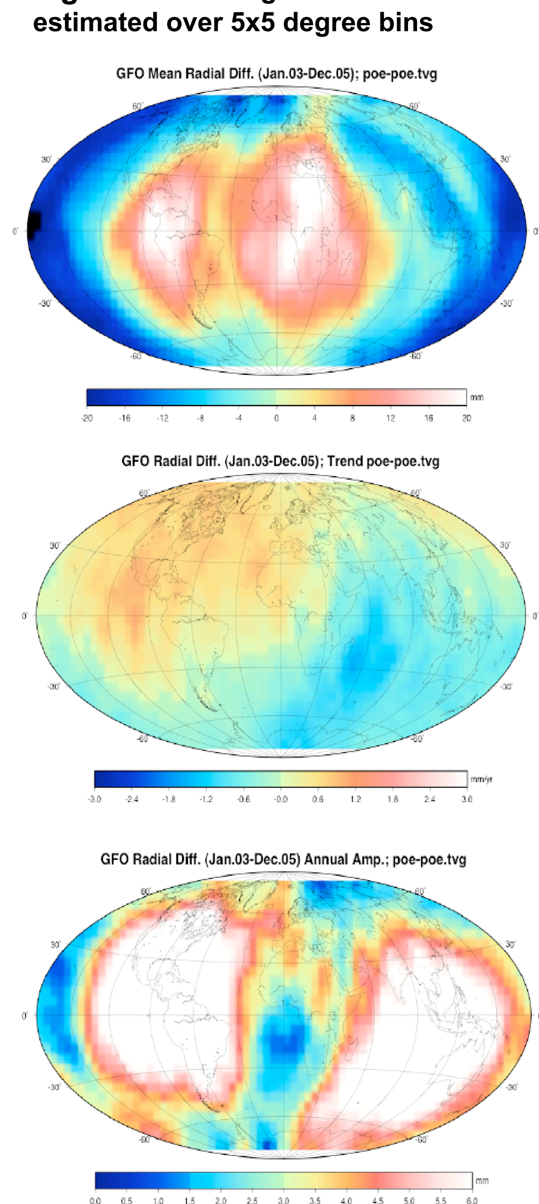
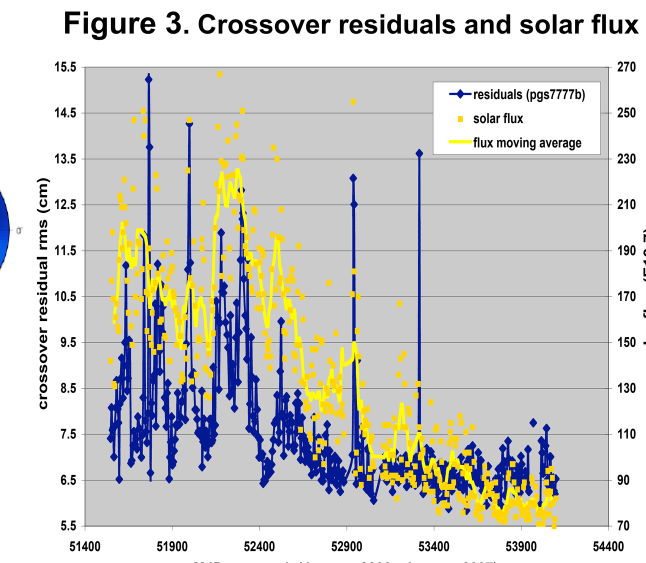


Figure 3. Crossover residuals and solar flux



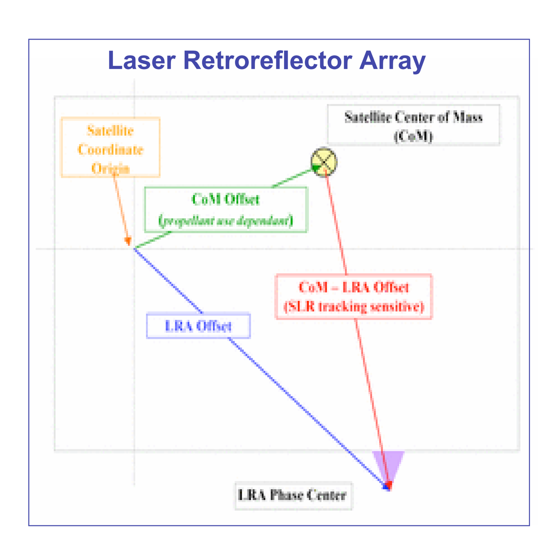


Table 3. LRA offset estimate using 14 arcs (2000-2006)

component	x (m)	y (m)	z (m)
center of mass	+0.9076	+0.0200	-0.0761
LRA *a priori*	+1.0896	+0.7730	+0.5229
LRA Updated Adjustment Sigma	+1.1002 .0106 ± .0067	+0.7822 .0092 ± .0017	+0.5208 -.0021 ± .0016

Table 4. Evaluate LRA and Doppler station tuning

summary over 5 independent arcs (Dec '06)	Doppler rms (cm/s)	SLR mean (cm)	SLR rms (cm)	Crossovers rms (cm)
GDR orbit	1.742	1.070	3.544	6.440
Cgmass history and apply Doppler station velocities from nearby IGS sites.	1.745	1.077	3.492	6.435
b) new LRA	1.745	0.916	3.463	6.434
c) new LRA + new positions for Doppler stations.	1.724	0.903	3.459	6.433

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