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Gravitational Model Improvement at the Goddard Space Flight Center

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ABSTRACT

Major new computations of terrestrial gravitational field models have been performed by the Geodynamics Branch of Goddard Space Flight Center [GSFC]. This development has incorporated the present state of the art results in satellite geodesy and have relied upon a more consistent set of reference constants than has heretofore been utilized in GSFC's GEM models. The solutions are complete in spherical harmonic coefficients out to degree 50 for the gravity field parameters. These models include adjustment for a subset of 66 ocean tidal coefficients for the long wavelength components of 12 major ocean tides. This tidal adjustment was made in the presence of 550 other fixed ocean tidal terms representing 32 major and minor ocean tides and the Wahr frequency dependent solid earth tidal model. In addition 5-day averaged values for Earth rotation and polar motion were derived for the time period of 1980 onward. Two types of models have been computed. These are "satellite only" models relying exclusively on tracking data and "combination" models which have incorporated satellite altimetry and surface gravity data. The satellite observational data base consists of over 1100 orbital arcs of data on 31 satellites. A large percentage of these observations have been provided by third generation laser stations [< 5 cm] . A calibration of the model accuracy of the GEM-T2 "satellite only" solution indicated that it was a significant improvement over previous models based solely upon tracking data. The rms geoid error for this field is 110 cm to degree and order 36. This is a major advancement over GEM-T1 whose errors were estimated to be 160cm. An error propagation using the covariances of the GEM-T2 model for the TOPEX radial orbit component indicates that the rms radial errors are expected to be 12 cm. The "combination" solution, PGS-3337, is a preliminary effort leading to the development of GEM-T3. PGS-3337 has incorporated global sets of surface gravity data and the Seasat altimetry to produce a model complete to [50,50]. A solution for the dynamic ocean topography to degree and order 10 was included as part of this adjustment.

INTRODUCTION

High precision ground based tracking of artificial satellites has provided an observational data set which has formed the basis for long-wavelength spherical harmonic models of the Earth's gravitational field. These data have been used at GSFC to calculate improved gravitational field models. Improvements in modeling the Earth's gravitational field are important for the calculation of artificial orbit trajectories, for point positioning, for studies

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Global Gravity Model Development

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of the Earth's rheology, and for ocean circulation studies with satellite altimetry.

The TOPEX ocean topography satellite, which is planned for launch in 1991, requires that the contribution of the uncertainty in the geopotential model to the radial component of the orbital error budget be on the order of 10 cm. The best previously available "satellite only" model, GEM-L2 [Lerch et al., 1982], predicted radial errors for TOPEX on the order of 65 cm. Meeting the error budget for TOPEX is one of the motivating factors behind the current efforts to improve the overall gravitational field modeling capabilities.

The general philosophy adopted in this computation process has been to analyze the observational data in stages. Within each step of the process, individual data sets are separately evaluated and combined in order to extract optimum subset solutions. The initial emphasis has been placed upon the computation of "satellite only" models. The first such model, designated GEM-T1 [Marsh et al., 1988] , was the first preliminary GSFC model computed in this effort. Recently, a very significant augmentation of the satellite observational data base has permitted the compution of the GEM-T2 model. In an attempt to provide additional short wavelength gravitational information over the ocean areas and to provide an observational basis for the derivation of short wavelength geoid features, a preliminary model, PGS-3337 has incorporated the SEASAT altimeter data set along with surface gravimetry. The final model will be based upon the best combination of optical, laser, altimeter, satellite-to-satellite tracking, and surface gravity data.

TECHNIQUE

The primary software tools used at GSFC for precision orbit and geodetic parameter estimation are the GEODYN and SOLVE programs. The GEODYN program [Martin et al., 1987] uses fixed-integration-step , high-order Cowell predictor-corrector numerical integration techniques. The force models used in the analyses are: gravitation-Earth,luni-solar, and planetary, solar radiation pressure, atmospheric drag, and solid earth and ocean tides. Observation modeling included Earth precession and nutation, polar motion and earth rotation, and solid earth tidal displacements. The normal equations formed within GEODYN for the force and measurement model parameters are output to a file for inclusion in large parameter estimations and error analyses.

The SOLVE program selectively combines and edits the least squares normal equations to form the solutions for the parameters of interest. These programs are run on the GSFC Cyber 205 super computer.

TRACKING DATA

Tracking data from 17 and 31 satellites respectively, were used in the GEM-T1 and GEM-T2 gravitational modeling solutions. The satellite names, inclinations, data types and number of orbital arcs are summarized in Table 1. Orbital arc lengths were typically seven days for the optical data, 5 days for laser/Doppler data arcs with the exception of 30-day arcs used for Lageos. These solution were primarily based upon high quality laser ranging observations with single point accuracies now approaching 1 cm. The inclusion of a carefully selected sets of optical and electronic observations from a diverse set of spacecraft provided a valuable complement to the limited inclination coverage provided by the laser data.

GRAVITATIONAL MODEL AND OCEAN TIDAL SOLUTIONS

The solutions consisted of simultaneous adjustments for the spherical harmonic invariant geopotential coefficients and a subset of 66 ocean tidal coefficients for the long-wavelength components of 12 major ocean tides. The GEM-T1 gravity model is complete to [36,36], while the GEM-T2 model has been extended to include selected coefficients out to degree 50. A unified coordinate system was developed for the tracking stations based upon the laser coordinate system developed at GSFC from LAGEOS tracking [Smith et al., 1985].

CALIBRATION OF THE MODEL ACCURACY

The method for determining reliable error variances for the GSFC gravity model solutions employs both independent and dependent data subset solutions. Calibration techniques have been developed which yield a full field coefficient by coefficient estimate of the model uncertainties. The accuracy of the new GSFC gravity field models is more than a factor of two better than any previous models. The details of the data weighting and calibration techniques are presented in [Lerch et al., 1988]. Figure 1 presents the rms radial error for the TOPEX satellite predicted from the calibrated covariance matrices. The total rms error on TOPEX estimated for the GEM-T1 model is 25cm and 12 cm for GEM-T2.

CONCLUSIONS

The present GSFC gravitational and geodetic parameter solutions have been the result of a complete re-evaluation of previous solution design. A level of internal consistency and accuracy higher than that of any previous GSFC models has been achieved. Error calibration techniques have been developed which now permit the computation of realistic error estimates for the accuracy of the field and satellite ephemerides. In subsequent solutions planned for the next few years additional parameters such as time dependency in the geopotential and tracking station coordinates will be included. The inclusion of satellite altimetry from Geos-3, Seasat, and Geosat as well as the global set of surface gravity data will permit computations complete to [50,50] and beyond.

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Table 1 GEM-T2 TRACKING DATA SUMMARY

SAT. NAME	INCLINATION (DEG)	DATA TYPE *	ARCS GEM-T1	ARCS GEM-T2
ATS-6/GEOS-3	0/115.0	SST	-	26
PEOLE	15.0	L,O	6	6
COURIER-1B	28.3	O	10	10
VANGUARD-2	32.9	O	10	10
VANGUARD-2RB	32.9	O	10	10
D1-D	39.5	L,O	15	15
D1-C	40.0	L,O	14	14
BEC	41.2	L,O	89	89
TELESTAR-1	44.8	O	30	30
ECHO-1RB	47.2	O	-	32
STARLETTE	49.8	L	46	157
AJISAI	50.0	L	-	36
ANNA-1B	50.1	O	30	30
GEOS-1	59.3	L,O	91	121
TRANSIT-4A	66.8	O	-	50
INJUN-1	66.8	O	-	44
SECOR-5	69.2	O	-	13
BE-B	79.7	O	20	20
OGO-2	87.4	O	-	16
OSCAR	89.2	D	13	13
OSCAR-7	89.7	O	-	4
5BN-2	90.0	O	-	17
NOVA	90.0	D	-	16
MIDAS-4	95.8	O	-	50
LANDSAT-1	98.5	S-BAND	-	10
GEOS-2	105.8	L,O	74	74
SEASAT	108.0	D,L	29	29
GEOSAT	108.0	D	-	13
LAGEOS	109.9	L	58	85
GEOS-3	114.9	L	36	86
OVI-2	144.3	O	-	4
TOTAL			581	1130

* SST Satellite-to-Satellite Tracking

L	Laser ranging
O	Optical
D	Doppler
S-Band	Unified S-Band average range-rate

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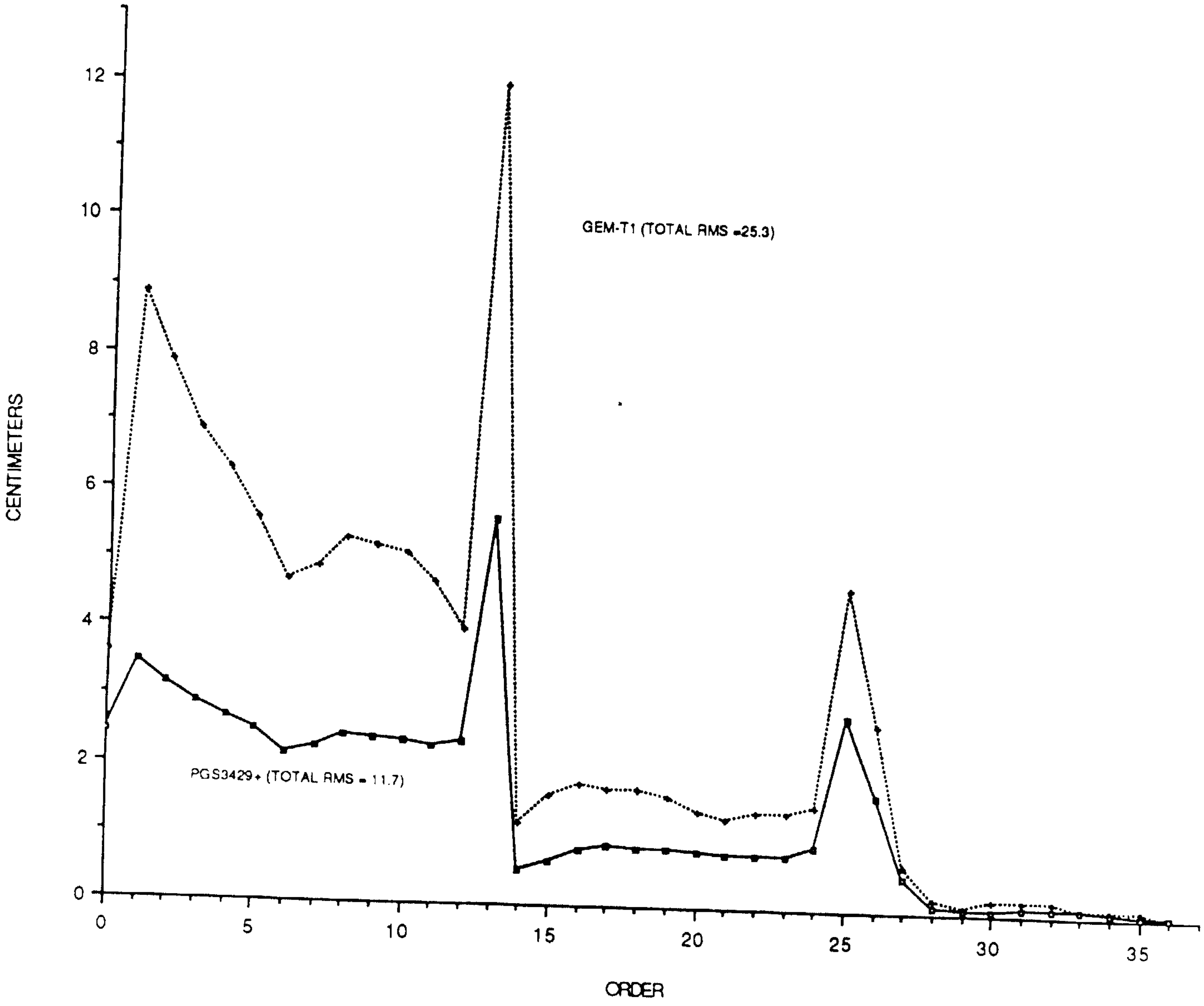
Figure 1 TOPEX PROJECTED RADIAL ERROR
RMS PER ORDER



+ PGS3429 = (PRELIM. GEM-T2)