AN IMPROVED ERROR ASSESSMENT FOR THE GEM-T1 GRAVITATIONAL MODEL

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ABSTRACT

Several tests have been designed to determine the correct error variances for the GEM-T1 gravitational solution which was derived exclusively from satellite tracking data. The basic method employs both wholly independent and dependent subset data solutions and produces a full field coefficient by coefficient estimate of the model uncertainties. The GEM-T1 errors have been further analyzed using a method based upon eigenvalue-eigenvector analysis which calibrates the entire covariance matrix. Dependent satellite and independent altimetric and surface gravity data sets, as well as independent satellite deep resonance information, confirm essentially the same error assessment.

OVERVIEW

The principal calibration technique (Lerch, 1985) is based upon the comparison of solutions (independent or dependent) which analyzes the consistency of the coefficient differences and the error estimates between the solutions as described in Table 1.

Calibrations utilizing each of the major data subsets within the solution yield very stable calibration factors which vary by approximately 10% over the range of tests employed. Measurements of gravity anomalies obtained from altimetry were also used directly as observations to show that GEM-T1 is calibrated. Based upon these calibrated error estimates, GEM-T1 is a significantly improved solution which to degree and order 8 is twice as accurate as earlier satellite derived models. By being complete to degree and order 36, GEM-T1 is much larger than earlier gravitational solutions calculated from direct satellite tracking and has significantly reduced aliasing effects that were present in previous models. The mathematical representation of the covariance error in the presence of unmodeled systematic error effects in the data is analyzed and an optimum weighting technique is developed for these conditions. This technique yields an internal self-calibration of the error model, a process which GEM-T1 is shown to approximate. This geopotential field with calibrated error estimates, predicts 25 cm (Table 2) for the radial RMS uncertainty of the TOPEX orbit. The TOPEX Mission has a requirement for 10 cm radial orbital modeling which is needed to support the oceanographic applications of a high quality spaceborne altimeter.

RESULTS

Taking full advantage of the "super-computing" environment available at NASA/Goddard Space Flight Center, many solutions have been compared providing a completeness of field testing heretofore impossible within earlier computing environments. The results show a model remarkably consistent in stability for the calibration of its errors. With the exception of a few known and understood high order resonance terms (and the limitations of the high altitude Lageos satellite providing data suitable for the calibration of a full 36x36 field), the calibrations show a stability in error assessment at the 10% level for each of the major data subsets employed in this evaluation. The published coefficient uncertainties for GEM-T1 and its error covariance matrix are herein found to be reasonably well calibrated and reliable. For example, the average calibration factor (k) for GEM-T1 using nine major sets of data in Table 3 (excluding the anomalous result for LAGEOS data) gave k=0.99 (± .08) for the coefficient calibration and k=0.95 (± .09) for the eigenvector calibration. This is a gratifying result, particularly, since formal least squares error formulae based on random variables were employed with compensating downweighting factors to account for more general formulae involving error sources with unknown systematic effects. The mathematical validity of the error estimation techique for the gravity model was studied extensively and an optimal weighting technique with internal self-calibration of the error model was developed.

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TABLE 1

FORMULAE FOR ERROR CALIBRATION

TWO FIELDS F & $\overline{F}$

F : $C_{l,m}$, $S_{l,m}$, σ 's (coeff. errors)

$\overline{F}$: $\overline{C}_{l,m}$, $\overline{S}_{l,m}$, $\overline{\sigma}$'s

$$RMS_l\ (\Delta F) = \left[\sum_{m=0}^{l} \frac{\Delta C_{l,m}^2 + \Delta S_{l,m}^2}{2l+1} \right]^{\frac{1}{2}}$$

$$\sigma_l = \left[\sum_{m=0}^{l} \frac{\sigma^2_{(C_{l,m})} + \sigma^2_{(S_{l,m})}}{2l+1} \right]^{\frac{1}{2}}$$

$$e_l^2 = E(RMS_l)^2$$

$$= \sigma_l^2 + \overline{\sigma}_l^2 \quad \text{when } F \text{ is independent of } \overline{F}$$

$$= \sigma_l^2 - \overline{\sigma}_l^2 \quad \text{when data in } F \subset \overline{F}$$

CALIBRATION FACTORS

$$k_l = \frac{RMS_l}{e_l} \quad \text{for degree } l$$

$$k_{l,m} = \frac{RMS_{l,m}}{e_{l,m}} \quad \text{for individual coeff. pair}$$

TABLE 2

Radial Orbital Errors (RMS) for Three Day Arc Lengths Using Calibrated Covariance Matrices

Geopotential Model	Radial RMS Error (cm)
GEM-L2	65
GEM-T1	25
GEM-T1 + Surface Gravimetry + Altimetry	17

TABLE 3

SUMMARY OF SOLUTION CALIBRATION FACTORS FROM GEM-T1 FIELD ASSESSMENTS

	COEFFICIENT CALIBRATION FACTOR	RMS WEIGHTED PROJECTED EIGENVECTOR CALIBRATION FACTOR ONTO GEM-T1
• (GEM-T1) vs (GEM-T1 minus DATA SUBSET)		
4-LASERS (GEOS 1,2,3, BE-C)	1.06	0.94
STARLETTE LASER	1.10	0.99
OSCAR + SEASAT DOPPLER	1.09	1.07
OPTICAL (11 SATS)	0.84	0.89
LAGEOS LASER	1.45	1.59
• GEM-T1 vs GEM-T1 + SURFACE GRAVITY	0.95	0.92
• GEM-T1 vs GEM-T1 + SURFACE GRAVITY + SEASAT ALTIMETRY	0.94	0.89
• GEM-T1 vs SURFACE GRAVITY + SEASAT + ALTIM	0.99	0.90
• GEM-T1 minus LAGEOS vs LAGEOS + SURFACE GRAVITY + SEASAT ALTIMETRY	0.95	0.88
• GEM-T1 vs. GEM-T1 + Lumped Resonance Data	1.00	1.06
• GEM-T1 with 10 times the Data Weight vs GEM-T1 minus 4-LASERS with 10 times the Data Weight	2.75	2.45