Gravity Field, Geoid and Ocean Surface by Space Techniques

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Abstract. Knowledge of the earth's gravity field continued to increase during the last four years. Altimetry data from the GEOS-3 satellite has provided the geoid over most of the ocean to an accuracy of about one meter. Increasing amounts of laser data has permitted the solution for 566 terms in the gravity field with which orbits of the GEOS-3 satellite have been computed to an accuracy of about one to two meters. The combination of satellite tracking data, altimetry and gravimetry has yielded a solution for 1360 terms in the earth's gravity field. A number of problems remain to be solved to increase the accuracy of the gravity field determination. New satellite systems would provide gravity data in unsurveyed areas and correction for topographic features of the ocean and improved computational procedures together with a more extensive laser network will considerably improve the accuracy of the results.

Major improvements in our knowledge of the earth's gravity field have been obtained since the GEOPS 4 Conference on The Geoid and Ocean Surface in August 1973 (Rapp, 1974). A dramatic improvement was obtained by use of the GEOS-3 satellite altimetry data, which has defined the geoid over most of the ocean areas to about a one meter accuracy (Brace, 1977, Hadgigeorge in press, Kahn et. al. 1977, Marsh et. al. 1978, Marsh et. al. in press, Rapp 1978, Rapp in press, Yionoulis et. al., in press). In each solution for the geoid based upon the altimetry data, errors in the satellite position were larger than uncertainties in the altimeter measurements. In order to reduce the effects of the orbit errors, bias parameters for each satellite pass were determined which minimized the discrepancy between geoid determinations at intersections of north-westerly satellite subtracks with south-westerly subtracks. Some analysts further reduced the dependence of the geoid determination on the accuracy of the satellite orbit by fitting the altimetric data to a low order reference geoid. Anderle (1977) raised the question of biases in the computed geoid arising from systematic errors in the computed satellite orbits, but Rapp (private communication) found that the different approaches to the computation of the geoid agreed to about one meter. The computed ocean geoids are also subject to effects of ocean tides and geostrophic effects. However, a new model of the principal ocean tide constituent for one degree areas agrees with tide measurements to 5 cm (Schwiderski, in press), and models for six additional constituents have been computed by Estes (1977).

Solutions for the earth's potential continued to include an ever increasing number of coefficients as additional satellite observations were acquired at higher levels of precision and as computer programs were extended. High quality laser data played an important role in the solutions by Gaposchkin (in press) and Lerch (1978). Table 1 lists the more recent solutions obtained at various agencies. Some solutions were based solely on observations of satellite motion while others, indicated by "general" under the column headed optimization, included gravimetric, astro-geodetic, and/or altimetric data. The solutions allowed the computation of the GEOS-3 satellite altitude to an accuracy of 1.5 m (Douglas and Anderle, 1977). The latest solution is believed to represent the ocean geoid to an accuracy of one or two meters (Lerch, et.al., 1978).

Another new source of data on the earth's gravity field acquired recently was from satellite-to-satellite tracking. Data were acquired between two low orbiting satellites in the Apollo-Soyuz experiment and also between high and low satellites, ATS-F and GEOS-3. Agreement of gravity anomalies for two degree and five degree squares computed from high-low satellite to satellite tracking data with anomalies computed from this data was around five to ten milligals (Hajela, 1977, Vonbun 1977, Vonbun 1978).

Highly precise values for effects of gravity coefficients of specific order have been obtained by analysis of resonance effects on satellite motion (King-Hele, et. al., 1978, Klokocnik, 1978, Reigber in press) and evaluated by Wagner (in press). Such results are useful in evaluation of general solutions based on less sensitive data.

A number of outstanding problems need to be addressed in the course of further refinement of our knowledge of the gravity field:

1. drag and solar radiation effects on satellite motion,
2. other small effects,
3. correlation of coefficients,
4. combination of heterogeneous data,
5. computational problems, and
6. instrument limitations.

The following comments expand briefly on these problems:

1. Changes in the atmospheric drag due to solar radiation and changes in magnetic flux affect the motion of satellites in ways which can be misinterpreted as effects of the earth's gravity field. The effects of direct solar radiation and earth's albedo on the more complicated satellite satellite configuration can similarly be misinterpreted.

2. Other smaller effects which must be accurately modeled or determined include

a. crustal motion,

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b. polar motion and earth's rotation,

c. solid earth, ocean and atmospheric tides,

d. ionospheric effects on electronic measurements,

e. tropospheric effects on measurements, and

f. ocean topography on geoids computed from altimetric data.

3. The separation of gravity coefficients computed from observed satellite motion is made difficult by the limited number of satellites with different orbital motion for which accurate observations are available because satellites with different orbital inclinations or orbital periods are sensitive to different orders and degrees of gravity coefficients. Yet, apart from resonance effects, satellite motion is insensitive to high order terms in the earth's gravity field. Separation of the coefficients is possible through the use of altimetric data over the oceans and gravimetric data. But such data are not available in many regions, and the precision of such data is insufficient to compute accurate satellite orbits.

4. Neglect of systematic instrument and environmental effects, truncation of the gravity field representation, and other model errors have generally yielded standard errors of solutions for gravity coefficients which are overly optimistic. As a result, solutions based on combinations of various types of data have usually required the use of arbitrary weights for the different data classes employed in order to obtain a reasonable contribution to the solution from each set of data.

5. The computation of the gravity field from observed satellite motion is a costly undertaking. The high cost is one factor which limits the number of coefficients used to define the gravity field in such computations, and the frequent use of an inconsistent number of gravity parameters for different data which are then combined in a single solution.

6. Instrument limitations for lasers include weather and the cost of installations. S-band radars require a transponder on the satellite, have limited availability due to their heavy workload, and are subject to ionospheric refraction errors. Doppler receivers require a transmitter on the satellite and are of lower precision than lasers on S-band radars.

Solutions to many of these problems will be addressed by the panel members. Gaposchkin and Smith will discuss primarily advanced computational techniques; Fishell and Reigber will discuss advanced measurement techniques, and Whitehead will address the topographic effects on the ocean geoid.

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GRAVITY FIELD DETERMINATIONS

AGENCY	DESIGNATION	NUMBER OF COEFFICIENTS	OPTIMIZATION	REFERENCE
DMA	DOD WGS-72	472	General	Seppelin, 1972
NSWC	NWL 10-E	401	NAVSAT	---------
NSWC	NWL 1G	396	GEOS-3	Anderle, 1976
NOAA	P = 4	252*	General	Chovitz, in press
GRGS/SFB	GRIM 2	950	General	Balmino, 1977
SAO	SE VI.3	604	General	Gaposchkin, in press
GSFC	GEM 9	566	Satellite	Lerch, 1977
GSFC	GEM 10B	1360	General	Lerch, 1978

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*104 density squares

TABLE 1

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