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Comparison of recent geopotential models with surface, airborne and satellite data in different areas of the earth

D. Arabelos[1], C.C. Tscherning[2]

1 University of Thessaloniki, Department of Geodesy and Surveying, GR-540 06 Thessaloniki
2 University of Copenhagen, Department. of Geophysics, Juliane Maries Vej 30, DK-2100 Copenhagen Oe

Introduction

The OSU91A geopotential model was for long time the most accurate reference model for many applications in geodesy and other geosciences. The growing accuracy of the satellite born data such as satellite altimeter data calls for more accurate geopotential models. Recently an attempt was set up for a new accurate geopotential model by DMA and NASA/Goddard Space Flight Centre. In the frame of this project five versions of a new geopotential model have been created. A Special Working Group has been established in order to test the quality of these versions and to help the decision for the final, most accurate geopotential model.

The aim of this work was to contribute in the frame of the SWG, in the assessment of the new model by comparing quantities computed from the model with surface, airborne and satellite data in different areas of the Earth. The results of these comparisons showed a clear improvement of the new versions in terms of the mean value and the standard deviation of the reduced observations against OSU91A at least in some test areas. No significant differences between the different versions of EGM were found. It seems that in some areas, EGM-X02 or EGM-X05 are slightly better than the other versions. After communicating the results of the contributions of the SWG members, a final geopotential model was created, named EGM96. This model gives slightly better results than the preliminary EGM versions in the most of the test fields examined in this study.

In the next sections the data used for the comparisons will be described and the results of the comparison will be shown. The results concern the mean value and standard deviation of the original data as well as of the differences between the original data and the same data after the removal of the contribution of OSU91A, the various preliminary versions of EGM and the final EGM96 geopotential model. The empirical covariance functions of free air gravity anomalies referred to OSU91A and to EGM are given for some test areas where the EGM and OSU91A present different behaviour.

Finally, a comparison of the anomaly error degree variances of OSU91A and EGM96 shows that the error estimation of the coefficients of the new model seems to be optimistic especially in the higher degrees.

Data

1. Airborne data

A set of 5,292 point free-air gravity anomalies covering the main part of Greenland bounded by $52.25" \leq \phi \leq 73.68", -58.32" \leq \lambda \leq 20.25"$ is available from (Forsberg and Brozena, 1992).

From "International Geoid Service Bulletin no 6"

The measuring height was about 4 km. These values are mean values along the plain tracks with a sampling rate corresponding to about 18 arcmin.

2. Surface data

Arctic zone

Searching the GEODAS CD-ROM (GEODAS-Marine Geological and Geophysical Data from NGDC, published by NOAA.) we have found out that the area bounded by the limits $70° \leq \phi \leq 83°, -10° \leq \lambda \leq 20°$ is covered by a number of 29,760 point gravity data coming from different Institutions and different surveys. For the main part of these data there is the information that the Gravity System is Potsdam and the reference system is International formula 1930. We assume that also in the cases that this information is missing, the gravity system and the reference gravity field are the same (Potsdam/Int.Form. 1930). However this assumption could introduce compatibility problem when merging all data sources. No information concerning the accuracy of the data is available.

Scandinavia

Two data sets were used for the comparison:

Deflections of the vertical in Scandinavia (300 points) and 13,802 free-air gravity anomalies in the Norwegian Sea, bounded by $61^{\circ} \leq \phi \leq 70^{\circ}$, $0^{\circ} \leq \lambda \leq 17^{\circ}$

The deflections of the vertical have been converted to WGS84 using a 7 parameter datum-shift with errors of 0.1 to 0.2 arcsec. The gravity anomalies are commercial data, with a zero-level uncertainty of 1 - 2 mGal and a internal consistency of about 1 - 2 mGal.

Antarctic zone

From the Gravity Earth System Data CD-ROM (Alpha Release), published by NOAA, March 1992, a file including 57,140 point free air gravity anomalies in the area bounded by $-90° \leq \phi \leq -50°, -180° \leq \lambda \leq 180°$ was extracted. Error estimates are given for each point, that varying between 0 and 25 mGal (Arabelos and Tscherning, 1996).

Mediterranean

Gridded 5' × 5' free air gravity anomalies have been used in Western and Central Mediterranean. Based on a number of previous studies, the accuracy of this data set is estimated to about 5 mGal (see Arabelos and Tziavos, 1996). In the Eastern Mediterranean, point free air gravity anomalies along ship tracks have been used (see e.g. Arabelos and Tscherning 1988). For the continental Greece, point gravity anomalies have been used, having a mean separation equal to about 5 km. The accuracy estimation of these data based on comparisons between values referred to the same station is equal to about 0.3 mGal (see Arabelos, 1989).

Taiwan

A 3' × 3' grid of free air gravity anomalies covering Taiwan has been used (see Tsuei et all. 1994, 1995).

3. Satellite data

Satellite data from ERS-1/ERM and ERS-1/GM Cycle I have been used for the comparisons in the Mediterranean Sea (see Arabelos and Vermeer, 1996). The time covered by the ERS-1/ERM data set is April 14, 1992 to August 16, 1993 (14 repeat periods, 35 days each, GEM-T2 model for orbit determination).

The ERS-1/GM data contained 69,384 records. The two data sets were selected in the area bounded by the limits $30^\circ \leq \phi \leq 46^\circ, -5^\circ \leq \lambda \leq 36^\circ$.

Results

The results in terms of the mean value and standard deviation of the original observations and of the differences between the observations and the corresponding quantities from OSU91A, the EGM-X01,...,EGM-X05 and EGM96 are given in the next tables (1 to 9). All the original data are referred to GRS80. The computations were carried out using the FORTRAN programs GEOCOL and GEOIP (Tscherning et all., 1994).

Table 1. Results of the reduction of gravity anomalies using OSU91A and EGM geopotential models in the Mediterranean Sea. Unit is (mGal).

Western Mediterranean (8,390 5'× 5' grid)								
		Differences between original and:						
	Original	OSU91A	EGM01	EGM02	EGM03	EGM04	EGM05	EGM96
Mean value	-1.90	-0.47	-0.17	-0.44	-0.78	-0.50	-0.21	0.34
Std. dev.	24.95	16.22	16.03	15.96	15.97	15.98	16.07	16.07
Central Mediterranean (15,062 5'× 5' grid)								
		Differences between original and:						
Original	Original	OSU91A	EGM01	EGM02	EGM03	EGM04	EGM05	EGM96
Mean value	-10.77	-0.16	-0.96	-0.81	-0.91	-0.69	-0.71	-0.90
Std. dev.	50.42	18.15	16.75	16.71	16.81	16.82	16.81	16.62
Eastern Mediterranean (2,085 point values)								
		Differences between original and:						
	Original	OSU91A	EGM01	EGM02	EGM03	EGM04	EGM05	EGM96
Mean value	-40.63	-1.75	-1.91	0.36	-1.27	-0.87	-0.73	0.95
Std. dev.	54.05	18.32	19.13	18.73	19.04	19.10	19.01	18.84
Continental Greece (7,504 point values)								
		Differences between original and:						
	Original	OSU91A	EGM01	EGM02	EGM03	EGM04	EGM05	EGM96
Mean value	20.35	-3.49	-4.59	-4.90	-4.86	-5.04	-5.27	-5.13
Std. dev.	52.52	33.53	33.33	33.55	33.36	33.31	33.36	33.31

From the statistics of Table 1 it is shown that almost similar results we obtain using OSU91A or EGM models in the Western and Eastern Mediterranean. In the Central Mediterranean EGM models seems to be better than OSU91A: The standard deviation of the observations reduced to

EGM models is about 2 mGal lower than the corresponding quantity of the observations reduced to OSU91A.

In continental Greece the results are very similar using OSU91A or EGM models for the reduction of the free air gravity anomalies.

The results concerning the altimeter data in the Mediterranean Sea are shown in Table 2. From this Table it is clear that in the case of ERS-1/ERM the results in terms of the mean value and standard deviation of the differences (observations - model) are almost identical for both, OSU91A and EGM models, while in the case of ERS-1/GM we have better results using the EGM models.

Table 2. Results of the reduction of altimeter data using OSU91A and EGM geopotential models, in the Mediterranean (entire area). The geopotential component has been computed in a 5' × 5' grid and the individual points have been interpolated using GEOIP program. Unit is (m).

Mediterranean (ERS-1/GM, 65,909)								
	Differences between original and:							
	Original	OSU91A	EGM01	EGM02	EGM03	EGM04	EGM05	EGM96
Mean value	32.53	0.41	0.27	0.27	0.29	0.30	0.31	0.37
Std. dev.	13.37	1.12	0.94	0.90	0.95	0.95	0.95	0.90
Mediterranean (ERS-1/ERM, 95,288)								
	Differences between original and:							
	Original	OSU91A	EGM01	EGM02	EGM03	EGM04	EGM05	EGM96
Mean value	32.31	0.95	0.92	0.96	0.96	0.97	0.98	1.04
Std. dev.	12.88	3.13	3.12	3.14	3.15	3.15	3.15	3.11

The empirical covariance function of the free air gravity anomalies in Greenland reduced to OSU91A and EGM-X05 are plotted in Fig. 1. From Table 3 as well as from Fig. 1 it is obvious that the airborne data used in this test have been used for the computation of the EGM models. This explains the considerable decrease of the mean value and standard deviation of the reduced to EGM free air anomalies comparing to the corresponding quantities (mean and standard deviation) of the reduced to OSU91A data.

Table 3. Results of the reduction of airborne gravity anomalies using OSU91A and EGM geopotential models, in Greenland. The geopotential component has been computed at the height of each measurement (about 4,000 m). Unit is (mGal).

Greenland (5,292 point values)								
	Differences between original and:							
	Original	OSU91A	EGM01	EGM02	EGM03	EGM04	EGM05	EGM96
Mean value	25.11	-2.49	-0.06	-0.12	-0.06	-0.08	-0.10	-0.11
Std. dev.	35.34	27.85	13.53	13.65	13.54	13.50	13.44	13.45

From Table 4 it is shown that in Canada the standard deviation of the free air gravity anomalies reduced to EGM models is slightly higher than the corresponding of the same data reduced to

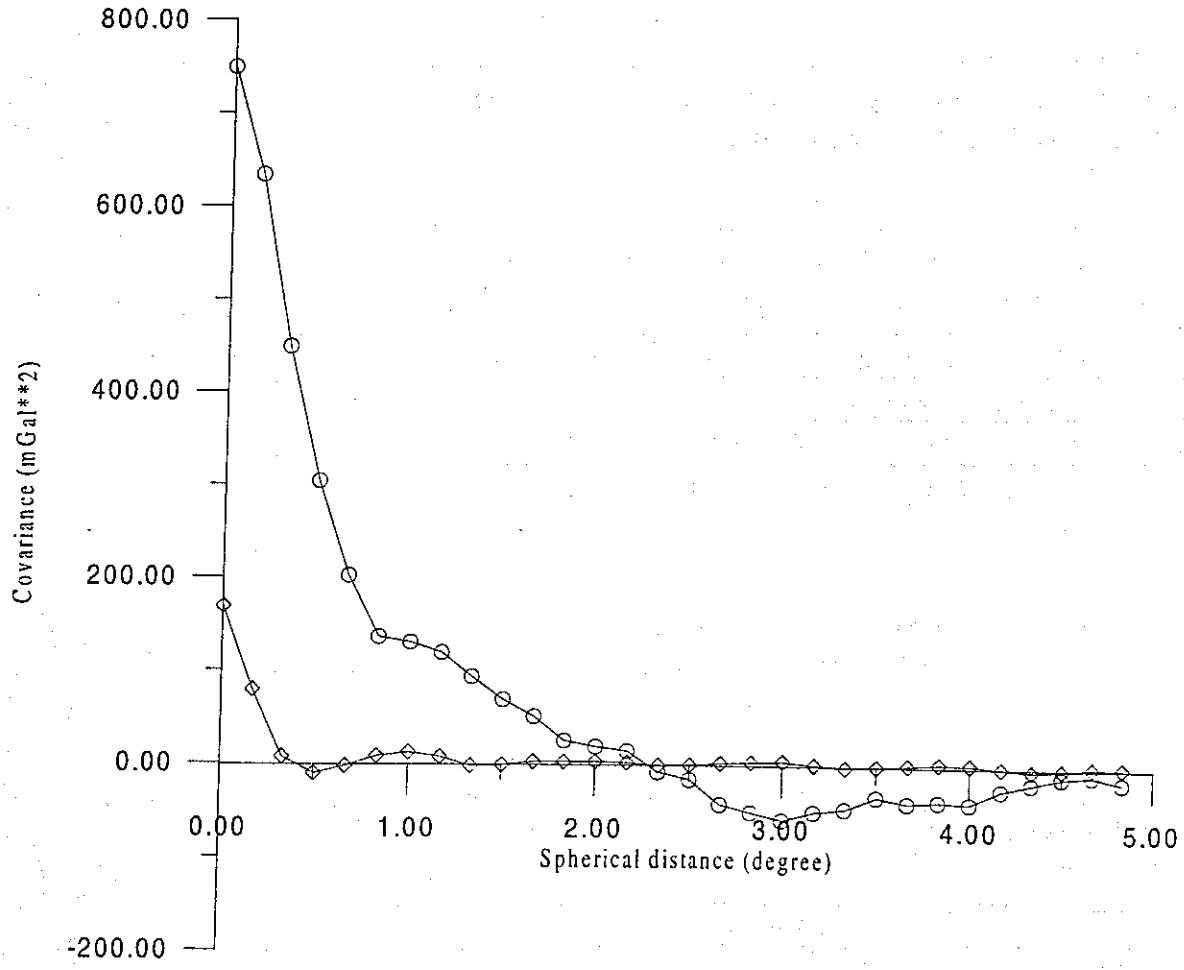


Figure 1. Empirical covariance functions of air borne free air gravity anomalies in Greenland reduced to: OSU91 (cyrcles) and to EGM-X05 (squares) geopotentiual models

OSU91A. Concerning the mean value, the EGM models fit better the gravity field in this area. The empirical covariance functions of the free air gravity anomalies in Canada reduced to OSU91A and EGM-X05 are plotted in Fig. 2. Considering Fig. 2 no significant differences between the two empirical covariance functions are shown.

Table 4. Results of the reduction of gravity using OSU91A and EGM geopotential models, in Canada. The geopotential component has been computed on a 3' × 3' grid and the individual points have been interpolated using GEOIP program. Unit is (mGal).

Canada (14,177 point values)								
	Differences between original and:							
	Original	OSU91A	EGM01	EGM02	EGM03	EGM04	EGM05	EGM96
Mean value	-10.77	0.95	-0.10	-0.23	-0.18	-0.20	-0.23	-0.27
Std. dev.	22.42	12.68	13.41	13.39	13.38	13.34	13.31	13.40

In the case of the Arctic zone (Table 5) we have a decrease of the mean value and of the standard deviation of the reduced to EGM gravity anomalies at the level of 2 mGal with respect to the corresponding mean value and standard deviation of the reduced to OSU91A data.

Table 5. Results of the reduction of gravity using OSU91A and EGM geopotential models, in the Arctic zone. The geopotential component has been computed in a 3' × 3' grid and the individual points have been interpolated using GEOIP program. Unit is (mGal).

Arctic (29,760 point values)								
	Differences between original and:							
	Original	OSU91A	EGM01	EGM02	EGM03	EGM04	EGM05	EGM96
Mean value	34.99	-2.80	-0.84	-0.77	-0.75	-0.77	-0.39	-0.38
Std. dev.	24.94	22.22	20.62	20.51	20.57	20.57	20.32	20.43

In the Antarctic zone (Table 6) no significant differences in terms of mean value and standard deviation of the reduced to OSU91A or to EGM models are observed.

Table 6. Results of the reduction of gravity anomalies using OSU91A and EGM geopotential models, in the Antarctic zone. The geopotential component has been computed in 57,140 individual points. Unit is (mGal).

Antarctic (57,140 point values)								
	Differences between original and:							
	Original	OSU91A	EGM01	EGM02	EGM03	EGM04	EGM05	EGM96
Mean value	6.14	4.37	4.40	4.36	4.36	4.34	4.17	4.10
Std. dev.	36.72	22.73	21.98	22.02	22.00	21.94	21.99	22.05

Also in Taiwan (Table 7) we have a decrease of the mean value and of the standard deviation of the reduced to EGM gravity anomalies at the level of 2 mGal with respect to the corresponding mean value and standard deviation of the reduced to OSU91A data.

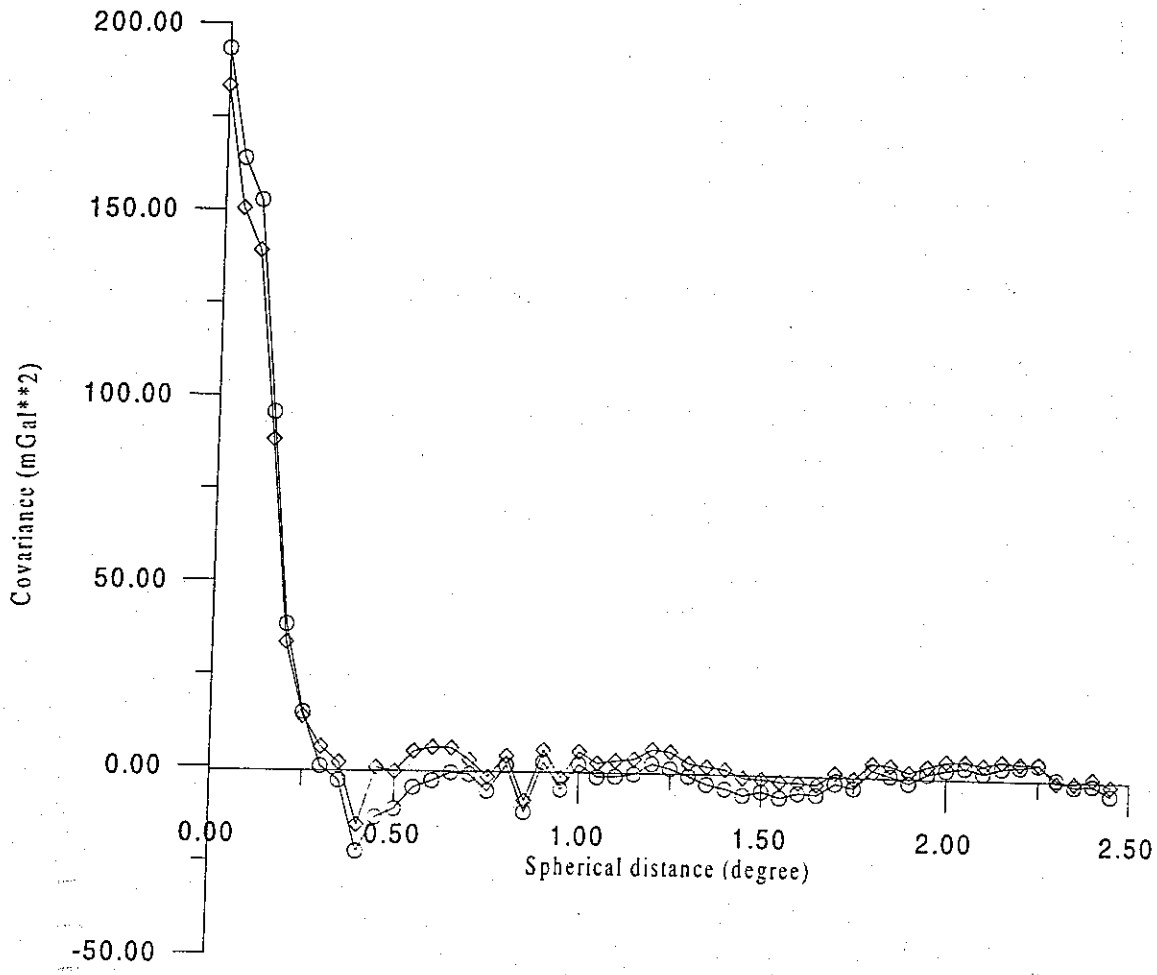


Figure 2. Empirical covariance functions of point free air gravity anomalies in Canada reduced to: OSU91 (cycles) and to EGM-X05 (squares) geopotential models

Table 7. Results of the reduction of gravity anomalies using OSU91A and EGM geopotential models in Taiwan. Unit is (mGal).

	Taiwan (4,800 values 3' × 3' grid)							
	Differences between original and:							
	Original	OSU91A	EGM01	EGM02	EGM03	EGM04	EGM05	EGM96
Mean value	15.25	1.21	-0.41	-0.79	-0.53	-0.10	-0.04	0.23
Std. dev.	70.13	39.32	37.38	37.19	37.38	37.12	36.82	36.78

The empirical covariance functions of the free air gravity anomalies in Taiwan reduced to OSU91A and EGM-X05 are plotted in Fig. 3. In this figure it is shown that the main features of both covariance functions are almost the same.

Table 8a. Comparison of North-component (ξ) of the deflection of the vertical with values computed from the EGM's in Scandinavia. Units arcsec.

	Scandinavia (300 points)							
	Differences between original and:							
	Original	OSU91A	EGM01	EGM02	EGM03	EGM04	EGM05	E°M96
Mean value	-2.56	-0.32	-	-0.29	-0.28	-0.27	-0.25	-0.28
Std. dev.	3.92	2.53	-	2.56	2.55	2.55	2.55	2.52

From Tables 8a and 8b it is shown that in Scandinavian we have no significant improvement in terms of mean value and standard deviation of the reduced to EGM deflections of the vertical in comparison to the mean value and standard deviation of the reduced to OSU91A values.

Table 8b. Comparison of East-component (η) of the deflection of the vertical with values computed from the EGM's in Scandinavia. Unit is arcsec.

	Scandinavia (300 points)							
	Differences between original and:							
	Original	OSU91A	EGM01	EGM02	EGM03	EGM04	EGM05	EGM96
Mean value	2.99	-0.19	-	-0.37	-0.35	-0.35	-0.36	-0.33
Std. dev.	4.80	2.74	-	2.61	2.60	2.60	2.59	2.54

Finally, as it is shown in Table 9, we have an improvement at the level of 1 mGal in terms of the standard deviation of the reduced to EGM gravity anomalies in the Norwegian Sea (comparing to the sd of the same anomalies reduced to OSU91A), but the mean value in the case of EGM03, EGM04 and EGM05 was increased by 1.5 mGal.

Table 9. Comparison of free gravity anomalies with values computed from the EGM's in the Norvegian Sea. Unit is mGal.

	Norwegian Sea(13,802 points)							
	Differences between original and:							
	Original	OSU91A	EGM01	EGM02	EGM03	EGM04	EGM05	E°M96
Mean value	20.14	1.3	-	0.6	2.8	2.7	2.6	2.6
Std. dev.	22.56	13.0	-	12.0	12.0	11.9	11.9	11.9

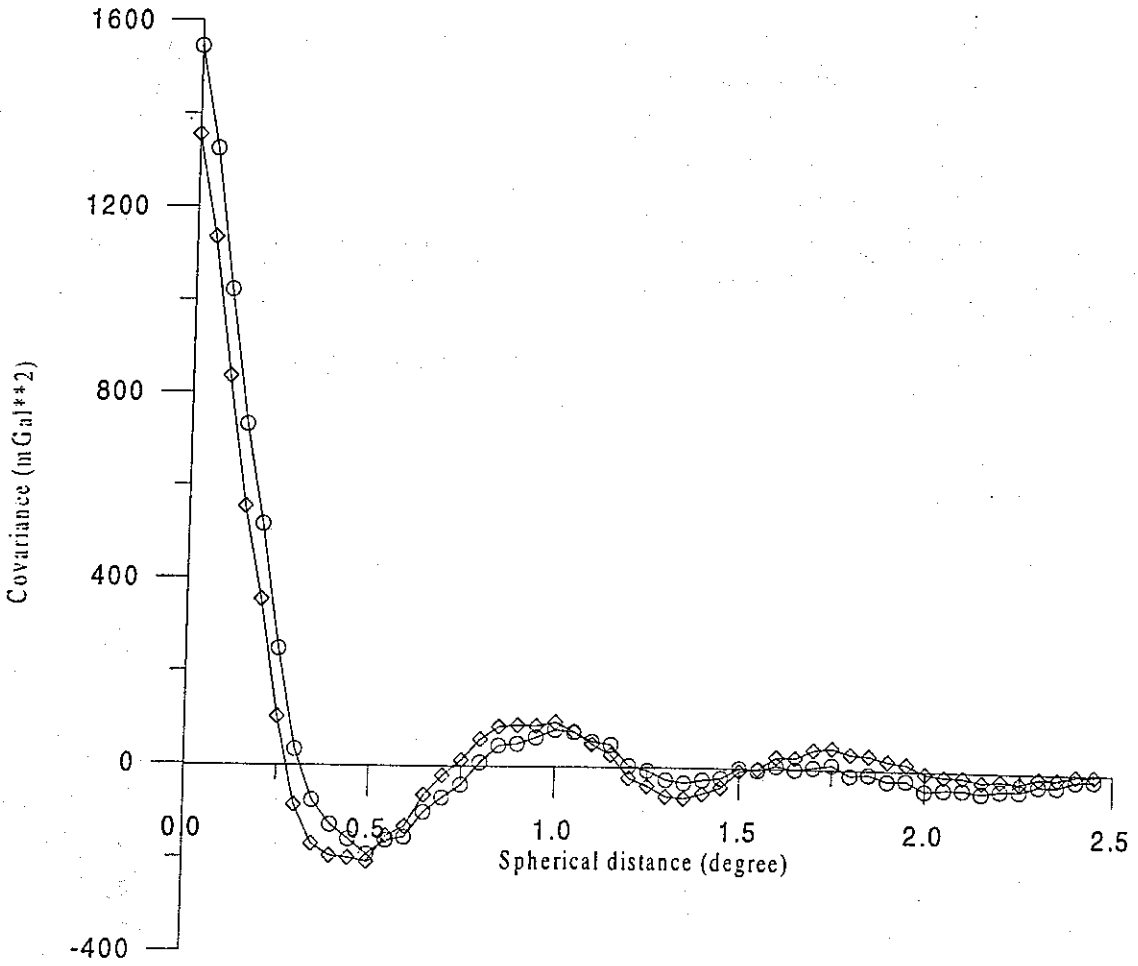
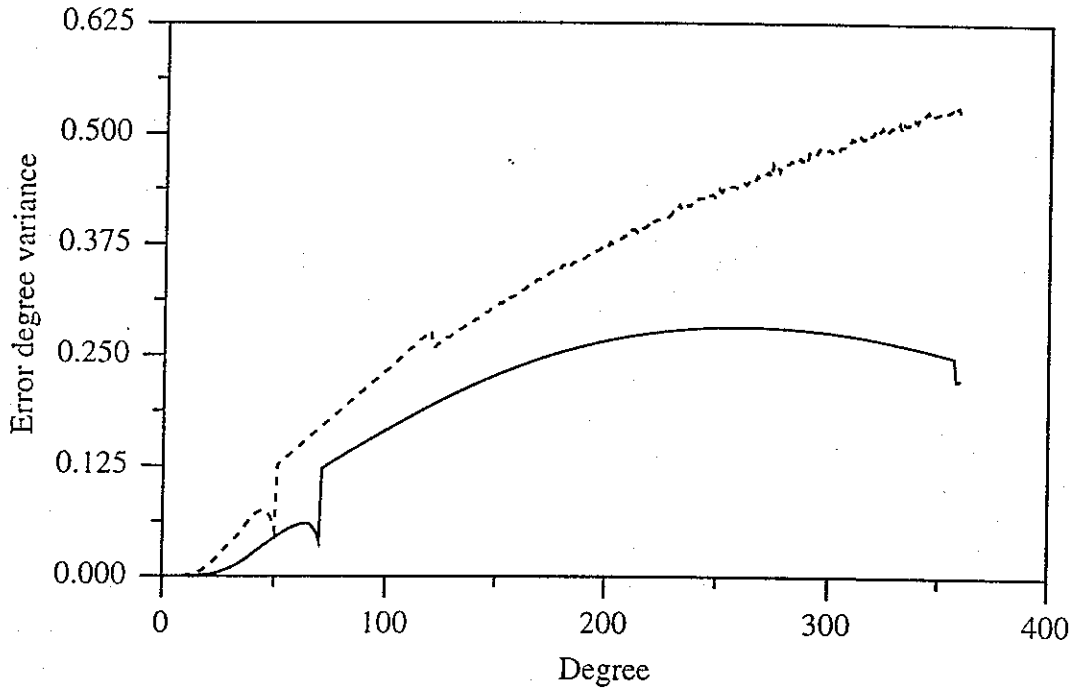


Figure 3. Empirical covariance functions of free air anomalies in Taiwan reduced: to OSU91A (cycles) and to EGM-X05 (squares) geopotential models

Error degree variances

The error estimation of the coefficients of a geopotential model is an essential information e.g. for the computation of analytical expressions for the covariance functions of quantities reduced to this geopotential model. This error estimation can be expressed in terms of the well known error degree variances. Usually, these error degree variances should be scaled by a factor (close to 1) in order to get a good agreement between the empirical and the analytical covariance function. Our experience with OSU91A was that the error estimation of the coefficients of this model was more or less pessimistic since in most test areas we had to multiply the error degree variances by a factor less than 1. In order to compare the error degree variances of the new model (EGM96) with the corresponding ones of OSU91A we have plotted the anomaly error degree variances of both models in Fig. 4.



Solid: EGM96, Dashed: OSU91A1F

Fig. 4. Anomaly error degree variances of OSU91A1F and EGM96.

From Fig. 4 it is clear that the error estimation of the new model is rather optimistic comparing to the corresponding of OSU91A, especially for the high degrees. This could be due to the new -short wave length data used for the computation of this model.

Conclusion

Concerning the gravity anomalies, from the tests presented in the above Tables it is obvious that a significant improvement of the EGM models over OSU91A has been observed in Greenland. This improvement is obviously due to the fact that the data set used in the test has been also used for the computation of EGM models.

In the other test areas, with the exemption of Canada and Antarctic zone, an improvement in terms of mean value and standard deviation of the reduced to EGM gravity data of the order of 2 mGal has been observed.

In the Antarctic zone the statistics has not been changed using OSU91A or EGM models.

Finally, in Canada we have a small increase of the standard deviation of the reduced gravity anomalies when using the EGM models instead of OSU91A.

With respect to altimeter data in the Mediterranean, a slight improvement has been observed in the case of ERS-1/GM mission (the standard deviation has been decreased from 1.12 to 0.90 using the EGM instead OSU91A). This improvement has not been observed in the case of ERS-1/ERM.

No significant differences between the preliminary EGM versions were found. It seems that at least in some areas, the EGM-X02 or the EGM-X05 are better than the other EGM versions. The final EGM96 model present in the test areas of this study, generally the same behaviour as the preliminary EGM versions.

The comparison of the anomaly error degree variances of EGM96 with corresponding quantities of OSU91A shows that the error estimation of the coefficients of the new model is optimistic especially in the higher degrees.

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