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REVISED ESTIMATION OF 550-KM × 550-KM MEAN GRAVITY ANOMALIES

M. R. WILLIAMSON

(NASA-CR-154101) REVISED ESTIMATION OF 550-km TIMES 550-km MEAN GRAVITY ANOMALIES (Smithsonian Astrophysical Observatory) 27 p HC A03/NF A01 CSCL 08N

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SPECIAL REPORT 377
REVISED ESTIMATION OF 550-KM × 550-KM MEAN GRAVITY ANOMALIES

M. R. Williamson

April 7, 1977

Smithsonian Institution
Astrophysical Observatory
Cambridge, Massachusetts 02138
TABLE OF CONTENTS

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>ABSTRACT</td>
<td>v</td>
</tr>
<tr>
<td>1 THE BLOCK COVARIANCE METHOD</td>
<td>1</td>
</tr>
<tr>
<td>2 THE 1° X 1° DATA</td>
<td>4</td>
</tr>
<tr>
<td>3 THE REFERENCE FIELD</td>
<td>7</td>
</tr>
<tr>
<td>4 THE BLOCK COVARIANCE ESTIMATES</td>
<td>8</td>
</tr>
<tr>
<td>5 DISCUSSION</td>
<td>20</td>
</tr>
<tr>
<td>6 REFERENCES</td>
<td>21</td>
</tr>
</tbody>
</table>
ILLUSTRATIONS

1  Distribution of $1^\circ \times 1^\circ$ mean surface-gravity data .................. 6
2  The block covariance functions of unit gravity anomalies .................. 10
3  The block covariance functions of residual unit gravity anomalies ....... 10

TABLES

1  Summary of available $1^\circ \times 1^\circ$ data .................................. 4
2  Comparison of $1^\circ \times 1^\circ$ gravity anomalies with DMAAC data .......... 5
3  Average values of $1^\circ \times 1^\circ$ mean gravity anomalies ................. 8
4  Block covariance functions of unit gravity anomalies ..................... 9
5  Block covariance functions of residual unit gravity anomalies .......... 9
6  Estimated block gravity anomalies ........................................ 11
ABSTRACT

The calculation of 550-km × 550-km mean gravity anomalies from 1° × 1° mean free-air gravimetry data is discussed. The block estimate procedure developed by Kaula is used to obtain 1504 of the 1654 possible mean block anomalies. The estimated block anomalies calculated from 1° × 1° mean anomalies referred to the 1967 reference ellipsoid and from 1° × 1° mean anomalies referred to a 24th-degree-and-order field are compared.
REVISED ESTIMATION OF 550-KM X 550-KM MEAN GRAVITY ANOMALIES

M. R. Williamson*

1. THE BLOCK COVARIANCE METHOD

To obtain estimates of mean gravity anomalies for 550-km x 550-km regions from an incomplete set of 1° x 1° mean free-air gravity anomalies, we have employed an estimation procedure based on the covariance analysis developed by Wiener (1966), Kolmogoroff, and Kaula (1967). A description and evaluation of the procedure are given in Williamson and Gaposchkin (1973).

For this analysis, the earth is divided into blocks of approximately equal area, with their boundaries adjusted to lie on integral degrees of latitude and longitude. Each block is subdivided into 25 units, the boundaries of which are also adjusted to lie on integral degrees of latitude and longitude. There are 1654 blocks of approximately 550 km x 550 km. At the equator, a block is 5° x 5° and a unit is 1° x 1°.

In order to derive the mean gravity anomaly for a 550-km x 550-km block, estimates of all unit mean gravity anomalies in that block are needed. For units where measurements of 1° x 1° mean gravity anomalies are available, the unit mean anomalies are taken to be the average of the 1° x 1° mean anomalies within the unit. The other unit mean anomalies are estimated from the measured unit anomalies in the same block. The linear estimate that minimizes the mean square error is

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This work was supported in part by Grant NGR 09-915-002 from the National Aeronautics and Space Administration.

*Currently on the staff at Massachusetts Institute of Technology Lincoln Laboratory, Lexington, Massachusetts.
\[ \hat{g}_i = \sum_{j=1}^{N} \left( \sum_{k} K_{jk}^{-1} \right) g_j, \]

where \( K_{jk} \) are elements of the block covariance matrix, given by

\[ K_{jk} = K(g, \tau_{jk}) ; \]

\( K \) is the intrablock covariance function of the unit anomalies \( g \), and \( \tau_{jk} \) is the distance between the \( j \)th and the \( k \)th units. Approximate values of the covariance function are calculated from

\[ K(g, \tau) = \frac{1}{N_{jk}} \sum_{jk} g_j g_k , \]

where the sum includes \( N_{jk} \) pairs of measurements with

\[ \tau - \frac{\Delta \tau}{2} < \tau_{jk} < \tau + \frac{\Delta \tau}{2} . \]

The block anomalies are then obtained by averaging the unit anomalies. Of course, the mean anomalies for blocks that include no measured \( 1^\circ \times 1^\circ \) mean anomalies cannot be estimated by this procedure.

The \( 1^\circ \times 1^\circ \) mean free-air anomalies are defined with respect to a reference ellipsoid. However, another, more detailed reference field may be used. In that case, residual anomalies \( g^R \) are defined by

\[ g^R = g - \gamma \sum_{\ell=2}^{\ell_{\text{max}}} \sum_{m=0}^{\ell} (\ell - 1) \left( \frac{\alpha}{\ell} \right) (C_{\ell m} \cos m\lambda + S_{\ell m} \sin m\lambda) P_{\ell m} (\sin \phi) , \]
where $C_{lm}$ and $S_{lm}$ are normalized harmonics coefficients of the earth's potential, $P_{lm}$ are normalized associated Legendre functions, $a$ is the equatorial radius of the earth, $\gamma$ is the value of gravity at the equator, and $\phi$, $\lambda$, and $r$ are geocentric coordinates. Estimates of residual unit anomalies $\hat{g}_R$ are obtained from equation (1) by using the block covariance function for residual anomalies $K(\hat{g}_R, \tau_{jk})$. By reversing equation (3), we can then calculate the estimated anomalies $\hat{g}$. 
2. THE $1^\circ \times 1^\circ$ DATA

We obtained the five sets of $1^\circ \times 1^\circ$ mean free-air gravity anomalies described in Table 1. The worldwide compilation of data from the Defense Mapping Agency Aerospace Center (DMAAC) was augmented by further data sent by DMAAC to us in 1974. DMAAC compiled the data using the Geodetic Reference System 1967 (International Union of Geodesy and Geophysics, 1967) and the 1971 international gravity standardization network (Morelli and Cantar, 1974). All the other data, however, are referred to the 1930 international gravity system and the Potsdam network; we converted them to the 1967 system by adding the correction $\Delta$, which, to an accuracy of 0.1 mgal, is

$$\Delta = 3.14 - 13.58 \sin^2 \phi + 0.02 \sin^2 2\phi \text{ mgal}.$$  

Table 1. Summary of available $1^\circ \times 1^\circ$ data.

<table>
<thead>
<tr>
<th>Coverage</th>
<th>Source</th>
<th>Number of points</th>
</tr>
</thead>
<tbody>
<tr>
<td>Australia</td>
<td>Mather (1970)</td>
<td>1454</td>
</tr>
<tr>
<td>North America and the North Atlantic</td>
<td>Talwani, Poppe, and Rabinowitz (1972)</td>
<td>4250</td>
</tr>
<tr>
<td>Indian Ocean</td>
<td>Kahle and Talwani (1973)</td>
<td>3944</td>
</tr>
<tr>
<td>Central Pacific</td>
<td>Watts (1976)</td>
<td>685</td>
</tr>
<tr>
<td>Worldwide</td>
<td>DMAAC, March 1976; augmented</td>
<td>36867</td>
</tr>
</tbody>
</table>

In combining the data, we used the first four sets from Table 1 wherever possible. The combined set has measured values for 37,415 out the possible 64,800 $1^\circ \times 1^\circ$ areas and gives 28,046 out of 41,350 unit anomalies. The map in Figure 1 shows the distribution of the data. The DMAAC data are compared in Table 2 with the other sets of data and with the previous compilation sent to us in 1974 at common points. When the
combined set was also compared to a previous combined set (Williamson and Gaposchkin, 1975), which had 31,654 1° × 1° mean anomalies, the mean difference was 0.04 mgal and the root-mean-square (rms) difference, 16.54 mgal.

Table 2. Comparison of 1° × 1° gravity anomalies with DMAAC data (March 1976).

<table>
<thead>
<tr>
<th>Data</th>
<th>Number of points compared</th>
<th>Mean difference (mgal)</th>
<th>rms (mgal)</th>
</tr>
</thead>
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<td>Australia (Mather, 1970)</td>
<td>1398</td>
<td>-0.25</td>
<td>20.41</td>
</tr>
<tr>
<td>North America and the North Atlantic (Talwani et al., 1972)</td>
<td>3275</td>
<td>-0.14</td>
<td>13.41</td>
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<tr>
<td>Indian Ocean (Kahle and Talwani, 1973)</td>
<td>3905</td>
<td>1.23</td>
<td>16.52</td>
</tr>
<tr>
<td>Central Pacific (Watts, 1976)</td>
<td>534</td>
<td>0.61</td>
<td>31.66</td>
</tr>
<tr>
<td>Worldwide DMAAC, December 1974 (DMAAC, 1973)</td>
<td>30296</td>
<td>-0.12</td>
<td>8.05</td>
</tr>
</tbody>
</table>

A complete data set of 1° × 1° mean topographic heights, obtained from Kaula and Lee (1967), was used to define oceanic and continental areas, where a 1-km depth was taken as the ocean—continent boundary. The combined data set of gravity anomalies has 17,602 of 36,199 1° × 1° measurements in oceanic areas and 19,813 of 28,601 1° × 1° measurements in continental areas.
Figure 1. Distribution of $1^\circ \times 1^\circ$ mean surface-gravity data.
3. THE REFERENCE FIELD

A reference field complete to degree and order 24 was used to obtain the residual gravity anomalies. This field is defined by the zonal-harmonics coefficients from the 1973 Smithsonian Standard Earth (III) (Gaposchkin, Williamson, Kozai, and Mendes, 1973) and the tesseral-harmonics coefficients from the second iteration of the Smithsonian Standard Earth IV (unpublished).
4. THE BLOCK COVARIANCE ESTIMATES

The covariance functions of the $1° \times 1°$ gravity anomalies and the $1° \times 1°$ residual gravity anomalies were calculated by using all the data, only the data in oceanic areas, and only the data in continental areas. In each case, the mean, given in Table 3, was first subtracted from the data. These functions were evaluated from equation (2) for $\tau_i = 0.75, 0.125, \ldots, 5.75$ and $\Delta \tau = 0.5$, and the results are given in Tables 4 and 5 and Figures 2 and 3. Figure 2 indicates that the data are not stationary. However, the nonstationarity differs in character and degree from previous results (Williamson and Gaposchkin, 1973); here, we have used both a better fitting reference ellipsoid and new data.

Block estimates calculated for 1504 of 1654 block anomalies, both from estimated $1° \times 1°$ anomalies and from estimated $1° \times 1°$ residual anomalies, are given in Table 6. The rms of the block anomalies is 17 mgal, while the mean and the rms differences between the two sets are 0.02 and 4.6 mgal, respectively.

<table>
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<th>Type of anomaly</th>
<th>Oceanic data</th>
<th>Continental data</th>
<th>Total</th>
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<td>Residual gravity</td>
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<td>0</td>
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<tr>
<td>anomalies</td>
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<td>Number of $1° \times 1°$ anomalies</td>
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<td>19813</td>
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*Punched cards of the block anomalies are available from the Analytical Satellite Geophysics Department, Smithsonian Astrophysical Observatory, 60 Garden Street, Cambridge, Massachusetts 02138.
Table 4. Block covariance functions of unit gravity anomalies.

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<td>904</td>
<td>870</td>
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<tr>
<td>0.9</td>
<td>465</td>
<td>556</td>
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<tr>
<td>1.2</td>
<td>363</td>
<td>470</td>
<td>417</td>
</tr>
<tr>
<td>1.8</td>
<td>327</td>
<td>405</td>
<td>358</td>
</tr>
<tr>
<td>2.2</td>
<td>268</td>
<td>337</td>
<td>284</td>
</tr>
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<td>2.8</td>
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<td>294</td>
<td>262</td>
</tr>
<tr>
<td>3.2</td>
<td>252</td>
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<td>233</td>
</tr>
<tr>
<td>3.7</td>
<td>252</td>
<td>260</td>
<td>235</td>
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<tr>
<td>4.2</td>
<td>254</td>
<td>248</td>
<td>222</td>
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<tr>
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<td>5.2</td>
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<tr>
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<td>209</td>
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</table>

Table 5. Block covariance functions of residual unit gravity anomalies.

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Figure 2. The block covariance functions of unit gravity anomalies.

Figure 3. The block covariance functions of residual unit gravity anomalies.
Table 6. Estimated block gravity anomalies.

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Table 6. (Cont.)
5. DISCUSSION

Block anomalies as obtained from estimated residual anomalies (column headed II in Table 0) are preferred for several reasons. First, surface-gravity data are augmented by the information contained in the reference field, the assumption, of course, being that the reference field is a good representation of the geoid. Second, the covariance function of the residual anomalies is nearly zero for \( r > 3^\circ \), so that estimates depend only on nearby measurements; thus, the effect of ignoring measurements outside the block is reduced. Third, the residual anomalies are more nearly stationary than are the original measurements. Figures 2 and 3 are typical of other partitionings of the data.

Nevertheless, there is a serious objection to using these estimates in combination with other kinds of data to solve for the coefficients of the earth's gravity field. The block anomalies obtained from estimated residual anomalies do not represent only information in the surface-gravity data. This fact blurs the meaning of the weights assigned to the anomalies and the statistics comparing solutions with the anomalies. The problem would be magnified by iteration.
6. REFERENCES

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