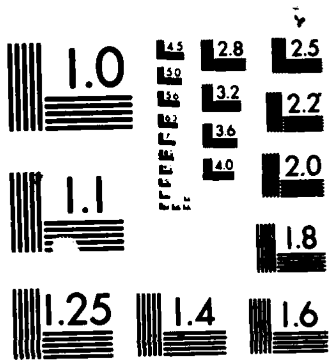
AD-A176 779 THE EFFECT OF TOPOGRAPHY ON AIRBORNE GRAVITY GRADIOMETER DATA(U) DEFENSE MAPPING AGENCY AEROSPACE CENTER ST LOUIS AFS MO J J GRAHAM ET AL 10 FEB 87 1/1

UNCLASSIFIED F/G 8/5 NL



MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

20 January 1987

NAMES AND TITLES:	John J. Graham, Geodesist Joseph L. Toohey, Geodesist
ORGANIZATION:	Data Services Department Defense Mapping Agency Aerospace Center 3200 South Second Street St. Louis, Missouri 63118-3399
TITLE OF ARTICLE:	The Effect of Topography on Airborne Gravity Gradiometer Data
WHERE & WHEN TO BE PUBLISHED:	Fifteenth Annual Gravity Gradiometry Conference, USAF Academy, Colorado Springs, Colorado, 10-12 February 1987
SUSPENSE DATE:	2 February 1987
I HAVE READ AND APPROVED THIS RELEASE:	John J. Graham JOHN J. GRAHAM, Geodesist Joseph L. Toohey JOSEPH L. TOOHEY, Geodesist

REPORT DOCUMENTATION PAGE

1a. REPORT SECURITY CLASSIFICATION UNCLASSIFIED	1b. RESTRICTIVE MARKINGS NONE
2a. SECURITY CLASSIFICATION AUTHORITY N/A 2b. DECLASSIFICATION / DOWNGRADING SCHEDULE N/A	3. DISTRIBUTION / AVAILABILITY OF REPORT UNLIMITED
4. PERFORMING ORGANIZATION REPORT NUMBER(S) None	5. MONITORING ORGANIZATION REPORT NUMBER(S) N/A
6a. NAME OF PERFORMING ORGANIZATION Defense Mapping Agency Aerospace Center 6b. OFFICE SYMBOL (If applicable) DSGT	7a. NAME OF MONITORING ORGANIZATION N/A
6c. ADDRESS (City, State, and ZIP Code) 3200 South Second Street St. Louis, MO 63118-3399	7b ADDRESS (City, State, and ZIP Code) N/A
8a. NAME OF FUNDING / SPONSORING ORGANIZATION 8b. OFFICE SYMBOL (If applicable)	9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER
8c. ADDRESS (City, State, and ZIP Code)	10. SOURCE OF FUNDING NUMBERS PROGRAM ELEMENT NO. / PROJECT NO. / TASK NO. / WORK UNIT ACCESSION NO.

11. TITLE (Include Security Classification)
The Effect of Topography on Airborne Gravity Gradiometry Data

12. PERSONAL AUTHOR(S)
Graham, John J. and Toohey, Joseph L.

13a. TYPE OF REPORT	13b. TIME COVERED	14. DATE OF REPORT (Year, Month, Day)	15. PAGE COUNT
Technical Paper	FROM ______ TO ______ N/A	1987, February 10	32

16. SUPPLEMENTARY NOTATION
For presentation at Fifteenth Annual Gravity Gradiometry Conference, USAF Academy, Colorado, Springs, Colorado, 10-12 February 1987

17. COSATI CODES			18. SUBJECT TERMS (Continue on reverse if necessary and identify by block number)
FIELD	GROUP	SUB-GROUP	"Terrain Effects" "Gradiometry"
08	05		

19. ABSTRACT (Continue on reverse if necessary and identify by block number)

The reduction and conversion of airborne gravity gradiometer data to ground level estimates of the gravity disturbance vector is currently of considerable interest in support of short wavelength gravity modeling. A pressing problem is the need for an accurate procedure for the downward continuation of data acquired at altitude by the Airborne Gravity Gradiometer Survey System (CGSS). As part of ongoing investigations, a prism method has been used to calculate the effect of topography on the gravity disturbance vector and the five independent second-order gravity gradients. Calculations of the contribution of topography to the magnitudes of these gravimetric parameters were made at both surface and elevated points in the Wichita Mountains of Oklahoma. Computations were made utilizing Digital Terrain Elevation Data (DTED) with an assumed constant density of 2.67 grams/centimeters^3 for the topographic masses. Results are presented which reflect the use of DTED sets of different horizontal extend and grid interval.

20. DISTRIBUTION / AVAILABILITY OF ABSTRACT ☒ UNCLASSIFIED/UNLIMITED ☐ SAME AS RPT. ☐ DTIC USERS	21. ABSTRACT SECURITY CLASSIFICATION UNCLASSIFIED
22a. NAME OF RESPONSIBLE INDIVIDUAL JOHN J. GRAHAM - JOSEPH L. TOOHEY	22b. TELEPHONE (Include Area Code) 314-263-8398 22c. OFFICE SYMBOL DSGT

20 January 1987

CERTIFICATION

ORGANIZATION:	DSGT
TITLE OF ARTICLE:	The Effect of Topography on Airborne Gravity Gradiometer Data
WHERE & WHEN TO BE PUBLISHED:	Fifteenth Annual Gravity Gradiometry Conference USAF Academy Colorado Springs, Colorado 10-12 February 1987
REVIEWED:	_X_ Technical Adequacy/Completeness _X_ Does Not Contain SAA Data _X_ This Document is Unclassified This Document has a Security Classification of UNCLASSIFIED.

I have reviewed _____ Abstract _X_ Paper and approve it for presentation.

DARRYL D. TAYLOR
Chief, Data Services
Department

THE EFFECT OF TOPOGRAPHY

ON

AIRBORNE GRAVITY GRADIOMETER DATA

by

John J. Graham

&

Joseph L. Toohey

Presented To

Fifteenth Annual Gravity Gradiometry Conference
United States Air Force Academy
Colorado Springs, Colorado
10-12 February 1987

Defense Mapping Agency Aerospace Center
3200 South Second Street
St. Louis, Missouri 63118-3399

ABSTRACT

The reduction and conversion of airborne gravity gradiometer data to ground level estimates of the gravity disturbance vector is currently of considerable interest in support of short wavelength gravity modeling. A pressing problem is the need for an accurate procedure for the downward continuation of data acquired at altitude by the Airborne Gravity Gradiometer Survey System (GGSS). As part of ongoing investigations, a prism method has been used to calculate the effect of topography on the gravity disturbance vector and the five independent second-order gravity gradients. Calculations of the contribution of topography to the magnitudes of these gravimetric parameters were made at both surface and elevated points in the Wichita Mountains of Oklahoma. Computations were made utilizing Digital Terrain Elevation Data (DTED) with an assumed constant density of 2.67 grams/centimeters^3 for the topographic masses. Results are presented which reflect the use of DTED sets of different horizontal extent and grid interval.

THE EFFECT OF TOPOGRAPHY ON AIRBORNE GRAVITY GRADIOMETER DATA

I. INTRODUCTION

The field testing of the airborne Gravity Gradiometer Survey System (GGSS), being built by Bell Aerospace/Textron for the Defense Mapping Agency, is scheduled to commence before midyear. Therefore, methods for validation of the system's ability to map the local gravity field to high detail through gravity gradient measurements and their subsequent downward continuation/conversion into surface gravity disturbance components are of pressing interest. Validation can in-part be accomplished by estimating the influence of local topography on the radial disturbance, the deflection components, and the second-order gravity gradients at both surface and aloft stations. This report summarizes the results of computing topographic terrain effects from the topography above mean sea level. The terrain effects are calculated on the basis of homogeneous rectangular prisms which model the terrain masses with an assumed constant density.

The surface computation points coincide with the two astro-geodetic stations located in the Wichita Mountains of Oklahoma. One is near Sunset Peak and the other is on Mount Scott as shown in Figure 1. Terrain effects were computed at these surface stations and at points directly overhead at altitude 5000 feet above the geoid. Digital Terrain Elevation Data (DTED) supplied the topographic model needed to compute the terrain effects. The main goal of the study was to determine which DTED field should make up an inner grid zone and to what radial extent outward. There was also a need to establish the coarsest DTED representaion permissible for the outer zone and its span of coverage for adequate modeling of the local terrain effects on selective gravimetric quantities.

II. DISCUSSION

a. Objective

A major part of the short wavelength variation of the gravity field in a local area is due to topography. Therefore, especially in mountainous areas, one would anticipate the need for the best available topographic elevation data in the immediate vicinity of a computation point. At some further distance beyond this, a coarser terrain representation could be utilized to make the computational process more efficient with a minimal affect on results. With this premise, terrain effects were computed for the stations shown in Figure 1 to establish the radius of an inner zone for 3" point DTED which is our finest grain DTED. The computations also allow the determination of the largest mean DTED representation that is permissible for an outer zone and its span of coverage for adequate modeling of the local terrain effects on selective gravimetric quantities. These quantities include the radial gravity disturbance, the deflection of the vertical components, and the second-order gravity gradients. Inner zone modeling with mean DTED will indicate whether there is a need for the exclusive use of point DTED for this area. Insight into upward continuation effects is afforded with the inclusion of aloft computation points.

b. Method of Analysis

A modified version of the Rene Forsberg prism program was run to compute the topographic terrain effects. The program is discussed in Reference 2. The right-handed coordinate system was centered at each computation station with X pointing east, Y pointing north, and Z pointing up. Prisms were formed from a geoid base up to the DTED topography of an assumed density of 2.67 gm/cm^3 as illustrated in Figure 2. The integration was performed numerically using the distances from station coordinates to the eight corners of each prism. The surface station height was offset 1 cm to avoid the central prism from being automatically eliminated from the program and to avoid the station from being located within the central prism boundaries.

c. DTED Fields Used

A 3" point DTED field was built around the stations from the same data that DMAAC sent to Bell Aerospace/Textron. Also created were 9", 12", 15", 30", 1', and 3' mean fields from the 3" point data. When using both an inner field and an outer field around a station, the prisms must properly fit together. If the inner field is the 3" DTED, then the outer mean field must be a multiple of 6" for the prisms to fit together.

d. Formulation

Terrain mass modeling is accomplished with homogeneous rectangular prisms in the calculations. Gravitational formulas for such prisms are known from MacMillan's work on potential theory in Reference 1. The prism dimensions for this study were controlled by the description of the topography. Figure 3 shows the indefinite integral solutions used to compute the exact evaluation of ten gravimetric quantities at the computation point P in Figure 2 for a single prism. When the separation between a prism and the computation point permits, approximate prism formulations are used instead of the exact ones. Figure 4 gives details on how a series expansion for a prism's potential may be derived by formulating the reciprocal distance "r" as an infinite series in terms of the Legendre polynomials. Using only the first few terms of the potential series, all first and second-order gravity gradients may be found by simple differentiation. The exact formulation is normally used for the central prism while the approximate formulation is used for all remaining prisms to obtain the desired gradients.

III. RESULTS

a. Tabular Output

Tables 1 and 2 show the effects of topographic modeling by different DTED fields within a 12' radius about the two surface stations. The various terrain fields used were 3", 9", 12", 15", 30", 1', and 3' DTED. The same investigation is repeated in Tables 3 and 4 for the computation points at elevation 5000 feet above the geoid and directly overhead. Terrain effect variations due to unit step increases over the interval, 6' to 13', in the radius of a central zone of 3" point DTED are shown in Tables 5 and 6 for the ground level stations. In the remaining tables, terrain effects are accounted for by employing the 3" point DTED in an inner zone and one of the mean DTED fields in an outer zone. It was discovered that the prism program requires the outer grid field to be a multiple of 6" for the prisms to properly fit together. This is the same as saying that if one extends the 3" field, then the outer mean field center coordinates must coincide with a 3" point. Examples of outer fields would then be 12", 30", 1', and 3'.

Tables 7 and 8 indicate variation in terrain effects caused by mean DTED representations in an outer zone of radius 30' and an inner zone radius of 12'. The means considered for the outer zone terrain modeling were 12", 30", 1' and 3' DTED. Each table displays results for one of the surface points, Sunset Peak or Mount Scott, and the related overhead point. Tables 9 and 10 reflect the usage of 1' mean DTED in two expanded outer zones, one of radius 2^{0} and the other 2.5^{0} with an inner zone radius of 12'. These are again composite tables for a pair of ground/aloft stations. For the ground level stations, Tables 11 and 12 indicate terrain variations due to inner zone modeling with different radial extents over the interval 1' to 10' while the outer 1' DTED zone was extended out to a radius of 2.5^{0}. Tables 13 and 14 are composite tables for a pair of ground/aloft stations where the terrain modeling was accomplished by an inner region of 3" point DTED and an outer zone of 3' mean DTED. The radii of the inner and outer regions were 5' and 2.5^{0}, respectively, in one case while 6' and 3^{0} in another.

b. Analysis

From Tables 1 through 4, it is obvious that the Sunset Peak station is not on a very sharp peak and that the Mount Scott station is on a very sharp peak which changed by 200 meters when using a 1' mean elevation field. Tables 1 through 4 make it obvious that the inner grid must be the 3" point DTED. Tables 5 and 6 show that the major contribution to the terrain effects is located very close to the stations. Tables 7 and 8 show that 1' and 3' mean DTED outer grids yield the same results as a 12" mean outer grid. Tables 9 and 10 show that an outer radius of 2.5^{0} allows the final effects to converge within acceptable limits. Tables 11 and 12 show that the inner grid radius may be reduced to at least 5' and still yield very acceptable results with a 2.5^{0} outer radius. Tables 13 and 14 show that an outer grid of 3' mean DTED yields acceptable results when compared with the 1' mean outer grid results.

When an outer grid is used, the inner grid values are extended further than they were in Tables 1 through 4. For instance when the 3' field was the outer grid and the inner radius was 5' as in Table 13, the portion of fine grid used in computations agrees with that of the 8' radius of Table 5. Another example is when the 1' field was the outer grid and the inner radius was 6' as in Table 11. This agrees with the portion of fine grid used in computations for the 7' radius of Table 5. The inner field is then extended by one unit of the outer grid spacing to form prisms that fit next to the prisms from the outer field. This explains why the outer grid must be a multiple of 6" for the prisms to fit together. This also explains the increase in number of prisms for Tables 7 and 8. The 3" field was extended further out by 1' and 3' which caused an increase in number of prisms. However, as one increases the outer radius to 3^{o}, a decrease in number of prisms would be seen by using a 3' outer mean field rather than an outer field of higher density. Computer time is thus reduced by using the 3' outer field.

IV. CONCLUSIONS AND FUTURE CONSIDERATIONS

The inner field must be the 3" point DTED with an inner radius of at least 5'. The outer field may be 3' mean DTED with an outer radius of at least 2.5^{o}. If the field is big enough it would be advisable to use an outer radius of 3^{o} and an inner radius of 6' in general. This would allow convergence of the topographic terrain effects within acceptable limits. The 3" inner grid contributes the major portions of the gradient values which means that the 3" elevations near the station coordinates must be as accurate as possible. An inner grid that is a less dense mean field would not yield the proper elevations near the station. The outer grid may be thought of as fine-tuning the values until convergence is achieved within acceptable limits. The 3" DTED tapes are written in 3' blocks which makes it convenient to form 3' mean DTED fields for the outer grid.

One must consider the computer time saved by using 3' mean DTED fields for the outer grid as large numbers of stations are computed. The number of prisms is cut down without sacrificing accuracy. About 90 seconds of CPU time is added per station with 3' mean DTED out to a radius of 3^{o} and 3" point DTED out to a radius of 6'. The radial gravity disturbance and second-order gradients converged within desired limits. The deflection components will not converge as the outer grid radial extent is increased. Conversion of the deflections into the other two disturbance components does not give near the magnitude of the radial disturbance. We see the high frequency nature of the second-order gradients by their rapid convergence. The much lower frequency nature of the deflection components will not allow convergence in the computation of the terrain effects.

In the future it would be desirable to augment the analysis with more stations in the Wichita mountains. The harmonic content of topographic terrain effects needs to be determined. Terrain effect computation by the FFT method may be investigated in the future. Comparisons of actual gradiometry data against simulated gradients derived from DTED fields will need to be made. It would be desirable to incorporate error propagation into the topographic terrain effects programs as errors in the DTED and density assumption become better defined. A major goal is to be able to add harmonic quantities to terrain effects for prediction of gravity in inaccessable areas.

REFERENCES

1. MacMillan, William Duncan; The Theory of Potential: Dover Publications, Inc., New York, New York; 1958

2. Forsberg, Rene; A Study of Terrain Reductions, Density Anomalies and Geophysical Inversion Methods in Gravity Field Modelling: OSU Report # 355, April, 1984

TOPOGRAPHIC TERRAIN EFFECTS

IN THE WICHITA MOUNTAINS

ON THE TOPOGRAPHIC SURFACE

AND AT 5000 FT ABOVE THE GEOID

OBJECTIVE

DETERMINE DTED FIELD REPRESENTAION NEEDED FOR CONVERGENCE OF LOCAL TOPOGRAPHIC TERRAIN EFFECTS ON THE RADIAL GRAVITY DISTURBANCE, DEFLECTION COMPONENTS, AND SECOND-ORDER GRADIENT COMPONENTS

STUDY AREA

WICHITA MOUNTAINS OF OKLAHOMA/ASTRO-GEODETIC STATIONS LOCATED AT SUNSET PEAK AND MOUNT SCOTT

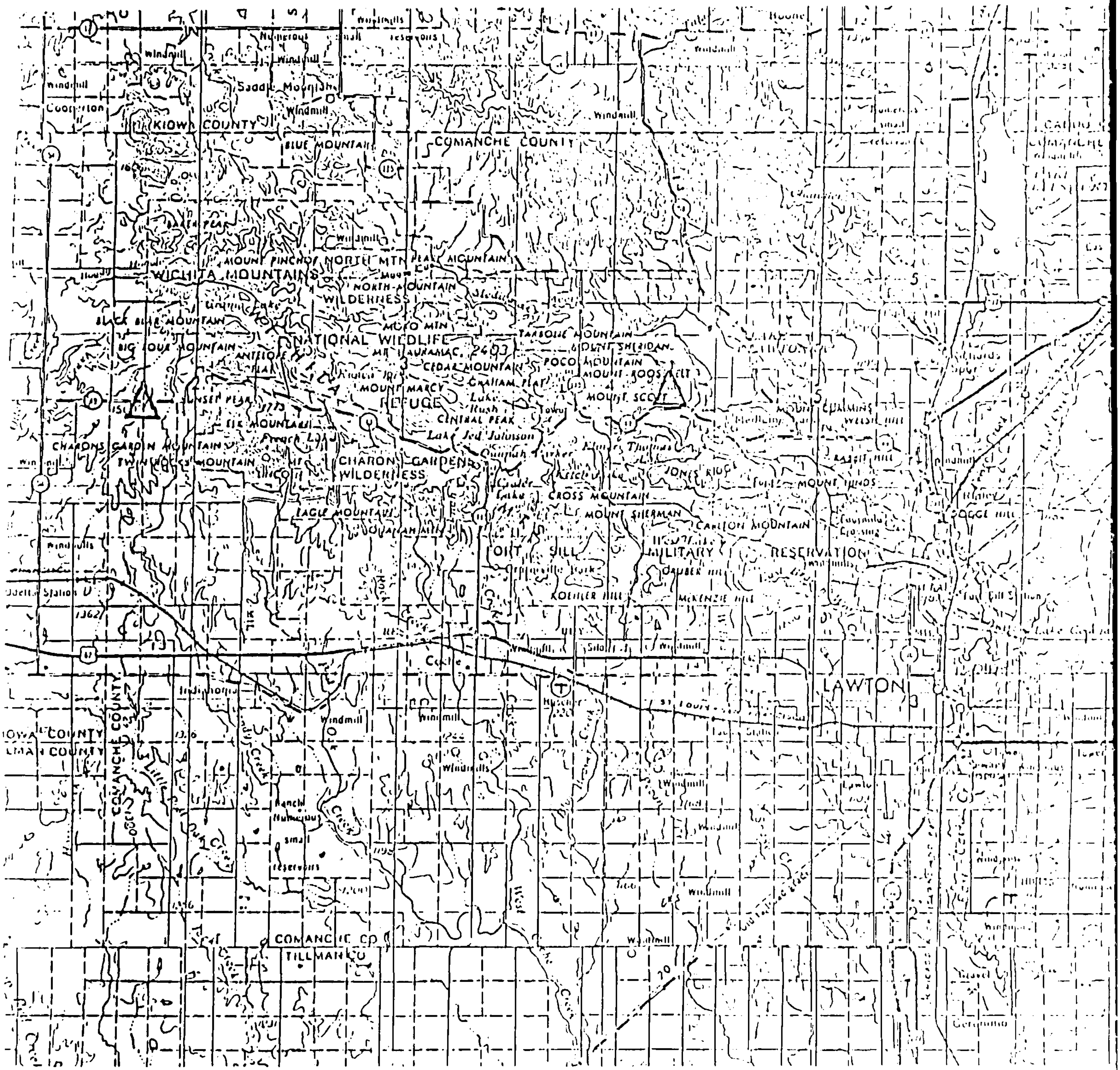


FIGURE 1. Area of Topographic Terrain Analysis - Wichita Mountains

METHOD OF ANALYSIS

MODIFIED FORSBERG PRISM PROGRAM BASED ON EXACT FORMULATION FOR CENTRAL PRISM AND APPROXIMATE FORMULATION FOR REMAINING PRISMS WITHIN RADII

DTED FIELDS USED

3" POINT DATA AND MEAN FIELDS OF THE 3" DATA FORMED INTO 9", 12", 15", 30", 1', AND 3' GRIDS

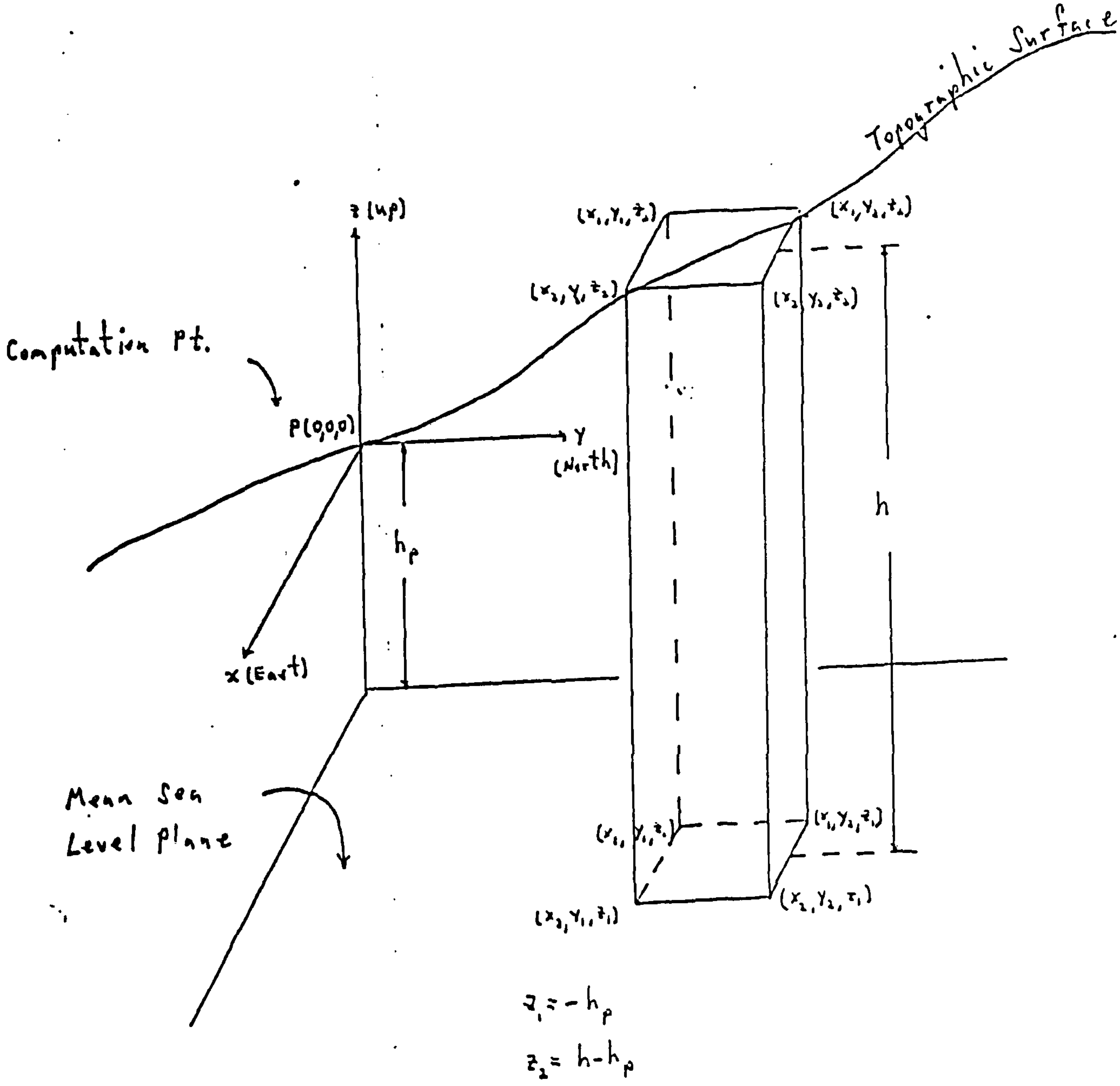


FIGURE 2. Prism Modeling of Terrain Masses

$$T_i(P) = k\rho \left\{ \left\{ \left\{ F_i(x,y,z) \Big|_{z_1}^{z_2} \right\} \Big|_{y_1}^{y_2} \right\} \Big|_{x_1}^{x_2} \right\}$$

WHERE $F_i(x,y,z)$ IS THE SOLUTION OF THE INDEFINITE INTEGRAL

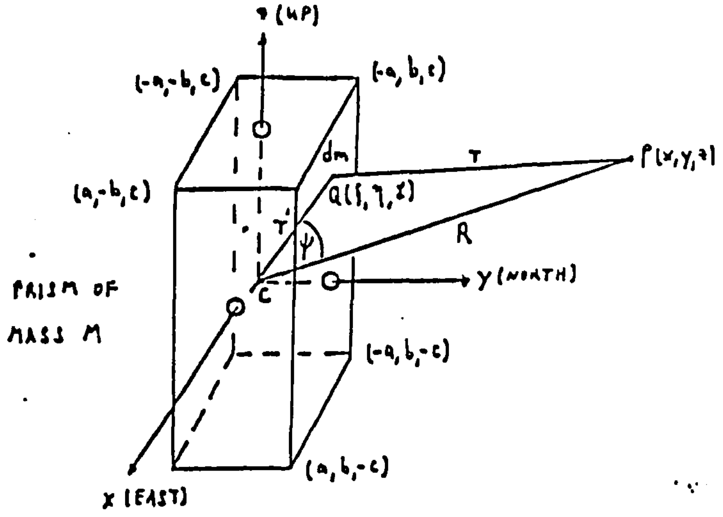
$$F_i(x,y,z) = \int\int\int k_i(x,y,z)\,dz\,dy\,dx$$

GRAVITY QUANTITIES AND FUNCTIONAL EXPRESSIONS

INDEX i	$T_i(P)$	$k_i(x,y,z)$	$F_i(x,y,z)$
1	$T(P)$	$1/r$	$xy\ln(z+r) + xz\ln(y+r) + yz\ln(x+r) - \frac{1}{2}\left[x^2\tan^{-1}\left\{\frac{yz}{xr}\right\} + y^2\tan^{-1}\left\{\frac{xz}{yr}\right\} + z^2\tan^{-1}\left\{\frac{xy}{zr}\right\}\right]$
2	$g_z(P)$	$-z/r^3$	$x\ln(y+r) + y\ln(x+r) - z\tan^{-1}\left\{\frac{xy}{zr}\right\}$
3	$\xi(P)$	$-\frac{1}{G}\frac{y}{r^3}$	$z\ln(x+r) + x\ln(z+r) - y\tan^{-1}\left\{\frac{zx}{yr}\right\}$
4	$\eta(P)$	$-\frac{1}{G}\frac{x}{r^3}$	$y\ln(z+r) + z\ln(y+r) - x\tan^{-1}\left\{\frac{yz}{xr}\right\}$
5	$T_{xx}(P)$	$\frac{3x^2-r^2}{r^5}$	$-\tan^{-1}\left\{\frac{yz}{xr}\right\}$
6	$T_{yy}(P)$	$\frac{3y^2-r^2}{r^5}$	$-\tan^{-1}\left\{\frac{zx}{yr}\right\}$
7	$T_{zz}(P)$	$\frac{3z^2-r^2}{r^5}$	$-\tan^{-1}\left\{\frac{xy}{zr}\right\}$
8	$T_{xy}(P)$	$\frac{3xy}{r^5}$	$\ln(z+r)$
9	$T_{xz}(P)$	$\frac{3xz}{r^5}$	$\ln(y+r)$
10	$T_{yz}(P)$	$\frac{3yz}{r^5}$	$\ln(x+r)$

$r = (x^2+y^2+z^2)^{1/2}$

FIGURE 3. Exact Prism Formulation for Different Gravimetric Quantities



$$\tau = \left[(\xi - x)^2 + (\eta - y)^2 + (\zeta - z)^2 \right]^{1/2}$$

$$R = \left[x^2 + y^2 + z^2 \right]^{1/2}$$

$$2a = \Delta x$$

$$2b = \Delta y$$

$$2c = \Delta z$$

$$M = 8abc\rho$$

POTENTIAL: $T(x,y,z) = k\rho \int_{-c}^{c} \int_{-b}^{b} \int_{-a}^{a} \frac{1}{\tau} \, d\xi \, d\eta \, d\zeta$

SUBSTITUTION OF

$$\frac{1}{\tau} = \sum_{n=0}^{\infty} \frac{(\tau')^n}{R^{n+1}} P_n(\cos\psi) \quad \text{AND} \quad \tau' \cos\psi = (x\xi + y\eta + z\zeta)/R$$

LEADS TO THE SERIES APPROXIMATION

$$T(x,y,z) = kM \Big[\frac{1}{R} + \frac{1}{24R^5} \Big\{ (2\Delta x^2 - \Delta y^2 - \Delta z^2) x^2 + (-\Delta x^2 + 2\Delta y^2 - \Delta z^2) y^2$$

$$+ (-\Delta x^2 - \Delta y^2 + 2\Delta z^2) z^2 \Big\} + \frac{1}{288R^9} \Big\{ \alpha_1(\Delta x, \Delta y, \Delta z) x^4$$

$$+ \alpha_2(\Delta x, \Delta y, \Delta z) y^4 + \alpha_3(\Delta x, \Delta y, \Delta z) z^4 + \cdots + \alpha_6(\Delta x, \Delta y, \Delta z) x^2 z^2 \Big\}$$

$$+ \cdots \Big]$$

FIGURE 4. Approximative Prism Formulation of Potential T

RESULTS OBTAINED FROM MODIFIED

FORSBERG PRISM PROGRAM USING

VARIOUS DTED FIELDS AS INPUT

TABLE 1

SUNSET PEAK EFFECTS USING ONLY INNER RADIUS OF 12'
AND STATION ELEVATION LOCATED ON TERRAIN SURFACE

FIELD	STN ELV	DTM ELV	DG	KSI	ETA	PRISMS
	(meters)		(mgals)	(arc secs)		
3"	483	483	53.47	-1.49	-1.02	220303
9"	485	485	53.71	-1.46	-1.12	24580
12"	487	487	53.92	-1.44	-1.15	13877
15"	488	488	54.03	-1.44	-1.20	8924
30"	485	485	53.71	-1.34	-1.27	2316
60"	486	486	53.82	-1.32	-1.25	664

FIELD	Txx	Tyy	Tzz	Txy	Txz	Tyz
			(units in eotvos)			
3"	11.67	-14.11	2.44	31.51	-2.37	-1.19
9"	-32.68	-9.91	42.59	15.88	1.12	-0.12
12"	-43.78	-17.85	61.62	13.14	0.77	-0.50
15"	-15.88	-31.46	47.35	12.78	0.09	-0.42
30"	-13.78	-23.94	37.72	6.87	-0.10	-0.19
60"	-13.15	-12.00	25.15	0.79	-0.03	-0.01

TABLE 2

MOUNT SCOTT EFFECTS USING ONLY INNER RADIUS OF 12'
AND STATION ELEVATION LOCATED ON TERRAIN SURFACE

FIELD	STN ELV	DTM ELV	DG	KSI	ETA	PRISMS
	(meters)		(mgals)	(arc secs)		
3"	701	701	71.94	-0.83	1.85	220303
9"	680	680	70.54	-0.18	1.48	24580
12"	663	663	69.31	0.11	1.35	13877
15"	643	643	67.90	0.26	1.38	8924
30"	580	580	62.87	0.49	1.61	2316
60"	499	499	55.08	0.19	2.04	664

FIELD	Txx	Tyy	Tzz	Txy	Txz	Tyz
			(units in eotvos)			
3"	-371.29	-371.17	742.46	-106.74	-12.48	-6.68
9"	-279.98	-349.15	629.13	-52.65	-26.52	27.72
12"	-178.41	-370.19	548.60	-52.64	-13.92	45.39
15"	-166.81	-245.44	412.24	-57.75	-4.06	24.71
30"	-48.27	-214.42	262.68	-55.98	5.05	26.15
60"	-28.51	-30.14	58.64	-7.95	1.14	0.96

TABLE 3

SUNSET PEAK EFFECTS USING ONLY INNER RADIUS OF 12′
AND STATION ELEVATION 5000 FT ABOVE MEAN SEA LEVEL

FIELD	STN ELV	DTM ELV	DG	KSI	ETA	PRISMS
	(meters)		(mgals)	(arc secs)		
3"	1524	483	50.84	-1.24	-1.05	220303
9"	1524	485	50.87	-1.23	-1.06	24580
12"	1524	487	50.87	-1.22	-1.06	13877
15"	1524	488	50.88	-1.22	-1.06	8924
30"	1524	485	50.91	-1.18	-1.08	2316
60"	1524	486	51.00	-1.14	-1.10	664

FIELD	Txx	Tyy	Tzz	Txy	Txz	Tyz
			(units in eotvos)			
3"	-10.88	-13.99	24.88	4.48	-5.66	-7.95
9"	-10.92	-14.05	24.97	4.45	-5.95	-7.70
12"	-10.93	-14.11	25.04	4.42	-6.10	-7.59
15"	-10.96	-14.10	25.06	4.38	-6.22	-7.51
30"	-10.76	-14.05	24.81	3.96	-6.62	-7.17
60"	-11.32	-14.30	25.62	3.51	-7.09	-7.05

TABLE 4

MOUNT SCOTT EFFECTS USING ONLY INNER RADIUS OF 12′
AND STATION ELEVATION 5000 FT ABOVE MEAN SEA LEVEL

FIELD	STN ELV	DTM ELV	DG	KSI	ETA	PRISMS
	(meters)		(mgals)	(arc secs)		
3"	1524	701	51.67	-0.71	1.76	220303
9"	1524	680	51.69	-0.63	1.73	24580
12"	1524	663	51.68	-0.60	1.71	13877
15"	1524	643	51.63	-0.57	1.71	8924
30"	1524	580	51.35	-0.43	1.66	2316
60"	1524	499	49.99	-0.32	1.63	664

FIELD	Txx	Tyy	Tzz	Txy	Txz	Tyz
			(units in eotvos)			
3"	-33.38	-51.51	84.89	-3.56	19.03	-4.61
9"	-31.60	-50.30	81.90	-3.49	16.34	1.42
12"	-30.50	-49.45	79.95	-3.59	15.29	3.93
15"	-29.31	-48.16	77.47	-3.61	14.86	5.93
30"	-24.03	-42.22	66.25	-3.07	13.32	12.80
60"	-17.26	-22.94	40.20	-0.11	14.64	13.60

TABLE 5

SUNSET PEAK EFFECTS USING ONLY 3" INNER FIELD
AND STATION ELEVATION LOCATED ON TERRAIN SURFACE

RADIUS	STN ELV	DTM ELV	DG	KSI	ETA	PRISMS
	(meters)		(mgals)	(arc secs)		
6'	483	483	52.85	-1.04	-0.75	55147
7'	485	485	53.02	-1.15	-0.84	75042
8'	487	487	53.15	-1.25	-0.91	97969
9'	488	488	53.26	-1.32	-0.95	123966
10'	485	485	53.34	-1.38	-0.98	153028
11'	486	486	53.41	-1.44	-1.00	185130
12'	486	486	53.47	-1.49	-1.02	220303
13'	486	486	53.52	-1.54	-1.04	258546

RADIUS	Txx	Tyy	Tzz	Txy	Txz	Tyz
			(units in eotvos)			
6'	-0.38	-25.12	25.50	30.74	-2.37	-1.18
7'	3.09	-21.80	18.71	31.03	-2.37	-1.18
8'	5.69	-19.41	13.72	31.19	-2.37	-1.18
9'	7.67	-17.60	9.93	31.29	-2.37	-1.19
10'	9.26	-16.19	6.93	31.36	-2.37	-1.19
11'	10.58	-15.05	4.47	31.44	-2.37	-1.19
12'	11.67	-14.11	2.44	31.51	-2.37	-1.19
13'	12.58	-13.33	0.75	31.58	-2.37	-1.19

TABLE 6

MOUNT SCOTT EFFECTS USING ONLY 3" INNER FIELD
AND STATION ELEVATION LOCATED ON TERRAIN SURFACE

RADIUS	STN ELV	DTM ELV	DG	KSI	ETA	PRISMS
	(meters)		(mgals)	(arc secs)		
6′	701	701	70.85	-0.27	1.24	55147
7′	701	701	71.16	-0.40	1.36	75042
8′	701	701	71.39	-0.52	1.47	97969
9′	701	701	71.57	-0.61	1.58	123966
10′	701	701	71.72	-0.70	1.68	153028
11′	701	701	71.84	-0.77	1.77	185130
12′	701	701	71.94	-0.83	1.85	220303
13′	701	701	72.02	-0.88	1.91	258546

RADIUS	Txx	Tyy	Tzz	Txy	Txz	Tyz
		(	units in eotvos)			
6′	-382.47	-381.84	764.31	-105.94	-12.58	-6.58
7′	-379.31	-378.39	757.90	-106.03	-12.55	-6.61
8′	-377.04	-376.19	753.23	-106.20	-12.52	-6.64
9′	-375.18	-374.44	749.61	-106.37	-12.51	-6.65
10′	-373.62	-373.10	746.72	-106.51	-12.50	-6.66
11′	-372.03	-372.03	744.38	-106.64	-12.49	-6.67
12′	-371.29	-371.17	742.46	-106.74	-12.48	-6.68
13′	-370.40	-370.46	740.86	-106.80	-12.47	-6.68

TABLE 7

SUNSET PEAK EFFECTS USING A 3" INNER FIELD OF 12' RADIUS AND A VARIABLE OUTER FIELD WITH A RADIUS OF 30'

FIELD	STN ELV	DTM ELV	DG	KSI	ETA	PRISMS
	(meters)		(mgals)	(arc secs)		
12"	483	483	53.93	-2.07	-0.81	352933
30"	483	483	53.93	-2.07	-0.81	300082
1'	483	483	53.93	-2.07	-0.81	307791
3'	483	483	53.94	-2.04	-0.79	356794
12"	1524	483	52.61	-1.82	-0.83	352933
30"	1524	483	52.61	-1.82	-0.83	300082
1'	1524	483	52.61	-1.82	-0.84	307791
3'	1524	483	52.62	-1.79	-0.81	356794

FIELD	Txx	Tyy	Tzz	Txy	Txz	Tyz
		(	units in eotvos)			
12"	17.56	-8.12	-9.44	31.76	-2.25	-1.21
30"	17.93	-8.14	-9.79	31.76	-2.31	-1.20
1'	17.80	-8.13	-9.68	31.76	-2.28	-1.21
3'	17.82	-8.11	-9.71	31.74	-2.28	-1.21
12"	-4.32	-8.09	12.41	4.74	-5.65	-8.04
30"	-4.30	-8.09	12.40	4.74	-5.65	-8.04
1'	-4.28	-8.09	12.37	4.73	-5.65	-8.04
3'	-4.23	-8.08	12.30	4.71	-5.65	-8.03

TABLE 8

MOUNT SCOTT EFFECTS USING A 3" INNER FIELD OF 12′ RADIUS AND A VARIABLE OUTER FIELD WITH A RADIUS OF 30′

FIELD	STN ELV	DTM ELV	DG	KSI	ETA	PRISMS
	(meters)		(mgals)	(arc secs)		
12"	701	701	72.65	-1.40	2.25	352933
30"	701	701	72.65	-1.39	2.25	300082
1′	701	701	72.65	-1.38	2.25	307791
3′	701	701	72.65	-1.34	2.26	356794
12"	1524	701	53.36	-1.27	2.15	352933
30"	1524	701	53.36	-1.27	2.15	300082
1′	1524	701	53.36	-1.26	2.15	307791
3′	1524	701	53.37	-1.22	2.16	356794

FIELD	Txx	Tyy	Tzz	Txy	Txz	Tyz
			(units in eotvos)			
12"	-364.17	-365.78	729.95	-106.72	-12.19	-6.63
30"	-364.44	-365.76	730.20	-106.76	-12.31	-6.65
1′	-364.32	-365.77	730.08	-106.08	-12.26	-6.64
3′	-364.27	-365.76	730.03	-106.73	-12.25	-6.63
12"	-26.91	-46.09	72.99	-3.69	19.13	-4.69
30"	-26.91	-46.08	72.99	-3.68	19.11	-4.69
1′	-26.91	-46.08	72.98	-3.67	19.12	-4.69
3′	-26.88	-46.07	72.96	-3.67	19.12	-4.69

TABLE 9

SUNSET PEAK EFFECTS USING A 3" INNER FIELD WITH A 12' RADIUS AND A 1' OUTER FIELD WITH A VARIABLE RADIUS

RADIUS	STN ELV	DTM ELV	DG	KSI	ETA	PRISMS
	(meters)		(mgals)	(arc secs)		
120'	483	483	54.76	-3.54	1.48	359412
150'	483	483	55.02	-3.70	2.50	390382
120'	1524	483	54.11	-3.29	1.46	359412
150'	1524	483	54.43	-3.45	2.47	390382

RADIUS	Txx	Tyy	Tzz	Txy	Txz	Tyz
		(units in eotvos)				
120'	21.22	-5.04	-16.18	31.54	-2.26	-1.22
150'	21.55	-4.85	-16.69	31.52	-2.25	-1.22
120'	-0.87	-5.01	5.88	4.52	-5.60	-8.08
150'	-0.54	-4.82	5.36	4.50	-5.58	-8.08

TABLE 10

MOUNT SCOTT EFFECTS USING A 3" INNER FIELD WITH A 12′ RADIUS AND A 1′ OUTER FIELD WITH A VARIABLE RADIUS

RADIUS	STN ELV	DTM ELV	DC	KSI	ETA	PRISMS
	(meters)		(mgals)	(arc secs)		
120′	701	701	73.56	-2.73	4.27	359412
150′	701	701	73.81	-2.90	5.20	390382
120′	1524	701	54.77	-2.60	4.17	359412
150′	1524	701	54.06	-2.78	5.10	390382

RADIUS	Txx	Tyy	Tzz	Txy	Txz	Tyz
		(units in eotvos)				
120′	-361.12	-362.88	724.00	-106.99	-12.22	-6.66
150′	-360.82	-362.70	723.52	-107.01	-12.22	-6.66
120′	-23.72	-43.19	66.91	-3.93	19.16	-4.73
150′	-23.41	-43.02	66.43	-3.95	19.18	-4.73

TABLE 11

SUNSET PEAK EFFECTS USING A 1′ OUTER FIELD WITH A 150′ RADIUS AND 3″ INNER FIELD WITH A VARIABLE RADIUS. THE STATION ELEVATION IS ON THE TERRAIN SURFACE

RADIUS	STN ELV (meters)	DTM ELV (meters)	DG (mgals)	KSI (arc secs)	ETA (arc secs)	PRISMS
1′	483	483	55.03	-3.59	2.45	90334
2′	483	483	55.02	-3.61	2.44	98115
3′	483	483	55.02	-3.62	2.45	109885
4′	483	483	55.02	-3.63	2.47	123850
5′	483	483	55.02	-3.65	2.48	145396
6′	483	483	55.02	-3.66	2.49	166543
10′	483	483	55.02	-3.70	2.50	299809

RADIUS	Txx	Tyy	Tzz	Txy	Txz	Tyz
			(units in eotvos)			
1′	21.84	-5.15	-16.69	31.39	-2.27	-1.23
2′	22.36	-5.39	-16.97	31.28	-2.25	-1.23
3′	22.16	-5.30	-16.86	31.22	-2.25	-1.23
4′	21.95	-5.24	-16.71	31.34	-2.25	-1.23
5′	21.79	-5.03	-16.75	31.42	-2.25	-1.22
6′	21.69	-4.98	-16.71	31.43	-2.25	-1.22
10′	21.57	-4.86	-16.71	31.51	-2.25	-1.22

TABLE 12

MOUNT SCOTT EFFECTS USING A 1′ OUTER FIELD WITH A 150′ RADIUS AND 3" INNER FIELD WITH A VARIABLE RADIUS. THE STATION ELEVATION IS ON THE TERRAIN SURFACE

RADIUS	STN ELV (meters)	DTM ELV (meters)	DG (mgals)	KSI (arc secs)	ETA (arc secs)	PRISMS
1′	701	701	73.85	-2.89	5.18	90334
2′	701	701	73.85	-2.90	5.22	98115
3′	701	701	73.83	-2.87	5.20	109885
4′	701	701	73.83	-2.86	5.21	123850
5′	701	701	73.82	-2.86	5.21	145396
6′	701	701	73.82	-2.82	5.20	166543
10′	701	701	73.81	-2.90	5.20	299809

RADIUS	Txx	Tyy	Tzz	Txy	Txz	Tyz
	(units in eotvos)					
1′	-361.73	-360.62	722.35	-105.67	-12.34	-6.62
2′	-359.97	-362.07	722.04	-105.62	-12.19	-6.68
3′	-360.67	-362.08	722.75	-105.76	-12.22	-6.65
4′	-360.58	-362.46	723.03	-105.81	-12.22	-6.65
5′	-360.64	-362.68	723.32	-105.86	-12.22	-6.65
6′	-360.70	-362.73	723.44	-105.89	-12.22	-6.66
10′	-360.82	-362.70	723.53	-105.99	-12.22	-6.66

TABLE 13

FINAL SUNSET PEAK EFFECTS USING A 3" INNER FIELD AND A 3' OUTER FIELD WITH BOTH RADII BEING VARIABLE

RADII	STN ELV (meters)	DTM ELV (meters)	DG (mgals)	KSI (arc secs)	ETA (arc secs)	PRISMS
5',150'	483	483	55.03	-3.56	2.50	90649
6',180'	483	483	55.31	-3.77	3.45	121846
5',150'	1524	483	54.45	-3.31	2.48	90649
6',180'	1524	483	54.79	-3.52	3.42	121846

(units in eotvos)

RADII	Txx	Tyy	Tzz	Txy	Txz	Tyz
5',150'	22.20	-5.44	-16.76	31.11	-2.24	-1.23
6',180'	22.17	-4.83	-17.35	31.31	-2.23	-1.22
5',150'	0.14	-5.40	5.26	4.09	-5.58	-7.98
5',180'	0.12	-4.80	4.68	4.28	-5.60	-8.04

TABLE 14

FINAL MOUNT SCOTT EFFECTS USING A 3" INNER FIELD AND A 3' OUTER FIELD WITH BOTH RADII BEING VARIABLE

RADII	STN ELV	DTM ELV	DG	KSI	ETA	PRISMS
	(meters)		(mgals)	(arc secs)		
5',150'	701	701	73.83	-2.81	5.19	90649
6',180'	701	701	74.10	-2.97	6.15	121846
5',150'	1524	701	55.11	-2.69	5.09	90649
6',180'	1524	701	55.39	-2.84	6.05	121846

RADII	Txx	Tyy	Tzz	Txy	Txz	Tyz
			(units in eotvos)			
5',150'	-360.34	-362.80	723.14	-106.66	-12.22	-6.65
6',180'	-360.40	-362.56	722.96	-106.69	-12.19	-6.65
5',150'	-22.97	-43.12	66.08	-3.61	19.14	-4.69
5',180'	-23.02	-42.88	65.90	-3.63	19.20	-4.69

ANALYSIS OF RESULTS

* MOUNT SCOTT IS A MUCH SHARPER PEAK THAN SUNSET PEAK
* THE INNER GRID MUST BE THE 3" POINT DATA TO OBTAIN PROPER TERRAIN ELEVATIONS AT THE STATION COORDINATES
* THE MAJOR CONTRIBUTION TO TERRAIN EFFECTS IS LOCATED VERY CLOSE TO THE STATION COORDINATES
* A 3′ MEAN OUTER GRID GIVES SIMILAR RESULTS TO THOSE OBTAINED BY USING A FINER GRAIN OUTER GRID
* AN INNER GRID RADIUS OF 5′ OR 6′ IS VERY ACCEPTABLE FOR CONVERGENCE OF THE TERRAIN EFFECTS
* AN OUTER GRID RADIUS OF 150′ OR 180′ IS ADEQUATE FOR CONVERGENCE OF THE TERRAIN EFFECTS

CONCLUSIONS FROM RESULTS

* THE INNER GRID MUST BE THE 3" POINT DTED FIELD
* THE OUTER FIELD MAY BE A 3′ MEAN DTED FIELD
* THE INNER GRID RADIAL EXTENT SHOULD BE 5′ OR 6′
* THE OUTER GRID RADIAL EXTENT SHOULD BE 150′ OR 180′
* THE 3" FIELD CONTRIBUTES THE MAJOR CONTRIBUTION TO THE TOPOGRAPHIC TERRAIN EFFECTS
* THE DEFLECTION COMPONENTS WILL NOT CONVERGE AS THE OUTER GRID RADIAL EXTENT IS INCREASED
* THE RADIAL GRAVITY DISTURBANCE AND SECOND-ORDER GRADIENTS CONVERGE WITHIN DESIRED LIMITS
* VERY ACCURATE 3" DTED IS NEEDED FOR CONVERGENCE TO THE CORRECT TOPOGRAPHIC TERRAIN EFFECT VALUES

FUTURE CONSIDERATIONS

* AUGMENT THE ANALYSIS WITH ADDITIONAL STATIONS IN THE WICHITA MOUNTAINS
* DETERMINE DEFINITION OF HARMONIC CONTENT OF TOPOGRAPHIC TERRAIN EFFECTS
* INVESTIGATE TERRAIN EFFECTS BY FFT METHOD
* COMPARE GRADIOMETRY DATA AGAINST SIMULATED GRADIENTS DERIVED FROM DTED FIELDS
* INCORPORATE ERROR PROPAGATION INTO TOPOGRAPHIC TERRAIN EFFECTS PROGRAMS

END
3-87
DTIC