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INVESTIGATION OF THE MODE OF COMPENSATION OF VENUS TOPOGRAPHY

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Introduction

The Venusian gravity data derived from Pioneer Venus Orbiter indicate a strong correlation of gravity to topography at all resolvable wavelengths (Phillips and Lanmbeck, 1980; Sjogren and others, 1980, 1983; Reasenberg and others, 1982; Esposito and others, 1982; Mottinger and others, 1983, 1985). This result is in marked contrast to Earth for which this correlation is very weak at similar wavelengths. Poor correlation between terrestrial gravity and topography at long wavelengths is a result of mixed modes of compensation of terrestrial topography which include crustal thickness variations, flexure, lateral hetrogeneity in the thermal lithosphere, and dynamic processes (e.g., Richards and Hager, 1984). The good Venusian gravity-topography correlation suggests a simple global compensation mode, at least to a first approximation. However, the character of this correlation shows high variability of different geographic regions of the planet (e.g., Sjogren and others, 1983), and both the correlation and its variability must be considered in any tectonic model of Venus (Phillips and Malin, 1984).

The Pioneer Venus topography and gravity sets have provided the first global examinations of Venus tectonics to be made (radar imaging has provided regional tectonic information), and both data sets indicate major differences between Venus and Earth. For rigorous analyses of these data, either the Pioneer Venus radio-tracking data must be used directly in a dynamical analysis (e.g., Esposito and others, 1982), or computation methods must be used which simulate spacecraft dynamics (e.g., Phillips and others, 1978). Most previous analyses of Venus topography and gravity data have concentrated in the wave number domain, using either simplifying assumptions about the effects of orbital dynamics (e.g., Sjogren and others, 1983; Bowin, 1983, 1985), or models to simulate the gravity field, typically an array of surface masses or spherical harmonic series (Esposito and others, 1982; Reasenberg and others, 1982; Bowin and others, 1983; Mottinger and others, 1983, 1984, 1985; Williams and others, 1983).

The present study has concentrated on analysis in the spatial domain, using a geophysical model of topographic compensation together with the topography data to compute gravity vectors corresponding to the observed data and comparison of the calculated and observed gravity vectors. This technique does not allow the coverage of such large areas as in wave number domain analyses, but has the advantage of being very sensitive spatially to breakdowns and changes in modes of compensation. This spatial domain forward modeling technique has been applied in a systematic manner to orbits at 40° spacing around the planet between the latitudes of 30° south and 60° north. The basic results of this analysis are presented here.

Method of Analysis

There are three basic components to the spatial domain forward modeling analysis in any selected are of study: 1) generation of geophysical compensation models; 2) computation of predicted orbital gravity values; and 3) comparison of calculated and observed gravity values and analysis of results. This analysis was carried out through remote access to the Lunar and Planetary Institute Geophysical Data Facilty in Houston, using a standard program for the calculation of theoretical orbital gravity, taking into account the effects of spacecraft orbital dynamics (Phillips and others, 1978), and special routines to calculate the effects of different geophysical models for the mode of topographic compensation. A flow chart for the modeling procedure is shown in Figure 1. Topography and compensation masses were approximated by point masses in this analysis placed at the center of mass of the topography and compensation. Analyses using different point mass spacings indicated the point masses are adequate representations of topography and compensation at orbital altitudes. In the present phase of the study, two compensation models were tests, crustal isosticy and thermal isosticy, the point mass equivalents of which are shown in Figure 2. Both compensation mass distributions were calculated relative to a mean effective compensation depth given by Z. Full documentation and access to the programs used in this study are available at the Lunar and Planetary Institute, Houston.

Results

After numerous tests of the main program and compensation mass calculation routines on small areas of the planet, theoretical gravity profiles were calculated for nine orbits around the planet spaced at approximately 40° intervals, and extending from 30° south to 60° north. The approximate locations of these profiles are shown in Figure 3. Each orbit was divided into a northern and southern section to reduce the sizes of the topography and compensation point mass arrays used in calculation of the orbital gravity. Topographic data was selected for each orbital segment extending at least 8 to 12° outside the orbital track to minimize edge effects, and 10° of overlap was calculated where the northern and southern orbital segments joined. Early analyses indicated that the crustal and thermal isostasy compensation models were essentially indistinguishable in the Pioneer Venus orbital gravity data, and for most of the models a constant density (crustal isostasy) model was used with a 2.8 gms/cc density for the topography and a compensating lithosphere/asthenasphere density contrast of 0.05 gms/cc. The main parameter that was allowed to vary was the mean effective depth of compensation. Preliminary results of these studies were presented by Morgan and others (1985) and Reagan (1986), and collaborative studies with wave number domain gravity analyses of Venus were presented by Phillips and Morgan (1984). It is anticipated that a short publication on the preliminary results will be prepared for submission during the next six months. Highlights of these preliminary results are given below. Results of the gravity analyses for orbits 548, 575, 602, 440, and 521 are shown in Figures 4-8 respectively. Each figure shows observed (solid line) and calculated (dashed lines) gravity values plotted as a function of latitude along the orbit, results for two model effective mean depths of compensation are shown for each profile, 100 kilometers (short dashes) and 200 kilometers (long dashes). These five orbits have been chosen as representative of the nine orbits analyzed in the study. The results for orbit 548 which passes to the west of Beta Regio are shown in Figure 4. The main long wavelength features of the observed gravity are reproduced by models for both compensation depths, with the 200 kilometer compensation depth best matching the 24 millagal range of the observed gravity. Between approximately 20° south and 12° north both compensation models underestimate the observed gravity suggesting a shallow mass excess or lack of low density compensation in this lowland region. More signal is apparent in the calculated gravity profiles between approximately 25 and 37° north, where the profile passes close to Rhea Mons, indicating very shallow compensation for this feature.

Orbit 575, the results for which are shown in Figure 5, passes through the southern portion of Beta Regio and to the east of Rhea Mons. Again, both compensation models match the gross long wavelength features of the observed gravity, with the 200 kilometer mean effective depth of compensation giving a closer match, but there are significant differences at shorter wavelengths. A large positive anomaly in the observed gravity just south of the equator is not matched by either model, although the 200 kilometer compensation depth model gives a better match. This result indicates that southern Beta Regio is compensated at a greater depth than 200 kilometers a result in agreement with results reported by Reasenberg and others (1982). In the lowlands north of 30° north, the observed profile is more negative than either model profiles, again indicating a greater depth of compensation than 200 kilometers.

Orbit 602, the results for which are shown in Figure 6, passes primarily through lowlands between Beta Regio and Aphrodite Terra. The observed gravity profile is well matched by the 200 kilometer effective mean depth of compensation model except in the region from approximately 20 to 37° north, where there is significant differences between observed and calculated. These differences occur over an area of rolling plains which extend into the lowlands, and may indicate shallow low density crust in this region.

The biggest differences between observed and calculated orbital gravity values were observed along orbits 440 and 521 (Figures 7 and 8, respectively). The 200 kilometer mean effective depth of compensation model gave a reasonable fit to the long wavelength features of orbit 440, but underestimated the maximum anomaly along orbit 521. These results indicate a different depth and perhaps mode of compensation between western and eastern Aphrodite, results consistent with wave number domain analyses by Phillips and others (1981), Bowin and others (1985), and Banedt (1986). Neither model gave a good fit to the observed gravity data in the region immediately to the north of Aphrodite Terra, indicating complex non-isostatic compensation of topography in this region. This region corresponds to an area mapped as parquet terrain from Soviet Venera data (Basilevsky and others, 1986), and may represent short wavelength crustal features flexurally supported.

These results indicate that while the long wavelength features of the Venusian gravity field are well matched by an isostatic compensation model with the mean effect depth of compensation around 200 kilometers, short wavelength features in the gravity field are complex. Preliminary analysis of the gravity field in the spatial domain has identified several areas of misfit between observed gravity and isostatic compensation models, suggesting regions for detailed future studies.

Discussion and Recommendations for Future Studies

Results of analyses of the Venusian gravity field in the spatial domain presented here indicates significant short wavelength anomalies in the field which cannot be explained by a simple global isostatic compensation model. Areas of misfit between observed and calculated gravity values do not appear to be restricted to any particular elevation range, but may have some correlation with map surface features. In an analysis of Venusian tectonics, it would seem fruitful to continue further detailed studies of local areas of misfit between observed and calculated gravity and their relationship to surface morphology. Recent advances in the mapping and understanding of the surface of Venus (Head and others, 1985; Garvin and others, 1985; Sharpton and Head, 1985, 1986; Basilevsky and others, 1986; Barsukov and others, 1986; Davis and others, 1986; Head and Wilson, 1986) suggest that the Venusian gravity field may be better understood in a combined analysis of local compensation mechanisms and surface tectonics.

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Flow Chart for Modeling

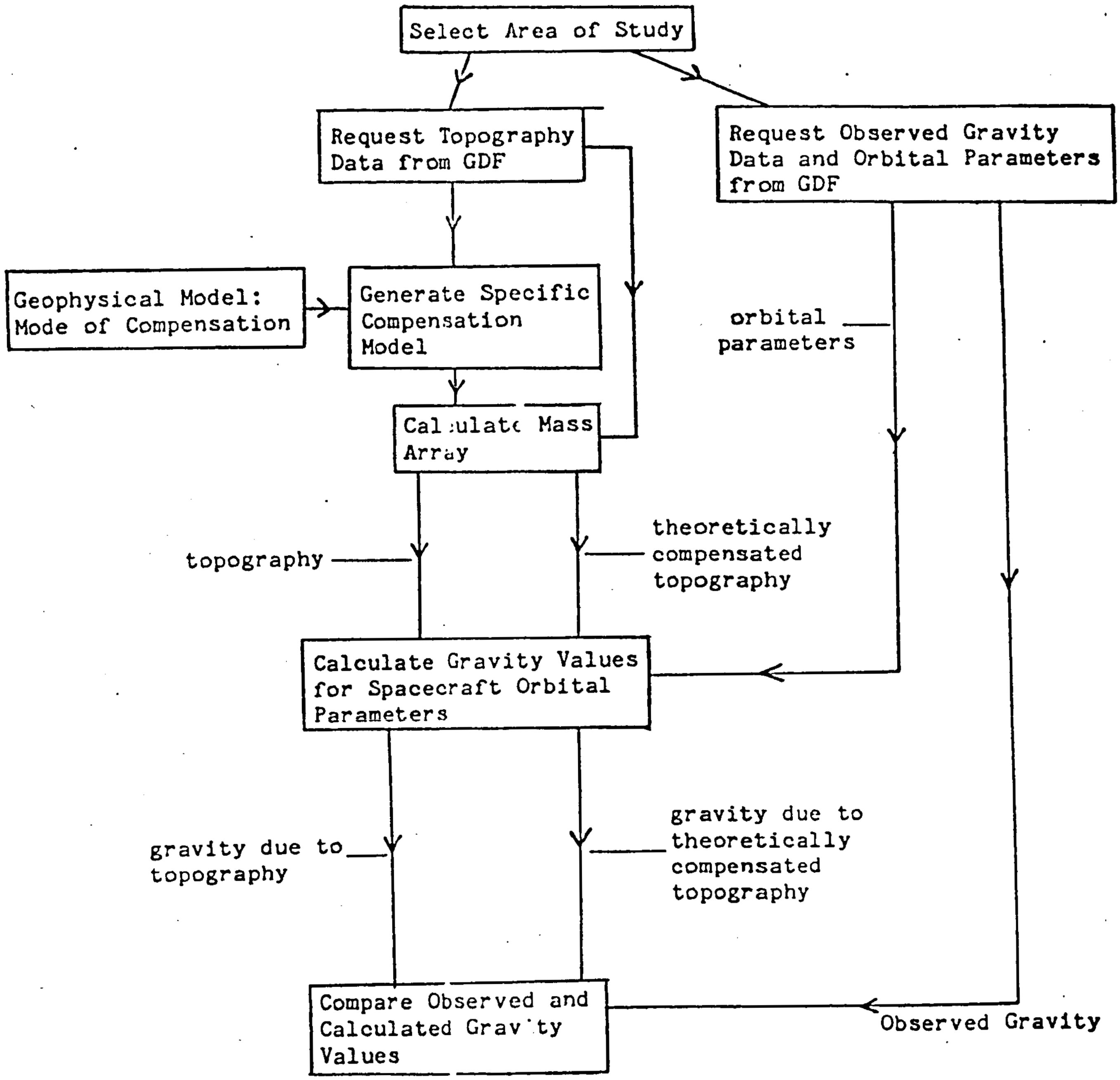

Figure 1. Flow chart for Spatial Domain forward modelling of Pioneer Venus Orbital Gravity Data.

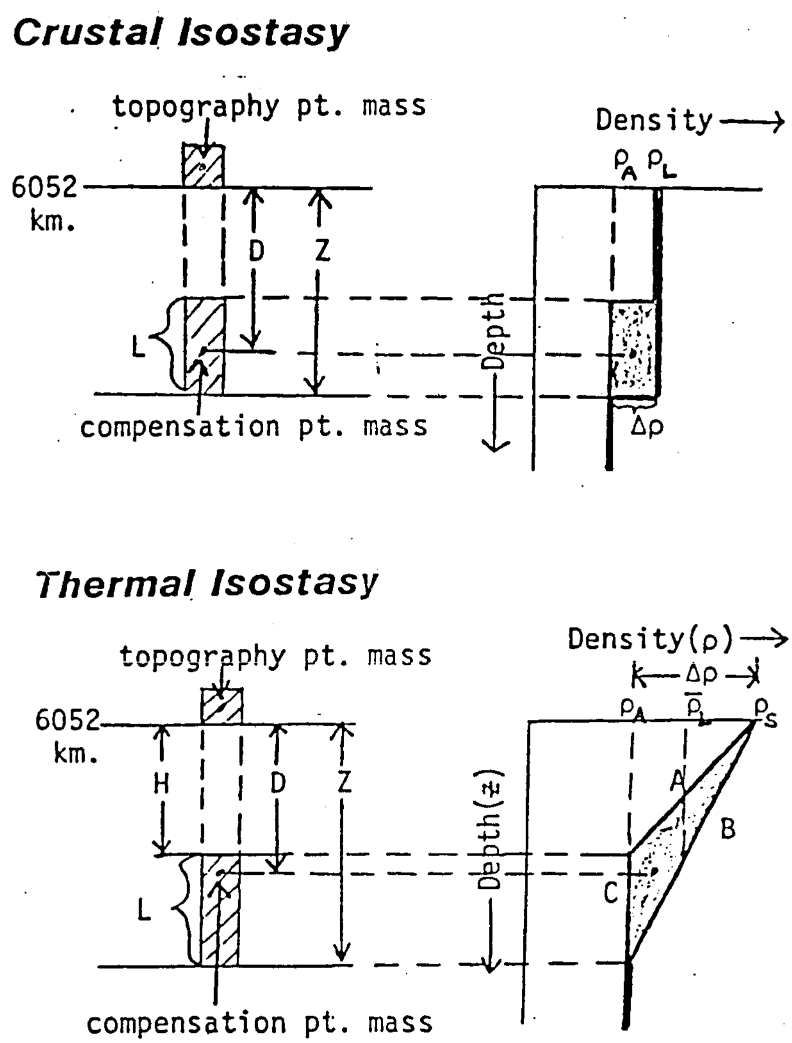

Figure 2. Density models for crustal isostasy and thermal isostasy compensation of venusian topography and their equivalent point masses.

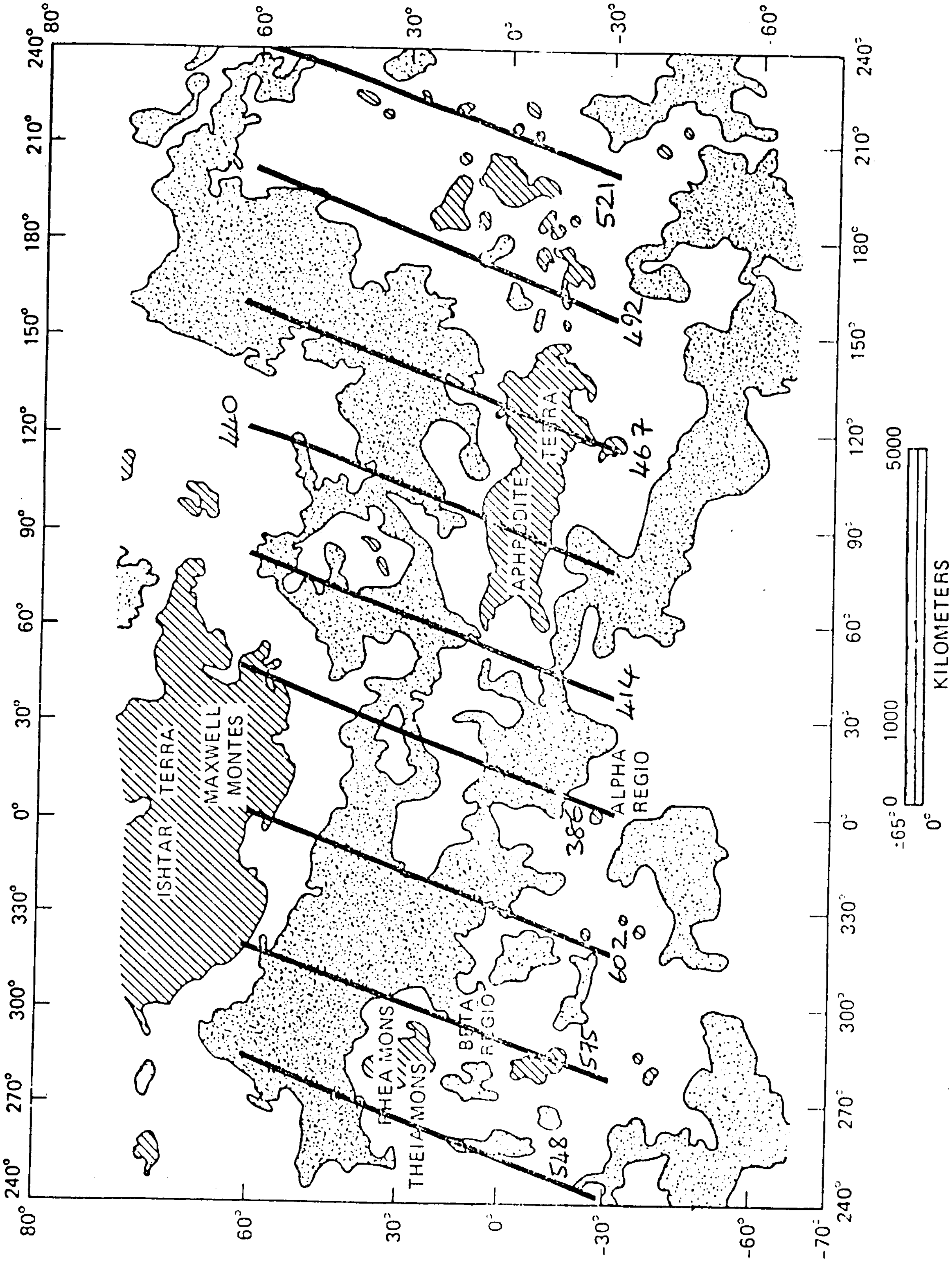

Figure 3. Map showing distribution of topographic provinces of Venus and approximate locations of orbits used in this study. White areas are the rolling plains, highlands are hatched and lowlands are the dotted areas. Orbit numbers are given by orbit tracks.

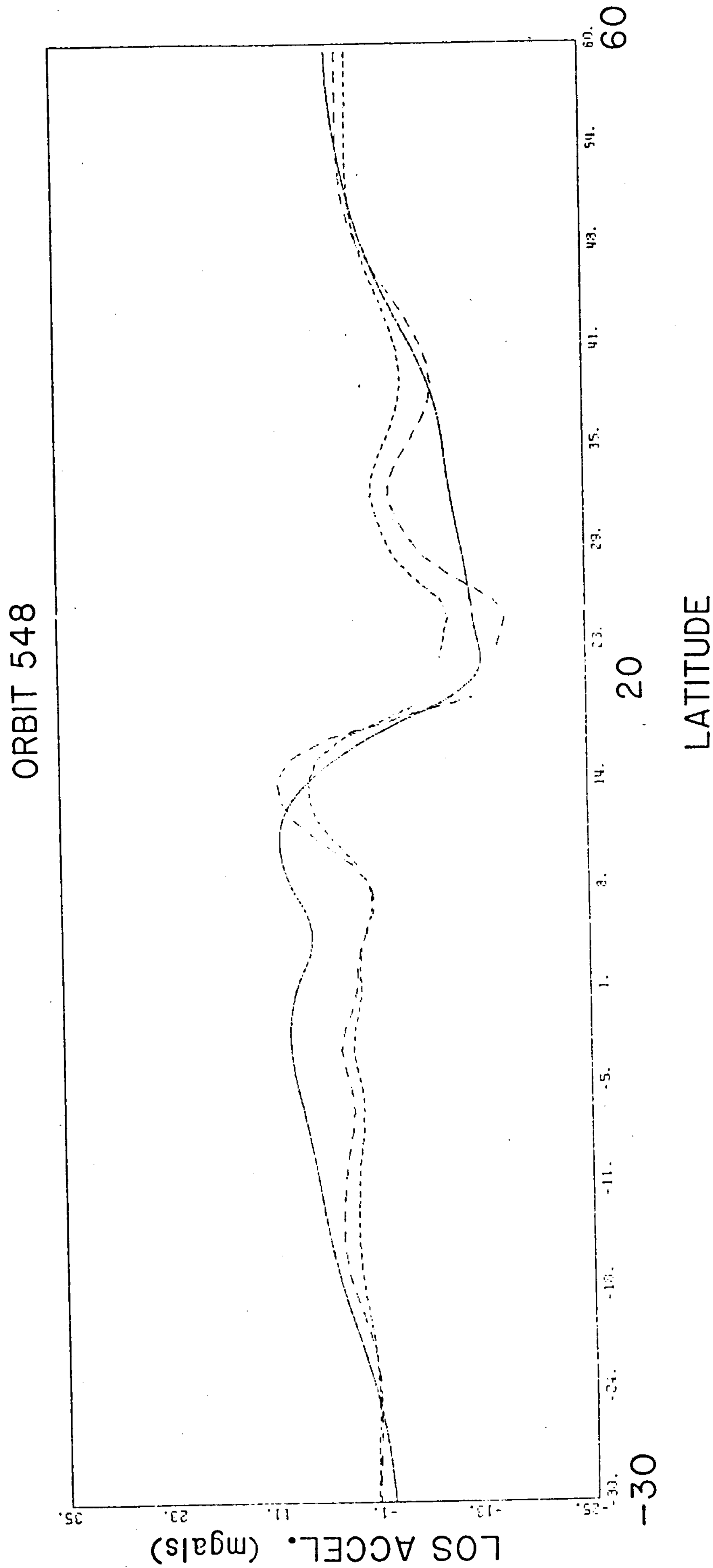

Figure 4. Calculated (100 km compensation short dashed line; 200 km long dashes) and observed gravity (solid line) for Orbit 548.

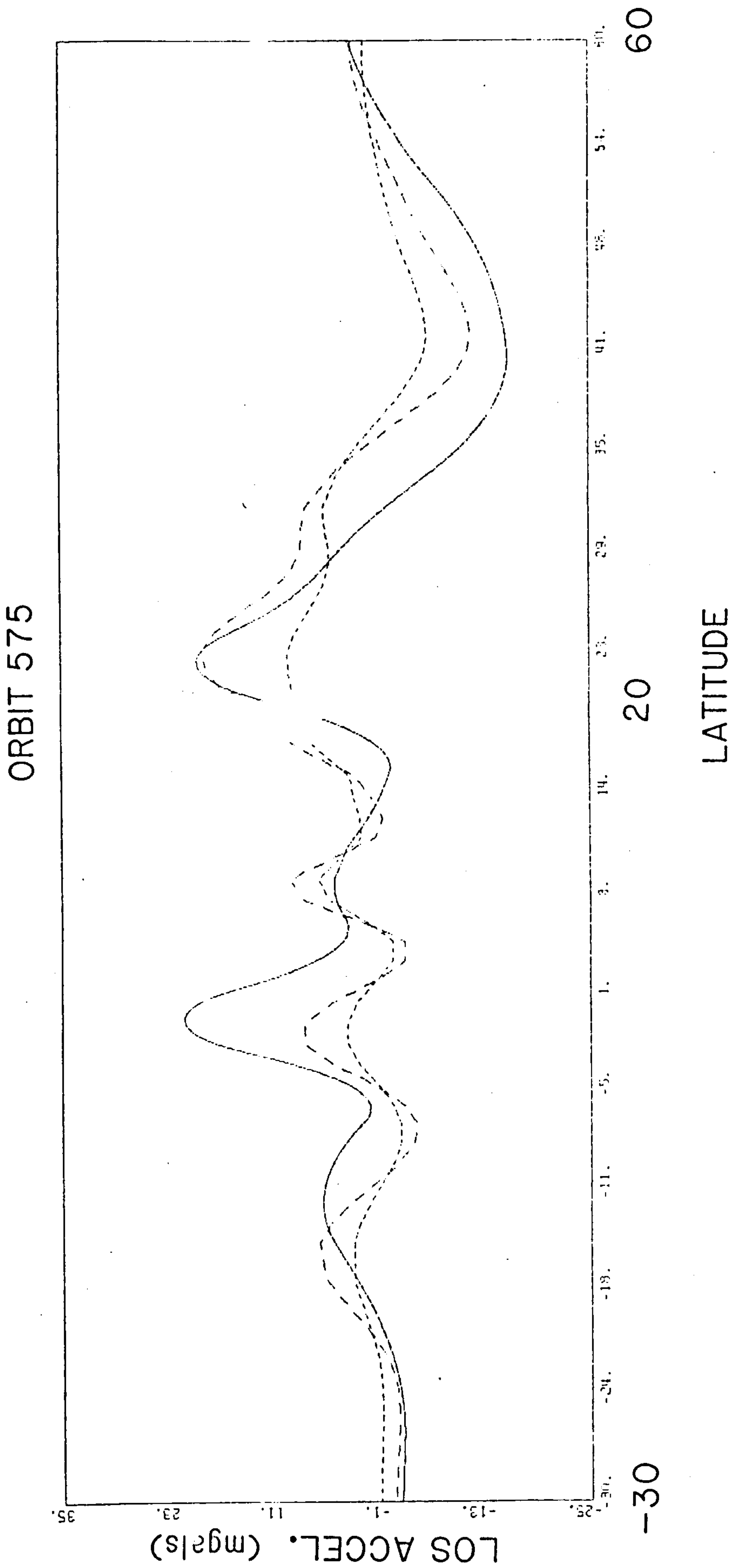

Figure 5. As fig. 4 for Orbit 575.

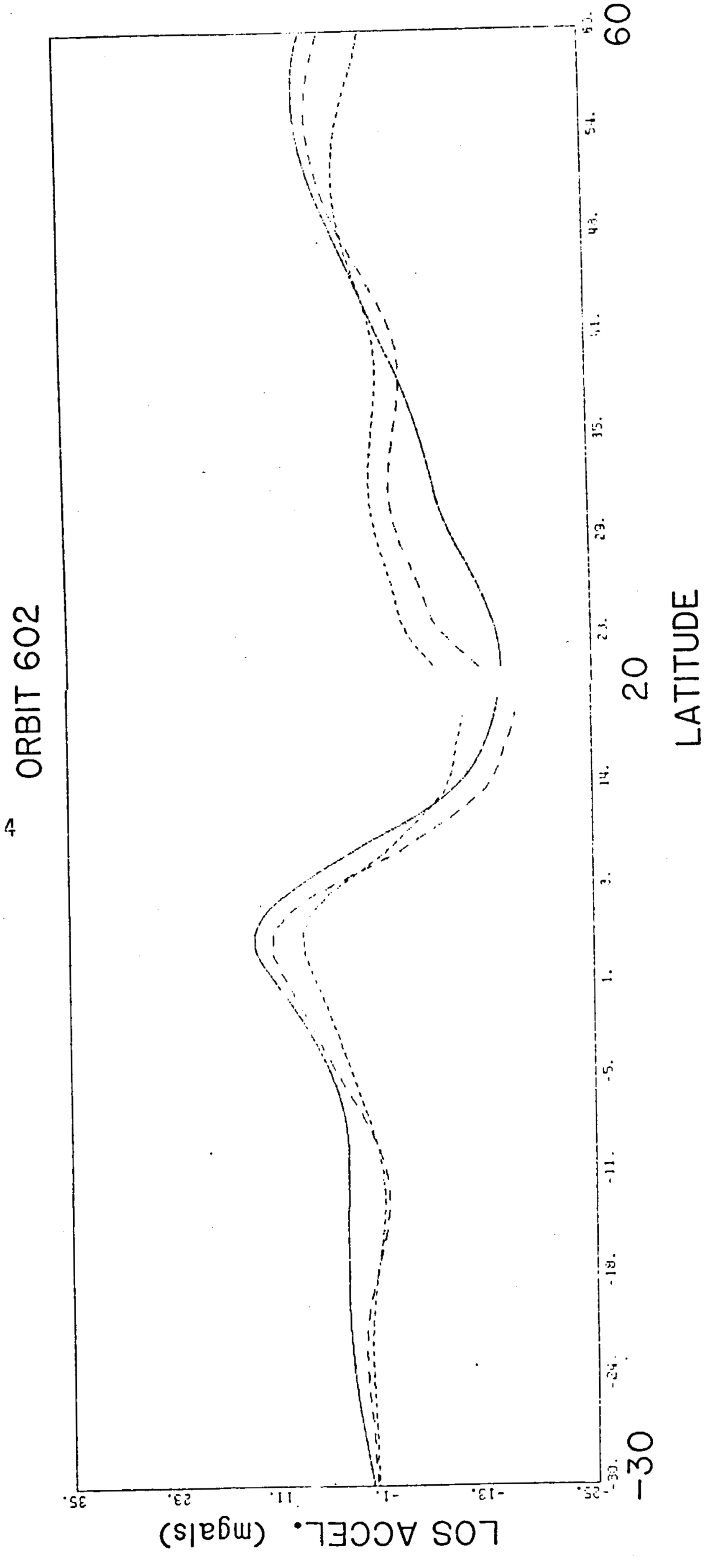

Figure 6. As fig 4
for Orbit 602.

Figure 7. As fig. 4
for Orbit 440.

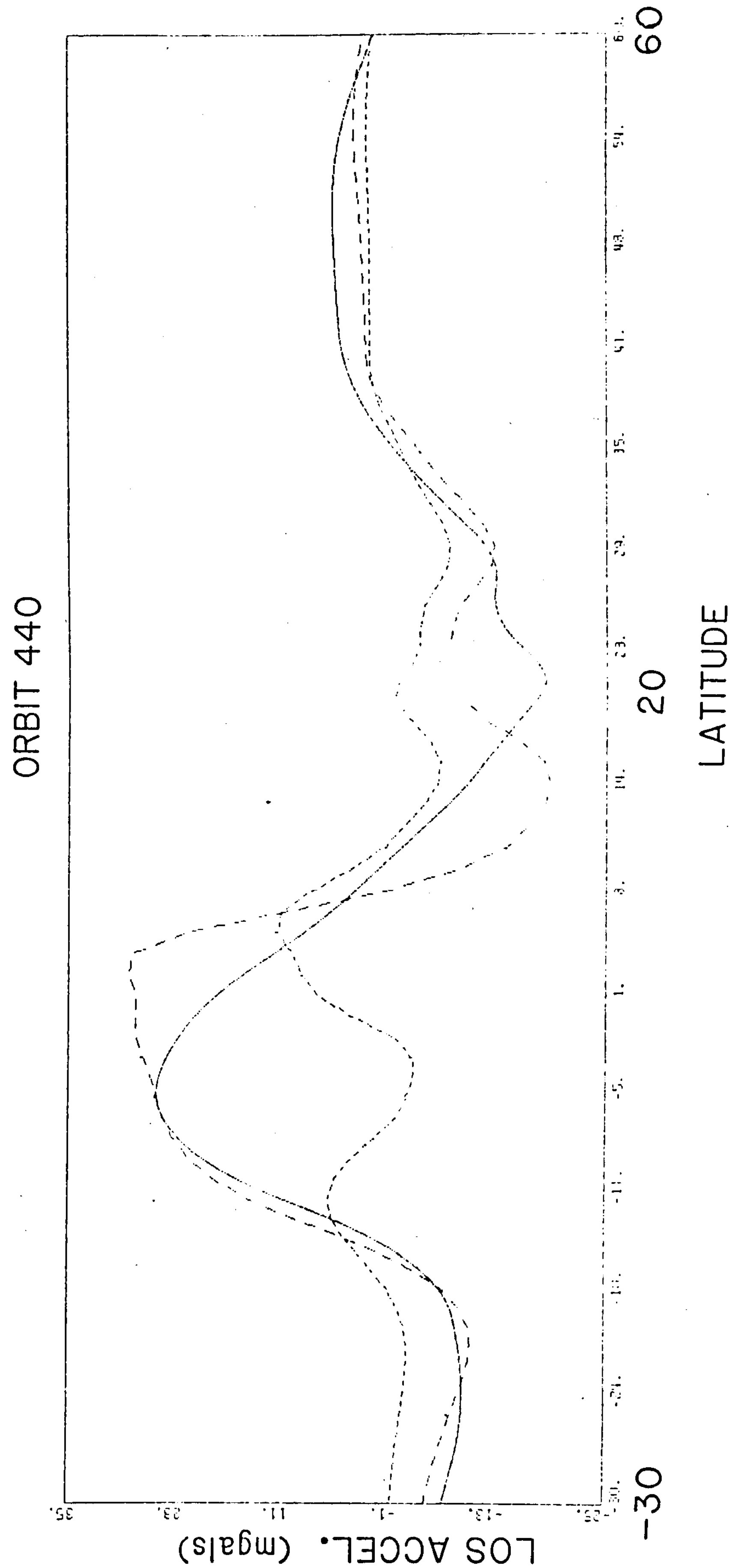

Figure 8. As fig. 4
for Orbit 521.