ABSTRACT

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MAGSAT: A SATELLITE FOR MEASURING NEAR EARTH MAGNETIC FIELDS

by

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INTRODUCTION

Although many earth-orbiting satellites have measured magnetic fields to study the magnetosphere, very few of these satellites provide data of any practical value to solid earth studies. This is unfortunate in that near-earth satellite magnetic field data have been shown to have a unique and valuable role in this area. For example, over the past few years there has been increasing interest in the studies of the broad-scale magnetic anomalies that appear in regional compilations of aeromagnetic data. These long wavelength anomalies, undoubtedly reflecting significant crustal structure, are so far proving enigmatic in their interpretation. One major problem is in their adequate definition. Satellite data are of considerable value both in defining such anomalies and, especially when combined with more conventional data, in their interpretation, as demonstrated in recent analyses by Regan et al (1975), Regan and Marsh (1977), Coles (1976), Coles et al (1976), and Mayhew and Davis (1976). Also, geomagnetic field models, spherical harmonic representations of the main geomagnetic field, are becoming of increased importance in exploration geophysics, as well as other areas. Regan and Cain (1975) detailed the concept of a field model for exploration geophysics, discussed their importance in magnetic surveys, and outlined some of the limitations of several models. Such limitations are primarily imposed by the poor spatial and temporal distribution of presently available data and affect all areas of field model applications. These limitations can be greatly reduced by the use of satellite measurements which provide global coverage in only a few weeks, as well as measurements of the field's temporal behavior.

To date, only the polar orbiting OGO 2, 4, and 6 (POGO) satellites provide such data. These satellites spanned the time interval between 1965 and 1971, and their alkali vapor magnetometers provided global measurements of the total field approximately every 1/2 second over an altitude range of about 400 to 1500 km. The Soviet satellite Kosmos-49, in orbit for only 11 days, provided total field measurements at latitudes up to 50^{o} with an average elevation of 375 km.

Although none of these satellites was ideally suited for solid-earth studies, results already cited demonstrate the utility of such satellite measurements. These results provided the initial basis for Magsat. This satellite, designed for solid-earth studies, is scheduled for launch in late 1979. In a low (325-525 km) nearly polar orbit, Magsat will provide scalar and vector magnetic measurements over the entire globe for a period of approximately four to eight months. Figure 1 is an artist's concept of Magsat in orbit. Planning for Magsat began as a cooperative effort between NASA's Goddard Space Flight Center and the U.S. Geological Survey in the late 1960's. It was realized that both the amplitude of the anomaly fields and the data resolution could be vastly improved if measurements were obtained at lower altitudes. At the same time it was becoming clear that real limitations existed in the vector field representations of the geomagnetic field which were derived solely from scalar data (Backus, 1968, 1970; Lowes, 1975; Stern and Bredekamp, 1975). Vector data from a satellite would solve this problem, and, if sufficiently accurate, contribute a new dimension to global mapping of long wavelength anomalies. Thus, the concept of a low altitude satellite dedicated to accurate, vector measurements of the Earth's magnetic field was born. This report summarizes some of the objectives and mission characteristics, as currently conceived.

MISSION OBJECTIVES

The Magsat project objectives are to:

1. Obtain an accurate, up-to-date quantitative description of the Earth's main magnetic field. Accuracy goals are 6 gamma (γ, 1γ = 1 nanotesla) root sum square (rss) in each component at the satellite altitude and 20γ in each component at the Earth's surface in its representation of the field from the Earth's core, at the epoch of the measurement.
2. Provide data and a worldwide magnetic field model suitable for the USGS to update and refine magnetic charts.
3. Compile global scalar and vector crustal magnetic anomaly maps. Accuracy goals are 3γ rss in magnitude and 6γ rss in each component. The spatial resolution goal for the anomaly map is 300 km.
4. Interpret the crustal anomaly map, in conjunction with correlative data, in terms of geologic/geophysical models of the Earth's

crust, thus providing information useful for assessment of natural resources and the determination of future exploration strategy.

These products, including individual measurement points, will be available to the scientific community for detailed investigations. Some of the anticipated results from such analyses include: enhanced knowledge of regional geological and physical crustal properties; indirect measurement of upper mantle conductivity; increased understanding of the structure and dynamics of the core, core-mantle boundary, and the mantle. In addition, the field model could provide the basis for more accurate and specialized models applicable to such areas as background removal in regional magnetic surveys.

The Magsat Project is an element of the Earth and Ocean Dynamics Applications Program (EODAP) in the NASA Office of Applications. It is aimed at making a significant contribution toward the resource assessment goal within this program. Because resource discovery is extremely localized while the Magsat measurements are of a broad scale, the actual contribution is indirect, occurring primarily through the application of the global magnetic anomaly map to regional geological and geophysical models which in turn should prove useful in long-range planning of mineral and hydrocarbon exploration programs. Such planning is concerned not with discovery of individual deposits, but with the delineation of entire regions, frequently of subcontinental extent, toward which major exploration programs could be oriented. The anomalies to be measured by Magsat will reflect important features such as composition, remanent magnetism, and geologic structure contrasts on a regional scale. Thus Magsat, with near-global coverage, will provide information on the broad structure of the Earth's crust, both in ocean basins and on continents.

MISSION CONSTRAINTS

In addition to the scientific objectives, certain spacecraft constraints enter into the definition of a satellite survey. The spacecraft will be constructed by the Johns Hopkins Applied Physics Laboratory utilizing some of the spacecraft design and left over hardware from the Small Astronomy Satellite (SAS-C), and will be launched on a Scout vehicle.

The launch vehicle and spacecraft determine the basic mission weight and power capability. Because mapping of crustal magnetic anomalies is one of the principal objectives, it is desirable to fly at a low altitude. This, however, conflicts with the need for a statistically significant data sample, because lower altitudes lead to shorter spacecraft lifetimes. Present orbit selection calls for perigee at 325 km. Apogee is then determined by the desired spacecraft lifetime. For a 4-8 month lifetime it is estimated that apogee will be near 550 km. Calculated orbit decay for the anticipated nominal orbit is shown in Figure 2. The overall resolution will be several hundred kilometers although increased resolution, with some sacrifice of amplitude accuracy, should be possible by obtaining lower-altitude data as the orbit decays. It is anticipated that such data can be obtained as low as 150 km.

Local time constraints stem from two considerations. First, to obtain adequate power it is necessary to remain in a configuration when the satellite is always in sunlight. Second, the Equatorial Electrojet and Sq current system dominate data within 2-3 hours of local noon making low latitude crustal anomaly studies difficult during these local times. Because of these factors it is presently planned to launch into a near sun-synchronous orbit at the dawn-dusk meridian. The anticipated ground track for a 25 hour period is shown in Figure 3. Geographic coverage will be good but to accumulate global coverage with data below 350 km will require 4-5 months.

Normal operation for the spacecraft will be in a fully stabilized earth oriented configuration with attitude controlled to within 2-3^{o}. However, actual attitude determination will be far more accurate than this. The goal is 10 arc-seconds, and will be accomplished by the use of star scanning sensors.

ERROR SOURCES

Accuracy goals for Magsat are 3γ rss in field magnitude and 6γ rss in each vector component. Planned instrumentation includes a Cesium vapor total field magnetometer and a three axis fluxgate magnetometer. Total (scalar) field magnetometers of this kind have been shown capable of accuracies on the order of $\pm 1\gamma$. For Magsat the principal error source affecting recovery of the scalar field is the accuracy to which the satellite position is known. Figure 4 shows contours of the 1σ error in scalar field due to orbital error under the assumption that the orbital error is randomly distributed with 1σ error of 300 m along track, 30 m across track, and 60 m vertically. The errors are everywhere less than 3γ and often less than 2γ. Orbital error for Magsat is expected to be somewhat less than that assumed in these calculations.

Vector measurements are more complex and some of the technology necessary to meet the Magsat goal is still under development. The fluxgate accuracy including digitization is designed to be about 3γ rss. Contributions to each component from satellite position error, under the same assumptions as for total field, are shown in Figures 5-7. Errors from this source are within 1-2γ rss almost everywhere for the latitudinal (θ) and longitudinal (ϕ) components, but exceed 3γ rss for the vertical component in some equatorial regions. Another important error source for the vector measurements is the knowledge of the attitude of the magnetometer. As noted, the star sensors are expected to allow determination of the spacecraft attitude to 10 arc-seconds. Because of spacecraft magnetic fields, the magnetometers will be located at the end of an extendable boom, approximately 20 ft. in length. Although very rigid extendable booms can be constructed, boom bending and twist can be expected to be in the 5-20 arc-minute range. To eliminate this error an optical attitude transfer system will be utilized to measure the orientation of the boom end with respect to the spacecraft. Accuracies of about 7 arc-second are expected.

Combining the four major error sources for vector data give the results shown in the following table:

Source	rss error (σ)	σ^2
Fluxgate sensor and electronics	3γ	$9\gamma^2$
Orbit accuracy	3γ	$9\gamma^2$
Spacecraft attitude	2.5γ	$6.25\gamma^2$
Attitude transfer	1.25γ	$1.56\gamma^2$
		$25.8\gamma^2$

This gives a projected rss error of 5.1γ.

DATA PROCESSING

Techniques developed and proven effective for scalar magnetometer data from the Pogo satellites (Langel, 1967) will be refined and utilized for Magsat. This includes extensive checking of the quality of the data prior to release for analysis. For scalar data, the goal is to have the data ready for analysis 2-3 months after acquisition. In so far as possible, the scalar data will be utilized to verify and calibrate the vector data. The success of this procedure depends upon the achieved accuracy of the scalar instrument, the noise levels in the two instruments, and the stability of the fluxgate magnetometer over a period of a few hours. It is anticipated that such inflight calibration will be possible to a 2-3γ level of accuracy in each component.

Vector data will first be processed and available in the magnetometer coordinate system. Any calibration of the vector instrument by the scalar instrument will be applied at this stage. Transformation of the vector data to an earth oriented system requires knowledge of the attitude of the magnetometer relative to the spacecraft and knowledge of the attitude of the spacecraft. These attitude determinations will be accomplished in two stages. First, overall attitude will be determined to about 20 arc-minutes. These results will be available 4-6 weeks after acquisition of the data. The final definitive attitude determination will require more extensive analysis and will not be available until about 6 months after acquisition of data.

Because of the time necessary to accomplish the definitive attitude determination, vector data in an earth-oriented system will be available for analysis in two stages, corresponding to the two stages of attitude determination. We anticipate processed data to be available at 20 arc-minute accuracy about 2-3 months after acquisition of data and at 20 arc-second accuracy about 8 months after data acquisition.

For users who require an up-to-date spherical harmonic model of the Earth's field, an initial model for the epoch of the measurements will be generated as soon as possible. Such a model could be available as early as two months after launch. It will not include secular variation. More definitive models will be developed after a substantial amount of data is acquired and the 20 arc-second attitude determination is accomplished.

DATA AVAILABILITY

Present plans call for release of the data to the National Space Science Data Center at GSFC as soon as it is ready for analysis. This data will be provided to the public at a nominal cost.

It is the intent of NASA Headquarters to issue an Announcement of Opportunity (AO) early in 1978 for the purpose of selecting Principal Investigators for data use investigations contributing to mission objectives. Those who may be interested in participating will be asked to so indicate by sending a letter of intent to propose to NASA. All who do so will then be invited to attend a pre-proposal briefing after which they will have a period of time to prepare a proposal.

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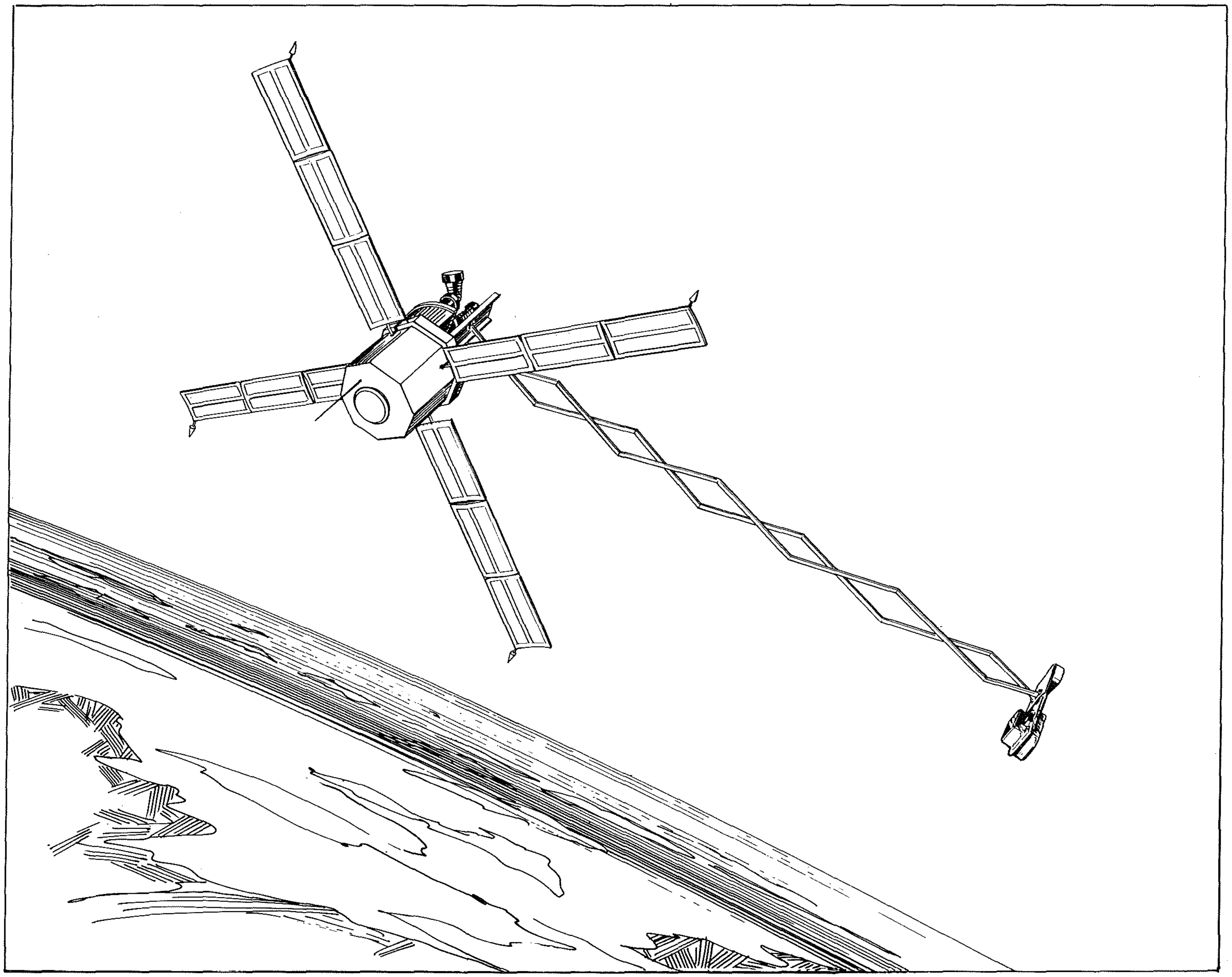

Figure 1: Artists Conception of Magsat

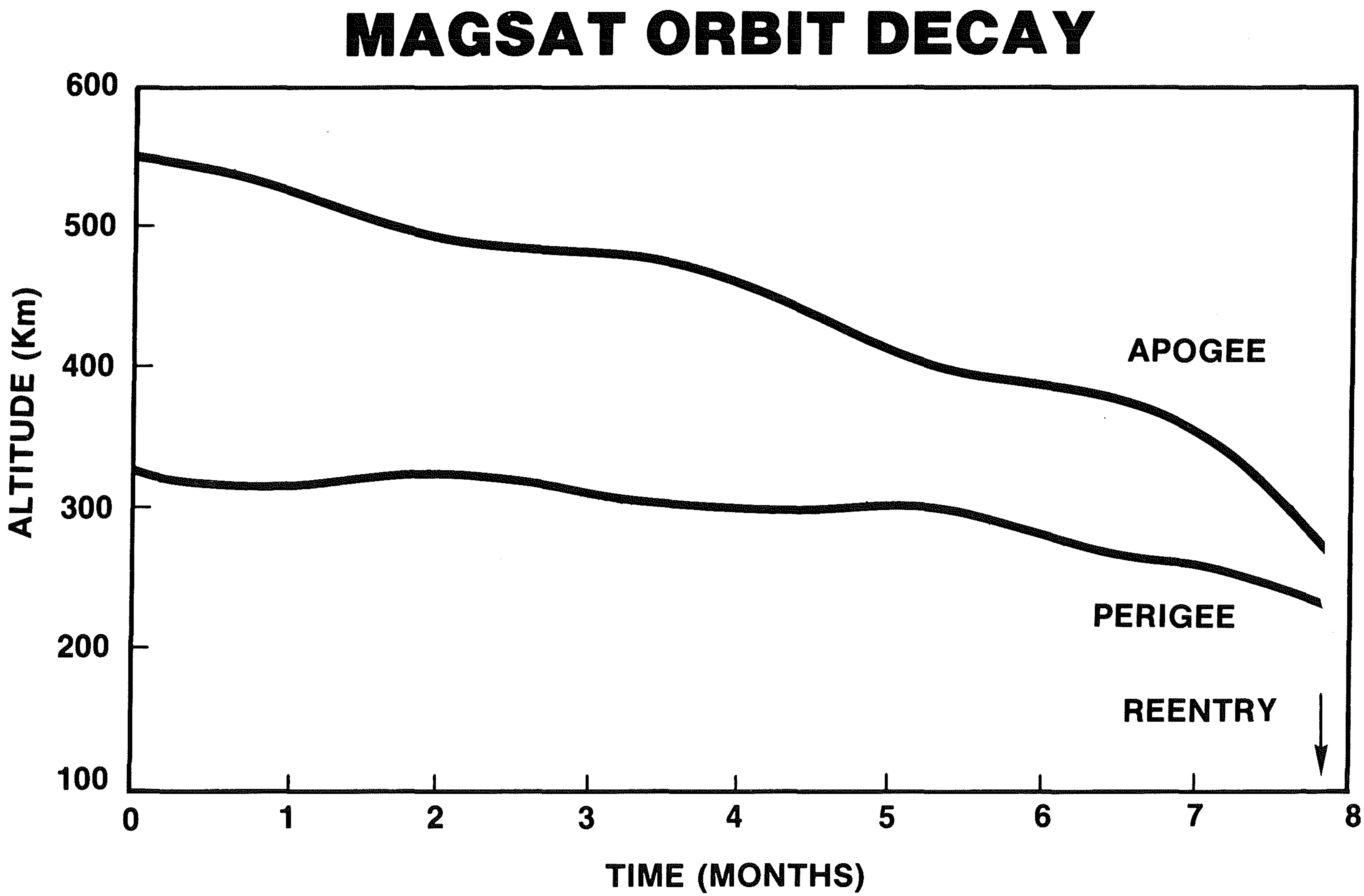
MAGSAT ORBIT DECAY
600
500
400
300
200
100
ALTITUDE (Km)
APOGEE
PERIGEE
REENTRY
0
1
2
3
4
5
6
7
8
TIME (MONTHS)

Figure 2

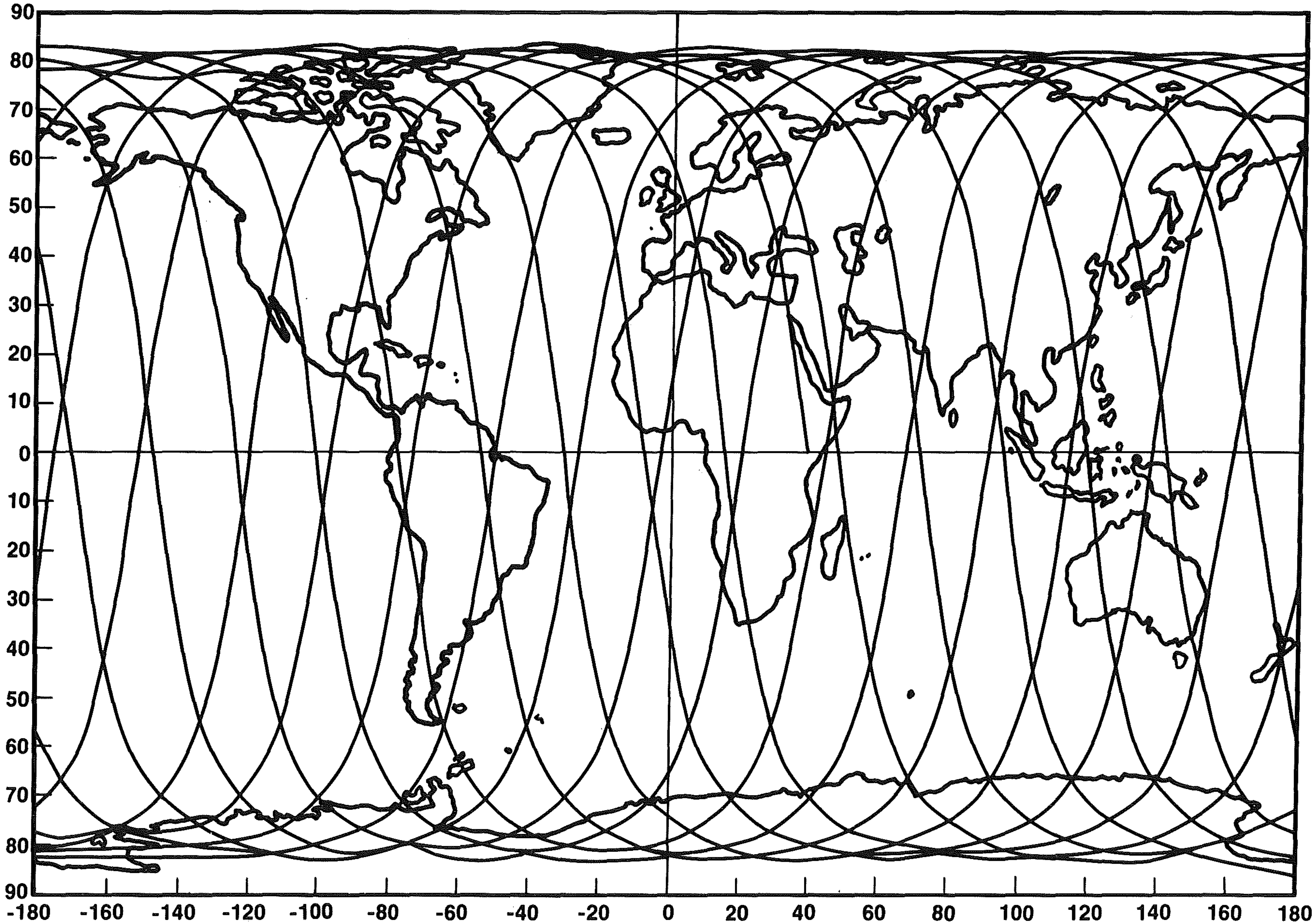

Figure 3: Magsat Ground Track for First 24 Hours

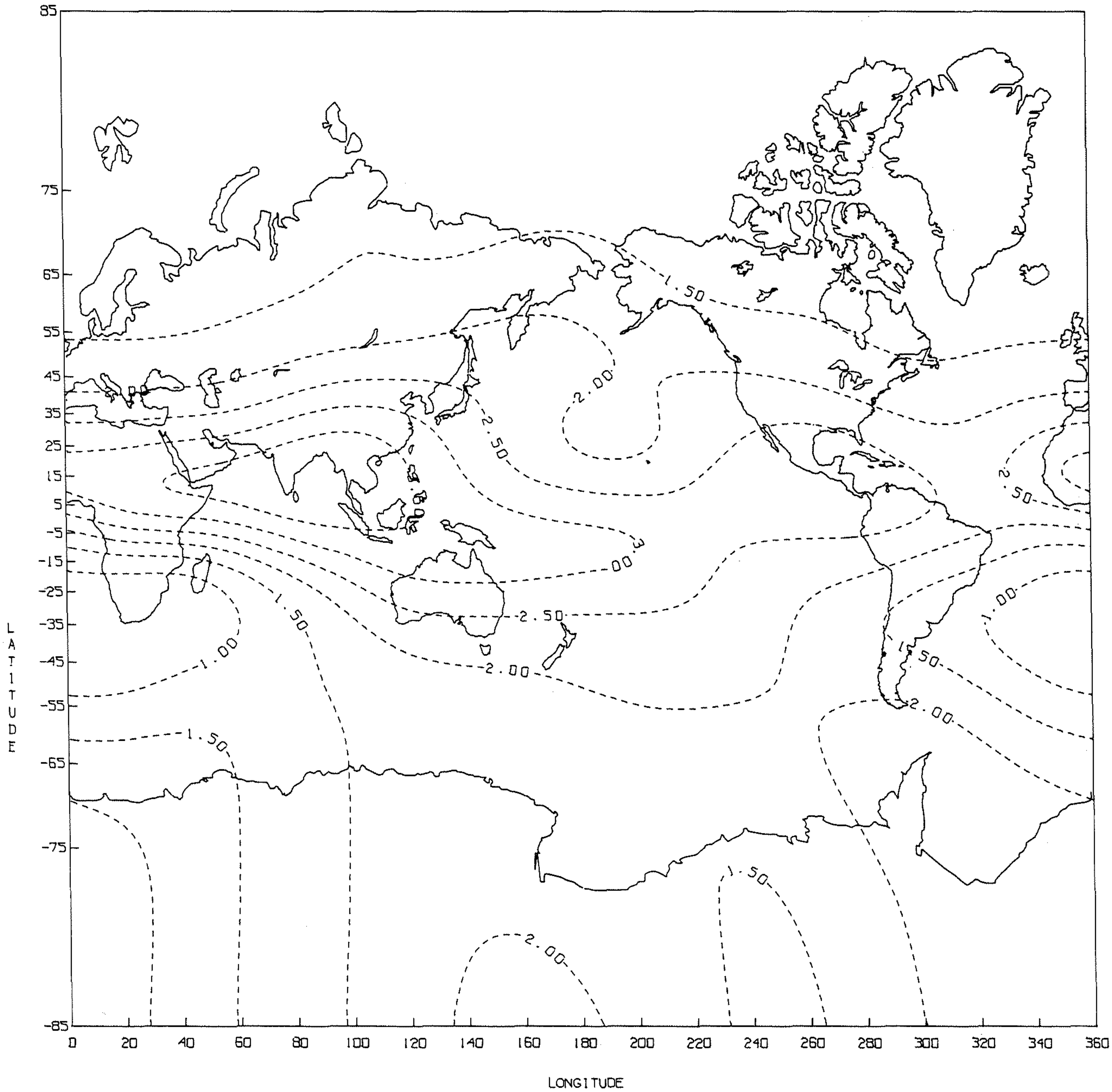

Figure 4: One-sigma error in B_r for one-sigma position error of 300 m along track and 60 m cross track and radial

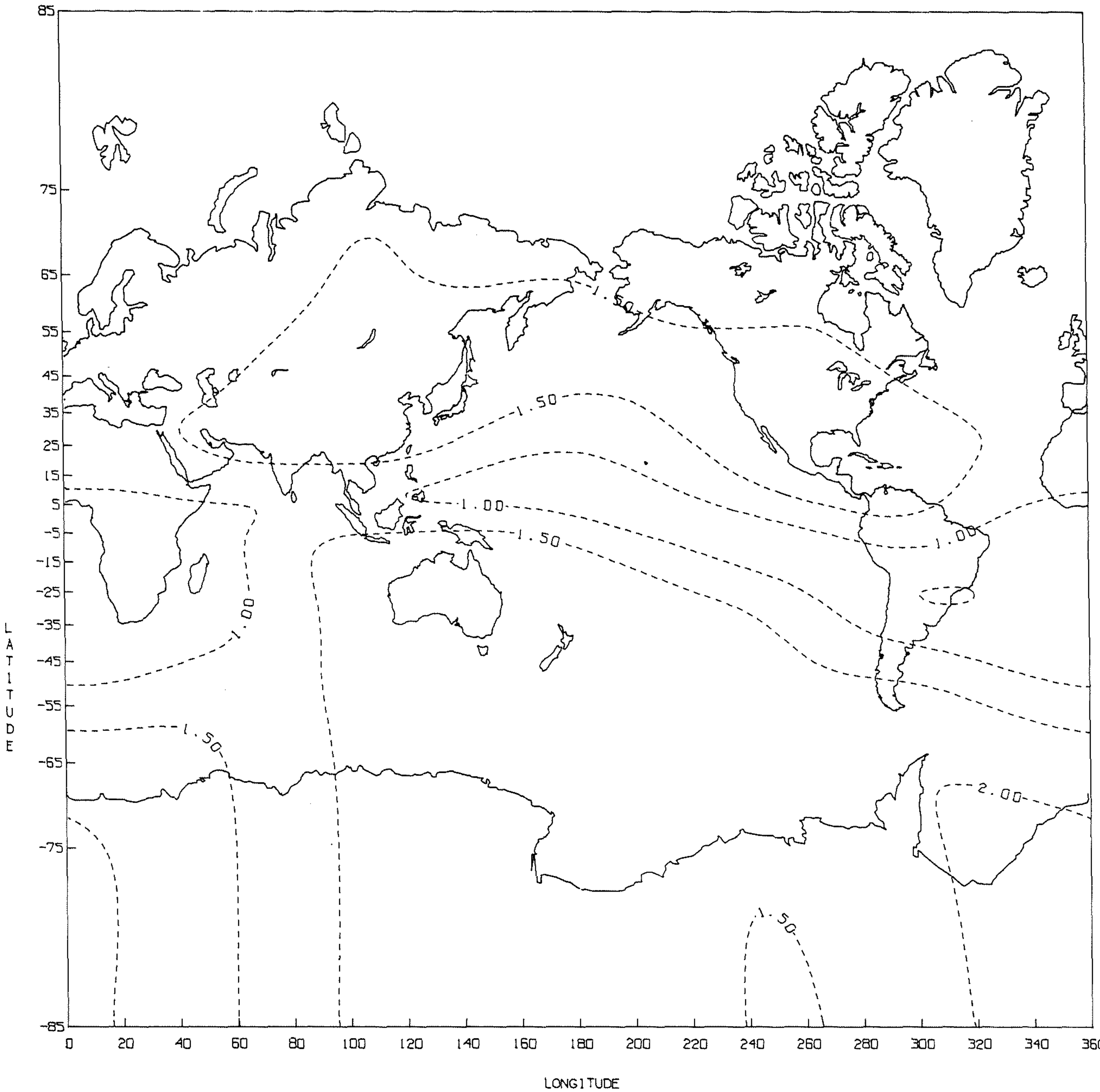

Figure 5: One-sigma error in field magnitude for one-sigma position estimation error of 300 m along track and 60 m cross track and radial

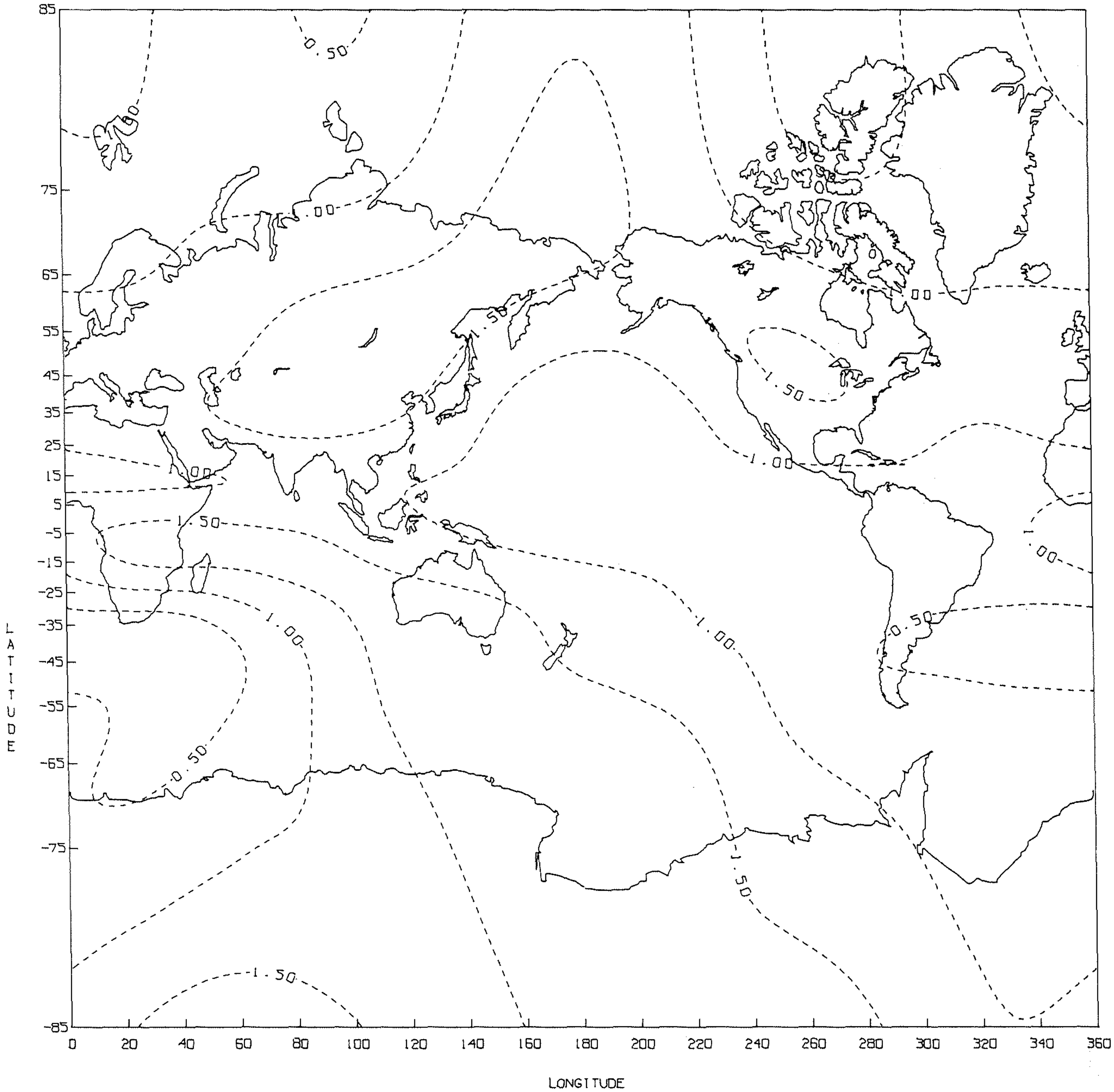

Figure 6: One-sigma error in B_θ for one-sigma position error of 300 m along track and 60 m cross track and radial

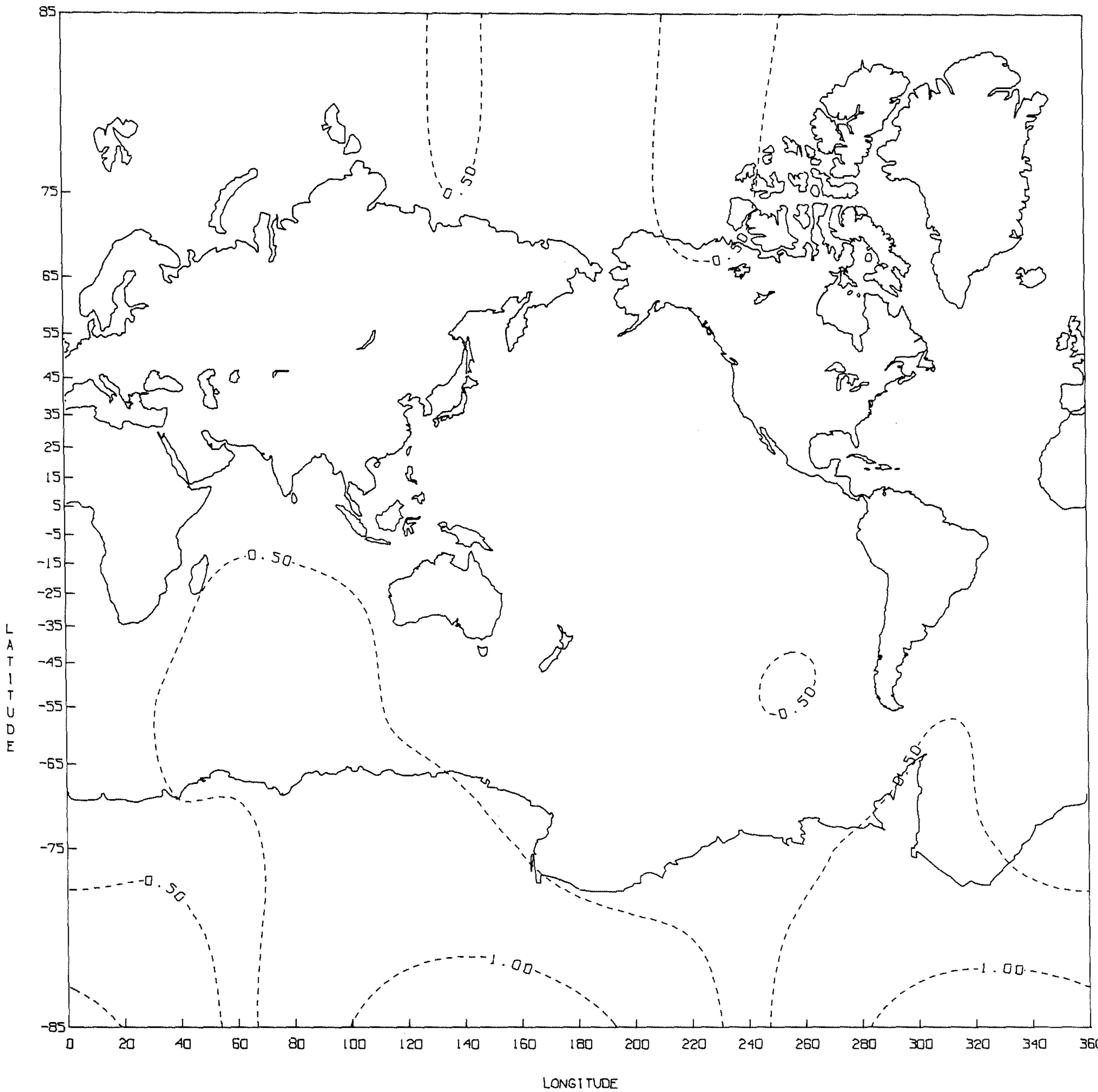

Figure 7: One-sigma error in B_ϕ for one-sigma position error of 300 m along track and 60 m cross track and radial