

SATELLITE ALTIMETER RESULTS OVER EAST ANTARCTICA

by

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ABSTRACT

During the operational lifetime of the Seasat altimeter from 3 July to 10 October 1978, more than 450 overflights were made over East Antarctica inland to latitude 72°S. An analysis of selected passes over a variety of ice features demonstrates that the oceanographic altimeter performed surprisingly well over the ice sheet and ice shelves, acquiring useful measurements during approximately 70% of each pass. The altimeter's onboard tracking system dampened out the ice-surface elevations, but post-flight retracing of the stored return waveforms reveals excellent ice-surface details. After waveform retracing, the altimeter repeatability is better than ± 1 m.

INTRODUCTION

The applicability of satellite radar altimetry for topographic mapping of continental ice sheets was initially demonstrated for southern Greenland and described by Brooks and others (1978). The altimeter data for this prior study was from the GEOS-3 satellite which provided Earth coverage between $\pm 65^\circ$ latitude. The achieved accuracy in ice-surface elevation was ~ 2 m. It was anticipated at that time that the radar altimeter onboard the Seasat satellite to be launched in mid-1978 would provide improved ice-sheet measurement precision. Additionally, the Earth coverage area from Seasat would be increased to $\pm 72^\circ$ latitude to include 3×10^6 km² of East Antarctica.

Initial analysis of the raw Seasat altimeter measurements revealed that, unlike GEOS-3, the onboard tracker was not sufficiently responsive to ice-sheet surface undulations. However, retracing of the Seasat altimeter waveforms provides ice-surface elevations of excellent quality. The GEOS-3 and Seasat altimeter trackers are compared by MacArthur (1978).

The Seasat retracing technique involves repositioning of the altimeter tracking gate on the leading edge of the surface return waveform. This technique was initially developed and evaluated over the Salar de Uyuni, the Earth's largest salt flat, in southern Bolivia. Subsequent corroborative analyses of the retraced Seasat altimeter measurements have been made in the Sonoran desert of Arizona, the Imperial Valley of California, the North Slope of Alaska, the Great Salt Lake desert of Utah (R L Brooks unpublished report*), and the Greenland and Antarctic ice sheets. When compared with large-scale maps, the surface elevations derived by retracing the altimeter waveforms were found to have an accuracy of ± 1 m with respect to the ellipsoid.

*Terrain profiling from Seasat altimetry.
GeoScience Research Corporation Final Report
for NOAA/National Geodetic Survey.

SEASAT ALTIMETER ANTARCTIC DATA BASE

Seasat was launched on 27 June 1978, into a near-circular orbit of 800 km with an inclination of 108°, providing coverage of the Earth's surface between $\pm 72^\circ$ latitude. The design precision of the Seasat altimeter was 10 cm, and its averaging area (over a calm ocean) was nominally 1.7 km. The comparable GEOS-3 values were 50 cm and 3.6 km, respectively. Due to the specular nature of the Antarctic ice sheet, the effective over-ice footprint of Seasat was found to be significantly less than the nominal 1.7 km. The altimeter acquired data continuously during the following time periods: 7-17 July, 26 July-28 August, and 6 September-10 October 1978, at which time the spacecraft failed due to an electrical problem.

Even though the useful life of Seasat was rather short, the altimeter data base includes more than 450 overflights of East Antarctica at a measurement rate of 10 s⁻¹. Considering the Seasat groundtrack velocity of 7 km s⁻¹, the data base represents potential Antarctic profiling lengths of approximately 1.2×10^6 km. Taking into account altimeter data drop-outs, approximately 1×10^6 ice-surface elevations are obtainable from the Seasat altimeter data base for East Antarctica.

The Seasat altimeter generally lost lock on crossing the Antarctic coastline. This loss of lock continued for 30 to 50 km. Once inland on the less sloping surfaces, Seasat maintained lock about 70% of the time.

WAVEFORM RETRACKING

The objective of the Seasat waveform retracing is to reposition the tracking gate with respect to the sampled waveforms. Over the open ocean, the goal of the altimeter designers was to position the tracking gate on the leading edge of the waveform at the point corresponding to 50% of the peak power in the waveform. Due to dynamic height changes of the open ocean being very small, the altimeter tracking design served its purpose and maintained tracking very well at the 50% point. The onboard height processor was optimized also for an expected non-specular return from the ocean surface.

Once over the ice sheets, however, the tracker encountered both specular returns and larger dynamic height rates. This usually resulted in mispositioning of the tracking gate; fortunately, the sampled waveforms were preserved in the data base and may be retraced.

The Seasat tracker had 60 waveform sampling gates with a separation of 3.125 ns, equivalent to 46.84 cm. The prior GEOS-3 altimeter tracker had gate separations of 12.4 ns. The Seasat gates are arbitrarily

numbered from -30 (early gate) to +30 (late gate) with the desired tracking point at the mid-point between the -1 and +1 gates (0th gate). The corrected surface elevation E_c is computed as

$$E_c = E - 0.4684 g,$$

where g is the interpolated gate number corresponding to the 50% level of the sampled peak power per waveform. The waveforms were telemetered to the ground at a rate of 10 s^{-1} , the same rate as the range measurements. Each of the recorded waveforms is the average of two consecutive waveforms sampled at a rate of 20 s^{-1} (Townsend 1980).

ALTIMETER LOSS-OF-LOCK OVER EAST ANTARCTICA

The Seasat altimeter lost lock frequently over the ice sheets. A typical Antarctic ice-sheet profile from Seasat is plotted in Figure 1; only the in-track portion of the altimeter data is shown. In this figure, the satellite direction was from left to right.

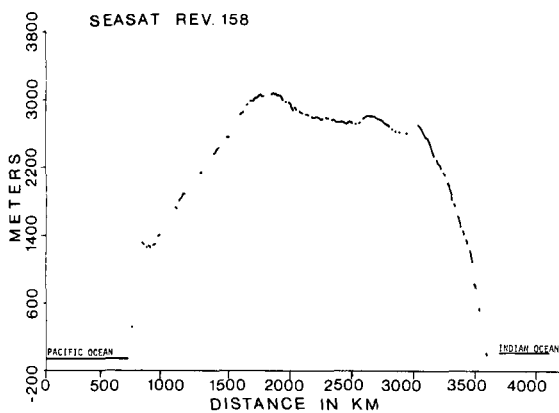


Fig.1. Typical Antarctic ice sheet surface elevation profile from Seasat altimetry. Solid lines indicate periods of surface lock. Elevations are with respect to the ellipsoid.

The altimeter was locked on the Pacific Ocean, but lost lock on reaching Antarctica. Very little track data were acquired over the up-slope portion of the ice sheet. Near the 3 000 m elevation, the ice sheet became more level and the altimeter performed better, but still frequently lost lock although the down-slope performance was much better than the up-slope performance. Good tracking resumed over the Indian Ocean.

Examination of the ice-sheet altimeter waveforms (R L Brooks unpublished report**) leads to the following conclusions. (1) The altimeter's pre-programmed acquisition algorithm was primarily responsible for the lack of measurements on the ice sheet up-slope. The acquisition system performed its design role, that of open-ocean acquisition, very well, but could not accommodate a rising surface. (2) The loss-of-lock on the down-slope and more level higher elevations were due almost exclusively to changes in the surface slope and the altimeter's failure to respond to these changes. The slope changes are due to surface waves, which are more prevalent at lower elevations. Changes in the surface height rate cause the waveforms to move with respect to the waveform sampling gates. If the height acceleration exceeds the response capability of the tracker and if the condition persists, the waveform will walk-out of the sampling gates and the altimeter will lose lock. The

**Ice sheet altimetry. GeoScience Research Corporation Final Report for NASA/Wallops Flight Center.

loss-of-lock occurs when the height acceleration results in a 14.05 m (30 gates) disparity between the sluggish on-board tracker and the true surface.

ICE-SHEET TOPOGRAPHY

With the 10^6 surface elevations available from the Seasat altimeter data, along with a retracking algorithm, an unprecedented number of accurate East Antarctic ice-sheet elevations can be computed. The Seasat coverage area of East Antarctica is shown in Figure 2; also shown in this figure are geographic areas A, B, C, and D for which surface elevations, profiles, and contours are presented below.

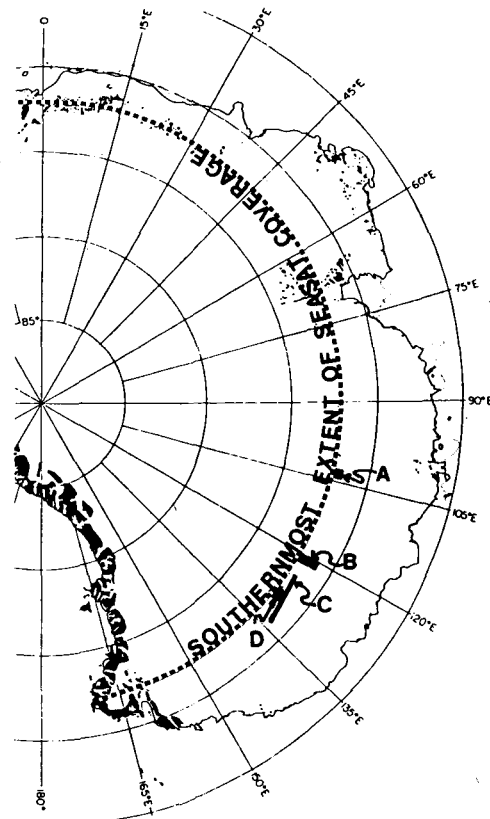


Fig.2. Index map of East Antarctica illustrating Seasat altimetry coverage area and study areas A, B, C, and D.

Area A

Three altimeter passes near an Australian geocenter site (GM-15) were analyzed to provide an accuracy assessment. To allow comparison, the geocenter height was transformed from the NWL-9D ellipsoid ($a = 6378.145 \text{ km}$, $f = 1/298.25$) to the Seasat reference ellipsoid ($a = 6378.137 \text{ km}$, $f = 1/298.257$). The resultant very favorable comparison of surface elevations is shown in Figure 3 and illustrates that the Seasat-derived surface elevation accuracy is within the uncertainty range of the geocenter elevation.

Area B

Ice profiles from six nearly parallel Seasat orbits between longitudes 120°E and 121°E are presented in Figure 4. Each orbit traversed Area B in an east-to-west direction; the elevations generally increased in the poleward direction. The absence of profile elevations, e.g., at the beginning and end of orbit 173, indicates that the altimeter momentarily lost lock.

Area C

The ice-surface profile from one of the longest

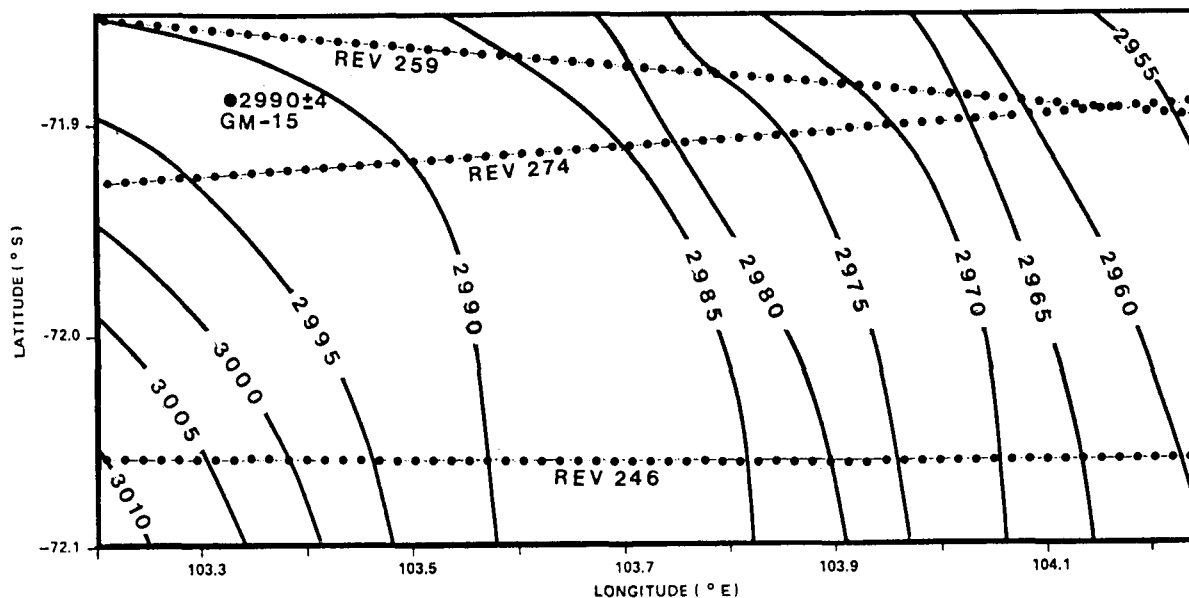


Fig.3. Seasat altimeter-derived surface elevation contours in metres from orbits 246, 259, and 274 for Area A, compared with the elevation at Australian geociever site GM-15. Contour interval is 5 m.

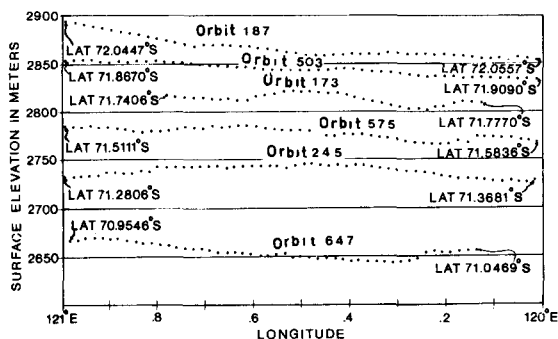


Fig.4. Six ice surface profiles in Area B from Seasat altimetry between longitudes 120°E and 121°E. Elevations are with respect to the ellipsoid.

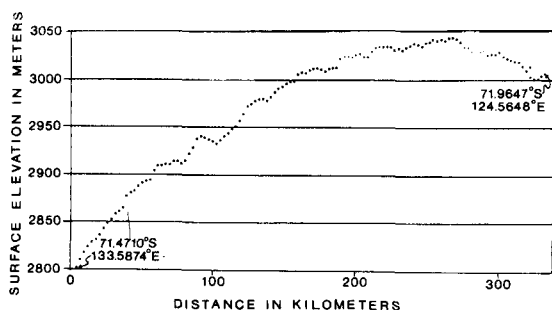


Fig.5. Area C continuous ice surface profile from Seasat orbit 187. Every fourth altimeter-derived elevation is shown. Elevations are with respect to the ellipsoid.

continuous Seasat tracks in East Antarctica is shown in Figure 5. The altimeter briefly lost lock prior to and subsequent to this profile acquisition. While the data rate for the presentations in Figures 3 and 4 are at the full data rate of 10 s^{-1} , the elevations shown in Figure 5 represent only every fourth data point, with a point-to-point separation of approximately 2.8 km.

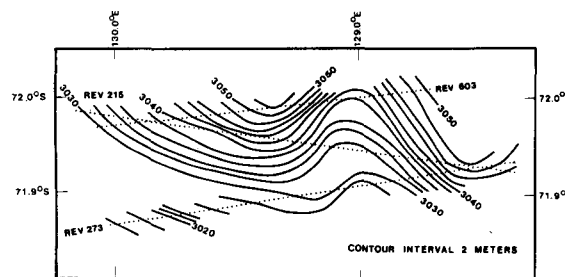


Fig.6. Area D contours from three Seasat altimeter revolutions. Elevations are with respect to the ellipsoid.

Area D

Three closely-spaced Seasat groundtracks were used to generate 2-m contours for Area D (Fig.6). Each dot represents an altimeter-derived surface elevation at the 10 s^{-1} data rate. Localized surface highs and lows are noted, sinusoidal in form.

SUMMARY

The ice-surface measurements from the Seasat altimeter's onboard tracker were not sufficiently responsive to the undulations of the East Antarctic ice sheet to provide detail. However, retracking the altimeter waveforms provides ice-surface elevations unprecedented in terms of quantity with the accuracy of each elevation comparable to that obtainable from geocivers. The ice-sheet topography presented is a very small sample of that achievable by retracking the Seasat waveforms over East Antarctica. Additional ice sheet topographic studies are in progress.

ACKNOWLEDGEMENTS

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