NOAA Technical Memorandum NOS NGS-48

THE NOAA GEOSAT GEOPHYSICAL DATA RECORDS:

SUMMARY OF THE FIRST YEAR OF THE EXACT REPEAT MISSION

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U.S. DEPARTMENT OF COMMERCE / National Oceanic and Atmospheric Administration / National Ocean Service / Office of Charting and Geodetic Services

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ABSTRACT. Since its launch in March 1985, the GEOSAT altimeter has provided more than 3 years of global observations of sea level, wind speed, and significant wave height. Sea level data collected during the first 18 months are classified, but the wind and wave data from this period have recently been released and are available through NOAA (Dobson et al., 1988). In October 1986, a series of maneuvers was performed to produce a ground track repeating within 1 km at a period of 17.05 days. Because the resulting sea surface profiles fall within a few kilometers of previously released Seasat data tracks, these new data are not classified. This new portion of the GEOSAT program, known as the Exact Repeat Mission (ERM), became operational November 8, 1986.

Under agreement with the U.S. Navy, and in cooperation with the Johns Hopkins University Applied Physics Laboratory, NOAA assumed responsibility for production of the unclassified GEOSAT ERM Geophysical Data Records (GDR's). This report summarizes the content of the primary GEOSAT ocean data set during the first year of the ERM. (A secondary set of ice/land GDR's is also produced, but will not be discussed in this summary.) For background information, see the "GEOSAT Altimeter Geophysical Data Record User Handbook" (Cheney et al., 1987), which describes the data flow and NOAA processing.

GLOBAL DATA DISTRIBUTION

GDR's are produced by the Geodetic Research and Development Laboratory in Rockville, Maryland by combining several different sets of input data: raw altimeter data in the form of Sensor Data Records (SDR's), the satellite ephemeris, and corrections for solid and fluid tides, plus path length effects due to the troposphere and ionosphere. Each GDR covers a period of approximately 24 hours and contains data for an integer number of revolutions (either 14 or 15), beginning and ending as close as possible to maximum latitude (72 degrees north). Because the satellite completes approximately 14.4 revolutions in 24 hours, every third GDR contains data for 15 revolutions, while all others include 14.

Figure 1 shows the total number of 1-second GDR records for each day in the first year of the ERM. Although the GEOSAT SDR's contain approximately 88,000

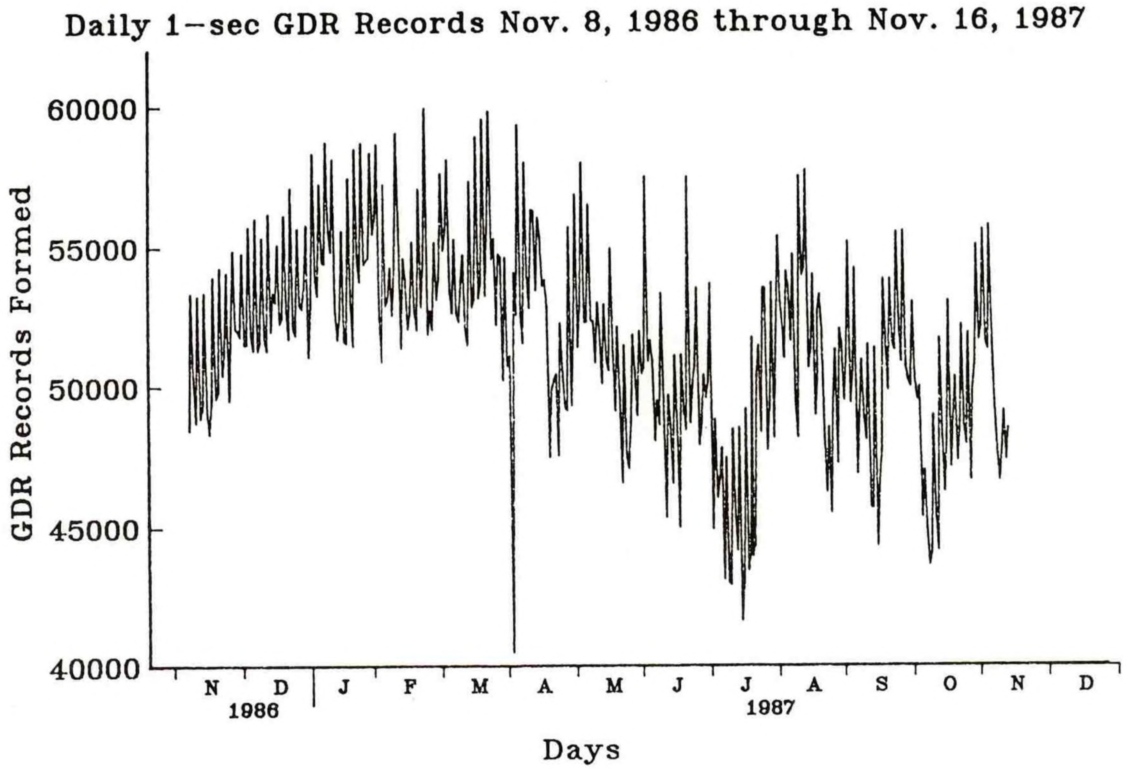

Figure 1.--Number of 1-second GDR records for each day of the ERM first year.

1-second records per day, only about two-thirds of these are passed to the final GDR. Data are edited based on SDR flags to remove outliers and segments along which the altimeter was not tracking. More detailed information on the editing process is contained in the User Handbook (Cheney et al. 1987).

Day-to-day changes in the number of records seen in figure 1 are caused primarily by the extra revolution of data in every third GDR. Some of this "jitter" is also due to daily variations of the satellite ground track with respect to land. The longer period variations are probably due to two effects: (1) varying amounts of data loss caused by large excursions of spacecraft attitude, and (2) data loss caused by seasonal variations of sea ice distribution. In general, the number of observations is high in boreal winter and low in summer, with an average of approximately 50,000 per day.

The sequence of global ground track plots for each 17-day repeat cycle (fig. 2 at end of publication) shows the changing areal coverage during the first year. Data gaps generally occur in five distinct regions in each hemisphere (cycle 8 is a good example) which change and migrate with time. These gaps are associated with large excursions of spacecraft attitude, as discussed in the next section. Although this has resulted in loss of 5 to 10 percent of data globally, seldom are both ascending and descending passes missing in any given area, so that complete global coverage is usually obtained every 17 days.

SPACECRAFT ATTITUDE

GEOSAT maintains nadir pointing for the altimeter antenna by means of a gravity gradient stabilization system. This method gives outstanding mechanical reliability, but allows excursions off-nadir of 1 degree or more. Because the beam width of the altimeter is only 2 degrees, the nadir footprint is not fully illuminated when attitude is greater than about 1 degree. As discussed by Kilgus (1987), large attitude excursions adversely affect altimeter performance in the following way. Before the altimeter can "lock-on" to the return radar pulse, an acquisition mode with a wide range window is used to determine the approximate distance to the surface. This measurement is then used to narrow the window and allow precise range tracking. Because the acquisition process is sensitive to signal distortion that occurs at high attitude angles, transitions from land to water occurring when off-nadir angle is greater than about 1.1 degrees cause irrecoverable data gaps. The altimeter continues in acquisition mode until attitude swings back to 1.1 degrees or less when precise tracking resumes.

The underlying cause of GEOSAT's attitude problem appears to be solar radiation pressure (with smaller contributions from magnetic imbalances, atmosphere, gravity, etc.). Holdridge (1988) has found that simulations involving solar radiation torques provide attitude disturbances with periods and spatial patterns that resemble the data gaps. Solar radiation torque applied at the orbital period combines with the pitch libration period of the spacecraft to produce a maximum pitch disturbance approximately every 5 hours. The Earth completes about one-fifth of a rotation in this time, creating five evenly spaced orbital bands of maximum attitude in each hemisphere. Migration of data gaps is due to motion of regions of maximum attitude with respect to land-sea crossings.

In addition, the 11-month cycle of the angle between the GEOSAT ascending node and solar ascending node should produce variations in data gaps with a comparable period. This is reflected in the series of maps in figure 2. For example, excellent coverage was obtained in the Southern Hemisphere at the beginning of the ERM, and again near the end of the first year, but significant data loss occurred during the middle of the year. This pattern will repeat for subsequent years with a period of approximately 11 months.

During normal altimeter operation, an accurate measure of attitude is obtained from characteristics of the return waveform. Figure 3 shows the percent of GDR records in each 17-day period for which attitude was greater than 1.2 degrees. During the month prior to the ERM, orbit maneuvers caused attitude to vary by as much as 5 to 10 degrees. Once these maneuvers were complete, the spacecraft stabilized and the altimeter was turned on. Figure 3 shows that attitude initially improved and reached a minimum during cycles 3 and 4. This is reflected in the ground track maps for this period when little data were lost in the entire region south of 30 degrees north latitude. Unfortunately, attitude grew steadily worse during the next 6 months, peaking at cycle 15. The corresponding map of global coverage during this cycle was relatively poor, with significant data loss in both ascending and descending passes. Gaps extended to the equator in both hemispheres and some small areas received no coverage (near Hawaii, for example). For the rest of the year, attitude remained high, with values greater than 1.2 degrees during 4 to 5 percent of the time.

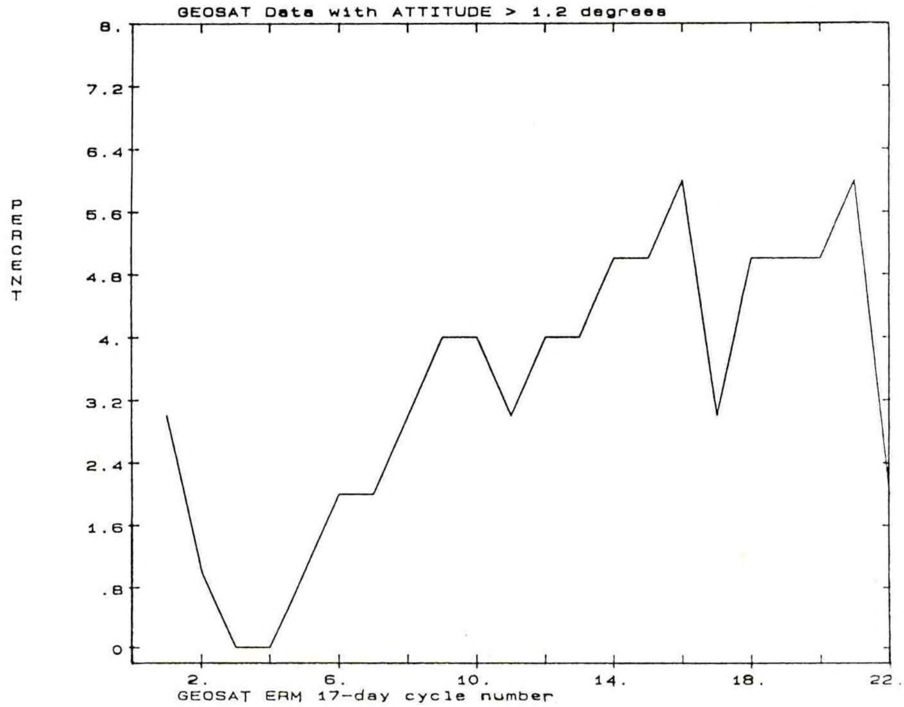

Figure 3.--Percentage of GDR data for each 17-day cycle for which attitude was greater than 1.2 degrees.

It is interesting to note that spacecraft maneuvers during the ERM, performed approximately monthly to maintain the collinear ground track, have not had any significant adverse impact on attitude. Only a very small thrust is required to compensate for atmospheric drag on GEOSAT.

Even though normal attitude variation has resulted in data loss, it should be pointed out that the rate of data return for GEOSAT is approximately 90 percent, an enormous success by almost any standard. Furthermore, our analyses of the data indicate that as long as the altimeter is in its precise tracking mode, attitude has no effect on quality of the sea height measurements. As an example, we show a comparison of two collinear sea height profiles in the eastern tropical Pacific for which spacecraft attitude was quite different (fig. 4). The pass from cycle 15 displays attitudes as high as 1.24 degrees just south of the equator while attitude for its collinear partner in cycle 1 was only about 0.4 degrees at this location. Nevertheless, the difference between the two sea height profiles is only at the level of the expected oceanic variability (5-10 cm). In contrast, sigma naught and significant wave height may be less reliable at large values of attitude since these measurements are more sensitive to attitude. Unfortunately, it is difficult to determine the effect of attitude of these parameters because, unlike the permanent geoid topography, their true values vary with time. In the User Handbook, we recommended that GEOSAT wind and wave data be used with caution when attitude is greater than approximately 1.1 degrees.

IONOSPHERIC CORRECTION

GEOSAT was launched near solar minimum, and path delay due to the ionosphere has not been a serious concern because of its small amplitude and large

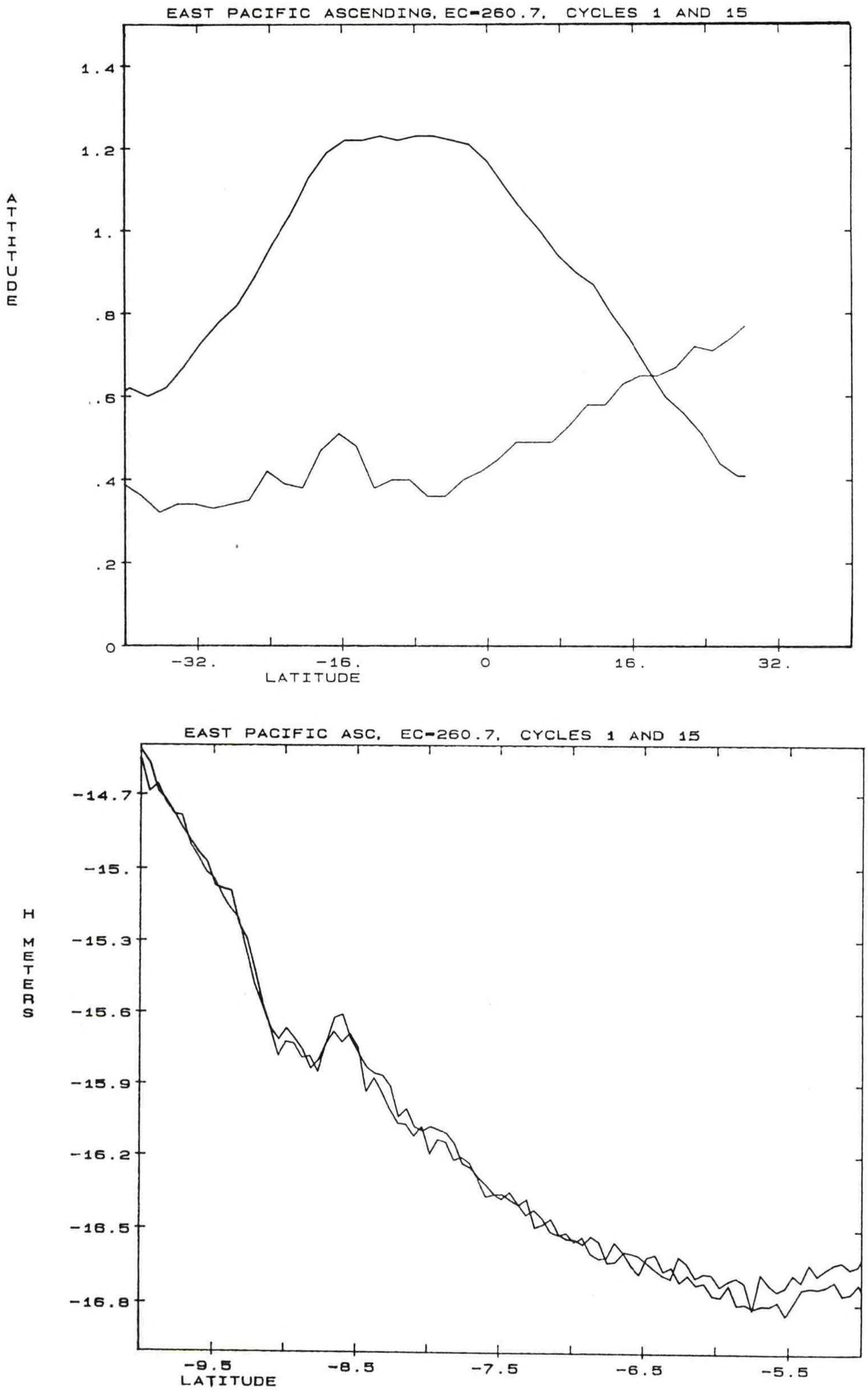

Figure 4.--(a) Attitude along two collinear GEOSAT passes in the Pacific. Passes are ascending and cross the equator at 260.7 E. (b) Sea height measured by the GEOSAT altimeter along a segment of the 2 passes where difference in attitude was nearly 1 degree. The profile from cycle 15 has been offset approximately 6.3 m to eliminate the difference due to orbit error.

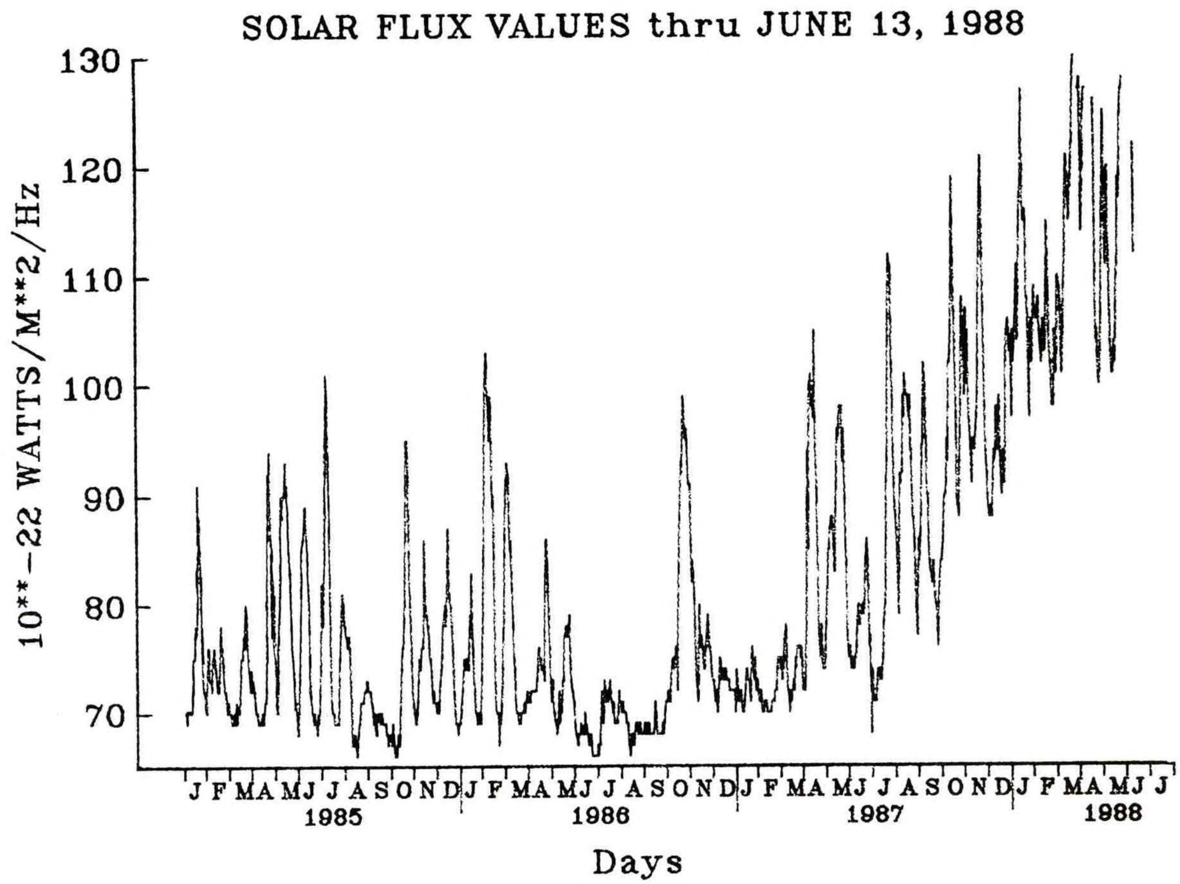

Figure 5.--Daily values of solar flux, 1985-88.

geographic scale. Figure 5 shows daily values of solar flux from January 1985 onward. Through the middle of 1987, low solar activity resulted in typical daytime GEOSAT ionosphere corrections of only 1-2 cm. During the latter half of 1987, however, solar flux began to rise dramatically. By the end of the first year of the ERM, the ionosphere correction given on the GEOSAT GDR's reached maximum values of about 7 cm. Although this is still a relatively small value, the situation will continue to worsen until solar maximum in 1990, when the path length correction may be as large as 25 cm and have significant variation over regional scales.

TROPOSPHERIC CORRECTION

The wet and dry tropospheric corrections in the GEOSAT GDR's are interpolated from global grids provided by the Fleet Numerical Oceanographic Center (FNOC). Each grid represents an interval of 12 hours. Occasionally, one or more of the grids are unavailable, and interpolation must be performed over longer intervals. These time periods are given in table 1. Three gaps of approximately 4 days each occurred during the first year of the ERM, and two of these fell within a 10-day period in February 1987.

Table 1.--Time periods when gaps exist in the series of 12-hour global grids of tropospheric data provided by FNOC

1986	Day 336 (0000 Z) to Day 340 (0000 Z) =	4.0 day gap
	Day 348 (1200 Z) to Day 349 (1200 Z) =	1.0
1987	Day 15 (1200 Z) to Day 16 (1200 Z) =	1.0
	Day 31 (0000 Z) to Day 35 (1200 Z) =	4.5
	Day 37 (0000 Z) to Day 41 (0000 Z) =	4.0
	Day 91 (1200 Z) to Day 92 (1200 Z) =	1.0
	Day 103 (1200 Z) to Day 104 (1200 Z) =	1.0
	Day 277 (1200 Z) to Day 282 (0000 Z) =	4.5
	Day 333 (0000 Z) to Day 334 (0000 Z) =	1.0

SATELLITE EPHEMERIS

As described in the User Handbook, each GDR consists of approximately 1 day of data, beginning and ending as close as possible to maximum latitude (72 degrees N). This is done to minimize the impact of discontinuities that exist between consecutive 1-day orbital arcs.

One case in which this procedure was not followed was brought to our attention by C. Koblinsky (NASA/Goddard). The result is an orbit discontinuity with a radial amplitude of approximately 1.2 m (fig. 6) between the last record on day 349 and the first record on day 350 (1986):

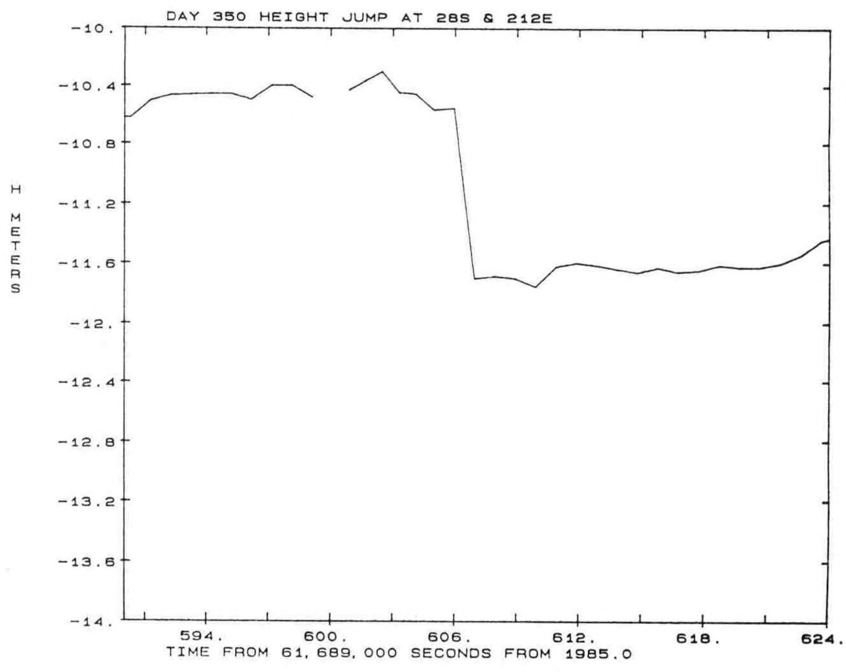

Figure 6.--GEOSAT sea height at the location of orbit discontinuity between day 349 and day 350 (1986).

Day 349 Time = 61689605.971867 sec
Lat = 28.401947 S
Lon = 212.379443 E

Day 350 Time = 61689606.951789 sec
Lat = 28.456847 S
Lon = 212.351966 E

For purposes of removing radial orbit error from the measured altimeter heights, the pass containing this discontinuity must be treated as two separate arcs. Analyses involving wind and wave data are not affected, however.

GEOID MODEL

Geoid heights interpolated from the 1-degree model of Rapp (1978) are included in the GDR records for the purpose of gross error checking. One would expect the geoid model and the GDR surface heights to always be within a few meters of each other. It has been brought to our attention by Pierre Flament (Woods Hole Oceanographic Institution) that the GDR geoid model profiles contain ripples with horizontal scales of 1 degree and amplitudes sometimes as large as 1 m. These are not associated with the Rapp model but were erroneously introduced by the interpolation routine, which was not well suited for this application. An example of these geoid ripples can be seen in the geoid model profile shown in figure 8 of the GDR User Handbook (Cheney et al. 1987). An enlarged segment of this profile is reproduced here in figure 7, and plotted on the same scale is sea height from the GEOSAT altimeter. It is apparent from this comparison that most of the short-scale geoid model undulations are not real, but are artifacts of our interpolation. This problem will be rectified in the near future by substituting a different method.

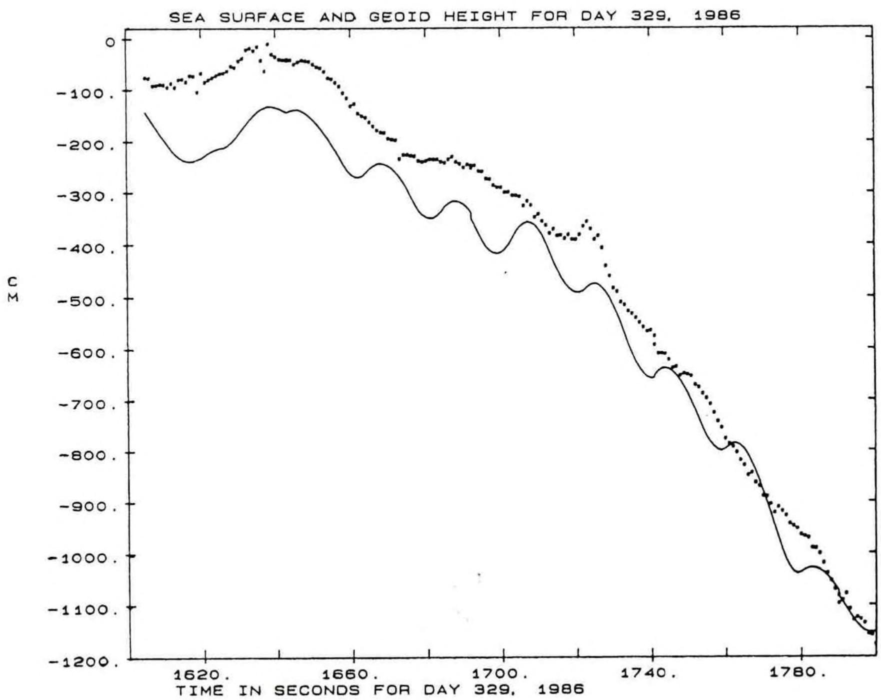

Figure 7.--Comparison of 1-second GEOSAT sea height (dotted line) and GDR geoid model height (smooth curve) for a segment in the North Pacific. Undulations in geoid profile were erroneously produced by the interpolation scheme employed.

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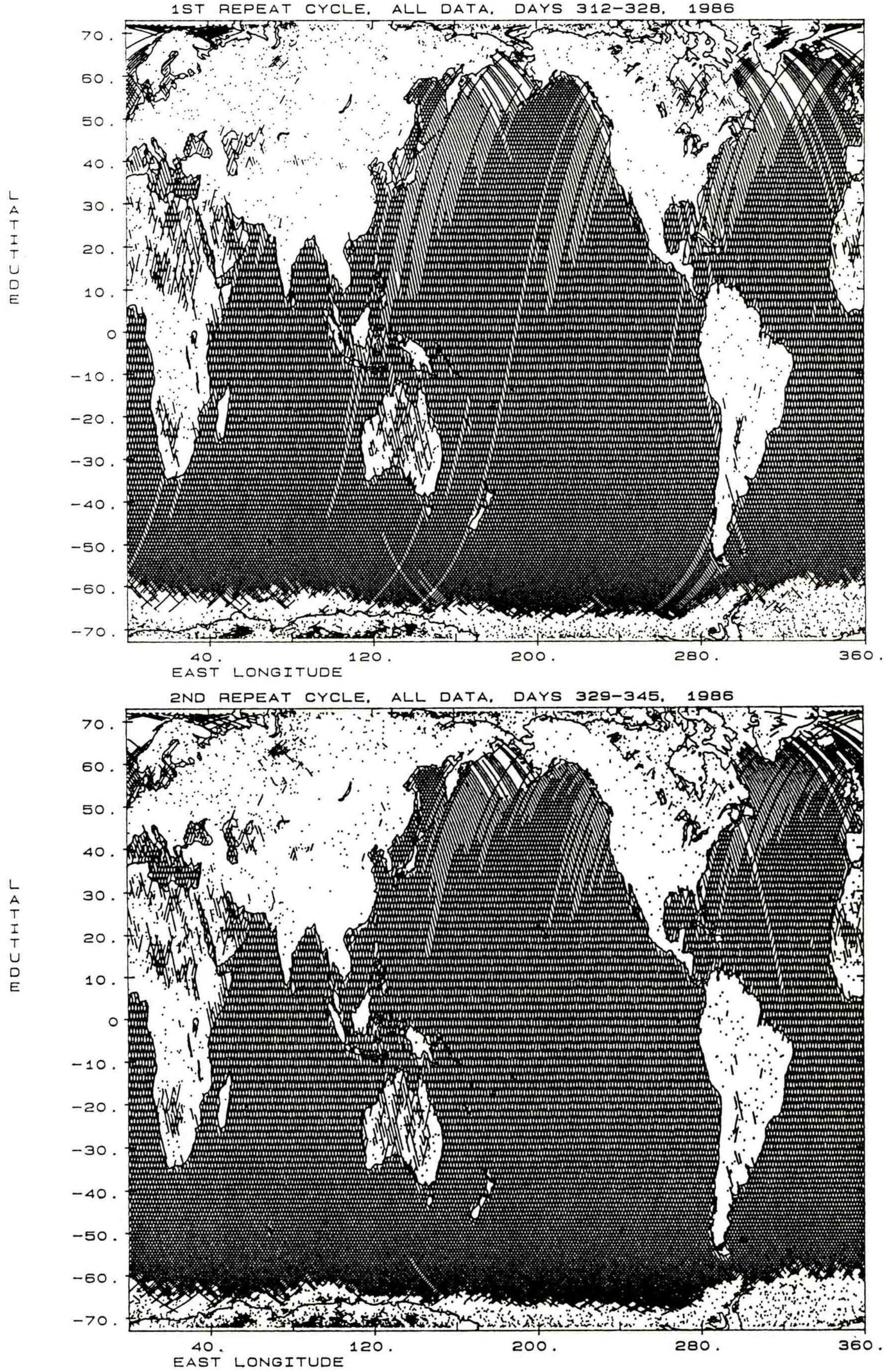
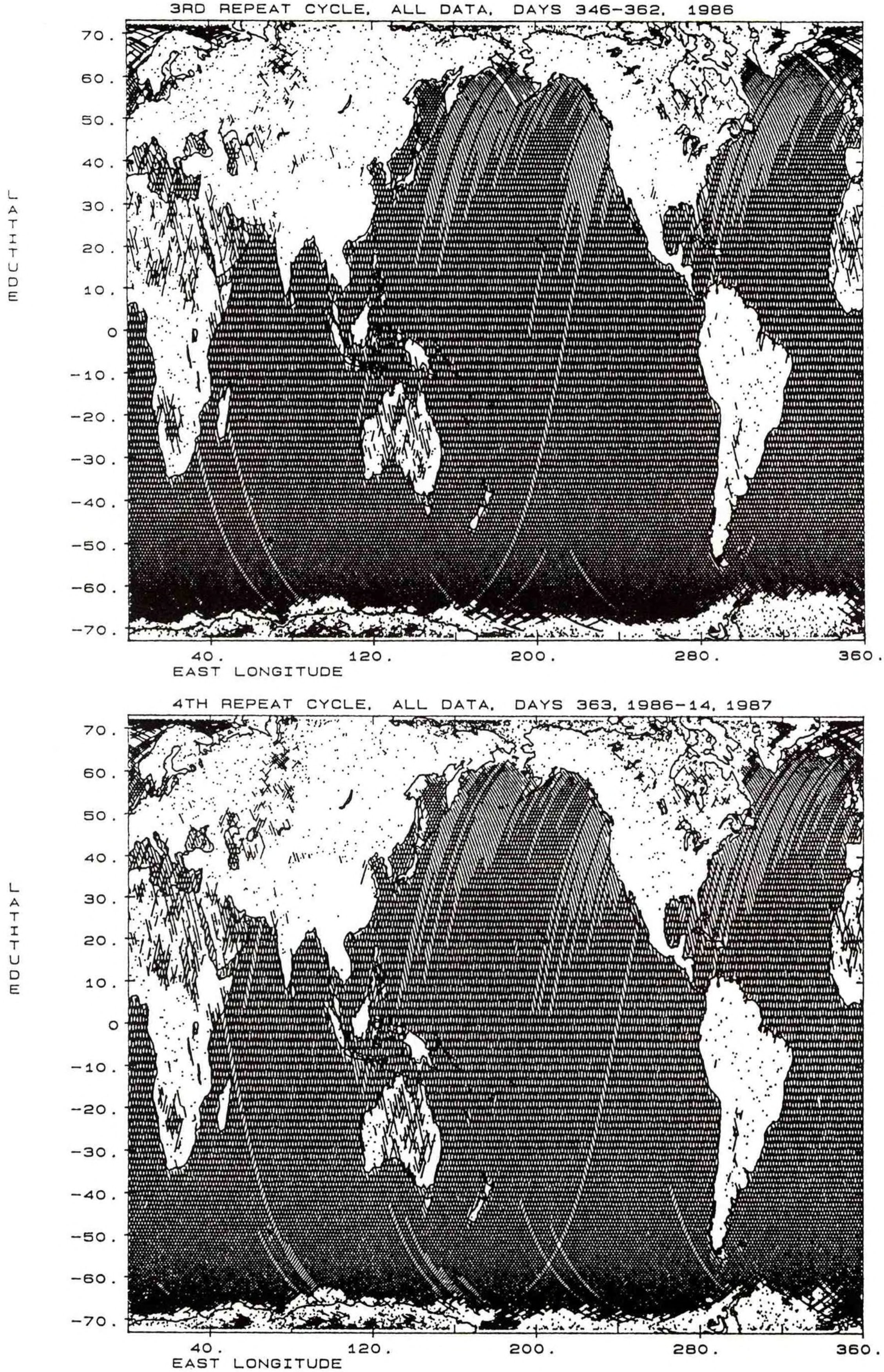


Figure 2.--GEOSAT GDR data distribution for the first 22 17-day cycles of the Exact Repeat Mission.



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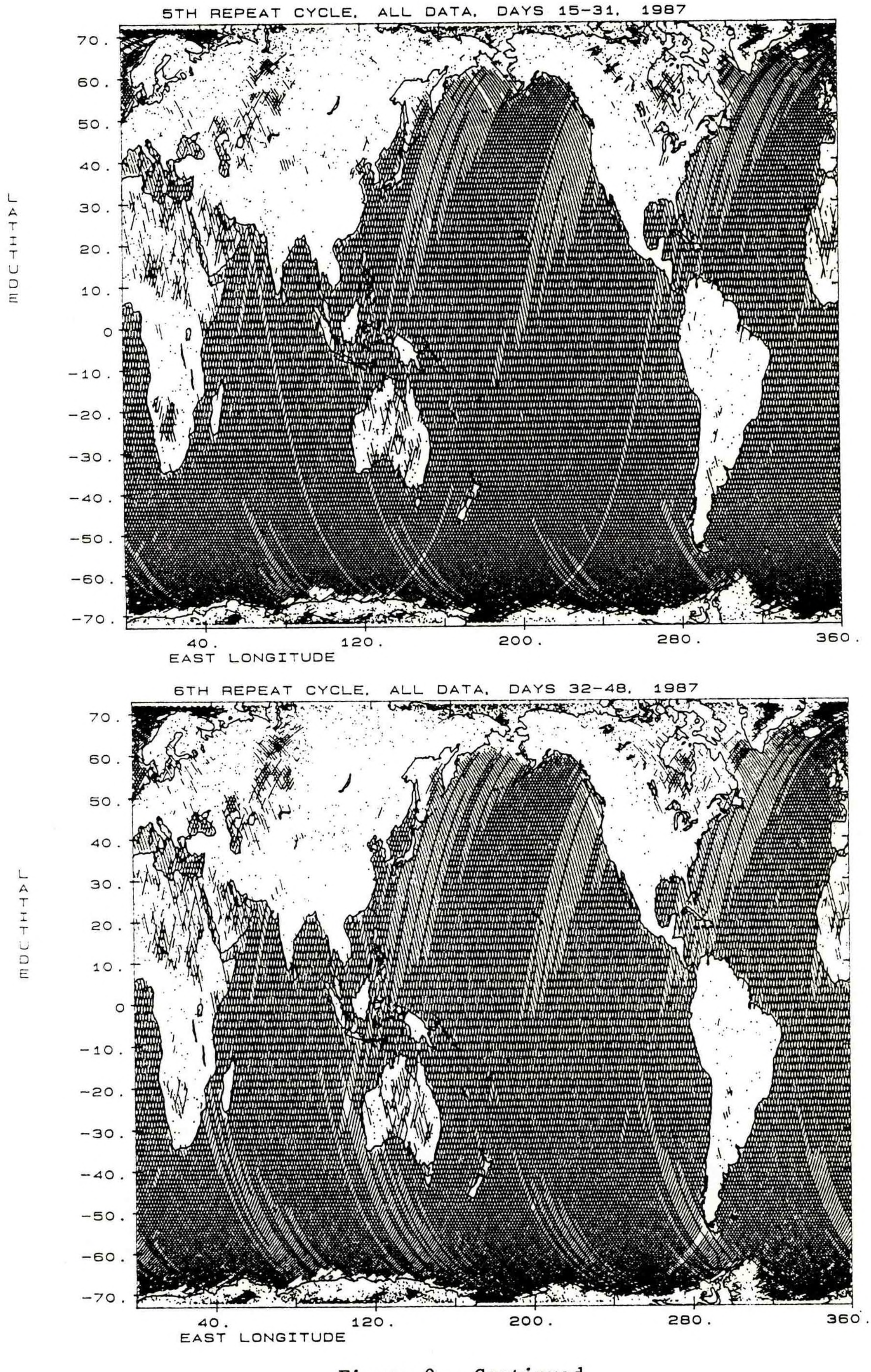

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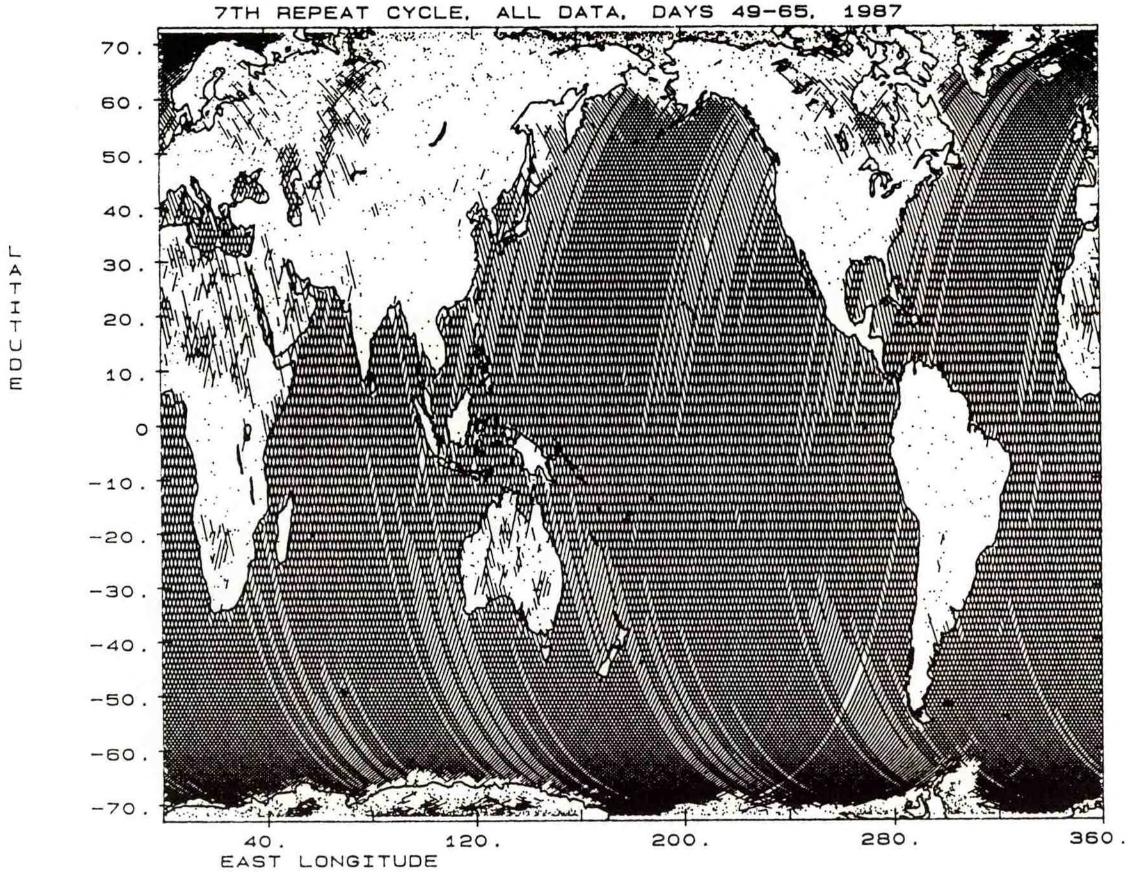

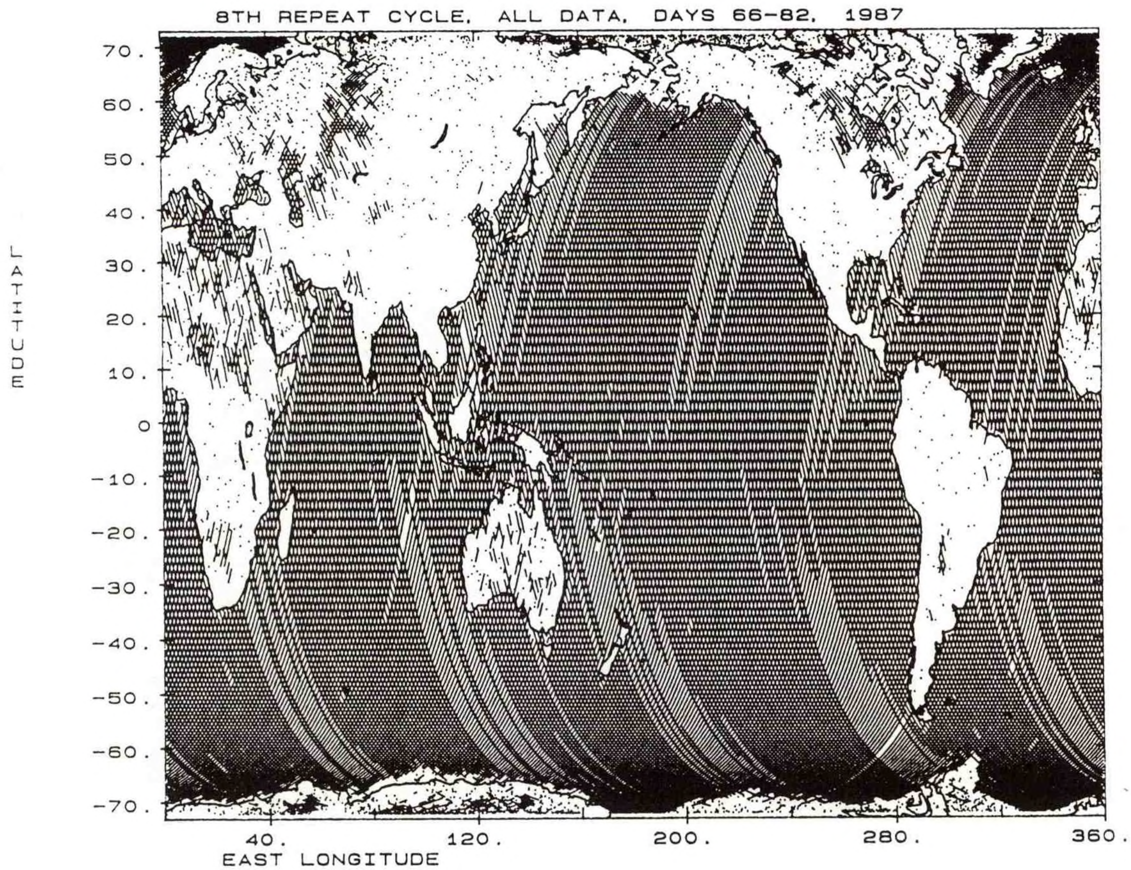

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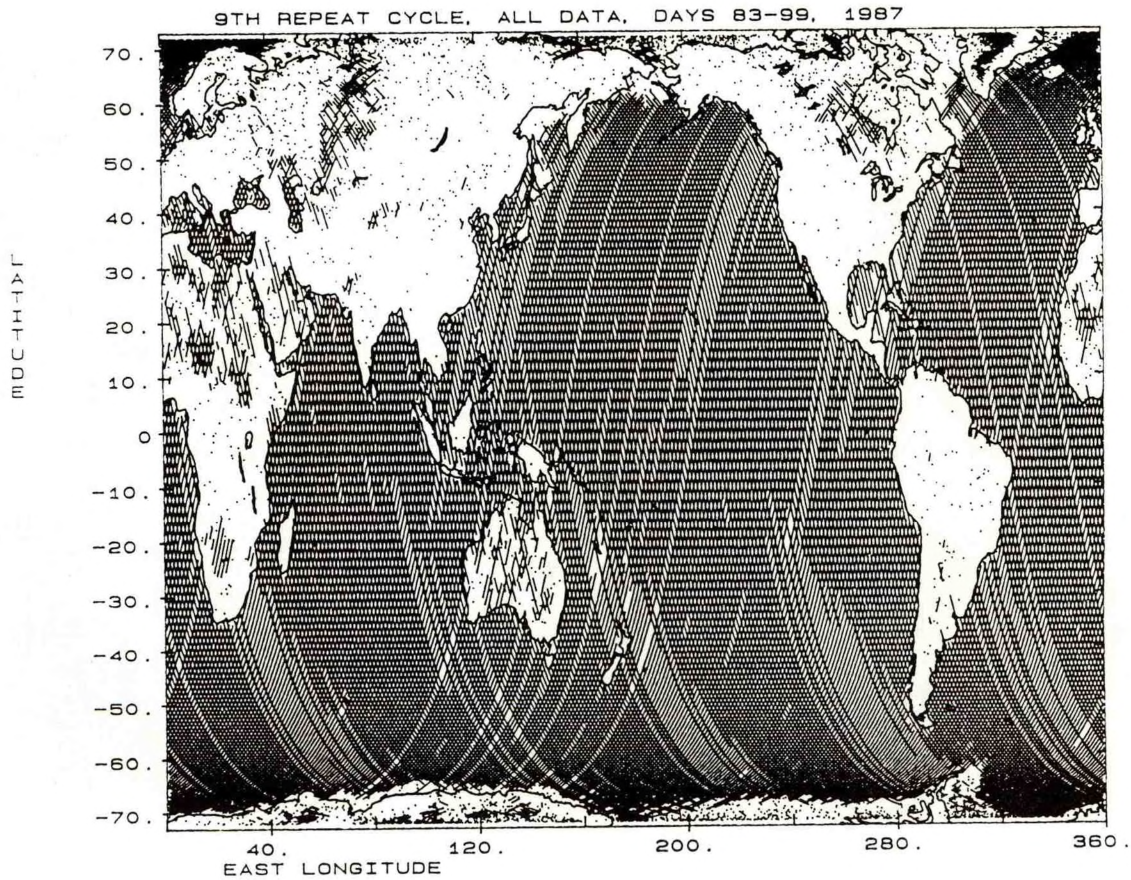

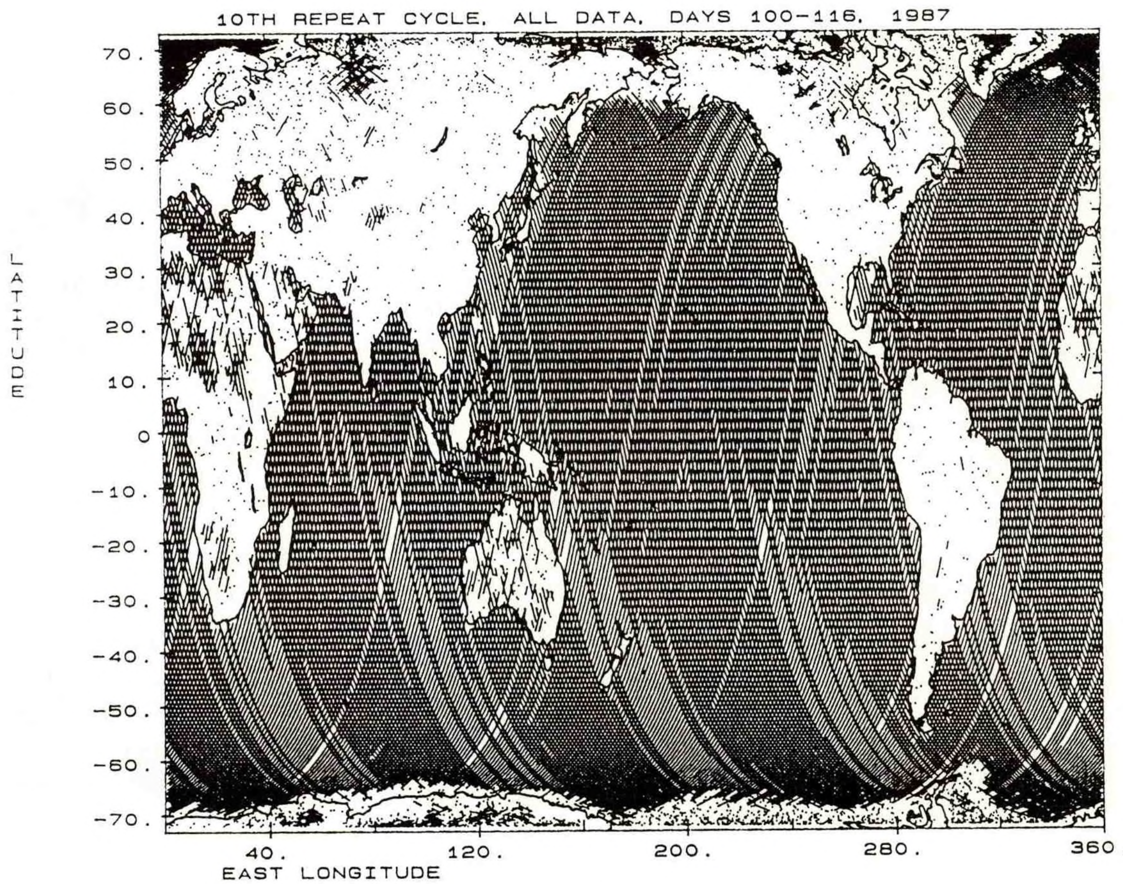

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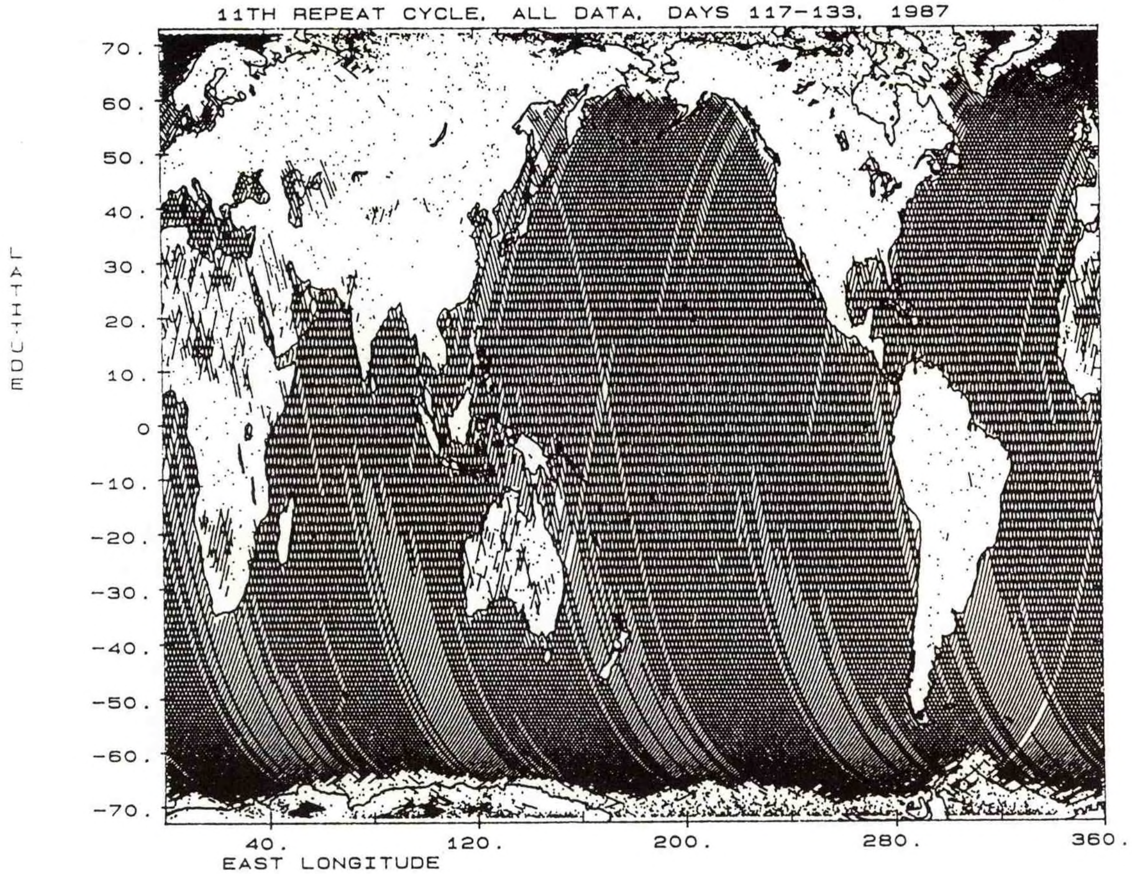

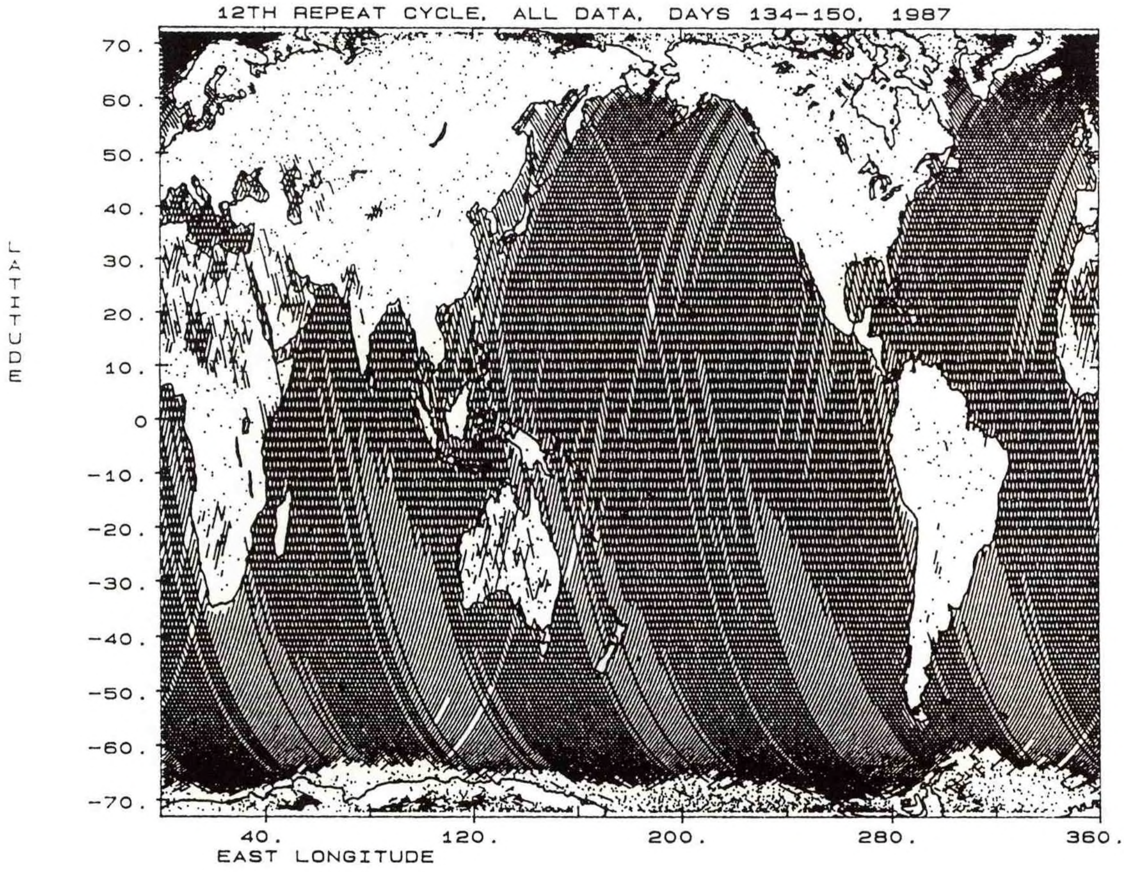

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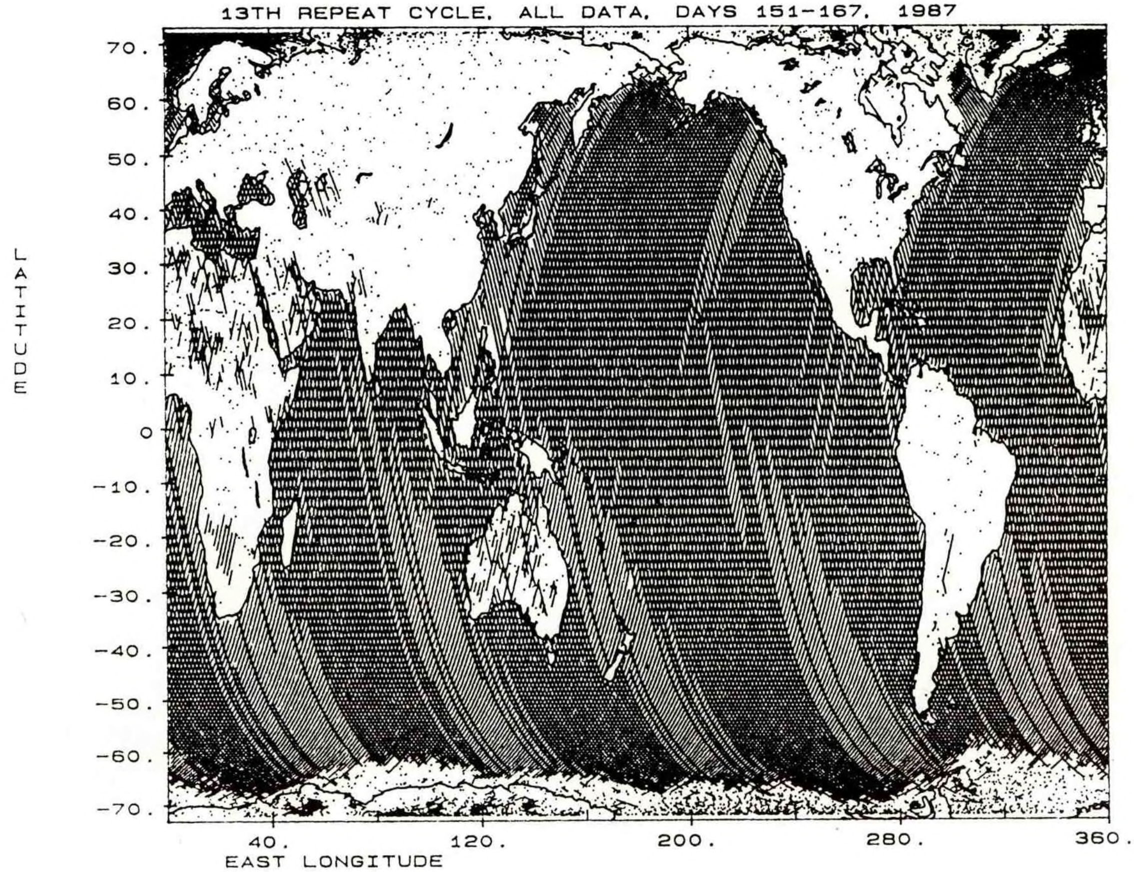

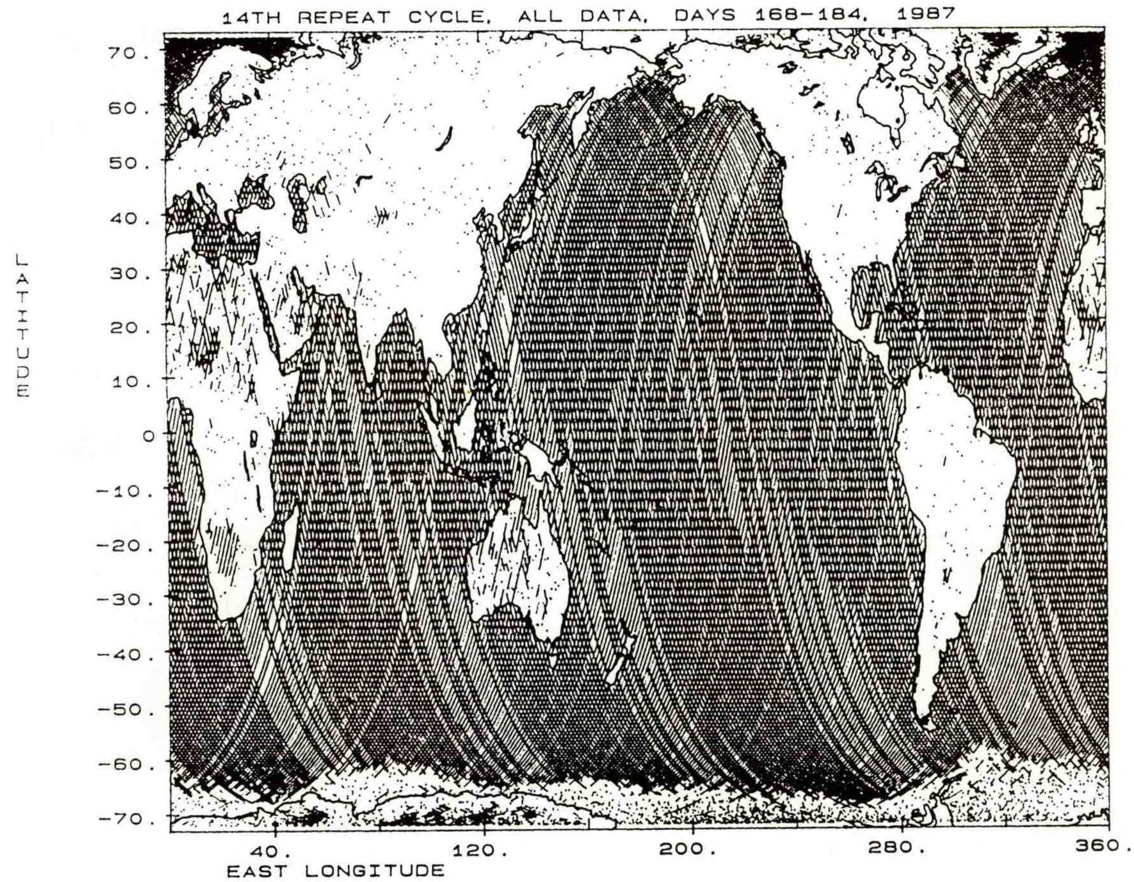

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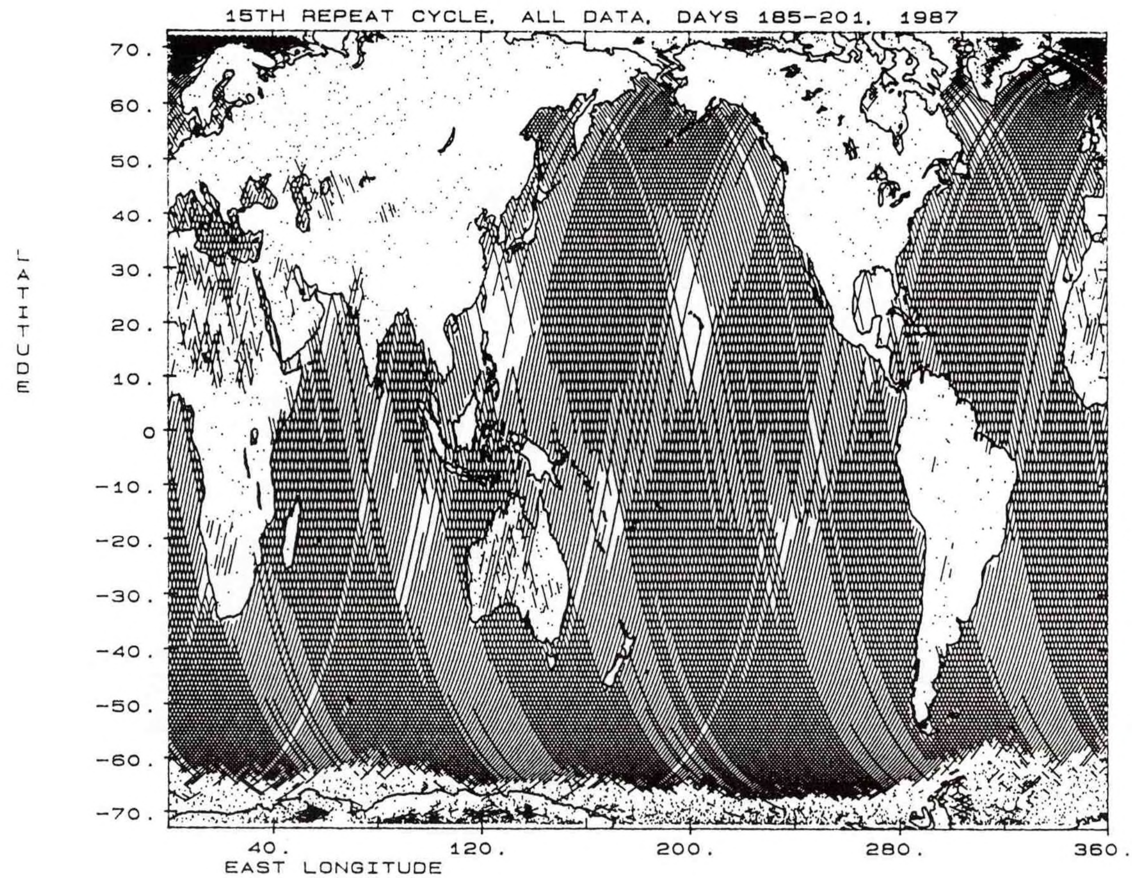

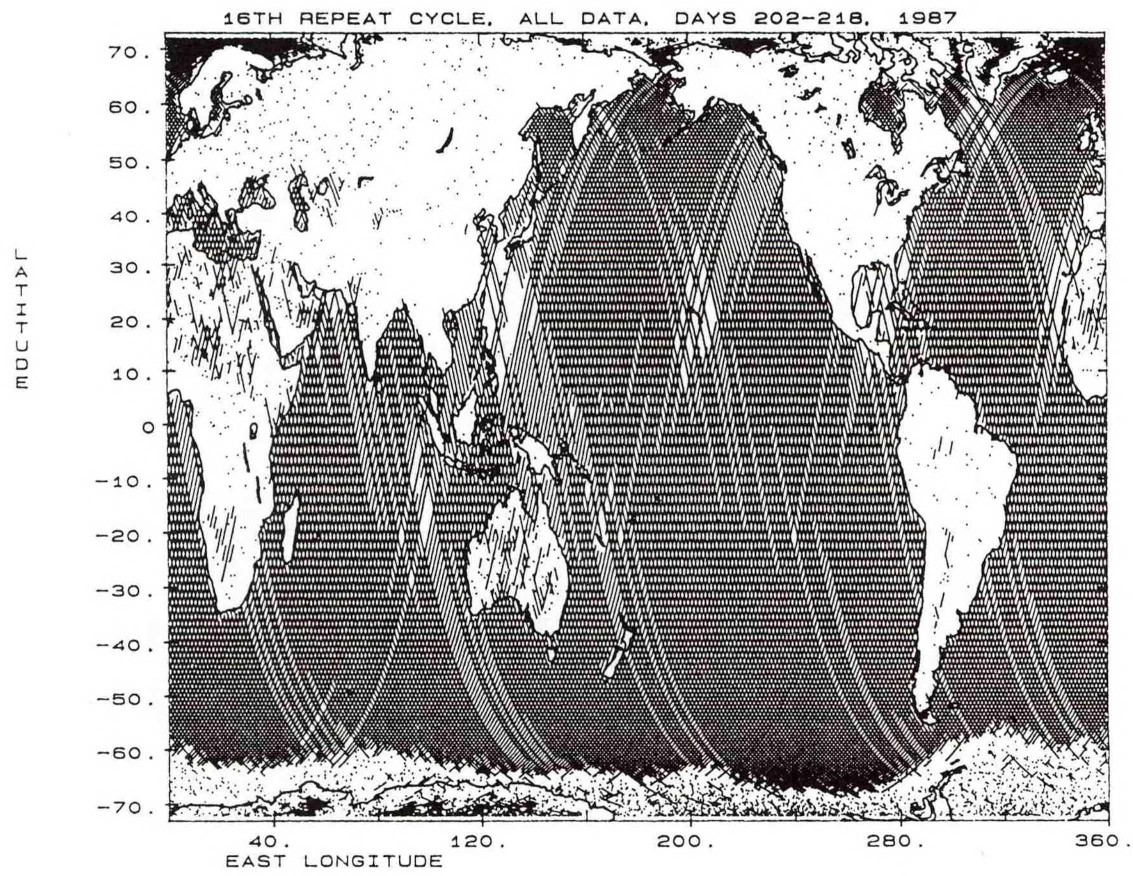

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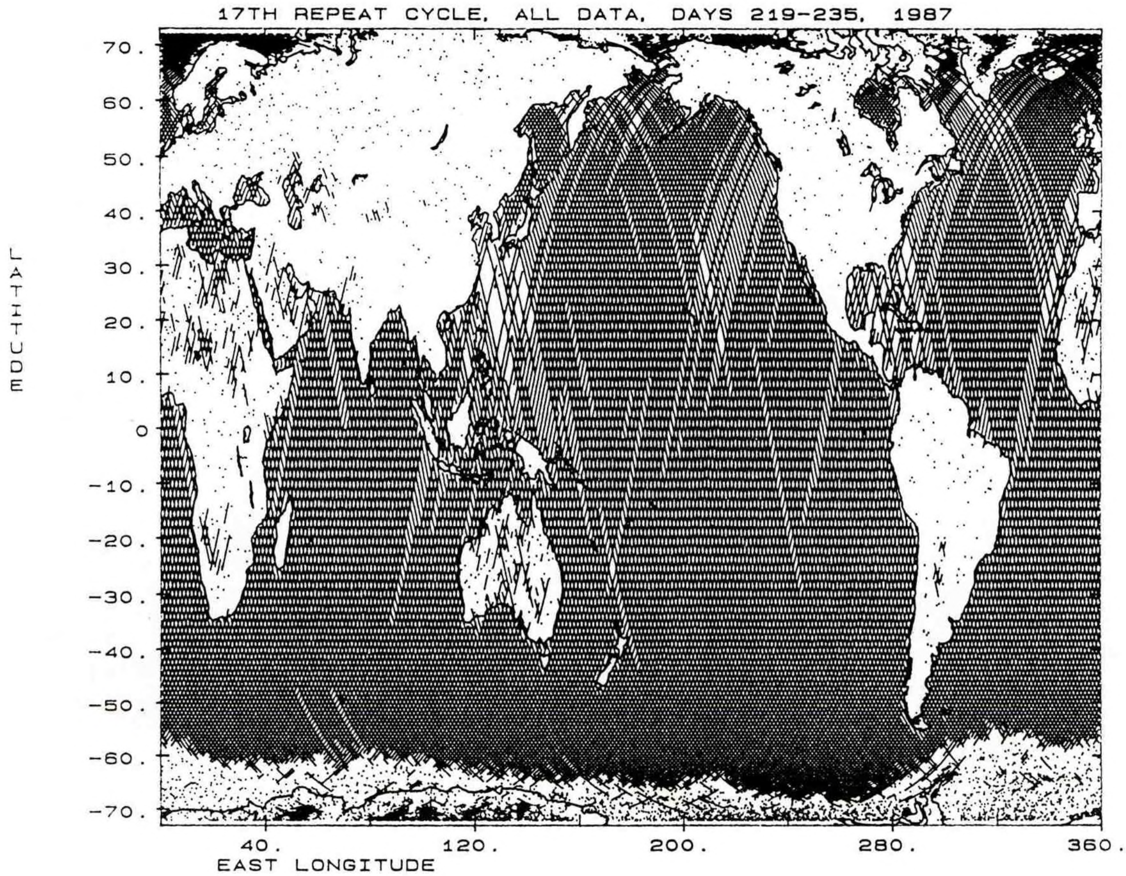

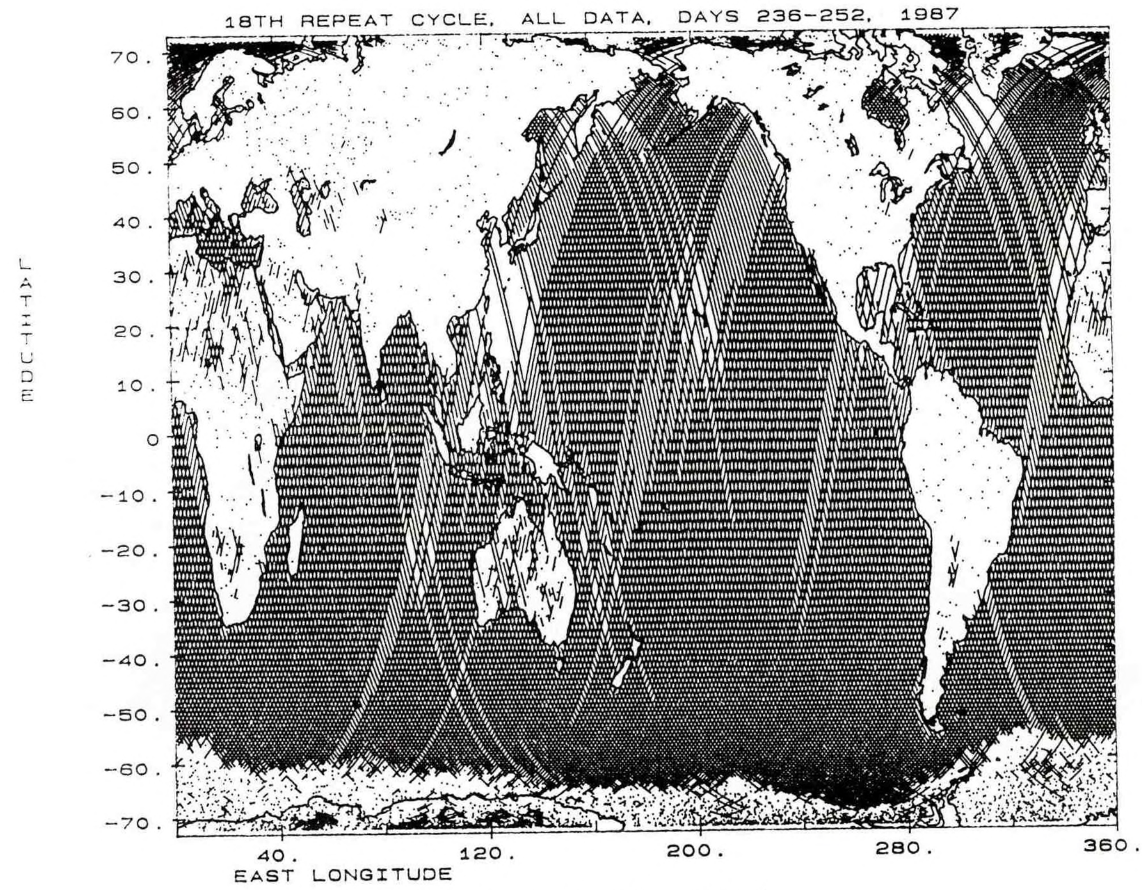

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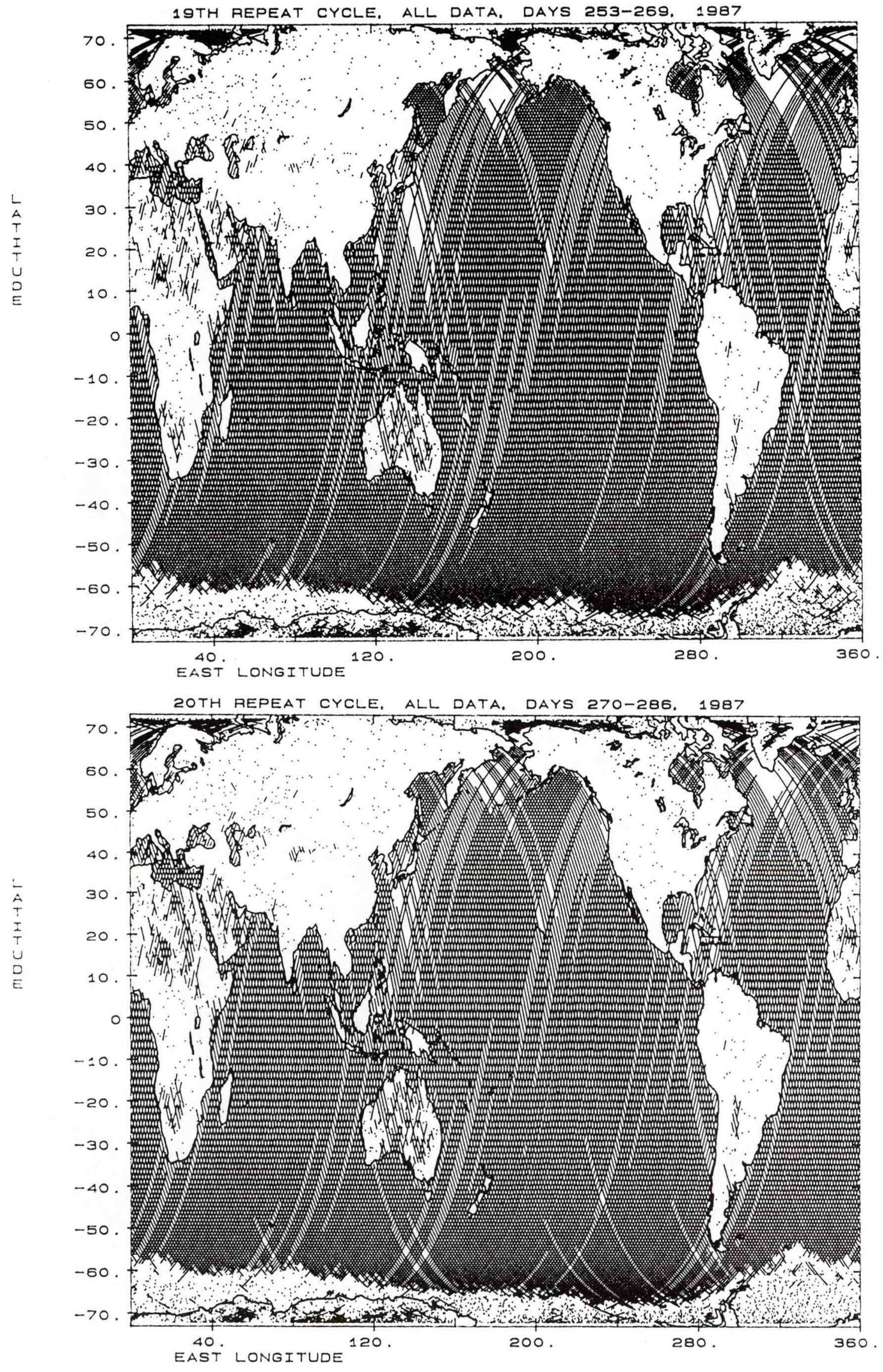

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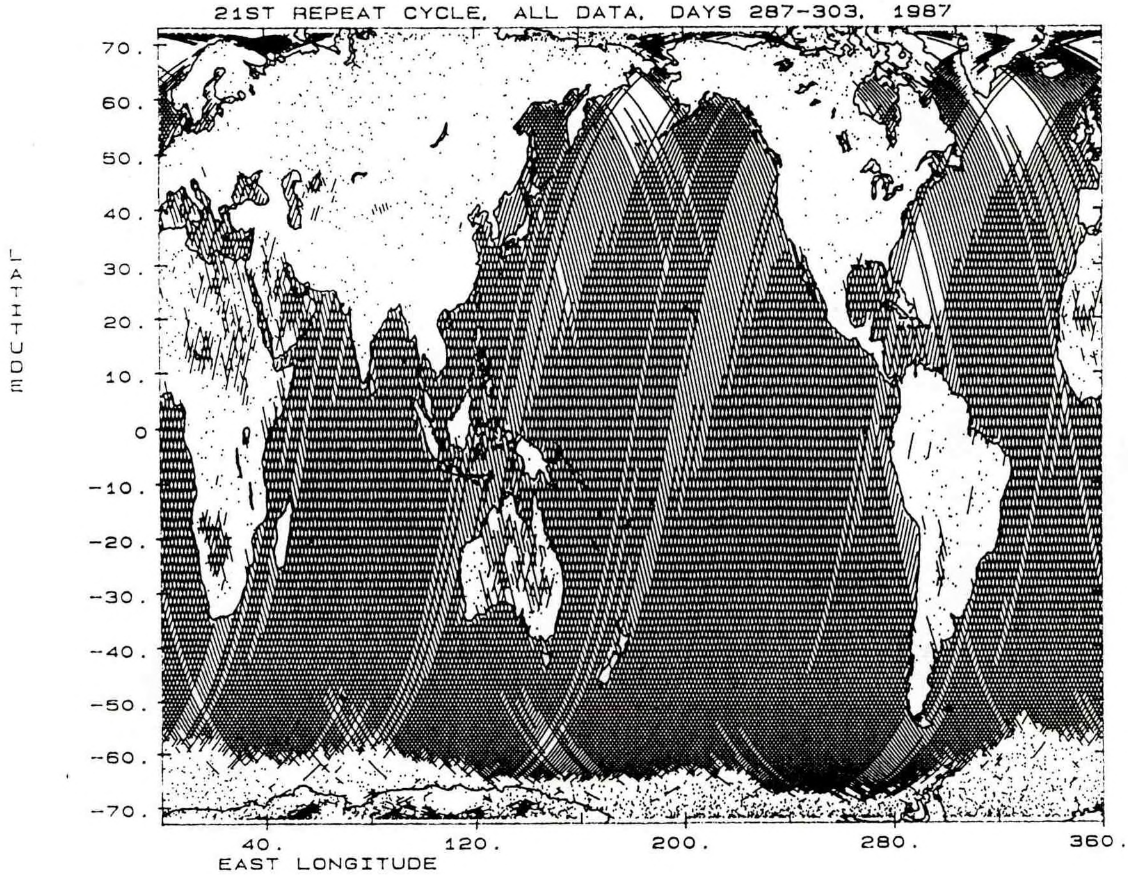

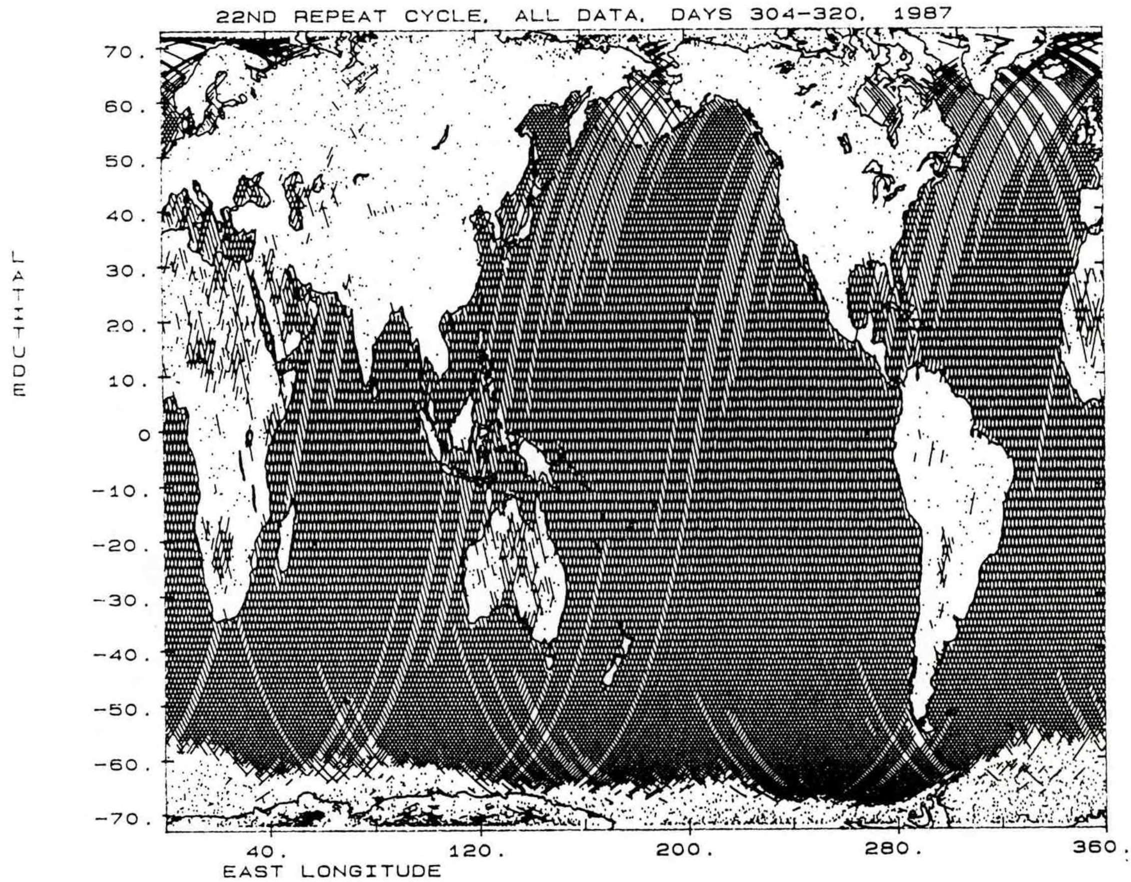

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