Seasat and GEOSAT Altimetry for the Antarctic and Greenland Ice Sheets, Version 1

USER GUIDE

How to Cite These Data

As a condition of using these data, you must include a citation:

Zwally, J. and A. Brenner 1997. *Seasat and GEOSAT Altimetry for the Antarctic and Greenland Ice Sheets, Version 1*. [Indicate subset used]. Boulder, Colorado USA. NASA National Snow and Ice Data Center Distributed Active Archive Center. https://doi.org/10.5067/MTIF60G86H86. [Date Accessed].

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National Snow and Ice Data Center

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This data set is now available for download via HTTPS. References to the CD-ROM have been retained for historical purposes and no longer apply.

1 DETAILED DATA DESCRIPTION

1.1 Data Set Overview

This data set contains surface elevations of the Antarctic and Greenland ice sheets derived from Seasat and GEOSAT radar altimetry data. The Seasat data were collected for a continuous 90 days in 1978, at latitudes of between 72 degrees South and 72 degrees North. GEOSAT was launched in 1985 and placed in a nearly identical orbit to Seasat, also at latitudes of between 72 degrees South and 72 degrees North. Data from GEOSAT were acquired between April 1985 and September 1986.

1.1.1 Objective/Purpose

The Seasat/GEOSAT altimetry data were collected to create surface elevation maps of the Greenland and Antarctic ice sheets (below 72°). Ice sheet surface topography is needed for determining ice dynamics (direction and magnitude of ice flow). Ice elevation is required for improved estimates of changes in ice sheet mass balance.

1.1.2 Summary of Parameters

The data set consists of radar ice altimetry data collected at latitudes of between 72 degrees South and 72 degrees North. Data from Seasat were acquired for a continuous 90 days in 1978; and data from GEOSAT, between April 1985 and September 1986.

1.2 Spatial Characteristics

Although designed for data collection over oceans, Seasat collected over 600,000 altimeter measurements from the continental Antarctic and Greenland ice sheets. Over sloping and undulating surfaces or surfaces with variable reflective characteristics, Seasat altimeter radar pulse measurements accelerated faster than the response capability of the altimeter tracking circuit, necessitating a retracking correction for each range value. For GEOSAT, the earliest return altimeter signals came from ocean wave crests. Its radar altimeter was better designed to track over undulating surfaces. During its mission, GEOSAT provided unprecedented ground coverage with a maximum ground track grid spacing of 2.7 kilometers at the equator and much denser spacing over the polar ice sheets.

1.2.1 Spatial Coverage

Seasat and GEOSAT covered the latitudes between 72 degrees South and 72 degrees North, as shown in the following figures:

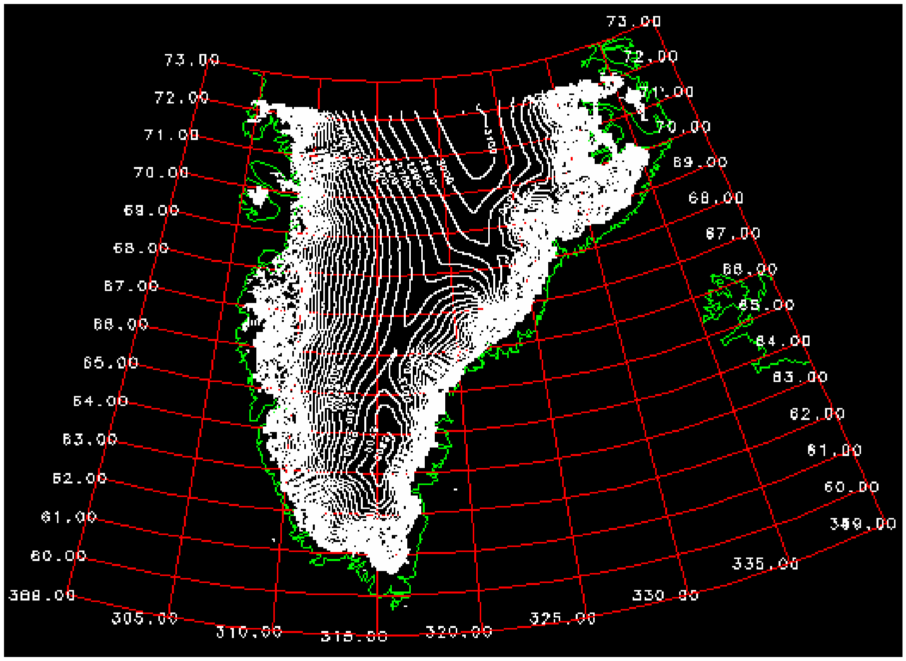

Figure 1. Greenland Spatial Coverage Map

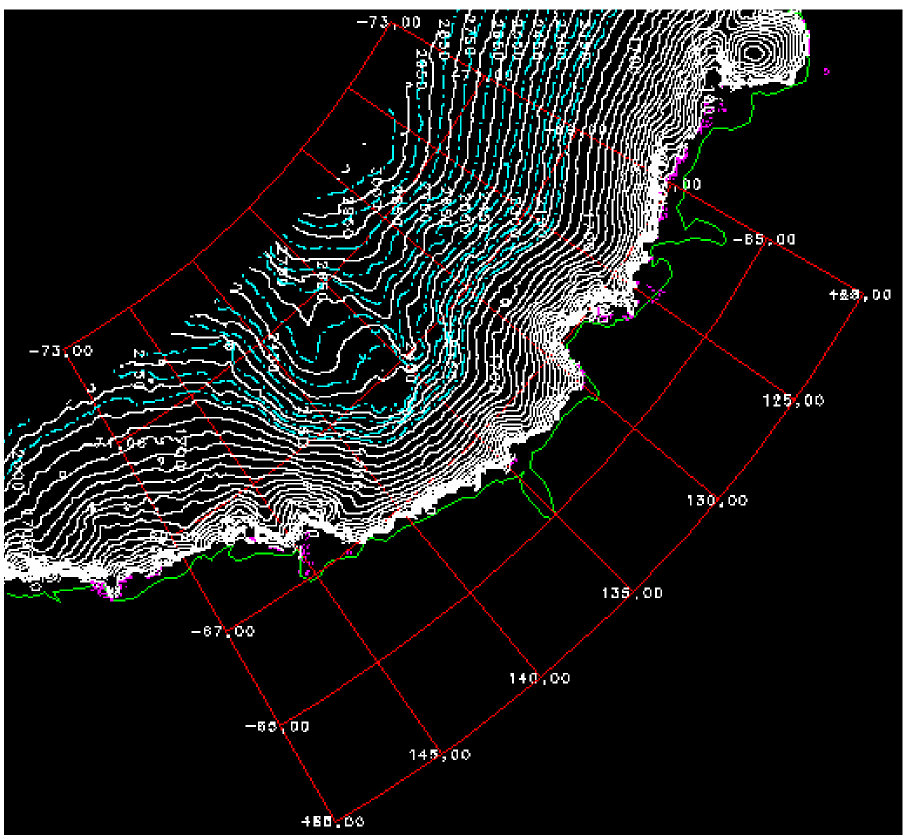

Figure 2. Partial Antarctic Coverage Map

1.2.2 Spatial Resolution

Gridded elevations are spaced at 10 km for GEOSAT data and 20 km for Seasat data.

1.2.3 Projection

The Seasat and GEOSAT grids provide the surface topography of the ice sheets relative to the OSU91A geoid. Grid points are on a polar stereographic projection.

1.2.4 Grid Description

The Seasat and GEOSAT data were gridded independently of each other. Gridded elevations are derived from the data by a weighted fitting of a biquadratic function to the elevation data that fall within a certain radius of the grid location. Where the data distribution is sparse, a bilinear function is used.

1.3 Temporal Coverage

Seasat: June 28, 1978 to October 10, 1978
GEOSAT Geodetic Mission (GM): March 12, 1985 to September 1986

1.4 Parameter or Variable

Surface elevations. See “Appendix A | GEOSAT Variables” for a complete list of variables.

1.4.1 Parameter Description

The heights of the Earth's surface measured from space.

1.4.2 Unit of Measurement

Meters

1.4.3 Data Source

See “Appendix B | Radar Altimeter”

1.4.4 Data Range

Table 1. Seasat Database

Hsc	=	The height of the spacecraft above the IUGG 1980 Geodetic Reference ellipsoid (Moritz 1980) calculated from the GEM-T2 orbits
Halt	=	The altimeter-measured range
dHret	=	The retracking correction
dHcg	=	The center of gravity correction to the range
dHion	=	The ionospheric delay correction to the surface height
dHtrop	=	The tropospheric delay correction to the surface height
dHtide	=	The solid tide value

For the GEOSAT database, the range is the same except for:

Table 2. GEOSAT Database

dHion	=	0; no correction has been applied due to the ionosphere delay (The range of this correction is approximately 2-3 cm)
Hsc		Based on the navy precision orbits Smith et al. 1987
dHslp	=	Slope correction

1.4.5 Sample Data Record

```
723
003 9  9999.9 1954 04 20 0000 -9 166 9999 86.60 182.80     3850    13000 99 9 99 018 ??????? -9 -9 -9 -9 -9 -9 -9 -9 -9 -9     Old latlon 86.60 182.85 E
99    3850 -9 1  600.00 -9 1 -32.10 -9 1 -99.9 0 210 -9 1   5.0 -9 1 9 99.9 -9 0 -99 ??????????????? ??
99    4000 -9 1  587.00 -9 1 -33.30 -9 1 -99.9 0 208 -9 1   5.0 -9 1 9 99.9 -9 0 -99 ??????????????? ??
99    5000 -9 1  509.00 -9 1 -40.80 -9 1 -99.9 0 204 -9 1   7.0 -9 1 9 99.9 -9 0 -99 ??????????????? ??
99    5120 -9 1  500.00 -9 1 -41.50 -9 1 -99.9 0 204 -9 1   7.0 -9 1 9 99.9 -9 0 -99 ??????????????? ??
99    5820 -9 1  448.00 -9 1 -48.90 -9 1 -99.9 0 215 -9 1   6.0 -9 1 9 99.9 -9 0 -99 ??????????????? ??
99    6000 -9 1  439.00 -9 1 -48.90 -9 1 -99.9 0 217 -9 1   6.0 -9 1 9 99.9 -9 0 -99 ??????????????? ??
99    6620 -9 1  400.00 -9 1 -48.90 -9 1 -99.9 0 207 -9 1   6.0 -9 1 9 99.9 -9 0 -99 ??????????????? ??
```

Figure 3. Sample Data Record

2 SOFTWARE AND TOOLS

2.1 Software Description

Software to extract and browse subsets of these data is included on one CD-ROM. Elevations from the full data rate (662.5 m along track) are provided in ASCII format in the georeferenced databases. Gridded elevations at 10-km and 20-km spacing are provided in the gridded data sets created from the GEOSAT and Seasat data, respectively. Software, referred to as the Ice Altimetry System (IAS), has been supplied to extract and browse subsets of these data. The IAS software also allows the user to view pre-generated contours created from the gridded data and ground tracks of the full-rate data.

The extracted subsets are written as ASCII files that can be read and processed by general graphics or data analysis packages or by custom user programs. The binary formats of the georeferenced databases and grids are provided with sample software for users who wish to directly read them.

2.2 Software Access

To order a CD-ROM, please contact NSIDC User Services.

3 DATA ACQUISITION AND PROCESSING

3.1 Data Acquisition Methods

Initially acquired by the Johns Hopkins APL (Applied Physics Lab) satellite tracking facility, the raw altimetry satellite data from Seasat and GEOSAT were passed on to NASA, via the U.S. Navy. NASA developed slope correction routines for the higher slopes over the ice sheets, relative to ocean surfaces. The data are height profile (Level 3) data and gridded height (Level 4) data provided by the Oceans and Ice branch of the Laboratory for Hydrospheric Physics of Goddard Space Flight Center. Elevations from the full data rate (i.e., one measurement every 662.5 m) are provided in georeferenced databases. These elevations are relative to the OSU91A geoid. Gridded elevations at 10-kilometer and 20-kilometer spacing are provided in the gridded data sets created from the GEOSAT and Seasat data, respectively.

3.2 Derivation Techniques and Algorithms

For the GEOSAT database, dHion = 0. No correction was applied due to ionosphere delay. The range of this correction is approximately 2-3 cm.

Hsc is based on the Navy precision orbits (Smith et al. 1987) and referenced to the WGS 84 ellipsoid.

A value for the slope correction, dHslp, is written on each database record, but has not been applied to Hdb. This correction accounts for the fact that the altimeter measurement is to the closest point within the radar beam, which over sloping surfaces is not the subsatellite point (Brenner et al. 1983).

When dHslp is undefined, a value of -999999999 is placed in that field. To obtain a slope-corrected surface elevation, Hcor, use the following:

Hcor = Hdb - dHslp

3.2.1 Trajectory and Attitude Data

3.2.1.1 Data Granularity

A granule is the smallest aggregation of data that is independently managed (i.e., described, inventoried, retrievable). Granules may be managed as logical granules and/or physical granules. The data in this data set represent satellite altimeter measurements of 1.6-km in diameter retrieved at 0.66-km intervals along the satellite tracks.

3.2.1.2 Data Format

The Seasat and GEOSAT Altimetry Data for the Antarctic and Greenland Ice Sheets is in Unix-compressed raw (.dat) format. ASCII tables of elevation data can also be accessed from software included on the CD-ROM.

3.2.2 Processing Steps

Seasat and GEOSAT topographical data were gridded independently of one another. The surface topography of the ice sheets is given relative to the OSU91A geoid. The gridding procedure is described in Zwally et al. 1990.

Gridded elevations are derived from the data by a weighted fitting of a biquadratic function to the elevation data that fall within a certain radius of the grid location. Where the data distribution is sparse, a bilinear function is used. Additional corrections are applied to the range measurements to account for atmospheric effects and satellite geometry. The elevation data without the slope correction are used and the resulting gridded heights are slope-corrected using the GEOSAT GM grids in an iterative manner. The retracking procedure is described in Zwally et al. 1983.

3.2.3 Error Sources

Precision of surface elevations derived from Seasat and GEOSAT altimetry measurements is directly proportional to the precision of the missions' orbits. NASA has been calculating more precise orbits using improved gravity models and the full complement of leased GEOSAT tracking data. Preliminary results show that the radial orbit errors which map directly into the elevation should reduce from 50- to 70-cm rms to under 20-cm rms. Updates are planned as better orbits for existing data sets are calculated and more data becomes available.

A significant source of error in the absolute elevations derived from the radar altimeters is the lack of accurate data for the Earth geoid in the Antarctic region. However, this has no effect on relative elevations and the mass balance and ice dynamics interpretations that are derived from them.

3.3 Data Manipulations

3.3.1 Formulae

The surface elevation in the Seasat database, Hdb, was calculated using the following:

Hdb = Hsc - Halt - dHret - dHcg + dHion + dHtrop - dHtide

The surface elevation in the GEOSAT database was calculated in a similar manner, except as stated "Section 3.2 | Derivation Techniques and Algorithms" above.

3.3.2 Notes

3.3.2.1 Limitations of the Data

At the highest latitudes, the ground track spacing is very dense. This spacing becomes greater (data points are more sparse) at lower latitudes, so there is less cross-track information available. The surface topography estimates are more smoothed at these lower latitudes as a result.

3.3.2.2 Application of the Data Set

This data set provides an accurate topographical map of the Greenland and Antarctic ice sheets against which future variations in surface characteristics can be detected. The collection of surface elevation data from the Antarctic and Greenland ice sheets contributes to the study of ice dynamics and to possible detection of changes in global ice volume.

3.4 Sensor or Instrument Description

See "Appendix B | Radar Altimeter"

3.4.1 Collection Environment

Satellite

3.4.2 Source/Platform

See "Appendix C | Seasat Instrument Description" and "Appendix D | GEOSAT Instrument Description."

4 REFERENCES AND RELATED PUBLICATIONS

Brenner, A. C., R. A. Bindschadler, R. H. Thomas, and H. J. Zwally. 1983. Slope-induced errors in radar altimetry over continental ice sheets. Journal of Geophysical Research 88.

Frain, William E., Michael H. Barbagallo, and Raymond J. Harvey. 1987. The design and operation of Geosat. Johns Hopkins APL Technical Digest 8(2): 184-9.

MacArthur, John L., Paul C. Marth, Jr., and Joseph G. Wall. 1987. The Geosat radar altimeter. Johns Hopkins APL Technical Digest 8(2): 176-81.

Moritz, H. 1980. Geodetic reference system. Bulletin of Geodesy 54.

National Snow and Ice Data Center. (n.d.). Ice Altimetry CD-ROM Users' Manual. Boulder, Colorado: NSIDC Distributed Active Archive Center, University of Colorado at Boulder.

Zwally, H. Jay, and R. A. Bindschadler. 1983. Surface elevation contours of Greenland and Antarctic ice sheets. Journal of Geophysical Research 88(C3): 1589-96.

Zwally, H. J., A. C. Brenner, J. A. Major, T. V. Martin, and R. A. Bindschadler. 1990. Satellite radar altimetry over ice: Volume 1-Processing and corrections of Seasat data over Greenland. NASA Reference Publication 1: 1233.

Zwally, H. Jay, Judy A. Major, Anita C. Brenner, and Robert A. Bindschadler. 1987. Ice measurements by GEOSAT radar altimetry. Johns Hopkins APL Technical Digest 8(2): 251-4.

Zwally, H. Jay, Judith A. Major, Anita C. Brenner, Robert A. Bindschadler, and Thomas V. Martin. 1990. Satellite radar altimetry over ice: Volume 2-Users' Guide for Greenland Elevation Data from Seasat. NASA Reference Publication 2: 1233.

4.1 Related Data Collections

Digital SAR Mosaic and Elevation Map of the Greenland Ice Sheet
ETOP05 Elevation Data for Areas Greater Than 50 degrees North

5 CONTACTS AND ACKNOWLEDGMENTS

5.1 Investigators

Ted A. Scambos, CIRES, National Snow and Ice Data Center, University of Colorado at Boulder, Boulder, Colorado, USA

Anne Nolin, CIRES, National Snow and Ice Data Center, University of Colorado at Boulder, Boulder Colorado, USA

Robert A. Bindschadler, NASA Goddard Space Flight Center, Greenbelt, Maryland USA

H. Jay Zwally, NASA Goddard Space Flight Center, Greenbelt, Maryland USA

6 DOCUMENT INFORMATION

6.1 Publication Date

February 1998

6.2 Date Last Updated

18 May 2021

7 APPENDIX A – GEOSAT Variables

7.1 Variables

7.1.1 Elevation Grid Header Record

Bytes	FORTRAN Variable Type	Description
1-4	I*4	Number of i values in the grid
5-8	I*4	Number of j values in the grid
9-12	I*4	Starting north latitude of grid in degrees North (x 10^6) (this will be approximate for a polar stereographic grid)
13-16	I*4	Starting east longitude of grid in degrees East (x 10^6) (this will be approximate for a polar stereographic grid)
17-20	I*4	Ending north latitude of grid in degrees North (x 10^6) (this will be approximate for a polar stereographic grid)
21-24	I*4	Ending east longitude of grid in degrees East (x 10^6) (this will be approximate for a polar stereographic grid)
25-28	I*4	4 byte status word of bit flags that indicate whether or not corrections were used to generate the grid. A "1" indicates the correction was applied, while a "0" indicates it was not. Bits 0-23 and 25 are unused, while bits 24 and 26—31 correspond to the following corrections: 24: Slope correction 25: (Unused) 26: Solid tides (1=removed; 0=not removed) 27: Retracking correction 28: Center of gravity bias correction 29: Tropospheric correction 30: Ionospheric correction 31: Time bias correction
29-32	I*4	Polar stereographic grid size conversion and scaling factor from half-inch grids on projection plane to the desired grid size (x 10^6)
33-36	I*4	The number of grids of desired size from the pole to the equator based on the grid size conversion and scaling factor (x 10^6)
37-40	I*4	Latitude of the map perimeter in degrees North (x 10^6)
41-44	I*4	Greenwich orientation in degrees (x 10^6)
45-48	I*4	Polar stereographic switch: 0 = Constant increment in latitude, longitude 1 = Polar stereographic projection

Bytes	FORTRAN Variable Type	Description
49-52	I*4	Number of I-axis divisions to the extent of the map perimeter
53-56	I*4	Number of J-axis divisions to the extent of the map perimeter
57-60	I*4	J coordinate of the projected pole
61-64	I*4	I coordinate of the projected pole
65-68	I*4	Minimum J index of the grid
69-72	I*4	Maximum J index of the grid
73-76	I*4	Minimum I index of the grid
77-80	I*4	Maximum I index of the grid
81-180	n/a	Padded to keep same size as data records

7.1.2 Elevation Grid Data Records

Bytes	FORTRAN Variable Type	Description
1-4	I*4	Condition number of the matrix used in the least squares solution to the function (x 10^6)
5-8	I*4	Capsize in degrees latitude -- radius from grid location defining area from which data was used to define grid (x 10^6)
9-12	I*4	North latitude of grid point in degrees (x 10^6)
13-16	I*4	East longitude of grid point in degrees (x 10^6)
17-20	I*4	Height values of the grid at location relative to sea level in meters (x 10^5)
21-24	I*4	Number of data values that were used to calculate grid value
25-28	I*4	Number of parameters used to define function, NPT, (equals 0, 3, or 6) 0 indicates a non-defined grid value
29-52	I*4	Six gridding function coefficients If NPT is < 6, then the rest of the coefficients are initialized to zero (x 10^5)
53-76	I*4	Set of null coefficients associated with any negligible singular values If NPT is < 6, then rest of coefficients are set to zero (x 10^6)
77-80	I*4	Distance in kilometers from grid locations to closest data point (x 10^6)
81-84	I*4	North latitude of closest data point to grid location in degrees (x 10^6)
85-88	I*4	East longitude of closest data point to grid location in degrees (x 10^6)

Bytes	FORTRAN Variable Type	Description
89-92	I*4	Height associated with closest data point to grid location in meters (x 10^5)
93-96	I*4	Standard deviation of the data with respect to the gridding function in meters (x 10^6)
97-180	I*4	Correlation matrix from solution This is a symmetrical 6 X 6 matrix, so only the upper triangular portion is stored The order of storage: Elements 1-6 are the first row elements; 7-11 columns are 2-6 of the second row, etc. (x 10^5)

7.1.3 Georeferenced Database Header Record

Bytes	FORTRAN Variable Type	Description
1-4	I*4	Number of latitude rows in the database
5-8	I*4	Northwesternmost latitude of database in degrees North (x 10^5)
9-12	I*4	Northwesternmost longitude of database in degrees East (x 10^5)
13-16	I*4	Southeasternmost latitude of database in degrees North (x 10^5)
17-20	I*4	Southeasternmost latitude of database in degrees East (x 10^5)
21-NROWS*4-1	I*4	Width of each latitude row in degrees (x 10^5), starting with the southernmost row This is dimensioned by the number of latitude rows in the database
next NROWS*4	I*4	The number of longitude divisions in each latitude row, starting with the southernmost row This is dimensioned by the number of latitude rows in the database
next 4 bytes	I*4	Logical record number in database at which directory starts
next 4 bytes	I*4	Unused
next 4 bytes	I*4	Maximum latitude of data (may not be equal to value in bytes 5-8 if data is subarea of the total bin configuration area) in deg N (x 10^6)
next 4 bytes	I*4	Minimum longitude of data (may not be equal to value in bytes 5-8 if data is subarea of the total bin configuration area) in deg E (x 10^6)

Bytes	FORTRAN Variable Type	Description
next 4 bytes	I*4	Minimum latitude of database (may not be equal to value in bytes 13-16 if data is subarea of the total bin configuration area) in deg E (x 10^6)
next 4 bytes	I*4	Maximum longitude of database (may not be equal to value in bytes 17-20 if data is subarea of the total bin configuration area) in deg E (x 10^6)
next 20 bytes	C*20	Character data description of orbit used in calculation of surface height in database
next 4 bytes	I*4	YYMMDD database beginning time
next 4 bytes	I*4	HHMMSS database beginning time
next 4 bytes	I*4	YYMMDD database ending time
next 4 bytes	I*4	HHMMSS database ending time
next 4 bytes	I*4	Mission word

7.1.4 Mission Status Words for Altimetry Data

Bits	Value	Description
0-22	0	Unused
23	1	Ocean tides removed
	0	Ocean tides not removed
24	1	Slope correction applied
	0	Slope correction not applied
25	1	Orbit adjustment 1 applied
	0	Orbit adjustment 1 not applied
26	1	Solid tides removed
	0	Solid tides not removed
27	1	Retracking correction applied
	0	Retracking correction not applied
28	1	Center of gravity bias applied
	0	Center of gravity bias not applied
29	1	Tropospheric correction applied
	0	Tropospheric correction not applied
30	1	Ionospheric correction applied
	0	Ionospheric correction not applied

Bits	Value	Description
31	1	Time bias applied
	0	Time bias not applied

7.1.5 Georeferenced Database

Subgroup 1: One logical record for each bin containing data

Bytes	FORTRAN Variable Type	Description
1-4	I*4	Indicates the number of logical records that follow which are located in the bin
5-32		Unused

Subgroup 2: One logical record for each data point in the bin

Bytes	FORTRAN Variable Type	Description
1-4	I*4	North latitude of datum point in degrees (x 10^6)
5-8	I*4	East longitude of datum point in degrees (x 10^6)
9-12	I*4	Surface height relative to the ellipsoid in centimeters
13-16	I*4	Height sigma, arbitrary value of 1.0 meter used (x 10^5)
17-24		Reserved for future use
25-28	I*4	Rev number
29-32	I*4	Slope correction in meters (x 10^5) <(-999999999 if unavailable)

Subgroups 1 and 2 are repeated for as many bins with data.

7.1.6 Georeferenced Database Bin Directory

Bytes	FORTRAN Variable Type	Description
1-4	I*4	Record number at which data for bin 1 starts
5-8	I*4	Record number at which data for bin 2 starts
9-12	I*4	Record number at which data for bin 3 starts
13-16	I*4	Record number at which data for bin 4 starts
17-20	I*4	Record number at which data for bin 5 starts
21-24	I*4	Record number at which data for bin 6 starts
25-28	I*4	Record number at which data for bin 7 starts
29-32	I*4	Record number at which data for bin 8 starts

Note: The directory contains as many 32-byte logical records as necessary to designate the record locations of all bins. Any geographical bin for which there is no data has a 0 put in as the starting record number.

8 APPENDIX B – RADAR ALTIMETER

8.1 Summary

A radar altimeter, which is carried aboard satellites, collects elevation signals from land and ocean surfaces. These data are used to determine topographical features.

8.2 Sensor/Instrument Name

Radar altimeter

8.2.1 Sensor/Instrument Name

Radar altimeter

8.2.2 Sensor/Instrument Introduction

The radar altimeter is an instrument on a satellite that measures the distance from the satellite to the Earth's surface using a radar signal. The instrument transmits an electronic pulse in the microwave frequency to the Earth's surface. The microwave pulse reflects off the surface and returns to the sensor. Altitude is determined from the pulse travel time (from transmit to receive) and from the waveform of the returned pulse.

8.2.3 Sensor/Instrument Mission Objectives

The radar altimeter measures the altitude of the Earth's surface to determine ice sheet topography and small-scale ocean roughness.

8.2.4 Key Variables

Satellite orbit, tropospheric/ionospheric signals, and geoid model.

8.2.5 Scanning or Data Collection Concept/Principles of Operation

The radar altimeter sends electromagnetic pulses at a microwave frequency to a land or ocean surface, then detects the reflected signals. The waveform data are then transmitted to a ground receiving station.

8.3 Sensor/Instrument Layout, Design, and Measurement Geometry

8.4 Sensor Description

The two major subsystems of the radar altimeter are: A peak power (RF) section and a signal processor.

*GEOSAT radar altimeter

Transmitter:

- Type -- traveling wave tube
- Peak power (RF) -- 20 Watts (minimum)
- Power consumption -- 70 Watts

Receiver:

- Type -- Dual conversion (500Mhz, 0h)
- Automatic gain control -- 0 to 63 decibels (1-dec steps)

Antenna:

- Type -- 1-m parabolic
- Gain -- >37.6 decibels
- Beamwidth -- 2.0 degrees

Weight:

- Signal processor -- 47 pounds
- RF Section -- 144 pounds

Envelope (in):

- RF section -- 41.25 (diameter) X 11.5 (height) = 15,369 cubic inches (-antenna)
- Antenna -- 41.25 (diameter) X 19.125 (height) = 25,559 cubic inches (incl. feed)
- Signal processor -- 20 (length) X 13.5 (width) X 10 (height) = 2700 cubic inches

*The GEOSAT and Seasat radar altimeters share mechanical, thermal, and electrical interface characteristics.

8.4.1 Radar Altimeter Characteristics for Various Satellites

Satellite	Frequency (GHz)	Bandwidth	Wavelength (m)	Range Resolution (m)	Pulse Compression	Wave Height
ERS-1	13.50	400.00	0.02	0.10	8000.00	
ERS-2	13.50		0.02	0.1	58000.00	.13 m
Geos-3	13.90	80.00	0.02	0.50	30.00	±25% (4-10 m)
GEOSAT	13.50	320.00	0.02	0.10	30000.00	±10% (1-20 m)
GEOSAT Follow-On	13.50		0.02	0.018	58000.00	.035 m
Seasat	13.50	320.00	0.02	0.10	1000.00	± 10% (1-20 m)
Skylab	13.90	100.00	0.02	1.00	13.00	1-2 m
TOPEX/Poseidon	5.3&13.6	320.00	.0566*amp;.02205	0.03	58000.00	.13 m

8.5 Calibration

8.5.1 Specifications

The GEOSAT radar altimeter contained an onboard calibration mode that was invoked twice daily to track waveform sample gain and attitude, wave height, automatic gain control, and height.

- For waveform sample gain correction, the onboard tracker operated on a set of 60 waveform samples in the power spectrum outputs of a digital filter bank. Effects, such as in-band ripple and band-edge roll-off of anti-aliasing low-pass filters in the altimeter receiver were removed by individual waveform sample gain correction factors.
- The correction processes of the attitude determination (and related corrections) started with computation of a voltage proportional to attitude (VATT) based on the amplitude of the last eight waveform samples.

9 APPENDIX C – SEASAT PLATFORM

9.1 Summary

During its brief 110-day lifetime, the Seasat-1 spacecraft, launched on June 28, 1978 by NASA's Jet Propulsion Laboratory, collected information on sea-surface winds, sea-surface temperatures, wave heights, internal waves, atmospheric water, sea ice features, ice sheet topography, and ocean topography. This was the first JPL mission to study Earth with the use of imaging radar.

9.2 Source/Platform or Data Collection Environment Overview

9.2.1 Source/Platform or Data Collection Environment Long Name, Source/Platform Acronym

Ocean Dynamics Satellite/Seasat

9.2.2 Source/Platform Introduction

Seasat supported five sensors: ALT (radar altimeter), SMMR (Scanning Multichannel Microwave Radiometer), SAR (Synthetic Aperture Radar), SASS (Seasat-A Scatterometer System), and VIRR (Visible and Infrared Radiometer). Seasat was in a near-circular, polar orbit at an altitude of 805 kilometers and at an inclination of 108 degrees. The satellite orbited the Earth 14 times daily and covered 95 percent of the world's oceans every 36 hours. On October 10, 1978, the satellite suffered a massive short-circuit in its electrical system and stopped functioning.

9.2.3 Source/Platform Program Management

Seasat was a NASA/Jet Propulsion Laboratory Earth observation mission.

Seasat's five onboard sensors were individually managed by the following centers:

- Radar altimeter: Wallops Flight Center;
- Scanning Multichannel Microwave Radiometer (SMMR) and Synthetic Aperture Radar (SAR): Jet Propulsion Laboratory;
- Seasat-A Scatterometer System (SASS): Langley Research Center; and
- Visible and Infrared Radiometer (VIRR): Goddard Space Flight Center.

9.2.4 Source/Platform Mission Objectives

Seasat was specifically designed to study oceanographic phenomena. The mission's purpose was to help determine the requirements for an operational ocean remote sensing satellite system.

9.2.5 Source/Platform Parameters

Seasat was launched on June 26, 1978 from the Vandenberg Air Force Base, California. The Seasat launch vehicle, Atlas-Agena, provided attitude control, power, guidance, telemetry, and command functions. A sensor module was attached to the Agena and carried the payload of five microwave instruments and their antennas. Together, the two modules measured 21 meters long and 1.5 meters in diameter. Once in orbit and after burnout of the Agena stage, the Seasat spacecraft weighed 2300 kilograms.

9.2.6 Coverage Information

Seasat was in a near-circular, polar orbit, at an altitude of 805 kilograms and an inclination of 108 degrees. The satellite completed 14 Earth orbits per day.

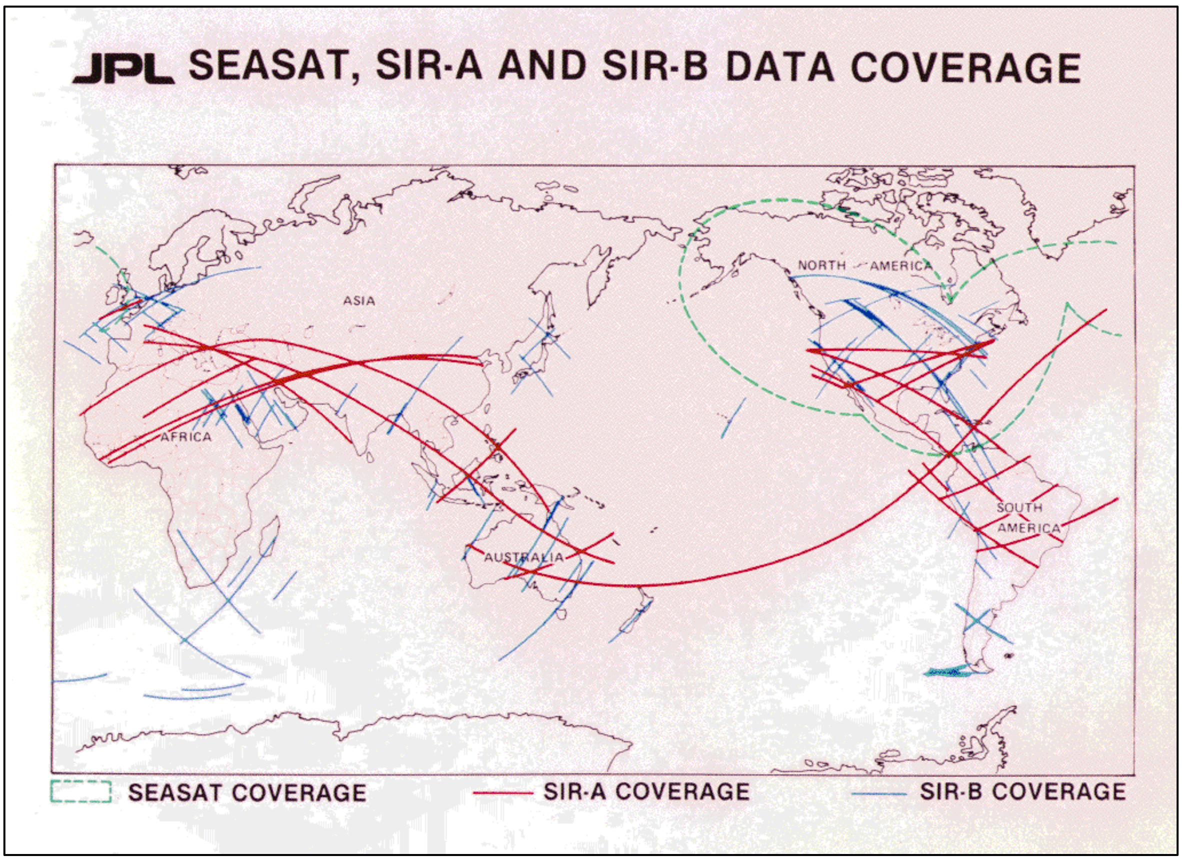

Figure C - 1. JPL Seasat Coverage Map

9.2.7 Attitude Characteristics

Atlas-Agena, the Seasat launch vehicle, provided attitude control for the satellite. In orbit, Seasat appeared to stand on end, with the sensor and communications antennas pointing toward Earth and the Agena rocket nozzle and solar panels pointing toward space. Seasat was stabilized by a momentum wheel/horizon sensing system.

9.2.8 List of Sensors/Instruments

9.2.8.1 ALT (radar altimeter)

For the Seasat mission, the radar altimeter determined ocean topography with height measurements to within 10 centimeters. The Seasat altimeter collected 90 days of data, specifically acquiring more than 600 thousand useful altimeter observations of the Greenland and Antarctic ice sheets. Parameters, which included satellite height, waveform data, wave height, and automatic gain control were telemetered to the ground processing system at a 10/second rate. The Seasat altimeter carrier frequency was 13.5 GHz and operated in chirp pulse mode with a 3.2-microsecond uncompressed pulse width and 3.125-nanosecond compressed pulse width. The limited pulse footprint diameter was 1.2 kilometers for calm seas and up to 12 kilometers for rough seas. The data volume for this product is approximately 20.3 gigabytes.

9.2.8.2 SAR (Synthetic Aperture Radar)

The SAR onboard Seasat monitored the global surface wave field and polar sea ice conditions, providing information on ice caps, snow coverage, and coastal regions. The experiment operated at L-band (1.275 GHz) with a 100-km swath and provided 25-m vertical resolution. About 42 hours of data were recorded.

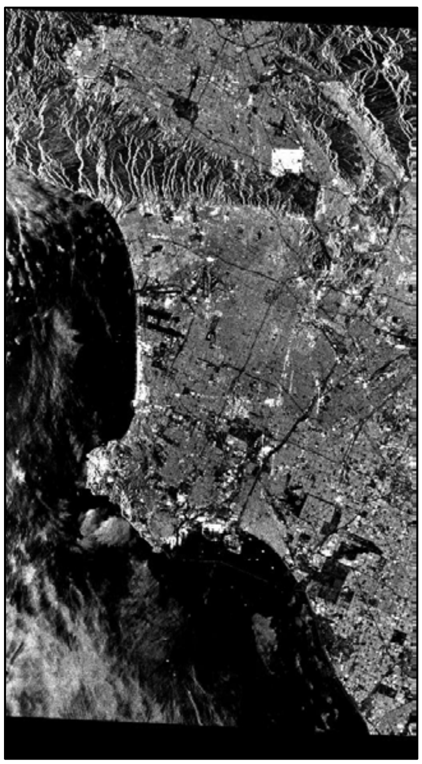

Figure C - 2. Seasat SAR image of Los Angeles, CA.

9.2.8.3 SASS (Seasat-A Scatterometer System)

SASS measured wind speed and direction on the Seasat mission. Global measurements of the surface wind velocity over the seas were obtained from SASS at least once every 36 hours; the high latitudes were more frequently covered. SASS collected data in two 500-km swaths. Pulse duration was 4.8 milliseconds, and the data stream was updated every 1.89 seconds. Resolution was 50 kilometers and the grid spacing of the output data product, 100 kilometers.

9.2.8.4 SMMR (Scanning Multichannel Microwave Radiometer)

The SMMR instrument acquired sea surface temperatures for the Seasat mission. SMMR measures dual polarized microwave radiation from the earth's surface and atmosphere in five frequencies: 6.63, 10.69, 18.0, 21.0, and 37.0 Gigahertz. Seasat data from SMMR were obtained in swath widths of 600 kilometers. Output was in the form of calibrated sensor data records. Data product volume is 45.7 gigabytes. For Seasat, coverage was within a +77/-72-degree latitude from July 7 to August 17, 1978, with a ground track equatorial spacing of 165 kilometers. From August 18 to October 10, 1978, the ground track equatorial spacing was 900 kilometers. From July 7 to August 26, 1978, the ground track was repeated every 17 days; from August 27 to October 10, 1978, once every three days. The temporal resolution was 10/second.

9.2.8.5 VIRR (Visible and Infrared Radiometer)

The VIRR identified cloud, land, and water features on the Seasat mission. It operated in the visible band (0.49-0.94 micrometers) and in the infrared band (10.5-12.5 micrometers). The swath of the VIRR is approximately 2280 kilometers wide, centered on nadir. Spatial coverage for the mission was global, and temporal coverage spanned July 4, 1978 to August 27, 1978. The normal scan period was 1.25 seconds, and 48 scans were completed per minute.

9.3 Ground Segment Information

9.3.1 Data Acquisition and Processing

Data were transmitted from the satellite in three separate streams: A 25-kbps real-time stream containing instrument data from ALT, SASS, SMMR, and VIRR and all engineering subsystem data, an 800-kbps playback stream of recorded real-time data, and a 20-MHz analog SAR instrument data stream.

Radar altimeter data, in the form of Geophysical Data Records (GDRs) and Sensor Data Records (SDRs) were produced by NASA's Seasat project at the Jet Propulsion Laboratory.

SAR data from Seasat were acquired digitally, and most of the data were optically processed into survey data products, available on 70-mm film. The Seasat 100-km swath data were processed into four 25-km wide products at JPL. A small percentage of the data were digitally processed. These products contain the complete 100-km wide swath of data. (JPL's Seasat digital processor operated from 1978 to 1982, converting approximately 10 percent of the total Seasat data set to precision data. JPL currently has no capability to process additional SAR data from Seasat.)

SASS data were produced by the NASA Goddard Space Flight Center, which processed the Wentz 100-km by 100-km scatterometer data using an objective ambiguity removal scheme.

SMMR output from Seasat is in the form of calibrated SDRs. Data product volume is 45.7 gigabytes. SMMR data are archived at JPL.

9.4 References

Belgian Federal Office for Scientific, Technical and Cultural Affairs. 1996. Seasat - Programme. The TELSAT Guide for Satellite Imagery, Programmes, Internet Page. http://www.belspo.be/telsat/seasat/sepg_001.htm.

Born, G. H., J. A. Dunne, and D. B. Lamb. 1979. Reports: Seasat mission overview. Science 204: 1405-6.

CEOS-IDN. 1997. Seasat-A scatterometer system. Internet page. http://www.neonet.nl/ceos-idn/sensors/SASS.html.

Martin, Thomas V., H. Jay Zwally, Anita C. Brenner, and Robert A. Bindschadler. 1983. Analysis and retracking of continental ice sheet radar altimeter waveforms. Journal of Geophysical Research 88 (C3): 1608-16.

NASA. Seasat-A. NASA Space Link, Internet page. http://spacelink.nasa.gov/NASA.Projects/Satellites/Seasat-A.

NASA/Jet Propulsion Laboratory. Seasat. Mission and Spacecraft Library, Internet page. http://spacepc.jpl.nasa.gov/msl/QuickLooks/seasatQL.html.

NASA/Jet Propulsion Laboratory. Seasat. Mission Thumbnail, Internet page. http://www.jpl.nasa.gov/mip/seasat.html.

NASA/Jet Propulsion Laboratory. Seasat 1978. JPL Imaging Radar, Internet page. http://southport.jpl.nasa.gov/gif/smap.gif.

NASA/Jet Propulsion Laboratory. Seasat altimeter geophysical record. Digital data available from http://podaac.jpl.nasa.gov. Jet Propulsion Laboratory (JPL) Physical Oceanography Distributed Active Archive Center (PO.DAAC), NASA, California Institute of Technology, Pasadena, CA.

NASA/Jet Propulsion Laboratory. Seasat (ocean monitor). Internet page. http://www.jpl.nasa.gov/mip/info/seasat.txt.

Zwally, H. Jay, Anita C. Brenner, Judith A. Major, Thomas V. Martin, and Robert A. Bindschadler. 1990. Satellite radar altimetry over ice. NASA Reference Publication 1233(1): 1.

10 APPENDIX D – GEOSAT PLATFORM

10.1 Summary

The U.S. Navy launched GEOSAT, or the Geodetic Satellite, in 1985. GEOSAT was designed to collect closely spaced tracks for precise mapping of the Earth's geoid over the ocean. GEOSAT provided global wind speed and significant wave height derived from radar altimeter, collected during the Geodetic Mission (GM), March 1985-September 1986 and the Exact Repeat Mission (ERM), November 1986-December 1989. The GEOSAT mission concluded in 1990.

10.2 Source/Platform or Data Collection Environment Overview

10.2.1 Source/Platform or Data Collection Environment Long Name, Source/Platform Acronym

Geodetic Satellite/GEOSAT

10.2.2 Source/Platform Introduction

GEOSAT supported a radar altimeter that collected elevation data from the Earth's ocean surfaces, as well as associated satellite tracking beacons and a C-band transponder system. It was placed in a circular orbit of 800 kilometers, with an inclination of 108 degrees. The orbit had a repeat period of 72 days for the GM and 17 days for the ERM. The sampling period was every second, which equates to every 7 kilometers along the ground track.

10.2.3 Source/Platform Program Management

The GEOSAT mission was originally managed by the Office of Naval Research, then was transferred to the Naval Electronics Systems Command (now the Space and Naval Warfare Systems Command). GEOSAT's contractor, the Applied Physics Laboratory, performed spacecraft command and control operations and collected satellite data.

10.2.4 Source/Platform Mission Objectives

GEOSAT, launched in 1985, exceeded its three-year mission, continuing to collect data through 1989. Its mission was to obtain a high-resolution image of the marine geoid. GEOSAT provided global wind speed and significant wave height derived from radar altimeter, collected during the GM and the ERM.

10.2.5 Source/Platform Parameters

GEOSAT was launched on March 12, 1985 from Vandenberg Air Force Base, California. Its mass: 635 kilograms; and principal components: 20-ft scissors boom with 100-lb end mass, redundant momentum wheels for roll and yaw stiffness, and pitch and roll attitude control thrusters.

GEOSAT contained a cold gas subsystem, which used 84 pounds of Freon 14R as a propellant. The fuel was stored in six tanks, each of which was initially pressurized to 2700 pounds per square inch. This was reduced to 15 pounds per square inch by pressure regulators.

10.2.6 Coverage Information

GEOSAT was placed in a circular orbit of 800 kilometers, with an inclination of 108 degrees. The orbit had a repeat period of 72 days for the GM and 17 days for the ERM. The sampling period was every second, which equates to every 7 kilometers along the ground track.

10.2.7 Attitude Characteristics

GEOSAT was equipped with one thruster pointing forward and one pointing aft for velocity control. Four additional thrusters produced both positive and negative pitch and roll torques. The system could provide a velocity change of 77 feet per second.

Attitude capture and stabilization involved a sequence of operations and maneuvers. First, a double yo-yo system was used to despin the spacecraft from the 90 revolutions per minute that resulted from spin stabilization of the launch-vehicle orbit-insertion stage. This involved the use of two pairs of yo-yo despin cables for both system despin and solar panel restraint during launch.

Next, three-axis local-vertical stabilization was achieved with this attitude capture scenario:

- scissors boom was extended 1 meter to enable the magnetically anchored eddy current damper to remove residual spacecraft motion;
- both momentum wheels were released and one wheel energized to full speed;
- momentum vector (the pitch axis) was maneuvered to the orbit normal by using the roll attitude-control thrusters;
- the scissors boom was extended to full length in order to achieve gravity-gradient capture; and
- attitude thrusters and passive damper were used to damp residual motions, to achieve less than 1-degree of nadir pointing.

10.2.8 Data Collection System

The GEOSAT subsystem received the digital data stream from the radar altimeter at 8.5 kilobits per second and combined it with housekeeping data at 1.5 kilobits per second collected from the spacecraft subsystems. The data are formatted into a single time-annotated frame and transmitted to the ground station via the S-band link.

10.2.9 Communication Links

Spacecraft command was achieved through a VHF uplink from the APL ground station. The microprocessor-based command subsystem received, verified, and executed commands for spacecraft configuration control on a real-time or delayed basis. Commands consisted of relay commands, pulse commands, and data commands.

S-band transmitter and tape recorder operations were managed through commands stored for delayed execution. These commands were transmitted to GEOSAT in one command block during a pass. Following this transmission, the command subsystem dumped the memory into the downlinked telemetry stream, where it was compared to a ground image of the intended command sequence.

The GEOSAT telemetry subsystem transferred consolidated radar altimeter information and spacecraft subsystem performance data to the ground station. The subsystem consisted of a redundant telemetry processor, two S-band transmitters, two tape recorders, and two encryption units. The telemetry processor's digital circuitry employed complementary metal oxide semiconductor chips.

10.3 Ground Segment Information

10.3.1 Tracking and Control

APL's Satellite Tracking Facility acquired, preprocessed, and distributed the data from GEOSAT, as well as commanded and controlled the satellite and monitored its performance. For this mission, this ground station was in operation 24 hour per day.

10.3.2 Data Acquisition and Processing

Two Odetics (5 X 108) dual-track high-density tape recorders independently recorded GEOSAT's 10.205-kilobit-per-second telemetry stream and replayed it at 844.5 kilobits per second for transmission to the ground. Tape recorder management was accomplished through spacecraft-delayed commands.

The ground station acquired altimetry data from the satellite during GEOSAT's cluster passes, which occurred about every 12 hours. During the recorders' playback (dump) pass, GEOSAT replayed data from its onboard tape recorder using the 2207.5-Mhz S-band downlink. Each recorder contained 450 megabits of encrypted data accumulated at 10.205 kilobits per second during the period since the last data dump. Playback at the 833.4-kilobit-per-second downlink dump rate required about 10 minutes.

The encrypted and unencrypted data streams were separated by filters, then bit-synchronized and recorded on separate tracks of an analog tape. Time was also recorded on the tape, which is useful for archiving purposes. These tapes were to be stored at APL for an extended time after the GEOSAT mission.

10.3.3 Latitude Crossing Times

Two to three satellite passes ("a cluster"), which were about 100 minutes apart, occurred in view of the ground station about every 12 hours. These passes occurred at various hours of the day over the mission's life and were the only opportunities for the ground station to acquire altimetry data, transmit commands, and monitor real-time telemetry.

10.4 References

Committee on Earth Observing Satellites International Directory Network. Geodetic satellite. Internet page. http://neonet.nlr.nl/ceos-idn/sources/GEOSAT.html.

Frain, William E., Michael H. Barbagallo, and Raymond J. Harvey. 1987. The design and operation of Geosat. Johns Hopkins APL Technical Digest 8(2): 184-9.

Jensen, Jack J., and Francis R. Wooldridge. 1987. The Navy Geosat mission: An introduction. Johns Hopkins Technical Digest 8(2): 169.

Jones, Samuel C., Barry E. Tossman, and Leo M. Dubois. 1987. The Geosat ground station. Johns Hopkins APL Technical Digest 8(2): 190-6.

Petroscan AB. 1997. Altimeter data. Marine Geoid, A Brief Description of Satellite Gravity, Internet page. http://www.petroscan.se/descrpt.html.

NASA/Jet Propulsion Laboratory. Geosat: Geodetic Satellite. Mission and Spacecraft Library, Internet page. http://msl.jpl.nasa.gov/QuickLooks/geosatQL.html.

Paras. Satellite data. Oceanography Group/Database, Internet page. http://www.paras.co.uk/satellit.htm.