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NSWC TR 86-149

DATA PROCESSING SYSTEM SPECIFICATIONS FOR THE GEOSAT SATELLITE RADAR ALTIMETER

BY GLADYS B. WEST
STRATEGIC SYSTEMS DEPARTMENT

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This report provides an overview of the Naval Surface Weapons Center's segment of the GEOSAT satellite project; specifically, it documents the radar altimeter data analysis and reduction system. Through the data channels described, radar altimeter measurements collected aboard GEOSAT are converted into best-estimated along-track heights and vertical deflections.			
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11. THE GEOSAT RADAR ALTIMETER

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FOREWORD

When the GEOSAT satellite was launched on March 12, 1984, it carried onboard a radio altimeter that continuously generated measurements. The Naval Surface Weapons Center (NSWC) was given responsibility for the reduction of this data to best-estimated along-track geoid heights and vertical deflections. *This report covers the analysis of the altimeter data.*

These geodetic results are currently distributed to the Defense Mapping Agency Aerospace Center (DMAAC), St. Louis, Missouri; the Naval Oceanographic Office (NAVOCEANO), Bay St. Louis, Mississippi; and other specified users for geodetic and oceanographic analyses.

This technical report was reviewed and approved by Ralph L. Kulp, Jr., Head, Space and Ocean Geodesy Branch, and by Carlton W. Duke Jr., Head, Space and Surface Systems Division.

Approved by:

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1.0 INTRODUCTION

The GEOSAT mission is comprised of a primary and secondary mission. The primary mission meets the geodesy requirement to provide the Department of the Navy (DON) with a global data base of 10 cm precision radar altimeter measurements. This data will allow for improvements in the gravitational models required by advanced Submarine Launched Ballistic Missile (SLBM) systems. The secondary mission meets the oceanography requirement to provide the DON with altimeter data for the GEOSAT Ocean Applications Program (GOAP). Several agencies are responsible for the GEOSAT mission.

The Naval Surface Weapons Center (NSWC) has as a responsibility the development of an analysis system for the reduction of radar altimeter measurements to the best-estimated along-track geoid heights and vertical deflections. These geodetic products are to be distributed to the Defense Mapping Agency Aerospace Center (DMAAC), St. Louis, Missouri, the Naval Oceanographic Office (NAVOCEANO), Bay St. Louis, Mississippi, and other specified users.

2.0 GEOSAT PROJECT DATA FLOW

Figure 1 illustrates the flow of data through the GEOSAT project, showing the source, data file type, and user(s) of the major data files. The Johns Hopkins University Applied Physics Laboratory (JHU/APL) is responsible for implementation of the altimeter, spacecraft, control center and ground station. Functions that are performed at the Control Center include health monitoring, command generation, and data management. Data collected by the altimeter and other spacecraft functions are stored on tape recorders and dumped to the APL ground station every 12 hr on the S-band downlink to the station's 60-ft dish. In addition to controlling the satellite, APL archives the raw data, uses station alerts from Defense Mapping Agency Hydrographic/Topographic Center (DMAHTC) and transmits preprocessed data to NSWC, the Naval Research Laboratory (NRL), and the Naval Research and Development Activity (NORDA). DMAHTC employs the standard DMA Doppler-combined Tranet/Magnavox 1502 D.S. tracking station network in collecting Doppler Data.

2.1 SENSOR DATA RECORD

The Sensor Data Record¹ (SDR) is the data interface between APL and NSWC. It consists of radar altimeter data with instrument and spacecraft system errors identified and quantified. NSWC began receiving SDR tapes via messenger on a regular schedule after the satellite was stabilized and the APL data processing procedures became operational. The SDR is the primary input to the radar altimeter data processing system at NSWC.

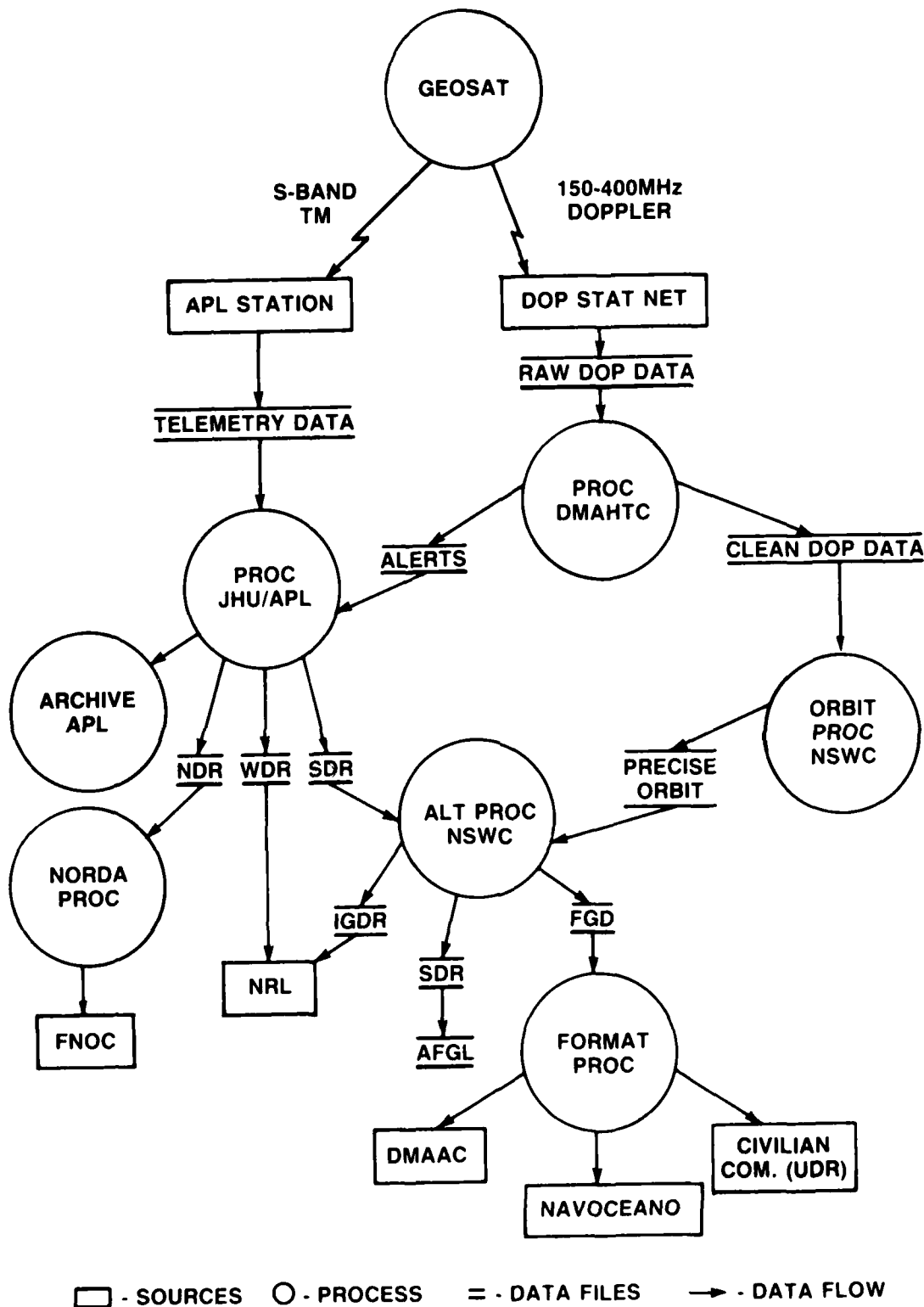


FIGURE 1. GEOSAT PROJECT DATA FLOW DIAGRAM

2.2 FILTERED GEOPHYSICAL DATA

Filtered Geophysical Data (FGD) files produced at NSWC are mailed to DMAAC, NAVOCEANO, and other specified users. The FGD consists of best-estimated along-track geoid heights, vertical deflections, sea surface heights, environmental corrections, statistics, and data quality indicators. The format is given in Section 10.3.

2.3 WAVEFORM DATA RECORD

The Waveform Data Record¹ (WDR) tape is the data interface between APL and NRL. It contains waveform samples taken at 10-points/sec (pps) intervals. NRL applies this information in conducting radar altimeter validation studies.

2.4 INTERMEDIATE GEOPHYSICAL DATA RECORD

In addition to the WDR from APL, NSWC sends NRL Intermediate Geophysical Data Record (IGDR) tapes for ocean and land/ice data produced at the 10-pps rate. These tapes, detailed in Section 10.2, are output from the preprocessor program. In addition to the altimeter measurements, the IGDR includes the precise orbit and environmental corrections.

2.5 NAVAL OCEAN RESEARCH AND DEVELOPMENT ACTIVITY DATA RECORD

To satisfy the GOAP requirement, Naval Ocean Research and Development Activity (NORDA)'s Data Record (NDR) is transmitted directly from APL via data line to NORDA, where it is employed for oceanographic studies. At a later point in the mission, the NDR may be transmitted from APL directly to Fleet Numerical Oceanography Center (FNOC), Monterey, California.

2.6 UNCLASSIFIED DATA RECORD

Possible distribution of an Unclassified Data Record (UDR) for civilian use is currently being discussed. The specific content and methods of creating the UDR have not yet been defined.

2.7 DOPPLER DATA RECORD

In addition to its altimeter, the satellite carries a Doppler beacon that transmits data to a worldwide network of Doppler stations. DMAHTC collects and preprocesses (cleans) the data, and then sends it to NSWC for use in generating precise orbits, one of the major inputs into the NSWC altimeter data processing system.

3.0 RADAR ALTIMETER DATA PROCESSING SYSTEM

3.1 GENERAL DESCRIPTION

The radar altimeter data processing system reduces the radar altimeter measurements to best-estimated along-track geoid heights and vertical deflections. This is accomplished by

- computing environmental corrections,
- preprocessing altimeter measurements,
- generating sea surface heights,
- computing geodetic position and velocity along track,
- smoothing the raw geoid heights,
- archiving, and
- distributing the final geodetic products to specified DMA users.

In generating the final geodetic products, the processing system uses several input data bases:

- world map coastline coordinates,
- environmental data,
- precise orbit,
- tide amplitudes and phases,
- the satellite revolution (rev) epoch table, and
- the SDR.

Figure 1 shows the data flow for the system and user data interfaces. The environmental corrections generator, preprocessor, segmenter, and smoother comprise the major software components.

3.2 DATA FLOW OF PROCESSING SYSTEM

The data flow diagram for the NSWC altimeter data processing system, Figure 2, shows major components of the NSWC radar altimeter data processing system and data interfaces. The SDR, world map coastline coordinates, precise orbit, tidal constants, satellite rev epoch table, sunspot number, and climatology data comprise the major inputs to the NSWC radar altimeter data processing system. Output files produced by the system are the ocean IGDR, land/ice IGDR, FGD, and plots.

The classified SDRs generated at the JHU/APL are written to tape and transported by messenger to NSWC, White Oak, Maryland, and then to NSWC, Dahlgren, Virginia. The SDR tapes are 9-track (1600 bpi) and data are written in ASCII format. The newly installed CDC/875 computer is used in the reduction of the altimeter measurements to along-track geoid heights and vertical deflections. Remote terminals are available for accessing the CDC/875, a secure computer.

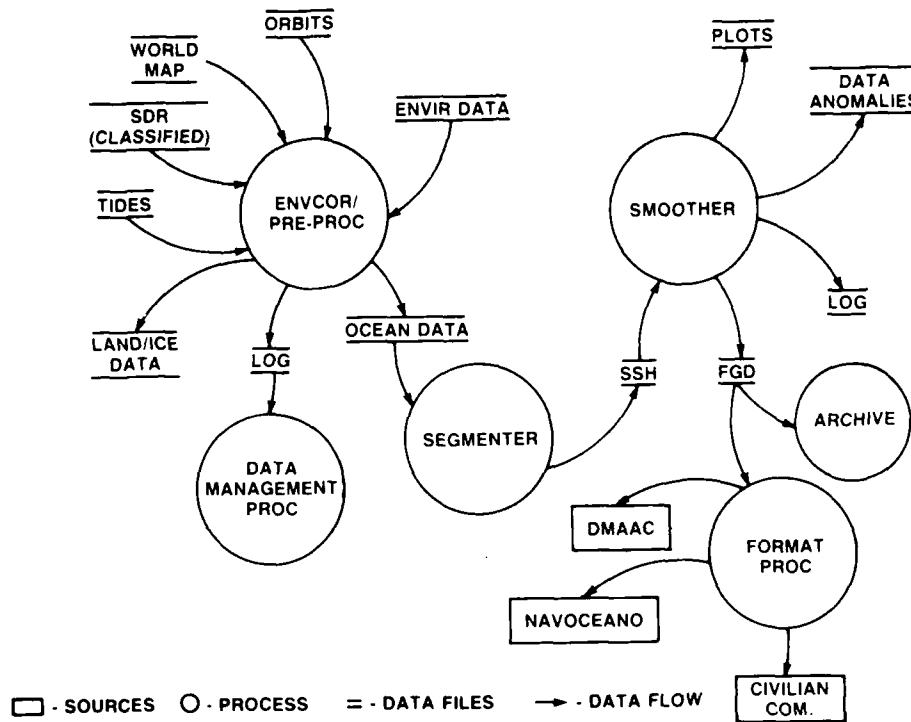


FIGURE 2. NSWC GEOSAT ALTIMETER DATA PROCESSING SYSTEM DATA FLOW

Three world map data bases are available for separating the land and ocean data: Hershey World0 (8000 data points); CIA World1 (60,000 data points); and NAVOCEANO World2 (1,700,000 data points). World2 contains the detail required by the GEOSAT project in the separation of land and ocean altimeter measurements. A masking grid was derived from the World2 data base. It consists of land/ocean latitude and longitude boundaries for determining whether a specific measurement is over land or ocean. The land/ice data tape also contains data that has failed ocean data tests criteria. These data are referred to as "other".

The precise orbits (long arcs) are computed in 2-day time spans using observations from the combined Tranet/Magnavox 1502 D.S. Doppler tracking network. The precise orbits are smoothed at two-day crossovers and stored on the CDC/875 computer as permanent files. The CELEST computer program for orbit computations and file formats are described by O'Toole². The orbit file names have a fixed format: N17YDDD, where N is either "L" or "S", designated long arcs or long arcs smoothed at

two-day crossovers respectively. The GEOSAT satellite identification number is 17; Y is last digit of year, and DDD denotes a 3-digit day number of first day of two-day fit.

The Schwiderski ocean tide model³ requires harmonic tidal constants (amplitudes and phases) along a standard GEOSAT satellite track. The amplitudes and phases of the leading harmonic ocean tidal modes (M2, S2, N2, K2, K1, O1, P1, and Q1 with solid earth tide and loading effects included) are stored as permanent files and used to determine the tidal effects on the altimeter measurements. Other input to the model includes year, day, sec, time interval, total number of points, latitude, longitude, longitude of ascending node, and the equator-crossing time.

The satellite rev epoch table consists of year, day, rev number, longitude of the ascending node, time of the ascending node, an average (over 2-day) period, and an average (over 2-day) shift of the longitude of the node. These values are computed using precise orbits, and are required because of the noncircularity of the GEOSAT orbit. The table entries are given for every 100th rev number.

Temperature, atmospheric pressure, and partial pressure of water vapor are the climatology data fields transmitted daily from FNOC via the Naval Oceanographic Data Distribution System to the NSWC Mohawk data communications computer. These parameters are acquired in two 12-hr periods/day and archived for use in the computation of barotropic, wet tropospheric, and dry tropospheric conditions.^{4,5}

Output files from the data analysis and reduction system include land/ice and ocean IGDRs, FGD, and plots. The land/ice data IGDRs are archived, sent to NRL in Washington, D.C., and applied in-house for topographic analyses. The ocean IGDRs at 2-pps are archived and used as the main input to the segmenter.

System 2000 was initially selected as the data base management system for maintaining an accurate record of the GEOSAT data files and related information. However, after this selection was made, a Relational Information Management (RIM) data base management system became available, a system that better satisfied the project's needs. Input to RIM consists of a Revs Table and a Days Table. The Revs Table is automatically updated with current information from the FGD file, while the Days Table is updated by manually created files. Section 6.0 provides a description of the data base management system elements.

The IGDR, the output from the preprocessor program, becomes input for the segmenter program. The file name formula is XYDDDBP, where X is an O or L that represents ocean data or land/ice data respectively; Y is the year; DDD is the day number; B indicates binary information; and P is a 1 or 2 representing 10- or 2-data pps respectively.

Continuous graphic output makes possible the validation and verification of geodetic products. Optional on-line plotting is available for displaying parameter-versus-time relationships. A parameter may be selected from several contained in the geophysical data, such as significant wave height (SWH), automatic gain control (AGC), altitude, or sea surface height. During production processing, geoid heights and vertical deflections-versus-time are plotted for each rev. Plots may also be viewed on the CRT via Tektronix equipment. Other graphic output can be accessed from a world map computer program called GEOMAP that displays geophysical data on a world map background.⁴ A preprocessor program generates the GEOSAT data file formats that are compatible with those required by GEOMAP. The GEOMAP program was developed for the SEASAT project by Sperry Univac at Dahlgren, Virginia.

The FGD data base is organized sequentially by rev. In addition to the best-estimated along-track geoid heights and vertical deflections, it includes sea surface height, environmental and system corrections, quality flags, and statistics. The FGD file, in binary format, is converted to ASCII format before its distribution to DMAAC, NAVOCEANO, and other specified users. Since requests for

smaller quantities of data are identified by rev, area, or time, an auxiliary computer program was written to extract data from the data base in fulfillment of these needs.

3.3 MAJOR SYSTEM COMPONENTS

3.31 Environmental Corrector

The altimeter measurement is determined by calculating the time it takes to transmit the radar signal from the spacecraft to the ocean surface and to reflect back to the spacecraft. The radar signal will encounter environmental effects during the transit. The measurement also contains errors caused by instrument and spacecraft biases. Corrections for these errors are described in Section 5.32.

Corrections for environmental effects are computed by the Environmental Corrector (ENVCOR), taking as input the precise orbit, sunspot number table, rev epoch table, climatology fields, World2 data base, tide amplitudes and phases, and the SDR header. Output, written to a temporary file, consists of the ionospheric, wet tropospheric, dry tropospheric, barotropic, and tide corrections for data points over the oceans. The corrections are computed for ocean data that exist in the time span specified in the SDR header record. Ocean data points are determined by a land check routine that uses a masking grid generated from the World2 data base coastline coordinates.

Subsatellite position at 1-sec intervals are obtained by an 8-point Lagrangian interpolation in the precise orbit (given at 60-sec intervals). The rev number, time of the ascending node, and longitude of the ascending node are computed for use in the tide correction procedure.

Wet tropospheric, dry tropospheric, and barotropic corrections require surface temperature, atmospheric pressure, and partial pressure of water vapor obtained from the FNOC climatology data base. The environmental corrections file, output from ENVCOR, is input to the preprocessor program.

3.32 Preprocessor

The altimeter measurements as acquired from APL consist of data taken over the earth's surface, including land, water, and ice. Measurements may also include spurious or wild data points. Before the measurements can be put into the form required by the Kalman smoother for reduction to best-estimated along-track geoid heights and vertical deflections (the final NSWC geodetic product), the preprocessor component must perform a number of operations. These major operations performed are computation of the subsatellite position and velocity at measurement time, tagging (and separation) of land/ice and ocean data, correlation of environmental corrections, elimination of spurious data points, aggregation of data points, and separation of data into revs. Input to the preprocessor consists of the SDR, Doppler precise orbit, environmental corrections, rev epoch table, World2 data base coastline coordinates, and tide amplitudes and phases.

Subsatellite position (geodetic latitude and longitude) and velocity at the altimeter measurement time are computed by employing an 8-point Lagrangian interpolation routine. The masking grid referred to in ENVCOR is also employed by the preprocessor in the separation of ocean and land/ice data.

A 10-point sliding linear least-squares fitting procedure eliminates spurious data points (see Section 5.14). The SWH and AGC are similarly processed. The altimeter measurements given at 10-pps are averaged to produce data at 2-pps. The number of points averaged is provided as an input parameter.

Each SDR tape contains 24-hr altimeter data that the preprocessor separates into revs and time-continuous segments. After this point in the system, data are processed according to rev, with the rev number as a primary identifier.

3.33 Sea Surface Height Generator (Segmenter)

The segmenter uses the Doppler precise orbit, altimeter range (height) and subsatellite position to compute the separation of the reference ellipsoid and the geoid. This separation is called the sea surface height. Raymond Manrique of NSWC Dahlgren's Space and Ocean Geodesy Branch prepared the algorithm for computing subsatellite position and sea surface height.⁶ The sea surface heights are corrected for environmental and systematic effects as shown in Section 5.3. Output from the segmenter, the Unfiltered Geophysical Data (UGD) file, is input to the smoother section.

3.34 Kalman Smoother for Sea Surface Heights (Smoother)

The sea surface (raw geoid) heights are reduced to best-estimated along-track geoid heights and vertical deflections by an adaptive nonsteady-state Kalman smoother. This smoother is based upon the third-order Markov process⁷, adapted for the altimeter by Dr. C.J. Cohen and described in West.⁶ An adaptive algorithm by Ugincius⁸ provides improvements to the set of *a priori* smoother parameters; autocorrection distance, geoid height variance, and the noise standard deviation.

The UGD file, input to the smoother, consists of ocean data for one satellite rev, divided into time-continuous segments. Each time-continuous segment is comprised of records, one for each sea surface height value. There is a constant time interval between records. An upper limit of 101 min (period of satellite) or approximately 12,000 records is used to determine computer storage for one time-continuous rev segment. The UGD file contains data at the 2-pps rate during the production mode of operation.

The time-continuous data segments are divided into sections of approximately 150 sec (or 1,000 km); for each section a cubic fit, fit derivative, filter parameters and differences between the raw geoid heights and the corresponding fit values are also computed. These differences, fit values, and derivatives are saved. Data sections that are approximately 1,000 km in length and having approximately the same autocorrelation distance, are grouped together. These are called clusters.

These data clusters are input to the Kalman smoothing procedure, that filters both forward and backward. For each raw geoid height value in a cluster, a smoothed (or best-estimated) geoid height value and a vertical deflection value are computed. Any dubbed-in data is de-weighted by setting the reciprocal of the observation error equal to zero.

The FGD file is the primary output from the smoother program and includes the best-estimated along-track geoid heights and vertical deflections. A detailed description of the FGD file is given in Section 10.3.

3.35 List and Plot Programs

The list and plot programs are controlled by LPGEO, a procedure that produces a menu. From this menu, list and plot options can be selected. The list programs have several options available for obtaining printed output from SDR, IGDR, and FGD files.

SDR List Programs Options

1. List the entire SDR file or a subset of the file.
2. Send output to the printer, laser, or microfiche.

3. Print subset of file using a start and stop frame count.
4. List all parameters in a data record or a predefined subset of the parameters in a data record.

Options for the IGDR List Programs Printout

1. Print output data on the printer or laser.
2. Print all parameters in the data record or a predefined subset of the parameters.
3. Print the entire data file or data identified by rev number, time, or area.

The FGD list programs have as input "packed" and "unpacked" data files. Unpacked files have one parameter per computer word. In order to conserve computer storage, these files are used to generate "packed" files that contain, where possible, several parameters per computer word.

The programs give printed output from the FGD files.

Printed Options from the FGD Files

1. Print all parameters in a record or a predefined subset of parameters.
2. Print entire rev of data, or a specified time span, or data through a specified area.
3. Print every nth data record.
4. Print output on printer, laser, or CRT (remote terminal screen).

The SDR plotting programs use the major and minor frame counts (computes corresponding times) as points of reference for plotted output. Plots may be generated for all or any of the following: SWH, altimeter height, and AGC.

SDR Plotting Program Options

1. Plot entire SDR file or a subset of the file. If subset, specify "start major and minor frame counts" and "stop major and minor frame counts".
2. Plot all data on one plot or a specified data span (given in sec) per plot.
3. Plot 1, 2, 5, or 10-pps data files.
4. Plot altimeter height, SWH, and/or AGC.

The IGDR plotting programs provide optional plots for 11 parameters. They are altimeter height, reference ellipsoid height, SWH, AGC, sea surface height, ionospheric correction, dry tropospheric correction, wet tropospheric correction, barotropic correction, tide correction, and altimeter height

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and reference ellipsoid height on same plot. The entire binary IGDR file, or one rev from the binary IGDR file may be plotted. The details of these two options are as follows.

IGDR Plotting Program Options

1. Plot 1 rev of binary IGDR File
 - Plot whole rev or 1 time interval of rev (if interval, give start and end times).
 - Select parameters to be plotted.
 - Plot whole rev on one plot or a specified number of sec per plot.
 - Plot 1 or 2 pps from a 2 pps IGDR file.
 - Plot 1, 2, 5, or 10 pps from a 10 pps IGDR file.
2. Plot entire binary IGDR file (batch) laser plotter.
 - Select parameter(s) to be plotted. The list of 11 parameters are given above.
 - Plot 1 rev/frame or a specified number of sec per frame.
 - Plot from a 2 or 10 pps IGDR file.
 - Plot 1 pps, or 2 pps from a 2 pps IGDR file.
 - Plot 1, 2, 5, or 10 pps from a 10 pps IGDR file.
3. Plot 1 FGD file (batch/interactive)
 - Output plots to laser or CRT.
 - Plot entire rev on 1 frame or a specified number of sec/frame
 - Give start and end sec if a time interval has been selected.
 - Select plot parameter(s), geoid height; vertical deflection, geoid height and corrected sea surface height; and geoid height and sea surface.
4. Plot many FGD file (batch/interactive)
 - Select output devices (fiche, laser, or CRT)
 - Plot entire rev on 1 frame or a specified time span on each frame.
 - Select parameter(s): geoid height, vertical deflection, geoid height and corrected sea surface height, or geoid height and uncorrected sea surface

4.0 PRECISE DOPPLER ORBIT

NSWC's GEOSAT effort is divided into three major tasks that are performed in parallel: the precise Doppler orbit computation; altimeter data analysis and reduction; and calibration and validation of the geodetic products. This section describes briefly the precise Doppler orbit computation.

The precise orbits are computed from observations collected by a worldwide network of Tranet/Magnavox 1502 D.S. Doppler tracking stations directed by DMAHTC. DMAHTC collects and preprocesses Doppler data and sends "clean" observations to NSWC. The orbits are generated for 2-day time spans by the CELEST orbit computation program, and stored as permanent files for use with the altimeter measurements. The orbit computation procedures and algorithms are described in Reference 2.

5.0 ALGORITHMS AND PROCEDURES

5.1 PREFILTERING

Before they can be reduced to best-estimate along-track geoid heights and vertical deflections, the altimeter heights must be prefiltered. Prefiltering entails the separation of land/ocean data and the elimination of incorrect (spurious) data that may be caused by telemetry bit errors, land data, ice data, and/or environmental effects. The procedure for prefiltering is outlined as follows.

1. Computation of parameters required for prefiltering, such as geodetic latitude and longitude, satellite rev number, longitude of the ascending node of current rev and next rev, and time of the ascending node.
2. Separation of land and ocean data.
3. Boundary value tests for altimeter height, SWH, and AGC.
4. Boundary value tests for SDR sigma height, SWH, and AGC.
5. Missing data test.
6. Linear least-squares fit to height, SWH, and AGC.
7. Sea surface height boundary test (segmenter).
8. Vertical deflection boundary test (after smoother).
9. Identification of time-continuous data segments.

5.1.1 Geodetic Latitude and Longitude

See Section 5.2.

5.1.2 Revolution Number

Data associated with a satellite revolution around the earth is identified by rev number, beginning with the number 1, increasing in increments of one until the end of the mission. One of the inputs to the data processing system is a rev table or file that is maintained and updated with epochs of known rev numbers, longitude of ascending node, period of satellite, and shift of longitude of the ascending node associated with each epoch time.

Procedure: Read the rev file and find the last epoch time recorded prior to the time of interest and compute r_n , the rev number of interest.

Input:

r_e = rev number at epoch

P_e = period of the satellite in sec at epoch

Δt = difference between current time and epoch (sec)

Computation: Calculate the new rev number, r_n .

$$r_n = r_e + \frac{\Delta t}{P_e}$$

5.13 Longitude and Time of the Ascending Node

The longitude and time of the ascending node are computed using inputs from the rev epoch table (Section 5.1.2). The algorithms are indicated below.

Procedure:

Values in the rev epoch table corresponding to the last epoch time recorded prior to the time of interest are used in the computation of the longitude and time of the ascending node.

Input:

r_e = rev number at epoch

r_n = new rev number

$\Delta\lambda_n$ = shift in longitude of the ascending node, λ_n , at epoch in deg

λ_{ne} = λ_n at epoch in deg

T_e = time of epoch in sec

P_e = period of epoch in sec

Computation: Calculate longitude of the ascending node, λ_n , for rev, r_n .

$$\lambda_n = A_1 \cdot (A_1/A_2) A_2$$

where

$$A_1 = \lambda_{ne} + \Delta\lambda_n(r_n - r_e)$$

$$A_2 = 360 \text{ deg}$$

Computation: Calculate time of the ascending node, T_{λ_n} .

$$T_{\lambda_n} = A_1 - (A_1/A_2) A_2$$

where

$$A_1 = T_e + (r_n - r_e) P_e$$

$$A_2 = 86,400 \text{ sec}$$

5.14 Data Editing

Data editing is performed to eliminate spurious data points caused by such factors as bit errors, system problems, land/ice contamination, and environmental conditions. Data editing consists of a series of tests and a linear least-squares fitting procedure. The tests are based on information provided on the SDR and experience gained from analysis of altimeter data from the GEOS-3 and SEASAT satellites. The boundary values of the tests are input and were determined during the initial calibration and evaluation phase.

The altimeter has several modes of operations, shown on page 90 of the ICD document.¹ Track 1, 2, 3, or 4 are the operational modes of interest for NSWC's altimeter data processing system. Data acquired during any other mode is automatically written to the land/ice data file. Data collected while the altimeter is in Tracks 1, 2, 3, or 4 are processed as follows.

1. Separation of Land and Ocean Data Test -- See Section 5.15

2. Radar Altimeter Height (H) Boundary Test

$$H_{\min} < H(n) > H_{\max}$$

where $H(n)$ are the measurements given at the 10 pps rate in the SDR data records, words 5-14, and H_{\min} and H_{\max} are the minimum and maximum radar altimeter heights expected. The minimum and maximum heights are input values determined from orbit predictions. Upper and lower limits for the altimeter heights are also given in the SDR header record. If the height is out of range, a flag is set. This flag is used in the linear least-squares fitting procedure for dubbing purposes and for determining whether data belong on the ocean or the land/ice/other data file.

3. The AGC Boundary Test

$$AGC_{\min} < AGC(n) > AGC_{\max}$$

$AGC(n)$ is given in the SDR data records, words 30-39, at the 10 pps rate and AGC_{\min} and AGC_{\max} are input values determined during the validation and calibration phase. If the AGC is out of bounds, a flag is set. This flag is used during the linear least-squares fitting procedure for dubbing purposes and for determining if data point is acceptable.

4. The SWH Boundary Test

$$SWH_{\min} < SWH(n) > SWH_{\max}$$

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SWH(n) is given in the SDR data records, words 18-27, at the 10 pps data rate and SWH_{min} and SWH_{max} are values determined during the calibration and validation phase. If SWH is out of bounds, a flag is set. This flag is used during the linear least-squares fitting procedure for dubbing, and for determining whether the data point is acceptable.

5. Sigma height, Sigma SWH, and Sigma AGC Boundary Value Test

The sigma height, sigma SWH, and sigma AGC values are tested in a manner similar to height, AGC, and SWH boundary value tests.

6. Mode Word Test

The SDR data record contains a mode word that describes the operational status of the altimeter. The mode word consists of three status/mode sections of 10 bits each. Status/mode section #1 is examined for the tracking status. Data are accepted as good ocean data if the altimeter is in Track 1, 2, 3, or 4; otherwise, data is written to the land/ice/other file. Flags in status/mode word section #3 are also examined for tracking information. The following flags must have the indicated values: gate index equals 1, 2, 3, 4, or 5; ACQ, ACQTC, attitude, DHa, and LMax are equal to zero; and the detect flag is equal to 1. These flags verify the quality of the ocean data.

7. Missing Data Test

Information on the SDR sequenced by major and minor frame count and is written in records that contain 10 minor frames each. Although the data is in sequence, complete records or data points within a record could be missing. Records are missing when there is a gap in the frame count; data points are missing when the height equals zero, AGC equals zero, or SWH equals zero and the SWH "reasonableness flag" is set. SWH may have zero as a valid value; therefore, the "reasonableness flag" must be examined to verify that the SWH value is not valid.

8. Identification of Time-Continuous Data Segments

During the data editing process, the altimeter data is divided into time-continuous segments, as required by the Kalman smoother. If any of the following conditions is found to exist, end of segment and begin new segment flags are set.

- Data over land/ice encountered.
 - AGC has an invalid value and land/ice exist in the surrounding records.
 - AGC has an invalid value and data is from an ice area. The bounds of the ice areas are input to the procedure since they change with the seasons.
- Invalid mode word
- Sigma height, sigma SWH, and sigma AGC from SDR are out of bounds
- Data are missing between records
- A combination of the following conditions exists for a specified number of consecutive data points.

Invalid AGC and data is not land/ice data

Invalid altimeter height

· Missing data within a record

9. Linear Least-Squares Fitting Procedure

A linear least-squares fitting procedure eliminates spurious data points.

Procedure:

A straight line is fitted to a maximum of 30 consecutive heights, and heights greater than "sigma x a multiplier" from the straight line are replaced with values from the line. The process is repeated until all heights are within the tolerance or a maximum number of iterations is reached. Sigma is computed for each fit and used with a multiplier obtained from input. Values tagged prior to the fit are not used in the fit.

The SWH and AGC are processed in a similar manner.

Input:

f_j = values to be fit ($1 \leq j \leq m$)

σ = Sigma multiplier

m = number of values to be fit

Computation:

Fit a straight line to the data points f_j at x_j ($1 \leq j \leq m$) as given by the equations below. Data points are given at a constant interval, but some points can be tagged.

$$Y(x_j) = C_0 + C_1 x_j \quad (1)$$

$$A(m) = \sum_{j=1}^m j \quad (2)$$

$$B(m) = \sum_{j=1}^m j^2 \quad (3)$$

$$F = m B(m) - A^2(m) \quad (4)$$

$$C_0 = \left\{ B(m) \sum_{j=1}^m f_j - A(m) \sum_{j=1}^m j f_j \right\} / F \quad (5)$$

$$C_1 = \left\{ -A(m) \sum_{j=1}^m f_j + m \sum_{j=1}^m j f_j \right\} / F \quad (6)$$

Since Formulas 2 and 3 are functions of the number of data points, they can be precomputed. If a point, for example (x_k, f_k) is tagged, then these sums are modified as follows for each tagged point.

$$A(m) = A(m) - k$$

$$B(m) = B(m) - k^2$$

The sums

$$\sum_{j=1}^m f_j \text{ and } \sum_{j=1}^m j f_j$$

should not include f_k .

Formulas 4, 5, and 6 are used to compute C_0 and C_1 , input to Formula 1, yielding the fitted values.

11. Sea Surface Height (SSH) Bounds Tests

The sea surface heights are globally known. In general, they have a consistent range of values, except in areas near the coast of India and the Phillipines. Values reach a minimum in the Indian Ocean and a maximum in the Pacific Ocean near the Phillipines. Boundary values used in the segmenter for eliminating sea surface heights out of range in these areas are as follows. In the Indian Ocean, the bounds are $-125\text{m} \leq \text{SSH} \leq 125\text{m}$. Latitude ranges from -11.5° to 20° , while longitude ranges from 63° to 90° . In the Pacific Ocean, bounds $-100\text{m} \leq \text{SSH} \leq 100\text{m}$. Latitude ranges from -12° to 8° , while longitude ranges from 123° to 158° . The general global bounds are $-80\text{m} \leq \text{SSH} \leq 80\text{m}$. Sea surface heights outside these bounds are set to the bound value.

12. Vertical Deflection Bounds Test

After vertical deflections (VD) are computed in the Kalman smoother, the following test is applied.

$$-100 \text{ arc sec} \leq \text{VD} \leq 100 \text{ arc sec}$$

Vertical deflections outside of these bounds are set to the bound.

5.15 Separation of Land/Ice and Ocean Data

The SDR is composed of land/ice and ocean data. One of the requirements of the processing system is to separate the two types of data. The land/ice data are written to tape and archived. The ocean data are reduced to best-estimated along-track geoid heights and vertical deflections and then sent to DMAAC, NAVOCEANO and other specified users. The procedure for separating the two types of data is described below.

Procedure:

A masking grid data file generated, by an offline computer program, from the World2 data base of coastline coordinates consist of land/ocean latitude and longitude boundaries. Longitude boundaries are given at 1-min intervals representing a total of 21,600 columns. Latitude boundaries within each column are ordered from zero min (South Pole) to 10,800 min (North Pole). The desired data column is retrieved by longitude. The column is then searched for the first latitude greater than the desired latitude. If the entry number of the latitude in the column is odd, the location is over land, an even

entry number is over water. Data values, representing min of latitude, are stored in a FORTRAN 77 direct access file keyed on minutes of longitude and can be randomly accessed. The actual check is performed as follows:

1. The given minute of longitude is used to access the proper record of the data file.
2. These latitude values are stored in a singularly dimensioned array.
3. This array is searched for the first data value greater than the given latitude.
4. If this array element has an odd index, the point is over land. If the index is even, the point is over water.

Input:

A masking grid generated from the World2 Data Base of coastline coordinates obtained from NAVOCEANO.

Output:

A land or ocean data point as determined from the permanent data file (10,800 X 21,600) of land/ocean latitude and longitude boundaries.

5.2 SEA SURFACE HEIGHT

The height of the geoid above the reference ellipsoid (See Figure 3) and subsatellite position (geodetic latitude and longitude) are computed from Equations 1, 2, and 3 as given below.

h - altimetric height above the geoid (km)

r_s - distance of satellite from center of reference ellipsoid (km)

N - height of geoid above reference ellipsoid (m)

ϕ - geodetic latitude (deg)

H - geometric height above the ellipsoid (km)

a - semimajor axis of reference ellipsoid (km)

e - eccentricity of the reference ellipsoid

$$N = H - h$$

where

$$H = \frac{z_s}{\sin\phi} - \frac{a(1-e^2)}{\sqrt{1-e^2\sin^2\phi}} \quad (1)$$

and h is corrected for systematic and environmental effects as described in Section 5.3.

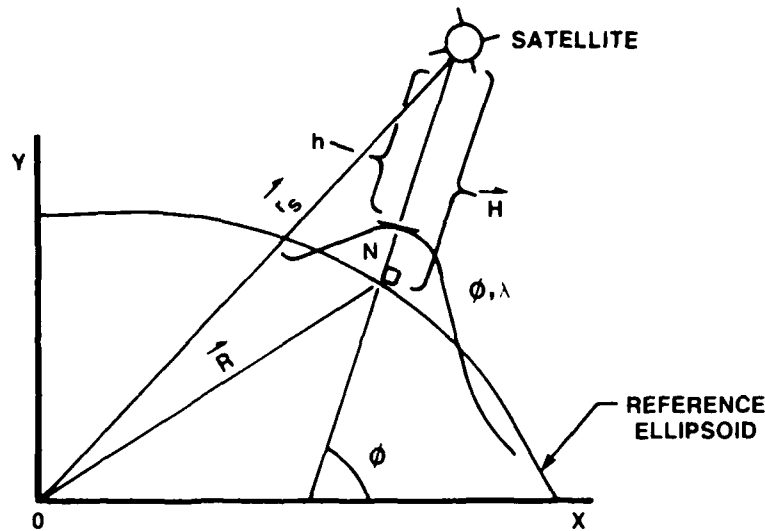


FIGURE 3. HEIGHT OF GEOID ABOVE REFERENCE ELLIPSOID

$$\tan \phi_0 = \frac{z_s}{\sqrt{x_s^2 + y_s^2}}$$

starting value for ϕ , and

$$\tan \phi_{k+1} + 1 = \frac{1}{\sqrt{x_s^2 + y_s^2}} \left| z_s + \frac{ae^2 \tan \phi_k}{\sqrt{1 + (1 - e^2) \tan^2 \phi_k}} \right|$$

iterate until $|\tan \phi_{k+1} - \tan \phi_k| \leq \tau$,

where

$$\tau = (1 + \tan^2 \phi_k) \times 10^{-9}, \text{ then}$$

$$\phi_{k+1} = \tan^{-1} \left\{ \frac{1}{\sqrt{x_s^2 + y_s^2}} \left| z_s + \frac{ae^2 \tan \phi_k}{\sqrt{1 + (1 - e^2) \tan^2 \phi_k}} \right| \right\}$$

$$\lambda_i = \tan^{-1} \frac{y_s}{x_s}, \text{ where } 0 \leq \lambda_i \leq 2\pi \quad (2)$$

$$\phi_i = \phi_{k+1} \text{ and } \lambda_i \text{ are computed for each observation time, } t_i. \quad (3)$$

$$a = 6378.137 \text{ km}, e^2 = 2f - f^2, \text{ and } f = 1/298.257223563$$

5.21 Subsatellite Velocity

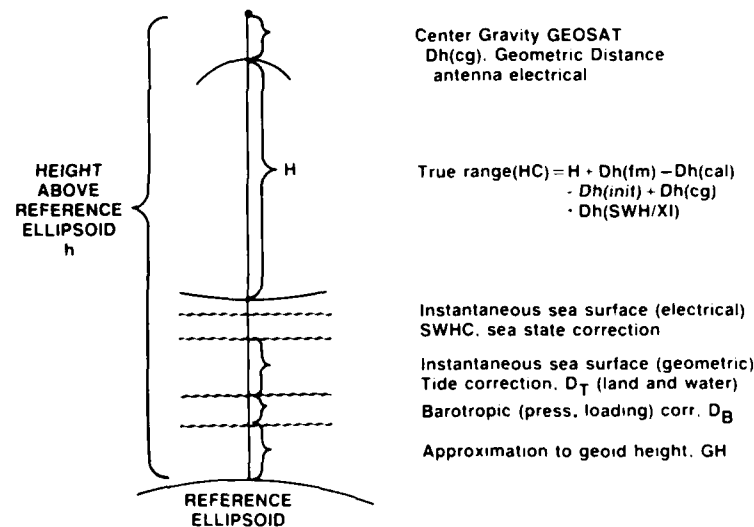
$$\begin{pmatrix} x \\ y \\ z \end{pmatrix} = \left(\frac{a}{\sqrt{1-e^2\sin^2\phi}} + h_s \right) \begin{pmatrix} \cos\phi \sin\lambda \\ \cos\phi \cos\lambda \\ \sin\phi \end{pmatrix} - \begin{pmatrix} 0 \\ 0 \\ \frac{ae^2\sin\phi}{\sqrt{1-e^2\sin^2\phi}} \end{pmatrix}$$

where $h_s = 0$, since it is the station altitude above the reference ellipsoid.

Routine NTERP8, described in "The User's Guide for NTERP8 Routines" by Evelyn C. Durling, Code K14, may be used to compute the velocity at the given subsatellite position by differential interpolation.

5.30 CORRECTIONS

The altimeter measurements are corrected for both environmental and systematic errors as shown in Figure 4. The description of each correction is given in Table 1.



Center Gravity GEOSAT
 Dh(cg). Geometric Distance
 antenna electrical

$$\text{True range(HC)} = H + Dh(\text{fm}) - Dh(\text{cal}) - Dh(\text{init}) + Dh(\text{cg}) - Dh(\text{SWH/XI})$$

Instantaneous sea surface (electrical)
 SWHC. sea state correction

Instantaneous sea surface (geometric)
 Tide correction, D_T (land and water)
 Barotropic (press. loading) corr. D_B

Approximation to geoid height. GH

$$\text{Sea Surface Height (SSH)} = h - \text{HC}$$

$$\text{Geoid Height} = \text{SSH} - D_T \cdot D_W \cdot D_D \cdot D_I - D_B$$

Note: Sea state correction is combined with tilt.

FIGURE 4. ENVIRONMENTAL AND SYSTEMATIC CORRECTIONS

5.31 Environmental Corrections

Environmental and system corrections applied to altimeter height measurements are shown in Table 1.

TABLE 1. CORRECTIONS APPLIED TO ALTIMETER HEIGHT MEASUREMENTS

<u>Corrections</u>	<u>Description</u>
Dh(fm)	Height bias resulting from FM crosstalk with the altimeter return signal
Dh(cal)	Systematic height bias derived from the analyses of calibration data
Dh(init)	Initial height measurement systematic bias determined through prelaunch tests
Dh(cg)	Height bias estimate caused by an attitude shift due to change in center of gravity (cg) as fuel is expended, and the physical separation between cg and the electrical center of the radar altimeter
Dh(SWH/XI)	Height bias, a function of the off-nadir spacecraft (s/c) orientation and the SWH
D _D	Dry tropospheric distance equivalent
D _W	Wet tropospheric distance equivalent
D _I	Ionospheric distance equivalent
D _B	Barotropic (pressure loading) correction (positive (+), if p < 1013 mB)
D _T	Tide correction includes land and water. High tides are assumed positive (+)

5.311 Tropospheric Refraction Correction. "The tropospheric effect results in an altitude change of the order of 2.5 m with the predominant portion of the correction coming from the dry component of the atmosphere. The maximum correction for the wet tropospheric effect will be less than 50 cm."¹¹ These limiting values are consistent with those used in the SEASAT data processing systems. Algorithms for the tropospheric corrections are given as follows.

Dry Tropospheric Correction

The dry tropospheric correction D_D, is computed from input pressure and latitude.

$$D_D(cm) = \frac{(2.277 - .011 \cos \phi) P}{10},$$

where

ϕ = Latitude from location data

P = Pressure (mB). If P is unavailable, use 1013.3.

Wet Tropospheric Correction

The wet tropospheric correction D_W , is computed from input surface temperature and partial pressure of water vapor.

$$D_W(cm) = 86400 \cdot P_W / (273 + T_S)^2$$

where

P_W = Partial pressure of water vapor (mB),

T_S = Surface temperature, deg. C.

If P_W is unavailable, use 12.272.

If T_S is unavailable, use 10.

5.312 Barotropic Correction. The barotropic correction, D_B , is computed from input atmospheric pressure.

$$D_B(m) = -.009948 (P_a - 1013.0)$$

where

P_a = Atmospheric pressure (mB) supplied by FNOC.

5.313 Ionospheric Refraction Correction. The ionospheric refraction model shown in Figure 5 was developed by Dr. James Clynych and Dr. Arnold Tucker of the Applied Research Laboratory, University of Texas, Austin, Texas, and modified by the late Dr. Ralph Gibson of NSWC. The model uses telecommunications predictions obtained from the National Oceanic and Atmospheric Administration, National Geophysical Data Center, Boulder, Colorado.

The ionospheric correction, $D_I = \Delta R$, given by the equation below, is illustrated by Figure 5.

$$\Delta R = \frac{c}{f^2} \int_{r_e}^{r_s} \frac{N(x,y,z) dr}{\sqrt{r^2 - k^2}}$$

where $k = r_e \sin z$

For the GEOSAT satellite altimeter $k = 0$, since the range is straight up and down, the ionospheric correction, D_I , is given by the equation below. The correction ranges between 3 and 15 cm with an accuracy of ± 15 percent.

$$D_I(cm) = \frac{c}{f^2} \int_{r_e}^{r_s} N(x,y,z) dr,$$

where

r_s = distance from center of earth to the satellite (km)

r_e = the radius of the earth (km)

f = transmitted frequency (MHz)

c = a known constant ($= 8.061389 \times 10^{-5}$)

$N(x,y,z)$ = electron density (el/cm³)

The vertical electron-density profile is shown in Figure 6. The E and F1 layers are modelled by a parabola; F2 layer up to H_mF2 is modelled by a fourth degree curve; H_mF2 to H_{Crit} is modelled by a parabola; and the remaining three portions of F2 are modelled by a decaying exponential with decay constants K_1 , K_2 , and K_3 .

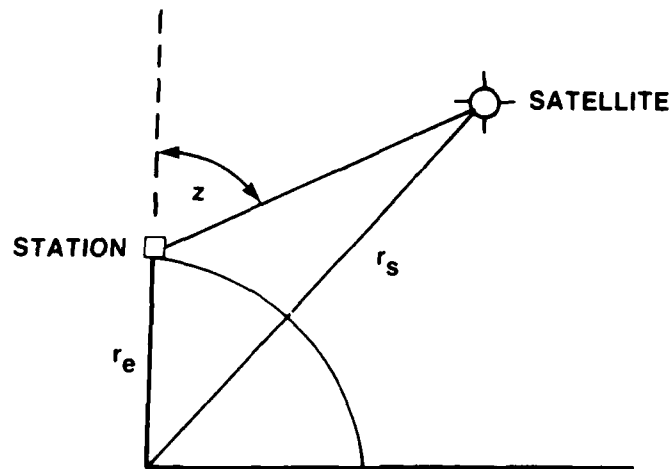


FIGURE 5. IONOSPHERIC REFRACTION MODEL

Parameters for Ionospheric Electron-Density Profile

F_oE	Critical frequency of E region
H_mE	Height of maximum ionization of E region
Y_mE	Semithickness of E region
F_oF1	Critical frequency of F1 region
H_mF1	Height of maximum ionization of F1 region
Y_mF1	Semithickness of F1 region
F_oF2	Critical frequency of F2 region
H_oF2	Height of maximum ionization of F2 region
Y_mF2	Semithickness of lower and middle F2 region

10. The data smoothing diagram is shown in Figure 7. In the filter or smoother model being used, no steady state is assumed for the filtering matrices. This practice is followed because of the possibility of bridging over missing points. At missing points, the filter procedure changes in the error of observation, $1/\sigma_k^2 = 0$. This is the add-on term in Dr. Cohen's earlier algorithm for computing B from L both forward and backward. At other points, σ_k^2 equals the assumed noise variance. In the procedure in Section 5.44, Dr. Cohen did not identify L separately, but it is computed in the same way as shown in earlier formulation.

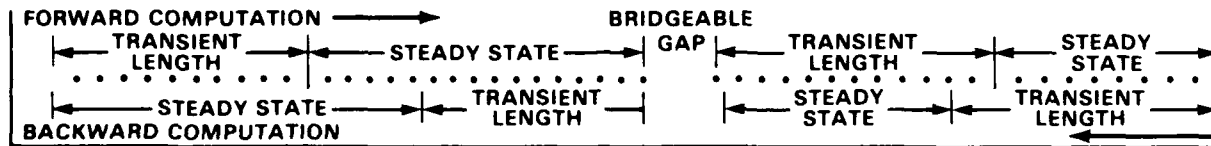


FIGURE 7. DATA SMOOTHING DIAGRAM

Points greater than a certain distance from either of the ends or from a bridged region may be assumed to be steady-state. That is, in the forward direction, it could be assumed to be steady state at some point from the beginning of valid data continuously to the end of valid data. At the first point in a gap, the B matrix may be computed from the previous one with de-weighting, as outlined (Section 5.44) by Dr. Cohen. The contribution of raw data to b is also zero in the gap. Similar computations are made all the way across the gap. Likewise, in the backward direction at some point from the end, a steady state may be assumed and continued until the data is interrupted.

The problem with assumption of steady state is that the distance required is a function of the filter parameters. Thus it is likely that the worst case must be assumed. Previously a constant autocorrelation distance permitted steady state to be assumed in approximately 11 sec. The time required to arrive at steady state could be an input.

11. Splice with adjacent clusters. Adjacent clusters are spliced together after smoothing with the same function as the fit removal weighting function. The difference is that for this splicing only about 20 points of overlapping data will be needed. That is to say, 20 points should be in both clusters when smoothed. As a practical approach, the overlapped 20 points can all be output with the second cluster involved in the overlap.

12. Restore fit removed and time derivative.

13. Convert resultant time derivative to arc sec. The X vector shown in Section 5.44 by Dr. Cohen is

X(1) = The geoid height

X(2) = The time derivative of geoid height

X(3) = The second time derivative (not needed)

X(1) is straightforward and ready for the removed fit value to be added to it

X(2) has the same units as the derivative of the removed fit curve ($a_2 + 2at_3 + 3at_4^2$). Consequently, the slope can be restored at the point where X(2) becomes available. To obtain deflections of the vertical in arc sec, multiply the sum of the two terms by $-206\ 2648062/\text{velocity}$, where velocity is

in km/sec. Note that a minus sign is present since a positive slope is a negative deflection of the vertical.

14. Compute statistics for output header.

15. Write output.

16. Go to 2.

5.42 Adaptive Algorithm. The computations for the adaptive filter parameters, S_N and σ_N appear in this section.

N = Raw data height (m)

V = Subsatellite velocity (km/sec)

Δt = Time between two N_j values

σ_N^2 = Variance of geoid heights

S_N = Autocorrection distance in km. Autocorrelation distance = distance for autocorrelation to fall to 1/e of value when no separation

σ_δ = Expected noise of data

1. Remove mean

$$\bar{N} = \frac{1}{N} \sum_{j=1}^N N_j = \text{mean geoid height (m)}$$

$$\tilde{N}_j = N_j - \bar{N}, 1 \leq j \leq N$$

$$L_0 = \frac{1}{N} \sum_{j=1}^N \tilde{N}_j^2, ACF(0) = \text{variance (m}^2\text{)}$$

Set $\Delta X = 200$ km

2. Let

$$K = INT \left\{ \frac{\Delta X}{V \Delta T} \right\}, \Delta S = KV \Delta t$$

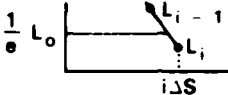
$$L_1 = \frac{1}{N-K} \sum_{j=1}^{N-K} \tilde{N}_j \tilde{N}_{j+K}, ACF(\Delta S) (m^2)$$

$$L_2 = \frac{1}{N-2K} \sum_{j=1}^{N-2K} \tilde{N}_j \tilde{N}_{j+2K}, ACF(2\Delta S) (m^2)$$

If either L_1/L_0 or L_2/L_0 are less than $\frac{1}{e}$, let $\Delta X = \frac{1}{2} \Delta X$ and go to 2. Continue calculating ACF ($i\Delta S$), $i > 2$

$$L_i = \frac{1}{N-iK} \sum_{j=1}^{N-iK} \tilde{N}_j \tilde{N}_{j+iK} \text{ until } L_i/L_0 < \frac{1}{e}$$

3. Interpolate for S_N

$$S_N = \left[i - \frac{\frac{1}{e}L_0 - L_i}{L_{i-1} - L_i} \right] \Delta S$$


4. Compute $\hat{\sigma}_N^2$

$$\beta(\text{wiener}) = \frac{2.90463}{\hat{S}_N}$$

$$X = \beta \Delta S$$

$$\phi(X) = (1 + X + \frac{1}{3}X^2)e^{-X}$$

$$\hat{\sigma}_N^2 = \frac{L_1}{\phi(X)}$$

5. Correct S_N

$$\tilde{S}_N = \hat{S}_N \left[1 + F(X) + 0.6117 \left(\frac{\sigma_6^2}{\hat{\sigma}_N^2} \right) \right] + \hat{S}_N$$

where

$$F(X) = \frac{17.74}{X} \left(1 - \frac{95}{X^2} + \frac{6740}{X^4} - \frac{396,000}{X^6} \right)$$

$$X^* = \hat{\beta} (L - \hat{S}_N), \hat{\beta} = \frac{2.90463}{\hat{S}_N}, L = n\Delta X$$

n = total number of points in array being processed

$$\Delta X = V\Delta t$$

$$S_N = \frac{1}{2} (\tilde{S}_N + \hat{S}_N)$$

If $S_N < 80$, $S_N = 80$

* Note. If $X \leq 5$, let $S_N = 3\hat{S}_N$

$$6. \quad \beta = \frac{2.90463}{S_N}$$

$$X = \beta \Delta S$$

$$\phi(X) = (1 + X + \frac{1}{3} X^2) e^{-X}$$

$$\sigma_N^2 = \frac{1}{0.85^2} \frac{L_1}{\phi(X)}$$

$$\sigma_N = \sqrt{\sigma_N^2}$$

$$\sigma_N = 119.087 \sigma_N \beta \text{ Wiener Beta}$$

N values are expressed in meters. Therefore, variances computed from them are in m². For that reason, σ_δ has to be brought in as meters. However, when the filtering matrices are computed, all three parameters must be expressed in kilometer units. S_N will always be expressed in kilometers.

5.43 Procedure for Removal of Cubic Fit

1 Generally, prior to computing adaptive filter parameters, a cubic fit is removed from the data. However, if there were a short segment (less than 20 points) not contiguous to other data, a linear fit would be sufficient for that case.

2 The manner of removing the fit is as follows:

Having divided the data into segments of approximately 150 sec each, take the segments by pairs and find the least-squares cubic fit values and slope values for the pair.

For $j = 1, L$, where $L =$ length of fit array

$$\text{Fit } Z(i, j) = a_1 + a_2 t(j) + a_3 t^2(j) + a_4 t^3(j)$$

$$\text{Slope } W(i, j) = a_2 + 2a_3 t(j) + 3a_4 t^2(j)$$

i is the fit index

Next move over one segment so that the $(i+1)$ th segment is included in both fits and make a similar calculation.

Use the results of both fits on the $(i+1)$ th segment to find for $j = 1, n$ where $n =$ segment length in data point

$$R(i+1, j) = Z(i, n+j) F(j) + Z(i+1, j) [1-F(j)]$$

$$S(i+1, j) = W(i, n+j) F(j) + W(i+1, j) [1-F(j)] + \frac{6}{(n-1) \Delta t} [Z(i, n+j) - Z(i+1, j)] (g^2 - g)$$

$$F(j) = 1.3g^2 + 2g^3$$

Δt = time interval between adjacent data points

$$g = \frac{j-1}{n-1}$$

3. Subtract the fit values (R) from the raw data values. These are the values for processing from that point on, until after smoothing, when R and S values are to be added to the smoothing results

4. The double fit removal procedure, as shown in Figure 8, assures continuity of the removed fit and removed derivative. Thus, when adjacent segments are clustered and smoothed, the restoration of the fit and derivative will not introduce a discontinuity in the smooth geoid height or deflections of the vertical. This procedure should also make for a smoother transition when ends of clusters are spliced together, when going to a new cluster

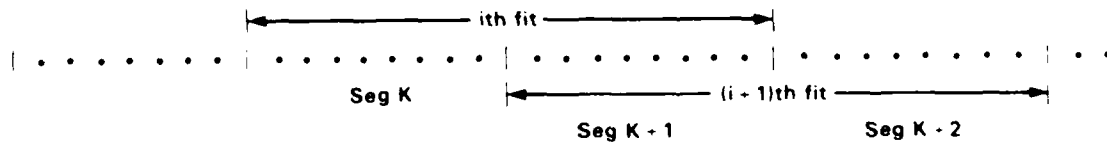


FIGURE 8. OVERLAPS FOR CUBIC FIT REMOVAL

5. If the data for which the fit is computed is \leq , the length of one segment only, no adjustment to the fit is necessary. For the first and last segments of a long span, no adjustments are made since no overlapping fit exists

6. The mean of each segment is not necessarily zero after fit removal, since more than one segment was involved. Thus it will still be necessary to remove the mean from the segment for computing filter parameters.

5.432 Cubic Fit Removal From Altimetry Data

$$\begin{aligned} \sum (A_1 + A_2T + A_3T^2 + A_4T^3 - Y)^2 &= \text{minimum} \\ \sum (A_1^2 + A_2^2T^2 + A_3^2T^4 + A_4^2T^6 + Y^2 + 2A_1A_2T + 2A_1A_3T^2 \\ &+ 2A_1A_4T^3 - 2A_1Y + 2A_2A_3T^3 + 2A_2A_4T^4 - 2A_2TY \\ &+ 2A_3A_4T^5 - 2A_3T^2Y - 2A_4T^3Y) = \text{minimum} \end{aligned}$$

The partial with respect to each A must be zero

$$\sum (2A_1 + 2A_2T + 2A_3T^2 + 2A_4T^3 - 2Y) = 0$$

$$\sum (2A_2 T^2 + 2A_1 T + 2A_3 T^3 + 2A_4 T^4 - 2TY) = 0$$

$$\sum (2A_3 T^4 + 2A_1 T^2 + 2A_2 T^3 + 2A_4 T^5 - 2T^2 Y) = 0$$

$$\sum (2A_4 T^6 + 2A_1 T^3 + 2A_2 T^4 + 2A_3 T^5 - 2T^3 Y) = 0$$

$$B = \begin{matrix} & \begin{matrix} A_1 & A_2 & A_3 & A_4 \end{matrix} \\ \begin{pmatrix} N & \sum T_i & \sum T_i^2 & \sum T_i^3 \\ \sum T_i & \sum T_i^2 & \sum T_i^3 & \sum T_i^4 \\ \sum T_i^2 & \sum T_i^3 & \sum T_i^4 & \sum T_i^5 \\ \sum T_i^3 & \sum T_i^4 & \sum T_i^5 & \sum T_i^6 \end{pmatrix} & \begin{pmatrix} A_1 \\ A_2 \\ A_3 \\ A_4 \end{pmatrix} & = & \begin{pmatrix} \sum Y_i \\ \sum Y_i T_i \\ \sum Y_i T_i^2 \\ \sum Y_i T_i^3 \end{pmatrix} & = & \begin{pmatrix} S0 \\ S1 \\ S2 \\ S3 \end{pmatrix} \end{matrix}$$

$$\begin{pmatrix} A_2 \\ A_3 \\ A_4 \end{pmatrix} = (B)^{-1} \begin{pmatrix} \sum Y_i \\ \sum Y_i T_i \\ \sum Y_i T_i^2 \\ \sum Y_i T_i^3 \end{pmatrix}$$

Since $T_i = k_i \Delta T$, replace T_i with k_i to obtain A array as function of integers

Note If T is made symmetrical (center point = 0), then

$$\sum T_i, \sum T_i^3, \text{ and } \sum T_i^5$$

are all zero. This makes the (B) matrix easier to invert analytically and the resultant expressions will involved fewer terms

The A 's are computed by removing powers of ΔT so that, instead of summing over $T^2, T^4,$ and T^6 , the summing is done over the integer coefficients to the appropriate powers

$$T2 = \sum_{i=1}^N \frac{T_i^2}{\Delta T^2} = \frac{1}{12} N(N^2 - 1) = 2(1 + 4 + 9 + \dots)$$

$$T4 = \sum_{i=1}^N \frac{T_i^4}{\Delta T^4} = \frac{1}{20} (3N^5 - 7N) = 2(1 + 16 + 81 + \dots)$$

$$T6 = \frac{\Sigma T_i^6}{\Delta T^6} = T2/112 * (3N^4 - 18N^2 + 31) = 2(1 + 64 + 729 + \dots)$$

$$\Delta = (T4 \cdot N - T2^2)(T2 \cdot T6 - T4^2)$$

$$B = \begin{pmatrix} N & 0 & T2 & 0 \\ 0 & T2 & 0 & T4 \\ T2 & 0 & T4 & 0 \\ 0 & T4 & 0 & T6 \end{pmatrix} \begin{pmatrix} A_1 \\ A_2 \\ A_3 \\ A_4 \end{pmatrix} = \begin{pmatrix} S0 \\ S1 \\ S2 \\ S3 \end{pmatrix}$$

$$\Delta = N(T2T4T6 - T4^3) + T2(T2T4^2 - T2^2T6)$$

$$= NT2T4T6 - NT4^3 + T2^2T4^2 - T2^3T6$$

$$= NT4(T2T6 - T4^2) - T2^2(T2T6 - T4^2)$$

$$= (NT4 - T2^2)(T2T6 - T4^2)$$

$$\Delta \bullet B^{-1} = \begin{pmatrix} T2T4T6 - T4^3 & 0 & T2T4^2 - T2^2T6 & 0 \\ 0 & NT4T6 - T2^2T6 & 0 & T2^2T4 - NT4^2 \\ T2T4^2 - T2^2T6 & 0 & NT2T6 - NT4^2 & 0 \\ 0 & T2^2T4 - NT4^2 & 0 & NT2T4 - T2^3 \end{pmatrix}$$

$$\Delta \bullet B^{-1} = \begin{pmatrix} (T2T6 - T4^2)T4 & 0 & (T2T6 - T4^2)(-T2) & 0 \\ 0 & NT4 - T2^2T6 & 0 & -NT4 - T2^2T4 \\ (T2T6 - T4^2)(-T2) & 0 & T2T6 - T4^2 - N & 0 \\ 0 & NT4 - T2^2T4 & 0 & NT4 - T2^2T2 \end{pmatrix}$$

$$\text{Let } \Delta 1 = \frac{1}{NT4 - T2^2} \text{ and } \Delta 3 = \frac{1}{T2T6 - T4^2}$$

Then

$$\begin{pmatrix} A_1 \\ A_2 \\ A_3 \\ A_4 \end{pmatrix} = \begin{pmatrix} \Delta 1 T4 & 0 & \Delta 1 (-T2) & 0 \\ 0 & \Delta 3 T6 & 0 & -\Delta 3 T4 \\ -\Delta 1 T2 & 0 & N \Delta 1 & 0 \\ 0 & -\Delta 3 T4 & 0 & \Delta 3 T2 \end{pmatrix} \begin{pmatrix} S0 \\ S1 \\ S2 \\ S3 \end{pmatrix}$$

And

$$A1 = \Delta 1 (T4S0 - T2S2)$$

$$A2 = \Delta 3 (T6S1 - T4S3)$$

$$A3 = \Delta 1 (NS2 - T2S0)$$

$$A4 = \Delta 3 (T2S3 - T4S1)$$

Note: These are now the coefficients of the integer multipliers of Δt .

5.44 Kalman Smoother with Unequal Weights

Algorithms for this Kalman smoother with unequal observation weights given in this section were provided by Dr. C. J. Cohen⁶. The same algorithms are applied in the GEOSAT program.

Precomputation

$$\beta = (\beta V) \text{ Wiener}$$

$$r = \beta \Delta t$$

$$M_0 = \begin{pmatrix} 1 & 0 & 0 \\ 0 & \beta & 0 \\ 0 & 0 & \beta^2 \end{pmatrix}$$

$$M_1 = \begin{pmatrix} \beta & 1 & 0 \\ 0 & \beta & 1 \\ \beta^3 & 3\beta^2 & 2\beta \end{pmatrix} \Delta t r$$

$$M_2 = \begin{pmatrix} \beta^2 & 2\beta & 1 \\ \beta^3 & 2\beta^2 & \beta \\ \beta^4 & 2\beta^3 & \beta^2 \end{pmatrix} \frac{\Delta t^2 r}{2}$$

$$M_3 = \begin{pmatrix} 3 & 0 & -\beta^2 \\ 0 & \beta^2 & 0 \\ -\beta^2 & 0 & 3\beta^4 \end{pmatrix} \frac{\sigma_N^2}{3}$$

$$M = \begin{pmatrix} 2r^4 - 4r^3 + 6r^2 - 6r + 3 & -2r^4 & 2r^4 + 4r^3 - 2r^2 + 2r - 1 \\ -2r^4 & 2r^4 + 4r^3 + 2r^2 - 2r + 1 & -2r^4 - 8r^3 - 8r^2 \\ 2r^4 + 4r^3 - 2r^2 + 2r - 1 & -2r^4 - 8r^3 - 8r^2 & 2r^4 + 12r^3 + 22r^2 + 10r + 3 \end{pmatrix}$$

$$\Phi_- = I_3 e^r \cdot M_1 + M_2$$

$$\Phi_+ = \Phi_-^{-1}$$

$$Q_+ = M_0 M M_0 \frac{\sigma_N^2}{3} e^{2r} - M_3$$

$$Q_- = \Phi_+ Q \Phi_+^T$$

Generation of B_f and b_f

By recurrence, generate $(B_f, b_f)_K$ and store B_f is 3x3 symmetric and b_f is 3x1

$$(B_f, b_f)_1 = (M_3^{-1}, 0) + \frac{e_1(e_1^T, N_1)}{\sigma_1^2}$$

$$(B_f, b_f)_{K+1} = \Phi_-^T (I_3 + B_{fK} Q_+)^{-1} (B_{fK} \Phi_-^{-1} b_{fK}) + \frac{e_1(e_1^T, N_{K+1})}{\sigma_{K+1}^2}$$

Here, $e_1 = \begin{pmatrix} 1 \\ 0 \\ 0 \end{pmatrix}$ and σ_K^2 is the variance of the error of observation

If the observation is missing

$$\frac{1}{\sigma_K^2} = 0$$

Backward generation of solutions

By recurrence backward, generate solutions.

$$(B_b, b_b)_{n_2} = (0_3, 0)$$

Where $K = n_2$ is the last of the observation times.

$$B_{bK-} = B_{bK} + \frac{e_1 e_1^T}{\sigma_K^2}$$

$$b_{bK-} = b_{bK} + e_1 \frac{N_K}{\sigma_K}$$

$$(B_{b'} - b_{b'K-1}) = \Phi_+^T (I_3 + B_{bK-} Q_-)^{-1} (B_{bK-} \Phi_+, b_{bK-})$$

$$P_K = (B_{fK} + B_{bK})^{-1}$$

$$\hat{X}_K = \begin{pmatrix} N \\ N \\ N \\ N \end{pmatrix}^{\wedge} = P_K (b_{fK} + b_{bK})$$

6.0 DATA BASE MANAGEMENT SYSTEM

There are several types of data files involved in the GEOSAT altimeter data processing system. These files are archived, distributed to users, and serve as inputs for geodetic studies.

The magnitude of GEOSAT data demands a systematic procedure for keeping track of it. After several data base management systems were investigated and System 2000 was selected. Subsequently, the RIM data base management system became available, and proved itself more user-friendly as well as needing less application software.

The basic requirement is to maintain a log file from which the status of data files can be obtained. In this way, any specific information may be retrieved, written to an output, and/or printed. Provisions for adding, deleting, and modifying entries are also required. The log information consists of a Revs Table and a Days Table, as described in Section 6.1.

6.1 LOG INFORMATION

The log information appears as two tables, the Revs Table and the Days Table. One record for each satellite revolution appears in the Revs Table and one record for each day appears in the Days Table. Tables 2 and 3 list the information contained on each.

TABLE 2. INFORMATION CONTAINED BY THE REV TABLE

<u>Description</u>	<u>Type</u>	<u>Format</u>
Satellite rev no.	I	xxxxx
Start year & day	A	xxxxx
Start time of rev in sec	R	xxxxx xxx
End year and day	A	xxxxx
End time of rev (sec)	R	xxxxx xxx
Date processed	A	xxxxx
Data quality	I	x
Start longitude (deg)	R	xxx xxx
Start latitude (deg)	R	xxx xxx
End longitude (deg)	R	xxx xxx

TABLE 2. INFORMATION CONTAINED BY THE REV TABLE (Cont.)

End latitude (deg.)	R	.xxx.xxx
Number of segments	I	xxxx
Longitude of ascending node	R	xxx.xxx
Year/day of ascending node	I	xxxxx
Sec of day of ascending node	R	xxxxx.xxx
Altimeter	I	x
Orbit adjust	I	xx

TABLE 3. INFORMATION CONTAINED BY THE DAYS TABLE

<u>Description</u>	<u>Type</u>	<u>Format</u>
Year/day	I	xxxxx
First rev in day	I	xxxxx
Last rev in day	I	xxxxx
Original SDR tape ny #	A	xxxxxx
Archive SDR tape ny #	A	xxxxxx
Date IGDR tape sent to AFGL	I	xxxxx
AFGL tape # for IGDR	A	xxxxxx
Archive ocean IGDR tape ny #	A	xxxxxx
Date ocean IGDR sent to NRL	I	xxxxx
NRL tape # for land IGDR	A	xxxxxx
Archive land IGDR sent to NRL	A	xxxxxx
Date land IGDR sent to NRL	I	xxxxx
NRL tape # for ocean IGDR	A	xxxxxx
Archive FGD tape ny#	A	xxxxxx
Date FGD date sent to DMAAC	I	xxxxx
Tape # of FGD sent to DMAAC	A	xxxxxx
Date FGD data sent to NAVO	I	xxxxx
NAVO tape # for FGD	A	xxxxxx
Climatology data status (m,a)	A	xx

6.1.1 Queried Information

The following operations may be performed on the log base: retrieve, print, write to permanent files, delete, modify, and update.

Retrieve and Print (and/or Write to a Permanent File)

- Rev records for a particular interval
- Rev records processed during a particular time interval
- Rev records with longitude of ascending node within a tolerance

Summary Given in Report Format

- Total number of revs (and/or list of rev numbers)
- Total number of revs for a particular time interval
- Total number of revs sent to AC
- Total number of revs sent to NAVO

- Total number of revs processed during a particular time interval
- Total number of SDR by tape number and revs contained on tape

- Total number of SDR sent to AFGL
- List SDRs by tape number and revs contained on tape

Delete, Modify, and/or Update Entries in the Data Base

6.2 GEODETIC INFORMATION

"Geodetic information" refers to the best-estimated along-track geoid heights and vertical deflections contained on the FGD file. These files are uniquely identified by rev number and are stored sequentially on archival tapes. Information regarding these files, such as their location and status can be extracted from the log; computer programs manipulate this data as required.

In addition to the distribution of complete rev files to users, there will be some requests for rev data located in a particular area of the world. This requires specialized data base management procedures. In the future, this problem will be treated in greater detail.

7.0 UTILITY SOFTWARE

The major software for this system generates along-track geoid heights and vertical deflections. Additional software permits such peripheral type processing as

- writing user compatible tapes
- reading tapes generated by other computers
- converting GEOSAT files for use in existing programs
- extracting rev data in an area
- archiving
- special plotting
- determining revs in an area
- validating data

8.0 GEOSAT DATA FILES, SOURCES, AND USERS

<u>Data File Name</u>	<u>Source (Computer)</u>	<u>User (Computer)</u>
Sensor Data Record	JHU/APL (SEL 32/77)	NSWC (CDC/865 and 875)
Average Data Record	JHU/APL (SEL 32/77)	NORDA
Intermediate Geophysical Data Record	NSWC (CDC/865 and 875)	NRI (Data General MV80000)
SDR/Precise Orbit	NSWC (CDC/865and 875)	AFGL (CYBER 72 CDC6600 VAX 11-780)
Unclassified Data Record	---	Civilian Community
Filtered Geophysical Data	NSWC (CDC/865and 875)	DMAAC (UNIVAC 1162)

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<u>Data File Name</u>	<u>Source (Computer)</u>	<u>User (Computer)</u>
Filtered Geophysical Data	NSWC (CDC/865 and 875)	NAVOCEANO (VAX or UNIVAC 1182)
Environmental Data	FNOC (CDC/NODDS)	NSWC (NODDS/Mohawk)

9.0 NEW GENERAL PURPOSE COMPUTERS

During development of the GEOSAT analysis and data reduction system, NSWC acquired new general purpose computers, CDC/865 and 875. Unclassified operations are performed on the CDC/865; classified operations on the CDC/875. While the computers have ample storage space for handling the huge number of GEOSAT data files, cost prohibits their use for archival purposes. Files are copied to tapes for archival.

10.00 DATA FILE FORMAT AND CONTENT

File formats and contents for the SDR, IGDR, FGD are listed in this section, as well as precise Doppler orbit data.

10.1 SDR

The SDR tape¹ is among the data products generated at APL. It consists of altimeter data for a 1-day (24 hr) period and has one header record, followed by a series of data records given at 1-sec intervals.

10.2 IGDR

The IGDR is an intermediate file generated by the preprocessor section of the data processing system. The file is basically the SDR with the addition of such information as the satellite rev number, height above the reference ellipsoid, longitude and time of the ascending node, geodetic latitude and longitude, and environmental data. The file consists of the header record taken from the SDR file, rev header record, rev data records for each second of data, and an end of file. The previous two record types are repeated for all revs processed from the SDR. The format and contents of the different records are given below.

10.21 IGDR Header Record Contents

<u>Word</u>	<u>Format</u>	<u>Approximate Range of Significance</u>	<u>Description</u>
First word	A12	SDRxxyydddnn	SDR Tape
SDR HEADER			Identification
.	.	.	.
.	.	.	.
.	.	.	.

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<u>Word</u>	<u>Format</u>	<u>Approximate Range of Significance</u>	<u>Description</u>
Last word of SDR + 1	A8	IGDRxxnn	Identification for IGDR file xx = Code Version nn = Tape Version
+2	I5	yyddd	Processing date of IGDR
+3	F7.6	.xxxxxx	Time interval (sec)
+4	F8.3	xxxx.xxx	Semimajor axis axis WGS 84 Ellip (km) for use in data reduction
+5	F7.3	xxx.xxx	Flattening (reciprocal) WGS84
+6	F4.3	.xxx	Timing correction (sec)
+7	I1	x	0 = ocean data
+7			1 = land data

10.22 IGDR Rev Header

<u>Word</u>	<u>Format</u>	<u>Approximate Range of Significance</u>	<u>Description</u>
1.	I5	xxxxx	rev number
2.	I2	yy	Year (first observation of rev)
3.	I3	ddd	Day (first observation of rev)
4.	F11.6	xxxxx.xxxxxx	Sec of day (first observation of rev)
5.	F6.5	x.xxxxx	Longitude of the ascending node(0 to 2 π , EOG) (RD)
6.	I2	yy	Year of longitude of ascending node
7.	I3	ddd	Day of longitude of ascending node
8.	F11.6	xxxxx.xxxxxx	Time of equator crossing (sec of day)
9.	F6.5	x.xxxxx	Longitude of the ascending node of next rev (0 to 2 π , EOG) (RD)

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<u>Word</u>	<u>Format</u>	<u>Approximate Range of Significance</u>	<u>Description</u>
10.	I2	yy	Year of longitude of ascending node of next rev
11.	I3	ddd	Day of longitude of ascending node of next rev
12.	F11.6	xxxxx.xxxxxx	Time of equator crossing of next rev
13.	I8	xxxxxxxx	Major frame count from SDR (first observation of rev)
14.	I2	xx	Minor frame count from SDR (first observation of rev)
15.	F7.3	xxxx.xxx	Period of satellite (sec)

10.23 IGDR Data Record

<u>Word</u>	<u>Format</u>	<u>Approximate Range of Significance</u>	<u>Description</u>
1.	I5	xxxxx	rev number
2.	I2	yy	Year of first observation in record
3.	I3	ddd	Day of first observation in record
4.	F11.6	xxxxx.xxxxxx	Sec of first observation in record
5.	I10	xxxxxxxxxxx	Mode from SDR Data Record
6.	I10	xxxxxxxxxxx	*FLAGWORD 1 (AGC, Height, Land)
7.	I10	xxxxxxxxxxx	*FLAGWORD 2 (Mode, Missing Data, rev)
8.	F9.6	xxx.xxxxxx	Height (1) from Altimeter (KM))
...
17.	F9.6	xxx.xxxxxx	Height (10) from Altimeter (KM)
18.	I4	xxxx	Sigma H (MM)

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<u>Word</u>	<u>Format</u>	<u>Approximate Range of Significance</u>	<u>Description</u>
19.	I5	± xxxx	Delta H (SWH/off-Nadir ang) (MM)
20.	I4	± xxx	Delta H-FM crosstalk (MM)
21.	F7.5	± x.xxxxx	Latitude (1) (Rad) (± π/2)
...
30.	F7.5	± x.xxxxx	Latitude (10) (Rad) (± π/2)
31.	F6.5	x.xxxxx	Longitude (1) (Rad) (0-to 2, EOG)
...
40.	F6.5	x.xxxxx	Longitude (10) (Rad) (0 to 2π, EOG)
41.	F9.6	xxx.xxxxxx	Height (10) above reference ellipsoid (KM)
...
50.	F9.6	xxx.xxxxxx	Height (10) above reference ellipsoid (KM)
51.	F5.2	± xx.xx	SWH (1) (M)
...
60.	F5.2	± x.xx	SWH (10) (M)
61.	F3.2	x.xx	*Sigma SWH (M)
62.	F4.2	± x.xx	Delta SWH (SWH/off Nadir Ang)(M)
63.	F6.2	± xxx.xx	AGC (1) (DB)
...
72.	F6.2	± xxx.xx	AGC (10) (DB)
73.	F4.2	xx.xx	*Sigma AGC (DB)
74.	F4.2	± x.xx	Delta AGC (SWH off Nadir Ang) (DB)
75.	F4.2	± x.xx	Delta AGC (H) (DB)
76.	F4.2	± x.xx	Delta AGC (T) (DB)

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<u>Word</u>	<u>Format</u>	<u>Approximate Range of Significance</u>	<u>Description</u>
77.	F3.0	± xx.	DH/DT (M/S)
78.	F3.2	x.xx	Off-nadir angle (Deg)
79.	F4.2	xx.xx	Sigma zero (backscatter coefficient) (dB)
80.	F3.1	xx.x	Windspeed (W (C)) (M/S)
81.	F4.3	x.xxx	Vatt-subT (V)
82.	F4.1	xxx.x	RCVTD (Deg C)
83.	F3.1	xx.x	Ionospheric correction (CM)
84.	F3.1	xx.x	Wet Tropospheric Correction(CM)
85.	F4.1	xxx.x	Dry Tropospheric Corr (CM)
86.	F4.2	± x.xx	Barotropic Correction (M)
87.	F5.2	± xx xx	Tide Correction (M)
88.	I4	xxxx	Atmospheric Pressure (MB)
89.	F4.3	x.xxx	Average Velocity (KM/S)

* From NSWC Preprocessor program (30-point fit)

10.3 FGD RECORD

The FGD file is the final output of the NSWC altimeter data processing system. The file contains information for one revolution of the satellite and is divided into time-continuous segments of data based upon autocorrection distance. Each segment is composed of a header record and data records for each data point in the segment. Segments are separated by an EOF

10.31 FGD Header Record Contents

<u>Word</u>	<u>Format</u>	<u>Approximate Range of Significance</u>	<u>Description</u>
1.	I4	xxxx	number of points in segment
2.	I5	xxxxx	rev number
3.	I5	yyddd	year/date data processed

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<u>Word</u>	<u>Format</u>	<u>Approximate Range of Significance</u>	<u>Description</u>
4.	I2	xx	starting year of segment
5.	I3	xxx	starting day of segment
6.	F9.3	xxxxx.xxx	starting sec of segment
7.	F7.6	.xxxxxx	time interval (sec)
8.	F5.0	xxxx.	autocorrelation distance (km)
9	F5.2	xx.xx	standard deviation of data (m)
10.	F5.2	xx.xx	standard deviation of geoid heights (m)
11.	F5.2	xx.xx	standard deviation of vertical deflections (arc sec)
12.	F4.2	x.xx	rms of filtered-raw differences (m)
13.	F5.3	x.xxx	average subsatellite velocity (km/s)
14.	F6.0	± xxxx.	height calibration bias (mm)
15.	F7.0	± xxxxx.	system height bias (mm)
16.	F6.0	xxxxx.	height bias due to change in center of gravity (mm)
17.	F4.3	.xxx	time correction (sec)
18.	F10.3	xxxxxx.xxx	speed of light (km/sec)
19.	F8.3	xxxx.xxx	semimajor axis WGS 84 ref. ellip (km)
20.	F7.3	xxx.xxx	flattening reciprocal-WGS 84
21.	F8.3	xxxx.xxx	satellite period (sec)
22.	F4.2	x.xx	orbit uncertainty in geoid heights (m)
23.	F4.3	.xxx	orbit uncertainty in vertical deflections (arc sec)
24.	F7.5	x.xxxxx	longitude of ascending node (rad)

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<u>Word</u>	<u>Format</u>	<u>Approximate Range of Significance</u>	<u>Description</u>
25.	I2	xx	year of longitude of ascending node
26.	I3	xxx	day of longitude of ascending node
27.	F9 3	xxxxx.xxx	sec of day of longitude of ascending node
28.	F7 5	x.xxxxx	longitude of ascending node of next rev (rad)
29.	I2	xx	year of longitude of ascending node of next rev
30.	I3	xxx	day of longitude of ascending node of next rev
31.	F9.3	xxxxx.xxx	sec of day of longitude of ascending node of next rev

A file is the consolidation of groups of 150 sec (or 1k/km) of time-continuous filtered data with approximately the same autocorrelation.

10.32 FGD Data Record Contents

<u>Word</u>	<u>Format</u>	<u>Approximate Range of Significance</u>	<u>Description</u>
1.	F9 3	xxxxx.xxx	time (sec)
2.	F8 5	± x xxxxx	latitude (rad)
3.	F7 5	x xxxxx	longitude (rad)
4.	F7 2	± xxx.xx	geoid height (m)
5.	F6 3	xx.xxx	*sigma h (m)
6.	F7 2	± xxx.xx	vertical deflection (arc sec)
7.	F7 2	± xxx.xx	raw geoid height uncorrected (m)
8.	F7 2	± xxx.xx	raw geoid height with correction applied (m)
9.	I5	xxxxx	flagword (see table)
10.	F6 2	± xx.xx	significant wave height (m)

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<u>Word</u>	<u>Format</u>	<u>Approximate Range of Significance</u>	<u>Description</u>
11.	F4.2	x xx	*sigma SWH (m)
12.	F7.2	± xxx.xx	AGC (db)
13.	F5.2	xx.xx	*sigma AGC (db)
<u>Height Corrections</u>			
14.	F5.0	± xxx.	FM crosstalk bias (mm)
15.	F6.0	± xxxx.	height (off-nadir, SWH component) (mm)
16.	F5.1	± xx x	ionospheric correction (cm)
17.	F4.1	xx.x	wet tropospheric correction (cm)
18.	F5.1	xxx x	dry tropospheric correction (cm)
19.	F5.2	± x.xx	barotropic correction (m)
20.	F6.2	± xx.xx	tidal correction (m)
21.	F4.2	x xx	tilt (off-nadir angle) (dg)
22.	F4.1	xx.x	windspeed (m/s)
23.	F5.2	xx.xx	ocean backscatter coeff (db)
24.	F6.2	± xx.xx	SWH correction (SWH/off-nadir angle) (m)
25.	F6.2	± xx.xx	AGC correction (SWH/off-nadir angle) (db)
26.	F6.1	± xxx.x	steric anomaly (cm)

*parameters from NSWC preprocessor program

The flagword is a 5-digit integer revealing the status of each of the parameters listed below. At present, the rightmost bits of integer are reserved for this purpose. Numbering is from right to left.

<u>Parameter</u>	<u>Status</u>
1. Unfiltered Geoid Height	1-out of bounds. Use -125m ≤ gh ≤ 125 m for area (deg) lat -11.5 long 64.0 lat 20.0 long 89.0

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<u>Parameter</u>	<u>Status</u>
	-100m ≤ gh ≤ 100m for area (deg) lat -12 0 long 123 0 lat 8 0 long 158 0 -80m ≤ gh ≤ 80m for remaining area 0-within bounds
2 Vertical Deflection	1-out of bounds Use (-100 arc sec ≤ vd ≤ 100 arc sec) 0-within bounds
3 Significant Wave Height	1-out of bounds Use (0m ≤ SWH ≤ 20m) 0-within bounds
<u>Parameter</u>	<u>Status</u>
4 Automatic Gain Control	1-out of bounds Use (22 db ≤ AGC ≤ 38 db) 0-within bounds
	<u>Environmental Corrections</u>
5 Ionospheric	1-out of bounds (0cm ≤ iono ≤ 25 cm) 0 model value
6 Wet Tropospheric	1-out of bounds (0cm ≤ wtrop ≤ 44cm) standard value used (13 2 cm) 0-model value
7 Dry Tropospheric	1 out of bounds (194 cm ≤ dtrop ≤ 247 cm) no data, use standard pressure value (1013 3) 0 model value
8 Barotropic	1 out of bounds (70 4 cm ≤ baro ≤ 156 2 cm) no data, use (0cm) 0 model value
9 Tide	1 out of bounds (-10m ≤ tide ≤ 10m) no data, use (0cm) 0 Schwiderski model
10 Dubbed In Data Point	1 data dubbed in to fill a small gap of missing data 0 no dubbing
11 Tilt	1 tilt value greater than allowed field width 0 within allowed field width

10.4 DOPPLER PRECISE ORBIT

The Celest computer program² takes as input raw data that is obtained by the network of Doppler tracking stations and generates a precise orbit. Ultimately, precise orbits will be generated for the entire mission and employed with altimeter measurements to compute raw geoid heights.

10.41 Propagated Trajectory File (earth-fixed or inertial) (Tape 10)

The propagated trajectory file² may consist of one or several trajectories, depending upon the running option selected. The file contains two record types: Type 1, a header for each trajectory that appears only once for each trajectory, and record Type 2, containing the position and velocity of the satellite for a given time. Record Type 2 is repeated for each time line for each trajectory. The last record of a trajectory is a record of Type 2 containing a negative value for the consecutive record number.

FORMAT OF PROPAGATED TRAJECTORY FILE

RECORD TYPE 1

<u>Word No.</u>	<u>Type</u>	<u>Symbolic Name</u>	<u>Description</u>
1.	I	NB	Record no. = 1
2.	F	Trat (1)	Year of epoch of trajectory
3.	F	Trat (2)	Day of epoch of trajectory
4.	F	Trat (3)	Sec of epoch of trajectory
5.	F	Trat (4)	Tve-to, time of vernal equinox minus epoch of the trajectory
6.	F	Trat (5)	Interval at which trajectory is written (sec)
7.	F	Trat (6)	Last time on trajectory (sec from epoch)
8.	F	Trat (7)	Integration interval used when creating the trajectory
9.	I	Iflow	Kind of trajectory = 10, 11, 12, or 13
10	I	ID (1)	Satellite number
11	I	KDS(1)	Indicates if trajectory was made using epoch of date = 1, or epoch of 1950 = 0
12	I	ID (3)	Improvement cycle number
13	A	Idate	Time clock value when trajectory was made

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<u>Word No.</u>	<u>Type</u>	<u>Symbolic Name</u>	<u>Description</u>
14.	I	Nrev	Revolution number of satellite
15.	I	None	Dummy word

RECORD TYPE 2

<u>Word No.</u>	<u>Type</u>	<u>Symbolic Name</u>	<u>Description</u>
1.	I	NB	Consecutive Record No. = 2, 3, ..., N
2.	F	TI	Ti-To (sec from epoch)
3.	F	Tra (2)	x - earth-fixed or inertial components of satellite position at time (Ti)
4.	F	Tra (3)	y - earth-fixed or inertial components of satellite position at time (Ti)
5.	F	Tra (4)	z - earth-fixed or inertial components of satellite position at time (Ti)
6.	F	Tra (5)	x $\dot{}$ - earth-fixed or inertial component of satellite velocity at time (Ti)
7.	F	Tra (6)	y $\dot{}$ - earth-fixed or inertial component of satellite velocity at time (Ti)
8.	F	Tra (7)	z $\dot{}$ - earth-fixed or inertial component of satellite velocity at time (Ti)

10.5 TIME CORRECTION TABLE

Each SDR spans approximately one day's worth of data. Time tag information (year, day, sec) and correlated frame count are provided in the header record for the beginning and end of each data span. This information allows accurate time to be assigned to each data record. Nevertheless, analyses have occasionally turned up errors in the SDR header, indicating that compensatory time corrections are required. Time corrections for the appropriate days are placed in a table and used as input to the altimeter data processing system. The format of the time corrections data table is given below

<u>Year</u>	<u>Begin Time Correction</u>	<u>End Time Correction</u>
I5	F11.6	F11.6

10.6 SUN SPOT TABLE

The ionospheric refraction model described in Section 5.313 includes the sun spot number in the computation of the ionospheric refraction correction to the altimeter height. These numbers are given on a monthly basis and stored in a table that is input into the altimeter data processing system. The format of the sun spot table is given below.

<u>Year/Month</u>	<u>Sun Spot Number</u>
I5	F10.3

10.7 SATELLITE REVOLUTION EPOCH TABLE

The satellite rev number, longitude and time of the ascending node are computed by the preprocessor program. The algorithms for computing these values require accurate reference values. Due to GEOSAT's orbital eccentricity, the reference values are updated every 100 revs and stored along with other pertinent information in a table. Included as pertinent information are the satellite period and the shift in longitude of the ascending node, computed from the precise orbit and averaged over a two-day period. The table is input to the preprocessor. Its format is given below.

<u>Rev #</u>	<u>Year</u>	<u>Day</u>	<u>Sec</u>	<u>Period</u>	<u>Longitude of Node</u>	<u>Longitude Shift</u>
I5	F3.0	F4.0	F12.6	F8.3	F9.5	F9.5

11.0 ACRONYMS AND ABBREVIATIONS

11.1 AGENCIES

AFGL	Air Force Geophysical Laboratory
ARL	Applied Research Laboratory, University of Texas
CIA	Central Intelligence Agency
DMA	Defense Mapping Agency
DMAAC	Defense Mapping Agency Aerospace Center
DMAHTC	Defense Mapping Agency Hydrographic Topographic Center
DON	Department of the Navy
FNOC	Fleet Numerical Oceanography Center
JHU/APL	Johns Hopkins University Applied Physics Laboratory
NASA	National Aeronautical Space Administration
NAVOCEANO	Naval Oceanographic Office
NOAA	National Oceanic and Atmospheric Administration
NORDA	Naval Ocean Research and Development Activity
NRL	Naval Research Laboratory
NSWC	Naval Surface Weapons Center

11.2 OTHER

NDR	NORDA data record
FGD	Filtered Geophysical Data
GOAP	GEOSAT Ocean Applications Program
IGDR	Intermediate Geophysical Data Record
pps	Points per sec
rev	One revolution of the satellite commencing at the equator (ascending node) and ending at the equator
s/c	spacecraft
SDR	Sensor Data Record
UDR	Unclassified Data Record
WDR	Waveform Data Record

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