WHOI-90-45
Copy 1

Woods Hole Oceanographic Institution

WOODS HOLE OCEANOGRAPHIC INSTITUTION 1930

Altimeter Processing Tools for Analyzing Mesoscale Ocean Features

by

Michael J. Caruso, Ziv Sirkes, Pierre J. Flament, and M.K. Baker

September 1990

Technical Report

Funding was provided by the Office of Naval Research through Contract No. N00014-86-K-0751.

WHOI-90-45

Altimeter Processing Tools for Analyzing Mesoscale Ocean Features

by

Michael J. Caruso
Ziv Sirkes*
Woods Hole Oceanographic Institution
Woods Hole, Massachusetts 02543

Pierre J. Flament
M.K. Baker
Oceanography Department
University of Hawaii
Honolulu, HI

September 1990

Technical Report

Funding was provided by the Office of Naval Research through Grant No. N00014-86-K-0751.

Approved for Distribution:

James R. Luyten, Chairman
Department of Physical Oceanography

*Present address: Institute for Naval Oceanography, Stennis Space Center, MS

Abstract

Satellite altimeters provide many opportunities for oceanographers to supplement their research with a valuable new data set. The recent GEOSAT exact repeat mission is the first of several altimetry missions proposed during the next decade. To utilize this new data, a software package was developed at the Woods Hole Oceanographic Institution and the University of Hawaii to facilitate the extraction of useful information from the NODC distributed GEOSAT data tapes. This software package was written with portability and modularity in mind. It should be possible to use this package with little or no modifications on data from future altimeters. The code was written in C and tested on Sun workstations and is oriented toward UNIX operating systems. However, since standard code was used, the programs should port easily to other computer systems. The modularity of the code should enable users to create addition programs. Additional programs designed to handle collocated water vapor corrections are also included for comparison.

Altimeter Processing Tools for Analyzing Mesoscale Ocean Features

Michael J. Caruso
Ziv Sirkes*
Woods Hole Oceanographic Institution
Woods Hole, MA

Pierre J. Flament
M. K. Baker
Oceanography Department
University of Hawaii
Honolulu, HI

September 20, 1990

*Present address: Institute for Naval Oceanography, Stennis Space Center, MS

Contents

List of Figures

List of Tables

1 Introduction

The altimeter is an active microwave radar that measures the distance between itself and the ocean surface. A pulse of known power and duration is directed toward the sea surface. By measuring the power of the return pulse, it is possible to determine the altimeter height. By fitting the shape of the return pulse, it is possible to calculate the significant wave height and the near-surface wind speed. The uses of satellite altimetry include the determination of ocean currents, measurement of significant wave height and ocean tides as well as estimation of surface wind speeds.

The U.S. Navy altimeter satellite GEOSAT (GEOdetic SATellite) was designed to provide the U.S. military with a highly improved marine geoid. In October 1986, when the satellite had completed this classified work, it was moved into a 17-day exact repeat orbit. The new orbital parameters corresponded to the 1978 Seasat mission. This new unclassified orbit was corrected periodically to provide a groundtrack repeatability to within 1 km.

The primary purpose of this project is to perform a "repeat" or "collinear" track analysis. This analysis requires sorting the data into collinear tracks, correcting the sea surface heights for various measurement errors and regridding the along-track data to a common grid. We developed generalized programs to read and assimilate the data into a usable data set. These programs were developed on a Sun Workstation[1], but could be easily ported to other computer systems.

Since GEOSAT does not have an onboard sensor to measure the effects of water vapor, two separate estimated water vapor corrections are supplied with the data. One alternative used here is the first Special Sensor Microwave/Imager (SSMI), launched in June 1987 aboard a Defense Meteorological Satellite Program spacecraft. The SSMI senses brightness temperatures. From those brightness temperatures environmental parameters such as wind speed and water vapor can be derived (Hollinger et al. 1987).

We decided to write several simple programs to read in the binary data tapes, format the data and write out the ASCII equivalents. We also worked out a naming convention to facilitate the storage and retrieval of individual subtracks. Programs were also written for repeat track analysis and to interpolate the data to a uniform latitude/longitude grid. These programs were designed with mesoscale motions in mind. However, since the programs are modular, users can easily use their own orbit and geoid corrections to study basin scale problems. We left programs that interpret the data for implementation by the individual users.

Section 2 describes the GEOSAT geophysical data record (GDR) and section 3 describes the SSMI data record. Section 4 illustrates the approach to handling the expansive data set and section 5 describes the programs and subroutines developed to handle the GEOSAT data along with explanations of input and output data. Section 6 describes the use of these programs to perform a repeat track analysis of a section of the North Atlantic from 22° N to 48° N and 284° E to 316° E. The appendices contain UNIX[2]-style manual pages, program and subroutine listings and UNIX shell scripts described throughout the text.

[1]Sun Workstation is a registered trademark of Sun Microsystems, Inc.

[2]UNIX is a trademark of AT&T Bell Laboratories

2 Geophysical Data Record GDR

The raw altimeter data are collected at the Johns Hopkins University Applied Physics Laboratory (JHU/APL) and are processed by the National Oceanographic and Atmospheric Administration (NOAA). The data are merged with ephemerides and corrections are added for tides and refractions (Cheney et al. 1987.) The National Ocean Data Center (NODC) in Washington, D.C. distributes the user handbook(Cheney et al. 1987) and the completed GDR which is available on tape.

Table 1 shows the parameters contained in each GDR. The parameter column contains the names used in the user handbook and the abbreviation column contains the names used for each parameter in the programs and in the text.

The first 5 items are stored as 4-byte integers. Parameters *utc* and *utcm* contain the time of the record since the 00:00 UTC, 1 Jan. 1985. The time of the record may be calculated by $t = utc + utcm * 10^{-6}$. The parameters *Lat* and *Lon* contain the latitude and longitude in microdegrees. A positive latitude is north of the equator and the longitude is measured east of the Greenwich meridian. The satellite orbit height, *Orb*, is given in mm above the reference ellipsoid.

The next 29 parameters are stored as 2-byte integers. The first of these parameters, *m_h*, is the average sea surface height of the record given in cm above the ellipsoid. The standard deviation of the heights used to calculate *m_h* is *s_h* . The height of the geoid above the ellipsoid in cm is *Geoid*. The measured 10-per-second sea surface heights used to calculate *m_h* are *h[1]-h[10]*. The average significant wave height in cm is *swh* and *s_swh* is the standard deviation of the measurements used to determine *swh*. The backscatter coefficient, *s_naught* is computed aboard the spacecraft in 0.01 dB. The automatic gain control, *agc*, is also determined aboard the spacecraft and *s_agc* is the standard deviation of the measurements used to determine *agc*. The height offset used for all measurements over land is *h_off* . The correction to *m_h* for the solid earth tide is *sol_tide* and the correction to *m_h* for the ocean tide is *oc_tide*. The correction to *m_h* to account for the time delay caused by water vapor in the troposphere, *wet_fnoc*, is derived from the Fleet Numerical Oceanographic Center (FNOC) NOGAPS model. An alternative correction for the water vapor is given as *wet_smmr*. The correction for the dry troposphere is given as *dry_fnoc*. A correction for the altimeter time delay due to molecules in the troposphere is given by *dry_fnoc*, which is also calculated from the FNOC NOGAPS model. The correction resulting from free electrons in the ionosphere is given by *iono_gps*. Two corrections are also given for height bias. The correction *dh_swh* is from a combination of significant wave height and attitude bias and *dh_fm* is due to compression of the altimeter pulse. The final parameter, *att* is the off-nadir satellite orientation angle. See the GEOSAT Altimeter GDR User Handbook (Cheney et al. 1987) for more information and references for these parameters.

3 SSMI Data Record

The raw SSMI data were collocated with the GEOSAT subtrack by Wentz [1989]. The collocated SSMI data records are at 10 second intervals and consist of 12 bytes as described in table 2. A wind speed value of 45 denotes no wind data available due to rain and a columnar water vapor value of 10 denotes no vapor data available due to rain.

Geophysical Data Record Contents					
Item	Parameter	Abbreviation	Units	Range	Bytes
1	UTC	utc	Seconds	0 to 2^{31}	4
2	UTC(cont'd)	utcm	Micro Second	0 to 1E6	4
3	Latitude	lat	Micro Degrees	+/- 7.21E7	4
4	Longitude	lon	Micro Degrees	0 to 360E8	4
5	Orbit	orb	Millimeter	7E8 to 9E8	4
6	H	m_h	Centimeter	+/- 32766	2
7	Sigma_H(σ_H)	s_h	Centimeter	0 to 32766	2
8	Geoid	geoid	Centimeter	+/- 1.5E5	2
9	H(1)	h[1]	Centimeter	+/- 32766	2
10	H(2)	h[2]	Centimeter	+/- 32766	2
11	H(3)	h[3]	Centimeter	+/- 32766	2
12	H(4)	h[4]	Centimeter	+/- 32766	2
13	H(5)	h[5]	Centimeter	+/- 32766	2
14	H(6)	h[6]	Centimeter	+/- 32766	2
15	H(7)	h[7]	Centimeter	+/- 32766	2
16	H(8)	h[8]	Centimeter	+/- 32766	2
17	H(9)	h[9]	Centimeter	+/- 32766	2
18	H(10)	h[10]	Centimeter	+/- 32766	2
19	SWH	swh	Centimeter	0 to 2E3	2
20	Sigma_SWH(σ_{swh})	s_swh	Centimeter	0 to 2E3	2
21	Sigma_naught(σ_o)	s_naught	0.01 dB	0 to 6.4E3	2
22	AGC	agc	0.01 dB	0 to 6.4E3	2
23	Sigma_AGC(σ_{AGC})	s_agc	0.01 dB	0 to 6.4E3	2
24	Flags				2
25	H Offset	h_off	Meters	0 to 5.4E4	2
26	Solid Tide	sol_tide	Millimeter	+/- 1000	2
27	Ocean Tide	oc_tide	Millimeter	+/- 10000	2
28	Wet (FNOC)	wet_fnoc	Millimeter	0 to -1000	2
29	Wet (SMMR)	wet_smmr	Millimeter	0 to -1000	2
30	Dry (FNOC)	dry_fnoc	Millimeter	-2000 to -3000	2
31	Iono (GPS)	iono_gps	Millimeter	0 to -500	2
32	dh (SWH/ATT)	dh_swh	Millimeter	+/- 9999	2
33	dh (FM)	dh_fm	Millimeter	+/- 999	2
34	Attitude	att	0.01 Degree	0 to 200	2

Table 1:

SSMI Data Record Contents				
Item	Parameter	Units	Range	Bytes
1	Time	Seconds	0 to 2^{31}	4
2	Latitude	Degrees	-	2
3	Longitude	Degrees	-	2
4	Encoded Data	-	See table 3	4

Table 2:

SSMI encoded data description				
Item	Parameter	Abbreviation	Range	Units
1	Data flag	fl	0 to 3	0 - Over ocean 1 - No orbit altitude information 2 - Over land 3 - Over sea ice
2	Wind speed	ws	-	ms^{-1}
3	Columnar water vapor	vp	-	$gr \cdot cm^{-2}$
4	Columnar cloud water vapor	cl	-	$gr \cdot cm^{-2}$
5	Rain rate	rn	-	$mm \cdot hr^{-1}$

Table 3:

4 Data Handling

In this text, the data received from NODC is referred to as "raw" and should not be confused with the data received directly from the satellite JHU/APL. Each data tape contains approximately 34 days of data for a total of more than 120 Megabytes so that it is impractical to keep all available data on disk.

Since these programs were developed to analyze mesoscale features, the data is split from the raw sequential input data into regional areas. The repeat analysis required developing an orbit numbering scheme to identify collinear orbits. This scheme separates the GDRs into ascending and descending orbit segments starting and ending at the most northern and most southern point of an orbit. An orbit is defined to be the combination of the ascending and descending segments beginning with the descending segment. A segment is defined as any part of a complete orbit. These orbits were numbered from 0 to 243 with zero being the first orbit on the first NODC data tape. Since the orbits repeat every 17.05 days, the orbits were also named by the repeat cycle from which they were extracted. A repeat cycle is defined as the combination of all orbits beginning with 0 and ending with 243. The cycles are also numbered consecutively starting with zero.

The resulting files are named *cmmm.dnnn* for descending orbit *nnn* and *cmmm.annn* for ascending orbit *nnn* from repeat cycle *mmm*. Table 4 shows the naming conventions used in this report for the various files created during analysis.

Naming conventions		
Convention	Example	Description
c*mmm*.a*nnn*	c002.a088	Raw GEOSAT binary files
c*mmm*.a*nnn*c	c002.a088c	Cleaned and corrected GEOSAT binary files
c*mmm*.a*nnn*cs	c002.a088cs	Cleaned, corrected and regridded GEOSAT binary files
c*mmm*.a*nnn*cs_r	c002.a088cs_r	Residuals from repeat analysis, ASCII format
a*nnn*cs_m	a088cs_m	Mean and variability for repeat analysis, ASCII format
c*mm*.a*nnn*asc	c002.a088asc	ASCII file containing extracted data

Table 4:

One alternative orbit numbering method is based on the longitude where the orbit crosses the equator. This method, however, does not convey the order of each orbit in time. Orbit c010.a045 passes the Gulf Stream approximately three days before c010.a088. Knowing the equatorial crossing of an orbit segment can be useful in quickly locating an orbit in space relative to another orbit or for comparing results with other numbering methods. A program was written to convert the sequential numbering to the equatorial numbering.

5 Programs and Subroutines

This section contains descriptions of programs and subroutines used to analyze GEOSAT data. In the examples given, the UNIX prompt is represented by a percent sign "%".

Most programs were designed to read and write the standard 78-byte GEOSAT GDR so that the output from one program may be used as the input for another. Programs are also simple and single-purpose. Instead of a program that removes spurious data points and applies orbit corrections, one program is used to apply the corrections and one program is used to remove unwanted data. This allows quick code modifications and substitutions. An alternative program to compute orbit corrections can be directly substituted for the supplied correction program. A single multi-purpose program would require major modifications to implement the new corrections.

Several programs were designed to read or write ASCII data for use with existing plotting packages and display programs. ASCII data allows users to choose their own display programs. One program which reads ASCII data was designed to interface directly with the high resolution color graphics capabilities of the Satellite Data Processing System (SDPS)(Caruso and Dunn, 1989) developed at the Woods Hole Oceanographic Institution. Complete UNIX style manual pages for all programs are included in appendix A.

Most programs have a single input file, a single output file and accept command line arguments as needed. This allows the output of one program to be piped into the input of another program. The simple and modular design of these programs allows users to combine programs to customize more complex programs. Several scripts were written for the UNIX shell (a command line interpreter)[3] to utilize this versatile feature. By combining several commands into a shell script, a user can quickly modify the analysis without changing program code and recompiling. For example, a simple shell script to perform a repeat analysis would look similar to this:

```
#
foreach i (c???.$1)
echo $i
#
cat $i | g_clean1 | g_correct | g_clean2 >! tmp
(cat tmp | g_spike | g_spline 1 22 48 3.3 0.97992165 > "$i"c)
end
#
echo Performing repeat analysis.
g_repeat "$i"c > mean."$1"
```

This uses three routines to clean the data, one routine to apply the standard corrections and one routine to spline the data onto an even grid for each cycle of a given

[3] Several shell programs are available. The examples given use the C shell.

orbit. Then the repeat analysis is done. The script takes as an argument the orbit number.

```
%repeat.sh a002
```

The user could use a program to apply non-standard corrections by substituting the program in the shell script.

```
#
foreach i (c???.$1)
echo $i
#
cat $i | g_clean1 | my_correct | g_clean2 >! tmp
(cat tmp | g_spike | g_spline 1 22 48 3.3 0.97992165 > "$i"c)
end
#
echo Performing repeat analysis.
g_repeat "$i"c > mean."$1"
```

5.1 GEOSAT Programs.

A list of available **GEOSAT** analysis programs is given in table 5 with a brief synopsis. More detailed descriptions of programs are listed below in alphabetical order. All GEOSAT programs begin with *g_* to help provide unique program names.

5.1.1 g_clean1

This program is used to delete raw GEOSAT GDRs which contain obviously bad data. This includes all records that have any of the following variables set to 32767: the sea surface height, *ha*, and the corrections for earth tide, *cet*, ocean tide, *cot*, FNOC wet, *wet_fnoc*, or dry troposphere, *dry_fnoc*, or the ionosphere, *iono*. Records are also removed if the standard deviation, *s_h*, of the 10-per-second sea height values, *h[1] - h[10]*, is greater than 30 cm, or if the backscatter coefficient, *s_naught*, is greater than 35 dB. This program reads in a binary GEOSAT file and removes all bad records. The number of bad records is printed along with the criteria for rejection. For example the command

```
%cat c000.a002 | g_clean1 > c000.a002c
```

produces:

```
g_clean1: Valid points:      345
          Rejected points:    16
          Height:              0
          Solid Tide:          0
          Ocean Tide:          7
          Wet FNOC:            0
          Dry FNOC:            0
          Iono:                0
          Sigma Height:       14
          Sigma Naught:        0
          Flags:              15
```

List of GEOSAT programs	
Program	Description
g_clean1	Initial cleaning of raw GDRs
g_clean2	Secondary cleaning of GDRs
g_compress	Compresses GDR to 18 bytes
g_correct	Applies GDR suggested corrections to sea surface height
g_crossnum	Converts sequential orbit numbers to equatorial crossing longitudes
g_date	Prints start and end date for GDR segment
g_date2	Prints start and end date given cycle and orbit number
g_ext	Extracts one or more parameters from GDR and converts to SI units
g_image	Converts ASCII GEOSAT data to a bitmap image.
g_interp	Linearly interpolates to a specific grid
g_print	Decodes GDRs and prints to a terminal
g_region	Separates raw GEOSAT GDRs into sequential orbits in a specified region
g_repeat	Performs "collinear" or repeat track analysis using a quadratic orbit correction
g_repeats	Performs "collinear" or repeat track analysis using a sinusoidal orbit correction
g_seporb	Separates raw GEOSAT GDRs into sequential orbits
g_spike	Removes data spikes from GDRs
g_spline	Splines GDRs to a specific grid
g_uncompress	Uncompressis 18 byte data record
g_which	Prints orbit numbers in a given lat/lon box

Table 5:

This shows that a total of 16 records were rejected. Of those 16 records, 15 were rejected because the flag records were bad, 14 were rejected because the standard deviation of the 10-per-second sea height values were greater than 30 cm. Seven were rejected because the ocean tide value was set to 32767. By default, all records over land are also rejected. This most likely accounts for the 15 records rejected because of a bad flag value. This default may be changed to also remove all records over shallow water by specifying the correct flag mask. Any of the available flags supplied in the GEOSAT GDR may be tested. This is done by setting the UNIX environment variable *GMASK*:

```
%setenv GMASK 1 - - - - - - 0 - - - - - - 0 0
```

where a "-" means ignore this bit, a "0" means skip this record if this bit is not 0 and a "1" means skip this record if ths bit is not 1. For more information, see the manual page in appendix A. The results of this program are shown in figure 1.

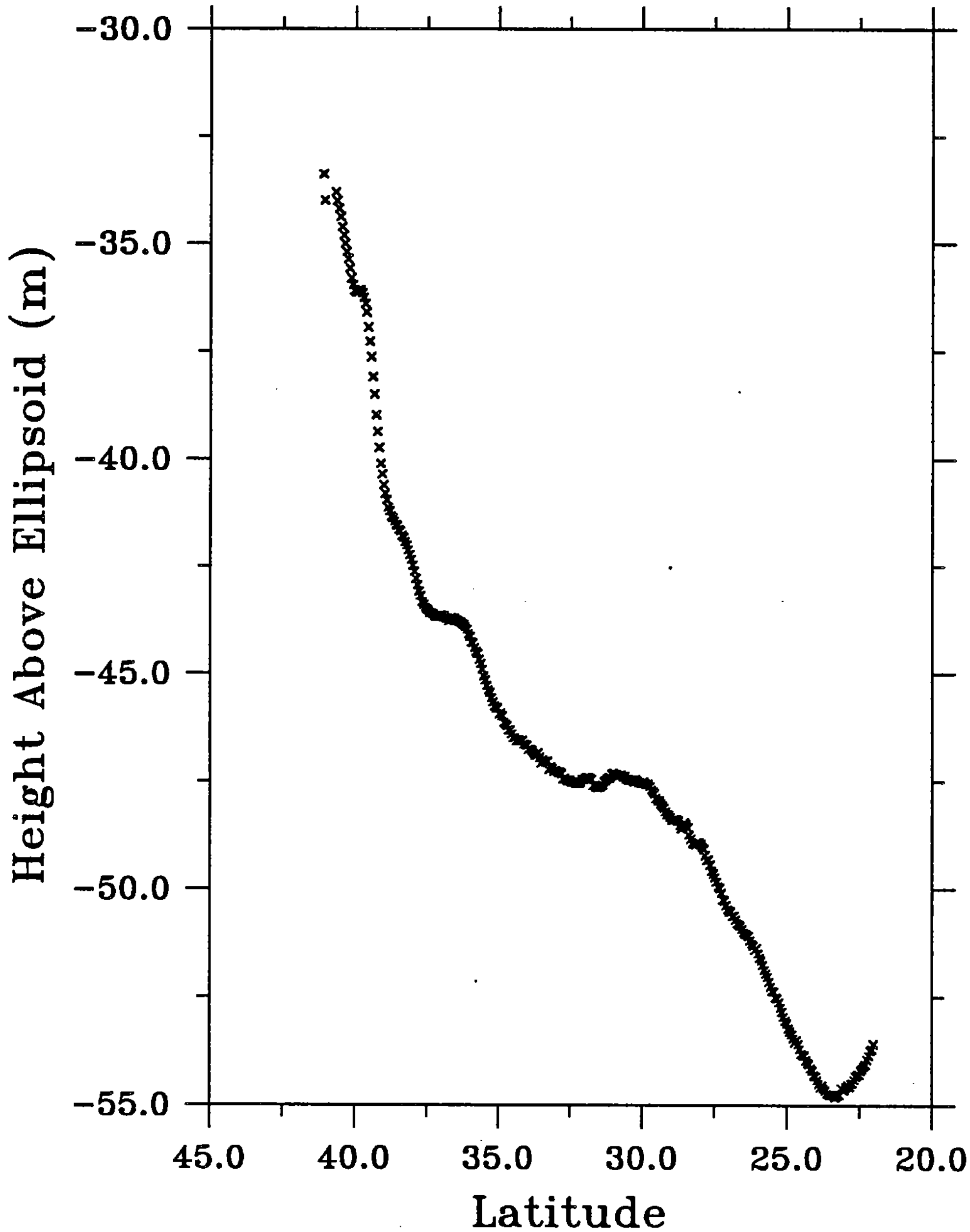

Figure 1: Raw sea surface heights plotted after running program g_clean1 to remove obviously bad data.

Compressed 18-byte Data Record Contents				
Item	Parameter	Units	Range	Type
1	Time	ms	0 to 1.47E9	long int (4-bytes)
2	Height	cm	0 to 32767	short int (2-bytes)
3	Cycle		0...	char (1-byte)
4	Latitude	10^4 Deg	0 to 18E5	unsigned int (3-bytes)
5	Longitude	10^4 Deg	0 to 36E5	unsigned int (3-bytes)
6	Sigma Height	cm	0 to 255	unsigned char (1-byte)
7	SWH	5cm	0 to 255	unsigned char (1-byte)
8	s_naught	0.1dB	0 to 255	unsigned char (1-byte)
9	Flags			char (1-byte)
10	Ocean Tide	cm	-128 to 128	char (1-byte)

Table 6:

5.1.2 g_clean2

This program is used to clean up records after *g_clean1* and *g_correct* have been used. It simply removes data records with sea surface heights greater than 10000 cm and less than –14000 cm. This removes any obvious outliers that may interfere with other analysis programs such as *g_spline.* As in *g_clean1,* a total of rejected points is printed. The command

%cat c000.a002 | g_clean2 > c000.a002c

produces:

```
g_clean2: Rejected points:   0
          Maximum Height:    0
          Minimum Height:    0
```

In this case, file *c000.a002* is the output from *g_clean1* and *g_correct.*

5.1.3 g_compress / g_uncompress

This is a set of programs designed to compress the standard 78-byte GDR to 18 bytes by reducing precision and removing less important fields such as the 10-per-second sea surface heights. The output is an 18-byte-per-record binary file and should be uncompressed before using any of the other analysis programs. These programs were designed for storing as much meaningful data as possible on limited systems. The format of the compressed 18-byte record is given in table 6. The time variable stored is the time since the start of *a000* for each cycle. The other variables are the same as for the full GDR except with reduced precision.

5.1.4 g_correct

This program allows the user to apply one or more of the suggested corrections to the sea surface height value of each record. All suggested corrections are optional and are applied by default. An example of applying all corrections would be:

%g_correct < c000.a002 > c000.a002c

In this example, the file *c000.a002* is the output from *g_clean1.* The output file *c000.a002c* has the same format as the original GDR, but the height field now contains the following corrections:

$$h = h - sol\_tide - oc\_tide - wet\_fnoc - dry\_fnoc - iono\_gps - inv\_bar$$

where the corrections are supplied in the GDR (table 1) except for *inv_bar* which is given as follows:

$$inv\_bar = -9.948(p - 1013.3)$$

and

$$p = \frac{dry\_fnoc}{(-2.277)\{1 + [0.0026 \cos(2LAT)]\}}$$

Individual corrections may be applied by specifying the abbreviation on the command line,

%g_correct cet cot < c000.a002c > c000.a002c

This would apply the corrections for the earth tide and the ocean tide supplied with the GEOSAT GDR. The list of available abbreviations is given in table 7 and in the manual page in appendix A. These abbreviations also correspond to the abbreviations for *g_ext*. The corrections for a section of *c000.a002* are given in figure 2.

Description of variables for program g_correct	
Abbreviation	Description
cet	correction for earth tide in m
cot	correction for ocean tide in m
cwf	correction for wet troposphere fnoc
cws	correction for wet troposphere smmr
cdf	correction for dry troposphere
ci	correction for ionosphere
cib	correction for inverse barometric effect

Table 7:

5.1.5 g_crossnum

This program finds the longitude where a given orbit crosses the equator. This program was designed to convert sequential orbit numbers to equatorial crossing numbers. The program may be used in two ways. First, the specific orbit can be specified:

```
%g_crossnum a002
306.43
```

Second, the program may be given a GEOSAT GDR:

```
%g_crossnum < c000.a002
306.43
```

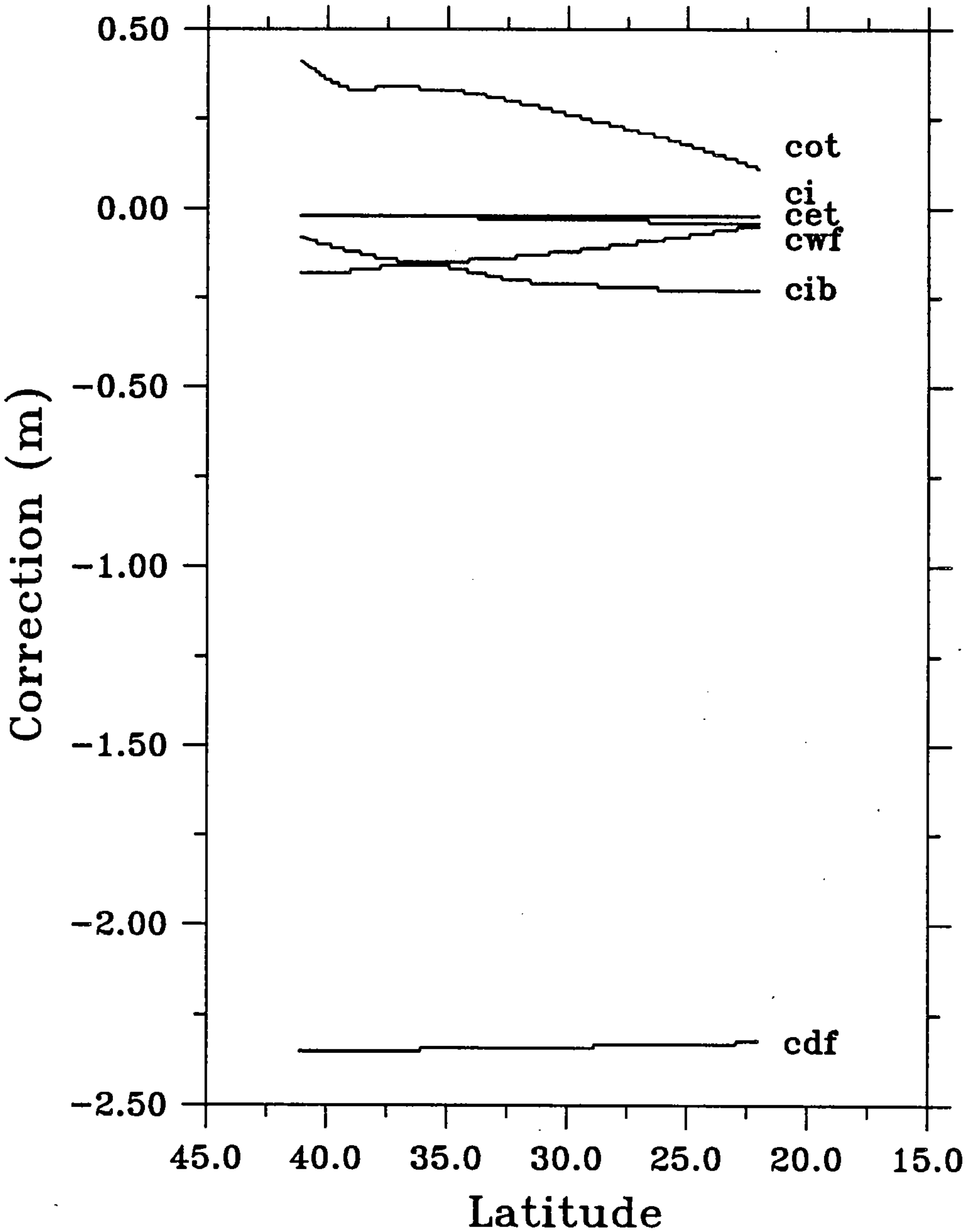

Figure 2: Corrections from a section of orbit c000.a002. *Cot* is for the ocean tide; *ci* is for the ionosphere; *cet* is for the earth tide; *cwf* is for the FNOC wet troposphere; *cib* is for the inverse barometric effect and *cdf* is for the FNOC dry troposphere.

5.1.6 g_date

This program prints the start and end date and time of a GEOSAT GDR segment. The program prints the *utc* value from the GDR, the date, the day of year, the Julian day and the day of the cycle.

```
%cat c053.a002 | g_date
UTC: 136497764.05
Date: 4/28/89 20:02:44
Day of year: 118
Julian: 1753685
Day of cycle: 0

UTC: 136498110.94
Date: 4/28/89 20:08:30
Day of year: 118
Julian: 1753685
Day of cycle: 0
```

5.1.7 g_date2

This program is similar to g_date except that it takes the orbit and cycle numbers as arguments. The program prints the approximate beginning and ending times of the specified orbit.

```
%g_date2 053 002
UTC: 136492860.00
Date: 4/28/89 18:41:00
Day of year: 118
Julian: 1753685
Day of cycle: 0

UTC: 136498897.00
Date: 4/28/89 20:21:37
Day of year: 118
Julian: 1753685
Day of cycle: 0
```

5.1.8 g_ext

This program was written to convert and extract one or more parameters in a GEOSAT GDR to ASCII format. It converts all parameters to SI units. To create an ASCII file of the latitude, longitude and uncorrected sea surface heights, the following command would be given:

```
%g_ext l L ha < c000.a002 > c000.a002asc
```

where c000.a002 is a file containing GDRs in binary format and c000.a002asc is the ASCII output from *g_ext*. This program allows the user to use almost any plotting package to display the data. For example, the command

```
%g_ext l w < c000.a002 | graph -g 1 -x 45 20 -5
```

uses the standard UNIX plotting utility *graph* to plot the significant wave height for orbit number 002 in cycle 000 over the Gulf Stream for figure 3. Compare this with the clean data plotted after using *g_clean1* in figure 1 to see how obviously bad points can be removed. The complete list of abbreviations is given in table 8 and in the manual page in appendix A. Figures 4 and 5 are examples of other fields that may be extracted and plotted using more sophisticated plotting packages.

Description of variables for program g_ext	
Abbreviation	Description
t	time in seconds since equator crossing of orbit c000.a000
l	latitude in degrees
L	east longitude in degrees
ho	orbit height above ellipsoid in m
ha	sea surface height above ellipsoid in m
sha	sigma ha
hg	geoid height above ellipsoid in m
w	significant wave height
sw	sigma w
so	backscatter coefficient in 0.01 dB
ag	agc in 0.01 dB
sag	sigma ag
fl	masked flags
HA	land surface height offset above ellipsoid
cet	correction for earth tide in m
cot	correction for ocean tide in m
cwf	correction for wet troposphere fnoc
cws	correction for wet troposphere smmr
cdf	correction for dry troposphere
ci	correction for ionosphere
b	attitude bias
bc	compression bias
att	attitude
cib	correction for inverse barometric effect
h	corrected sea surface height above ellipsoid
dh	corrected sea surface height above geoid

Table 8:

5.1.9 g_image

This program converts ASCII GEOSAT data in the form *latitude*, *longitude* and *z* to a bitmap image. An example of Gulf Stream variability calculated from the repeat track analysis using ascending orbits is shown in figure 6. The coastline and grid overlays on this figure were generated using SDPS.

This program takes six parameters, the minimum latitude and longitude, the maximum latitude and longitude and the number of rows and columns in the output image. The following was used to generate the image in figure 6:

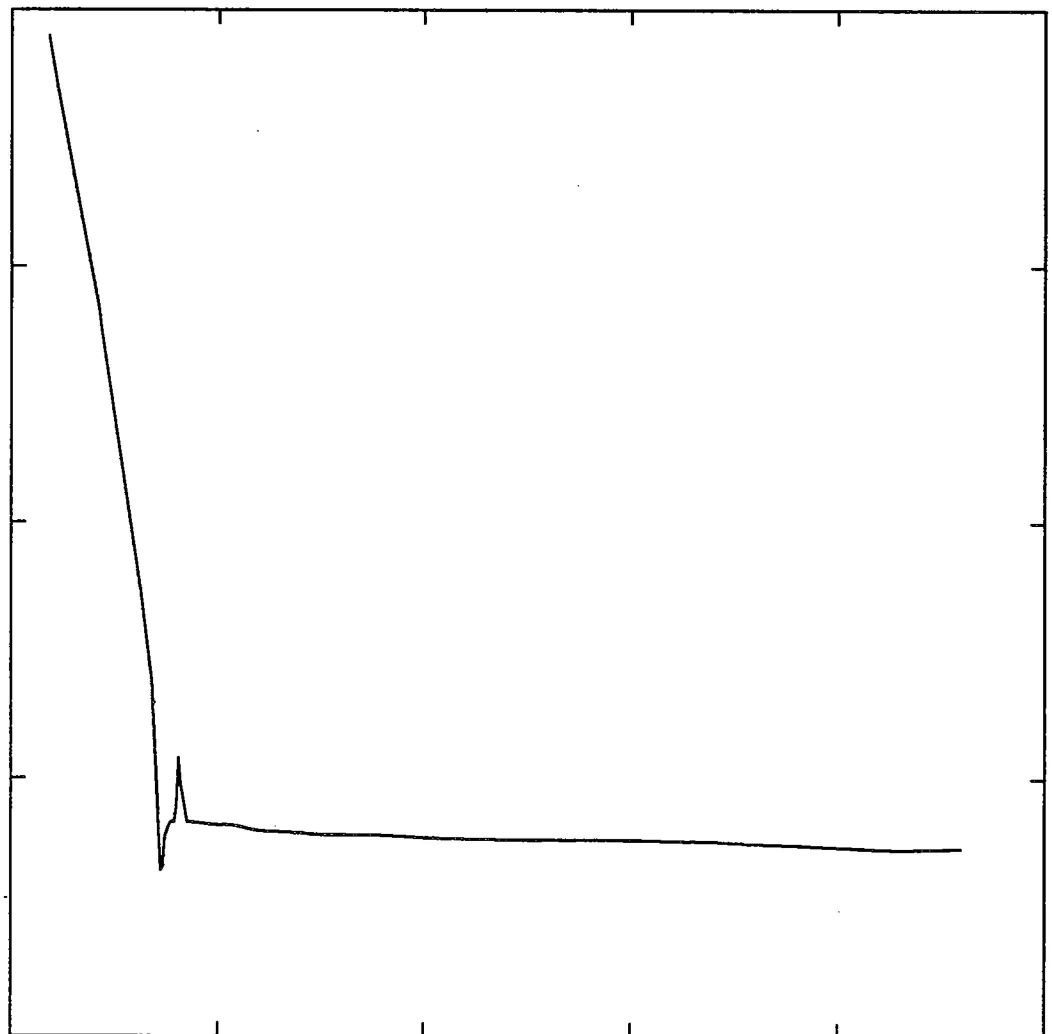

Figure 3: An example of using *g_ext* to extract raw sea surface heights. The UNIX utility *graph* was used to plot this figure.

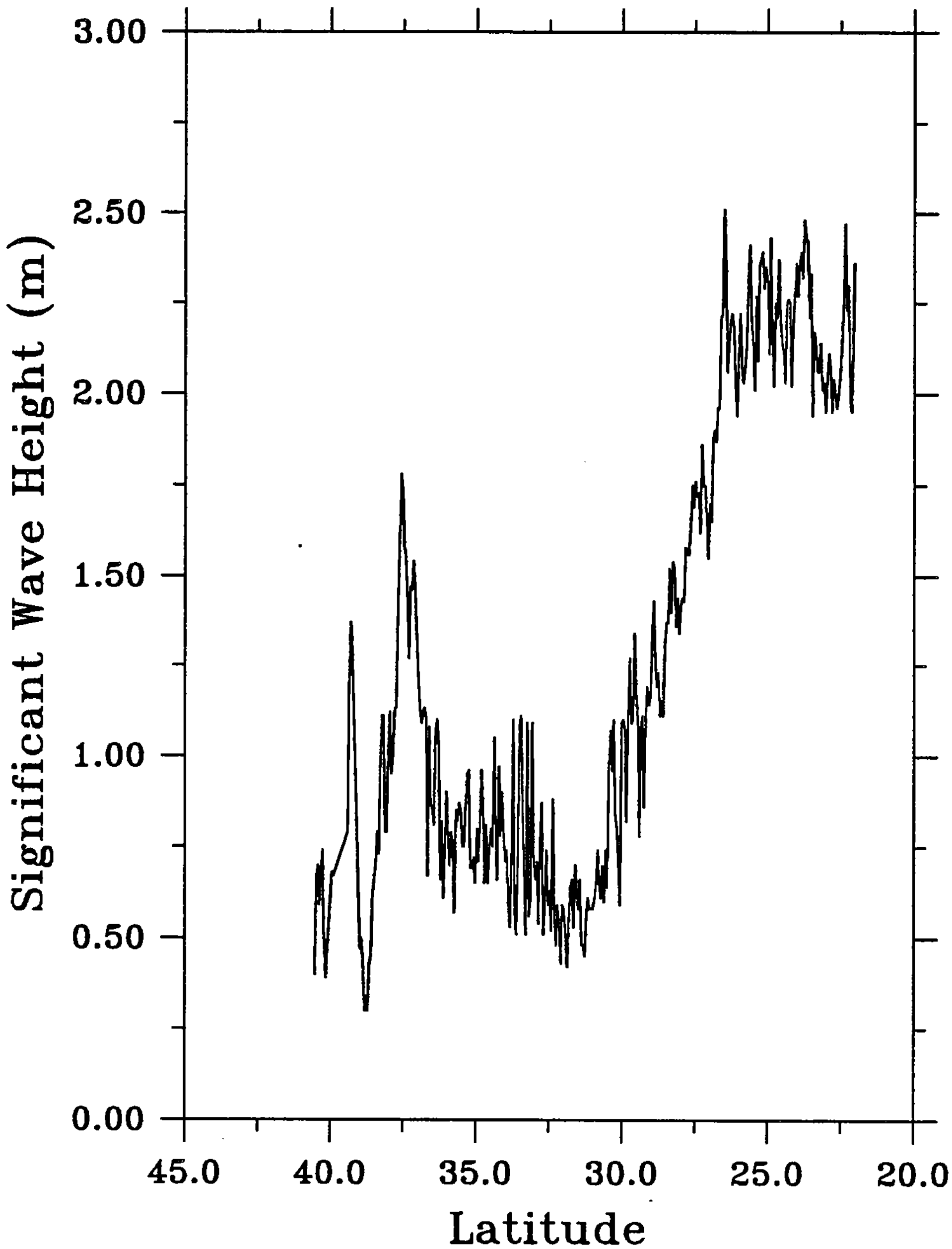

Figure 4: An example of using *g_ext* to extract the significant wave heights for orbit c000.a002 over the Gulf Stream.

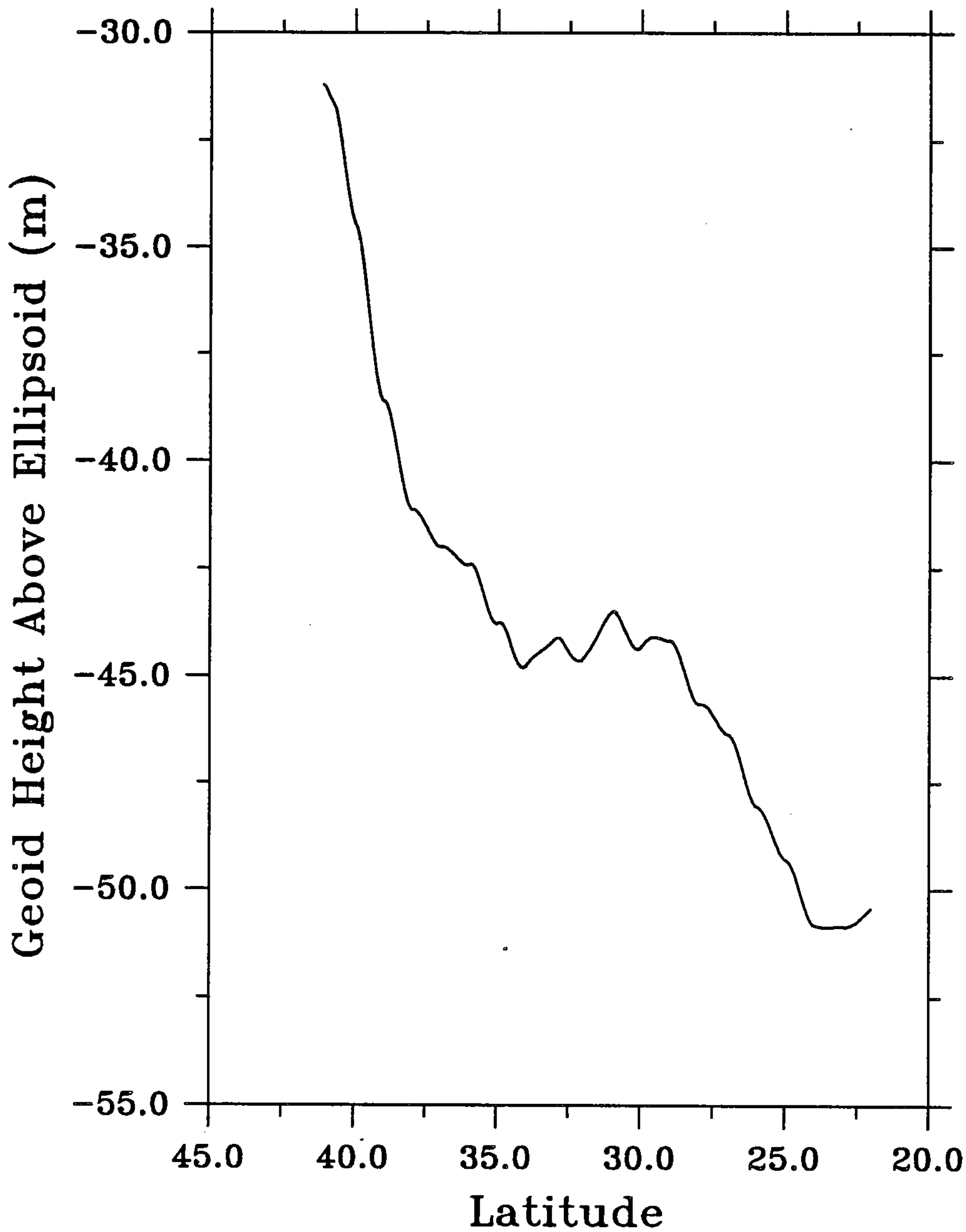

Figure 5: An example of using *g_ext* to extract included geoid heights for orbit c000.a002 over the Gulf Stream.

%cat a*cs_m | cut -f2,5 | g_image 22 48 284 316 416 512 > vara.sdpsf

The input is all the output files from *g_repeat* for each orbit in the region. The command *cut* is a standard UNIX command and illustrates how these programs are designed to be used with existing commands. The output image has 416 rows, 512 columns and is on an equirectangular grid 22N, 284E to 48N, 316E. This image is in SDPS floating point format and may be converted to byte format for display using the SDPS routine *sdps_ftb*:

%cat vara.sdpsf | sdps_ftb > vara.sdps

5.1.10 g_interp

This program is used to regrid the GEOSAT data to a common grid by linearly interpolating between supplied data points. All variables in the GDR are interpolated except the 10-per-second sea surface heights and the data flags since these fields are no longer meaningful to the regridded data. The output is regridded so that at least one value is positioned on the equator. This ensures that segments from areas that overlap, i.e. 10° N to 40° N and 25° N to 50° N, can be directly compared. The output file contains complete segments in GDR format.

Input segments should be cleaned and corrected and five arguments are required by the program:

%cat c000.a002 | g_interp *dir min max gap delta_t* > c000.a002c

where *dir* is 1 for an interpolation bounded by a minimum and maximum latitude and 2 for an interpolation bounded by a minimum and maximum longitude (see *g_region* section 5.1.12). A *gap* is the maximum time between good segments. The program does not spline across gaps, but labels the points as bad (32767). Gaps and incomplete cycles are filled to the boundaries defined by *min* and *max* with the correct latitude. The time between interpolated points is *delta_t*. One point is placed on the equator crossing and subsequent points are splined *delta_t* seconds apart. There are no default parameters. An example for the Gulf Stream region is:

%cat c000.a002 | g_interp 1 22 48 3.3 0.97992165 > c000.a002c

Here, the data is interpolated between 22° N and 48° N. If the segment has more than 3.3 seconds of missing data, it is considered to be a gap. The output points are interpolated to be 0.97992165 seconds apart, which is the same spacing as the raw GDRs.

5.1.11 g_print

This program decodes each GEOSAT GDR and prints the variables to a terminal. An example of the output is shown below: