NASA/TM—2002–209984/VER. 1/VOL. 3

GEOSAT Follow-On (GFO) Altimeter Document Series

Volume 3
GFO Altimeter Engineering Assessment Report

The First 20 Cycles Since Acceptance
November 29, 2000 to November 21, 2001

Version 1

D. W. Lockwood
D. W. Hancock, III
G. S. Hayne
R. L. Brooks

March 2002

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Acknowledgments

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Foreword

The Navy's Geosat Follow-On (GFO) Mission, launched on February 10, 1998, is an altimetric satellite with heritage that includes Seasat, Geosat, TOPEX/POSEIDON (T/P), and ERS-1. Data derived from these missions has and will lead to improvements in the knowledge of ocean circulation, ice sheet topography, and climate change. In order to capture the maximum amount of information from the altimetric data, accurate altimeter calibrations are required for the GFO civilian data set that NOAA will produce. NASA/Goddard Space Flight Center/Wallops Flight Facility (GSFC/WFF) has provided these calibrations for the Seasat, Geosat and T/P missions, and is doing the same for GFO.

Wallops' multiple roles with regard to GFO are:

- NASA Representative for Radar Altimeter Performance
- Calibration Collaboration
- Member of GFO Cal-Val Team
- Data distribution to members of Cal-Val Team
- Validate sensor-related corrections
- Provide corrections for sensor changes

For the latest updates on the performance of the GFO Radar Altimeter, and for accessing many of our reports, readers are encouraged to contact our WFF/GFO Home Page at http://gfo.wff.nasa.gov/

This WFF GEOSAT Follow-On (GFO) Altimeter Engineering Assessment Report has been prepared by Raytheon/ITSS under Contract NAS5-00181 with the NASA Goddard Space Flight Center, Greenbelt, Maryland. This work was performed under the direction of David W. Hancock, III, WFF GFO Altimeter Verification Manager, Observational Science Branch, Laboratory for Hydrospheric Processes, NASA Goddard Space Flight Center, Wallops Flight Facility, Wallops Island, Virginia. Mr. Hancock may be contacted at (757) 824-1238 (voice), hancock@osb1.wff.nasa.gov (e-mail), or (757) 824-1036 (fax).

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Section 1

Introduction

1.1 Identification of Document

The purpose of this document is to present and document GFO performance analyses and results. It is the second of a series of Wallops GFO performance documents, each of which will update WFF's assessment results. This report covers the altimeter performance from Acceptance on November 29, 2000, until the end of Cycle 20 on November 21, 2001.

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1.2 Definition of a GFO Cycle

Like its predecessor, GEOSAT, the GFO groundtrack has a repeat (+/-1 km) period of 17.05 days. For our analyses, the repeat periods are referred to as cycles, and are used as data dividers to assess sensor internal consistency, taking into account seasonal differences.

For simplification in tracking the performance of the satellite, the Navy is using exactly 17-day boundaries in the definition of a cycle. The first 17-day cycle after acceptance by the Navy is numbered 000 and is used as a reference for the succeeding cycles. The 17-day cycle which started on December 16, 2000 (Julian day 2000352) is the beginning of the first evaluation cycle, Cycle 001, which ended on January 2, 2001 (Julian day 2001002). Each subsequent cycle is consecutively numbered.

1.3 Data Flow to/from Wallops

1.3.1 To Wallops

The daily near-real time GFO data flow from the Naval Oceanographic Office (NAVO), Altimetry Data Fusion Center (ADFC), Stennis Space Center, Bay St. Louis, MS, to Wallops Flight Facility (WFF) consists of:

- Science data without waveforms (ra_data)
- Science data with waveforms (ra_cal_data)
- Engineering data (eng_data)
- Water Vapor Radiometer data (wvr_data)
- Sensor data (sdr)

Additional data are forwarded by the Navy to Wallops as soon as it is available, consisting of:

- Navy Geophysical Data (ngdr)
- Operational Orbital Determination data (oodd)

1.3.2 From Wallops to Cal/Val Team Members

Wallops forwards the following GFO data types to the other members of the Cal/Val Team:

- Sensor data (sdr)
- Science data with waveforms (ra_cal_data)
- Operational Orbital Determination data (oodd)

Section 2

On-Orbit Instrument Performance

As of November 21, 2001, the GFO altimeter had acquired, since launch, a cumulative total of approximately 1030 days of data out of a possible 1276 days. During the initial year-and-a-half of the GFO on-orbit mission, altimeter data collection was sporadic due to various spacecraft systems and software problems, the descriptions of which are outside the scope of this report.

During the 20 cycles addressed in this report, the altimeter operated a total of approximately 335 days out of the possible 340 days. The down-periods were the result of the following three episodes: 1) 10.5 hours attributable to a commanding error on 2000 / 341; 2) 93.0 hours due to a spacecraft-level safehold that began on 2001 / 043; and 3) 24.0 hours attributable to a spacecraft attitude configuration that began on 2001 / 297.

The following subsections will illustrate that the altimeter tracking data have been internally consistent. The subsections discuss:

- internal calibrations
- cycle summaries
- key events

2.1 Internal Calibrations

The GFO's internal calibration mode has two submodes, designated CAL-1 and CAL-2. CAL-1 is designed to detect changes in the internal path delays, to measure range drift. CAL-1 also monitors changes in the receiver automatic change control (AGC); the altimeter's estimates of the ocean surface radar backscattering cross-section are obtained from the AGC values. The purpose of the second mode, CAL-2, is to characterize the response of the receiver and digital filter bank.

During CAL-1, a portion of the transmitter output is fed back to the receiver through a digitally controlled calibration attenuator and a delay line, whereupon the altimeter acquires and tracks the signal. Then, during CAL-2, the altimeter processes receive thermal noise with no transmitted signal present, to characterize the waveform sampler response.

The GFO Project provides two internal calibrations per day.

Prior to Wallops' receiving the calibration data, the GFO ground data processing system routinely performs the following: (1) adds a large constant bias to the CAL-1 range, such that the magnitude of the resultant range sum is comparable to a nominal nadir altimeter range to the surface of the earth, and then (2) applies an oscillator drift correction to the total range.

To reconstruct a meaningful CAL-1 range, Wallops performs the following: (1) using the GFO-Project-provided VTCW (Vehicle Time Code Word), removes the oscillator drift correction, and then (2) removes a large constant bias.

2.1.1 Range

The CAL-1 range calibrations are shown in the middle of Figure 2-1, denoted by (+) and are referenced to the left vertical scale in millimeters. The data plotted nearer the bottom of the figure, denoted by the diamonds, are the Composite Temperature corresponding to the times of the calibrations; the temperatures are referenced to the right vertical scale in degrees centigrade. A minor temperature dependence of approximately +0.5 mm per degree is noted, which is within the centimeter specification.

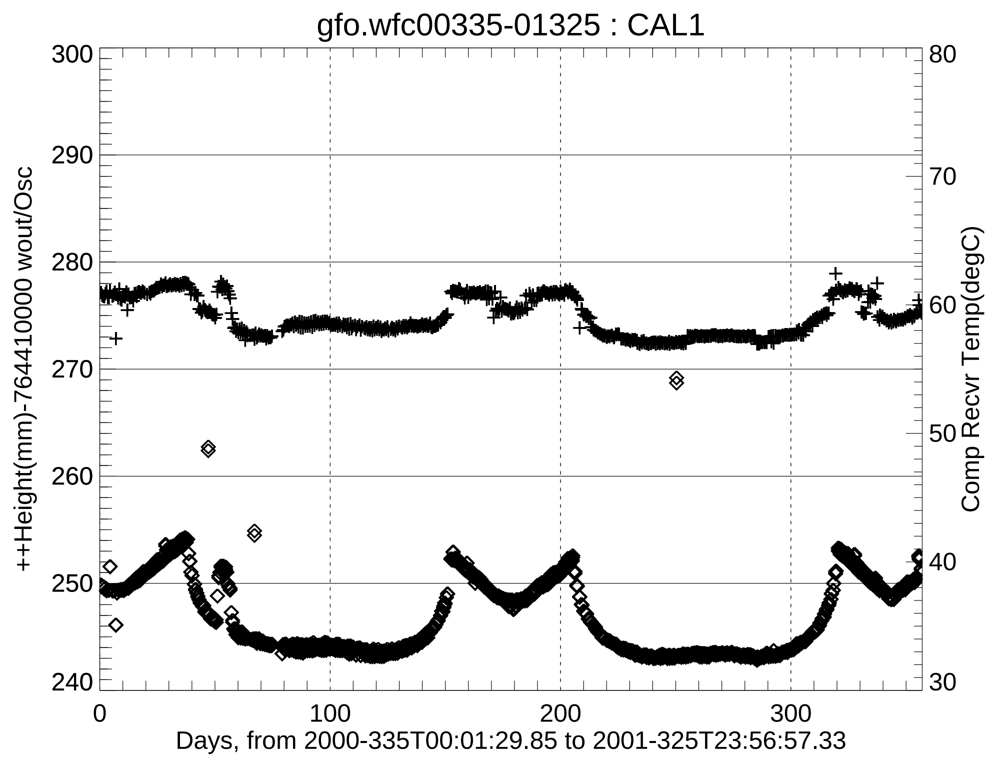

Figure 2-1 CAL-1 Range/Temperatures for the First 20 Cycles

2.1.2 AGC

The CAL-1 and CAL-2 AGCs have been routinely temperature-corrected at the GFO processing center using an algorithm derived by Wallops. The AGC temperature correction algorithms are the same for both CAL-1 and CAL-2, and were based on the initial CAL-1 results.

During the first 20 cycles, the CAL-1 AGCs remained in a fairly narrow band of 42.62+0.06 dB. No significant AGC drift is noted, and no further temperature dependency is indicated. The CAL-1 AGC is shown in Figure 2-2.

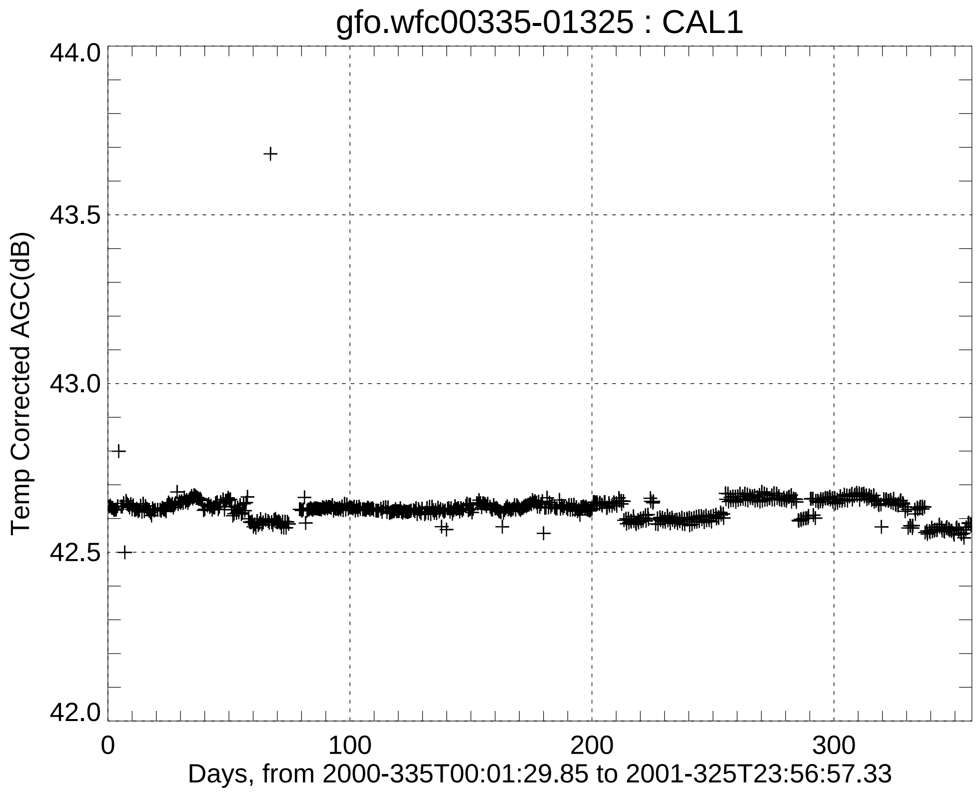

Figure 2-2 CAL-1 AGC for the First 20 Cycles

A CAL-2 AGC temperature dependence is evident in Figure 2-3 "CAL-2 AGC for the First 20 Cycles" on page 2-4. The CAL-2 shows variations, but these are correctable with temperature as can be seen by the temperature plot in Figure 2-1. WFF selected to apply the temperature correction for CAL-1 and not CAL-2 as best for normal AGC processing.

2.2 GFO Cycle (17-day) Summaries

Another indication of the GFO altimeter's internal consistency is the agreement of cycle-to-cycle means for: global significant waveheights, sigma-naughts, and wind-speed. For this analysis, the measurements for complete cycles (17 days) were meaned, standard deviations were computed, and measurement histograms were produced.

Prior to the computations, the data sets were edited to eliminate suspect measurements. Our edit criteria are as follows:

- Quality Word #1
  - Bit 2: Record is zero-filled
  - Bit 3: Altimeter not in Fine Track
  - Bit 5: Receiver Temperature error

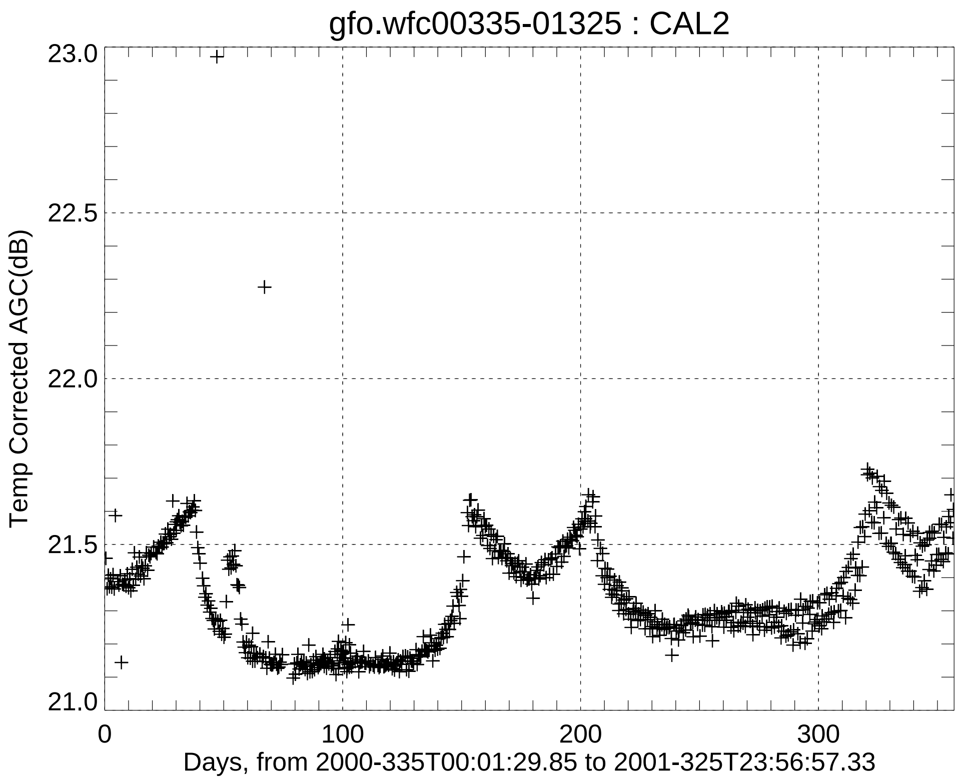

Figure 2-3 CAL-2 AGC for the First 20 Cycles

- Bit 7: No smoothed VATT
- Bit 10: SWH bounds error
- Bit 18: Off-Nadir error
- Bit 19: SWH standard error
- Bits 22-31: More than 5 frames missing

- Quality Word #2
  - Bit 11: Land contamination
- Default fill values indicative of bad data

Note: Bit 0 is defined as LSB

We suggest the use of above criteria by data users for editing the GFO data.

The process by which the cycle summaries were produced involved the following criteria:

- 60 second averaging interval
- $0.2 < SWH < 12.0$
- $-66.0 < Latitude < 66.0$

- 6.0 < Sigma0 < 16.0
- 44 < Numpoints in intervals < 62

All the cycle summaries produced at Wallops so far indicate excellent cycle-to-cycle consistency. Summaries for the first 20 cycles are shown in Table 2-1 "Cycle Summaries" on page 2-5.

Column Definitions for Table 2-1 Cycle Summaries	
Cycle	Equivalent to Exactly 17 Days
Days in Cycles	Beginning Year and Julian Day through the Ending Year and Julian Day of the Cycle
SSHUSTD (m)	Cycle Average Uncorrected Sea Surface Height Standard Deviation
SWH (m)	Cycle Average Significant Wave Height
Sigma0 (dB)	Cycle Average Sigma0
AGC (dB)	Cycle Average Automatic Gain Control
Attitude (deg)	Cycle Average Attitude
RecvrTemp (C)	Cycle Average Receiver Temperature
WindSpeed (.1m/s)	Cycle Average Wind Speed
# Points Used	Total Number of Points Processed in the Cycle Period used in the Cycle Average

Table 2-1 Cycle Summaries

Cycle	Days in Cycle	SSHUSTD (m)	SWH (m)	Sigma0 (dB)	AGC (dB)	Attitude (deg)	RecvrTemp (C)	WindSpeed (.1m/s)	#Points Used
0	00335 - 00351	0.0426	2.4634	11.3467	43.2169	0.2392	38.1004	82.2133	661930.0
1	00352 - 01002	0.0435	2.5893	11.5076	43.3676	0.2502	39.7169	76.9435	670179.0
2	01003 - 01019	0.0421	2.4539	11.5464	43.4072	0.2422	38.1625	76.1032	705661.0
3	01020 - 01036	0.0424	2.5145	11.3383	43.2053	0.2105	35.9461	82.4006	705066.0
4	01037 - 01053	0.0428	2.5048	11.2909	43.1539	0.2340	33.6365	83.9581	575112.0
5	01054 - 01070	0.0440	2.5950	11.3143	43.1754	0.2362	33.5342	83.6164	792452.0
6	01071 - 01087	0.0443	2.6296	11.3496	43.2111	0.2335	33.3062	82.7288	778777.0
7	01088 - 01104	0.0448	2.6688	11.2597	43.1205	0.2255	33.2810	85.4292	727955.0
8	01105 - 01121	0.0442	2.6110	11.3374	43.1974	0.2270	35.3536	82.6415	781960.0
9	01122 - 01138	0.0445	2.5979	11.5202	43.3821	0.2361	38.7920	77.0297	682787.0
10	01139 - 01155	0.0429	2.4273	11.5259	43.3883	0.2254	37.1360	77.1754	769511.0
11	01156 - 01172	0.0431	2.4743	11.5309	43.3925	0.2301	38.9564	77.0553	761652.0
12	01173 - 01189	0.0442	2.6248	11.3143	43.1751	0.2200	36.1441	83.6154	767214.0
13	01190 - 01206	0.0437	2.5423	11.3137	43.1745	0.2083	33.2537	81.3067	750630.0
14	01207 - 01223	0.0441	2.6452	11.1944	43.0576	0.2097	32.7243	87.3751	747226.0

Table 2-1 Cycle Summaries (Continued)

Cycle	Days in Cycle	SSHUSTD (m)	SWH (m)	Sigma0 (dB)	AGC (dB)	Attitude (deg)	RecvrTemp (C)	WindSpeed (.1m/s)	#Points Used
15	01224 - 01240	0.0428	2.5422	11.2748	43.1381	0.2180	32.9023	84.7361	757575.0
16	01241 - 01257	0.0440	2.5988	11.2864	43.1472	0.2232	32.8176	84.7772	752352.0
17	01258 - 01274	0.0441	2.5846	11.3227	43.1835	0.2298	33.1715	83.4550	708963.0
18	01275 - 01291	0.0442	2.6115	11.4142	43.2758	0.2441	36.5931	80.1253	733146.0
19	01292 - 01308	0.0422	2.3769	11.5406	43.4015	0.2506	39.0869	76.0492	740202.0
20	01309 - 01325	0.0431	2.4908	11.3894	43.2502	0.2456	38.0352	80.7366	763436.0

2.2.1 Sigma0

The Sigma0 cycle-averages are plotted in Figure 2-4. Sigma0 has remained in a band between 11.19 and 11.55dB.

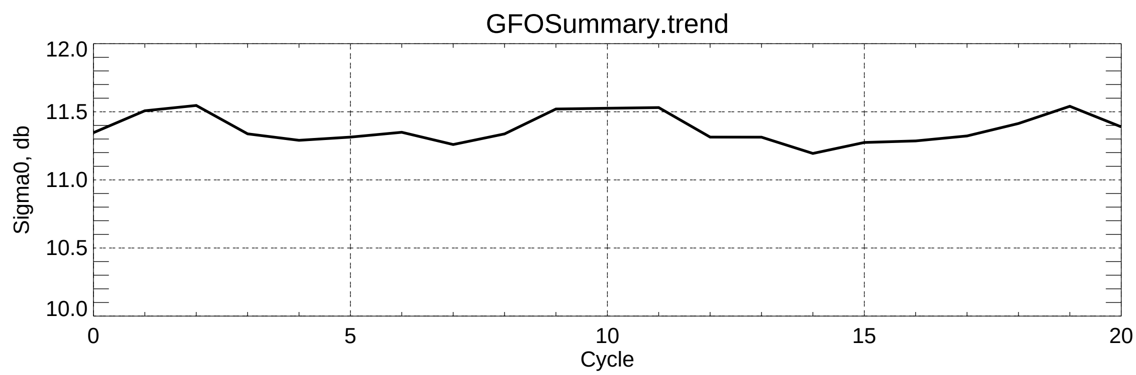

Figure 2-4 Cycle-Averages Sigma0 in dB

2.2.2 Significant Wave Height

The significant wave height (SWH) cycles-averages are shown in Figure 2-5. SWH has remained between 2.37 and 2.67 meters.

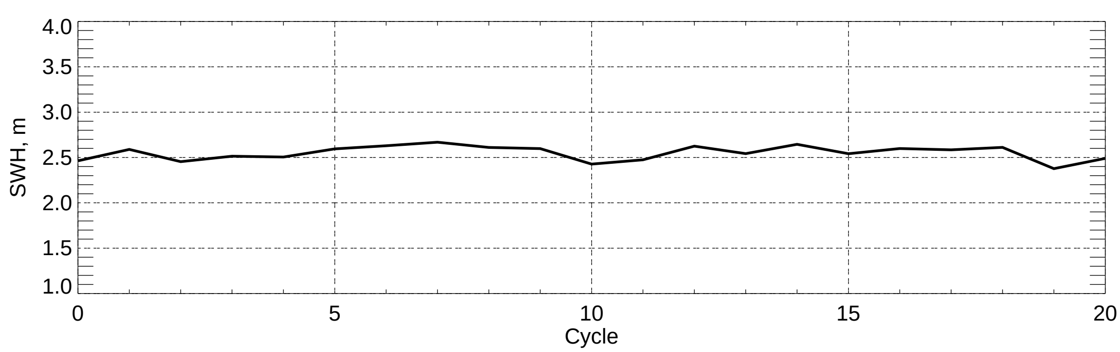

Figure 2-5 Cycle-Averages Significant Wave Height in Meters

2.2.3 Attitude

The attitude (Off-Nadir) cycle-averages are shown in Figure 2-6. Attitude has remained between 0.20 and 0.25 degrees.

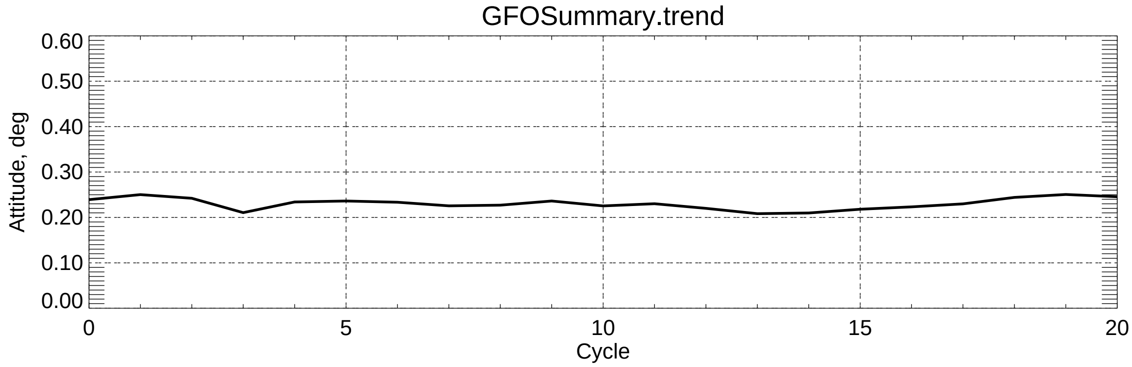

Figure 2-6 Cycle-Averages Attitude in Degrees

2.2.4 Windspeed

The windspeed cycle-averages are shown in Figure 2-7. Windspeed has remained between 7.60 and 8.74 meters/second.

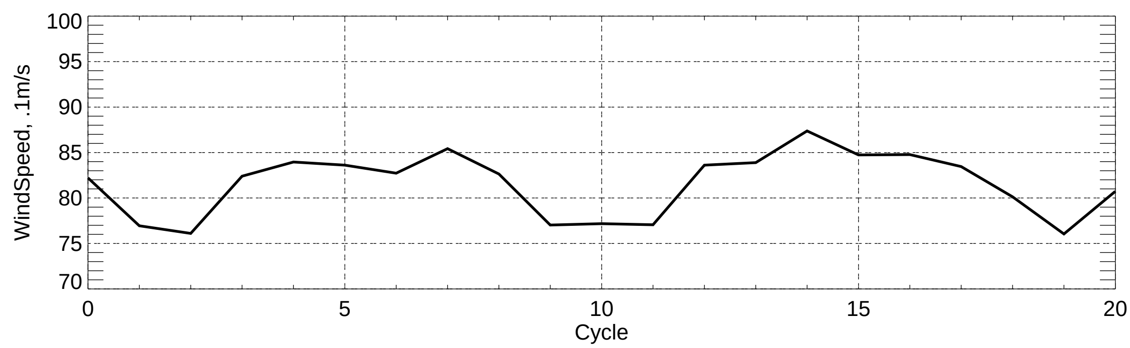

Figure 2-7 Cycle-Averages Windspeed in Meters Per Second

2.2.5 Receiver Temperature

The receiver temperature cycle-averages are shown in Figure 2-8 "Cycle-Averages Receiver Temperature in Celsius" on page 2-8. Receiver temperature has remained between 32.72 and 39.71 Celsius.

2.2.6 Sigma0 vs. Receiver Temperature

In Figure 2-9 "Cycle-Averages Sigma0 vs. Temperature" on page 2-8, there is an apparent small Sigma0 dependence on temperature, similar in magnitude to the CAL-2 dependence on temperature. As mentioned in Section 2.1.2, Wallops is currently quantifying the relationship. Our ongoing study is described in Section 4.3 of this report.

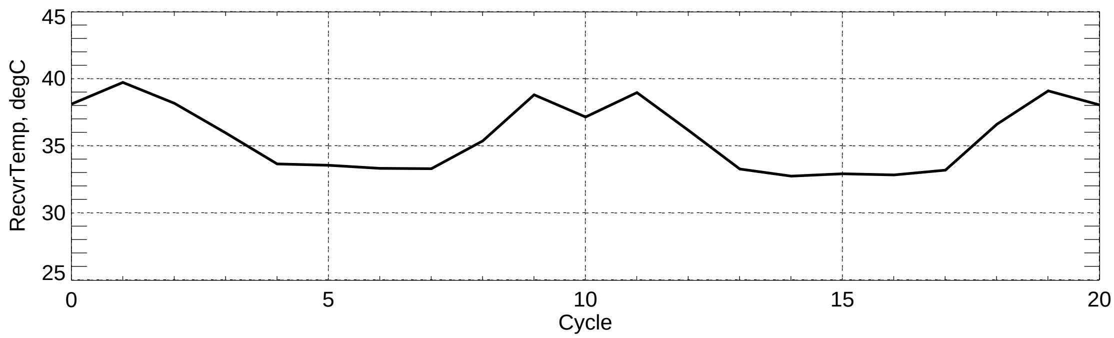

Figure 2-8 Cycle-Averages Receiver Temperature in Celsius

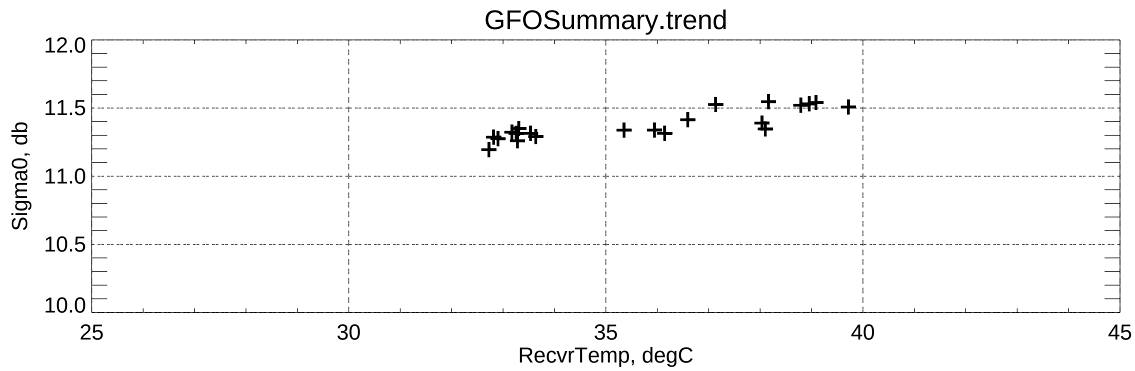

Figure 2-9 Cycle-Averages Sigma0 vs. Temperature

2.2.7 Cycle Summary Conclusions

We have found with TOPEX that, if the geophysical data are strictly edited, a global cycle average of parameters provides very stable results, and that variations can indicate changes in the altimeter instrument. The GFO cycle summary, Table 2-1, shows consistent values for the key parameters.

The GFO Sigma0, Figure 2-4, as expected exhibits a small variation with SWH, Figure 2-5, due to seasonal changes. We have not applied a seasonal correction to the data, but this raw Sigma0 still remains within 0.5 dB which is well within the 1 dB specification.

The waveform estimated attitude (Off-Nadir), Figure 2-6, has remained stable. This means that the data are consistent, and that the waveform samples have not changed their calibrations. The GFO Project has plans to initiate Attitude Boresight Calibration (ABCAL) tests in the near future (see Section 5.2), and those tests may lead to reducing the attitudes to less than 0.2 degrees.

The windspeed, Figure 2-7, is directly related to the Sigma0 and shows approximately a 1 meter variation. For calibration purposes, one could remove the seasonal variation, but again the raw average is better than the specification of 2 meters per second.

There appears to still be a minor temperature effect on Sigma0, Figure 2-9, but with the limited amount of data and small range, we have not considered this to be an issue at this time. We will study temperature effects in more detail over the next year.

2.3 GFO Key Events

The key events for the GFO altimeter since acceptance are summarized in Table 2-2. These sensor-related key events are extracted from:

http://gfo.bmpcoe.org/Gfo/Event_Log/gfo_event_log.htm.

Additionally, key events from a Wallops perspective have been included.

Table 2-2 GFO Key Events

Event	Date & Time of Event	Comments
Acceptance	29 Nov 2000 2000334T00:00:00Z	GFO Acceptance. SPAWAR authorizes DD250s.
Trim Burn	04 Dec 2000 2000339T06:55:00Z	ERO Trim Burn. 33.8 mm/sec at 0 deg yaw. Purpose is to raise the SMA and maintain the ERO.
Commanded	06 Dec 2000 2000341T13:34:00Z	A ground system planning error resulted in data outage of about 10.5 hours. The last command in the sequence, for an RA Calibration via CSM was omitted. This command normally sends the RA back to the Track mode. Since this last command was not sent, the RA was left in Standby mode until the next Calibration sequence was executed. Returned to track 06 Dec 2000, 2000341T23:59:00Z.
Moon Intrusion	07 Dec 2000 2000342T11:46:25Z	Moon Intrusion affected GFO pointing. Intrusion resulted in the nadir error exceeding acceptable limits (.27 degrees).
Moon Intrusion	07 Dec 2000 2000342T13:27:10Z	Moon Intrusion affected GFO pointing. Intrusion resulted in the nadir error exceeding acceptable limits (.27 degrees).
Moon Intrusion	07 Dec 2000 2000342T15:07:40Z	Moon Intrusion affected GFO pointing. Intrusion resulted in the nadir error exceeding acceptable limits (.27 degrees).
Trim Burn	08 Dec 2000 2000343T02:19:00Z	ERO Trim Burn. 6.9 mm/sec at 180 deg yaw (-6.9 mm/s). Purpose is to lower the SMA and keep the ground track from exceeding the western limit of the ERO.
Moon Intrusion	14 Dec 2000 2000349T12:48:53Z	Moon Intrusion affected GFO pointing.
Moon Intrusion	14 Dec 2000 2000349T14:48:34Z	Moon Intrusion affected GFO pointing.
Trim Burn	28 Dec 2000 2000363T12:53:00Z	ERO Trim Burn. 27.011 mm/sec at 0 deg yaw. Purpose is to raise the SMA and keep the ground track from exceeding the eastern limit of the ERO.

Table 2-2 GFO Key Events (Continued)

Event	Date & Time of Event	Comments
Moon Intrusion	14 Jan 2001 2001014T05:06:00Z	The maximum pointing error (ADNADER) was 0.55 degrees.Other intrusions at around this time may have occurred. None exceeded 0.27 degrees.
Commanded	19 Jan 2001 2001019T18:02:00Z	The attitude changed from above.25 to below.20 degrees and the Receiver Temperature started to increase from 35 degrees. Explanation: Navsoc started the battery reconditioning sequence. Among other things, this sequence turns on the second horizon scanner, which would explain the improved pointing. In addition to the horizon scanner, a GPS Receiver and the catbed heaters are also turned on - this would explain the increase in Temperatures. Battery deep discharge reconditioning was initiated on Jan 19 at 18:02z.
Behavior	20 Jan 2001 2001020T15:28:00Z	“Anomalous behavior in GFO reaction wheel 3 torques”. Wheel torque for wheel 3 displaying unusually large swings in the applied wheel torque. Does not appear to be affecting the satellite pointing.
Variations	21 Jan 2001 2001021T00:00:00Z	Doppler problem (noise/degraded orbits). The Doppler Beacon Signal is rather noisy.
Commanded	24 Jan 2001 2001024T03:13:00Z	“GFO reaction wheel 3”. Commanded spacecraft to run with horizon scanner 2 instead of the 2 horizon scanner configuration. During the horizon scanner switch there were transient nadir pointing errors in the order of 0.58 degrees. The attitude returned back to above.25 from below.20 degrees at this time. The Receiver Temperature did not change.
Power Cycled	24 Jan 2001 2001024T23:57:42Z	Reaction wheel 3 was power cycled. No change was seen in the satellites behavior.
Commanded	25 Jan 2001 2001025T18:10:00Z	Extra Loads used for battery deep discharge conditioning were shed. This should return the satellite to normal power and thermal balance. The satellite is being kept in the 1 failed cell configuration at VT 7.5.
Variations	26 Jan 2001 2001026T00:00:00Z	Doppler problem (noise/degraded orbits). The Doppler Beacon Signal noise has subsided and tracks are good/improving. The oscillator on beacon 1 can not handle increased temperature adequately.
Commanded	26 Jan 2001 2001026T17:39:54Z	Switched to the redundant wheel (wheel 4) and disabled wheel 3. This involves putting the satellite into acquire sun and the radar altimeter in stand-by. Running on redundant wheel, in point state and the radar altimeter back in track.

Table 2-2 GFO Key Events (Continued)

Event	Date & Time of Event	Comments
Maneuver	30 Jan 2001 2001030T01:47:00Z	The magnitude will be 29.4 mm/s and the yaw will be 0 degrees. GFO has drifted out of the ERO and is currently about 1.3 km east of the centerline (300 m out of limits). After the maneuver, GFO should drift back into the ERO by 1/31 at 16:15Z. Satellite had drifted 300 m out of ERO.
Moon Intrusion	05 Feb 2001 2001036T12:31:35Z	GFO horizon scanner has experienced a moon intrusion event which has caused excursions from acceptable nadir pointing limits (.27 degrees). The time of this excursion and maximum amplitude is: 12:31:35 - 12:31:45Z (0.40 degrees max)
Moon Intrusion	05 Feb 2001 2001036T14:12:00Z	The time of this excursion and maximum amplitude is: 14:12:00 - 14:12:30Z (0.95 degrees max)
Moon Intrusion	05 Feb 2001 2001036T15:52:50Z	The time of this excursion and maximum amplitude is: 15:52:50 - 15:53:10Z (0.47 degrees max)
Moon Intrusion	10 Feb 2001 2001041T06:30:00Z	The time of the excursion and maximum amplitude is: 06:30:00 - 06:30:15Z (0.43 degrees max)
Moon Intrusion	10 Feb 2001 2001041T08:10:50Z	The time of the excursion and maximum amplitude is: 08:10:50 - 08:11:20Z (0.86 degrees max)
Moon Intrusion	10 Feb 2001 2001041T09:51:45Z	The time of the excursion and maximum amplitude is: 09:51:45 - 09:52:10Z (0.87 degrees max)
Moon Intrusion	11 Feb 2001 2001042T04:32:25Z	The time of the excursion and maximum amplitude is: 04:32:25 - 04:32:40Z (0.35 degrees max)
Moon Intrusion	11 Feb 2001 2001042T13:47:05Z	The time of the excursion and maximum amplitude is: 13:47:05 - 13:47:10Z (0.60 degrees max)
Under Voltage	12 Feb 2001 2001043T21:57:00Z	GFO apparently suffered an under-voltage (UV1) event. As a consequence, the payload bus was powered off. Due to the load shedding effect of the UV1, GFO is in a safe power configuration. The payloads are off and GFO is not collecting data.
Payloads On	15 Feb 2001 2001045T06:49:00Z	Payloads turned back on. GFO in standby mode.
In Operation	16 Feb 2001 2001047T19:00:00Z	GFO collecting data, payloads switched from standby mode to track mode. The reconditioning reset, the battery voltages, temperatures and pressures appeared normal. The payloads were turned back on, software patches installed and then set to track and produce data over the weekend to test the batteries under load. Examination of the battery and other satellite data yesterday and today indicates that the bus voltages is about 27.8 (28 volt bus), the NiH battery temperatures are in the normal range of 8 to 9 deg C, and the pressures are running between 495 and 620 psi as they should. The system will be left in this condition (VT is 6.0) and closely monitored.

Table 2-2 GFO Key Events (Continued)

Event	Date & Time of Event	Comments
Trim Maneuver	01 Mar 2001 2001060T23:06:00Z	The purpose of the maneuver will be to raise the semi-major axis and maintain the ERO. The burn magnitude will be 28.719 mm/sec with a zero degree yaw offset.
Moon Intrusion	06 Mar 2001 2001065T00:54:00Z	The time of the excursion and maximum amplitude is: 00:54:00Z - 00:54:20Z (0.34 degrees max)
Moon Intrusion	06 Mar 2001 2001065T02:34:10Z	The time of the excursion and maximum amplitude is: 02:34:10Z - 02:34:40Z (0.39 degrees max)
Moon Intrusion	06 Mar 2001 2001065T04:14:35Z	The time of the excursion and maximum amplitude is: 04:14:35Z - 04:15:10Z (0.48 degrees max)
Moon Intrusion	06 Mar 2001 2001065T05:54:55Z	The time of the excursion and maximum amplitude is: 05:54:55Z - 05:55:05Z (0.40 degrees max)
Moon Intrusion	06 Mar 2001 2001065T19:52:45Z	The time of the excursion and maximum amplitude is: 19:52:45Z - 19:53:15Z (0.63 degrees max)
Moon Intrusion	12 Mar 2001 2001071T04:12:30Z	The time of the excursion and maximum amplitude is: 04:12:30Z - 04:12:45Z (0.49 degrees max)
Moon Intrusion	12 Mar 2001 2001071T05:52:35Z	The time of the excursion and maximum amplitude is: 05:52:35Z - 05:53:10Z (0.67 degrees max)
Moon Intrusion	12 Mar 2001 2001071T07:33:05Z	The time of the excursion and maximum amplitude is: 07:33:05Z - 07:33:40Z (0.86 degrees max)
Moon Intrusion	12 Mar 2001 2001071T09:13:40Z	The time of the excursion and maximum amplitude is: 09:13:40Z - 09:14:05Z (0.74 degrees max)
Moon Intrusion	12 Mar 2001 2001071T18:10:20Z	The time of the excursion and maximum amplitude is: 18:10:20Z - 18:10:40Z (0.41 degrees max)
Moon Intrusion	12 Mar 2001 2001071T19:50:43Z	The time of the excursion and maximum amplitude is: 19:50:43Z - 19:51:10Z (0.59 degrees max)
Test Support	14 Mar 2001 2001073T21:48:30Z	Due to a Momentum Wheel 3 Testing support, the satellite yaw was about 0.47 degrees. GFO experienced pointing errors that exceeded the .27 degrees limit. The time of the excursion is: 21:48:30Z - 21:53:00Z
Trim Maneuver	21 Mar 2001 2001080T00:55:00Z	The burn magnitude will be 30.4 mm/sec with a zero degree yaw offset.
Trim Maneuver	30 Mar 2001 2001089T01:13:00Z	The burn magnitude will be 36 mm/sec with a zero degree yaw offset.
Trim Maneuver	03 Apr 2001 2001093T00:51:00Z	The next burn will be in 100 minutes.
Trim Maneuver	03 Apr 2001 2001093T02:31:00Z	The total burn magnitude will be 70 mm/sec with a zero degree yaw offset.

Table 2-2 GFO Key Events (Continued)

Event	Date & Time of Event	Comments
Trim Maneuver	04 Apr 2001 2001094T03:22:00Z	The burn magnitude will be 40 mm/sec with a 180 degree yaw offset.
Moon Intrusion	10 Apr 2001 2001100T19:53:33Z	The time of the excursion and maximum amplitude is: 19:53:33Z - 19:53:45Z (0.33 degrees max)
Moon Intrusion	10 Apr 2001 2001100T21:33:50Z	The time of the excursion and maximum amplitude is: 21:33:50Z - 21:34:40Z (0.59 degrees max)
Moon Intrusion	10 Apr 2001 2001100T22:38:13Z	The time of the excursion and maximum amplitude is: 22:38:13Z - 22:38:48Z (0.40 degrees max)
Moon Intrusion	10 Apr 2001 2001100T23:14:35Z	The time of the excursion and maximum amplitude is: 23:14:35Z - 23:15:03Z (0.72 degrees max)
Moon Intrusion	11 Apr 2001 2001101T00:18:45Z	The time of the excursion and maximum amplitude is: 00:18:45Z - 00:19:20Z (0.68 degrees max)
Moon Intrusion	11 Apr 2001 2001101T00:55:02Z	The time of the excursion and maximum amplitude is: 00:55:02Z - 00:55:07Z (0.31 degrees max)
Moon Intrusion	11 Apr 2001 2001101T01:59:20Z	The time of the excursion and maximum amplitude is: 01:59:20Z - 01:59:47Z (0.74 degrees max)
Trim Maneuver	13 Apr 2001 2001103T00:30:00Z	The burn magnitude will be 30 mm/sec with a 0 degree yaw offset.
CSM Upload	30 Apr 2001 2001120T00:00:00Z	CSM Time Tag Anomaly. A CSM upload was planned on Wednesday (Day 115) to be uploaded on Friday (Day 117) with commands for Monday and Tuesday (Days 120 and 121). The times in the ASCII CSM .dat file are correct. The ground system uses the SCC on the ground system at HQ to convert the times to VTCW when building the CSM command. All of the commands in that CSM were 3 days 3 hours and 40 minutes earlier than they should have been. The commands for Day 121 executed on Day 118. The commands for Day 120 were changed to Day 116 which was in the past, so GFO interpreted that as 6 days and 8.7 hours in the future from Day 116 or Day 123-124. (CSM commands can be uploaded a maximum of 6 days 8.7 hours before they execute.)
Trim Maneuver	02 May 2001 2001122T05:39:00Z	The burn magnitude will be 30.9 mm/sec with a 0 degree yaw offset. GFO out of point: 122T05:32:00Z - 122T05:44:00Z.
Trim Maneuver	08 May 2001 2001128T05:05:00Z	The purpose of the maneuver will be a small "stopping" maneuver. The burn magnitude will be 4.4 mm/sec with a 180 degree yaw offset. GFO out of point: 128T04:58:00Z - 128T05:10:00Z.
Trim Maneuver	31 May 2001 2001151T23:49:00Z	The burn magnitude will be 16.8 mm/sec with a 0 degree yaw offset. GFO out of point: 151T23:42:00Z - 151T23:54:00Z
Reconditioning	04 Jun 2001 2001155T00:00:00Z	Battery reconditioning. This will continue until 14 June. Expected to have no affect on normal operations.

Table 2-2 GFO Key Events (Continued)

Event	Date & Time of Event	Comments
Moon Intrusion	11 Jun 2001 2001162T01:00:27Z	The time of the excursion and maximum amplitude is: 01:00:27Z - 01:00:29Z (0.31 degrees max)
Moon Intrusion	11 Jun 2001 2001162T02:41:02Z	The time of the excursion and maximum amplitude is: 02:41:02Z - 02:41:25Z (0.63 degrees max)
Moon Intrusion	11 Jun 2001 2001162T04:21:42Z	The time of the excursion and maximum amplitude is: 04:21:42Z - 04:21:50Z (0.52 degrees max)
Antenna Swap	20 Jun 2001 2001171T00:00:00Z	The doppler system antenna at Headquarter has been swapped yesterday (6/20) afternoon (Pacific Time). As a result, the doppler system is out of degraded mode, and working nominally.
Antenna Swap	28 Jun 2001 2001179T00:00:00Z	The doppler system antenna at Headquarter is now back up and functioning again.
Trim Maneuver	29 Jun 2001 2001180T00:03:00Z	The burn magnitude will be 14.6 mm/sec with a 0 degree yaw offset. GFO out of point: 179T23:56:00Z - 180T00:08:00Z
Moon Intrusion	02 Jul 2001 2001183T02:48:53Z	The time of the excursion and maximum amplitude is: 02:48:53Z - 02:49:00Z (0.28 degrees max)
Moon Intrusion	02 Jul 2001 2001183T04:29:37Z	The time of the excursion and maximum amplitude is: 04:29:37Z - 04:29:42Z (0.29 degrees max)
Moon Intrusion	02 Jul 2001 2001183T17:29:02Z	The time of the excursion and maximum amplitude is: 17:19:02Z - 17:19:33Z (1.07 degrees max)
Moon Intrusion	02 Jul 2001 2001183T18:59:45Z	The time of the excursion and maximum amplitude is: 18:59:45Z - 19:00:15Z (0.92 degrees max)
Moon Intrusion	02 Jul 2001 2001183T20:40:23Z	The time of the excursion and maximum amplitude is: 20:40:23Z - 20:40:55Z (0.95 degrees max)
Moon Intrusion	02 Jul 2001 2001183T22:20:52Z	The time of the excursion and maximum amplitude is: 22:20:52Z - 22:20:58Z (0.34 degrees max)
Moon Intrusion	31 Jul 2001 2001212T07:55:22Z	The time of the excursion and maximum amplitude is: 07:55:22Z - 07:55:25Z (0.31 degrees max)
Moon Intrusion	01 Aug 2001 2001213T10:08:07Z	The time of the excursion and maximum amplitude is: 10:08:07Z - 10:08:30Z (0.94 degrees max)
Moon Intrusion	01 Aug 2001 2001213T11:48:34Z	The time of the excursion and maximum amplitude is: 11:48:34Z - 11:49:03Z (0.98 degrees max)
Moon Intrusion	01 Aug 2001 2001213T13:28:59Z	The time of the excursion and maximum amplitude is: 13:28:59Z - 13:29:36Z (0.51 degrees max)
Moon Intrusion	01 Aug 2001 2001213T15:09:59Z	The time of the excursion and maximum amplitude is: 15:09:59Z - 15:10:12Z (0.61 degrees max)
Moon Intrusion	07 Aug 2001 2001219T16:59:40Z	The time of the excursion and maximum amplitude is: 16:59:40Z - 16:59:55Z (0.28 degrees max)

Table 2-2 GFO Key Events (Continued)

Event	Date & Time of Event	Comments
Moon Intrusion	07 Aug 2001 2001219T18:39:27Z	The time of the excursion and maximum amplitude is: 18:39:27Z - 18:39:48Z (0.90 degrees max)
Moon Intrusion	07 Aug 2001 2001219T20:20:17Z	The time of the excursion and maximum amplitude is: 20:20:17Z - 20:20:45Z (0.81 degrees max)
Moon Intrusion	07 Aug 2001 2001219T22:00:58Z	The time of the excursion and maximum amplitude is: 22:00:58Z - 22:01:03Z (0.29 degrees max)
Moon Intrusion	08 Aug 2001 2001220T23:28:25Z	The time of the excursion and maximum amplitude is: 23:28:25Z - 23:28:33Z (0.29 degrees max)
Trim Maneuver	14 Aug 2001 2001226T00:55:00Z	The burn magnitude will be 18.6 mm/sec with a 0 degree yaw offset. GFO out of point: 226T00:48:00Z - 226T01:00:00Z
Point Test	27 Aug 2001 2001239T17:05:40Z	GFO normally uses the vector method in point mode, but this method does not allow the use of the Target Table (Table 39) to generate offsets for the upcoming ABCAL maneuvers. The quaternion method does allow the use of the Target Table, but can be susceptible to coupling between Z-axis rotation and nadir pointing errors. A test was performed on GFO today (DOY 239) to determine the amount of coupling between Z-axis rotation and nadir errors while in quaternion point mode. GFO was placed in quaternion point mode for one rev (239/17:05:40 through 239/18:45:34) in order to collect the necessary data, then switched back into vector point mode.
Trim Maneuver	31 Aug 2001 2001243T00:27:00Z	The burn magnitude will be 23.6 mm/sec with a 0 degree yaw offset. GFO out of point: 243T00:20:00Z - 243T00:32:00Z
Moon Intrusion	07 Sep 2001 2001250T04:06:15Z	The time of the excursion and maximum amplitude is: 04:06:15Z - 04:06:40Z (0.39 degrees max)
Moon Intrusion	07 Sep 2001 2001250T05:46:45Z	The time of the excursion and maximum amplitude is: 05:46:45Z - 05:47:13Z (0.49 degrees max)
Moon Intrusion	07 Sep 2001 2001250T07:27:02Z	The time of the excursion and maximum amplitude is: 07:27:02Z - 07:27:35Z (0.46 degrees max)
Moon Intrusion	07 Sep 2001 2001250T09:07:34Z	The time of the excursion and maximum amplitude is: 09:07:34Z - 09:08:05Z (0.67 degrees max)
Moon Intrusion	07 Sep 2001 2001250T10:48:10Z	The time of the excursion and maximum amplitude is: 10:48:10Z - 10:48:35Z (0.68 degrees max)
Moon Intrusion	07 Sep 2001 2001250T12:28:45Z	The time of the excursion and maximum amplitude is: 12:28:45Z - 12:28:50Z (0.37 degrees max)
Trim Maneuver	15 Sep 2001 2001258T02:44:00Z	The burn magnitude will be 32.0 mm/sec with a 0 degree yaw offset. GFO out of point: 258T02:37:00Z - 258T02:49:00Z
Trim Maneuver 1 of 2	28 Sep 2001 2001271T01:03:00Z	The total burn magnitude will be 48.8 mm/sec with a 0 degree yaw offset. GFO out of point: 271T00:56:00Z - 271T01:08:00Z

Table 2-2 GFO Key Events (Continued)

Event	Date & Time of Event	Comments
Trim Maneuver 2 of 2	28 Sep 2001 2001271T02:43:00Z	The total burn magnitude will be 48.8 mm/sec with a 0 degree yaw offset. GFO out of point: 271T02:36:00Z - 271T02:48:00Z
Moon Intrusion	05 Oct 2001 2001278T01:54:20Z	The time of the excursion and maximum amplitude is: 01:54:20Z - 01:55:10Z (0.83 degrees max)
Moon Intrusion	05 Oct 2001 2001278T03:35:05Z	The time of the excursion and maximum amplitude is: 03:35:05Z - 03:35:35Z (0.71 degrees max)
Moon Intrusion	06 Oct 2001 2001279T20:52:20Z	The time of the excursion and maximum amplitude is: 20:52:20Z - 20:52:30Z (0.30 degrees max)
Moon Intrusion	06 Oct 2001 2001279T22:32:25Z	The time of the excursion and maximum amplitude is: 22:32:25Z - 22:33:00Z (0.42 degrees max)
Moon Intrusion	07 Oct 2001 2001280T00:13:05Z	The time of the excursion and maximum amplitude is: 00:13:05Z - 00:13:25Z (0.34 degrees max)
Trim Maneuver 1 of 2	11 Oct 2001 2001284T02:46:00Z	The total burn magnitude will be 42.2 mm/sec with a 0 degree yaw offset. GFO out of point: 284T02:39:00Z - 284T02:51:00Z
Trim Maneuver 2 of 2	11 Oct 2001 2001284T04:26:00Z	The total burn magnitude will be 42.2 mm/sec with a 0 degree yaw offset. GFO out of point: 284T04:19:00Z - 284T04:31:00Z
Trim Maneuver 1 of 2	23 Oct 2001 2001296T03:29:00Z	The total burn magnitude will be 46.3 mm/sec with a 0 degree yaw offset. GFO out of point: 296T03:22:00Z - 296T03:34:00Z
Trim Maneuver 2 of 2	23 Oct 2001 2001296T05:09:00Z	The total burn magnitude will be 46.3 mm/sec with a 0 degree yaw offset. GFO out of point: 296T05:02:00Z - 296T05:14:00Z
Configuration	24 Oct 2001 2001297T18:46:50Z	As a result of the Wheel 3 patch activation and configuration change performed on GFO today, the satellite radar altimeter was out of track 1 mode between the following times: 297T1846:50Z - 296T18:53:12Z. As a result, payload data will be affected accordingly. Also, the Satellite was out of point state during the following times: 297T18:47:02Z - 297T18:51:52Z
Moon Intrusion	27 Oct 2001 2001300T21:16:00Z	The time of the excursion and maximum amplitude is: 21:16:00Z - 21:16:10Z (0.33 degrees max)
Moon Intrusion	27 Oct 2001 2001300T22:56:35Z	The time of the excursion and maximum amplitude is: 22:56:35Z - 22:56:40Z (0.30 degrees max)
Moon Intrusion	28 Oct 2001 2001301T03:30:30Z	The time of the excursion and maximum amplitude is: 03:30:30Z - 03:30:40Z (0.33 degrees max)
Moon Intrusion	28 Oct 2001 2001301T05:11:00Z	The time of the excursion and maximum amplitude is: 05:11:00Z - 05:11:30Z (0.64 degrees max)
Moon Intrusion	28 Oct 2001 2001301T06:51:35Z	The time of the excursion and maximum amplitude is: 06:51:35Z - 06:51:50Z (0.67 degrees max)
Moon Intrusion	28 Oct 2001 2001301T08:32:10Z	The time of the excursion and maximum amplitude is: 08:32:10Z - 08:32:25Z (0.40 degrees max)

Table 2-2 GFO Key Events (Continued)

Event	Date & Time of Event	Comments
Trim Maneuver	01 Nov 2001 2001305T05:28:00Z	The burn magnitude will be 31.5 mm/sec with a 0 degree yaw offset. GFO out of point: 305T05:21:00Z - 305T05:33:00Z
Moon Intrusion	04 Nov 2001 2001308T06:19:15Z	The time of the excursion and maximum amplitude is: 06:19:15Z - 06:19:45Z (0.65 degrees max)
Moon Intrusion	04 Nov 2001 2001308T07:59:50Z	The time of the excursion and maximum amplitude is: 07:59:50Z - 08:00:20Z (0.63 degrees max)
Moon Intrusion	04 Nov 2001 2001308T09:40:30Z	The time of the excursion and maximum amplitude is: 09:40:30Z - 09:40:35Z (0.33 degrees max)
Moon Intrusion	05 Nov 2001 2001309T05:17:10Z	The time of the excursion and maximum amplitude is: 05:17:10Z - 05:17:20Z (0.29 degrees max)
Moon Intrusion	05 Nov 2001 2001309T06:57:50Z	The time of the excursion and maximum amplitude is: 06:57:50Z - 06:58:00Z (0.35 degrees max)
ERO Violation	06 Nov 2001 2001310T01:45:00Z	Due to a decrease in drag, the GFO ground track is going to exceed the ERO (Tuesday 11/6) for about 6.5 days. The ERO is predicted to exceed 1000 m West on 11/6 at 01:45Z. The maximum excursion of 1227 m West will be on 11/9 at 06:54Z and the ground track will re-enter the ERO on 11/12 at 17:04Z.
Configuration	07 Nov 2001 2001311T19:51:34Z	On GFO rev Det A 19549 a switch of the reaction wheel configuration from 1-2-3 to 1-2-4.
Back in ERO	08 Nov 2001 2001312T21:00:0Z	GFO's ground track has turned around. The average ground track will be back inside the 1 km limit 312T21:00.
Trim Maneuver	15 Nov 2001 2001319T01:21:00Z	The burn magnitude will be 28.2 mm/sec with a 0 degree yaw offset. GFO out of point: 319T01:14:00Z - 305T01:27:00Z

2.4 GFO Ground Processing Errors

The ground processing errors are problems that have been noticed at NASA Wallops Flight Facility from the processing of ground data at the Payload Operations Center located at NAVOCEANO. Table 2-3, GFO Ground Processing Errors, is a table that indicates the problems.The majority of these problems are listed in “Segment data for.........appears to be bad”. The determination on these data is that there are more than 40 messages indicating problems with the data. An example of a log for segment ra_data01298_19_59_38 follows.

```
---------------------------------------------------------------------------
 WFF VERSION : asc RA Software = Version 1.0 07/21/97
---------------------------------------------------------------------------

 First Sci frame number ;   0
 First Sci frame seconds:     71978.546332350
 First Sci frame UTC    : 2001-298T19:59:38.546875
```

```
First Eng frame number ;   0
First Eng frame seconds:     71978.760512470
First Eng frame UTC    : 2001-298T19:59:38.757813

Delta EngTime Gap  0.    57311978.757813      5.73120E+07
Delta SciTime Gap    71978.546332350    71978.546332350    0.
Delta SciTime Gap    71986.287645230    71986.483696520     0.196051
Delta SciTime Gap    74166.024907280    74163.590053530    -2.43485
Delta SciTime Gap    74163.590053530    74166.318883720      2.72883
Delta SciTime Gap    74168.082742330    74168.209404180     0.126662
Delta SciTime Gap    74168.209404180    74168.278726630      6.93225E-02
Delta SciTime Gap    74170.042585230    74168.567839490    -1.47475
Delta SciTime Gap    74168.567839490    74170.238569520      1.67073
Delta EngTime Gap    57314190.578125    57314190.578125    0.
Delta EngTime Gap    57314190.578125    57314198.765625      8.18750
Delta SciTime Gap    74192.090817960    74193.364715860      1.27390
Delta SciTime Gap    74193.952668730    74183.955848360    -9.99682
Delta SciTime Gap    74183.955848360    74194.246645170    10.29080
Delta SciTime Gap    74194.344637320    74178.843179380    -15.5015
Delta SciTime Gap    74178.843179380    74181.922001510      3.07882
Delta SciTime Gap    74181.922001510    74179.136640860    -2.78536
Delta SciTime Gap    74179.234633010    74180.410538750      1.17591
Delta SciTime Gap    74180.704515190    74193.285437360      12.5809
Delta SciTime Gap    74193.285437360    74180.998491630    -12.2869
Delta SciTime Gap    74181.096483770    74183.677793790      2.58131
Delta SciTime Gap    74183.677793790    74198.166331000      14.4885
Delta SciTime Gap    74198.362315290    74198.331287780    -3.10275E-02
Delta SciTime Gap    74198.331287780    74198.656291730     0.325004
Delta EngTime Gap    57314198.765625    57321617.421875      7418.66
Delta SciTime Gap    74199.244244600    74199.011511270    -0.232733
Delta SciTime Gap    74199.011511270    74199.440228890     0.428718
Delta SciTime Gap    74200.420150350    81613.584303520      7413.16
Delta SciTime Gap    81615.740130740    74202.771961850    -7412.97
Delta SciTime Gap    74217.274799440    74218.120228650     0.845429
Delta SciTime Gap    74218.120228650    74217.568775880    -0.551453
Delta SciTime Gap    74217.568775880    74243.800875400      26.2321
Delta SciTime Gap    74243.800875400    74213.412215190    -30.3887
Delta SciTime Gap    74213.412215190    74217.960744460      4.54853
Delta SciTime Gap    74218.744681630    74218.940665920     0.195984
Delta SciTime Gap    74219.038658070    74220.410548110      1.37189
Delta SciTime Gap    74221.684446010    74221.847273950     0.162828
Delta SciTime Gap    74221.847273950    74221.978422440     0.131148
Delta SciTime Gap    74222.174406730    74242.403762600      20.2294
Delta SciTime Gap    74242.403762600    74222.468383170    -19.9354
Delta SciTime Gap    74222.468383170    74223.840273210      1.37189
Delta SciTime Gap    74224.722202520    74242.477994770      17.7558
Delta SciTime Gap    74243.555908370    74226.878029730    -16.6779
Delta SciTime Gap    74234.423424960    74257.220373940      22.7969
Delta SciTime Gap    74257.220373940    74234.717401400    -22.5030
Delta SciTime Gap    74237.951142230    74258.744665440      20.7935
Delta SciTime Gap    74258.842683150    74237.356646080    -21.4860
Delta SciTime Gap    74237.356646080    74259.234651740      21.8780
Delta SciTime Gap    74259.332643890    74235.076492930    -24.2562
Delta SciTime Gap    74235.076492930    74259.626620320      24.5501
```

Delta SciTime Gap	74259.822348640	74260.116581060	0.294232
Delta SciTime Gap	74260.214573200	74243.536694560	-16.6779
Delta SciTime Gap	74243.732678850	74238.676636290	-5.05604
Delta SciTime Gap	74238.676636290	74243.929065330	5.25243
Delta SciTime Gap	74244.124647440	74238.917368000	-5.20728
Delta SciTime Gap	74238.917368000	74244.418984250	5.50162
Delta SciTime Gap	74244.418984250	74244.614608170	0.195624
Delta SciTime Gap	74244.614608170	74247.492424410	2.87782
Delta SciTime Gap	74247.492424410	74245.104568900	-2.38786
Delta SciTime Gap	74245.202561050	74246.574451090	1.37189
Delta SciTime Gap	74246.966419680	74247.260396110	0.293976
Delta SciTime Gap	74247.848348990	74245.978138960	-1.87021
Delta SciTime Gap	74245.978138960	74248.142325430	2.16419
Delta SciTime Gap	74248.828286460	74249.024254750	0.195968
Delta SciTime Gap	74249.220239040	74275.387728740	26.1675
Delta SciTime Gap	74275.387728740	74249.514215480	-25.8735
Delta SciTime Gap	74259.999375160	74255.362617980	-4.63676
Delta SciTime Gap	74255.362617980	74260.293351600	4.93073
Delta SciTime Gap	74260.881304480	74249.183762480	-11.6975
Delta SciTime Gap	74249.183762480	74261.077288770	11.8935
Delta SciTime Gap	74261.077288770	74262.211227850	1.13394
Delta SciTime Gap	74262.211227850	74261.469257360	-0.741970
Delta EngTime Gap	57321617.421875	57314202.859375	-7414.56
Delta SciTime Gap	74261.567249510	110944.45403039	36682.9
Delta EngTime Gap	57314217.195313	57314221.296875	4.10156
Delta EngTime Gap	57314221.296875	57314227.437500	6.14062
Delta EngTime Gap	57314237.679688	57314243.820313	6.14062
Delta EngTime Gap	57314243.820313	57314247.921875	4.10156
Delta EngTime Gap	57314260.203125	57350945.042969	36684.8
Delta EngTime Gap	57350945.042969	57314266.351563	-36678.7
Delta EngTime Gap	57314286.828125	57314297.070313	10.24219
Delta EngTime Gap	57314297.070313	57314297.070313	0.
Delta EngTime Gap	57314297.070313	57314303.210938	6.14062
Delta EngTime Gap	57314309.359375	57363330.394531	49021.0

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Delta SciTime Gap	81929.762984040	81910.685101780	-19.0779
Delta SciTime Gap	81910.685101780	81930.056959940	19.3719
Delta SciTime Gap	81930.154952070	81905.309249430	-24.8457
Delta SciTime Gap	81905.309249430	81930.448928650	25.1397
Delta SciTime Gap	81930.742712460	78986.748371090	-2943.99
Delta SciTime Gap	78987.042347310	78988.678665090	1.63632
Delta SciTime Gap	78988.678665090	78987.434315930	-1.24435
Delta SciTime Gap	78987.532308090	78987.728292400	0.195984
Delta SciTime Gap	78987.728292400	78979.373904250	-8.35439
Delta SciTime Gap	78979.373904250	78989.488069790	10.11417
Delta SciTime Gap	78989.488069790	78990.962032230	1.47396
Delta SciTime Gap	78991.060024350	78979.909484400	-11.1505
Delta SciTime Gap	78979.909484400	78991.354000840	11.4445

```
Delta SciTime Gap    78991.549984840    78992.576292960      1.02631
Delta SciTime Gap    78992.576292960    78992.195430310    -0.380863
Delta SciTime Gap    78992.195430310    78980.620713380     -11.5747
Delta SciTime Gap    78980.620713380    78992.235930410      11.6152
Delta SciTime Gap    78992.823883260    78991.483006200     -1.34088
Delta SciTime Gap    78991.483006200    78980.947617480    -10.53539
Delta SciTime Gap    78981.045609570    78995.165572960      14.1200
Delta SciTime Gap    78995.165572960    78981.339587200     -13.8260
Delta SciTime Gap    78981.927539840    74082.065038090     -4899.86
Delta SciTime Gap    74082.065038090    74084.303018720      2.23798
Delta SciTime Gap    74084.303018720    74082.261023160     -2.04200
Delta SciTime Gap    74084.220866760    79001.055223370      4916.83
Delta EngTime Gap    57323701.375000    57323701.375000    0.
Delta SciTime Gap    83703.698105550    83703.698105550    0.

Final Sci frame number ;   114815
Final Sci frame seconds:     83703.698105550
Final Sci frame UTC    : 2001-298T23:15:03.695313
Final Eng frame number ;   5484
Final Eng frame seconds:     83699.327774790
Final Eng frame UTC    : 2001-298T23:14:59.328125
```

Table 2-3 GFO Ground Processing Errors

Data Type	Data Date	Comments
	29 November 2000 - 2000334	Acceptance
RA	02 December 2000 - 2000337	Segment data for ra 00337_14_28_34 appears to be bad. Noisy time tagging, plus & minus time gaps and time slips. Segment time is 14:28 to 20:46.
RA	04 December 2000 - 2000339	Segment data for ra 00339_09_40_47 appears to be bad. Noisy time tagging, plus & minus time gaps and time slips. Segment time is 09:40 to 15:09.
RA	06 December 2000 - 2000341	Segment data for ra 00341_09_59_50 appears to be bad. Noisy time tagging, plus & minus time gaps and time slips. Segment time is 09:59 to 14:07.
RA	15 December 2000 - 2000341	Segment data for ra 00350_02_11_25 appears to be bad. Noisy time tagging, plus & minus time gaps and time slips. Segment time is 02:11 to 11:57.
RA	Unknown	Segment data for ra 03246_13_20_01 with time of 11:47 to 16:33 received. No data was received for ra data segment 01009_11_47_42 which this appears to coincide with. Received this data segment on 2001010.
SDR	09 January 2001 - 2001009	Data segment for sdr01009_11_47_42_16871 appears to be bad. The Receiver Temperature is at a constant value of 34.633205. Segment time is 11:47 to 16:33.

Table 2-3 GFO Ground Processing Errors (Continued)

Data Type	Data Date	Comments
SDR	10 January 2001 - 2001010	Data segment for sdr01010_17_38_13_23271 appears to be bad. The Receiver Temperature is at a constant value of 41.799999. Segment time is 17:38 to 23:59.
SDR	16 January 2001 - 2001016	Data segment for sdr01016_00_38_03_11687 appears to be bad. The Receiver Temperature is at a constant value of 41.799999. Segment time is 00:38 to 03:59.Data segment for sdr01016_14_35_10_12139 appears to be bad. The Receiver Temperature is at a constant value of 41.799999. Segment time is 14:35 to 17:53.
RA	21 January 2001 - 2001021	Segment data for ra 01021_14_26_17 appears to be bad. Noisy time tagging, plus & minus time gaps and time slips. Segment time is 14:26 to 17:00.
NGDR	21 January 2001 - 2001021	ngdr_gfoo_2001021_00001_86175. SSH anomaly due to Doppler problem.
RA	22 January 2001 - 2001022	Segment data for ra 01022_04_12_37 appears to be bad. Noisy time tagging, plus & minus time gaps and time slips. Segment time is 04:12 to 11:43.
SDR	22 January 2001 - 2001022	Data segment for sdr01022_04_12_37_27597 appears to be bad. The Receiver Temperature is at a constant value of 30.540167. Segment time is 04:12 to 11:43.
NGDR	22 January 2001 - 2001022	ngdr_gfoo_2001022_00289_86399. SSH anomaly due to Doppler problem.
NGDR	23 January 2001 - 2001023	ngdr_gfoo_2001023_00000_86400. SSH anomaly due to Doppler problem.
NGDR	24 January 2001 - 2001024	ngdr_gfoo_2001024_00001_86399. SSH anomaly due to Doppler problem.
NGDR	25 January 2001 - 2001025	ngdr_gfoo_2001025_00000_86399. SSH anomaly due to Doppler problem.
RA	Unknown	Segment data for ra 00122_20_39_02 with time of 15:53 to 16:30 received. Received this data segment on 2001024.
NGDR	29 January 2001 - 2001029	ngdr_gfoo_2001029_00304_86400. SSH anomaly.
NGDR	30 January 2001 - 2001030	ngdr_gfoo_2001030_00001_86319. SSH anomaly.

Table 2-3 GFO Ground Processing Errors (Continued)

Data Type	Data Date	Comments
NGDR	30 January 2001 - 2001030	“Implementation of CR ADFC-2001-005: Modify Land/Quality Flag Filtering on GFO NGDRs”. The Change Request to modify the land and quality flag filtering on GFO NGDRs was implemented on the operational processing systems at NAVOCEANO. Starting with the NGDRs for DOY 030, we will no longer filter the data for land and quality flags as we have in the past. It will be up to the user to filter NGDR data for land and quality flags from this date forward. During testing of the software change on the backup system at NAVOCEANO, there was a 1 to 1 correlation between the number of SDR records collected and the number of NGDR records produced on any given day.
SDR	Unknown	Segment data for sdr01032_02_32_49_298 received. Received this data segment on 2001031.
RA	31 January 2001 - 2001031	Segment data for ra 01031_00_09_49 appears to be bad. Noisy time tagging, plus & minus time gaps and time slips. Segment time is 00:09 to 04:34.
SDR	31 January 2001 - 2001031	Data segment for sdr01031_00_09_50_15584 appears to be bad. The Receiver Temperature is at a constant value of 38.043720. Segment time is 00:09 to 04:34.
RA	04 February 2001 - 2001035	Segment data for ra 01035_05_48_09 appears to be bad. Noisy time tagging, plus & minus time gaps and time slips. Segment time is 05:48 to 18:03.
SDR	05 February 2001 - 2001036	Data segment for sdr01036_02_02_24_11393 appears to be bad. The Receiver Temperature is at a constant value of 41.799999. Segment time is 02:02 to 05:18.
RA	06 February 2001 - 2001037	Segment data for ra 01037_18_43_54 appears to be bad. Noisy time tagging, plus & minus time gaps and time slips. Segment time is 18:43 to 19:55.
RA	07 February 2001 - 2001038	Segment data for ra 01038_18_15_42 appears to be bad. Noisy time tagging, plus & minus time gaps and time slips. Segment time is 18:15 to 22:01.
RA	08 February 2001 - 2001039	Segment data for ra 01039_19_21_21 appears to be bad. Noisy time tagging, plus & minus time gaps and time slips. Segment time is 19:21 to 21:05.
RA	21 February 2001 - 2001052	Segment data for ra 01052_07_03_33 appears to be bad. Noisy time tagging, plus & minus time gaps and time slips. Segment time is 07:03 to 17:30.
SDR	21 February 2001 - 2001052	Data segment for sdr01052_07_03_33_38237 appears to be bad. The Receiver Temperature is at a constant value of 33.525787. Segment time is 07:03 to 17:30.

Table 2-3 GFO Ground Processing Errors (Continued)

Data Type	Data Date	Comments
RA	02 March 2001 - 2001061	Segment data for ra 01061_02_27_45 appears to be bad. Noisy time tagging, plus & minus time gaps and time slips. Segment time is 02:27 to 07:24.
RA	07 March 2001 - 2001066	Segment data for ra 01066_06_29_42 appears to be bad. Noisy time tagging, plus & minus time gaps and time slips. Segment time is 06:29 to 16:55.
RA	07 March 2001 - 2001066	Segment data for ra 01066 NORMS includes FINEL,CAL1,&CAL2.
SDR	08 March 2001 - 2001067	New SDR Software. Modified to improve record timing.
RA	08 March 2001 - 2001067	Segment data for ra 01067 NORMS includes FINEL,CAL1,&CAL2.
RA	09 March 2001 - 2001068	Segment data for ra 01068 NORMS includes FINEL,CAL1,&CAL2.
RA	10 March 2001 - 2001069	Segment data for ra 01069 NORMS includes FINEL,CAL1,&CAL2.
RA	11 March 2001 - 2001070	Segment data for ra 01070 NORMS includes FINEL,CAL1,&CAL2.
RA	12 March 2001 - 2001071	Segment data for ra 01071 NORMS includes FINEL,CAL1,&CAL2.
RA	13 March 2001 - 2001072	Segment data for ra 01072 NORMS includes FINEL,CAL1,&CAL2.
SDR	13 March 2001 - 2001072	New SDR Software modified at 1700Z. Revision to correct Cal/Val file errors and lack of full waveform data caused by incorrect SDR software.
SDR	Unknown	Segment data for sdr01080_18_08_19_1413 received. Received this data segment on 2001079.
RA	04 April 2001 - 2001094	Segment data for ra 01094_22_55_14 appears to be bad. Noisy time tagging, plus & minus time gaps and time slips. Segment time is 22:55 to 095T07:45.
SDR	Unknown	Segment data for sdr01099_08_35_45_4333 received. Received this data segment on 2001098.
RA	03 May 2001 - 2001123	Segment data for ra 01123_10_34_23 appears to be bad. Noisy time tagging, plus & minus time gaps and time slips. Segment time is 10:34 to 16:04.
RA	04 May 2001 - 2001124	Segment data for ra 01124_23_13_24 appears to be bad. Noisy time tagging, plus & minus time gaps and time slips. Segment time is 23:14 to 125T07:43.

Table 2-3 GFO Ground Processing Errors (Continued)

Data Type	Data Date	Comments
RA	22 May 2001 - 2001142	Segment data for ra 01142_02_38_13 appears to be bad. Noisy time tagging, plus & minus time gaps and time slips. Segment time is 02:38 to 08:55.
SDR	Unknown	Segment data for sdr01145_11_29_27_35696 received. Received this data segment on 2001145. Data is actually for day 144 time 11:29 to 21:22. The Receiver Temperature is at a constant value of 37.16.
RA	07 June 2001 - 2001158	Segment data for ra 01158_04_21_18 appears to be bad. Noisy time tagging, plus & minus time gaps and time slips. Segment time is 04:21 to 10:38.
SDR	Unknown	Segment data for sdr01161_13_13_27_4401 received. Received this data segment on 2001160. Data is actually for day 160 time 13:13 to 14:35. The Receiver Temperature is at a constant value of 38.0566.
RA	15 June 2001 - 2001166	Segment data for ra 01166_03_34_05 appears to be bad. Noisy time tagging, plus & minus time gaps and time slips. Segment time is 03:34 to 11:31.
RA	20 June 2001 - 2001171	The start of Full waveform data. Erroneous CAL/VAL data generated.
RA	25 June 2001 - 2001176	Segment data for ra 01176_05_04_43 appears to be bad. Noisy time tagging, plus & minus time gaps and time slips. Segment time is 05:44 to 08:11.Segment data for ra 01176_14_37_56 appears to be bad. Noisy time tagging, plus & minus time gaps and time slips. Segment time is 176t14:37 to 177t01:13.
RA	02 July 2001 - 2001183	Segment data for ra 01183_01_50_19 appears to be bad. Noisy time tagging, plus & minus time gaps and time slips. Segment time is 01:50 to 02:45.
RA	05 July 2001 - 2001186	Segment data for ra 01186_04_56_05 appears to be bad. Noisy time tagging, plus & minus time gaps and time slips. Segment time is 04:56 to 09:52.
RA	12 July 2001 - 2001193	Segment data for ra 01193_04_59_32 appears to be bad. Noisy time tagging, plus & minus time gaps and time slips. Segment time is 04:59 to 09:24.
RA	23 July 2001 - 2001204	Segment data for ra 01204_04_43_23 appears to be bad. Noisy time tagging, plus & minus time gaps and time slips. Segment time is 08:13 to 12:17.
RA	28 July 2001 - 2001209	Segment data for ra 01209_17_33_24 appears to be bad. Noisy time tagging, plus & minus time gaps and time slips. Segment time is 209t17:33 to 210t09:14.

Table 2-3 GFO Ground Processing Errors (Continued)

Data Type	Data Date	Comments
RA	30 July 2001 - 2001211	New software patch installed. Modified to capture all full waveform data.
RA	Unknown	Segment data for 00122_20_39_03 received. Received this data segment on 2001209.
RA	03 August 2001 - 2001215	Segment data for ra 01215_15_31_02 appears to be bad. Noisy time tagging, plus & minus time gaps and time slips. Segment time is 215t15:31 to 216t04:23.
RA	07 August 2001 - 2001219	Segment data for ra 01219_17_24_50 appears to be bad. Noisy time tagging, plus & minus time gaps and time slips. Segment time is 219t17:24 to 220t02:53.
RA	08 August 2001 - 2001220	Segment data for ra 01220_18_32_47 appears to be bad. Noisy time tagging, plus & minus time gaps and time slips. Segment time is 220t18:32 to 221t05:09.
RA	09 August 2001 - 2001221	Segment data for ra 01221_18_01_38 appears to be bad. Noisy time tagging, plus & minus time gaps and time slips. Segment time is 221t18:01 to 222t04:18.
SDR	27 August 2001 - 2001239	The ADFC has implemented the software patch, provided by Ball, to correct the generation of anomalous SDR files due to the presence of duplicate VTCW in the RA frames. The first sdr produced with the new s/w mod is sdr01239_15_29_41_17989.dat.
RA	Unknown	Segment data for 08080_07_49_27 received. Received this data segment on 2001246.
RA	05 September 2001 - 2001248	Segment data for ra 01248_20_45_07 appears to be bad. Noisy time tagging, plus & minus time gaps and time slips. Segment time is 248t20:45 to 249t06:42.
RA	13 September 2001 - 2001256	Segment data for ra 01256_21_37_32 appears to be bad. Noisy time tagging, plus & minus time gaps and time slips. Segment time is 256t21:37 to 257t07:50.
RA	17 September 2001 - 2001260	Segment data for ra 01260_21_12_39 appears to be bad. Noisy time tagging, plus & minus time gaps and time slips. Segment time is 260t21:12 to 261t07:26.
RA	04 October 2001 - 2001277	Segment data for ra 01277_22_31_01 appears to be bad. Noisy time tagging, plus & minus time gaps and time slips. Segment time is 277t22:31 to 278t08:39.
RA	05 October 2001 - 2001278	Segment data for ra 01278_12_21_47 appears to be bad. Noisy time tagging, plus & minus time gaps and time slips. Segment time is 278t12:21 to 278t18:39.

Table 2-3 GFO Ground Processing Errors (Continued)

Data Type	Data Date	Comments
RA	14 October 2001 - 2001287	Segment data for ra 01287_23_56_24 appears to be bad. Noisy time tagging, plus & minus time gaps and time slips. Segment time is 287t23:56 to 288t10:09.
RA	16 October 2001 - 2001289	Segment data for ra 01289_13_20_55 appears to be bad. Noisy time tagging, plus & minus time gaps and time slips. Segment time is 289t13:20 to 288t18:01.
RA	21 October 2001 - 2001294	Segment data for ra 01294_12_27_22 appears to be bad. Noisy time tagging, plus & minus time gaps and time slips. Segment time is 294t12:27 to 294t20:25.
RA	25 October 2001 - 2001298	Segment data for ra 01298_19_59_38 appears to be bad. Noisy time tagging, plus & minus time gaps and time slips. Segment time is 298t19:59 to 298t23:15.
RA	09 November 2001 - 2001313	Segment data for ra 01313_14_23_10 appears to be bad. Noisy time tagging, plus & minus time gaps and time slips. Segment time is 313t14:23 to 313t17:30.

Section 3

Assessment of Instrument Performance

The following sub-sections report several assessments performed by the WFF GFO team. All analysis indicates the altimeter instrument is performing within pre-launch specifications.

Section 3.1 addresses the range noise performance. Section 3.2 shows the groundtrack coverage of full-waveform GFO data for a typical 17-day cycle; these data are acquired for ice studies over southern Greenland. Then, Section 3.3 provides both an update on CAL-2 waveforms and an analysis of GFO's attitude (off-nadir) angles.

3.1 Range Measurement Noise

The GEOSAT Follow-on (GFO) altimeter white noise levels have been evaluated using a new technique based on high-pass filtering of 1-Hz sea surface height time series. High-pass filtering removes the geoid and oceanography signals while revealing the random noise. The new filtering technique is simpler to use than the repeat-track method, gives essentially the same results, and makes it easier to analyze much larger amounts of data to investigate subtle variations in noise levels. The new noise level measurements provided here all show a stable noise process from cycle-to-cycle with a linear dependence of the noise level upon significant waveheight (SWH). The GFO altimeter noise level is estimated to be about 2.5 cm for an SWH of 2m. Table 3-1 summarizes the results.

The data used for Table 3-1 had slightly different data editing criteria than the data that were used in Section 2. The cycle SWH mean is the SWH for the data used in each cycle, and the Noise Level mean is the mean of the noise estimated by the high-pass filter method. The 2m SWH is the noise estimate from fitting the individual noise estimate as a function, then solving the fitted equation for a 2m SWH.

Table 3-1 Statistical Indicators for GFO Based on 1-Minute Track Segments

Time Period			SWH (m)		Noise Level (cm)		
Cycle	Cycle Start Date	Cycle End Date	Mean	STD	Mean	STD	at 2m SWH
01	2000-352	2001-002	2.629	1.221	2.996	1.162	2.542
02	2001-003	2001-019	2.506	1.185	2.903	1.115	2.547
03	2001-020	2001-036	2.552	1.158	3.044	1.271	2.680
04	2001-037	2001-053	2.520	1.144	2.914	1.108	2.545
05	2001-054	2001-070	2.603	1.237	3.006	1.149	2.596
06	2001-071	2001-087	2.644	1.231	3.022	1.123	2.592
07	2001-088	2001-104	2.680	1.242	3.032	1.136	2.573
08	2001-105	2001-121	2.600	1.252	2.962	1.115	2.563
09	2001-122	2001-138	2.605	1.326	3.015	1.212	2.590
10	2001-139	2001-155	2.466	1.258	2.886	1.153	2.560
11	2001-156	2001-172	2.504	1.261	2.906	1.145	2.557
12	2001-173	2001-189	2.674	1.401	3.047	1.282	2.567
13	2001-190	2001-206	2.583	1.379	3.007	1.247	2.599
14	2001-207	2001-223	2.699	1.406	3.059	1.259	2.572
15	2001-224	2001-240	2.561	1.293	2.953	1.161	2.569
16	2001-241	2001-257	2.626	1.435	3.009	1.261	2.572
17	2001-258	2001-274	2.623	1.343	3.006	1.190	2.583
18	2001-275	2001-291	2.612	1.287	2.998	1.164	2.581
19	2001-292	2001-308	2.379	1.141	2.813	1.069	2.552
20	2001-309	2001-325	2.488	1.165	2.898	1.102	2.567

3.2 Groundtrack Coverage for GFO Full-Waveform Data

On June 20, 2001, Julian Day 171, GFO started collecting full waveform data over Greenland. Collection of these waveforms was agreed upon to help study acquisition and for the study of changes in the Greenland icesheet.

Because of the limited GFO ground commanding and the fact that all Greenland passes occur on consecutive orbits, it was decided to implement the waveform collection in conjunction with the two daily commanded calibration modes. After the first calibration mode, the GFO altimeter stays in the long format and collects waveforms until the second calibration mode is executed.

Daily, the first calibration mode is commanded prior to the first Greenland overpass and the second calibration mode is commanded after the last Greenland pass. This provides approximately 7 hours of continuous waveform data per day and provides waveforms for all the ascending and descending passes over Greenland. Figure 3-1 shows the coverage for 17 days (1 cycle) of data over Greenland.

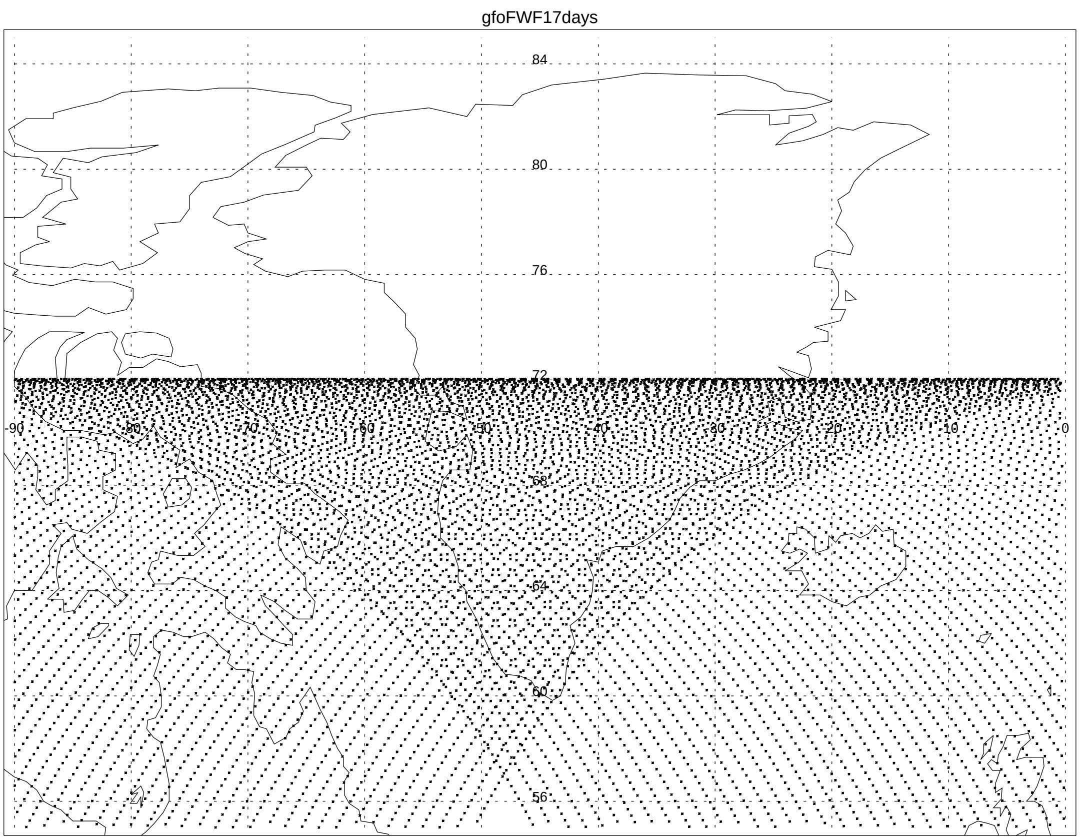


Figure 3-1 17 Days of Track Data over Greenland

3.3 Additional Observations

3.3.1 Calibration Mode 2 Waveforms

It was noted in the "GFO Altimeter Engineering Assessment Report, From Launch to Acceptance" that Calibration Mode 2 data should be flat waveforms, but the pre-launch data exhibited a "smile" pattern. This "smile" introduces errors during normal processing. A software patch (Smile Patch) was developed to correct this. During the period from launch to acceptance there were several resets that caused the "smile patch" to be reloaded. During the period since acceptance there has not been any occurrences of a reset to cause loss of the software patch (Smile Patch) and there is no data that has the "smile" effect.

3.3.2 Attitude

It was noted that during Cycles 18 and Cycle 19, Julian days 01275 to 01291 and 01292 to 01308 respectively, there were a much higher than usual number of attitudes that were above 0.3 degrees, as shown in Figure 3-2 and Figure 3-3.

Greg Jacob first noted and emailed attitude messages to us at WFF. We at WFF have examined the altimeter data, and do see that the larger attitudes are now generally in the high 0.2's degree where at one time it was in lower 0.2's (see cycle averages http://gfo.wff.nasa.gov/data/Cycle-by-Cycle Trend Analysis and today's data http://gfo.wff.nasa.gov/data/Today,s Data). Also, during a period in 2000 around day 60, the attitude was generally less than 0.2 degrees. We do not know why these attitude fluctuations occur.

Cycle 18, Figure 3-2 , and Cycle 19, Figure 3-3, do have an attitude increase to slightly

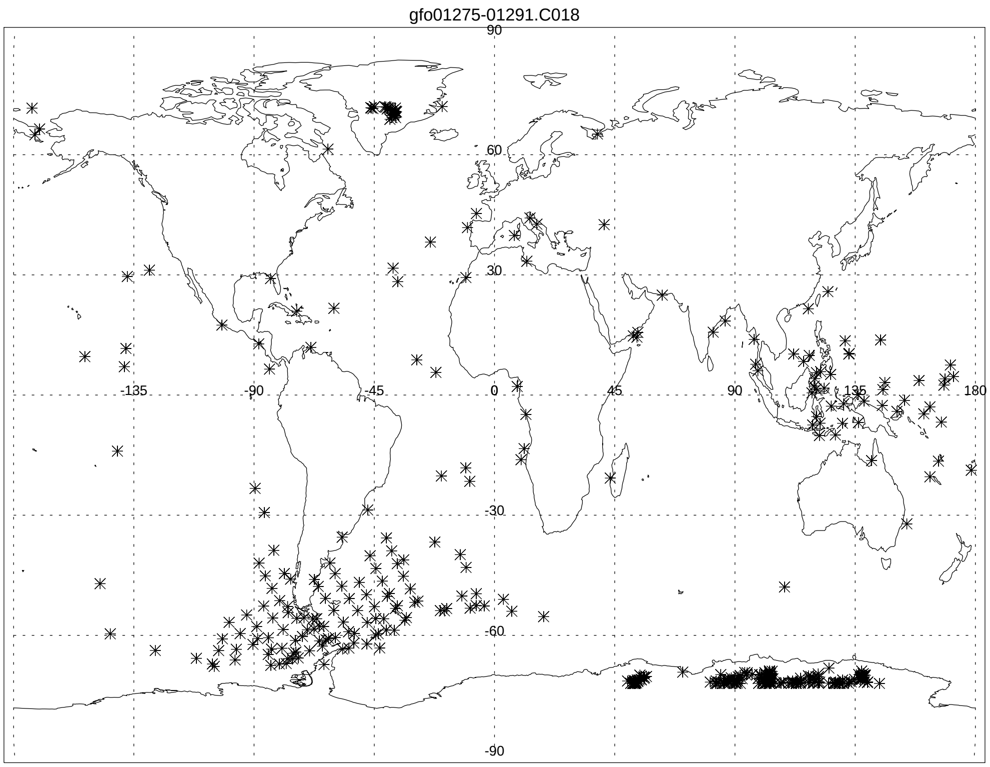


Figure 3-2 Attitudes > .3, Cycle 18

above 0.3 degree coming off Antarctica near South America. We believe these may be just higher attitudes reflective of the normal small oscillation with orbit, and now that the mean attitude is larger, the peak attitude is above 0.3 degree. In cycle 17, Figure 3-4, and Cycle 20, Figure 3-5, the periods of the attitude exceeding 0.3 lessened. We do not see anything in the data during any of these periods, however, that would indicate the altimeter data is bad.

The GFO altimeter should be able to provide quality data at higher attitudes than TOPEX because of the larger GFO antenna beam width. GFO will probably maintain

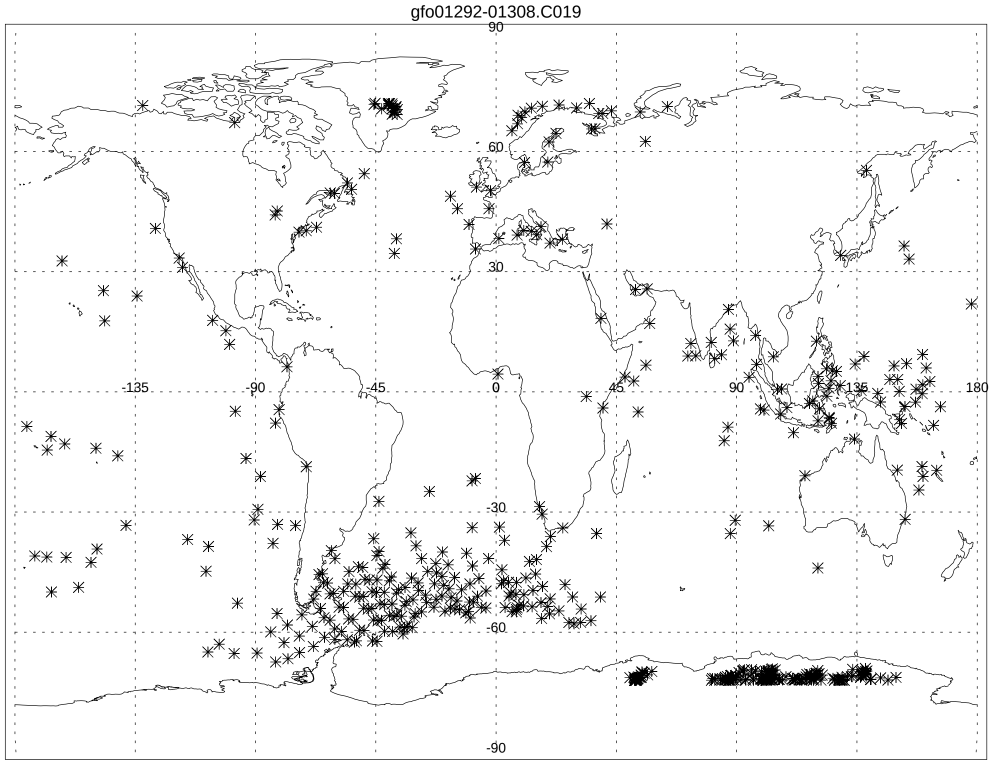


Figure 3-3 Attitude > .3, Cycle 19

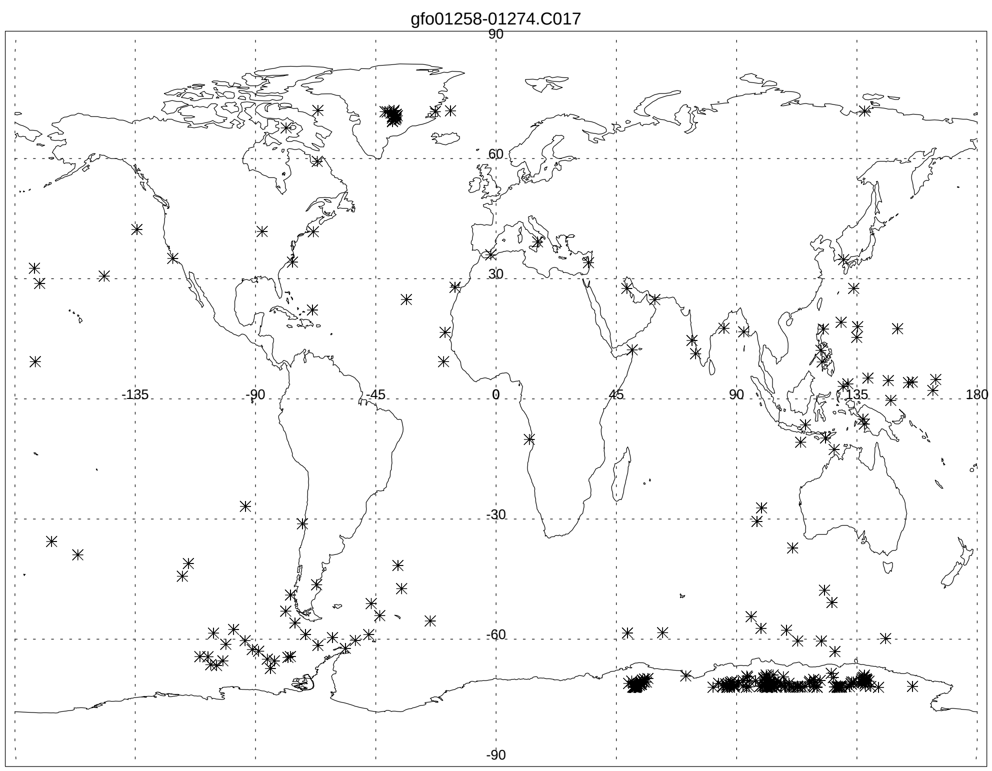


Figure 3-4 Attitude > .3, Cycle 17

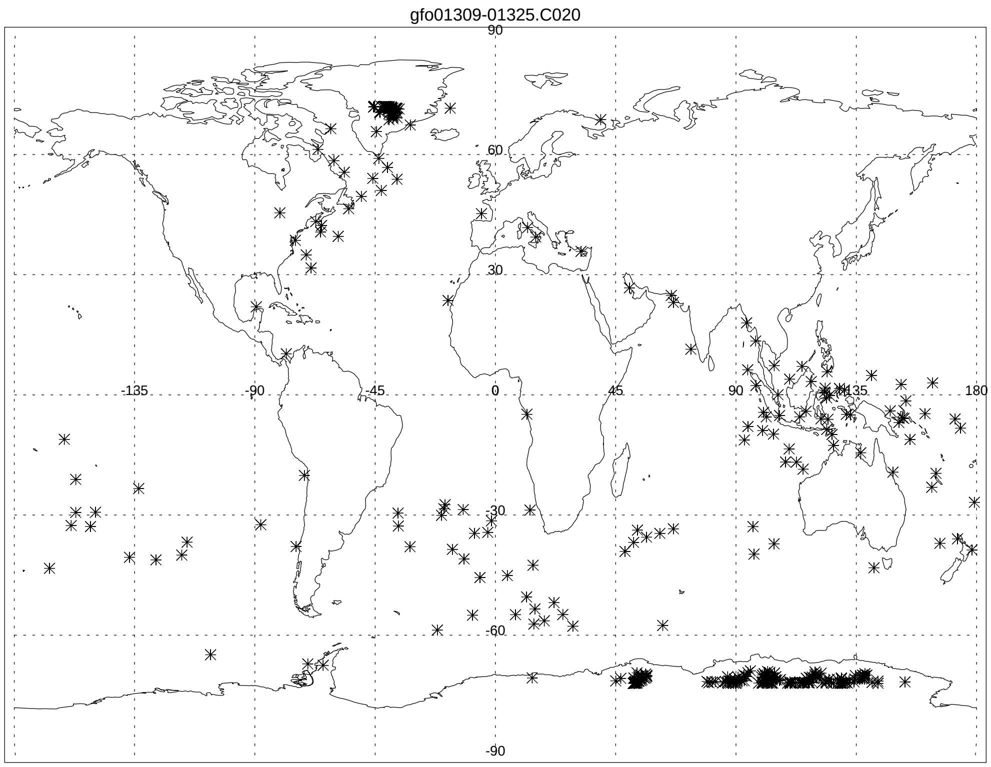


Figure 3-5 Attitude > .3, Cycle 20

track to near 0.7 degree attitude with good usable data to some point below this, perhaps 0.5 degrees or so.

We also note that there was a period in Cycle 5, Figure 3-6, during which the attitude pushed over 0.3 degree just south of the equator a number of times. During Cycle 3, Figure 3-7, the north Atlantic had an effect similar to the recent cycles.

The 0.3 degree attitude edit is conservative and helps edit out what we call "Sigma 0 blooms." We do not know why the mean GFO attitude cannot be held steady near 0.2 degrees. Hopefully someone on the s/c team can look into this and adjust the attitude control so it is more centered in the 0.2 degree range. It appears such an adjustment was done on 2001d054 when both horizon scanners were used.

If the attitude remains in the high 0.2 degrees or low 0.3s, we need to adjust our data editing limits. We do not want to recommend a new limit at this time, but the data we have examined, which runs to 0.35 degree or so, appears to be good and can be used. As stated, the 0.3 degree edit helps with outlier editing, but if near 0.3 degree is going to be the normal attitude, then we need to adjust our data editing limits. If we do adjust the limit, we would like the s/c team estimate the maximum we should see under normal operations.

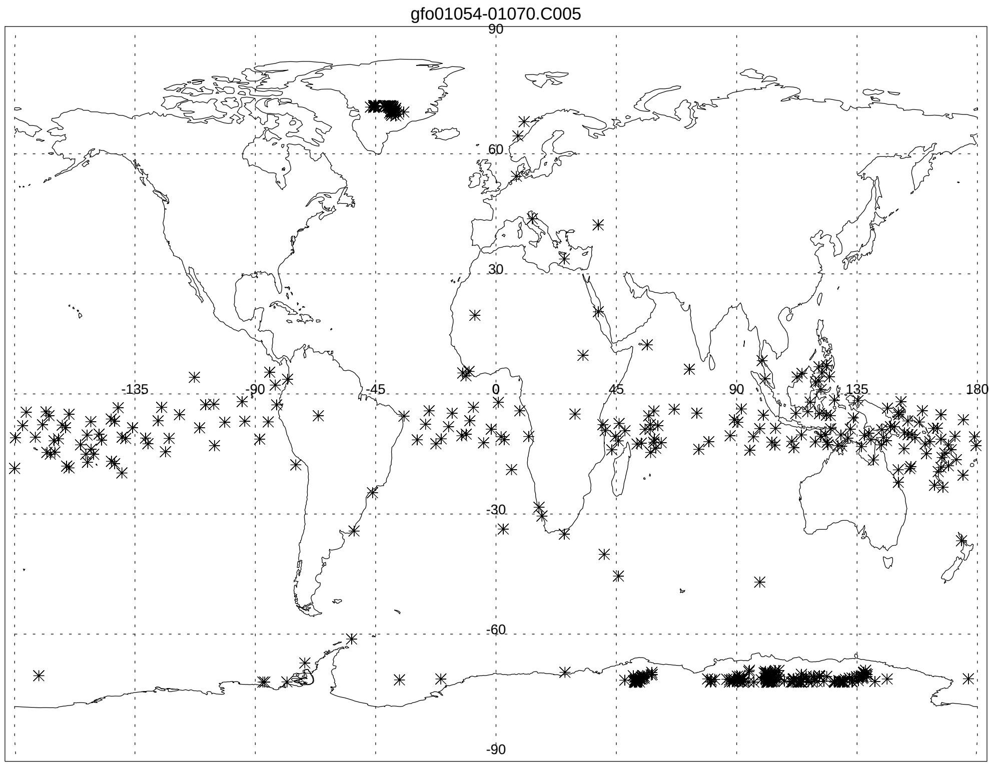


Figure 3-6 Attitude > .3, Cycle 5

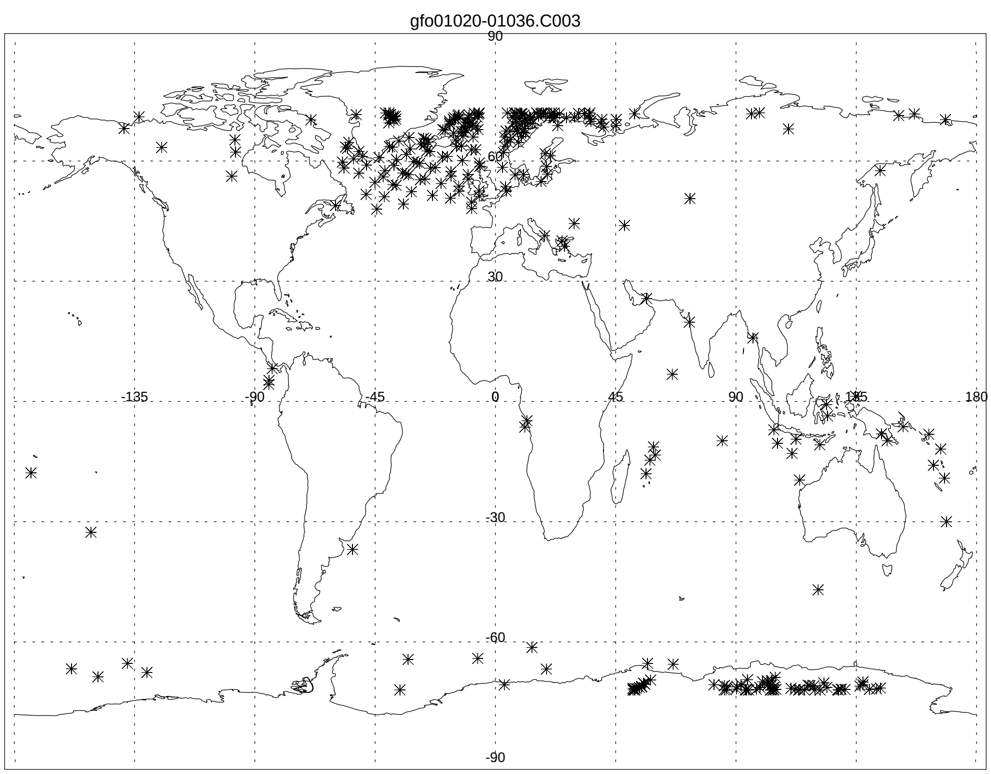


Figure 3-7 Attitude > .3, Cycle 3

Section 4

Other Studies

4.1 Great Lakes Study, from work contributed by Ron Brooks, et al

The performance of the GEOSAT Follow-On (GFO) Radar Altimeter over the Great Lakes was assessed. Measurements from a 17-day set of GFO passes were analyzed to ascertain the following:

- At times of transition from land-to-water, how long does it take for the altimeter tracker to lock-up on the water surface
- What is the agreement of altimeter-derived lake elevations at crossovers of altimeter groundtracks
- What is the agreement of altimeter-derived lake elevations with lake elevations independently determined by the U.S. Army Corps of Engineers
- Are the over-lake altimeter-derived values for Sigma0 and SWH reasonable
- What values for Quality Word 1 correspond with times when the altimeter tracker is locked onto the lake surfaces

The data used for this study are the Navy Geophysical Data Records (NGDR), for days 122 through 138 of 2001.

4.1.1 Land-to-Water Acquisition Times

For this aspect of the study, the goal was to ascertain the interval between the time when the groundtrack crosses a land-to-water shoreline and when the altimeter tracker settles on the water surface. To accomplish this goal, the following steps were performed:

- The groundtracks were plotted on 1:400,000 scale nautical charts
- The latitude and longitude of the shoreline crossing of each groundtrack were noted
- The 10-per-second over-water delta SSH were reviewed to ascertain when the tracker settled, and the latitude and longitude of that event were computed
- The latitude/longitude of the shoreline crossing and the latitude/longitude of the settled tracker were differenced, to compute the distance. The distance was then converted to delta time, using the GFO groundtrack rate of 6.77 km/sec.

Data were deleted whenever complex shorelines with near-offshore islands or with other features such as inlets or spits occurred. Such features would affect the acquisition cycle.

The results of the acquisition study are summarized in Table 4-1. A total of 23 land-to-water acquisition events were available for study. For 19 of the events, the tracker appeared to be tracking the land surface prior to the land-to-water transition, and the acquisition times varied between 0.6 and 5.4 seconds. During the other four events, the tracker had clearly lost lock prior to the shoreline crossing, and the acquisition times were larger, varying between 4.4 and 7.8 seconds.

Table 4-1 GFO Altimeter Acquisition Times for the Great Lakes Study Area

Day Identifier yyyy/ddd	Lake Area	Shoreline Latitude Longitude (E) in Degrees	Acquisition Time from Land in Seconds	Acquisition Distance from Land in Kilometers	Comments
2001/122	Lake Huron	45.89 276.95	2.7	18.6	
2001/123	Lake Superior	47.45 271.87	3.2	21.9	
2001/123	Lake Superior	48.11 271.31	2.2	14.7	Passed over Isle Royale
2001/128	Lake Huron	43.69 278.27	0.6	4.0	
2001/128	Lake St. Clair	45.50 277.42	1.0	6.8	Not one of Great Lakes, but a target of opportunity
2001/128	Lake Erie	41.99 277.06	2.8	19.3	
2001/129	Lake Erie	41.85 279.04	3.1	21.3	
2001/129	Lake Huron	43.22 278.08	2.4	15.9	
2001/129	Lake Huron	45.34 276.50	2.9	19.9	Passed over land, then went back over water
2001/130	Lake Superior	47.94 274.24	2.5	16.6	
2001/130	Lake Superior	47.73 274.05	2.6	17.9	Passed over Michipicoten Island
2001/131	Lake Erie	42.65 279.00	3.4	23.2	
2001/132	Lake Erie	42.27 280.24	3.0	20.6	
2001/132	Lake Huron	44.50 278.63	1.9	12.9	
2001/134*	Lake Michigan	45.92 274.06	7.4	50.1	Lost lock prior to crossing shoreline
2001/134	Lake Michigan	41.78 273.20	4.2	28.5	
2001/134	Lake Superior	46.58 269.62	2.4	15.9	
2001/134	Lake Ontario	43.89 281.38	1.0	6.8	
2001/134*	Lake Erie	42.85 280.62	5.5	37.2	Lost lock prior to crossing shoreline
2001/137	Lake Michigan	43.34 273.60	1.5	10.2	

Table 4-1 GFO Altimeter Acquisition Times for the Great Lakes Study Area (Continued)

Day Identifier yyyy/ddd	Lake Area	Shoreline Latitude Longitude (E) in Degrees	Acquisition Time from Land in Seconds	Acquisition Distance from Land in Kilometers	Comments
2001/137*	Lake Superior	46.94 270.81	4.4	29.8	Lost lock prior to crossing shoreline
2001/137*	Lake Ontario	43.86 282.93	7.8	52.8	Lost lock prior to crossing shoreline
2001/138	Lake Ontario	43.24 282.50	5.4	36.6	

* Denotes Altimeter had lost lock and performed a full acquisition.

4.1.2 Over-Lake Crossovers

Crossover delta-heights over the lakes were computed for the purpose of evaluating the pass-to-pass consistency. The measurements used for the crossover analysis were the one-per-second corrected SSH relative to the ellipsoid.

Table 4-2 provides the latitude / longitude of each crossover, along with the SSH for each of the crossover passes, and the delta SSH in terms of ascending minus descending. The deltas vary from 0 cm to +14 cm. The majority of the deltas are positive, possibly indicating some minor systematic radial errors in the GFO orbital ephemeris.

The small magnitude of the differences lends further credence that the GFO altimeter is collecting meaningful data over the Great Lakes. However, it should be noted that the attitude correction has not been applied.

Table 4-2 Delta SSH at Crossovers for the Great Lakes Study Area. SSH Values are Referenced to the Ellipsoid

Lake Area	Latitude Longitude (E) (degrees)	Ascending Pass Day Number yyyy/ddd	Descending Pass Day Number yyyy/ddd	Ascending Pass SSH in meters	Descending Pass SSH in meters	Delta SSH Ascending minus Descending in cm
Lake Erie	42.283 278.743	2001 / 129	2001 / 131	138.62	138.51	+11
Lake Huron	44.333 277.276	2001 / 129	2001 / 125	140.27	140.13	+14
Lake Huron	45.313 278.006	2001 / 132	2001 / 125	138.22	138.21	+1
Lake Huron	43.329 278.012	2001 / 129	2001 / 128	140.43	140.38	+5
Lake Superior	47.134 272.139	2001 / 123	2001 / 127	146.67	146.62	+5
Lake Superior	47.145 270.642	2001 / 137	2001 / 124	151.05	150.95	+10

Table 4-2 Delta SSH at Crossovers for the Great Lakes Study Area. SSH Values are Referenced to the Ellipsoid (Continued)

Lake Area	Latitude Longitude (E) (degrees)	Ascending Pass Day Number yyyy/ddd	Descending Pass Day Number yyyy/ddd	Ascending Pass SSH in meters	Descending Pass SSH in meters	Delta SSH Ascending minus Descending in cm
Lake Michigan	44.347 272.854	2001 / 137	2001 / 134	139.26	139.32	-6
Lake Michigan	45.303 273.600	2001 / 123	2001 / 134	139.03	139.03	0

4.1.3 Comparison of GFO-Determined Lake Elevations with Ground Truth

As a further verification of the tracking data, the GFO-determined lake elevations have been compared with an external source, the U.S. Army Corps of Engineers (USACE). To accomplish the comparison, the geoid heights on the NGDR records were algebraically subtracted from the GFO-determined SSH to compute a reference to mean sea level (msl).

The USACE maintain daily records of the lake elevations referenced to msl, based on the mean of water-level gauges at shoreline locations encompassing each lake. Their lake level records may be found at http://www.great-lakes.net/lakes/. At that site, click on the lake name on the left, and then scroll down for the USACE data. The USACE lake elevations are plotted therein as a function of date, and the elevation data were extracted for the same dates as the GFO data. The USACE lake elevations at the website are also available in tabular form, with an indicated precision of one centimeter.

As each GFO groundtrack traversed a lake, a picked-at-random spot elevation was extracted from the locked-on portion over ‘deep’ water. The top portion of Table 4-3 lists these elevations, and the associated date and lake identifier. Then, the averaged GFO-determined lake elevation is compared (GFO mean elevation minus the USACE mean elevation) with the USACE results. The GFO-determined elevations are consistently lower than the USACE elevations, perhaps attributable to a different reference elevation datum.

Table 4-3 GFO-Determined Lake Elevations Referenced to Mean Sea Level

Date yyyy/ddd	Lake Superior [meters]	Lake Michigan [meters]	Lake Huron [meters]	Lake Erie [meters]	Lake Ontario [meters]
2001 / 122			175.9		
2001 / 123	181.7	175.6			
2001 / 124	182.2				
2001 / 125			175.6		
2001 / 126					
2001 / 127	181.9				
2001 / 128			175.6	173.6	

Table 4-3 GFO-Determined Lake Elevations Referenced to Mean Sea Level (Continued)

Date yyyy/ddd	Lake Superior [meters]	Lake Michigan [meters]	Lake Huron [meters]	Lake Erie [meters]	Lake Ontario [meters]
2001 / 129	182.6		175.8	174.0	
2001 / 130	182.4				
2001 / 131				173.8	
2001 / 132			175.9	173.9	
2001 / 133					
2001 / 134-a		175.6		173.8	75.2
2001 / 134-b	182.7	175.6			
2001 / 135					74.4
2001 / 136					
2001 / 137-a	182.0	75.7			74.2
2001 / 137-b		175.1			
2001 / 138					74.8
GFO-Determined Average Elevation	182.2	175.5	175.8	173.8	74.7
U.S. Army Corps of Engineers (USACE)	183.3	176.0	176.0	174.0	74.9
GFO minus USACE	-1.1 m	-0.5 m	-0.2 m	-0.2 m	-0.2m

Several observations can be made based on the Table 4-3 results. One observation is that the geoid model for Lake Superior is not as good as the model for the other lakes. Another observation is that the GFO-determined lake elevations are lower, by 20 cm or more, than the USACE data. A final observation is that the consistent elevation agreement with the USACE data provides evidence that the altimeter is tracking the lake surfaces.

However, these GFO elevation results over the Great Lakes should not be considered to be an absolute calibration of the GFO system. As noted in the following sections, all of the GFO tracking data over the Great Lakes for this 17-day study period had data flags. These data flags are related primarily to the absence of valid fitted Vatt values. Vatt is the voltage proportional to attitude, and the existence of these flags is interpreted to mean that normal (over-ocean) processing could not be performed by the GFO ground-processing system.

4.1.4 GFO's AGC and Sigma0 Measurements for the Lake Surfaces

AGC levels during the tracking of the lake surfaces are generally 44-to-48 dB, with some AGC levels observed to be as high as 57 dB. However, the corresponding Sigma0 for about 90% of all the over-lake data have default values of 655.35. When valid-appearing Sigma0 values appear, they are approximately 12-13 dB.

A review of the NGDR data shows that there is a 1:1 correlation between the appearance of a fitted (non-zero) Vatt on the NGDR and the occurrence of a non-defaulted Sigma0. Over the Great Lakes, however, there are very few instances of fitted Vatt, and thus there are very few non-defaulted Sigma0s. Even when there was a fitted Vatt, however, its value was flagged as being too low.

The nominal GFO first-order polynomial fit to Vatt is based on a sliding window containing 60 sec of data (62 records). Over the Great Lakes, there are no instances of 60 sec of contiguous data points, but it appears that a non-nominal SDR fit to Vatt occurs whenever there are 20 or more contiguous points.

4.1.5 GFO's SWH Measurements for the Lake Surfaces

Approximately 50% of the over-lake SWH values are defaulted to 655.35 on the NGDR records. When not defaulted, the SWH is generally less than 1 meter.

Regarding GFO's SWH values over the Great Lakes, a non-defaulted one-per-record SWH value occurs only when the number of intra-record 'valid' SWHs is 6-10. From the GFO documentation, it is not clear what the onboard-tracker basis is for deciding whether a 10-per-second SWH is valid, but it is probably based on waveform specularity.

4.1.6 GFO Quality Word 1

The valid lake elevation measurements have been correlated them with Quality Word 1 on the NGDR. The valid elevation measurements are all associated with Quality Word 1 values of 64, 192, 1088, 1216, or 1728

- Value 64 corresponds to bit 6 (VATT estimate error).
- Value 192 corresponds to bit 6 plus bit 7 (no smoothed VATT).
- Value 1088 corresponds to bit 6 plus bit 10 (SWH bounds error).
- Value 1216 corresponds to bit 6 plus bit 7 plus bit 10.
- Value 1728 corresponds to bit 6 plus bit 7 plus bit 10 plus bit 9 (rate error).

For the GFO lake data, there are no instances of Quality Word 1 equaling zero. By the editing criteria we apply to GFO open-ocean altimetry data, the Great Lakes data are technically invalid.

4.1.7 Great Lake Study Summary

A review of GFO data for a 17-day period over the Great Lakes demonstrates that, after land-to-water acquisition times of a few seconds, the altimeter tracks well over the lake surfaces. This fact is evidenced by: (1) intrapass point-to-point SSH consistency; (2) interpass SSH consistency at ground crossovers; and (3) surface elevation comparisons with USACE ground truth elevations.

The Great Lakes (or other lakes), however, are seen to be not useful for absolute calibration of the GFO system. The GFO processing system requires a long-duration (60-second) period of tracking for the appropriate smoothing of Vatt, and even the Great

Lakes are not sufficiently large in areal extent to accommodate that smoothing. Normal NGDR processing does not provide proper data corrections.

4.2 GFO Correction to Range for the Effects of Oscillator Drift

During the Navy's ground processing of the GFO altimeter data, a number of corrections are made to the measured range. One of the range corrections is based on the drift of the onboard oscillator from the reference rate, where the additive range correction, R_Corr, is:

R_Corr = [Osc_Meas / Osc_Ref] – 1.] * Altitude,

where Osc_Meas is the measured oscillator rate

Osc_Ref is the reference oscillator rate (9.9992E-07)

Altitude is the measured GFO range (789 km - 811 km)

The Osc_Meas value that is used by the Navy for the correction is recorded as part of the NSDR header. NASA / Wallops, as part of its GFO performance analysis, maintains an Excel file of the Osc_Meas values extracted from the headers.

Using a nominal GFO altitude of 800 km, the calculated correction (in mm) for the GFO oscillator drift from 1998 day 133 to the end of Cycle 20 is shown in Figure 4-1. If the GFO minimum or maximum altitude had been used for the calculation instead of the 800 km, the oscillator correction would change, at the most, 2 mm.

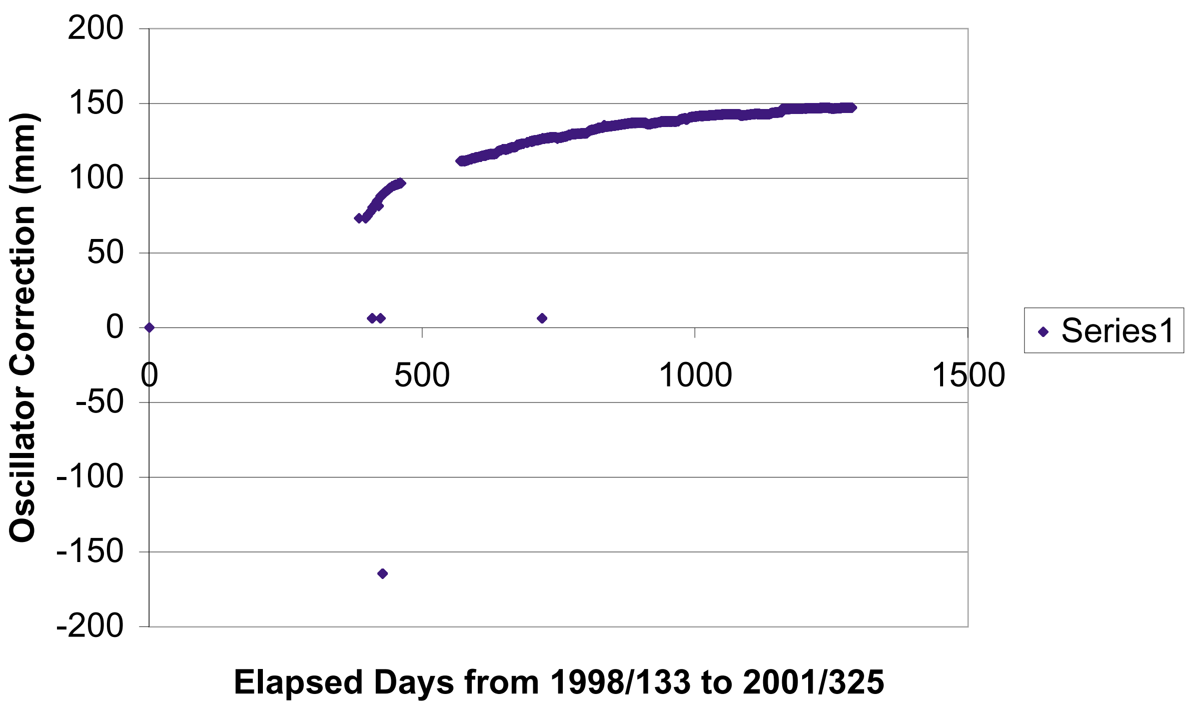


Figure 4-1 GFO Oscillator Correction

It is apparent from the Figure 4-1 that, for a few early-mission segments, the oscillator corrections applied to the GFO data were in error. The effect of these particular errors is that the additive corrections to the range for those segments were too small, and therefore the resultant calculated sea surface heights on the NGDR were too high.

The effect of these errors is summarized in Table 4-4. The table contains:

- dates and times of affected data
- additive oscillator range correction applied during ground processing
- additive range correction that should have been applied, based on neighboring values
- delta between the applied range correction and the correction that should have been applied
- resultant additive corrections needed to be applied by the data user to the NGDR sea surface heights for those segments
- NSDR file identifiers for those data segments

The general trend of the oscillator appears to be reasonable.

Table 4-4 Oscillator Correction Errors

YEAR	Day of Year	TIME OF DAY IN SECONDS	ADDITIVE OSCILLATOR RANGE CORRECTION APPLIED (mm)	ADDITIVE OSCILLATOR RANGE CORRECTION FOR DATE (mm) *	USER'S ADDITIVE CORRECTION TO MEASURED RANGE (mm)	USER'S ADDITIVE CORRECTION TO SEA SURFACE HEIGHT (mm)	NSDR FILE NAMES
1999	176	66464 - 86400	+ 6.2	+78.4	+72.2	-72.2	sdr99176_18_27_44_31
1999	177	22622 - 86400	+ 6.2	+78.9	+72.7	-72.7	sdr99177_06_17_02_23165
1999	179	83830 - 86400	+ 6.2	+79.9	+73.7	-73.7	Sdr99179_23_17_10_2622
1999	180	00000 - 44290	+ 6.2	+80.5	+74.3	-74.3	sdr99180_00_00_00_3914 sdr99180_01_03_56_23159 sdr99180_07_22_11_18122
1999	192	00000 - 45999	+ 6.2	+87.3	+81.1	-81.1	sdr99192_01_28_32_23483 sdr99192_07_52_03_18036
1999	198	46849 - 86400	-164.7	+88.6	+253.3	-253.3	sdr99198_13_00_49_30279 sdr99198_21_15_20_9461
1999	199	00000 - 45012	-164.7	+89.7	+254.4	-254.4	sdr99199_00_00_00_10777 sdr99199_02_56_03_23016 sdr99199_09_11_57_11516
2000	122	74343 - 86400	+ 6.2	+125.9	+119.7	-119.7	sdr00122_20_39_03_12306
2000	123	00000 - 32254	+ 6.2	+125.9	+119.7	-119.7	sdr00123_00_00_00_5820 sdr00123_00_04_55_16982 sdr00123_04_41_57_18228
2000	123	34780 - 86400	+ 6.2	+125.9	+119.7	-119.7	sdr00123_09_39_40_43609 sdr00123_21_31_56_7337
* Oscillator Range Correction for Date is Based on Neighboring Values							

4.3 AGC Trends for the First 17 GFO Cycles, from work contributed by George Hayne/NASA GSFC, et al

The observations reported here are based on a GFO data file produced on 31 October 2001 by D. Lockwood (filename *osb3:/gen/gfo/wrk/GHAGCCalCor/NewSummary.trend*). This file contained cycle averages for the first seventeen GFO cycles. These cycle averages include only valid (i.e., non-flagged) over-ocean GFO altimeter data. The GFO AGC and Sigma0 should have 1:1 variation. The AGC discussed in this memo is obtained from the Navy GDR (the NGDR) and has been corrected for temperature, height dependence, and attitude/sea-state dependence.

In general an altimeter's cycle-average over-ocean Sigma0 estimate should be constant, independent of cycle number (except for a small annual signal discussed in the second paragraph below), and the altimeter's over-ocean cycle-average AGC should also be constant except for the possibility of a small (usually downward) drift over time as a result of ageing of the altimeter components related to return power estimation. Such drift will be slow initially, and in the first year or two of altimeter operation is usually representable as a linear function of time. Questions to be addressed in this memo are: 1) whether any long-term drift in the AGC estimates is yet visible; and 2) whether there is any remaining AGC dependence on receiver temperature.

The attached Figure 4-2 shows GFO cycle-averaged over-ocean AGC vs. GFO cycle

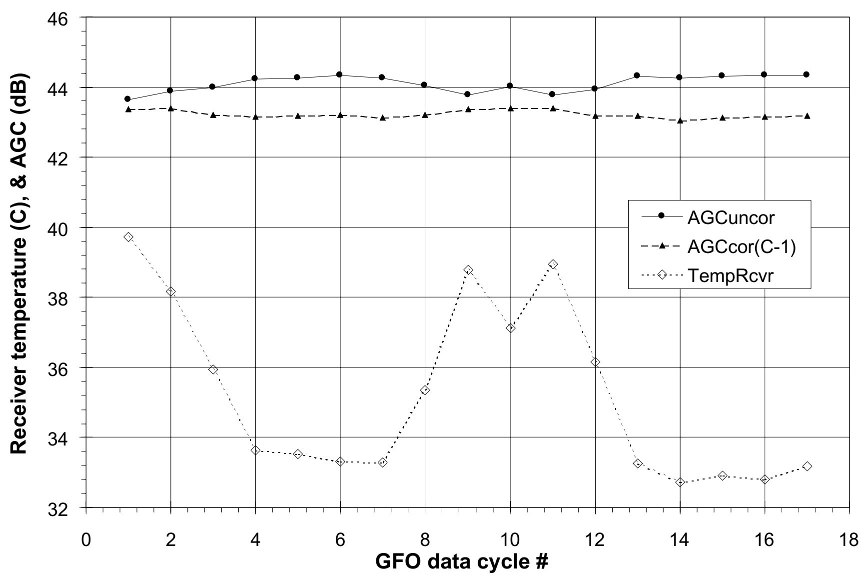


Figure 4-2 GFO Receiver Temperature and AGC vs. Cycle Number

number. The AGC on the NGDR has been temperature-corrected based on analysis by R. Brooks and D. Lockwood of the GFO Calibration Mode 1 (Cal-1) AGC data as a function of receiver temperature. The Cal-1-based correction is

$$CorCal1 = -5.5301 + 0.1323*Trcv,$$

where Trcv is the GFO receiver temperature in C and CorCal1 is the correction in dB to be added to the altimeter's AGC value. In Figure 4-2 the NGDR AGC is designated as AGCcor(C-1); this awkward notation is meant to remind the reader that the temperature correction is based on the earlier Cal-1 AGC data analysis. If the temperature correction were perfect, and if there were no drifts in the GFO power estimation, the AGCcor(C-1) vs. cycle would be perfectly flat and completely uncorrelated with temperature. It is also interesting to look at the AGC with temperature correction removed, and this uncorrected AGC is designated as AGCuncor in Figure 4-2. It is important to note that the AGCuncor has only had the temperature correction removed, but that this AGC still has been corrected for altimeter height and for attitude / sea-state.

Because the Northern and Southern hemispheres contain different percentages of ocean to total area, and because the ocean roughness will vary annually, there should be a small annual variation in any altimeter's over-ocean AGC cycle averages. Figure 4-3 shows the expected annual adjustment to GFO cycle AGC cycle averages, based

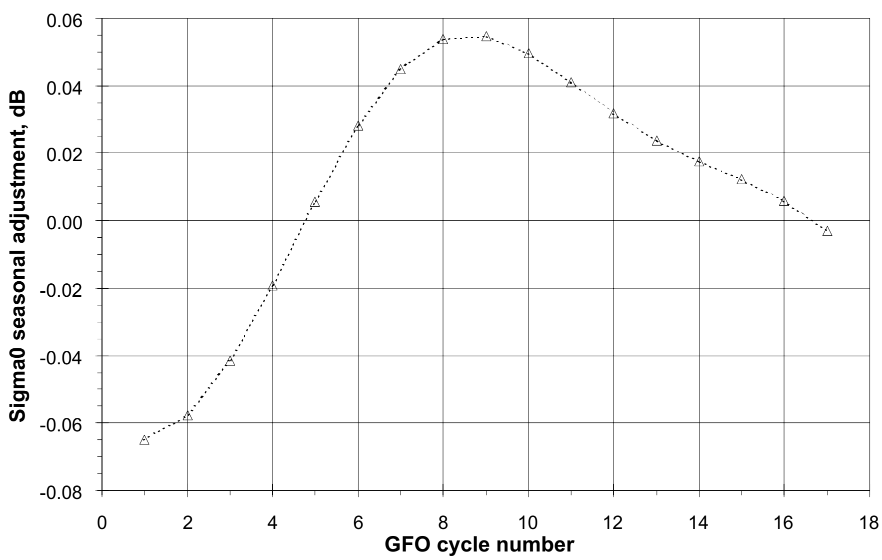


Figure 4-3 TOPEX Sigma0 Seasonal Adjustment vs. GFO Cycle

on analysis of the TOPEX Sigma0 cycle averages for about 300 TOPEX 10-day data cycles. This is a small effect, only about 0.12 dB peak to peak, but the GFO AGC data will be examined with and without this seasonal correction being applied.

Figure 4-4 replots the AGCuncor from Figure 4-2, and also the AGCuncorr with seasonal correction applied (designated AGCu, s-adj. in the figure) as a function of GFO data cycle. Figure 4-4 has a different vertical scale than Figure 4-2. Also plotted in Figure 4-4 is a shifted and (negatively) scaled function of the receiver temperature. This figure shows strikingly the negative correlation of AGCuncor with receiver temperature, and also shows the relative unimportance of the seasonal correction.

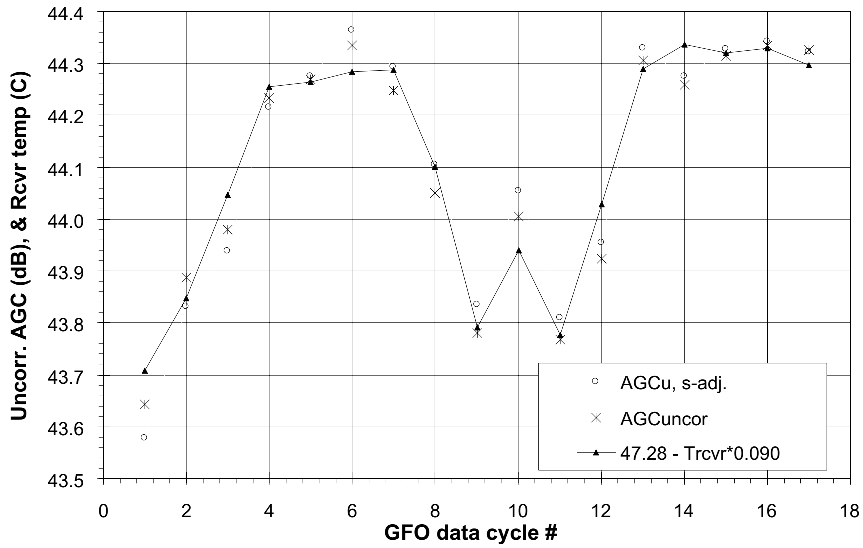


Figure 4-4 GFO Receiver Temperature and AGC vs. Cycle Number

The seasonally adjusted AGCuncor was then least-squares fitted by a function linear in cycle number and in receiver temperature. The fit coefficient for the cycle number dependence had the value +0.00457, indicating that the GFO AGC (and Sigma0) estimation may have increased by about 0.07 dB from cycle 1 to cycle 17. It's probably too early to decide whether this increase is real, and the 0.07 dB should for now be regarded only as an upper bound on the possible drift. The fit coefficient for the receiver temperature dependence was -0.0899, indicating that an additive correction would have the coefficient +0.0899. This value is somewhat different from the temperature correction coefficient value +0.1323 in the Cal-1 based correction CorCal1. Brooks and Lockwood had also derived a GFO Cal-2 based temperature correction CorCal2 given by

$$\text{CorCal2} = -3.2813 + 0.0785 * \text{Trcv},$$

but had decided that the CorCal1 was the better function to use in the GFO processing.

Figure 4-5 shows the variation with data cycle of: i) the GFO AGCuncorr with and without the TOPEX-based seasonal correction; ii) the AGCc(Cal-1), which is the AGC on the NGDR; iii) the AGCc(Cal-2), which is the NGDR AGC with the CorCal1 removed and replaced by the CorCal2; and iv) the seasonally-adjusted NGDR AGC with the CorCal1 removed and replaced by the temperature correction (but not the time trend) from our least-squares fit of cycle averages to a function linear in temperature and cycle number (on the figure this corrected AGC is designated AGCc(fit), s-adj.). Ideally the corrected AGC would be a horizontal straight line, and Figure 4-5 suggests that either the GFO Cal-2-based correction or the correction from our least-squares fit would be better than the Cal-1-based correction. Figure 4-6 shows the same GFO AGC cycle aver-ages as Figure 4-5 except that the horizontal axis is receiver temperature rather than cycle number. This figure also suggests that the

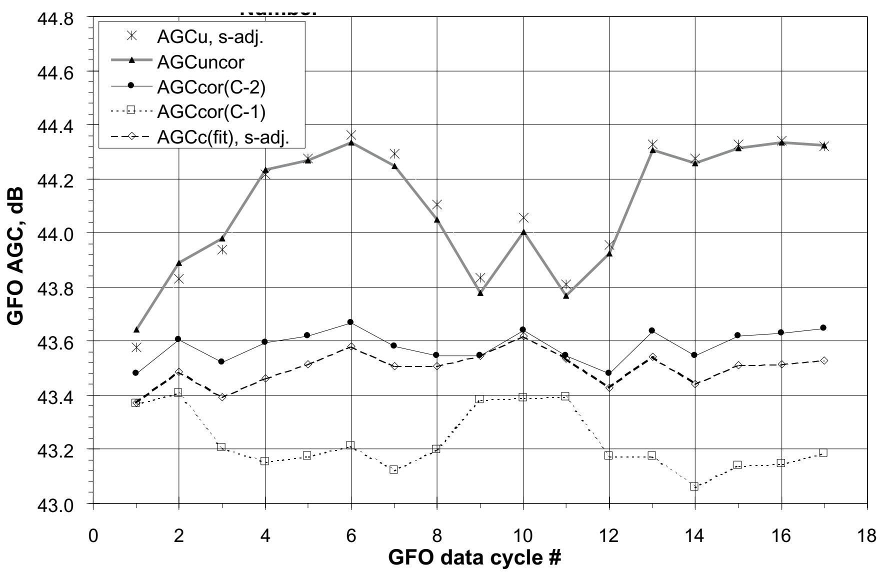


Figure 4-5 GFO AGC vs. Cycle Number

CorCal1 is less effective at removing receiver temperature effects than either the CorCal2 or the least-squares fit.

Some more work must be done before we will be able to recommend a “final” temperature correction for the GFO AGC. For instance, I recently looked at one complete GFO cycle of the 1-minute over-ocean averages from which the GFO cycle averages are formed here at WFF, and found a number of records that should have been edited out of the dataset. There were 14892 1-minute averages before editing, and after quite conservative editing there remained 14166 averages; the editing removed about almost 5% of the original data. Before editing, there were AGC values ranging from 22.6 to 61.1 dB, a range of almost 40 dB. There were Sigma0 values ranging from 3.1 to 655.35 dB, where this upper limit is clearly invalid data (65535 would be the maximum value of an unscaled 16-bit integer). The cycle average AGC value changed by about 0.14 dB as a result of the editing. Probably all of the cycle averages suffer similar errors but it’s not clear whether the AGC shift is the same cycle to cycle. This AGC shift is mentioned only as an example of some of the work yet to be done.

In conclusion, GFO cycle averages of AGC indicate that there may still be some uncorrected receiver temperature effects in the NGDR AGC (and Sigma0). There is still work to do before a final decision can be made about the correct form of temperature correction to use. It is reassuring that the receiver temperature is available on the NGDR so that the AGC (and Sigma0) data will easily be correctable to remove remaining temperature effects, once the final temperature correction is decided upon.

4.4 GFO Altimeter Wind Speed Monitoring, from work contributed by Ngan Tran/Raytheon ITSS, et al

As part of the validation of GFO data, we monitor the surface wind speed retrieved from the radar cross-section measurements for possible trends. This analysis helps to

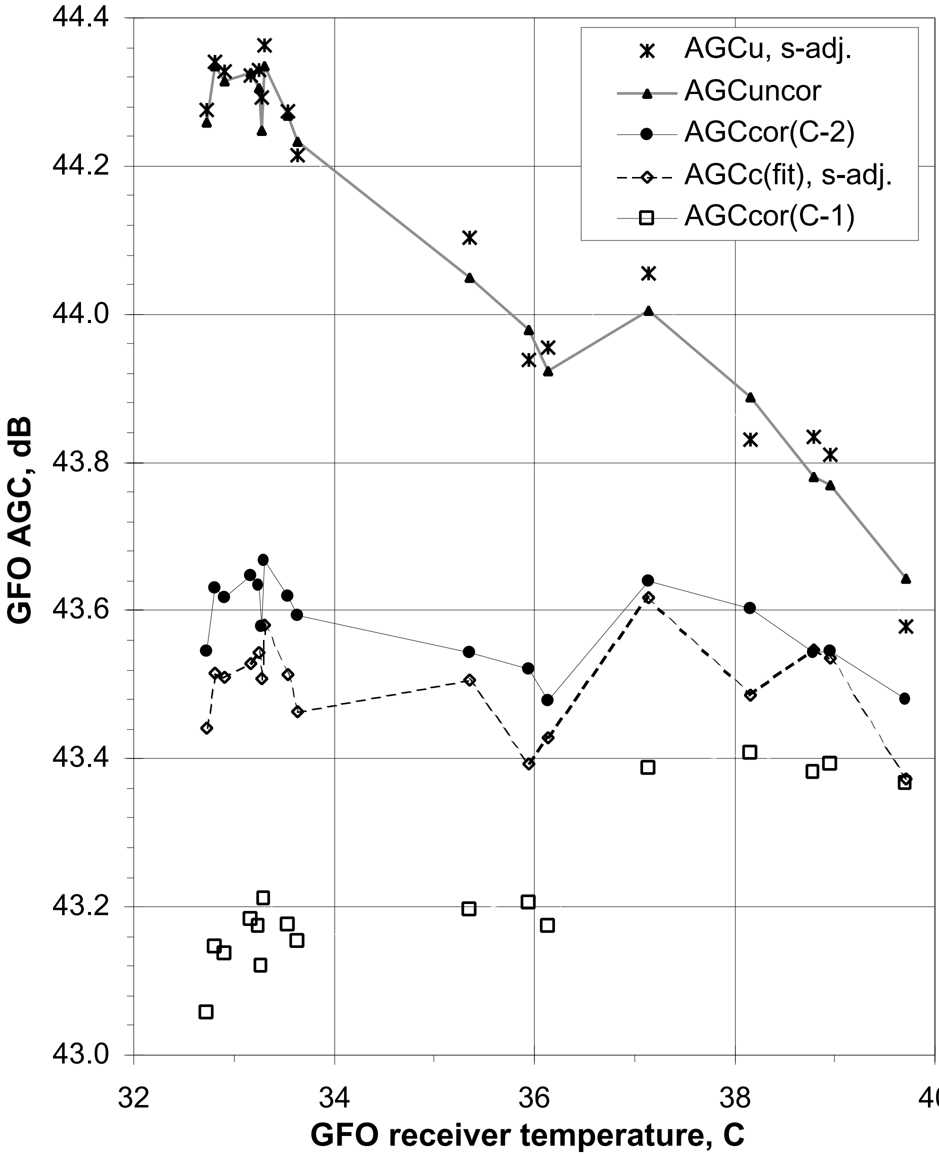


Figure 4-6 GFO AGC vs. Receiver Temperature

check the proper functioning of GFO instrument related to the altimeter return power estimation. For that purpose we use the National Centers for Environmental Prediction (NCEP) winds. The following sections will provide a description of the collocation process and results of the routine analysis.

4.4.1 Method and Data

Following last year's comparison between GFO and TOPEX altimeters for the radar cross section based on collocations of each altimeter data with the National Centers for Environmental Prediction (NCEP) winds as a common reference (Appendix A: GFO Altimeter Sigma0 and SWH Calibration Correction of the "GFO Altimeter Engineering Assessment Report - Volume 1: From Launch to Acceptance", December

2000), we keep doing collocations between GFO measurements and NCEP winds on a cycle basis.

The different measurements used are a 10 second average. GFO altimeter data are limited in space between 60º N. and 60º S. These sets allow us to determine biases between GFO and NCEP wind speeds.

4.4.2 Results

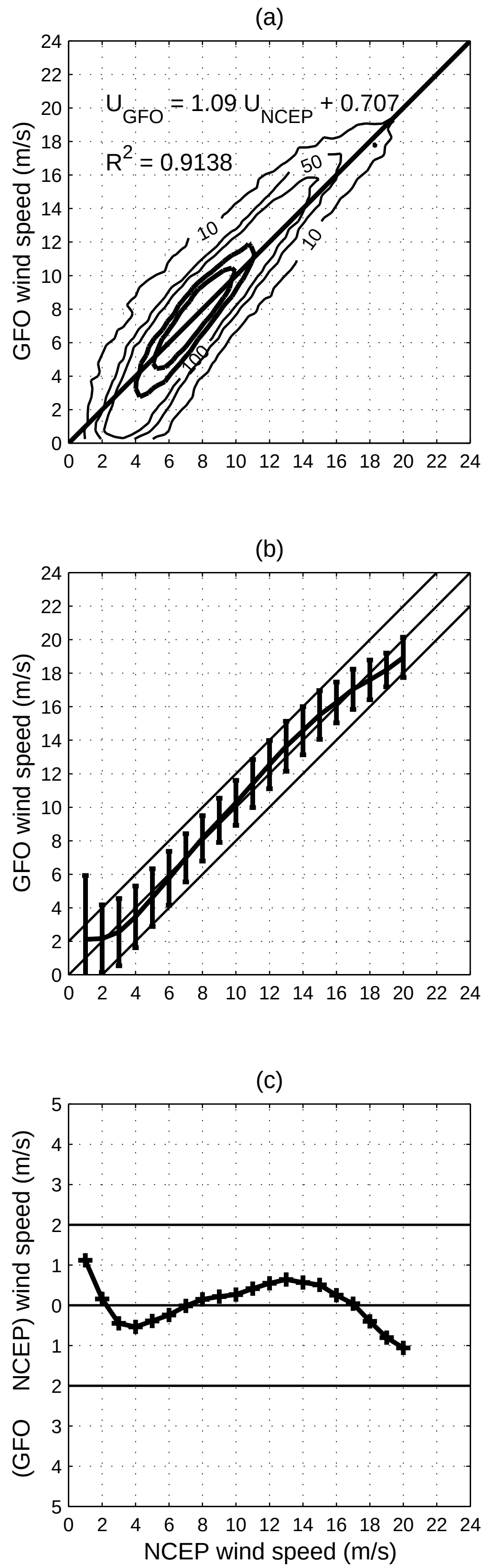
Figure 4-7 "Comparison between GFO and NCEP Wind Speeds for Cycle #8" on page 4-15 and Figure 4-8 "Comparison between GFO and NCEP Wind Speeds for Cycle #14" on page 4-16 present the one cycle summary results for respectively cycle #8 and #14. Panels (a), (b), and (c) present respectively the scatter diagram between GFO and NCEP wind speeds, the bin-averaged data of GFO with respect to the 1 m/s bin NCEP winds, and finally the bias between GFO and NCEP estimates as a function of NCEP wind speed. As we can see, the data are close to the perfect line and the difference between the two wind speed estimates are in average almost between ±1 m/s. The biases depend on the wind speed interval and the cycle considered.

Table 4-5 "Statistical Indicators" on page 4-17 provides the cycle-per-cycle statistical indicators. In order to have indicators free of problems linked to low and high wind speed estimates, we computed the averaged radar cross-section and SWH values and the bias between GFO and NCEP wind speed over a subset of selected data (between ±1 standard deviation from the mean of the NCEP wind speed for a given cycle). These subsets contain ~60 percent of data from the global sets GFO/NBCEP. The minimum value of NCEP wind speed is about 4.4 m/s and the maximum value is about 11.4 m/s. The global bias computed on these subsets shows values ranging in magnitude between 0.03 and 0.68 m/s. Data from cycle #8 exhibit the lowest bias and data from cycle #14 exhibit the largest bias in magnitude.

Figure 4-9 "Plot of Selected Statistical Indicators from Table 1" on page 4-18 shows the variation of the averaged value of NCEP wind speed, the bias between the two wind speed estimates, the averaged value of radar cross-section and SWH, given in Table 4-5, as a function of the cycle number. Note the semi-annual modulation in the bias between GFO and NCEP wind speeds which is anti-correlated with the radar cross-section measurement features.

4.4.3 Conclusion

This comparison shows small biases between GFO and NCEP wind speeds. The averaged bias for a cycle range between ±0.5 m/s except for the cycle #14. Within a cycle biases depend on the wind speed interval considered. An interesting feature that need more work to understand is the semi-annual modulation shown in the bias between GFO and NCEP wind speeds which is anti-correlated with the radar cross-section measurement feature.



GFO, 2001, cycle # 08

of data (10 s average): 74331

(1) NCEP wind speed distribution

mean: 7.9446
std: 3.109
min: 0.79
max: 25.512

(2) GFO wind speed distribution

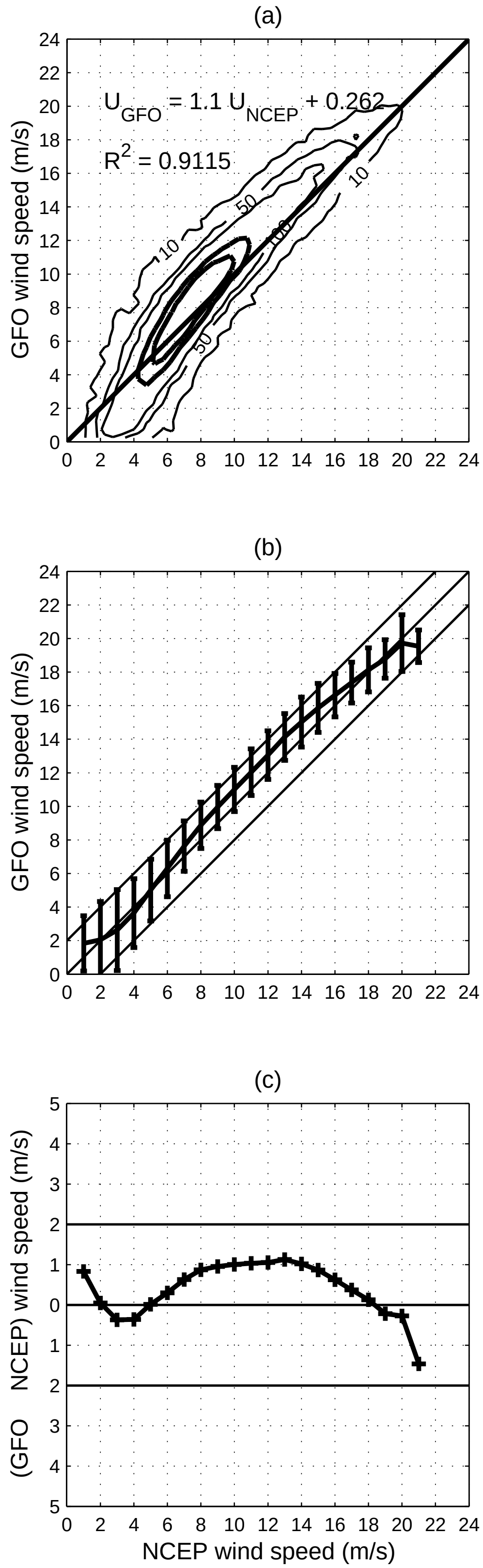
mean: 7.975
std: 3.718
min: 0.098
max: 38.894

(3) <GFO>   <NCEP> = 0.030366

(4) <σ0> and <SWH> for NCEP wind speed in the range mean ± 1 std

NCEP (mean 1std): 4.8356
NCEP (mean+1std): 11.0536
<σ0>: 11.3981
<SWH>: 2.2784
<GFO>   <NCEP>: 0.03202

Figure 4-7 Comparison between GFO and NCEP Wind Speeds for Cycle #8



GFO, 2001, cycle # 14

of data (10 s average): 74243

(1) NCEP wind speed distribution

mean: 8.0299
std: 3.1934
min: 0.554
max: 24.697

(2) GFO wind speed distribution

mean: 8.6053
std: 3.869
min: 0.071
max: 49.74

(3) <GFO> <NCEP> = 0.57536

(4) <σ0> and <SWH> for NCEP wind speed in the range mean ± 1 std

NCEP (mean 1std): 4.8365
NCEP (mean+1std): 11.2233
<σ0>: 11.2049
<SWH>: 2.3256
<GFO> <NCEP>: 0.67835

Figure 4-8 Comparison between GFO and NCEP Wind Speeds for Cycle #14

Table 4-5 Statistical Indicators

cycle	limit 1 (m/s)	limit2 (m/s)	$<\sigma_0>$ (dB)	<SWH> (m)	$<U_{gfo}>$ (m/s)	$<U_{ncep}>$ (m/s)	$<U_{gfo}> - <U_{ncep}>$
1	4.865	11.122	11.526	2.334	7.236	7.618	-0.382
2	4.862	10.885	11.543	2.229	7.190	7.521	-0.331
3	5.039	11.055	11.284	2.313	8.051	7.793	0.258
4	4.896	10.846	11.269	2.288	8.103	7.604	0.499
5	4.558	10.960	11.369	2.307	7.803	7.355	0.448
6	4.498	10.902	11.412	2.327	7.673	7.337	0.336
7	4.746	11.207	11.275	2.413	8.115	7.682	0.433
8	4.836	11.054	11.398	2.278	7.678	7.646	0.032
9	4.660	10.990	11.585	2.258	7.067	7.432	-0.365
10	4.667	10.856	11.566	2.124	7.134	7.379	-0.245
11	4.768	11.025	11.537	2.173	7.213	7.578	-0.365
12	4.968	11.353	11.312	2.312	7.949	7.786	0.163
13	4.740	10.997	11.319	2.233	7.952	7.505	0.447
14	4.836	11.223	11.205	2.326	8.334	7.656	0.678
15	4.763	11.150	11.292	2.239	8.031	7.607	0.424
16	4.534	11.256	11.342	2.255	7.899	7.487	0.412
17	4.627	11.230	11.375	2.247	7.775	7.486	0.289
18	4.694	11.024	11.481	2.287	7.390	7.459	-0.069
19	4.648	10.778	11.589	2.104	7.035	7.365	-0.330
20	4.842	10.962	11.433	2.215	7.544	7.578	-0.034

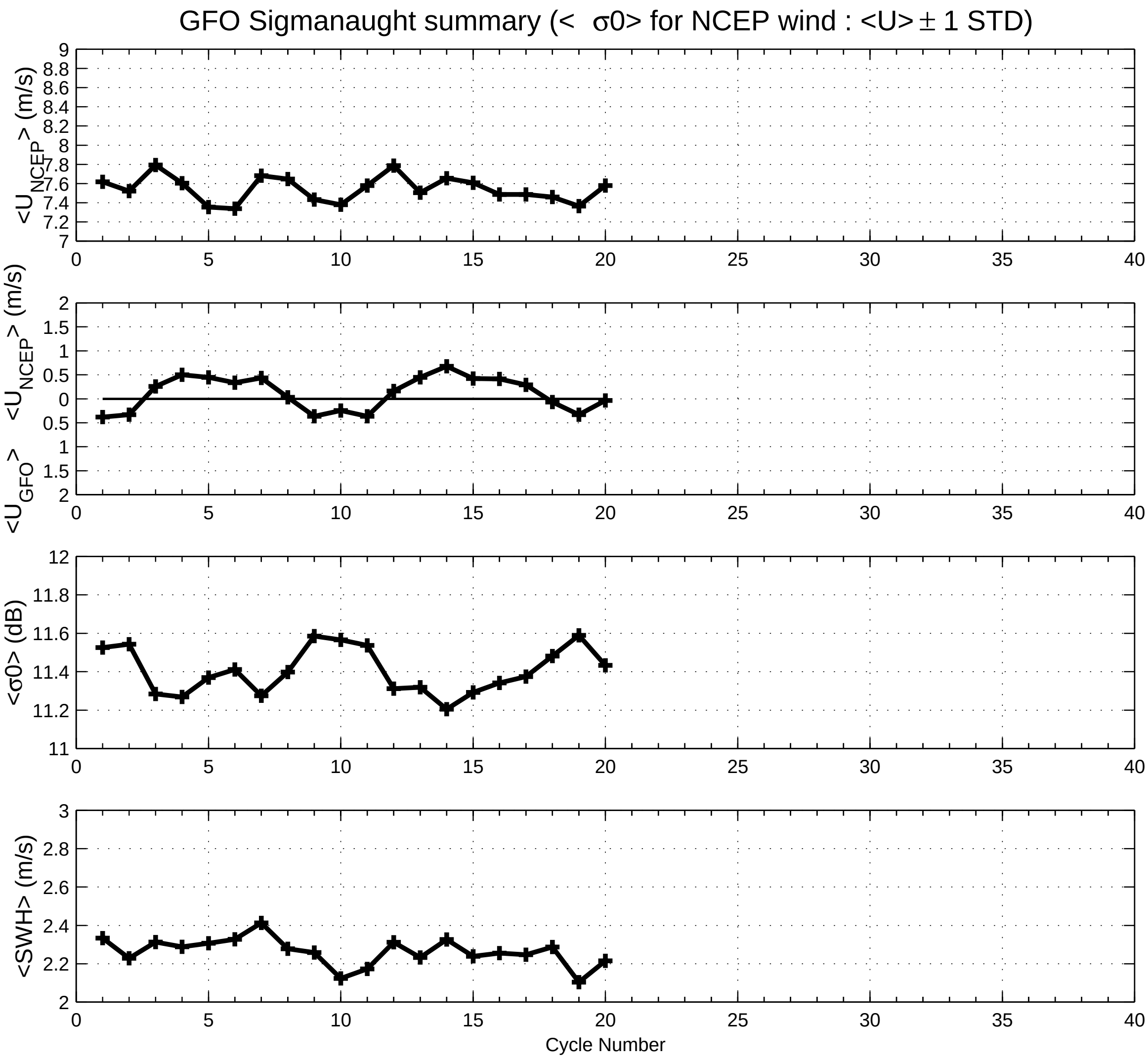


Figure 4-9 Plot of Selected Statistical Indicators from Table 1

Section 5

WFF's Recommendation to GFO Project

5.1 Greenland Waveforms

The Wallops request for taking waveform data over Greenland was successfully implemented during this period. See Section 3.2.

5.2 Altimeter Boresight Calibration (ABCAL)

The WFF team recommended an altimeter boresight calibration. See Appendix B.

Section 6
Engineering Assessment Synopsis

6.1 Performance Overview

Our analyses of the GFO altimeter demonstrate that it is performing well. Its range measurement precision is comparable with contemporaneous satellite radar altimeters, including TOPEX. Its internal calibrations and its cycle-to-cycle global averages have been very consistent. Comparisons with other sensors indicate that measurement biases are within GFO's pre-flight specifications of: SWH +/- 0.5m, Sigma0 +/- 1 dB, and windspeed +/- 2 m/s.

During the assessment of the GFO altimeter performance, WFF has encountered a number of data problems that are the result of ground data processing errors. These processing errors are noted in Section 2.4.

We are continuing our GFO altimeter performance assessment on a daily basis, and are continuing to develop improved analysis techniques. Supplemental performance reports will be issued on a regular basis, and special reports will be prepared as warranted.

Section 7

References

7.1 Supporting Documentation

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Appendix A

Accumulative Index of Studies

GFO Altimeter Sigma0 and SWH Calibration Correction - *GFO Altimeter Engineering Assessment Report, From Launch to Acceptance,* NASA / TM-2001-209984 / Ver.1 / Vol.1, March 2001.

GFO "Smile Patch" and Its Consequences - *GFO Altimeter Engineering Assessment Report, From Launch to Acceptance,* NASA / TM-2001-209984 / Ver.1 / Vol.1, March 2001.

GFO Sigma0 and SWH Calibration Correction - *GFO Altimeter Engineering Assessment Report, From Launch to Acceptance,* NASA / TM-2001-209984 / Ver.1 / Vol.1, March 2001.

GFO Sigma0 Comparison of GFO and TOPEX - *GFO Altimeter Engineering Assessment Report, From Launch to Acceptance,* NASA / TM-2001-209984 / Ver.1 / Vol.1, March 2001.

GFO SWH Comparison of GFO and TOPEX - *GFO Altimeter Engineering Assessment Report, From Launch to Acceptance,* NASA / TM-2001-209984 / Ver.1 / Vol.1, March 2001.

GFO Range and SWH Consequences of Thermal Change - *GFO Altimeter Engineering Assessment Report, From Launch to Acceptance,* NASA / TM-2001-209984 / Ver.1 / Vol.1, March 2001.

Sigma0 Blooms and Examples in GFO Data - *GFO Altimeter Engineering Assessment Report, From Launch to Acceptance,* NASA / TM-2001-209984 / Ver.1 / Vol.1, March 2001.

Temperature Correction for AGC - *GFO Altimeter Engineering Assessment Report, From Launch to Acceptance,* NASA / TM-2001-209984 / Ver.1 / Vol.1, March 2001.

WFF Recommended Sigma0 and SWH Corrections - *GFO Altimeter Engineering Assessment Report, From Launch to Acceptance,* NASA / TM-2001-209984 / Ver.1 / Vol.1, March 2001.

Appendix B
WFF Recommendation for ABCAL

The following e-mail message, posted by George Hayne on June 29, 2001, recommends to the GFO Project an attitude bias calibration.

Date: Fri., 29 Jun. 2001 11:26:55 -0400
To: M. Rau <mrau@bmpcoe.org>
From: "George S. Hayne" <hayne@osb1.wff.nasa.gov>
Subject: Re: Cruciform Maneuver to verify off-Nadir
Cc: "David Hancock" <hancock@osb1.wff.nasa.gov>,
"Jay L Finkelstein" <finkelsj@surffirst.net>,
"George Hayne" <hayne@osb1.wff.nasa.gov>,
"Dennis Lockwood" <lockwood@osb1.wff.nasa.gov>

Mort,

As you probably know, David Hancock is on leave this week but will be back here next week. He may have comments to add upon his return, but I'm sending you this now to help get started. In the following I will review the TOPEX attitude bias maneuver (the ABCAL), and then what that might mean for GFO.

Call the two orthogonal angle axes X and Y for the following discussion. It is not important for now which axis is the pitch angle and which is roll angle. The TOPEX ABCAL starts at nominal (X,Y) value (0,0) and drives the spacecraft attitude to the following (X,Y) values in succession: (+Xmax, 0), (0,0), (-Xmax,0), (0,0), (0,+Ymax), (0,0), (0,-Ymax), and finally (0,0). The off-nadir angle is the square root of the sum of the squares of pitch and roll, so for a properly functioning attitude control system a plot of the off-nadir value vs. time over the ABCAL will start at nominal zero and then show four successive peaks after which the off-nadir angle will again be at nominal zero at the conclusion of the ABCAL. For TOPEX each of these peaks is about 200 seconds wide, and the entire ABCAL takes about 840 seconds to execute. The TOPEX Xmax and Ymax are both about 0.45 degrees.

Any altimeter ABCAL requires that the entire time of the ABCAL should be over open ocean, and that the waveform data be available from that time (meaning that GFO should be in its RA CAL LONG telemetry mode during an ABCAL). A good rule of thumb might be that an altimeter ABCAL should have maximum angle excursions of the order of half the antenna's beamwidth, maybe just slightly less. TOPEX with an antenna beamwidth of 1.05 degrees has an ABCAL excursion of 0.45 degrees as described above. For GFO with its 1.6 degree beamwidth, an ABCAL excursion of 0.70 to 0.75 degrees would be useful, and the GFO ABCAL probably should take about 840 seconds or so. This implies slightly higher slew rates than for TOPEX, since one would be doing larger angle excursions in the same time. If slew rate is a problem, there's nothing wrong with an ABCAL lasting longer than 840 seconds except for the requirement that the entire ABCAL be over open ocean.

Although TOPEX normally operates at off-nadir angles of 0.1 degree or less, the ground processing algorithms are designed to correct for off-nadir angles as large as 0.45 degrees, so the altimeter's end user sees no loss of useful data from the time during which the ABCAL was being executed. TOPEX makes its waveform-based attitude estimates frame by frame, for the nominal 1 second data frame, and the corrections for attitude are also made frame by frame. The GFO situation is somewhat different because of the relatively heavy time filtering used in producing the fitted Vatt which is used in the GFO data corrections for off-nadir angle. I would expect some several centimeters of range error in the GFO final range estimate as a result of a GFO ABCAL; I could make a somewhat better estimate of the GFO range error bounds during an ABCAL if this is a crucial question, but it would take me a day or so to do that.

We would expect to process the GFO data from an ABCAL to produce our best guess at the off-nadir angle vs. time, and we can forward those results to the appropriate people in the GFO spacecraft attitude control business.

George

The following e-mail message, posted by George Hayne on October 24, 2001, recommends to the GFO project attitude control during calibration maneuvers.

Date: Wed, 24 Oct 2001 13:13:38 -0400
To: "Weiss, Michael" <mweiss@ball.com>
From: "George S. Hayne" <hayne@osb.wff.nasa.gov>
Subject: Re: FW: GFO Attitude Control During Calibration Maneuvers
Cc: Finkelstein_J, Rau_M, Hancock_D

Mike,

.... (unrelated paragraph deleted).

In a previous email I had described the TOPEX attitude bias calibration maneuver (ABCAL). Then I extrapolated from the TOPEX ABCAL to a proposed GFO ABCAL. You suggested that GFO maneuvers too quickly to provide the profile I suggested, but I think we're in pretty good shape anyhow. The GFO slew rates are higher than I might have wished, but there would be useful information to be gained even in the limiting case of a square-wave-looking attitude vs. time.

I think we could get some reasonable attitude estimates from 1-second waveform averages in the 0.7 degree pitch maneuver shown in Doug's Figure 1, and certainly from the last couple of tens of seconds in this example. There is the possibility that the overshoot in angle would cause the altimeter to lose lock, but it would acquire track again within 5 seconds or so as the angle came back to 0.7 degrees from its overshoot. I had originally proposed 0.7 degrees as the angle excursion, but I think that we would get good enough data from 0.6 degree attitude excursions, and this choice would reduce the time that the tracker might be out of lock because of the attitude. A reasonable proposal would be to allocate 120 seconds for each of the steps in a cruciate ABCAL; this would give enough time for track acquisition even if the track were to be lost at the attitude extremes. Here is a proposed GFO ABCAL sequence in pitch and roll (in degrees), and Tstrt and Tfinish are the start and finish times of each segment in seconds:

- - - - - - - POSSIBLE GFO ABCAL SEQUENCE - - - - - - - - - -

Segment	Tstrt	Tfinish	Xstart	Ystart	Xfinish	Yfinish
------	-----	-------	------	------	-------	-------
1a	0	120	0.0	0.0	+0.6	0.0
1b	120	240	+0.6	0.0	0.0	0.0
2a	240	360	0.0	0.0	-0.6	0.0
2b	360	480	-0.6	0.0	0.0	0.0
3a	480	600	0.0	0.0	0.0	+0.6
3b	600	720	0.0	+0.6	0.0	0.0
4a	720	840	0.0	0.0	0.0	-0.6
4b	840	960	0.0	-0.6	0.0	0.0

I refer to X and Y in this; one of these is pitch and one is roll, but I don't care at all which is which. This maneuver will give us several tens of seconds of data at each of the four extremes in pitch and roll. The entire sequence is completed within 960 seconds and has to be scheduled so that the entire 960 seconds is over-water, a not unreasonable time (the TOPEX ABCAL is 840 seconds, for example). As compared to TOPEX, this GFO ABCAL would give us faster attitude slew rates and relatively longer dwell times at the attitude extremes. This proposed GFO ABCAL is a replacement for an earlier version I proposed; that earlier version should now be ignored.

It should go without saying that we will need the GFO waveform data for the entire ABCAL sequence - but I'll say it here just to be safe. Those waveforms reach us in GFO's RA Cal LONG format. If there's any question or uncertainty about what I'm saying please check back with me, because it is crucial that we at Wallops receive the waveforms for the GFO ABCAL.

The other crucial requirement for the GFO ABCAL is that we would have to be given enough information and data to derive second-by-second attitude control system estimates of the pitch and roll angles relative to the nadir direction. This will involve some education as well as we don't normally deal with quaternions, body axes, and so forth. Is it Doug Wiemer who is going to help us with this? We have to be able to compare our altimeter waveform-derived attitude estimates to the attitude-control-system derived ones, and so we will have to be sure that we have access to the needed attitude control system data second-by-second through the entire GFO ABCAL sequence.

I hope this helps. Where do we go from here?

Regards,

George

Abbreviations & Acronyms

CAL	Calibration Mode or Calibration Mode data
Cal / Val	Calibration and Validation
CPU	Central Processing Unit
EDAC	Error Detection and Correction Circuits
EEPROM	Electrically Erasable Programmable Read Only Memory
ENG	Engineering Data
ERO	Exact Repeat Orbit
FTP	File Transfer Protocol
GEOSAT	Geodetic Satellite
GFO	GEOSAT Follow-On
GPSR	Global Positioning Satellite Receiver
GSFC	Goddard Space Flight Center
HW	Hardware
IAP	Integrated Avionics Processor
IDL	Interactive Data Language
NCEP	National Centers for Environmental Prediction
NGDR	NOAA Geophysical Data Record
NSI	NASA Science Internet
OODD	Operational Orbit Determination Data
POC	Payload Operations Center
QSCAT	NASA QuikSCAT satellite
RA	Radar Altimeter
RAM	Read Access Memory
RASE	Radar Altimeter System Evaluator
SCI	Science Data
SDR	Science Data Record
SDT	Science Definition Team
SMA	Semi-Major Axis of the orbit
SW	Software

UTC	Universal Time Code
VTCW	Vehicle Time Code Word
WF	Waveform Data
WFF	Wallops Flight Facility
WVR	Water Vapor Radiometer

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13. ABSTRACT *(Maximum 200 words)*

The U.S. Navy's Geosat Follow-On (GFO) Mission, launched on February 20, 1998, is one of a series of altimetric satellites which include Seasat, Geosat, ERS-1, and TOPEX/POSEIDON (T/P). The purpose of this report is to document the GFO altimeter performance determined from the analyses and results performed by NASA's GSFC and Wallops altimeter, calibration team. It is the second of an anticipated series of NASA's GSFC and Wallops GFO performance documents, each of which will update assessment results. This report covers the performance from instrument acceptance by the Navy on November 29, 2000, to the end of Cycle 20 on November 21, 2001. Data derived from GFO will lead to improvements in the knowledge of ocean circulation, ice sheet topography, and climate change. In order to capture the maximum amount of information from the GFO data, accurate altimeter calibrations are required for the civilian data set which NOAA will produce. Wallops Flight Facility has provided similar products for the Geosat and T/P missions and is doing the same for GFO.

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