U. S. DEPARTMENT OF COMMERCE

National Oceanic and Atmospheric Administration

The Geosat Altimeter JGM-3 GDRs on CD-ROM

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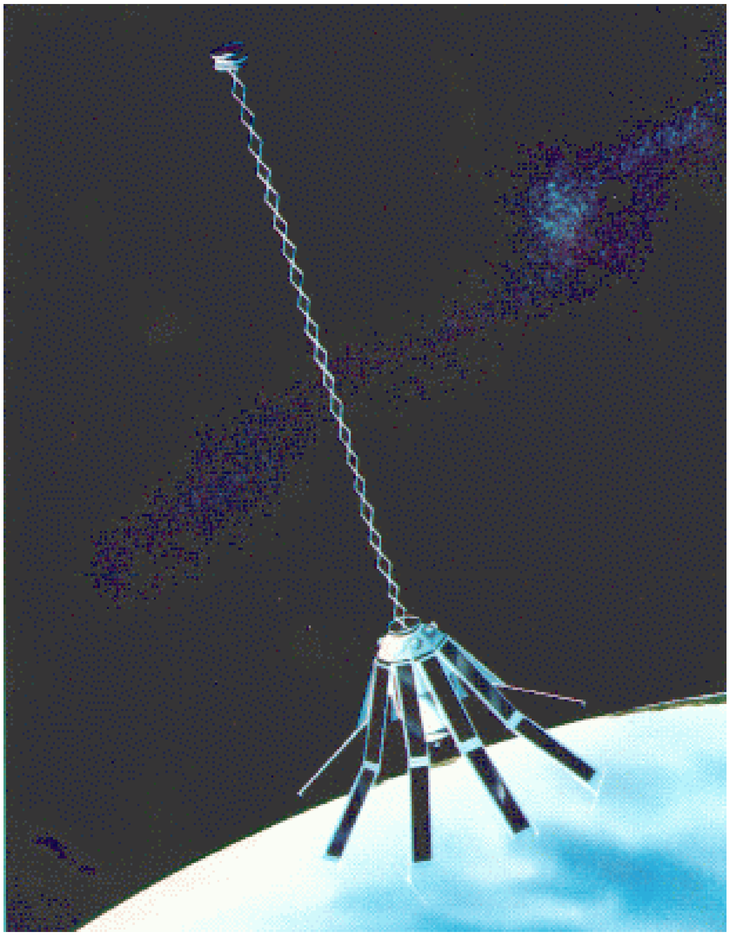
1. Introduction

The purpose of this handbook is to provide basic information about the 1997 release of the Geosat altimeter JGM-3 geophysical data records (GDRs). More extensive documentation and analysis will be provided in the online handbook, which will be available from the National Oceanographic Data Center home page, under the description of the Geosat JGM-3 GDRs.



From March 1985 until January 1990, the U.S. Navy satellite Geosat generated a new data set with unprecedented spatial and temporal coverage of the global oceans (Douglas and Cheney, 1990). Designed and built at the Johns Hopkins University Applied Physics Laboratory, Geosat carried a radar altimeter which produced profiles of sea level, wave height, and wind speed along the satellite ground track. Such records have applications in many areas of geodesy, ocean dynamics, and global climate research. Experience with GEOS-3 and Seasat in the 1970s had demonstrated the enormous potential of altimetry, but neither mission provided such complete long-term global coverage. Geosat paved the way for a series of highly-successful altimeter missions that followed it: ERS-1 (1991-96), TOPEX/POSEIDON (1992-), and ERS-2 (1995-).

1(a) Geodetic Mission

Geosat was launched on March 12, 1985, and altimeter data collection began on March 30. The acronym "Geosat" was derived from geodetic satellite, because its primary mission was to obtain a high-resolution description of the marine geoid up to latitudes of 72 degrees. This goal was achieved during the first 18 months, known as the geodetic mission (GM). During this time the ground track had a near-repeat period of about 23 days (330 revolutions in 23.07 days; average orbital period of 6039.84 sec). The drifting orbit resulted in a dense, global network of sea level profiles separated by about 4 km at the equator. Because of the military significance of this unique set of observations, the GM data were initially classified but in 1995 were released to NOAA in their entirety for public distribution.

1(b) Transition to the Exact Repeat Mission

At the conclusion of the GM on September 30, 1986, the satellite orbit was changed, and the exact repeat mission (ERM) began on November 8, 1986. This produced sea level profiles along tracks that repeated themselves within 1-2 km at intervals of about 17 days (244 revolutions in 17.05 days; average orbital period of 6037.55 sec). The ERM covered 62 complete 17-day cycles before tape recorder failure in October 1989 terminated the global data set. A limited amount of data was subsequently collected by direct broadcast in the North Atlantic and Gulf of Mexico. By January 1990 continued degradation of the altimeter output power finally ended the Geosat mission

1(c) Upgraded JGM-3 GDRs

The JGM-3 GDRs for Geosat represent the culmination of a decade of progress in refining the data set first distributed by NOAA in 1987. The previous release of the ERM data, referred to as the "T2" GDRs, is documented by Cheney et al. (1991). The initial *full* release of the GM data in 1995 was based on the original NSWC orbits. The 1997 release comprises the entirety of the GM + ERM data, with consistent JGM-3 orbits and enhanced geophysical corrections.

Most of the improvement has come in the area of orbit determination. For example, the initial satellite orbits for the ERM contained radial errors of 2-3 m. These were reduced to the 50-cm range in the T2 release in 1991. The present ephemeris, computed by the NASA Goddard Space Flight Center, is accurate at the level of 10 cm for most of the mission (*the exception being the last year of the ERM mission, see Chapter 5 Precautions*).

This remarkable achievement was made possible by (1) the 1993 release of the complete archive of Doppler tracking data and (2) development of the Joint Gravity Model-3 (JGM-3) (Tapley et al., 1994). Derivation of the JGM-3 orbit for Geosat, and the improvements gained from it, are discussed by Williamson and Nerem (1994). In the process of replacing the old NSWC (GM) and T2 (ERM) orbits, a timing bias correction of 5 msec was also applied to the GDRs. The time tags on the altimeter data were increased by a constant 5 msec over the duration of the mission, and the JGM-3 orbits were interpolated at the corrected GDR times. This timing bias correction greatly reduces the "twice-per-rev" orbit errors present in earlier releases of the Geosat data.

In addition to the improved orbits, nearly all of the geophysical corrections have been upgraded:

- ocean and load tides from the CSR 3.0 model (Eanes and Bettadpur, 1995)

- solid tide from an updated version of the Cartwright and Edden (1973) tide model

- wet and dry troposphere corrections based on the NCEP/NCAR reanalysis model (Kalnay et al., 1996)

- climatological wet troposphere correction based on the NASA NVAP dataset (Randel et al., 1996)

- ionosphere correction from the IRI95 model (Bilitza, 1997)

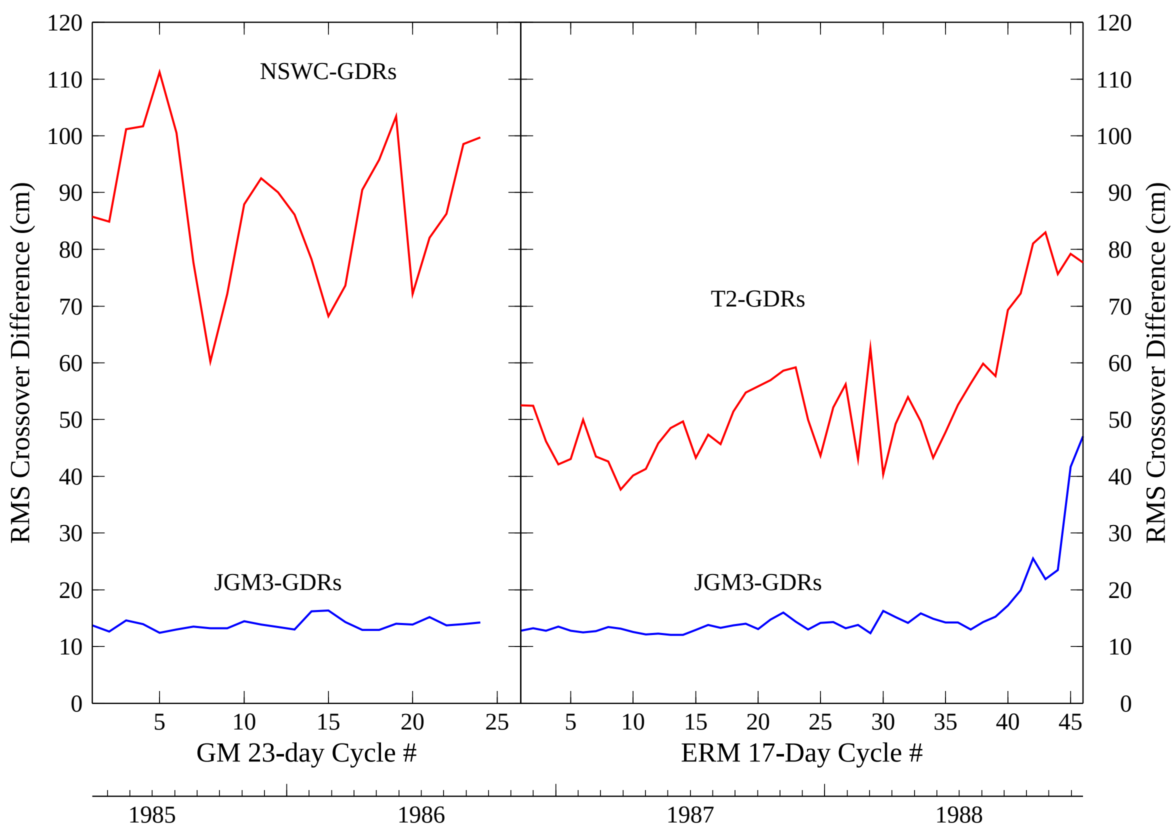
- wind speed from the Freilich and Challenor (1994) model

- a new sea state bias algorithm dependent on wind speed, wave height, and satellite attitude (Gaspar, Ogor, and Hamdaoui, 1996)

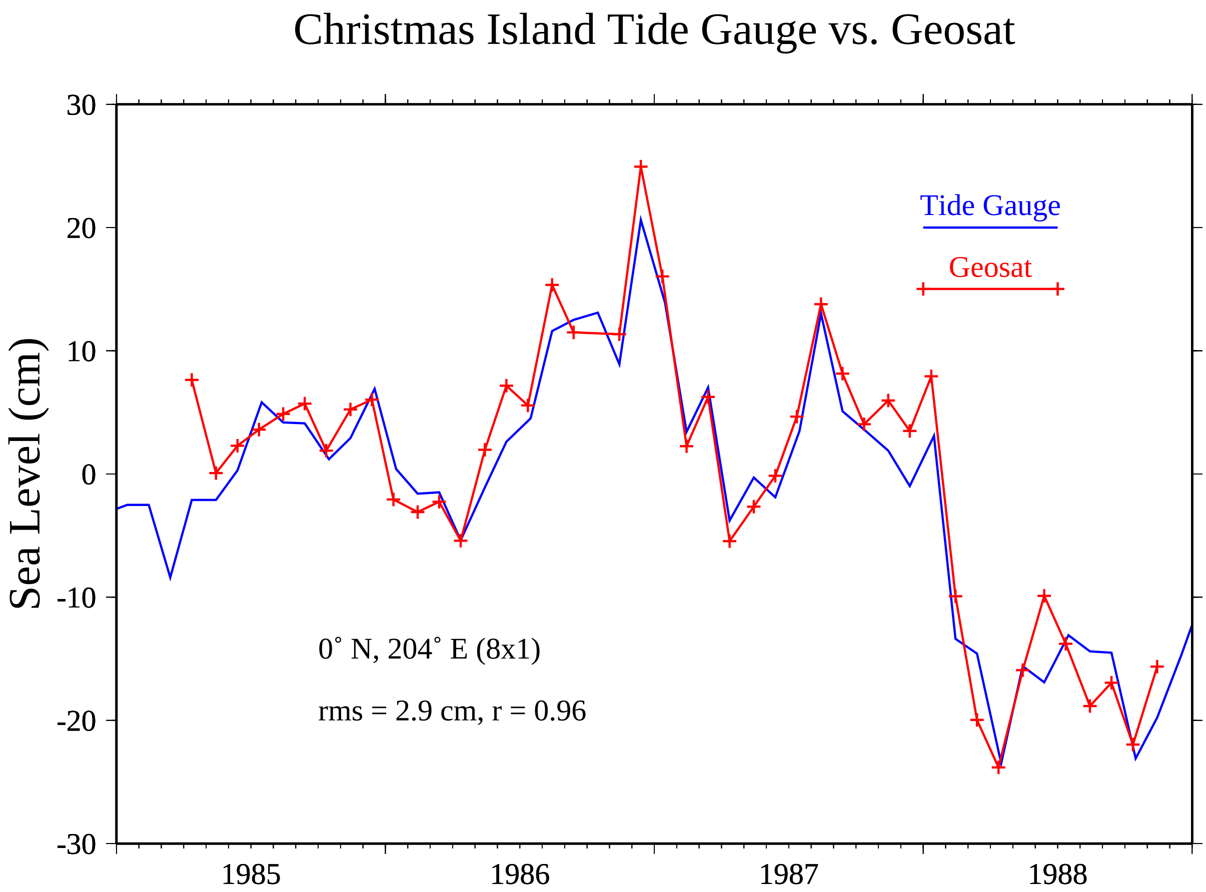
- the Ohio State 1995 mean sea surface (Yi, 1995)

The enhanced GDRs yield a relatively consistent 13-cm rms global crossover difference (computed over periods of about 3 weeks) during the first 3.5 years of the mission, as shown in the figure below. By comparison, a value of about 10 cm is obtained for similar spans of data from Topex/Poseidon (T/P), the present state-of-the-art altimeter satellite.

Geosat Intra-Cycle Crossovers: JGM-3 GDRs vs. Previous GDRs



The Geosat data can therefore be used, without performing separate orbit adjustments, to derive relatively accurate sea level variability. An example is provided by comparison with the tide gauge at Christmas Island in the central equatorial Pacific Ocean. For the 3.5-year period beginning in April 1985, monthly averages computed from Geosat crossover differences in an 8x1 (longitude x latitude) cell adjacent to the gauge yield an rms difference of 2.9 cm with 0.96 correlation, as shown below. Comparison of T/P data with the same tide gauge yields 1.4 cm and 0.98 correlation for collinear differences over a similar time span during 1992-96.



2. Organization of the CD-ROM Files

The daily GDR data files, from both the Geodetic Mission (GM) and Exact Repeat Mission (ERM), are stored on a set of 10 CD-ROM disks as indicated in the table below:

CD	Mission	Start Yr_Day	End Yr_Day	# GDRs
1	GM	1985_090	1985_227	138
2	GM	1985_228	1985_365	138
3	GM	1986_001	1986_138	138
4	GM	1986_139	1986_273	135
5	ERM	1986_312	1987_082	136
6	ERM	1987_083	1987_235	153
7	ERM	1987_236	1988_040	163
8	ERM	1988_041	1988_210	170
9	ERM	1988_211	1989_031	187
10	ERM	1989_032	1989_364	298

Each GDR covers a period of approximately 24 hours and contains data for either 14 or 15 complete revolutions, beginning and ending near 72 N. The first CD (beginning of the GM) and fifth CD (beginning of the ERM) contain documentation, example source code, secondary correction files, figures, and HTML files which allow the user's Web browser to navigate the information on those disks. The remaining eight disks contain only GDR data files.

2(a) Information Files on CD#1 and CD#5

The HTML file, "index.htm", is at the root level of the CD along with the "read_me.txt" file, which gives a brief introduction to the data set and instructions for viewing the files on the CDs. Several directories are found at the root level of the CD:

/docs - text, HTML, and PostScript versions of this handbook, plus tabular information related to the overall mission (see 2b below).

/code - example programs allowing the user to make listings of the binary GDR files, and to convert between Unix and PC/VAX binary formats (see 2c below).

/figures - high-quality "PostScript" and bit-mapped "GIF" illustrations that are referred to by this handbook.

/cyc_maps - maps showing the global distribution of Geosat data for each cycle of the GM and ERM. The "gif" subdirectory contains images that can be viewed directly with a Web browser; the "ps" subdirectory contains PostScript versions of the cycle maps. CD#1 contains the 23-day cycle GM maps and CD#5 contains the 17-day cycle ERM maps. Note that these maps were generated from daily GDRs, starting from the beginning of the GM and ERM, so the "cycle" definitions don't exactly agree with the cycle definitions in the equator crossing tables.

/scnd_cxn - files to be used to make secondary corrections to the altimeter data, as discussed in Section 4 of this handbook.

/gdrs - daily GDR data files (on all 10 of the CDs).

2(b) Documentation Files

Several files in the "docs" directory provide the user with additional tabular information. The format of the GDR files is contained in gdr_fmt.txt and is also presented in Section 3 below.

The gm_eqc.txt and erm_eqc.txt files provide lists of all Geosat equator crossings for the GM and ERM. These tables are useful for describing the collinear aspects of the two mission phases. Cycle periods are approximately 23 days for the GM (the near-repeat period) and 17 days for the ERM. A pass is defined as a half-revolution from pole-to-pole and pass # 1 in each cycle is defined as the ascending pass closest to the Greenwich meridian. All subsequent passes follow in time order. The ascending passes are therefore all odd numbered and the descending passes are even. Note that because of this arbitrary numbering system, the first cycle of both the GM and ERM do not begin with pass #1.

The relationship between equator crossing longitudes and pass numbers for all GM and ERM cycles is illustrated graphically in four plots: GM ascending, GM descending, ERM ascending, and ERM descending. In all four plots, the symbols are color-coded by cycle number. During the GM the slow drift of the orbit causes a rainbow effect as the equator crossing longitude moves westward for subsequent cycles. During the collinear ERM mission, the equator crossing longitudes are within +/- 2 km for all passes so that only the last cycle (in red) is displayed.

The orb_epoc.txt file documents the relationship between the (nominally 6-day) orbit ephemerides files generated at NASA/GSFC and the GDR data set. The start and stop times of each of the orbital solutions (arcs) is given, so the user will know when a "break" from one solution to the next occurs within the altimeter data. (Note there is no connection between the arc numbers given in this table and the pass numbers given in the equator crossing tables above.)

2(c) Source Code

Two programs can be built from the contents of the "code" directory. Program gdr_swab.c is used to swap bytes in a GDR binary file to make the internal format compatible with PC, VAX, and other "Little-Endian" machines. The native format of the GDR files in this data set are compatible with "Big-Endian" machines, typical of most Unix workstations. The usage of this program (under Unix or DOS) is simply:

"gdr_swab orig.gdr swabbed.gdr".

Program ligdr.f is used to make text listings of the contents of the binary GDR files. The simplest usage is: "ligdr gdr". This lists a subset of the most important variables in the "gdr". With the "-a" option, the user gets a complete listing of all the variables in each data record (refer to Section 3 below). The user can restrict the listing to a certain sequence of records using "-#" and/or "+#" where "#" is a lower or upper limit on the data records to list. A complete listing between records 1000 and 2000 would be given by:

"ligdr -a -1000 +2000 gdr".

3. GDR Format

Item	Parameter	Units	Bytes	Description
1	UTC	sec	4	UTC time since 01/01/85. Includes +5 msec timing bias correction.
2	UTC (cont'd)	microsec	4	UTC time, microseconds part.
3	LAT	microdeg	4	Latitude, microdegrees N.
4	LON	microdeg	4	Longitude, microdegrees E.
5	ORB	mm	4	JGM-3 orbit relative to reference ellipsoid: ae = 6378136.3 m; 1/f = 298.257.
6	H	cm	2	1-second average sea height relative to reference ellipsoid.
7	SIG_H	cm	2	Standard deviation of the 10/sec values about the 1–second H.
8	MSSH	cm	2	Mean sea surface height from the Ohio State MSS95 model.
9-18	H1-H10	cm	10*2	10/sec sea height values. To derive time tags, see footnote #1.
19	SWH	cm	2	Significant wave height (see footnote #2).
20	WS	cm/sec	2	Wind speed at 10 m height, from Freilich and Challenor (1994) model.
21	SIG_0	0.01 dB	2	Sigma naught, radar backscatter coefficient (see footnote #3).
22	SSB	mm	2	Sea state bias derived by Gaspar, Ogor, and Hamdaoui (1996).
23	L_TID	mm	2	Load tide from CSR 3.0 model.
24	FLAGS	-	2	See table below for flag bit definitions.
25	H_OFF	m	2	H offset to be added to all heights over land (flag bit 0 = 0).
26	S_TID	mm	2	Solid tide from T/P "TIDPOT" algorithm, based on Cartwright & Edden (1973).
27	O_TID	mm	2	Ocean tide from CSR 3.0 model.
28	WET_NCEP	mm	2	Wet troposphere correction from NCEP/NCAR reanalysis model.
29	WET_NVAP	mm	2	Wet troposphere correction from NASA NVAP climatology.
30	DRY_NCEP	mm	2	Dry troposphere correction from NCEP/NCAR reanalysis.
31	IONO	mm	2	Ionosphere correction from IRI95 model.
32	WET_T/S	mm	2	Wet troposphere correction from TOVS/SSMI observations.
33	DRY_ECMWF	mm	2	Dry troposphere from ECMWF model.
34	ATT	0.01 deg	2	Attitude (Spacecraft off-nadir orientation).
Total			78	Bytes

Footnote #1: Time tags for the H1-H10 heights can be computed with the formula:

$$t(i) = UTC(sec) + UTC(microsec) + 0.98 * (i/10.0 - 0.55); i=1\text{-}10$$

Footnote #2: SWH has been increased by 13%; see Carter, Challenor, and Srokosz (1992).

Footnote #3: Sigma-0 values in the GM have been modified by several tenths of a db (Ella Dobson, JHU/APL, personal communication).

Definition of Bits in Flag Word (Item #24)

Bit	**On (Bit = 1)**	**Off (Bit = 0)**	**Notes**
0	Ocean location	Land location	Based on 5-minute CSR land mask.
1	Ocean depth > 2250 m	Ocean depth < 2250 m	Based on 1-degree shallow sea mask.
2	dh(swh/att) or dh(fm) suspect	dh(swh/att) or dh(fm) nominal	See JHU/APL (1985).
3	Any 10/sec height invalid	All 10/sec heights valid	Invalid heights = 32767.
4-6	ATT flags suspect	ATT flags nominal	See JHU/APL (1985).
7	Wind speed suspect	Wind speed valid	Suspect if WS < 1.5 or > 20 m/s.
8	Sea state bias suspect	Sea state bias valid	SSB suspect if SWH < 0 or > 11m; if WS < 1.5 or > 20 m/s; or if ATT > 1.1 deg.
9-15	All remaining bits set to 0.		

For a plain text version of this table, click here.

4. How to Construct Corrected Sea Height

As discussed in this chapter, a number of corrections must be applied to the altimeter sea height, H, to obtain the most accurate value:

H corrected (mm) = 10 * H (cm) - WET_NCEP - DRY_NCEP - IONO - O_TID - S_TID - L_TID - SSB - IB - glo_ib - hcal - uso

The first 8 corrections (in all caps) are the primary ones. Of these, the first 7 are provided explicitly in each 1-sec record, and the eighth (IB: inverted barometer) can be computed from the 1-sec values of DRY_NCEP.

The last 3 corrections (in lower case) are secondary, more slowly varying terms and are provided in separate tables found on this CD-ROM.

4(a) Primary Corrections to H

The fundamental altimeter measurement contained in the GDRs is the sea height, H. This quantity is the difference between the satellite's orbital height above the reference ellipsoid (ORB) and the altimeter's range measurement (not explicitly provided in the GDR, but defined as the distance from the altimeter to the sea surface, determined from the round-trip travel time of the radar pulse). Thus the sea height is the distance (positive upwards) from the reference ellipsoid to the instantaneous sea surface. Both the 1-sec averaged height (H) and the 10 Hz heights (H1 - H10) are sea heights formed from "orbit-range" differences. The GDR heights have been corrected for instrumental effects, but not for environmental or geophysical influences. The sense of all the corrections above is that they should be *subtracted* from the sea height.

Instrumental effects and timing bias -

The instrumental effects which have already been applied include the center-of-gravity, FM crosstalk, ATT/SWH bias, and Doppler corrections (refer to JHU/APL ,1985, for a further discussion of these corrections). Additionally, a 5.0 msec timing bias (a bias between the orbit determination timing and the radar altimeter timing) has been applied while switching to the new JGM-3 orbits. The time tags on the GDR records were increased by 5 msec prior to computing the orbit height at the corrected GDR time.

Wet troposphere -

The radar pulse is slowed down by water vapor in the troposphere. The user has a choice of three corrections: WET_NCEP, WET_NVAP, or WET_T/S.

Recommendation - Use WET_NCEP

WET_NVAP is based on a monthly climatology and is suitable for checking the validity of the other two wets, or can be used as a backup if the primary wet correction is missing. However, it is not suitable, for most applications, as the primary wet correction. WET_NCEP, based on the NCEP/NCAR reanalysis meteorological model, is computed from synoptic model grids and should always be available on the GDR. Its advantage is full coverage in space/time and the synoptic nature of the grids. The model grid size of 2.5 degrees, however, makes it a relatively low-resolution wet correction. WET_T/S is computed from satellite measurements of integrated water vapor, based on the Tiros Operational Vertical Sounder data (prior to 7/9/87), and subsequently from the Special Sensor Microwave Imager data. The TOVS/SSMI data, in the form of 1 degree grids, have more spatial structure than the NCEP model data, but suffer from data gaps and aliasing from non-synoptic temporal compositing. Over the duration of the GM+ERM missions, WET_NCEP will guarantee a consistent correction with some loss of resolution and perhaps model bias. We believe WET_NCEP is superior to WET_T/S from the TOVS time period, but is probably not as good as WET_T/S based on the SSMI portion of the data.

Dry troposphere -

The radar pulse is slowed down by air molecules in the troposphere. The user has a choice of two corrections: DRY_NCEP and DRY_ECMWF.

Recommendation - Use DRY_NCEP

The two dry corrections on the GDR are comparable, with DRY_NCEP based on a more modern meteorological model. The presence of the new DRY_NCEP, and the older DRY_ECMWF (present on the previous T2 GDRs), allows the user a measure of verification on the dry correction values.

Ionosphere -

The radar pulse is slowed down by the ionosphere. Only one ionosphere correction, IONO, is provided. It is derived from the IRI95 model.

Tides -

The altimeter height measurement must be corrected for several effects unrelated to the propagation of the radar pulse. The largest of these are tides, which include the familiar ocean tide (O_TID), the solid earth tide (S_TID), and the load tide (L_TID, deformation of the solid earth caused by the ocean tide).

Sea state bias -

Sea state bias is another surface effect, related to wave height, wind speed, and satellite attitude, which should be applied to correct the height measurements. The SSB term provided in the GDR was derived by Gaspar, Ogor, and Hamdaoui (1996) based on Geosat crossover differences.

Local inverse barometer -

The response of the sea surface to changes in atmospheric pressure, the so-called "inverse barometer" correction, has a large effect on measured surface height. The simplest form for this correction is a purely local response of the sea surface to atmospheric pressure at the measurement point. Though not explicitly provided in the GDR records, the local inverse barometer correction can be easily computed from the dry correction, by first computing sea level pressure:

$$P \text{ (mbar)} = - \text{DRY\_NCEP (mm)} / (2.277 * (1.0 + 0.0026 * \cos (2.0 * \text{LAT}))$$

The inverted barometer correction is then:

$$\text{IB (mm)} = -9.948 * (P \text{ (mbar)} - 1013.3)$$

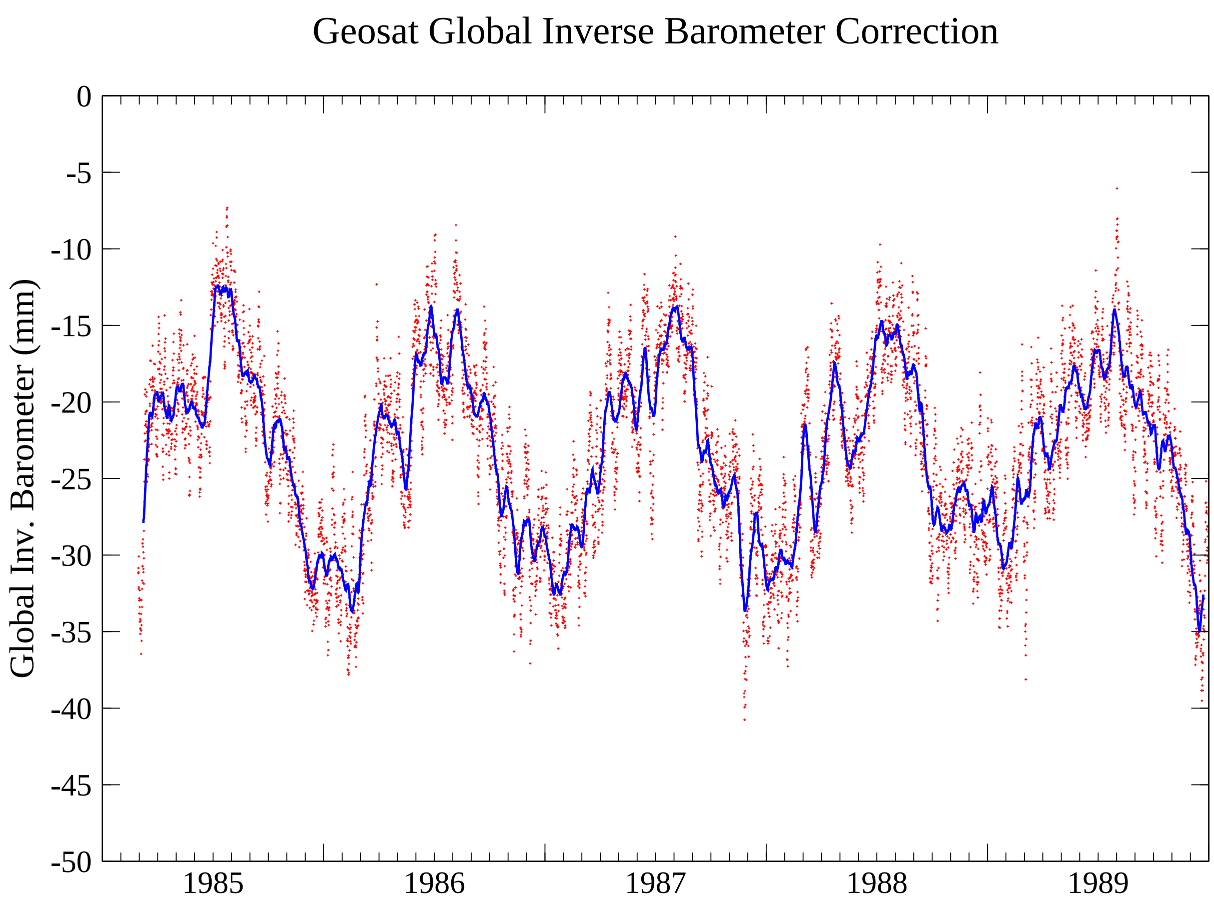
4(b) Secondary Corrections to H

In addition to the first order corrections supplied in each 1-sec record, we have included three "secondary" corrections via external files. These are located in the scnd_cxn folder on the first CD of the GM and ERM data sets. The secondary corrections are relatively small (< 3 cm peak-to-peak) and vary more slowly in time than the primary corrections. It is therefore more efficient to provide them in the form of look-up tables.

Global inverse barometer -

The glo_ib correction is provided at 6-hour intervals and augments the local inverse barometer correction, IB. The values in the file glo_ib.txt should be subtracted from the sea height, H.

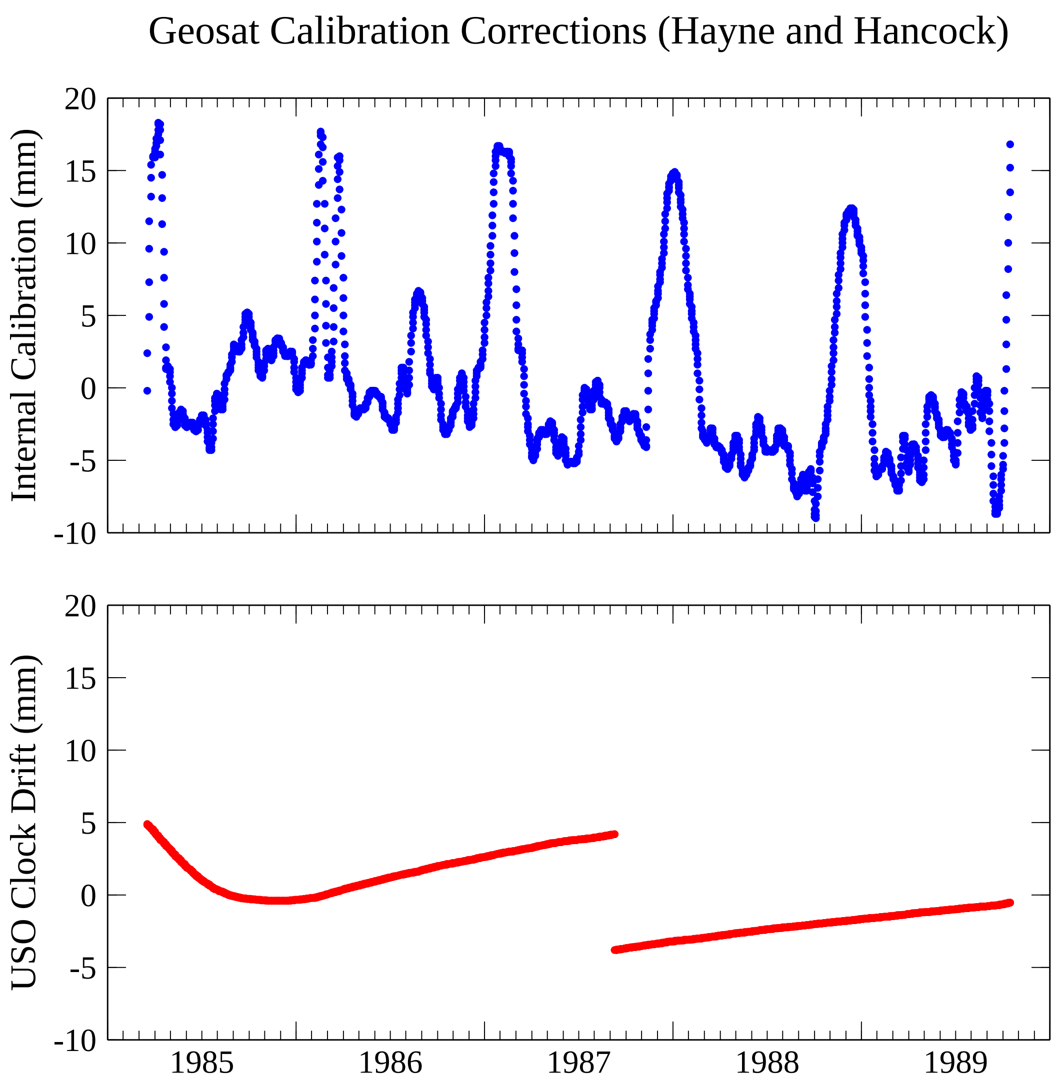
The true response of the sea surface to changes in atmospheric pressure must account for changes in the globally averaged (over-ocean) sea level pressure (Ponte et al., 1991). The glo_ib values were derived from the NCEP sea level pressure grids by (1) averaging over all ocean points, (2) computing a mean inverse barometer value using the IB formula above, and (3) changing the sign to enable the correction to be applied by subtracting it from H (the same convention as all other corrections). The variations of the 6-hourly values, as well as a smoothed version of this correction, are shown in the figure below.



Oscillator drift and internal calibration -

"hcal" and "uso" are refinements of two instrumental corrections previously applied to the sea surface heights on the GDRs. Both are supplied in one file, hcal_uso.txt. Each line in this file contains a daily value of hcal and uso (George Hayne and David Hancock, NASA/ WFF, personal communication). Both values provide the difference between these instrumental corrections as already applied and the new estimate of the correction. As with the primary corrections, they should be subtracted from the sea height H.

The hcal correction is based on the internal calibration measurement of the altimeter electronics, primarily reflecting the internal temperature of the altimeter system. This correction shows large semi-annual fluctuations.



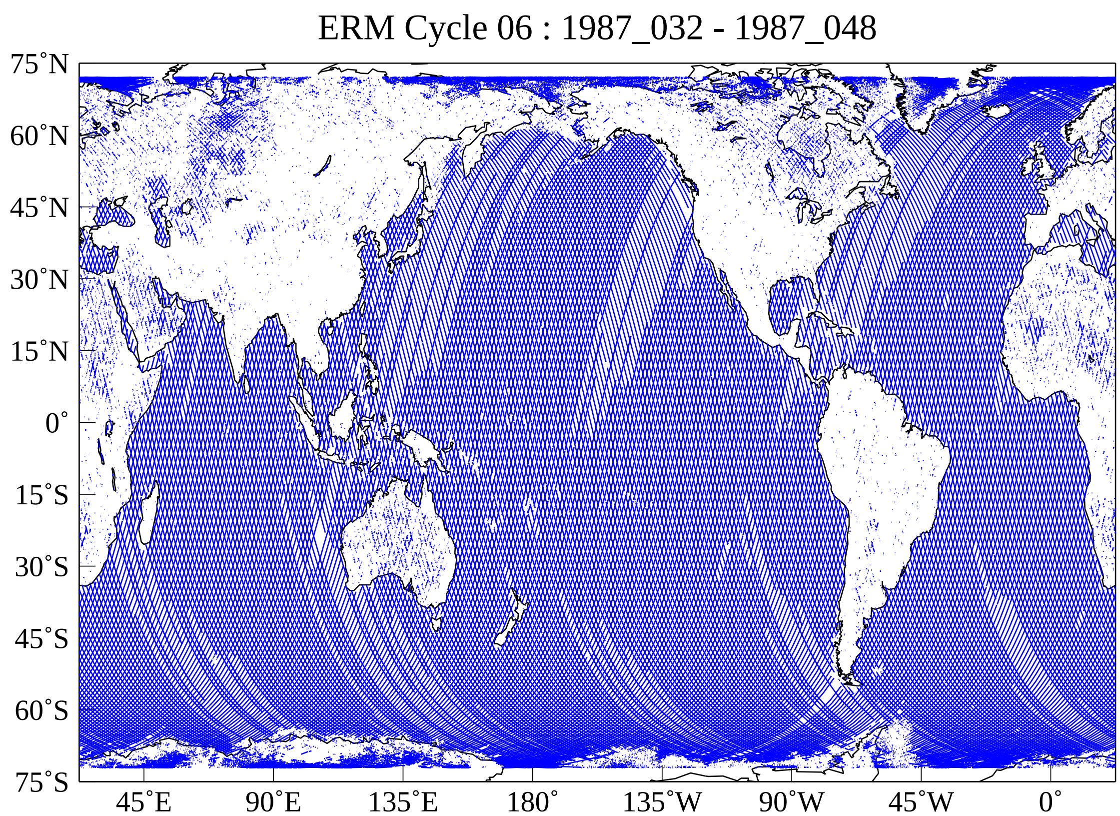
The uso correction is based on the altimeter's ultra-stable-oscillator (USO) which monitors the frequency of the altimeter's radar pulse generator. Changes in the USO frequency have a direct effect on the altimeter range measurement. The uso correction also removes a single step correction, applied on 9/12/87, which was a coarse correction applied to the GDRs to account for changes in the USO frequency.

5. Precautions

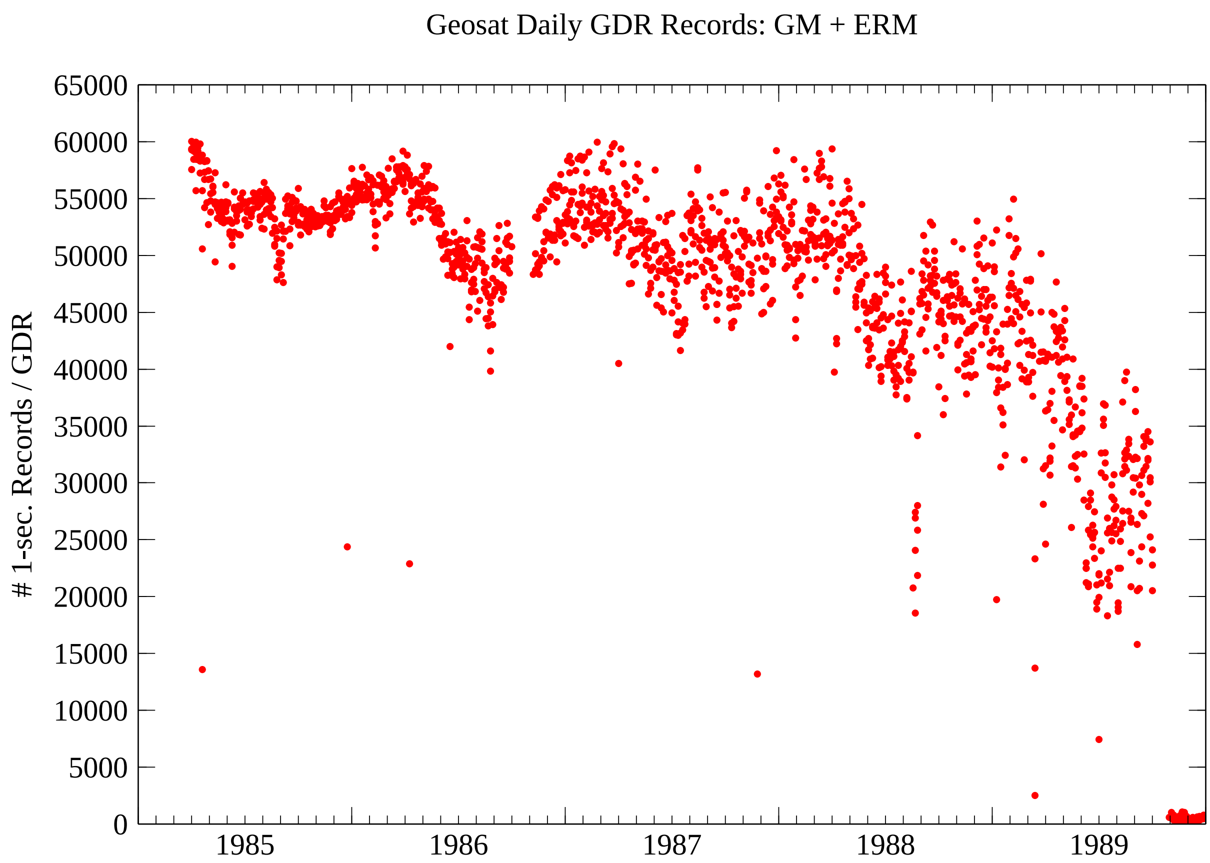
During the last year of the Geosat mission (late-1988 onward), both the coverage and accuracy of the altimeter data rapidly degraded compared to the first 3.5 years of observations. These data should therefore be used with some caution. As described below, both problems were related to the approach of solar maximum in mid-1989.

5(a) Data Loss

Geosat maintained nadir pointing of the altimeter antenna by means of a gravity gradient stabilization system. This method gave outstanding mechanical reliability, but allowed excursions off-nadir of 1 degree or more. Because the beam width of the altimeter was only 2 degrees, the nadir footprint was not always fully illuminated, making it difficult for the onboard tracker to lock-on to the return pulse during transitions from land to water. This resulted in permanent losses of data as shown by the sample coverage map below. (Coverage maps for each cycle of the GM and ERM can be found in subdirectory cyc_maps).



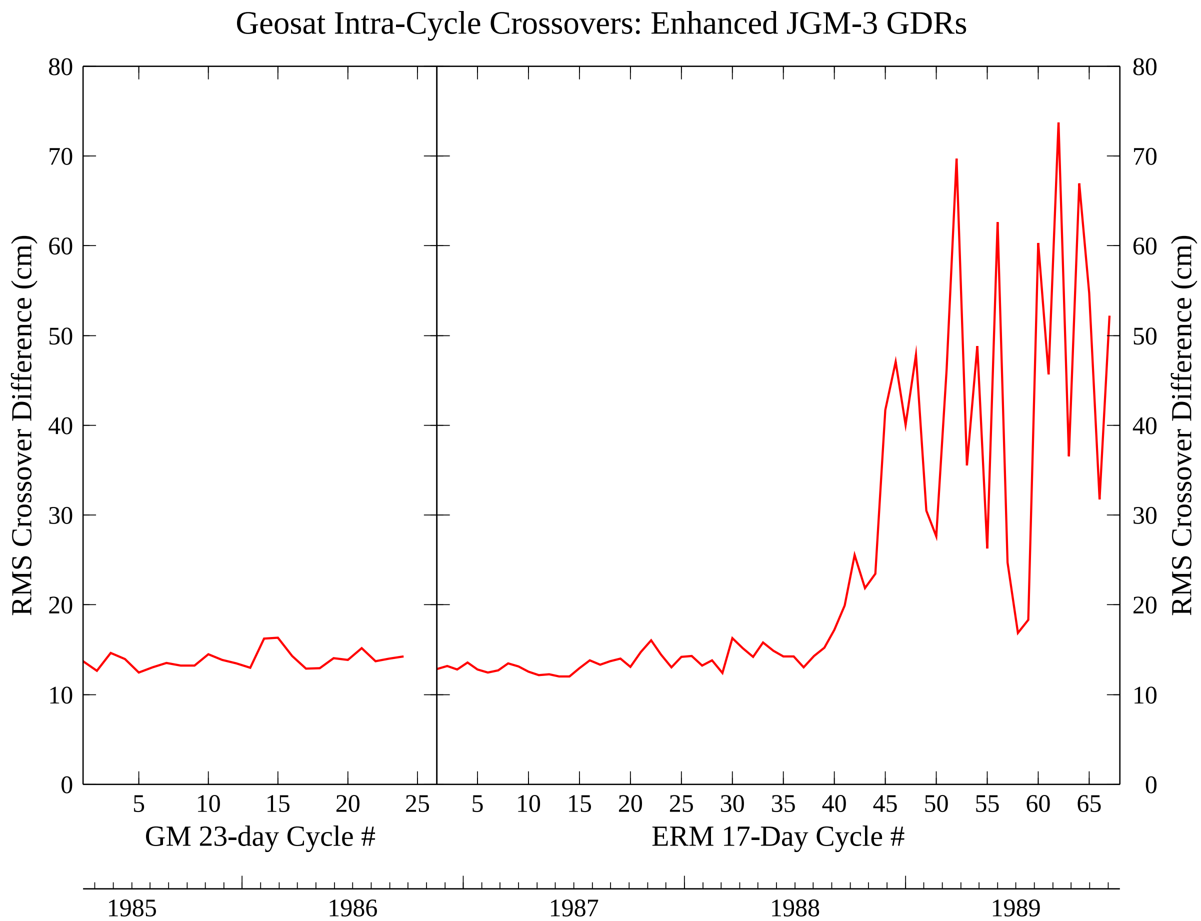
The problem of data loss existed during both the GM and ERM, but became increasingly severe as the mission progressed because of added drag and solar radiation pressure associated with the approach of solar maximum. The figure below shows the number of records for each day of the mission.



5(b) Orbit Accuracy

Orbit accuracy is also related to the solar cycle. When the sun is more active, the increased drag and solar radiation forces on the satellite become more difficult to model. At the same time, the quality of the Doppler tracking data is degraded by the ionosphere.

Global crossover differences, shown in the figure below, can be interpreted as a measure of orbit precision. (A crossover is defined as the intersection of the satellite ground track with itself. At this location, the two crossing passes provide independent sea level measurements at the same place but at different times). During the first 3.5 years of the Geosat mission, the crossover differences are about 13 cm for both 23-day (GM) and 17-day (ERM) cycles. This is consistent with 10-cm orbit precision, taking sea level variability into account. But near the end of 1988 the values rise to more than 30 cm and then fluctuate wildly, indicating that the orbit is not well-determined.



5(c) Other Periods of Data Loss

In addition to data gaps caused by routine attitude excursions, there were several periods of extreme data loss associated with satellite operations. These are summarized below.

Nov 19-25, 1987 - Geosat carried two momentum wheels to reduce off-nadir pointing. Only one wheel was used during the first 2.5 years, but mechanical degradation was noted, and the second wheel was activated on Nov 18, 1987. During spin-up, spacecraft attitude was disturbed by as much as 7 degrees, and altimeter data collection was reduced for several days thereafter.

Aug 18-25, 1988 - Less than half of the normal number of observations were collected during this time when one of Geosat's batteries was reconditioned.

Mar 16-22, 1989 - Severe magnetic storms associated with solar disturbances resulted in a total loss of Geosat data during this time.

Oct 4, 1989 -Collection of global data ended when the altimeter amplifier was shut down by an automatic protection circuit. Although by-passing this circuit enabled the amplifier to be powered back up in mid-October, failure of both onboard tape recorders limited subsequent data collection to the western North Atlantic using direct broadcast to the Johns Hopkins APL ground station.

Jan 4, 1990 - Degradation in the output power of the Geosat altimeter resulted in termination of the mission on this date.

6. Acronyms

CSR - Center for Space Research (University of Texas)
ECMWF - European Center for Medium-Range Weather Forecasting
ERM - Exact Repeat Mission
GEOSAT - Geodetic Satellite
GDR - Geophysical Data Record
GM - Geodetic Mission
GSFC - Goddard Space Flight Center (NASA)
HTML - Hypertext Markup Language
IRI95 - International Reference Ionosphere 1995
JGM-3 - Joint Gravity Model 3
JHU/APL - Johns Hopkins University Applied Physics Lab
NCAR - National Center for Atmospheric Research
NCEP - National Centers for Environmental Prediction (NOAA)
NSWC - Naval Surface Weapons Center
NVAP - NASA Water Vapor Project
SSMI - Special Sensor Microwave Imager
TOVS - Tiros Operational Vertical Sounder
T/P - Topex/Poseidon
USO - Ultra Stable Oscillator
UTC - Universal Time Coordinated
WFF - Wallops Flight Facility (NASA)

7. References

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