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Global Altimeter Processing Scheme
User Manual: v1

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ABSTRACT

This document defines the specific data sources, formats and corrections used for the GAPS (Global Altimeter Processing Scheme) v1 data.

Content Overview

Section 1: Introduces the conventions used in this document and the GAPS data, briefly describes the altimeter missions included in the GAPS and defines the sources for the altimeter data.

Section 2: Defines the GAPS data files formats.

Section 3: Defines the GAPS fields.

Section 4: Explains the Quality Control Procedures and Corrections applied to the data.

Section 5: Provides comments and advice on the use of the GAPS data.

Section 6: References.

Notes on problems or changes to the standard GAPS for specific satellites and cycles and be found in the "GAPS Data Cycle Information" web pages (http://www.soc.soton.ac.uk/ALTIMETER/cycles.html).

KEYWORDS

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Global Altimeter Processing Scheme

The GAPS (Global Altimeter Processing Scheme) strategy is explained in the "GAPS strategy" document, available online at http://www.soc.soton.ac.uk/ALTIMETER/GAPS_strategy.pdf.

Fortran and matlab routines to read the GAPS data can be found at ftp://ftp.soc.soton.ac.uk/pub/GAPS/

This document defines the specific data sources, formats and corrections used for the GAPS data.

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Section 1:	Introduces the conventions used in this document and the GAPS data, briefly describes the altimeter missions included in the GAPS and defines the sources for the altimeter data.
Section 2:	Defines the GAPS data files formats.
Section 3:	Defines the GAPS fields.
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1 Introduction

1.1 Conventions

In order to avoid confusion, the following conventions have been employed throughout this document.

a) Naming

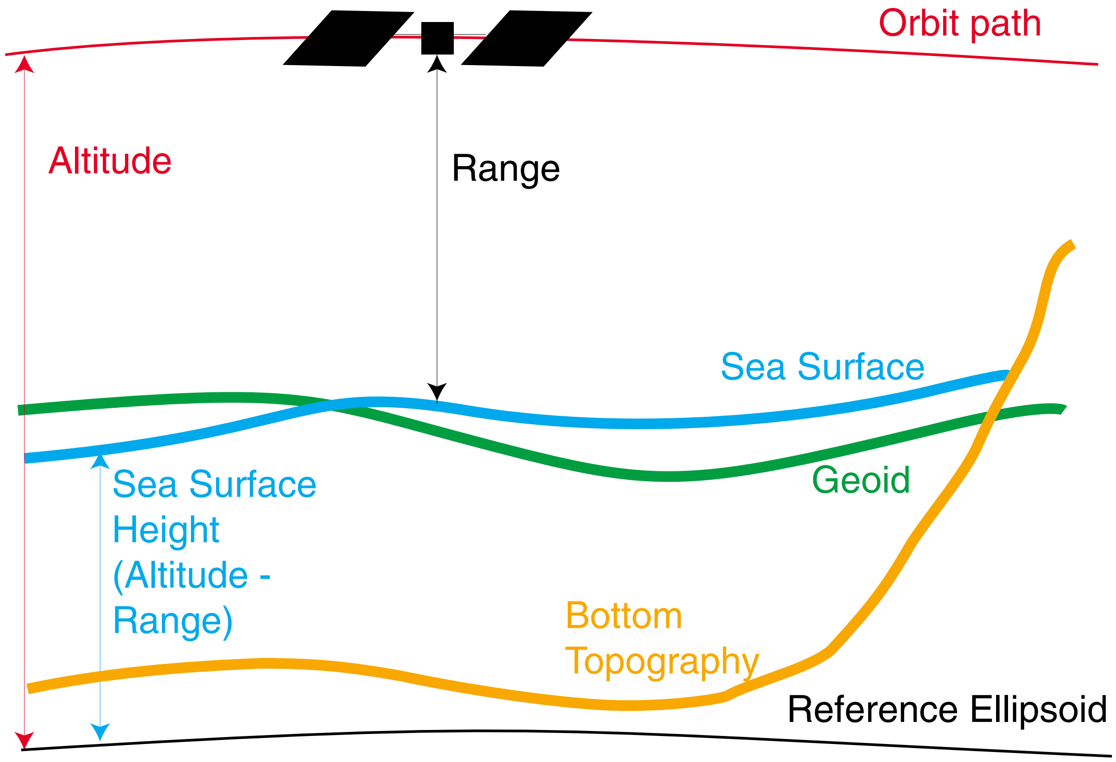

Figure 1-1 Relationship between altimeter distance measurements

Range

Range is the distance from the centre of gravity of the satellite to the surface of the earth as measured by the altimeter.

Height

Height is the distance above the reference ellipsoid. Hence, Sea Surface Height is the height of the sea surface above the reference ellipsoid.

Altitude

Altitude is the height above the reference ellipsoid of the centre of gravity of the satellite.

Pass

A pass is half a revolution of the satellite, from minimum to maximum latitude or maximum to minimum latitude.

All ascending passes (minimum to maximum latitude) are odd numbered.

All descending passes (maximum to minimum latitude) are even numbered.

Cycle

A cycle is the time between exact overpasses of the same ground point.

b) Reference Ellipsoid

The reference ellipsoid selected for the GAPS data is that defined for the TOPEX/POSEIDON mission. It is defined as:

flattening coefficient = 1/298.257, semi-major axis = 6378.1363 km (AVISO, 1996).

c) Time

All times are given as UTC referenced to 00:00:00 1 Jan 1985.

d) Location

All locations are given as decimal degrees latitude and longitude. All longitude values are specified to lie in the range ±180˚, with zero degrees along the Greenwich Meridian.

e) Flagging

The convention used for flagging is that a flag refers to a bit within an integer variable. The flag is considered set if the bit is set to 1. A flag being set implies that an error exists, or the specified condition is true, so that a flag word of 0 implies there are no errors or problems with the associated record.

f) Bit Numbering

Bits are numbered from 0 to N, bit 0 being the least significant bit (LSB). Bits 0-7 are the representations of a byte and bits 8-15 are bits 0-7 of the next byte.

g) Default Values

Where data do not exist, a default value is assigned to the appropriate data fields. The default value is the maximum possible positive value for the appropriate integer field.

Undefined 4 byte integer = 2147483647(2^{31}-1)

Undefined 2 byte integer = 32767 (2^{15}-1)

1.2 Missions

Data are included for three altimeter missions; ERS-1 , TOPEX/POSEIDON and ERS-2.

ERS-1

ERS-1 was launched in July 1991 into a sun-synchronous, near polar repeating retrograde orbit, with a mean altitude of 785 km and an inclination of approximately 98.5˚. The orbit repetivity is maintained by ad-hoc orbit manoeuvres to keep the ground track within ±1 km of a nominal ground position. In support of the altimeter, the satellite carries a two-frequency, nadir-viewing microwave sounder to determine the atmospheric water content. The satellite also carries a Laser retroreflector, used as target for ground-based laser stations to enable accurate satellite tracking.

The mission for ERS-1 was general earth observation and the satellite underwent several mission phases to achieve its varied objectives. Only the two 35-day repeat, or multidisciplinary, phases have been included in the GAPS v1 data: Phase C (14 Apr 1992 - 20 Dec 1993) and Phase G (from 21-March 1995). Although ERS-1 is still maintained in a 35-day repeat, the altimeter is not switched on and no altimeter data have been available since 2 June 1996.

TOPEX/POSEIDON

TOPEX/POSEIDON was launched in August 1992 into a prograde orbit, with a reference altitude of 1336 km and an inclination of 66.039˚. The platform holds two altimeters; TOPEX, a dual frequency altimeter, and POSEIDON, an experimental solid state altimeter. The two altimeters share a common antenna and so only one of them can be used at a time. Data from the two altimeters are merged to form a single data set.

The platform also carries a three-frequency microwave sounder. For high accuracy satellite tracking, the satellite also has a laser retroreflector array and a Dual-frequency Doppler tracking System DORIS receiver.

ERS-2

ERS-2 was launched in March 1995 and was placed into the same sun-synchronous orbit as ERS-1 during its multidisciplinary phases.

The platform and sensors are essentially the same as that of ERS-1 with respect to altimetry, with the addition of a Precision Range and Range-rate Equipment (PRARE) system to allow all weather satellite tracking.

1.3 Data Sources

The input data for the Global Altimeter Processing Scheme are Geophysical Data Records (GDR) from three sources:

ERS-1

European Space Agency (ESA) altimeter offline product (OPR02) data version 3 on CD-ROM (CERSAT, 1993) for cycles 84-102 (Phase C) and version 6 on CD-ROM (CERSAT, 1996) for cycles 144-156 (Phase G). There are no present plans for ESA to reprocess the earlier cycles to version 6.

TOPEX/POSEIDON

Archivage, Validation et Interprétation des données des Satellites Océanographiques (AVISO) Merged Geophysical Data Records (MGDR) version 3 on CD-ROM (AVISO, 1996).

ERS-2

European Space Agency (ESA) altimeter offline product (OPR02) data version 6 on CD-ROM (CERSAT, 1996).

Each of these data sources provides altimeter derived corrections and related geophysical parameters at a frequency of approximately 1 Hz. The exact frequency depends on the altimeter, the values being an average of approximately 1000 pulses at 1000Hz.

More details for each of the altimeters and satellite missions can be found in the relevant GDR manuals as referenced above.

2 GAPS Formats

2.1 GAPS Collocated Data Files

The GAPS collocated altimeter data are arranged in binary format files, one file for each cycle of each satellite. The files have a record length of 48 bytes. Each record contains a single one-second, collocated value for each of the geophysical parameters described in Table 1.

Table 1 GAPS Collocated Data File Format

Start Byte	[1]***Size (bytes)***	***Parameter Name***	***Description***	***Units***	[2]***ga_conf bit***
1	2	satid	Satellite Identification Number		
3	2	cyc_no	Cycle Number		
5	2	ga_ver	Version Number		
7	2	ga_conf	Confidence Word		
9	2	swh	Significant Wave Height	mm	13
11	2	sigma0	Radar Backscatter (σ_0)	0.01dB	12
13	2	atm_p	Atmospheric Surface Pressure	0.1mbar	4
15	2	wet_trop	Wet Tropospheric Correction	mm	6
17	2	iono	Ionospheric Correction	mm	3
19	2	geoid_cor	Across Track Geoid Slope Correction	10^{-4}m	8
21	2	sig0cor	Atmospheric Liquid Water Correction to σ_0	0.01dB	
23	2	ssh_res	Sea Surface Height Residual	mm	15
25	2	passno	Pass Number		
27	2	pass_ind	Along Pass Index		
29	4	lat	Latitude	μ°	
33	4	lon	Longitude	μ°	
37	4	ssh	Sea Surface Height	μm	0,1
41	4	t_1	Time (part 1)	s	
45	4	t_2	Time (remainder)	μs	

[1] All parameters are stored as signed integers, apart from *ga_conf* which is a bit field.

[2] Refers to the bit in the confidence word giving status of the parameter. See *ga_conf* definition.

Each parameter is defined in full in §3.1 (GAPS Collocated Data Element Definitions).

2.2 GAPS Statistics Files

The GAPS statistics files are arranged in binary format files, one file for each satellite. The files have a record length of 40 bytes. Each record contains the statistical information for each reference point as described in Table 2.

Table 2 GAPS Statistics File Format

Start Byte	***Parameter Name***	***Description***	***Units***
1	s_passno	Pass Number	
5	s_lat	Reference Latitude	μ°
9	s_lon	Reference Longitude	μ°
13	s_mss	Reference Mean Sea Surface Height	μm
17	s_mean	Calculated Mean Sea Surface Height	μm
21	s_geoid	Geoid Height	μm
25	s_sd	Standard Deviation of Sea Surface Height Values	μm
29	s_num	Number of Valid Sea Surface Height Values	
33	s_ssq	Sum of Squares of Sea Surface Height Values	μm
37	s_sum	Sum of Sea Surface Height Values	μm

All parameters are stored as four byte integers.

Each parameter is defined in full in §3.2 (GAPS Statistics Data Element Definitions).

3 GAPS Data Element Definitions

3.1 GAPS Collocated Data Element Definitions

Unless otherwise stated, the values of parameters in the collocated data files are collocated directly from values given on the source GDR using the method given in §4.4 (Collocation).

satid

Definition Satellite Identification Number

Storage Type 2byte signed integer

Unit N/A

Range 1 -> 7

2	ERS-1
4	TOPEX
5	POSEIDON
6	ERS-2

(1, 3 and 7 are reserved for satellite data not included in the GAPS)

Default Value 0

Comment The satellite identification number can be used to determine which altimeter was active at the time of the record and will determine the exact correction set and quality controls applied to that record.

cyc_no

Definition Cycle Number

Storage Type 2byte signed integer

Unit N/A

Range 1 -> 32766

Satellite		***cyc_no***	***Start orbit***
ERS-1	Phase C	84-102	7801 (cycle 84 pass 497)
	Phase G	144-156	38295 (cycle 144 pass 243)
TOPEX/POSEIDON		1->	1
ERS-2		1->	711

Default Value 32767

Comment The cycle number is continuous from the start of the mission for all satellites.

ga_ver

Definition	Version Number
Storage Type	2byte signed integer
Unit	N/A
Range	1
Default Value	32767
Comment	Defines the source data and corrections used for each of the altimeter data sets, and the mean field used to calculate the height residuals (*ssh_res*).

ga_conf

Definition	Confidence Word
Storage Type	2byte bit field
Unit	N/A
Range	N/A
Default Value	N/A
Comment	Each bit in the confidence word corresponds to the validity of a collocated parameter or correction field. If the bit is set (i.e. = 1) the corresponding value is considered bad, or the corresponding error condition is true.

Bit	***Value***	***Flag***
0	1	Total Height
1	2	Range
2	4	Ocean Tide Correction
3	8	Ionospheric Correction
4	16	Dry Tropospheric Correction/Atmospheric Surface Pressure
5	32	Inverse Barometer Correction
6	64	Wet Tropospheric Correction
7	132	EM/Sea State Bias Correction
8	256	Across-Track Geoid Correction
9	512	Shallow Sea
10	1024	Ice
11	2048	Rain
12	4096	σ_0
13	8192	Significant Wave Height
14	16382	Body Tide Correction
15	32768	Height Residual

The flags are set according to criteria set out in §4.2 (Quality Control Procedures).

Use of *ga_conf* to determine 'good data' is explained in §5.1 (Selection of 'Good Data').

swh

Definition	Significant Wave Height
Storage Type	2byte signed integer
Unit	mm
Range	-32767 -> 32766
Default Value	32767
Comment	Flagged in *ga_conf* bit 13.

sigma0

Definition	Radar Backscatter (σ_0) corrected for atmospheric liquid water content
Storage Type	2byte signed integer
Unit	0.01 dB
Range	-32767 -> 32766
Default Value	32767
Comment	The correction for atmospheric liquid water content (*sig0cor*) has been applied if available. Flagged in *ga_conf* bit 12. The wind speed can be calculated from σ_0 using an appropriate algorithm (see §5.2).

atm_p

Definition Atmospheric Surface Pressure from model atmospheric fields (see source GDR manuals for model used)

Storage Type 2byte signed integer

Unit 0.1 mbar

Range 0 -> 32766

Default Value 32767

Comment For ERS-1 and ERS-2 *atm_p* is collocated from values calculated from the dry tropospheric correction (*dry_trop*) in millimetres on the source GDR using:

$$atm\_p = \frac{10 \times dry\_trop}{-2.277\left(1 + 0.0026\cos 2\left(lat \times 10^{-6}\right)\right)}$$

The dry tropospheric correction can be calculated from *atm_p* using the inverse of the above equation (see §5.3).

For TOPEX and POSEIDON, *atm_p* is collocated from values calculated from the inverse barometer correction (*inv_baro*) in millimetres on the source GDR using:

$$atm\_p = 10 \times \left(\left(\frac{inv\_baro}{-9.948}\right) + 1013.3\right)$$

The inverse barometer correction can be calculated from *atm_p* using the inverse of the above equation (see §5.3).

Flagged in *ga_conf* bit 4.

wet_trop

Definition Wet Tropospheric Correction determined from radiometer measurements of the atmospheric water vapour concentration.

Storage Type 2byte signed integer

Unit mm

Range -32767 -> 32766

Default Value 32767

Comment For ERS-2 the value of *wet_trop* is re-calculated from cycle 12 (26 June 1996) onwards. For these cycles, the values of the 23.8 GHz radiometer brightness temperature (BT23 in K) given on the source GDR are corrected using:

$$BT\,23_{corrected} = (0.95238 \times BT\,23) + 16.25$$

as notified in documentation accompanying the GDR (Ogor *et al.*, 1996 and subsequent documents). The wet tropospheric correction is then re-calculated using the algorithm in the OPR Handbook (CERSAT, 1996) before collocation.

Flagged in *ga_conf* bit 6.

iono

Definition Ionospheric Correction

Storage Type 2byte signed integer

Unit mm

Range -32767 -> 32766

Default Value 32767

Comment For TOPEX *iono* is collocated from 12 point running average values of the dual frequency ionospheric correction given on the source GDR.

For POSEIDON the DORIS model ionospheric correction is used.

For ERS-1 and ERS-2 the Bent model (CERSAT, 1996) ionospheric correction is used.

Flagged in *ga_conf* bit 3.

geoid_cor

Definition	Across Track Geoid Slope Correction
Storage Type	2byte signed integer
Unit	10-4m
Range	-32767 -> 32766
Default Value	32767
Comment	The correction applied to *ssh* to account for across-track geoid slope between the nominal location of the collocated value and the actual location (see §4.4 Collocation). Flagged in *ga_conf* bit 8.

sig0cor

Definition	Atmospheric Liquid Water Correction to σ_0
Storage Type	2byte signed integer
Unit	0.01 dB
Range	-32767 -> 32766
Default Value	32767
Comment	This correction has been applied (added) to *sigma0*. If this value is not available it is set to the default value, the corresponding value of *sigma0* does not have the correction applied and is flagged as bad.

ssh_res

Definition	Sea Surface Height Residual
Storage Type	2byte signed integer
Unit	mm
Range	-32767 -> 32766
Default Value	32767
Comment	The sea surface height residual relative to *s_mean* at this reference point, found using: $ssh\_res = ssh - s\_mean$ Flagged in *ga_conf* bit 15. (For a definition of *s_mean* see page 27)

passno

Definition Pass Number

Storage Type 2byte signed integer

Unit N/A

Range 1 -> 32766

Default Value 32767

Comment The maximum value is determined by the repeat cycle of the satellite. The valid values for each satellite are given below.

ERS-1	1	-	1002
TOPEX/POSEIDON	1	-	254
ERS-2	1	-	1002

pass_ind

Definition Along Pass Index

Storage Type 2byte signed integer

Unit N/A

Range 1 -> 32766

Default Value 32767

Comment Each reference collocated data point has a unique pass and index number, allowing all repeats of a data point to be easily located within the data.

The Along Pass Index runs from 1 for each pass. The maximum value is typically less than 6,000 for each pass, and is dependent on the number of data points over land along the pass.

lat

Definition Latitude

Storage Type 4byte signed integer

Unit μ°

Range -90,000,000 -> 90,000,000 (±90˚)

Default Value N/A

Comment The latitude of the reference point to which data have been collocated.

lon

Definition	Longitude
Storage Type	4byte signed integer
Unit	μ°
Range	-180,000,000 -> 180,000,000 (±180˚)
Default Value	N/A
Comment	The longitude of the reference point to which data have been collocated.

ssh

Definition	Sea Surface Height, corrected for atmospheric and geophysical factors
Storage Type	4byte signed integer
Unit	μm
Range	-2147483647 -> 2147483646
Default Value	2147483647
Comment	If a correction is flagged as bad it has not been applied to *ssh*. If any correction is flagged as bad, *ssh* is flagged as bad. The corrections applied are defined in §4.3 (Height Correction). The TOPEX and POSEIDON values are calculated using the altitude from the NASA orbit model. The ERS values are calculated using the altitude from the Delft dgm-e04 orbit model (Scharroo and Visser, 1998) using software available from their web site (http://www.deos.tudelft.nl/ers/precorbs/).

t_1

Definition	Time since 1/1/85 00:00:00
Storage Type	4byte signed integer
Unit	s
Range	0 -> 2147483646
Default Value	N/A
Comment	Complete seconds.

t_2

Definition	Time (remainder)
Storage Type	4byte signed integer
Unit	μs
Range	0 -> 999,999
Default Value	N/A
Comment	Fractional part of time.

3.2 GAPS Statistics Data Element Definitions

s_passno

Definition Pass Number

Storage Type 4byte signed integer

Unit N/A

Range 1 -> 1002

Default Value N/A

Comment The maximum value is determined by the repeat cycle of the satellite. The valid values for each satellite are given below.

ERS-1	1	-	1002	1	-	1002
TOPEX/POSEIDON	1	-	254	1	-	254
ERS-2	1	-	1002	1	-	1002

This value corresponds directly with *passno*. The corresponding value of *pass_ind* can be found using

$$pass\_ind = rec\_no_{current} - rec\_no_{start} + 1$$

where $rec\_no_{current}$ is the current record number within the file and rec_no_{start} is the first record number for this pass.

s_lat

Definition Reference Latitude

Storage Type 4byte signed integer

Unit μ˚

Range -90,000,000 -> 90,000,000 (±90˚)

Default Value N/A

Comment The latitude of the reference point to which data are collocated.

s_lon

Definition Reference Longitude

Storage Type 4byte signed integer

Unit μ˚

Range -180,000,000 -> 180,000,000 (±180˚)

Default Value N/A

Comment The longitude of the reference point to which data are collocated.

s_mss

Definition	Reference Mean Sea Surface Height
Storage Type	4byte signed integer
Unit	µm
Range	-2147483647 -> 2147483646
Default Value	2147483647
Comment	The reference model mean sea surface height at the reference point from OSUMSS95A (Yi 1995).

s_mean

Definition	Calculated Mean Sea Surface Height
Storage Type	4byte signed integer
Unit	µm
Range	-2147483647 -> 2147483646
Default Value	2147483647
Comment	The mean sea surface height calculated from all (*s_num*) valid values of *ssh* at this reference point.

The mean at each reference point along track is found using the following ranges:

ERS-1 phase C:	1 year of data	01/09/1992 -> 31/08/1993
ERS-1 phase G:	1 year of data	01/09/1995 -> 31/08/1996
TOPEX/POSEIDON:	3 years of data	01/01/1993 -> 31/12/1995
ERS-2:	1 year of data	01/09/1995 -> 31/08/1996

The ERS-1 data from OPR v3 (phase C) cannot be merged with those from OPR v6 (phase G) as a complete change in the processing scheme between the versions makes them incompatible.

s_geoid

Definition	Geoid Height
Storage Type	4byte signed integer
Unit	µm
Range	-2147483647 -> 2147483646
Default Value	2147483647
Comment	The reference model geoid height at the reference point from JGM-3/OSU91A (Rapp *et al.*, 1991; Tapley *et al.*, 1996).

s_sd

Definition	Standard Deviation of Sea Surface Height
Storage Type	4byte signed integer
Unit	µm
Range	-2147483647 -> 2147483646
Default Value	2147483647
Comment	The standard deviation of the *s_num* values of *ssh* around *s_mean*.

s_num

Definition	Number of Valid Sea Surface Height Values
Storage Type	4byte signed integer
Unit	N/A
Range	-2147483647 -> 2147483646
Default Value	2147483647
Comment	Number of valid values of *ssh* used to calculate *s_mean*. Valid values have *g_conf* bit 0 set to 0.

s_ssq

Definition	Sum of Squares of Sea Surface Height
Storage Type	4byte signed integer
Unit	$10^{-6}m^2$
Range	-2147483647 -> 2147483646
Default Value	2147483647
Comment	The sum of squares of the *s_num* values of *ssh*.

s_sum

Definition	Sum of Sea Surface Height
Storage Type	4byte signed integer
Unit	µm
Range	-2147483647 -> 2147483646
Default Value	2147483647
Comment	The sum of the *s_num* values of *ssh*.

4 Quality Control and Height Correction

4.1 Data Extraction and Record Updating

The data are first extracted from the input GDR into Rennell Data Record (RDR) standard format files. The RDR format holds all the measured values and corrections from the GDR which are necessary to create the GAPS data. A single file is created for each cycle of each altimeter mission containing all available data for that cycle in time order.

After extraction, only fields that are directly obtainable from the input data exist. In order to correct some errors in the input GDR data, and to use consistent correction sets, the RDR format data are then updated.

The flags are also set according to standardised criteria.

Some differences between missions are inevitable due to differences in altimeter characteristics and the data sources available.

4.2 Quality Control Procedures

Once all records have been updated, the data are passed through quality controls.

First, all data that are flagged in the source GDR as being over land are removed. Then the quality control fields defined below are used to set *ga_conf*, as summarised in Table 3 and explained in §4.3b).

a) Quality Control Fields

The following fields are present in the extracted RDR format files, but are used only for quality control purposes. Unless otherwise stated, the values used are taken directly from the source GDR.

Parameter	***Description***
sd_ssh	Standard Deviation of *10 or 20 Hz Values used to Calculate *ssh*
att	Satellite Attitude
nrec	Number of *10 or 20 Hz Sea Surface Height Values used to Calculate *ssh*
sd_sig0	Standard Deviation of *10 or 20 Hz Values used to Calculate *sigma0*
sd_swh	Standard Deviation of *10 or 20 Hz Values used to Calculate *swh*
gdr_flag	Copy of some of source GDR Flag Bits

*In order to calculate the 1 s (1 Hz) average values of parameters provided on the source GDR, the parameters are first averaged to give data at approximately 10 Hz (TOPEX) or 20 Hz (ERS-1, POSEIDON and ERS-2). The standard deviation of these values is then reported on the source GDR to be used as quality control parameters.

sd_ssh

Definition Standard Deviation of 10 or 20 Hz Values used to Calculate *ssh*

Comment ERS-1 phase C: The value given on the source GDR is the standard deviation of range. The value of *sd_ssh* is recalculated from the range values and interpolated orbit heights from the source GDR.

att

Definition Satellite Attitude

Comment For POSEIDON the attitude value used is the platform attitude if available. For all other satellites, and for POSEIDON when the platform attitude is not available, the attitude is from the waveform.

nrec

Definition Number of 10 or 20 Hz Sea Surface Height Values used to Calculate *ssh*

Comment Only estimates considered 'good' are included.

sd_sig0

Definition Standard Deviation of 10 or 20 Hz values used to calculate *sigma0*

sd_swh

Definition Standard Deviation of 10 or 20 Hz values used to calculate *swh*

gdr_flag

Definition Copy of some of source GDR Flag Bits

Comment Bits are set within this flag according to flags in the source GDR if:

ERS-1 / ERS-2:	the return is flagged as non-ocean
	the range value is flagged as downgraded
	the SWH value is flagged as downgraded
	the σ_0 value is flagged as downgraded
ERS-1 phase G / ERS-2:	the orbit manoeuvre flag is set
TOPEX/POSEIDON:	the rain flag is set
	the shallow water flag is set
TOPEX/POSEIDON/ERS-1 phase C:	the ice flag is set

b) Quality Controls

Table 3 Quality Control Criteria Used to set ga_conf

Bit	*Flag*	*Criteria*
0	Total Height	Any of bits 1 -> 8 or 10 -> 14 is set
1	Range	[1]
2	Ocean Tide Correction	Tidal correction outside range -5 m -> +5 m
3	Ionospheric Correction	*iono* outside range: ERS-1/2 -20 cm -> -1 mm T/P: -40 cm -> 0 mm
4	Dry Tropospheric Correction	Dry tropospheric correction outside range -2.5 -> 1.9 m
5	Inverse Barometer Correction	Dry tropospheric flag (bit 4) set
6	Wet Tropospheric Correction	*wet_trop* outside range -50 cm -> -1 mm
7	EMbias Correction	*embias* outside range -50 cm -> 0 cm Significant Wave Height flag (bit 13) set Sigma0 flag (bit 12) set (not ERS-1 phase C)
8	Across-Track Geoid Correction	*geoid_cor* outside range -1 m -> +1 m
9	Shallow Sea	Sea less than 2000m according to shallow sea mask. Not set for ERS-1 or ERS-2
10	Ice	ERS-1 phase G and ERS-2 [2]Ice Criteria is true ERS-1 phase C, TOPEX and POSEIDON source GDR ice flag is set
11	Rain	TOPEX and POSEIDON source GDR rain flag is set. ERS-1 and ERS-2 [2]Rain Criteria is true
12	Sigma0	Value outside range: ERS-1 6 -> 30 dB TOPEX 7 -> 30 dB POSEIDON 7 -> 25 dB ERS-2 6 -> 30 dB ERS-1 and ERS-2 source GDR σ_0 flag is set or *sig0cor* is default[3]
13	Significant Wave Height	Value outside range 0 -> 11 m ERS-1 and ERS-2 source GDR SWH flag is set
14	Body Tide Correction	Body tide correction outside range -1 m -> +1 m
15	Height Residual	*ssh* flag (bit 0) set or *s_num* <=2

[1]Range flag is set according to a number of different criteria set out in the following section.

[2]The Ice and Rain Criteria for ERS-1/2 are set out in the following section.

[3]The default *sig0cor* test should also be applied to TOPEX and POSEIDON but was omitted in error. However, no default values of *sig0cor* have been found in the GAPS data.

Total Height

Set if any of *ga_conf* bits 1 -> 8 or 10 -> 14 is set.

Range

Set if any of the following conditions are true:

ssh

<130 m or > 100 m

sd_ssh

ERS-1	>45 cm
TOPEX	>20 cm
POSEIDON	>20 cm
ERS-2	>45 cm

nrec

ERS-1	<10 of 20Hz
TOPEX	< 6 of 10Hz
POSEIDON	<16 of 20Hz
ERS-2	<10 of 20Hz

gdr_flag

ERS-1 / ERS-2:	the return is flagged as non-ocean.
	the range value is flagged as downgraded.
ERS-1 phase G / ERS-2:	the orbit manoeuvre flag is set.

Ocean Tide Correction

Set if the ocean tide correction is outside the range -5 m -> +5 m.

Ionospheric Correction

Set if the value of *iono* is outside the range:

ERS-1/2	-20 cm -> -1 mm.
T/P:	-40 cm -> 0 mm.

Dry Tropospheric Correction

Set if the dry tropospheric correction is outside the range -2.5 -> 1.9 m.

Inverse Barometer Correction

Set if the dry tropospheric correction flag (bit 4) is set.

Wet Tropospheric Correction

Set if the value of *wet_trop* is outside the range -50 cm -> -1 mm.

EMbias Correction

Set if any of the following conditions is true:

the value of *embias* is outside the range -50 cm -> 0 cm

the Significant Wave Height flag (bit 13) set

the Sigma0 flag (bit 12) set (not ERS-1 phase C)

The inclusion of tests for the *sigma0* and *swh* flags is dependent on the *embias* correction algorithm used (see §5.3)

Across-Track Geoid Correction

Set if the value of *geoid_cor* is outside the range -1 m -> +1 m.

Shallow Sea

Set if the sea is less than approximately 2000m according to a shallow sea mask.

This flag is set according to masks used in the source GDR and as there is no flag in the ERS-1 or ERS-2 source GDR, the flag is never set.

Ice Flag Set

Set if either of the following conditions is true:

ERS-1 phase C, TOPEX and POSEIDON:

the source GDR ice flag is set (from *gdr_flag*).

ERS-1 phase G and ERS-2:

latitude > 50˚N/S **and**

either the difference between the model and radiometer wet tropospheric corrections on the source GDR is greater than 10cm

or *nrec* < 17

Rain Flag Set

Set if any of the following conditions are true:

TOPEX and POSEIDON:

the source GDR rain flag is set (from *gdr_flag*).

ERS-1 and ERS-2:

sd_sig0 > 2.5 dB

sig0cor > 0.1 dB

Sigma0

Set if any of the following conditions are true:

the value of *sigma0* is outside the range:

ERS-1:	6 -> 30 dB
TOPEX:	7 -> 30 dB
POSEIDON:	7 -> 25 dB
ERS-2:	6 -> 30 dB

ERS-1 and ERS-2:

the source GDR σ_0 flag is set (from *gdr_flag*)

the value of *sig0cor* is default

Significant Wave Height

Set if either of the following conditions is true:

the value of *swh* is outside the range 0 -> 11 m.

ERS-1 and ERS-2:

The source GDR SWH flag is set (from *gdr_flag*).

Body Tide Correction

Set if the body tide correction is outside the range -1 m -> +1 m.

Height Residual

Set if either of the following conditions is true:

the *ssh* flag (bit 0) set.

s_num <= 2

NB. Some additional flags may be set for data which pass the above quality controls due to notification in quality assessment reports for the source GDR. Where this occurs, there will be a cycle comments file associated with the data. These may be found as text files on the ftp site when retrieving extracted data, or from the web site (http://www.soc.soton.ac.uk/ALTIMETER/cycles.html).

4.3 Height Correction

The uncorrected sea surface height (ssh_{raw}) is calculated from the altitude and range on the source GDR using:

$$ssh_{raw} = altitude - range$$

For TOPEX and POSEIDON the altitude used is the NASA orbit model height on the source GDR.

For ERS 1 and ERS 2 the altitude used is calculated from the Delft dgm-e04 orbit model (Scharroo and Visser, 1998) using software available from their web site (http://www.deos.tudelft.nl/ers/precorbs/).

After quality controls have been applied, a consistent set of corrections is removed from the sea surface height value on the source GDR to give a corrected sea surface height value.

a) Corrections Applied

The sea surface height corrected for atmospheric and geophysical effects *ssh* is calculated using:

$$ssh = ssh_{raw} - iono - dry\_trop - wet\_trop - oc\_tide - body\_tide - pol\_tide - embias - inv\_baro$$

The corrections determined from direct measurements, or models that are not readily available, have been included in the collocated data files. These are *iono* and *wet_trop* (see §3.1 GAPS Collocated Data Element Definitions).

Other corrections can be determined from parameters that are included in the collocated data files. These are *dry_trop*, *embias* and *inv_baro* (see §5.3 Removal of Applied Corrections).

The remaining corrections (*oc_tide*, *body_tide* and *pol_tide*) can be calculated from readily available models and so have not been included in the collocated data files. These corrections are described in the following section

b) Correction Fields

Unless otherwise stated, the correction used is taken from the source GDR.

oc_tide

Ocean Tidal Correction

The model used is the CSR 3.0 model (Eanes and Bettadpur, 1995) which is determined using a combination of altimeter derived tidal components and hydrodynamic model tidal components. The correction includes the ocean loading tide, or the response of the earth to the ocean tide. The model can be obtained from ftp://ftp.csr.utexas.edu/pub/tide.

The correction is calculated for ERS-1 and ERS-2.

body_tide

Body (or solid earth) Tidal Correction

The model used is the Cartwright model (Cartwright and Edden, 1973; Cartwright and Taylor, 1971) as implemented for TOPEX/POSEIDON. The model is available from NOAA NESDIS (contact John Lillibridge via http://www.nesdis.noaa.gov/).

The correction is calculated for ERS-1 and ERS-2.

pol_tide

Geocentric Polar Motion Tidal Correction.

The model used is the TOPEX/POSEIDON algorithm (AVISO, 1996):

$$pol\_tide = -69.435\sin\left(2 \times lat \times 10^{-6}\right)\left(\left(xpole - 0.042\right)\cos\left(lon \times 10^{-6}\right) - \left(ypole - 0.293\right)\sin\left(lon \times 10^{-6}\right)\right)$$

where: *xpole* and *ypole* are the polar positions.

The polar position data files are obtained from ftp://ftp hpiers.obspm.fr/iers/eop/eopc04.

The correction is calculated for ERS-1 and ERS-2.

4.4 Collocation

After correction, the data are collocated to a consistent reference grid. A reference grid exists for each satellite mission, defined as the nominal ground track at 1 s spacing for the relevant satellite mission. Due to differences in the orbit heights and altitudes, the resultant spatial resolution of the data will vary slightly between altimeter missions.

The fields that are collocated are those that are from direct measurements from the altimeter (height, σ_0, SWH) and measured fields or model fields that cannot be calculated from a generally available source (wet tropospheric correction, ionospheric correction, atmospheric surface pressure). Any applied correction can therefore be removed (see §5.2).

For collocation to occur, the two closest data points to a reference point must both be non-default values. Data will be collocated even if flagged as bad. If either of the data values used to calculate a collocated value is default, the resultant collocated value is also default. If either value is flagged as bad, the collocated value is also flagged as bad.

The method used to collocate data is simple bilinear interpolation of the 2 closest data points (A and B) to the perpendicular bisector through the reference point (R), as shown in Figure 4-1. This gives the 'collocated' data point X which is considered as being at the reference location (R). The separation of points X and R (*i.e.* the separation of a repeat track from the nominal ground track) is usually less than 1 km for all satellite missions. The along track separation of data points (A to B) is generally of the order of 5 - 7 km.

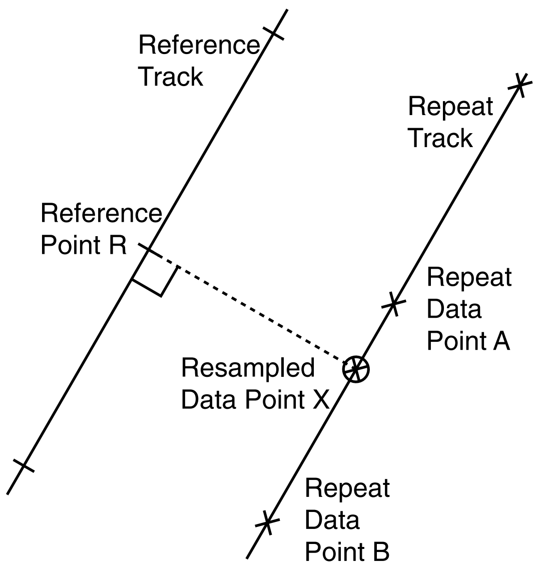

Figure 4-1Method of Collocation.

This method of collocation is considered sufficiently accurate for most of the geophysical parameters, where the cross-track separation is small compared with the scale of features being measured, and the size of the altimeter footprint. However, a slight modification of the method is made for collocation of the sea surface height. Changes in the geoid height between the nominal and actual re-sampled point locations may be of the same magnitude as the dynamic height signal caused by ocean circulation. In this case, a correction for the difference in the mean sea surface height between point R and point X is included

(Rapp and Yi, 1994). The magnitude of this correction is given as *geoid_cor*.

4.5 Calculation of Mean and Residual Heights

As all repeat passes of the data are now collocated to the reference track, calculation of a time mean of the sea surface height can be carried out at each reference point location. A time mean is calculated using all valid data points for the specific altimeter mission within specified time limits (see §3.2 *s_mean* for the time periods used in this GAPS version). The time limits are always selected to cover complete years in order to minimise seasonal affects on the mean calculated. No correction is made for possible along track changes in the number of data points used in the mean.

This mean is then removed from each repeat value of the sea surface height to give the height residual. The present orbit models are considered sufficiently accurate that no along track orbit reduction is carried out.

5 Advice for use of GAPS Data

5.1 Selection of 'Good Data'

When using the GAPS data for individual parameters such as *swh* (significant wave height) or *sigma0*, then the appropriate single bit in the confidence word (*ga_conf*) should be checked (see §3.1). When using the *ssh* (sea surface height) or *ssh_res* (height residual) information, several confidence word bits apply to the final value. In the open ocean, restricting the use of data to records where the confidence word is set to 0 will ensure that only data that have passed all quality controls are included in the analysis. However, there will be occasions when this test is too stringent, *e.g.* when working in marginal seas, the shallow sea flag may be ignored. In this case, including all data where the confidence word is set to 0 or 512 (bit 9 only set) would be acceptable. In this case, the ocean tidal model is likely to be less accurate in the shallow sea areas and the user may wish to replace the tide model used.

Where a height value is flagged as being bad (bit 0 is set) there will also be at least one other bit set which will allow the cause of invalidity to be determined.

If any correction is flagged as being bad (the appropriate bit is set in *ga_conf*) then that correction has not been applied to the height data. There may be a jump between this height value and a coincident value where the correction has been applied. If the correction exists (*i.e.* is not set default) it may be applied to the height value by the user but this height should be used with care. If the correction value is default, then the correction does not exist for that location and time.

The ice flags are based largely on high values of σ_0, typical of ice conditions. However, there are occasions when calm-sea conditions cause near-specular returns, giving spurious occurrences of ice flagging.

5.2 Calculation of Wind Speed

The 10 m Wind Speed can be calculated from the σ_0 value using any appropriate algorithm.

The algorithm used for processing the GAPS data (for calculating *embias*) is a least squares fit of a fifth order polynomial to the Witter and Chelton, (1991) wind speed tabular model:

$$u10 = \sum_{n=0}^{4} a_n \left(\sigma_{0b}\right)^n$$

where:

$u10$ is the 10 m wind speed (ms^{-1})

σ_{0b} is the biased backscatter coefficient (dB): $\sigma_{0b} = \sigma_0 + \delta\sigma$

σ_0 is the backscatter coefficient in dB (*sigma0**100.) and $\delta\sigma$ is a bias added to the backscatter coefficient to fit GEOSAT data, set to –0.63 dB for TOPEX and POSEIDON, and 0 dB for ERS-1 and ERS-2.

a_0, a_1, a_2, a_3 and a_4 are polynomial coefficients (AVISO, 1996) defined as follows:

σ_{0b} limits	a_0	a_1	a_2	a_3	a_4	*u10*
$\sigma_{0b} < 10.8$	51.045307042	-10.982804379	1.895708416	-0.174827728	0.005438225	$u10 > 7.30$
$10.8 \le \sigma_{0b} \le 19.6$	317.474299469	-73.507895088	6.411978035	-0.248668296	0.003607894	$0.01 \le u10 \le 7.30$
$19.6 < \sigma_{0b}$	0.0	0.0	0.0	0.0	0.0	$u10 = 0.0$

5.3 Removal of Applied Corrections

Some of the applied corrections, those derived directly from the altimeter data, measured corrections, or those derived from models not readily available, are included in the GAPS data.

Other corrections that can be calculated from the included parameters are:

dry_trop

The dry tropospheric correction (in mm).

This can be calculated from the atmospheric surface pressure using:

$$dry\_trop = -2.277 \times atm\_p \times 10\left(1 + 0.0026\cos 2\left(lat \times 10^{-6}\right)\right)$$

inv_baro

Inverse Barometer Correction (in mm).

This can be calculated from the atmospheric surface pressure using:

$$inv\_baro = -9.948 \times \left(\left(p\_atm \times 10\right) - 1013.3\right)$$

embias

The Electromagnetic, or Sea State, Bias. (in mm).

Strictly speaking the two are different, but cannot be fully separated,

The algorithms used are the empirical Gaspar algorithms, which are dependent on altimeter and processing scheme:

ERS-1 phase C

$$embias = 0.055 \times hs$$

(Gaspar and Ogor, 1994)

ERS-1 phase G

$$embias = hs\left(-0.048 + (-0.0026 \times u10) + \left(0.000126 \times u10^{2}\right)\right)$$

(Gaspar and Ogor, 1996)

TOPEX

$$embias = hs\left(-0.0203 + (-0.00369 \times u10) + \left(0.000149 \times u10^{2}\right) + (0.00265 \times hs)\right)$$

(Gaspar *et al.*, 1996; Gaspar *et al.*, 1994)

POSEIDON

$$embias = hs\left(-0.0539 + (-0.00225 \times u10) + \left(0.000097 \times u10^{2}\right) + (0.00183 \times hs)\right)$$

(Gaspar *et al.*, 1996; Gaspar *et al.*, 1994)

ERS-2

$$embias = hs\left(-0.048 + (-0.0026 \times u10) + \left(0.000126 \times u10^{2}\right)\right)$$

(Gaspar and Ogor, 1996)

Where:

hs is the significant wave height in m ($swh \times 1000$)

$u10$ is the 10 m wind speed in ms^{-1} (see §5.2)

NOTE: As both TOPEX and POSEIDON altimeters operate at the same frequency, the true Sea State Bias values (caused by interaction of the radar with the sea surface) would be expected to be identical. In view of this, the value of the Sea State Bias given in the POSEIDON GDRs is that calculated using the TOPEX algorithm from above. The difference between values from the two algorithms is attributed to system differences and is included in the POSEIDON bias field, added to the range measurement. On production of the POSEIDON RDRs, the Sea State Bias value is replaced with *embias* calculated using the above algorithm, and the corresponding bias is removed from the range field.

5.4 Further Information

Further information on the GAPS data, including possible poor quality data reported by the source GDR providers and cycle-specific comments is available in the cycle comments files (http://www.soc.soton.ac.uk/ALTIMETER/cycles.html).

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