GRACE Level 1B Data Product User Handbook

DRAFT

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January 21, 2004

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JPL D-22027

1 INTRODUCTION

1.1 Handbook Purpose

The purpose of this document is to assist investigators of the Gravity Recovery and Climate Experiment (GRACE) Mission by providing a comprehensive description of the content and format of the GRACE Level 1B data. The document also provides an overview of the GRACE mission and a description of the measurements and corrections. More information on data algorithms and instruments can be found in GRACE project documents (see section 1.6).

In addition to the GRACE Level-1B instrument data described in this document, two ancillary Level-1B products are generated by GFZ Potsdam:

- Atmosphere and Ocean De-aliasing level-1B product (AOD1B): Spherical harmonic coefficients of combined barotropic sea level and vertical integrated pressure at 6-hour sample rate.

- Ocean level-1B product (OCN1B): Hourly grids of barotropic sea level determined from JPL barotropic ocean model.

Both products are described in the "AOD1B Product Description Document", GRACE 327-750, October 2003 by Frank Flechtner.

GRACE data are archived and distributed through two agencies:

- **JPL Physical Oceanography Distributed Active Archive Center (PO.DAAC)**
  The PO.DAAC is one element of the Earth Observing System Data and Information System (EOSDIS), developed by NASA. The goal of the PO.DAAC is to serve the needs of the oceanographic, geophysical and interdisciplinary science communities that require physical information about the oceans.

- **GeoForschungsZentrum Potsdam, Information System and Data Center (GFZ/ISDC)**
  The GFZ is a non-university geoscientific research institute that combines all solid earth science fields including geodesy, geology, geophysics, mineralogy and geochemistry, in a multidisciplinary research center.

1.2 Handbook Overview

This is a combination of a guide to data usage and a reference handbook.

Section 1 provides background information about the GRACE Level 1B data and this document.

Section 2 is an overview of the GRACE mission.

Section 3 is an introduction to the GRACE level 1B algorithms.

Section 4 is an introduction to using the GRACE level 1B data.

Section 5 provides a description of the content and format of the GRACE Level 1B data products.

Section 6 provides a detailed description of all level 1B data products and fields.

Appendix A contains acronyms.

Appendix B contains report files containing data quality information.

Appendix C describes how to order information or data from PO.DAAC and lists related web sites.

1.3 Purpose of the GRACE Level 1B data

The GRACE Level 1B data provide all necessary inputs to derive monthly time-variations in the Earth's gravity field. L1B data are also used for GRACE orbit determination and mean gravity field determination.

1.4 Document reference and contributors

When referencing this document, please use the following citation:

K. Case, G. Kruizinga, and S. Wu, 2002, "GRACE Level 1B Data Product User Handbook", JPL Publication D-22027.

Other contributors include:

M. Watkins, W. Bertiger, and L. Romans from JPL
S. Bettadpur from UTCSR
F. Flechtner from GFZ

1.5 Conventions

1.5.1 Units

All quantities reported are given in SI units:

- Acceleration is reported in meters per seconds squared (m/s^2).
- Angular acceleration is reported in radians per seconds squared (rad/s^2).
- Range is reported in meters (m).

- Magnetic field strength is reported in nanoteslas (nT).
- Current is reported in ampere (A).
- Temperature is reported in degrees Celsius (C).

1.5.2 GPS Time

For the GRACE mission GPS time is defined as seconds past January 1, 2000, 12:00:00. This definition is different from other missions where GPS time is defined as seconds past January 6, 1980, 00:00:00. The GRACE GPS time has the same rate as UTC but no leap seconds are applied, as follows:

GPS time = UTC time + leap seconds since epoch

where UTC is expressed in seconds past January 1, 2000, 12:00:00.

For example:

GPS time	= 90000000 sec (8-NOV-2002 04:00:00.0000 GPS)
UTC time	= 89999987 sec (8-NOV-2002 03:59:47.0000 UTC)
leap seconds at 90000000 UTC	= 13 sec

For a table of leap seconds past epoch see the International Earth Rotation Service (IERS) Earth Orientation Center at the U.S. Naval Observatory:

http://maia.usno.navy.mil/

1.5.3 Coordinate Systems

Several coordinate systems are used to define the various GRACE data products. The definitions are summarized in this section. The satellite body-fixed frames are shown in Figure 1-1.

1.5.3.1 Satellite Frame (SF)

The origin is within 0.1mm of the accelerometer frame origin. The Satellite Frame has its coordinate axes directed as follows:

X_{SF} = from the origin to a target location of the phase center of the K/Ka Band horn (Roll Axis)
Y_{SF} = forms a right-handed triad with X_{SF} and Z_{SF} (Pitch Axis)
Z_{SF} = normal to X_{SF} and to the plane of the main equipment platform, and positive towards the satellite radiator (Yaw Axis)

During flight, the satellites have nadir-pointing Yaw axis orientation, with the Roll axes in the anti-flight and in-flight directions for the leading and trailing satellites, respectively.

1.5.3.2 Accelerometer Frame (AF)

The origin is within 0.1mm of the ACC origin. The Accelerometer Frame is *aligned* by the reference optical marks on the exterior surface. The coordinate axes are directed as follows:

$X_A \cong +Y_{SF}$ (ACC Least Sensitive Axis)
$Y_A \cong + Z_{SF}$
$Z_A \cong + X_{SF}$

1.5.3.3 Science Reference Frame (SRF)

The origin of the SRF is the origin of the accelerometer frame. The Science Reference Frame has its coordinate axes directed as follows:

$X_{SRF} \equiv +Z_A$
$Y_{SRF} \equiv + X_A$ (ACC Least Sensitive Axis)
$Z_{SRF} \equiv +Y_A$

Note: The GRACE ground calibrations and in-flight measurements utilize several of the coordinate systems. However, for consistency all level 1B products are provided in the Science Reference Frame (SRF).

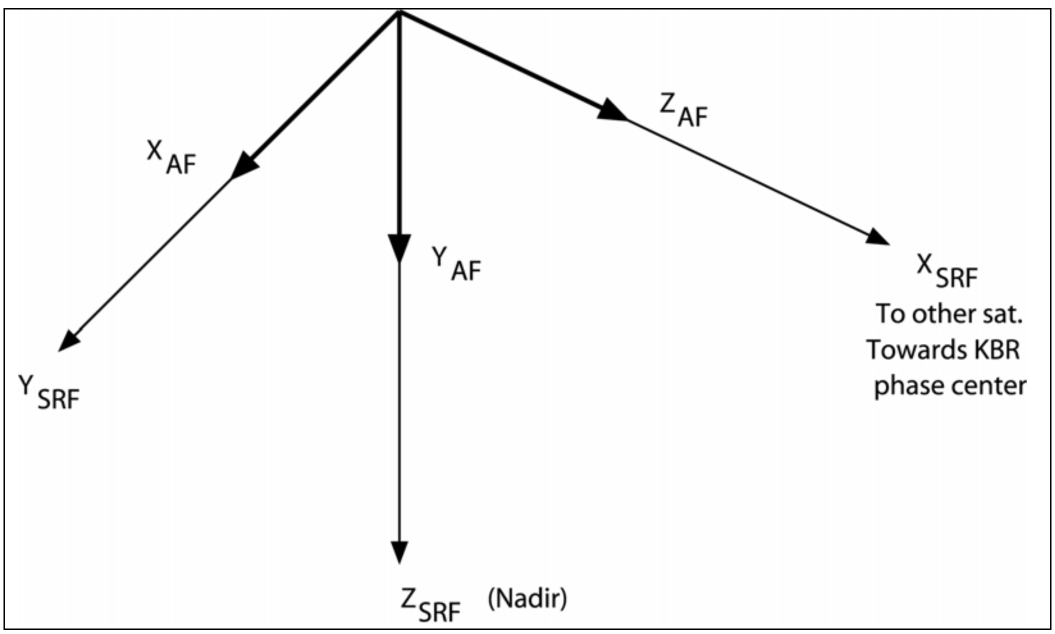

Figure 1-1 Satellite body-fixed frames figure

1.5.4 Data Quality Flags

Every product has its own data quality flag. See sections 4 and 6 for more detail.

1.5.5 Default Values

The GPS Navigation Level 1B Format Record (GNV1B) is the only product with default values. Data values default to zero for formal errors on position and velocity when not available.

1.5.6 Byte Order

All data files are generated according to the big endian byte-ordering convention, which stores the most significant byte in the lowest memory address (the word is stored `big-end-first').

Motorola 680x0 microprocessors (and therefore Macintoshes), Hewlett-Packard PA-RISC, and Sun SuperSPARC processors are big endian. The Silicon Graphics MIPS and IBM/Motorola PowerPC processors are both little and big endian (bi-endian). The Intel 80X86 and Pentium and DEC Alpha RISC processors are little endian. Windows NT and OSF/1 are little endian.

NOTE: The read software provided byte swaps internally.

1.5.7 Bit Fields Order

Regarding the bitfield notation, the convention is to number the bits from right to left:

- The least significant bit (LSB) at location 0 and the most significant bit (MSB) at location 7, for a one byte bitfield
- The least significant bit (LSB) at location 0 and the most significant bit (MSB) at location 15, for a two byte bitfield

This convention is represented below for one and two bytes bitfield.

One Byte

7	6	5	4	3	2	1	0
MSB							LSB

Two bytes

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
MSB															LSB

1.6 Applicable Documents

Flechtner, F., AOD1B Product Description Document, GRACE 327-750, Revision 1.0, October 22, 2003.

Fowler, W. and P.A.M. Abusali, GRACE Mission Plan, UTCSR, April 2, 2001.

GRACE Science Data System Development Plan, JPL 327-710, Revision C, June 30, 2000.

GRACE Satellite System Specification, GRACE 327-400, December 6, 1999.

GRACE Product Specification Document, GRACE 327-720, Version 4.0, January 9, 2004.

Kim, J.R., Simulation Study of a Low-Low Satellite-to-Satellite Tracking Mission, Ph.D. dissertation, University of Texas at Austin, May 2000.

Stanton, R.H., Science and Mission Requirements Document, Revision C, GRACE 327-200, JPL D-15928, August 16, 2000.

Stanton, R.H., Functional Specifications of the Twin GRACE satellites, GRACE-327-220, JPL D-18862, February 25, 2000.

Thomas, J.B., An Analysis of Gravity-Field Estimation Based on Inter-satellite Dual One-Way Biased Ranging, JPL Publication 98-15, 1999

Wu, S.-C. and G.L.H. Kruizinga, Algorithm Theoretical Basis Document for GRACE Level-1B Data Processing, JPL Publication D-27672, Version 1.0, January 2004.

2 GRACE MISSION OVERVIEW

The Gravity Recovery And Climate Experiment (GRACE) is a joint US/German satellite mission that will accurately map variations in the Earth's gravity field over its 5-year lifetime. The twin GRACE satellites were launched March 17, 2002.

GRACE is a joint partnership between the National Aeronautics and Space Administration (NASA) in the United States and Deutsches Zentrum für Luft- und Raumfahrt (DLR) in Germany. Dr. Byron Tapley of The University of Texas Center for Space Research (UTCSR) is the Principal Investigator (PI), and Dr. Christoph Reigber of the GeoForschungsZentrum (GFZ) Potsdam is the Co-Principal Investigator (Co-PI). The Jet Propulsion Laboratory carries out project management and systems engineering activities.

2.1 GRACE Mission

The primary objective of the GRACE mission is to obtain accurate global models for the mean and the time variable components of the Earth's gravity field for a period up to five years. This objective will be achieved by making measurements of inter-satellite range and its derivative of co-planar, low altitude, near-polar orbiting satellites, using a microwave tracking system. In addition, each satellite will carry Global Position System (GPS) receivers and high accuracy accelerometers to enable accurate orbit determination, spatial registration of gravity data and the estimation of gravity field models.

In the oceanographic community the knowledge of the static geoid, in conjunction with satellite altimeter data, will allow significant advances in the studies of ocean heat flux, long term sea level change, upper oceanic heat content, and the absolute surface geostrophic currents. Further, the estimates of time variations in the gravity field obtained from GRACE, in conjunction with other in-situ data and geophysical models, will help the science community unravel complex processes in oceanography (e.g. deep ocean current changes and sea level rise), hyrdology (e.g. large scale evapo-transpiration and soil moisture changes), glaciology (e.g. polar and Greenland ice sheet changes), and the solid Earth sciences.

An additional science goal of the GRACE mission is to enable advances in the atmospheric sciences by the recovery of refractivity (and the derived quantities of temperature and water vapor profiles) and fine ionospheric structure from the use of GPS radio occultation data.

2.2 GRACE Requirements

To ensure that science and mission goals are accomplished, the following requirements were established. The Earth's geopotential field shall be characterized by the coefficients of a spherical harmonic expansion. These coefficients shall be estimated to degree and order 160 or more for the long-term mean part, and to degree and order 100 or less for the time variable part. The temporal variability shall be characterized by mean values of the coefficients over 30 days or so. In addition, approximately 200 GPS atmospheric profile soundings per day shall be acquired, subject to data system limitations. These data will provide globally distributed profiles each day of the excess delay, or bending angle of the GPS measurements due to the ionosphere and the atmosphere.

2.3 Satellite Description

The two GRACE satellites are identical, except for the S-band radio frequencies used for communication with the ground, and the K-band frequencies used for the inter-satellite link. Both satellites are capable of flying either in the lead or trailing positions, forward or backward into the residual atmospheric wind. The combined mass of the two satellites is less than 950 kg. The spacecraft is designed as a prismatic body with side panels at a 50 angle. The panels are designed to support the stringent requirements for alignment and stability.

The GRACE satellites were launched together on a single ROCKOT launch vehicle from Plesetsk, Russia (62.7^{o} N, 40.3^{o} E) on March 17, 2002.

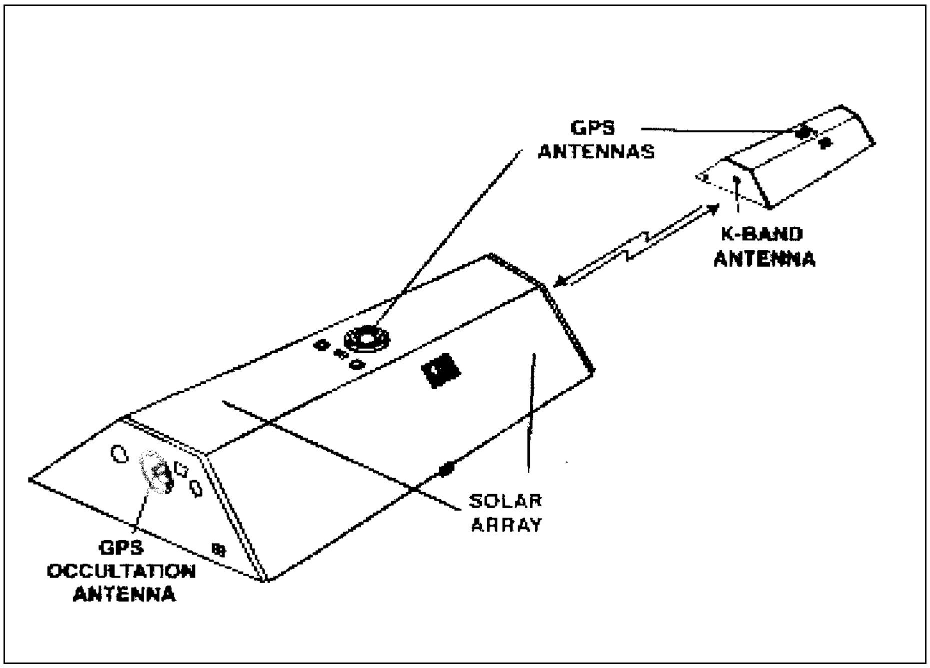

Figure 2-1 Twin GRACE satellites

2.3.1 Sensors

The mission goals are carried out using the following science instruments.

- SuperSTAR Accelerometer (ACC)

  The accelerometer, located at the center of mass of each satellite, measures all non-gravitational forces acting on each satellite. These forces include air drag, solar radiation pressure, and attitude control activator operation.

- Global Positioning System Receiver Assembly (GPS)

  The GPS Receiver Assembly provides navigation data and atmospheric occultation science measurements.

- Star Camera Assembly (SCA)

  The two star cameras mounted close to the accelerometer on each satellite provide the precise attitude references for the satellites when making science measurements.

- K-Band Ranging System (KBR)

  This instrument precisely measures the changes in the separation between the two GRACE satellites using phase tracking of K- and Ka-band signals sent between the two satellites

- Laser Retro Reflector (LRR)

  The LRR on board each satellite provides the external calibration of the onboard microwave orbit determination system (GPS). Laser ranging data can be used to support the precise orbit determination in connection with GPS data for gravity field recovery.

2.3.2 Orbit

The twin GRACE satellites fly a polar orbit with an initial altitude of 500 km decaying to 300 km near the end of mission. The End-of-Mission (EOM) column denotes the desired conditions after five years.

Orbit Characteristics

Orbit Parameter	Initial Value	Tolerance	EOM
Semi-major axis	6878 km (500 km height)	± 10 km	6678 km (300 km height)
Eccentricity	< 0.005	N/A	< 0.005
Inclination	89 deg	± 0.05 deg	89 deg

Over the mission lifetime, the two satellites will remain in co-planar orbits. Due to drag force differences, the along-track separation will be variable. Station-keeping maneuvers will be carried out every 30 to 60 days, as necessary, to keep the two satellites at their nominal separation of 220 km ±50 km. To ensure the uniform exposure and aging of the K-Band antennae in the two satellites, once during the mission the leading and trailing satellites will exchange positions. The altitudes of the two satellites will decay in tandem, from near 500 km at the beginning of the mission, to 300 km and lower at the end of mission. In order to ensure an overall mission lifetime of five years, the altitudes of the two satellites may be re-boosted once, if deemed necessary.

2.3.3 Ground-Track Coverage

The GRACE orbit period will change as the orbit decays from an initial altitude of about 500 km to the end of mission altitude of 300 km. This will cause the spacing between the ground tracks on successive orbits to decrease slowly. When the time required for m orbital periods (m is an integer) is approximately equal to n sidereal days (n is another integer) and m and n are sufficiently small, the ground tracks will repeat.

Over any typical 30-day span (the nominal interval of solution for gravity field) of non-repeating orbit configurations, there will be no discernible systematic patterns in the ground-tracks, and a geographically dense data coverage is obtained. In the repeating configurations, on the other hand, there will be large and systematic gaps in the geographical layout of the ground-tracks. These tracks will fill the gaps only after a long duration (more than 30 days), or after the natural altitude decay carries the satellites through such configurations.

2.4 GRACE Mission Phases

2.4.1 Launch and Early Operations Phase (LEOP)

In addition to the German Space Operations Center (GSOC) ground stations at Weilheim and Neustrelitz, NASA tracking stations at McMurdo, Spitzbergen, and Poker Flat shall be available for telemetry and command uplink during the LEOP phase.

The LEOP phase nominally ends when the following conditions have been met:

1) Both satellites are in safe, stable orbits with no danger of collision with each other, with launch vehicle, or co-passenger satellites.
2) Both satellites have attained nominal attitude control including successful star-camera acquisition.
3) Nominal uplink and downlink communications are achieved with GSOC stations.
4) No anomalies exist that pose a near-term threat to the mission.
5) The nominal separation distance between the satellites (220 km ± 50 km) has been achieved and stabilized.

2.4.2 Commissioning Phase

Following LEOP, there will be a one month Commissioning Phase. The aim of the Commissioning Phase is to check out the individual satellite bus and payload instrument functions.

2.4.3 Validation Phase

Following the Commissioning Phase, there will be a Validation Phase in which the instrument checkout is performed in detail, and GPS, KBR, ACC, and SCA data are evaluated. This Validation Phase will last approximately until May 2004. Initial calibrations will be completed for the distance between the satellite center-of-mass and the accelerometer proof mass, the orientation of each SCA with respect to the K-Band boresight vector, and accelerometer bias and scale factors. Using these calibrations, preliminary gravity field solutions will be computed, and verified through a combination of internal consistency checks and comparison with in-situ and ocean bottom pressure data.

2.4.4 Observational Phase

Following the Validation phase, the mission will enter the Observational Phase, in which science data are routinely gathered from the science payload. This phase will continue until the end of mission, with the exception of brief periods for orbit maintenance and recalibrations.

2.5 Data Processing and Distribution

The Science Data System (SDS) is a distributed data system. System development, data processing and archiving are shared between the Jet Propulsion Laboratory (JPL), The University of Texas, Center for Space Research (UTCSR), and GeoForschungsZentrum (GFZ). The SDS functions include science data processing, archiving, distribution, and product verification. The SDS also receives, processes, and archives ancillary data (e.g., meteorological fields) necessary for data processing and verification.

2.6 GRACE SDS Products

2.6.1 Level 0 Data

The Level 0 data products are the result of telemetry data reception, collection and decommutation by the GRACE Raw Data Center (RDC) at DLR in Neustrelitz. This telemetry data from each downlink pass is separated into the Science Instrument and Spacecraft Housekeeping data streams, and placed in a rolling archive at the RDC. From each satellite, as a result, two files from each pass are made available in the rolling archive. These two files are defined to be the Level 0 data.

2.6.2 Level 1A Data

The Level 1A data are the result of a non-destructive processing applied to the Level 0 data. The sensor calibration factors are applied in order to convert the binary encoded measurements to engineering units. Where necessary, time tag integer second ambiguity is resolved and data are time tagged to the respective satellite receiver clock time. Editing and quality control flags are added, and the data is reformatted for further processing. The Level 1A data are reversible to Level 0, except for the bad data packets. This level also includes the ancillary data products needed for processing to the next data level.

2.6.3 Level 1B Data

The Level 1B data are derived from the (possibly irreversible) processing applied to both the Level 1A and Level 0 data. The data are correctly time-tagged, and the data sample rate is reduced from the high rate data of previous levels. Collectively, the processing from Level 0 to Level 1B is called the Level 1 Processing. This level also includes the ancillary data products generated during this processing, and the additional data needed for further processing. These data will be made available to the scientific community no later than 12 days following receipt of Level 0 data.

2.6.4 Level 2 Data

The Level-2 data include the orbits for the GRACE spacecraft, estimates of spherical harmonic coefficients for the Earth gravitational potential, and excess path delay/refractivities from the occultation data. The Level 2 gravity field model data will be available within 60 days of acquisition.

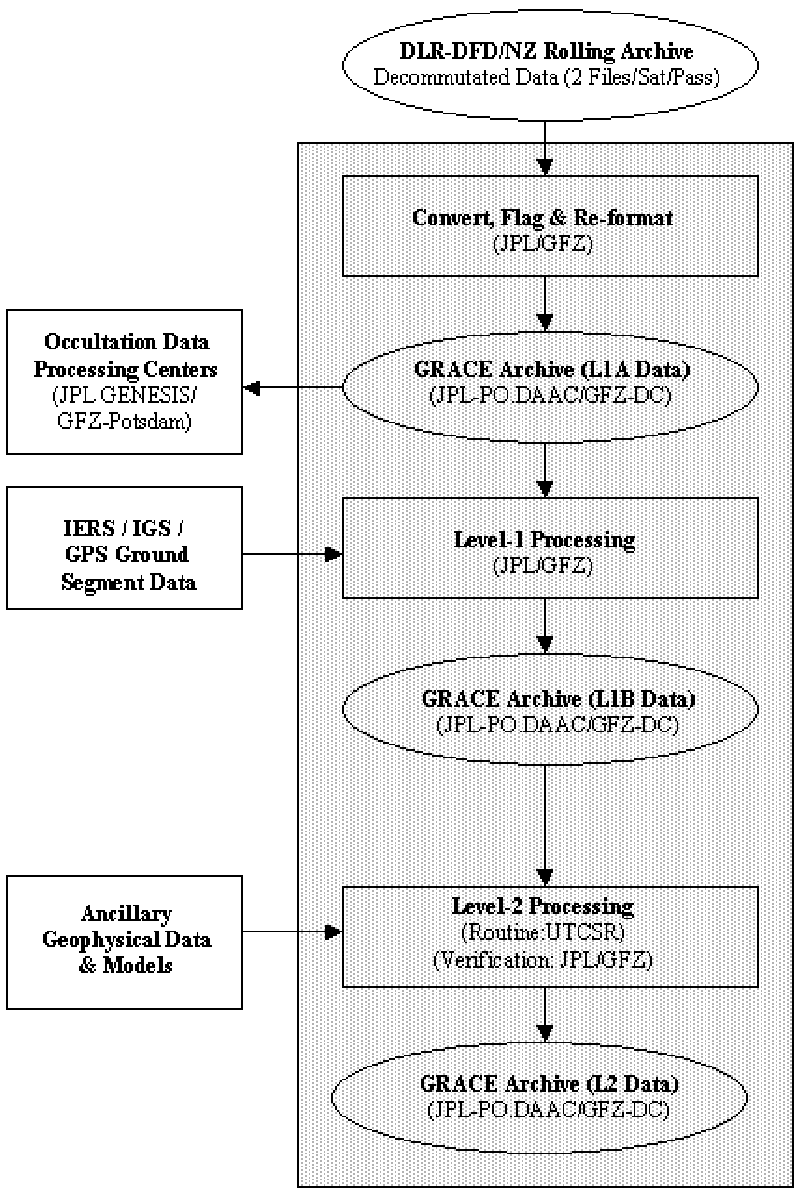

Figure 2-2 GRACE Science Data Flow (Shaded areas denote the SDS)

3 GRACE LEVEL 1B DATA

This section presents a short discussion of the algorithms producing the main quantities on the Level 1B data and is based on "Algorithm Theoretical Basis Document for GRACE Level-1B Data Processing", JPL Publication D-27672, January 2004 by Sien-Chong Wu and Gerhard L.H. Kruizinga.

3.1 Dual-One-Way Ranging Data

The line-of-sight distance change, partially induced by the variations in Earth's gravity field, is derived from the phase change measurements made between the respective antenna phase centers on the two satellites using the microwave (K-band) ranging instruments onboard.

3.1.1 Biased Range

The KBR1B data provide the biased ranges between the GRACE A and B spacecrafts. The biased range is the true range plus an unknown bias. The bias is arbitrary for each piecewise continuous segment of phase change measurements and may change over day boundaries. The biased range also include range changes introduced by the time of flight of the K band signal, referred to as light time corrections, as well as geometric range changes due to spacecraft attitude variations.

K band ranging level 1A (KBR1A) data are pre-processed and flagged for phase breaks. The data quality flag [see parameter qualflg (bit=0) in KBR1B] is set if the (K – 0.75 Ka) phase discontinuity exceeds 0.2 cycle. Data gaps of 2 seconds or shorter are filled by forming a least squares estimate, then using quadratic interpolation when at least 2 points per side are available. If there are less than two points per side, then linear interpolation is used to fill the data gap. Data gaps exceeding 2 seconds are filled after forming dual one-way range. The KBR1A timetags are corrected to GPS time for the receiver-clock offsets using GPS clock solutions supplied by CLK1B data. KBR1A measurements with corrected timetags are then re-sampled to 0.1-second intervals using linear interpolation.

Dual one-way biased range combinations are calculated for both K- and Ka- band frequencies:

$$\Psi_K = [(\phi_{A,K} + \phi_{B,K}) / (f_{A,K} + f_{B,K})] * c$$
$$\Psi_{Ka} = [(\phi_{A.Ka} + \phi_{B,Ka}) / (f_{A,Ka} + f_{B,Ka})] * c$$

where ϕ_A = phase of GRACE A
ϕ_B = phase of GRACE B
f_A = frequency of GRACE A
f_B = frequency of GRACE B
c = speed of light

Ion-free dual one-way biased range combination is calculated as:

biased range = (ion_Ka * Ψ_{Ka}) - (ion_K * Ψ_K)

where ion_Ka = 16/7
ion_K = 9/7

Finally, each 0.2 Hz “frame” of the K- and Ka- band biased range measurements [biased_range] are compressed using a CRN digital filter [*Thomas*, 1999] of the respective 10 Hz measurements every 5 seconds. Weighting functions for range, range rate and range acceleration, each spanning 70.7 seconds, are adopted. Data are flagged according to the severity of the filled missing data from the center.

3.1.2 Range Rate

The KBR1B data provide the range rate, which is the first time derivative between the GRACE A and B spacecrafts.

3.1.3 Range Acceleration

The KBR1B data provide the range acceleration, which is the second time derivative between the GRACE A and B spacecrafts.

3.1.4 Light time Correction

The distance traveled by both satellites during the time-of-flight of the K band signal from the transmit-to-receiver time must be accounted for to convert the observed dual one-way biased range into instantaneous range [*Kim*, 2000]. This is referred to as the light time correction [see parameter lighttime_corr in KBR1B]. It is derived from the GRACE orbit positions and velocities from the two GPS1B files. Respective light time corrections are also reported for range rate and range acceleration.

3.1.5 Geometric Correction

In-flight GRACE A and B satellites do not usually have perfect line-of-sight pointing. The biased range must be corrected to account for the effects due to misalignment of spacecraft attitude variations [see parameter ant_centr_corr in KBR1B]. This range correction is calculated by first rotating the antenna phase center offset vector into inertial space using the spacecraft attitude information from the two input SCA1B files and then taking dot products with the line-of-sight vector between the two spacecrafts. Respective geometric corrections are also reported for range rate and range acceleration.

3.2 Star Camera Data

Star camera level 1A (SCA1A) data can have up to two star camera measurements: 1-second high-rate samples from the primary star camera and/or 5-second samples from the secondary star camera.

The two data streams are edited. A reference quaternion is computed using line-of-sight orbit. Residuals are then formed for one day. Outliers are removed using a global three-sigma editing and then a refined localized three-sigma editing. Resulting quaternions are verified for sign ambiguity.

For the primary star camera data gaps of 10 seconds or shorter are filled using quadratic interpolation when at least 2 points per side are available. If there are less than two points per side, then linear interpolation is used to fill the data gap. Data gaps exceeding 10 seconds are not filled. Secondary star camera data gaps are not filled.

Timetag corrected data are then re-sampled to 1-second intervals for the primary star camera and 5-second intervals for the secondary star camera using linear interpolation. Primary star camera measurements are then compressed to 5-second intervals with a quadratic fit over five 1-second data points.

Resulting primary and secondary quaternions are combined using a weighted summation. The measurements are reported at 5-second intervals.

3.3 Accelerometer Data

The accelerometer data provide the linear (high rate) and angular (low rate) acceleration components of the proof mass of each spacecraft.

Accelerometer level 1A (ACC1A) data are pre-processed and quality flags are checked. Data gaps of 10 seconds or shorter are filled using quadratic interpolation when at least 2 points per side are available. If there are less than two points per side, then linear interpolation is used to fill the data gap. Data gaps exceeding 10 seconds are not filled. Timetags are mapped from the On Board Data Handling (OBDH) time to receiver time using TIM1B data, then corrected to GPS time using GPS clock solutions supplied by CLK1B data. Timetag corrected data are then re-sampled to 0.1-second intervals using linear interpolation.

ACC1A linear measurements are compressed using a CRN digital filter [*Thomas*, 1999] over a 70.7 second span. Angular measurements are sampled at integer multiples of 5 seconds. Data are flagged according to the severity of the filled missing data from the center.

3.4 GPS Tracking Flight Data

GPS Level 1B data consist of three range measurements (CA, L1, and L2) and three phase measurements (CA, L1, and L2) all at 10-second intervals.

3.4.1 Range Measurements

GPS Level 1A data are checked for L1-L2 and CA-L2 phase continuity. The data quality flag [see parameter qualflg in GPS1B] is set if phase discontinuity exceeds one L1–cycle. Cycle slips, i.e., phase discontinuities within an arc, are also identified.

As with all GRACE Level 1B data, the timetags are corrected to GPS time using GPS clock solutions supplied by CLK1B data. However, in order to interpolate the 10-second range data with greatest accuracy, the large dynamic range must first be removed from the absolute range bias. This separation is achieved by forming differences of range data and the following negative-ion phase combinations, in order to have the same ionospheric effects as the corresponding range data:

negative-ion CA phase = $(2.54+1.54)\,\phi_{CA} - 2(1.54)\,\phi_2$
negative-ion L1 phase = $(2.54 + 1.54)\,\phi_1 - 2(1.54)\,\phi_2$
negative-ion L2 phase = $2(1.54)\,\phi_1 - (2.54 + 1.54)\,\phi_2$

where ϕ_{CA} = CA carrier phase
ϕ_1 = L1 carrier phase
ϕ_2 = L2 carrier phase

Timetag corrections are applied to the negative-ion phase, and then are re-sampled to 10-second intervals with linear interpolation. Re-sampled negative-ion phases are added back to the corresponding raw (range minus negative ion phase) data to form the re-sampled CA, L1, and L2 ranges that are reported on the GPS Level 1B data.

3.4.2 Phase Measurements

GPS Level 1A data are flagged for phase discontinuity. Raw phase measurements are timetag corrected to GPS time using GPS clock solutions supplied by CLK1B data. Timetag corrected data are then re-sampled to 10-second intervals with cubic interpolation over a 10-second data span.

3.5 Housekeeping Data

The Housekeeping Products contain instrument health and calibration data, which are collected onboard and can be used to make corrections to the main measurements.

Housekeeping Data includes the following ancillary data products:

- Accelerometer Housekeeping Data (AHK1B)
- IPU Housekeeping Data Level 1B (IHK1B)
- Thrusters Level 1B Data (THR1B)
- Cold Gas Tank Level 1B Data (TNK1B)
- Magnetometer and Magnettorquer Level 1B Data (MAG1B)
- Spacecraft Mass Level 1B Data (MAS1B)
- Mapping of OBDH time to Receiver time (TIM1B)

3.6 Timing

All Level 1B data products are time tagged with GPS time. Time tags are mapped from the On Board Data Handling (OBDH) time to receiver time using TIM1B data, then corrected to GPS time using GPS clock solutions supplied by CLK1B data. No further time tag corrections are needed to all Level 1B data. TIM1B and CLK1B are provided merely as ancillary products.

Note: the relative timing between GRACE A and GRACE B has an accuracy requirement of 0.16 nanoseconds.

3.7 Orbit

The GPS Navigation Level 1B Format Record (GNV1B) provides the location of the orbit in an Earth fixed frame.

4 USING THE GRACE LEVEL 1B DATA

This section will give the reader a guide to usage of the GRACE Level 1B data. The current document provides the best description and correction as possible. Further changes, e.g., new quality flag definitions, based on discussions at SDS workshops or based on remarks/questions of other users will be distributed to all users in an updated version of the handbook. Please direct questions and comments to the contacts given on the last page of this handbook.

Data usage notes and editing criteria are provided below for the Level 1B data products. The user should review these criteria before using them and may wish to modify them! It is recommended to check the web sites listed in Appendix C for updates.

In this section references are made to specific parameters by name. All parameters are described in section 6, GRACE Level 1B Product Format.

4.1 K-Band Ranging Data Product (KBR1B)

4.1.1 Biased Range, Range Rate and Range Acceleration

The KBR1B data provide the biased ranges and their two time derivatives between the GRACE A and B spacecrafts. The reported biased ranges are corrected for ionospheric effects. The biased ionospheric correction is reported separately for the Ka band frequency. The biased ranges must be corrected for light time and geometric effects (i.e., antenna offsets). All range corrections are defined so that they should be ADDED to the range. The corrected biased range is given by

```
Corrected Biased Range = biased range + light time correction
                                      + antenna offset correction
```

Biased range = biased range between GRACE A and B (biased_range from KBR1B)

Light time correction = light time range correction between GRACE A and B (lighttime_corr from KBR1B)

Antenna offset correction = antenna phase center range correction (ant_centr_corr from KBR1B)

The reported range rates and range accelerations must also be corrected with their respective light time and geometric effects:

```
Corrected Range Rate = range rate  + light time rate correction
                                   + antenna offset rate correction
```

Range rate = range rate between GRACE A and B (range_rate from KBR1B)

Light time rate correction = light time range rate correction between GRACE A and B (lighttime_rate from KBR1B)

Antenna offset rate correction = antenna phase center range rate correction (ant_centr_rate from KBR1B)

```
Corrected Range Acceleration =  range acceleration
                                + light time acceleration correction
                                + antenna offset acceleration correction
```

Range acceleration = range acceleration between GRACE A and B (range_accl from KBR1B)

Light time acceleration correction = light time range acceleration correction between GRACE A and B (lighttime_accl from KBR1B)

Antenna offset acceleration correction = antenna phase center range acceleration correction (ant_centr_accl from KBR1B)

4.1.2 KBR1B Data Flagging/Editing

The following editing criteria are a recommended guideline for finding good records from the KBR1B data.

First, check the following condition to identify phase breaks:

qualflg bit 0=1 **phase break**

The following quality flags are provided as additional informative flags, and do not usually indicate further data editing recommendations:

qualflag bit 1 = extrapolated states for lighttime_corr
qualflag bit 2 = model eci attitudes for ant_centr_corr
qualflag bit 3 = extrapolated clock correction > 5s from fit center
qualflag bit 4 = extrapolated clock correction < 5s from fit center
qualflag bit 5 = data corrected for timetag bias of either K or Ka phase
qualflag bit 6 = filled data ≥ 5s from fit center
qualflag bit 7 = filled data < 5s from fit center

In addition to checking for phase breaks, it is also recommended to filter the data as follows to retain only the most valid data:

SNR_{K*} > 450.0 0.1 db-Hz

However, prior to 3 February 2003 for GRACE B and 8 May 2003 for GRACE A, constant low SNR values of approximately 340 were observed, for which data are valid.

These constant low SNR values are erroneous and should not be filtered. Occurrences of constant values can last up to ~2 days.

To convert SNR to a 1-second error in cycles of phase use the following formula:

y = 1 sec SNR voltage = $10^{[x/(10*20)]}$
sigma_phase = $1/(2\pi y)$ cycles

where

x = any of SNR_{K*} numbers: $SNR_{A,K}$, $SNR_{A,Ka}$, $SNR_{B,K}$, $SNR_{B,Ka}$

4.1.3 Total Electron Content Change from Biased Ionosphere Correction

The biased ionospheric correction that is reported for the Ka band frequency contains an arbitrary bias. Therefore, the correction indicates the change in the ionosphere as a function of time. To calculate the change in ionospheric total electron content (TEC), use the following formula:

Δ Total Electron Content = $-(dR*f^2_{Ka})/40.3$

where

Total Electron Content is the TECU (1 TECU = 10^{16} electrons/m^2)

dR = change in ionospheric range correction in m from KBR1B
(For example, $ion\_corr_n - ion\_corr_{n-1}$)

f = frequency in Hz (Ka=32GHz)

4.2 Star Camera Data Product (SCA1B)

4.2.1 SCA1B Data Flagging/Editing

The following editing criteria are a recommended guideline for finding good records from the SCA1B data.

Quality flags that indicate data gaps filled, according to severity:

qualflg bit 0=1 **filled data at T**
qualflg bit 1=1 **filled data at T ± 1 second**
qualflg bit 2=1 **filled data at T ± 2 seconds**

Additional quality flags include:

qualflg bit 3=1 **only one star camera enabled**

qualflg bit 4=1	**extrapolated clock correction used**
qualflg bit 6=1	**low rate data from 2nd star camera**
qualflg bit 7=1	**low rate data from 1st star camera**

4.3 Accelerometer Data Product (ACC1B)

4.3.1 Linear and angular acceleration components

The ACC1B data provide the linear and angular acceleration components of the proof mass of each spacecraft.

4.3.2 ACC1B Data Flagging/Editing

The following editing criteria are a recommended guideline for finding good records from the ACC1B data.

Quality flags that indicate data gaps filled, according to severity:

qualflg bit 7=1	**filled data < 5s from fit center**
qualflg bit 6=1	**5s ≤ filled data < 15s from fit center**
qualflg bit 5=1	**filled data ≥ 15s from fit center**

Quality flags that indicate extrapolated clock corrections, according to severity:

qualflg bit 4=1	**extrapolated clock correction < 5s from fit center**
qualflg bit 3=1	**5s ≤ extrapolated clock correction < 15s from fit center**
qualflg bit 2=1	**linear ACC component has fit residual > 10 microns/s^2**

4.4 GPS Data Product (GPS1B)

The following editing criteria are a recommended guideline for finding good records from the GPS1B data.

Quality flags that identify phase breaks and cycle slips:

qualflg bit 0=1	**phase break occurred in L1/CA**
qualflg bit 1=1	**phase break occurred in L2**
qualflg bit 2=1	**cycle slip detected in L1/CA**
qualflg bit 3=1	**cycle slip detected in L2**

NOTE: Software is provided to convert the binary GPS data to RINEX (Receiver Independent Exchange Format.)

4.5 Vector Products (VGN1B, VGO1B, VGB1B, VCM1B, VKB1B, VSL1B)

The Vector Products contain the vector offsets for the GPS main antenna, the GPS backup navigation antenna, the GPS occultation antenna, the SLR corner cube reflector, the center of mass solution from calibration maneuvers, and KBR phase centers. These products are only released when values are reset. Each file provides an update and contains the history for the entire mission.

The Vector Products contain the magnitude and direction cosine of the vector with respect to the satellite x-, y-, and z-axes in the Science Reference Frame, where the X, Y, and Z coordinates are defined as follows:

X = mag * cosx
Y = mag * cosy
Z = mag * cosz

4.6 Quaternion Products (QSA1B, QSB1B, QKS1B)

The Quaternion Products contain the spacecraft alignment quaternions for each GRACE satellite. These products are ancillary because the alignment quaternions (QSA1B) have been used in producing the SCA1B product. QSB1B is not used at this time and QKS1B is a quaternion used on board to point the KBR phase center at the opposite spacecraft. These products are only released when values are reset. Each file provides an update and contains the history for the entire mission.

4.7 Housekeeping Products (AHK1B, IHK1B, THR1B, TNK1B, MAG1B, MAS1B, TIM1B)

The Housekeeping Products contain instrument health and calibration data, which are collected onboard and are mainly used to monitor the health and consumables onboard the spacecrafts. This data is considered ancillary, but has been used in analysis of the science data. The following two paragraphs are examples on how these data may be used for this type of analysis.

4.7.1 Accelerometer bias and scale determination

The accelerometer has an unknown scale and bias in each direction. The bias and scale are solved for simultaneously with the gravity field. A parameter reported in the AHK1B file called the proof mass voltage (Vp) has a direct effect on the bias and scale. In some time spans the Vp was off its nominal value and caused a jump in mainly bias and possibly scale. Using the time series of Vp (from AHK1B) it is possible to adjust the bias and scale parameters in the gravity field estimation process to account for time spans where the Vp is not nominal. This specific information is also available in the Sequence of Events (SOE) file, see section 4.8. In the SOE file, a time series for non-nominal Vp values is given, using the Sensor/Event identifier ICUVP.

4.7.2 Center of Mass Offset management

The Center of Mass Offset (COM) of the GRACE spacecraft is managed to not deviate more than .1 mm from the ACC proof mass COM. This control is necessary to avoid parasitic linear accelerations of the ACC proof mass that are introduced by COM when the spacecraft experiences angular accelerations. The main change in the COM is in the X direction because two spherical cold gas tanks are positioned on opposite sites of the COM on the X-axis of the spacecraft. Any differential draining of these tanks results in a change of the COM. In order to monitor the COM change, it is important to monitor the amount of mass in the gas tanks. The mass in the tanks can be determined in two ways:

1) use pressure and temperature measurements (TNK1B) and estimate gas mass
2) use thruster firing durations (THR1B) and use accumulate on-time and the mass flow rate to estimate the total gas drained from a tank

For the real COM monitoring the data from step 2) is calibrated with step 1) and provides the best COM estimate.

4.8 Sequence of Events file

The Sequence of Events (SOE) file records the change of the state of a specific satellite sensor or a satellite event, which may alter the processing parameters used for the L1B processing. The SOE file contains sensor and event time series, which describe the changes in their state. These time series should be interpreted in the following way: The sensor/event state remains unchanged until a new valid record appears in the file with new state information. Next you will find a detailed description and format information on how the SOE file is organized and the state information for each sensor and event that is recorded.

The SOE file is a white space delimited file. If the first field is an "x" the line has been deleted from active use. The fields in the active lines are defined as follows:.

Active lines:

Field 1: gps seconds past J2000, 0 = 1-JAN-2000 12:00:00.0000 GPS = 1-JAN-2000 11:59:47.0000 UTC

Field 2: Spacecraft, "GRACEA" "GRACEB"

Field 3: Sensor/Event identifier
Currently the following sensor/event identifiers are recognized:
ACC AOCS ICUVP IPU IPUR KAMI KBR K_MI KTOFF MTE1 MTE2 QKS QSA QSB SCA USO VCM VGB VGN VGO VKB VSL
See below for numerical field meanings

Field 4: Number of numerical fields to follow, N

Fields 5: 4+N: Numerical values, for instance which USO is active, GPS antenna POD (precision orbit determination) dual-freq. antenna offset. For a description of the fields for each Sensor/Event identifier see list below.

Fields 5+N: After these field any comment may be place, in general time tag information on when the active line was inserted in the SOE file

The following Sensor/Event identifiers are defined which include the state information:

ACC #fields = 1
 field value = 1: main ICU active
 field value = 2: redundant ICU active
 Note: ACC identifier is currently not set in the SOE file

AOCS #fields = 1
 field value = 0 = AOCS NO_MODE
 field value = 1 = AOCS CMCMP (course pointing mode)
 field value = 2 = AOCS CIMCMP (course pointing mode)
 field value = 3 = AOCS AHM (attitude hold mode)
 field value = 4 = AOCS BAHM (back up attitude hold mode)
 field value = 5 = AOCS SM (science mode)
 field value = 6 = AOCS BSM (back up science mode)

ICUVP #fields =1
 field value = 0 = NOMINAL Vp value
 field value = 1 = OFF NOMINAL Vp value

IPU #fields = 1
 field value = 1 = main IPU active derived from IPU log message
 field value = 2 = redundant IPU active derived from IPU log message

IPUR #fields = 3
 column 1: field value = 1 Main IPU active
 field value = 2 Redundant IPU active
 field value = -1 IPU active not known from IPU log message
 column 2: field value = time of IPU nudge from IPU log message (gps seconds)
 column 3: field value = 1 IPU flash OK
 field value = 2 IPU flash corrupted
 field value = -1 IPU flash state not known from IPU log message

KAMI #fields = 1
 field value = time tag offset to be applied to (KBR) Ka-phase measurement (sec)

KBR #fields = 1
 1 = main KBR
 2 = redundant KBR
 Note KBR key is currently not set in the SOE file

K_MI #fields = 1

field value = time tag offset to be applied to (KBR) K-phase measurement (sec)

KTOFF #fields = 1
field value = time tag offset to be applied to (KBR) K and Ka-phase measurement (sec)

MTE1 #fields = 3
column1: field value = X-axis distance traveled by Trim Mass Assembly 1 since launch (mm)
column2: field value = Y-axis distance traveled by Trim Mass Assembly 1 since launch (mm)
column3: field value = Z-axis distance traveled by Trim Mass Assembly 1 since launch (mm)

MTE2 #fields = 3
column 1: field value = X-axis distance traveled by Trim Mass Assembly 2 since launch (mm)
column2: field value = Y-axis distance traveled by Trim Mass Assembly 2 since launch (mm)
column3: field value = Z-axis distance traveled by Trim Mass Assembly 2 since launch (mm)

QKS #fields = 8
column 1: field value = q0 quaternion of SCA1 to K frame rotation
column 2: field value = q1 quaternion of SCA1 to K frame rotation
column 5: field value = q0 quaternion of SCA2 to K frame rotation
column 8: field value = q3 quaternion of SCA2 to K frame rotation where q0 is the scalar

QSA #fields = 8
column1: field value = q0 quaternion of SCA1 to SRF frame rotation
column2: field value = q1 quaternion of SCA1 to SRF frame rotation
column5: field value = q0 quaternion of SCA2 to SRF frame rotation
column8: field value = q3 quaternion of SCA2 to SRF frame rotation

QSB #fields = 4
column1: field value = q0 quaternion of S/C body to SRF frame rotation
column2: field value = q1 quaternion of S/C body to SRF frame rotation
column4: field value = q3 quaternion of S/C body to SRF frame rotation
Note: QSB is currently not set in SOE file

SCA #fields = 2
column1: field value = 1 = SCA1 is primary head
field value = 2 = SCA2 is primary head
column2: field value = 1 = SCA1 is primary head
field value = 2 = SCA2 is primary head

USO #fields = 1
field value = 1 main USO for GRACE A
field value = 3 redundant USO on GRACE A
field value = 2 main USO for GRACE B
field value = 4 redundant USO on GRACE B

VCM #fields = 3
column1: field value = X-coordinate of CM in SRF (m)
column2: field value = Y-coordinate of CM in SRF (m)
column3: field value = Z-coordinate of CM in SRF (m)

VGB #fields = 6
column1: field value = X-coordinate of L1 phase center for the backup GPS antenna in SRF (m)
column2: field value = Y-coordinate of L1 phase center for the backup GPS antenna in SRF (m)
column3: field value = Z-coordinate of L1 phase center for the backup GPS antenna in SRF (m)
column4: field value = X-coordinate of L2 phase center for the backup GPS antenna in SRF (m)
column5: field value = Y-coordinate of L2 phase center for the backup GPS antenna in SRF (m)
column6: field value = Z-coordinate of L2 phase center for the backup GPS antenna in SRF (m)

VGN #fields = 6
column1: field value = X-coordinate of L1 phase center for the navigation GPS antenna in SRF (m)
column2: field value = Y-coordinate of L1 phase center for the navigation GPS antenna in SRF (m)
column3: field value = Z-coordinate of L1 phase center for the navigation GPS antenna in SRF (m)
column4: field value = X-coordinate of L2 phase center for the navigation GPS antenna in SRF (m)
column5: field value = Y-coordinate of L2 phase center for the navigation GPS antenna in SRF (m)
column6: field value = Z-coordinate of L2 phase center for the navigation GPS antenna in SRF (m)

VGO #fields = 6
column1: field value = X-coordinate of L1 phase center for the occultation GPS antenna in SRF (m)
column2: field value = Y-coordinate of L1 phase center for the occultation GPS antenna in SRF (m)

column3: field value = Z-coordinate of L1 phase center for the occultation GPS antenna in SRF (m)
column4: field value = X-coordinate of L2 phase center for the occultation GPS antenna in SRF (m)
column5: field value = Y-coordinate of L2 phase center for the occultation GPS antenna in SRF (m)
column6: field value = Z-coordinate of L2 phase center for the occultation GPS antenna in SRF (m)

VKB #fields = 3
column1: field value = X-coordinate of KBR phase center in SRF (m)
column2: field value = Y-coordinate of KBR phase center in SRF (m)
column3: field value = Z-coordinate of KBR phase center in SRF (m)

VSL #fields = 3
column1: field value = X-coordinate of SLR phase center in SRF (m)
column2: field value = Y-coordinate of SLR phase center in SRF (m)
column3: field value = Z-coordinate of SLR phase center in SRF (m)

The remainder of the line is arbitrary but will include the UTC time that the line was added to the file and possible other arbitrary comments.

Currently the file is sorted on the Time Field (field 1 of non-deleted lines).

Examples:

```
0.0         GRACEB ACC   1            1

0.0         GRACEB QKS   8  0.3800290947 0.9249498818 -0.0067473944
0.0002758285 0.3789188498 -0.9253766203 0.0028558974 0.0095110300

0.0         GRACEB QSB   4          0.0          0.0           0.0
0.0

0.0         GRACEB VGB   6      -1.56125       -0.300          -0.19     -
1.56125       -0.300        -0.19

0.0         GRACEB VGN   6      0.000602     0.000754      -0.45173
0.000602     0.000754      -0.47596

0.0         GRACEB VGO   6      -1.56125        0.000          -0.19     -
1.56125        0.000      -0.19

0.0         GRACEB VSL   3       -0.6000       -0.3275         0.3300

100302780.0 GRACEA MTE1  3     16.115e-3   -3.0225e-3       4.03e-3

101531422   GRACEA AOCS  1             5  SM KBR-Calibrations

105746450   GRACEA KTOFF 1           0.0

1.0         GRACEB VKB   3      1.472580    -0.000088      0.003319

121227065   GRACEA SCA   2             2            1
```

```
122997938    GRACEB ICUVP 1             0  NOMINAL

123715827    GRACEB AOCS  1             6  BSM Normal-Operations

123853640.0 GRACEA K_MI  1          0.00

127123270.0 GRACEA KAMI  1          0.00

127947910    GRACEB IPUR  3            -1    127947897             2

128032830    GRACEB IPU   1             1

73346640.0   GRACEA VCM   3    -0.2350e-3   0.12561e-3   -0.11442e-3

73945590.0   GRACEA MTE2  3    23.7825e-3    -12.71e-3    11.5775e-3

87316760.0   GRACEA QSA   8   0.3758022940 0.9266991916 0.0003448607 -
0.0010607145 0.3835688821 -0.9235064871 -0.0007310729 -0.0031853829

95910570     GRACEB USO   1             4
```

4.9 Report files

Daily processing report files are provided for all GRACE Level 1 products. These reports provide further data quality analysis and contain detailed information on time gaps, RMS fit to data, quality flag counts, overview of quality flags per product, etc. See Appendix B for content and format information.

Report files for all processed Level 1B data are visualized at the following GRACE Data monitoring URL:
http://podaac.jpl.nasa.gov/grace_mon

5 LEVEL 1B DATA CONTENT AND FORMAT

5.1 Overview

PO.DAAC processes, archives and distributes GRACE Level 1B data. The Level 1B data are organized into separate files for the related science instruments and subsystems onboard the twin GRACE spacecrafts. Each Level 1B product file has a different format that is described in detail in section 6, GRACE Level 1B File Formats. All data from one GPS day are stored in one file.

5.2 File Structure

Each file contains an ASCII header and is a constant record length, except for GPS1B, TNK1B, and MAS1B. The header record consists of multiple 80 byte records. The last header record is labeled "END OF HEADER". After the last header record, multiple data records are written. The data records are defined according to the product identification labels specified in section 5.3.

5.2.1 Header Description

Headers provide identification, processing history and content information. Processing history includes software version and processing time. Content information includes data start and end times and number of data records. Processing time and build/version should be used to ensure that the latest version is being used if file reissue is necessary.

The ASCII header for each data format contains the following information:

```
/  PRODUCER AGENCY                : NASA
/  PRODUCER INSTITUTION           : JPL
/  FILE TYPE ipACC1BF             : 8
/  FILE FORMAT 0=BINARY 1=ASCII   : 1
/  NUMBER OF HEADER RECORDS       : 19
/  SOFTWARE VERSION               : @(#) Bin2AsciiLevel1.c       1.5 03/11/01
/  SOFTWARE LINK TIME             : @(#) 2001-04-17 08:10:27 glk  bart
/  REFERENCE DOCUMENTATION        : GRACE Level 1 Software Handbook
/  SATELLITE NAME                 : GRACE B
/  SENSOR NAME                    : ACC GRACE B
/  TIME EPOCH (GPS TIME)          : 2000-01-01 12:00:00
/  TIME FIRST OBS(SEC PAST EPOCH): 99921000.000000 (2003-03-02 23:50: 0.00)
/  TIME LAST OBS(SEC PAST EPOCH) : 99935400.000000 (2003-03-03 03:50: 0.00)
/  NUMBER OF DATA RECORDS         : 2881
/  PRODUCT CREATE START TIME(UTC): 2001-04-17 15:10:59
/  PRODUCT CREATE END TIME(UTC)  : 2001-04-17 15:10:59
/  FILESIZE (BYTES)               : 157194
/  FILENAME                       : ACC1B_2003-03-02_B_01.pass
/  PROCESS LEVEL (1A OR 1B)       : 1B
/  INPUT FILE NAME                : TMBJ0<-GR1-0-RDC-RT-
SC+NZ_2003_158_10_24_1_2.bj
/  INPUT FILE TIME TAG (UTC)      : TMBJ0<-2003-06-07 10:24:00 by RDC
/          ..
/  (list of all input files plus)
/  (creation time tag information)
/          ..
/  END OF HEADER
```

5.2.2 Data Description

To find the associated data format for each product, see Chapter 6, GRACE Level 1B Data Formats.

5.3 File Naming Convention

The file naming convention for level-1B data is

PRDID_YYYY-MM-DD_S_RL.EXT

where

PRDID	= product identification label, e.g. ACC1B (see table below)
YYYY	= year
MM	= month
DD	= day of month
S	= GRACE satellite identifier (A, B, or X = combined product of GRACE A and B)
RL	= data product version number
EXT	= file extension indicating binary (dat) or ascii (asc) files

For example, the file **ACC1B_2003-03-03_A_00.dat** contains Level-1B Accelerometer data for March 3, 2003 from the GRACE-A satellite, version 0, in binary format.

Product Identification Labels

PRDID	Description
ACC1B	Level 1B Accelerometer data
AHK1B	Level 1B Accelerometer House keeping data
CLK1B	Level 1B Satellite clock solution (from OD software + CLK1A)
GNV1B	Level 1B navigation solution (from OD software)
GPS1B	Level 1B GPS flight data
IHK1B	Level 1B IPU Housekeeping data
KBR1B	Level 1B KBR ranging data
MAG1B	Level 1B Magnetic Torque Rod Activation data + Magnetometer data
MAS1B	Level 1B Spacecraft mass as a function of time
QKS1B	Rotation from Star Camera Frames into K-Band Frame
QSA1B	Rotation From Star Camera Frames into SRF
QSB1B	Rotation From Satellite Body Frame into SRF
SCA1B	Level 1B star camera data (compressed/combined SCA data)
THR1B	Level 1B thruster activation data
TIM1B	Level 1B OBDH time mapping to GPS time
TNK1B	Level 1B Gas tank sensor data + auxiliary data for COM management
USO1B	Oscillator frequency data (derived from OD software output)
VCM1B	Vector offset file for Center of Mass solution from calibration maneuvers or tracking model in SRF

VGB1B	Vector offset file for GPS Backup Navigation Antenna in SRF
VGN1B	Vector offset file for GPS Main Antenna in SRF
VGO1B	Vector offset file for GPS Occultation Antenna in SRF
VKB1B	Vector offset file for KBR phase centers in SRF
VSL1B	Vector offset file for SLR Corner cube reflector offset in SRF

5.4 ASCII versions of Level-1B format

For all Level-1B formats an ASCII version of the data is defined. The headers for the ASCII files are identical to the binary data files with only relevant information changed (e.g. FILE FORMAT). The sequence of the data is the same as defined in Chapter 6, GRACE Level 1B File Formats. All data entries are white-space delimited. The binary Level-1B files can be converted into ASCII Level-1B format files by using the Bin2AsciiLevel1 software utility, which is distributed with Level 1B data.

NOTE: Bitfields are defined in section 1.5.7 Bit Fields Order, e.g., bit 0 is the last entry in bitfield.

6 GRACE LEVEL 1B DATA PRODUCT FORMATS

6.1 Overview

Section 6 describes the format of the data records for all GRACE Level 1B data files.

6.2 Accelerometer Data Format Record (ACC1B)

Parameter	Definition	Data Type	Byte Length	Units
gps_time	GPS time, seconds past 12:00:00, noon 01-Jan-2000	Integer	4	s
GRACE_id	GRACE satellite identifier	Character	1	N/A
lin_accl_x	Linear acceleration along x-axis	Double Precision	8	m/s^2
lin_accl_y	Linear acceleration along y-axis	Double Precision	8	m/s^2
lin_accl_z	Linear acceleration along z-axis	Double Precision	8	m/s^2
ang_accl_x	Angular acceleration about x-axis	Double Precision	8	rad/s^2
ang_accl_y	Angular acceleration about y-axis	Double Precision	8	rad/s^2
ang_accl_z	Angular acceleration about z-axis	Double Precision	8	rad/s^2
acl_x_res	Linear acceleration along x-axis residual with fit	Double Precision	8	m/s^2
acl_y_res	Linear acceleration along y-axis residual with fit	Double Precision	8	m/s^2
acl_z_res	Linear acceleration along z-axis residual with fit	Double Precision	8	m/s^2
Qualflg	Data quality flag (LSB = bit 0) bit 0 = Proof mass voltage out of nominal range bit 1 = Not Defined bit 2 = if any linear ACC component has fit residual > 10 $microns/s^2$ bit 3 = extrapolated clock correction >5s but < 15s from fit center bit 4 = extrapolated clock correction < 5s from fit center bit 5 = filled data > 15s from fit center bit 6 = filled data > 5s but < 15s from fit center bit 7 = filled data < 5s from fit center	Unsigned Character	1	N/A

6.3 Clock Data Format Record (CLK1B)

Parameter	Definition	Data Type	Byte Length	Units
rcv_time	Receiver time, seconds past 12:00:00, noon 01-Jan-2000	Integer	4	s
GRACE_id	GRACE satellite identifier	Character	1	N/A
clock_id	Clock identifier	Byte	1	N/A
eps_time	Level 1B clock offset where GPS time = time_rcv + eps_time	Double Precision	8	s
eps_err	Formal error on eps_time	Double Precision	8	s
eps_drift	Clock drift	Double Precision	8	s/s
drift_err	Formal error on eps_drift	Double Precision	8	s/s
qualflg	Data quality flag (LSB = bit 0) bit 0 = 1 > linear extrapolation not valid after rcv_time bit 1 = 1 > linear extrapolation not valid before rcv_time bit 2 = overlap data missing before start midnight bit 3 = overlap data missing after start midnight bit 4 = overlap data missing before end midnight bit 5 = overlap data missing after end midnight bit 6 = Not Defined bit 7 = Not Defined	Unsigned Character	1	N/A

6.4 GPS Flight Data Format Record (GPS1B)

Parameter	Definition	Data Type	Byte Length	Units
rcvtime_intg	Receiver time, seconds past 12:00:00, noon 01-Jan-2000	Integer	4	s
rcvtime_frac	Receiver time, microseconds part	Integer	4	microseconds
GRACE_id	GRACE satellite identifier	Character	1	N/A
prn_id	GPS spacecraft PRN number or GRACE id number	Byte	1	N/A
ant_id	GPS or KBR antenna id on GRACE spacecraft ant_id = 1 GPS navigation antenna ant_id = 2 GPS occultation antenna ant_id = 3 KBR antenna	Byte	1	N/A

prod_flag	Product flag (LSB = bit 0) Bitmask set to indicate presence of data type according to the following: bit 0 = C/A pseudo range bit 1 = L1 pseudo range bit 2 = L2 pseudo range bit 3 = C/A carrier phase bit 4 = L1 carrier phase bit 5 = L2 carrier phase bit 6 = SNR C/A channel bit 7 = SNR L1 channel bit 8 = SNR L2 channel bit 9 = C/A receiver channel bit 10 = L1 receiver channel bit 11 = L2 receiver channel bit 12 = Not used for GPS1B bit 13 = Not used for GPS1B bit 14 = Not used for GPS1B bit 15 = Not used for GPS1B	Unsigned Integer	2	N/A
qualflg	Data quality flag (LSB = bit 0) bit 0 = phase break occurred in L1/K/CA bit 1 = phase break occurred in L2/Ka bit 2 = cycle slip detected in L1/K/CA bit 3 = cycle slip detected in L2/Ka bit 4 = Not defined bit 5 = Not defined bit 6 = Not defined bit 7 = Not defined	Unsigned Character	1	N/A
CA_range	C/A pseudo range	Double Precision	8	m
L1_range	L1 pseudo range	Double Precision	8	m
L2_range	L2 pseudo range	Double Precision	8	m
CA_phase	C/A carrier phase	Double Precision	8	m
L1_phase	L1 carrier phase	Double Precision	8	m
L2_phase	L2 ion-smoothed carrier phase	Double Precision	8	m
CA_SNR	SNR C/A channel (units + integration time)	Unsigned Integer	2	V/V
L1_SNR	SNR L1 channel	Unsigned Integer	2	V/V
L2_SNR	SNR L2 channel	Unsigned Integer	2	V/V
CA_chan	C/A receiver channel	Unsigned Integer	2	V/V
L1_chan	L1 receiver channel	Unsigned Integer	2	V/V

L2_chan	L2 receiver channel	Unsigned Integer	2	V/V

6.5 GPS Navigation Data Format Record (GNV1B)

Parameter	Definition	Data Type	Byte Length	Units
gps_time	GPS time, seconds past 12:00:00, noon 01-Jan-2000	Integer	4	s
GRACE_id	GRACE satellite identifier	Character	1	N/A
coord_ref	Coordinate reference frame where E = Earth-fixed 'I' = Inertial	Character	1	N/A
xpos	Position, x value (ITRF)	Double Precision	8	m
ypos	Position, y value (ITRF)	Double Precision	8	m
zpos	Position, z value (ITRF)	Double Precision	8	m
xpos_err	Formal error on x position	Double Precision	8	m
ypos_err;	Formal error on y position	Double Precision	8	m
zpos_err	Formal error on z position	Double Precision	8	m
xvel	Velocity along x-axis (ITRF)	Double Precision	8	m/s
yvel	Velocity along y-axis (ITRF)	Double Precision	8	m/s
zvel	Velocity along z-axis (ITRF)	Double Precision	8	m/s
xvel_err	Formal error in velocity along x-axis	Double Precision	8	m/s
yvel_err	Formal error in velocity along y-axis	Double Precision	8	m/s
zvel_err	Formal error in velocity along z-axis	Double Precision	8	m/s
qualflg	Data quality flag (LSB = bit 0) bit 0 = Not Defined bit 1 = Not Defined bit 2 = overlap data missing before start midnight bit 3 = overlap data missing after start midnight bit 4 = overlap data missing before end midnight bit 5 = overlap data missing after end midnight bit 6 = Not Defined bit 7 = Not Defined	Unsigned Character	1	N/A

6.6 IPU Housekeeping Data Format Record (IHK1B)

Parameter	Definition	Data Type	Byte Length	Units
time_intg	Measurement time, integer seconds past 12:00:00, noon 01-Jan-2000	Integer	4	s
time_frac	Measurement time, microseconds part	Integer	4	microseconds
time_ref	Time reference frame where R = Receiver time G = GSP time	Character	1	N/A
GRACE_id	GRACE satellite identifier	Character	1	N/A
qualflg	Data quality flag (LSB = bit 0) bit 0 = Not Defined bit 1 = Not Defined bit 2 = Not Defined bit 3 = Not Defined bit 4 = Not Defined bit 5 = Not Defined bit 6 = Not Defined bit 7 = Not Defined	Unsigned Character	1	N/A
sensortype	Observation type V = Voltage in Volts T = Temperature in Deg C A = Current in Amperes	Character	1	N/A
sensorvalue	Value of observation	Double Precision	8	
sensorname[MAXSENSORNAME]	Null terminated sensor name	Character	1	N/A

6.7 KBR Data Format Record (KBR1B)

Parameter	Definition	Data Type	Byte Length	Units
gps_time	GPS time, seconds past 12:00:00, noon 01-Jan-2000	Integer	4	s
biased_range	Biased range between GRACE A and B digitally filtered but uncorrected except for the ionosphere to correct for the light time, and the antenna offsets use: biased_range + lighttime_corr +ant_centr_corr meters	Double Precision	8	m
range_rate	Range rate between GRACE A and B	Double Precision	8	m/s

range_accl	Range acceleration between GRACE A and B	Double Precision	8	m/s^2
iono_corr	Ionospheric range correction between GRACE A and B for Ka frequencies	Double Precision	8	m
lighttime_corr	light time range correction between GRACE A and B	Double Precision	8	m
lighttime_rate	light time range rate correction between GRACE A and B	Double Precision	8	m/s
lighttime_accl	light time range acceleration correction between GRACE A and B	Double Precision	8	m/s^2
ant_centr_corr	Antenna phase center range correction	Double Precision	8	m
ant_centr_rate	Antenna phase center range rate correction	Double Precision	8	m/s
ant_centr_accl	Antenna phase center range acceleration correction	Double Precision	8	m/s^2
K_A_SNR	SNR K band for GRACE A	Unsigned Integer	2	0.1 db-Hz
Ka_A_SNR	SNR Ka band for GRACE A	Unsigned Integer	2	0.1 db-Hz
K_B_SNR	SNR K band for GRACE B	Unsigned Integer	2	0.1 db-Hz
Ka_B_SNR	SNR Ka band for GRACE B	Unsigned Integer	2	0.1 db-Hz
qualflg	Data quality flag (LSB = bit 0) bit 0 = phase break bit 1 = extrapolated states for lighttime_corr bit 2 = model eci attitudes for ant_centr_corr bit 3 = extrapolated clock correction > 5s from fit center bit 4 = extrapolated clock correction < 5s from fit center bit 5 = data corrected for timetag bias of either K or Ka phase bit 6 = filled data > 5s from fit center bit 7 = filled data < 5s from fit center	Unsigned Character	1	N/A

6.8 Magnetometer and Magnettorquer Data Format Record (MAG1B)

Parameter	Definition	Data Type	Byte Length	Units
time_intg	Activation time, integer seconds past 12:00:00, noon 01-Jan-2000	Integer	4	s
time_frac	Activation time, microseconds part	Integer	4	

time_ref	Time reference frame where R = Receiver time G = GSP time	Character	1	N/A
GRACE_id	GRACE satellite identifier	Character	1	N/A
MfvX_RAW	x-axis (SF) component of measured earth magnetic field	Real	4	microT
MfvY_RAW	y-axis (SF) component of measured earth magnetic field	Real	4	microT
MfvZ_RAW	z-axis(SF) component of measured earth magnetic field	Real	4	microT
torque1A	Current of magnettorquer 1 A (positive current x)	Real	4	mA
torque2A	Current of magnettorquer 2 A (positive current y)	Real	4	mA
torque3A	Current of magnettorquer 3 A (positive current z)	Real	4	mA
torque1B	Current of magnettorquer 1 B (positive current x)	Real	4	mA
torque2B	Current of magnettorquer 2 B (positive current y)	Real	4	mA
torque3B	Current of magnettorquer 3 B (positive current z)	Real	4	mA
MF_BCalX	Magnetic field calibration factor for X	Real	4	
MF_BCalY	Magnetic field calibration factor for Y	Real	4	
MF_BCalZ	Magnetic field calibration factor for Z	Real	4	
torque_cal	Magnetic torquer calibration factor	Real	4	
qualflg	Data quality flag (LSB = bit 0) bit 0 = 0 > GPS Receiver Time bit 0 =1 > Space Craft Elapsed Time bit 1 = 0 > Pulse Sync = 1 > no Pulse Sync bit 2 = Not Defined bit 3 = Not Defined bit 4 = Not Defined bit 5 = Not Defined bit 6 = Not Defined bit 7 = Not Defined	Unsigned Character	1	N/A

6.9 Spacecraft Mass Data Format Record (MAS1B)

Parameter	Definition	Data Type	Byte Length	Units

time_intg	Measurement time, integer seconds past 12:00:00, noon 01-Jan-2000	Integer	4	s
time_frac	Measurement time, microseconds part	Integer	4	microseconds
time_ref	Time reference frame where R = Receiver time G = GSP time	Character	1	N/A
GRACE_id	GRACE satellite identifier	Character	1	N/A
qualflg	Data quality flag (LSB = bit 0) bit 0 = Not Defined bit 1 = Not Defined bit 2 = Not Defined bit 3 = Not Defined bit 4 = Not Defined bit 5 = Not Defined bit 6 = Not Defined bit 7 = Not Defined	Unsigned Character	1	N/A
prod_flag	Product flag (LSB = bit 0) Bitmask set to indicate presence of data type according to the following: bit 0 = SC Mass from thruster usage bit 1 = SC Mass error bit 0 bit 2 = SC Mass from tank observations bit 3 = SC Mass error bit 2 bit 4 = gas mass tank 1 (thr. usage) bit 5 = gas mass tank 2 (thr. usage) bit 6 = gas mass tank 1 (tank obs) bit 7 = gas mass tank 2 (tank obs)	Character	1	N/A
mass_thr	Spacecraft mass based on thruster usage	Double Precision	8	kg
mass_thr_err	Spacecraft mass error from thruster usage	Double Precision	8	kg
mass_tnk	Spacecraft mass from tank observations	Double Precision	8	kg
mass_tnk_err	Spacecraft mass error from tank observations	Double Precision	8	kg
gas_mass_thr1	Mass of gas in tank 1 based on thruster usage	Double Precision	8	kg
gas_mass_thr2	Mass of gas in tank 2 based on thruster usage	Double Precision	8	kg
gas_mass_tnk1	Mass of gas in tank 1 based on tank observations	Double Precision	8	kg
gas_mass_tnk2	Mass of gas in tank 2 based on tank observations	Double Precision	8	kg

6.10 Star Camera Assembly Data Format Record (SCA1B)

Parameter	Definition	Data Type	Byte Length	Units
gps_time	GPS time, seconds past 12:00:00, noon 01-Jan-2000	Integer	4	s
GRACE_id	GRACE satellite identifier	Character	1	N/A
sca_id	SCA identification number: 1 = Star camera number 1 2 = Star camera number 2 3 = IMU 4 = Combination of 1 + 2	Byte	1	N/A
quatangle	Cos mu/2 element of quaternion	Double Precision	8	N/A
quaticoeff	I element of quaternion rotation axis	Double Precision	8	N/A
quatjcoeff	J element of quaternion rotation axis	Double Precision	8	N/A
quatkcoeff	K element of quaternion rotation axis	Double Precision	8	N/A
qual_rss	rss of formal error of quaternions	Double Precision	8	N/A
qualflg	Data quality flag (LSB = bit 0) bit 0 = filled data at T bit 1 = filled data at T ± 1 sec bit 2 = filled data at T ± 2 sec bit 3 = data from 1 star camera only bit 4 = extrapolated clock correction bit 5 = Not Defined bit 6 = low rate data from 2nd SCA bit 7 = low rate data from 1st SCA	Unsigned Character	1	N/A

6.11 Thrusters Data Format Record (THR1B)

Parameter	Definition	Data Type	Byte Length	Units
time_intg	Activation time, integer seconds past 12:00:00, noon 01-Jan-2000	Integer	4	s
time_frac	Activation time, microseconds part	Integer	4	microseconds
time_ref	Time reference frame where R = Receiver time G = GSP time	Character	1	N/A

GRACE_id	GRACE satellite identifier	Character	1	N/A
thrust_count[MAXTHRSTRS]	Count of number of work cycles that each thruster has been activated (integer will wrap after 4294967295)	Unsigned Integer	4	
on_time[MAXTHRSTRS]	Thruster on time for this time epoch	Unsigned Integer	4	millisec
accum_dur[MAXTHRSTRS]	Accumulated thruster firing duration time (integer will wrap after 4294967295)	Unsigned Integer	4	millisec
qualflg	Data quality flag (LSB = bit 0) bit 0 = 1 On time not calculated bit 1 = 1 Multiple unaccounted thrusts prior to current record bit 2 = Not Defined bit 3 = Not Defined bit 4 = Not Defined bit 5 = Not Defined bit 6 = No OBDH->Receiver time mapping bit 7 = No Clock correction available	Unsigned Character	1	N/A

6.12 Mapping of OBDH Time to Receiver time (TIM1B)

Parameter	Definition	Data Type	Byte Length	Units
obdh_time	OBDH time, can be the following: 1) Receiver time seconds past 12:00:00 noon 01-Jan-2000 2) Pseudo receiver offset time due to sync 4) Space Craft elapsed time	Integer	4	s
GRACE_id	GRACE satellite identifier	Character	1	N/A
TS_suppid	OBDH timestamp supplementary ID value bits description: 0 = [00000000] = SCET 1 = [00000001] = GPS time 2 = [00000000] = SCET + Pulse Sync 3 = [00000011] = GPS time + Pulse Sync 7 = [00000111] =GPS time + Pulse Sync + plus IPU time pkt received	Integer	4	N/A
gpstime_intg	Measurement time, integer seconds past 12:00:00 noon 01-01-2000	Integer	4	s
gpstime_frac	Measurement time, microseconds part	Integer	4	microseconds
first_icu_blknr	First ICU block number for Timestamp -1 indicates no ACC data available	Integer	4	N/A

final_icu_blknr	Final ICU block number for Timestamp -1 indicates no ACC data available	Integer	4	N/A
qualflg	Data quality flag (LSB = bit 0) bit 0 = Delta OBDH time != 1 sec bit 1 = Multiple ICU blocks bit 2 = Sync process started bit 3 = GPS time mapping not defined bit 4 = Missed Antenna state packet bit 5 = gdel flag set in one or more ICU data blocks bit 6 = Unable to compute GPS mapping bit 7 = Not Defined	Unsigned Character	1	N/A

6.13 Cold Gas Tank Data Format Record (TNK1B)

Parameter	Definition	Data Type	Byte Length	Units
time_intg	Activation time, integer seconds past 12:00:00, noon 01-Jan-2000	Integer	4	s
time_frac	Activation time, microseconds part	Integer	4	microseconds
time_ref	Time reference frame where R = Receiver time G = GSP time	Character	1	N/A
GRACE_id	GRACE satellite identifier	Character	1	N/A
tank_id	Cold gas tank id: Tank 1 on -x axis Tank 2 on +x axis	Character	1	N/A
qualflg	Data quality flag (LSB = bit 0) bit 0 = 0 > GPS Receiver Time bit 0 =1 > Space Craft Elapsed Time bit 1 = 0 > Pulse Sync = 1 > no Pulse Sync bit 2 = Not Defined bit 3 = Not Defined bit 4 = Not Defined bit 5 = Not Defined bit 6 = Not Defined bit 7 = Not Defined	Unsigned Character	1	N/A
prod_flag	Product flag (LSB = bit 0) Bitmask set to indicate presence of data type according to the following: bit 0 = Tank pressure bit 1 = Regulator pressure bit 2 = Tank Skin temp (nominal) bit 3 = Tank Skin temp (redundant)	Character	1	N/A

	bit 4 = Tank adaptor temp bit 5 = Not Defined bit 6 = Not Defined bit 7 = Not Defined			
tank_pres	Cold tank internal pressure	Real	4	bar
reg_pres	Pressure at the reference point on the pressure regulator housing	Real	4	bar
skin_temp	Skin temperature of cold tank	Real	4	Deg C
skin_temp_r	Skin temperature of cold tank (redundant)	Real	4	Deg C
adap_temp	tank adaptor temperature	Real	4	Deg C

6.14 Ultra Stable Oscillator Frequency Data Format Record (USO1B)

Parameter	Definition	Data Type	Byte Length	Units
gps_time	GPS time, seconds past 12:00:00, noon 01-Jan-2000	Integer	4	s
GRACE_id	GRACE satellite identifier	Character	1	N/A
uso_id	USO satellite identifier	Character	1	N/A
uso_freq	Frequency of USO	Double Precision	8	Hz
K_freq	K band frequency of KBR	Double Precision	8	Hz
Ka_freq	Ka band frequency of KBR	Double Precision	8	Hz
qualflg	Data quality flag (LSB = bit 0) bit 0 = 1 -> linear extrapolation not valid AFTER rcv_time bit 1 = 1 -> linear extrapolation not valid BEFORE rcv_time bit 2 = Not Defined bit 3 = Not Defined bit 4 = Not Defined bit 5 = Not Defined bit 6 = Not Defined bit 7 = Not Defined	Unsigned Character	1	N/A

6.15 Vector Orientation Data Format Record (VGN1B,

VGO1B, VGB1B, VCM1B, VKB1B, VSL1B)

Parameter	Definition	Data Type	Byte Length	Units
gps_time	GPS time, seconds past 12:00:00, noon 01-Jan-2000	Integer	4	s
GRACE_id	GRACE satellite identifier	Character	1	N/A
mag	Magnitude of vector	Double Precision	8	m
cosx	Direction cosine of vector with satellite x-axis	Double Precision	8	
cosy	Direction cosine of vector with satellite y-axis	Double Precision	8	
cosz	Direction cosine of vector with satellite z-axis	Double Precision	8	
qualflg	Data quality flag (LSB = bit 0) bit 0 = L1 phase center offset vector bit 1 = L2 phase center offset vector bit 2 = Not Defined bit 3 = Not Defined bit 4 = Not Defined bit 5 = Not Defined bit 6 = Not Defined bit 7 = Not Defined	Unsigned Character	1	N/A

Appendix A ACRONYMS

ACC	SuperSTAR Accelerometer
AF	Accelerometer Frame
AOD1B	Atmosphere and Ocean De-aliasing level-1B product
CHAMP	Challenging Minisatellite Payload
DLR	Deutsches Zentrum für Luft- und Raumfahrt
ECI	Earth Centered Inertial
GFZ	GeoForschungsZentrum
GHz	gigahertz
GPS	Global Positioning System
GRACE	Gravity Recovery And Climate Experiment
GSOC	German Space Operations Center
ISDC	Information System and Data Center
ITRF	International Terrestrial Reference Frame
JPL	Jet Propulsion Laboratory
KBR	K-Band Ranging Assembly
LRR	Laser Retro Reflector
NASA	National Aeronautics and Space Administration
OCN1B	Ocean level-1B product
PO.DAAC	Physical Oceanography Distributed Active Archive Center
RDC	Raw Data Center at DLR
RINEX	Receiver Independent Exchange Format
SDS	Science Data System
SF	Satellite Frame
SOE	Sequence of Events file
SRF	Science Reference Frame
USO	Ultra-Stable Oscillator
UTC	Coordinated Universal Time
UTCSR	University of Texas at Austin, Center for Space Research

Appendix B REPORT FILES

Appendix B describes the format of the report files for all GRACE Level 1B data.

Report files are organized into separate files for each of the Level 1A and Level 1B data products. Data entries are white-space delimited.

Level 1B Parameters 1-10*

Parameter Number	Definition	Units	Minimum Value	Maximum Value
01	FileName			
02	FileTtag			
03	ProcessTtag	sec in GPS time		
04	FirstDataPointTtag	sec in GPS time		
05	LastDataPointTtag	sec in GPS time		
06	Nrecs (number of data records)		1	
07	TimeGapAvg (average data gap)	sec		
08	TimeGapVar (variance data gap)	sec		
09	TimeGapMin (minimum time gap)	sec	0	
10	TimeGapMax (maximum time gap)	sec		

*Note: The first ten parameters are the same for every report file.

ACC1B : Level 1B Accelerometer data

Parameter Number	Definition	Units	Minimum Value	Maximum Value
11	NQualBits value=8			
12	BitCount0 : Vp out of nominal range			
13	BitCount1			
14	BitCount2 : any linear ACC component has fit residual > 10 microns/s^2			
15	BitCount3 : extrapolated clock correction >5s but < 15s from fit center			
16	BitCount4 : extrapolated clock correction < 5s from fit center			
17	BitCount5 : filled data > 15s from fit center			
18	BitCount6 : filled data > 5s but < 15s from fit center			
19	BitCount7: filled data < 5s from fit center			

20	Nr_nodatagapfill : number of data gaps not filled			
21	CRMS_lin_accl_x : compression rms	m/sec^2		
22	CRMS_lin_accl_y : compression rms	m/sec^2		
23	CRMS_lin_accl_z : compression rms	m/sec^2		
24	CRMS_ang_accl_x :compression rms	rad/sec^2		
25	CRMS_ang_accl_y :compression rms	rad/sec^2		
26	CRMS_ang_accl_z :compression rms	rad/sec^2		
27	rel_bias_x : relative bias in x-direction	nm/sec^2		
28	rel_bias_y : relative bias in y-direction	nm/sec^2		
29	rel_bias_z : relative bias in z-direction	nm/sec^2		
30	rel_scale_x : relative scale in x-direction			
31	rel_scale_y : relative scale in y-direction			
32	rel_scale_z :r elative scale in z-direction			
33	rel_res_x : relative res in x-direction	nm/sec^2		
34	rel_res_y : relative res in y-direction	nm/sec^2		
35	rel_res_z : relative res in z-direction	nm/sec^2		

AHK1B : Level 1B Accelerometer Housekeeping data

Parameter Number	Definition	Units	Minimum Value	Maximum Value
11	NQualBits value=8			
12	BitCount0 : 0 -> GPS Receiver Time; 1 -> Space Craft Elapsed Time			
13	BitCount1 : 0 -> Pulse Sync; 1 -> no Pulse Sync			
14	BitCount2 : ICU board (0 = nominal, 1 = redundant)			
15	BitCount3 : Invalid ACC (GDEL) timing			
16	BitCount4 : ACC Mode (0 = Normal Range Mode; 1 = Low Range Mode)			
17	BitCount5			
18	BitCount6 : No OBDH->Receiver time mapping			
19	BitCount7 : No Clock correction available			

TIM1B : Level 1B OBDH time mapping to GPS time

Parameter Number	Definition	Units	Minimum Value	Maximum Value
11	NQualBits value=8			

12	BitCount0 : Delta OBDH time != 1 sec			
13	BitCount1 : Multiple icu blocks			
14	BitCount2 : Sync process started			
15	BitCount3 : GPS time mapping not defined			
16	BitCount4 : Missed Antenna state packet			
17	BitCount5 : gdel flag set in one or more ICU data blocks			
18	BitCount6 : Unable to compute GPS mapping			
19	BitCount7			

IHK1B : Level 1B IPU Housekeeping data

Parameter Number	Definition	Units	Minimum Value	Maximum Value
11	NQualBits value=8			
12	BitCount0			
13	BitCount1			
14	BitCount2			
15	BitCount3			
16	BitCount4			
17	BitCount5			
18	BitCount6 : No OBDH->Receiver time mapping			
19	BitCount7 : No Clock correction available			

CLK1B : Level 1B Satellite Clock solution (from OD software + CLK1A)

Parameter Number	Definition	Units	Minimum Value	Maximum Value
11	NQualBits value=8			
12	BitCount0 : linear extrapolation not valid AFTER rcv_time			
13	BitCount1 : linear extrapolation not valid BEFORE rcv_time			
14	BitCount2 : overlap data missing before start midnight			
15	BitCount3 : overlap data missing after start midnight			
16	BitCount4 : overlap data missing before end midnight			
17	BitCount5 : overlap data missing after end midnight			
18	BitCount6			

19	BitCount7			
20	overlap_bias_start : Time offset at start midnight from linear fit	nano-sec		
21	overlap_bias_sigma_start : Sigma Time offset at start midnight	nano-sec		
22	overlap_slope_start : Relative drift at start midnight from linear fit	nano-sec/sec		
23	overlap_slope_sigma_start : Sigma Relative drift at start midnight	nano-sec/sec		
24	overlap_rms_zero_start : raw RMS of overlap clock difference at start midnight	nano-sec		
25	overlap_rms_fit_start : linear fit RMS of overlap clock diff. at start midnight	nano-sec		
26	overlap_npoints_start : number of data points used in clock overlap at start midnight			
27	overlap_bias_end : Time offset at end midnight from linear fit	nano-sec		
28	overlap_bias_sigma_end : Sigma Time offset at end midnight	nano-sec		
29	overlap_slope_end : Relative drift at end midnight from linear fit	nano-sec/sec		
30	overlap_slope_sigma_end : Sigma Relative drift at end midnight	nano-sec/sec		
31	overlap_rms_zero_end : raw RMS of overlap clock difference at end midnight	nano-sec		
32	overlap_rms_fit_end : linear fit RMS of overlap clock diff. at end midnight	nano-sec		
33	overlap_npoints_end : number of data points used in clock overlap at end midnight			
34	nobs_formal_edit : number of tdp solutions edit based on formal error in tdp file			

GNV1B : Level 1B navigation solution (from OD software)

Parameter Number	Definition	Units	Minimum Value	Maximum Value
11	NQualBits value=8			
12	BitCount0			
13	BitCount1			
14	BitCount2 : overlap data missing before start midnight			
15	BitCount3 : overlap data missing after start midnight			
16	BitCount4 : overlap data missing before end midnight			
17	BitCount5 : overlap data missing after end midnight			
18	BitCount6			
19	BitCount7 : formal errors are not available and set to 0.0			
20	npoints_start : number of overlap point at midnight start			

21	hpos_rms_start : H position overlap RMS for midnight start	m		
22	cpos_rms_start : C position overlap RMS for midnight start	m		
23	lpos_rms_start : L position overlap RMS for midnight start	m		
24	hvel_rms_start : H velocity overlap RMS for midnight start	m/sec		
25	cvel_rms_start : C velocity overlap RMS for midnight start	m/sec		
26	lvel_rms_start : L velocity overlap RMS for midnight start	m/sec		
27	npoints_end : number of overlap point at midnight end			
28	hpos_rms_end : H position overlap RMS for midnight end	m		
29	cpos_rms_end : C position overlap RMS for midnight end	m		
30	lpos_rms_end : L position overlap RMS for midnight end	m		
31	hvel_rms_end : H velocity overlap RMS for midnight end	m/sec		
32	cvel_rms_end : C velocity overlap RMS for midnight end	m/sec		
33	lvel_rms_end : L velocity overlap RMS for midnight end	m/sec		

GPS1B : Level 1B GPS flight data

Parameter Number	Definition	Units	Minimum Value	Maximum Value
11	NQualBits value=8			
12	BitCount0 : phase break occurred in L1/K/CA			
13	BitCount1 : phase break occurred in L2/Ka			
14	BitCount2 : cycle slip detected in L1/K/CA			
15	BitCount3 : cycle slip detected in L2/Ka			
16	BitCount4 : L1 SNR < 5			
17	BitCount5 : L2 SNR < 5			
18	BitCount6			
19	BitCount7			
20	crms_CA : compression rms for CA phase	m		
21	CA_nobs : number of CA phase points			
22	crms_L1 : compression rms for L1 phase	m		
23	L1_nobs : number of L1 phase points			

24	crms_L2 : compression rms for L2 phase	m		
25	L2_nobs : number of L2 phase points			

KBR1B : Level 1B KBR ranging data

Parameter Number	Definition	Units	Minimum Value	Maximum Value
11	NQualBits value=8			
12	BitCount0 : phase break			
13	BitCount1 : extrapolated states for lighttime_corr			
14	BitCount2 : extrapolated attitudes for ant_centr_corr			
15	BitCount3 : extrapolated clock correction > 5s from fit center			
16	BitCount4 : extrapolated clock correction < 5s from fit center			
17	BitCount5 : data corrected for timetag bias of either K or Ka phase			
18	BitCount6 : filled data > 5s from fit center			
19	BitCount7 : filled data < 5s from fit center			
20	crms_dowr : compression rms for dual-1way range	m		
21	crms_ion : compression rms for biased Ka-band ion correction			
22	arc_length : total arc length of valid dowr data			
23	resid_nobs : number of obs in KBR-GPS range residuals			
24	resid_rms : RMS of KBR-GPS range residuals	cm		
25	resid_min : minimun KBR-GPS range residual	cm		
26	resid_max : maximum KBR-GPS range residual	cm		
27	number_of_arcs : Number of continous data arcs			
28	clkdd_nobs : number of clk dd obs			
29	clkdd_mean : mean of clk dd obs	picosec		
30	clkdd_sigma : sigma of clk dd obs	picosec		
31	clkdd_min : minimum of clk dd obs	picosec		
32	clkdd_max : maximum of clk dd obs	picosec		
33	clkdd_rms : rms of clk dd obs	picosec		

MAG1B : Level 1B Magnetic Torque Rod Activation + Magnetometer data

Parameter Number	Definition	Units	Minimum Value	Maximum Value

11	NQualBits value=8			
12	BitCount0 : 0 -> GPS Receiver Time; 1 -> Space Craft Elapsed Time			
13	BitCount1 : 0 -> Pulse Sync; 1 -> no Pulse Sync			
14	BitCount2			
15	BitCount3			
16	BitCount4			
17	BitCount5			
18	BitCount6 : No OBDH->Receiver time mapping			
19	BitCount7 : No Clock correction available			

USO1B : Oscillator frequency data (derived from OD software output)

Parameter Number	Definition	Units	Minimum Value	Maximum Value
11	NQualBits value=8			
12	BitCount0 : linear extrapolation not valid AFTER rcv_time			
13	BitCount1 : linear extrapolation not valid BEFORE rcv_time			
14	BitCount2			
15	BitCount3			
16	BitCount4			
17	BitCount5			
18	BitCount6			
19	BitCount7			

SCA1B : Level 1B star camera data (compressed/combined SCA data)

Parameter Number	Definition	Units	Minimum Value	Maximum Value
11	NQualBits value=8			
12	BitCount0 : filled data at T			
13	BitCount1 : filled data at T $\pm$ 1 sec			
14	BitCount2 : filled data at T $\pm$ 2 sec			
15	BitCount3 : data from 1 star camera only			
16	BitCount4 : extrapolated clock correction			
17	BitCount5			

18	BitCount6 : low rate data from 2nd SCA			
19	BitCount7 : low rate data from 1st SCA			
20	crms_q0_prim : compression rms for q0 for primary SCA			
21	crms_q1_prim : compression rms for q1 for primary SCA			
22	crms_q2_prim : compression rms for q2 for primary SCA			
23	crms_q3_prim : compression rms for q3 for primary SCA			
24	crms_q0_sec : compression rms for q0 for secondary SCA			
25	crms_q1_sec : compression rms for q1 for secondary SCA			
26	crms_q2_sec : compression rms for q2 for secondary SCA			
27	crms_q3_sec : compression rms for q3 for secondary SCA			
28	mean_yaw_prim : mean yaw angle (deg) when eci (primary)	deg		
29	rms_yaw_prim : RMS yaw angle (deg) when eci (primary)	deg		
30	badn_yaw_prim : bad data points yaw angle if eci			
31	mean_pitch_prim : mean pitch angle when eci (primary)	deg		
32	rms_pitch_prim : RMS pitch angle when eci (primary)	deg		
33	badn_pitch_prim: bad data points pitch angle if eci			
34	mean_roll_prim : mean roll angle when eci (primary)	deg		
35	rms_roll_prim : RMS roll angle when eci (primary)	deg		
36	badn_roll_prim : bad data points roll angle if eci			
37	mean_yaw_sec : mean yaw angle when eci (secondary)	deg		
38	rms_yaw_sec : RMS yaw angle when eci (secondary)	deg		
39	badn_yaw_sec : bad data points yaw angle if eci			
40	mean_pitch_sec : mean pitch angle when eci (secondary)	deg		
41	rms_pitch_sec : RMS pitch angle when eci (secondary)	deg		
42	badn_pitch_sec: bad data points pitch angle if eci			
43	mean_roll_sec : mean roll angle when eci (secondary)	deg		
44	rms_roll_sec : RMS roll angle when eci (secondary)	deg		
45	badn_roll_sec : bad data points roll angle if eci			
46	nr_offset : number of offset used in statistics			

47	q2_avg_dif : daily average x-component of diff quat			
48	q3_avg_dif : daily average y-component of diff quat			
49	q4_avg_dif : daily average z-component of diff quat			
50	q2_stdev_dif : daily stddev x-component of diff quat			
51	q3_stdev_dif : daily stddev y-component of diff quat			
52	q4_stdev_dif : daily stddev z-component of diff quat			

TNK1B : Level 1B Gas tank sensor + auxiliary data for COM management

Parameter Number	Definition	Units	Minimum Value	Maximum Value
11	NQualBits value=8			
12	BitCount0 : 0 -> GPS Receiver Time; 1 -> Space Craft Elapsed Time			
13	BitCount1 : 0 -> Pulse Sync; 1 -> no Pulse Sync			
14	BitCount2			
15	BitCount3			
16	BitCount4			
17	BitCount5			
18	BitCount6 : No OBDH->Receiver time mapping			
19	BitCount7 : No Clock correction available			

THR1B : Level 1B thruster activation data

Parameter Number	Definition	Units	Minimum Value	Maximum Value
11	NQualBits value=8			
12	BitCount0 : On time not calculated			
13	BitCount1 : Multiple unaccounted thrusts prior to current record			
14	BitCount2			
15	BitCount3			
16	BitCount4			
17	BitCount5			
18	BitCount6 : No OBDH->Receiver time mapping			
19	BitCount7 : No Clock correction available			

MAS1B : Level 1B Spacecraft Mass as a function of time

Parameter Number	Definition	Units	Minimum Value	Maximum Value
11	NQualBits value=8			
12	BitCount0			
13	BitCount1			
14	BitCount2			
15	BitCount3			
16	BitCount4			
17	BitCount5			
18	BitCount6 : No OBDH->Receiver time mapping			
19	BitCount7 : No Clock correction available			

QKS1B : Rotation from Star Camera Frames into K-Band Frame

Parameter Number	Definition	Units	Minimum Value	Maximum Value
11	NQualBits value=8			
12	BitCount0			
13	BitCount1			
14	BitCount2			
15	BitCount3			
16	BitCount4			
17	BitCount5			
18	BitCount6			
19	BitCount7			

QSB1B : Rotation from Satellite Body frame into SRF

Parameter Number	Definition	Units	Minimum Value	Maximum Value
11	NQualBits value=8			
12	BitCount0			
13	BitCount1			
14	BitCount2			
15	BitCount3			
16	BitCount4			
17	BitCount5			

18	BitCount6			
19	BitCount7			

QSA1B : Rotation From Star Camera Frames into SRF

Parameter Number	Definition	Units	Minimum Value	Maximum Value
11	NQualBits value=8			
12	BitCount0			
13	BitCount1			
14	BitCount2			
15	BitCount3			
16	BitCount4			
17	BitCount5			
18	BitCount6			
19	BitCount7			

VCM1B : Vector offset file for Center of Mass solution from calibration maneuvers or tracking model in SRF

Parameter Number	Definition	Units	Minimum Value	Maximum Value
11	NQualBits value=8			
12	BitCount0			
13	BitCount1			
14	BitCount2			
15	BitCount3			
16	BitCount4			
17	BitCount5			
18	BitCount6			
19	BitCount7			

VKB1B : Vector offset for KBR phase centers in SRF

Parameter Number	Definition	Units	Minimum Value	Maximum Value
11	NQualBits value=8			
12	BitCount0			
13	BitCount1			

14	BitCount2				
15	BitCount3				
16	BitCount4				
17	BitCount5				
18	BitCount6				
19	BitCount7				

VSL1B : Vector offset file for SLR Corner cube reflector offset in SRF

Parameter Number	Definition	Units	Minimum Value	Maximum Value
11	NQualBits value=8			
12	BitCount0 : L1 phase center offset vector			
13	BitCount1 : L2 phase center offset vector			
14	BitCount2			
15	BitCount3			
16	BitCount4			
17	BitCount5			
18	BitCount6			
19	BitCount7			

VGO1B : Vector offset file for GPS Occultation Antenna in SRF

Parameter Number	Definition	Units	Minimum Value	Maximum Value
11	NQualBits value=8			
12	BitCount0 : L1 phase center offset vector			
13	BitCount1 : L2 phase center offset vector			
14	BitCount2			
15	BitCount3			
16	BitCount4			
17	BitCount5			
18	BitCount6			
19	BitCount7			

VGB1B : Vector offset file for GPS Backup Navigation Antenna in SRF

Parameter Number	Definition	Units	Minimum Value	Maximum Value

Number			Value	Value
11	NQualBits value=8			
12	BitCount0 : L1 phase center offset vector			
13	BitCount1 : L2 phase center offset vector			
14	BitCount2			
15	BitCount3			
16	BitCount4			
17	BitCount5			
18	BitCount6			
19	BitCount7			

VGN1B : Vector offset file for GPS Main Antenna in SRF

Parameter Number	Definition	Units	Minimum Value	Maximum Value
11	NQualBits value=8			
12	BitCount0 : L1 phase center offset vector			
13	BitCount1 : L2 phase center offset vector			
14	BitCount2			
15	BitCount3			
16	BitCount4			
17	BitCount5			
18	BitCount6			
19	BitCount7			

Appendix C CONTACTS

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