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Product User Manual : Barystatic and Manometric Sea Level Datasets

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Document evolution sheet

Ed.	Rev.	Date	Purpose evolution	Comments
1	0	01/02/2023	Creation of document	
1	2	15/02/2023	Release of first product version (v1-0)	Calculation of barystatic and manometric sea level changes using an ensemble of GRACE solutions with 240 solutions, including: - 5 processing centers (CSR, JPL, GFZ, ITSG CNES), - 4 geocenter models (Lemoine and Reinquin, 2017, Dahle et al., 2012, Uebbing et al., 2019, Sun et al., 2016), - 3 oblateness (C20) models (Lemoine and Reinquin, 2017 updated with combined SLR and GRACE measurements) - 2 GIA models (Peltier et al., 2018; Caron et al., 2018)) - 2 filters (DDK6 and DDK3 applied on all ensemble members except CNES) Calculation of barystatic and manometric sea level changes using the combination of altimetry product (C3S) and steric products (EN4, Ishii, IAP)
1	3	27/04/2023	Release of new product version (v2-0)	Use of a new ensemble of GRACE solutions with 140 solutions, including: - 5 processing centers (unchanged), - 2 geocenter models (***Lemoine and Reinquin, 2017 updated using a 7-month lowpass filter*** ; Sun et al., 2016 unchanged) - 3 oblateness (C20) models (***Lemoine and Reinquin, 2017 updated with combined SLR and GRACE measurements***) - 2 GIA models (***same models recalculated using correct Love numbers***) - 2 filters (DDK6 and DDK3 applied on all ensemble members ***including*** CNES) Use of an ***updated mask*** to compute the barystatic component with the sea level budget approach.

				Application of the ***correction for deep ocean*** to the thermosteric component in the sea level budget approach. No changes to the SLB manometric product.

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1 INTRODUCTION

The PRODUCT USER MANUAL (PUM) describes estimates of the mass contribution to sea level changes and their associated uncertainties over the satellite gravimetry (April 2002 - August 2022) period and over the satellite altimetry (1993 - December 2020) period. According to Gregory et al., 2019, we define the local and global mass contribution to sea level changes as the manometric and barystatic sea level changes.

Manometric sea level changes are provided online as fully documented ready-to-use three dimensional (time, latitude, longitude) grids interpolated at a monthly and one degree resolution. The effective resolution of satellite gravity-based products is of the order of a few hundred kilometers (~300 km). Manometric and barystatic sea level changes are expressed as anomalies with respect to the temporal average over the period covered by the product.

2 METHODOLOGY

2.1 GRACE AND GRACE-FO DATASETS

The GRACE and GRACE Follow-On missions monitor the time-variations in the gravity field almost continuously since 2002. Numerous centers distribute time-lapse solutions of the Earth's gravitational potential, delivered as Stokes coefficients, known as Level 2 solutions. The Level 2 solutions need to be corrected for several geophysical effects and instrumental errors, converted into surface mass anomalies and projected onto the ellipsoid. The resulting gridded surface mass anomalies with appropriate corrections applied are referred to as Level 3 solutions. Several sources of errors affect the solutions of Level 2 and 3, imposed by the satellite configuration, instrumental errors and uncertainties in the geophysical corrections used to process the measurements. We use the ensemble approach of Blazquez et al., (2018), to robustly estimate the manometric and barystatic sea level changes and their uncertainties.

2.1.1 Manometric sea level changes

GRACE LEGOS MAGELLIUM MANOMETRIC V2.0 provides manometric sea level anomalies and their uncertainties from April 2002 to August 2022 at a monthly timescale and with a spatial resolution of 1 degree. Monthly manometric sea level changes are estimated from an ensemble of 140 GRACE and GRACE-FO solutions corrected for GIA, mass displacements associated with large earthquakes and atmosphere loading. The ensemble is based on L2 spherical harmonic solutions from five different centers: CNES RL5.0, CSR RL06, GFZ RL06, JPL RL06, and TUGRAZ ITSG2018. The ocean dealiasing model (GAB) is restored using AOD1B RL06 (Dobslaw et al., 2017) except for the CNES solution where ERA-Interim and TUGO models were used. The C0 coefficients are corrected to compensate for the total amount of water vapor in the atmosphere expressed in C0 GAA (Chen et al., 2019). A large variety of post-processing corrections is applied in the ensemble, including two geocentre motions (Lemoine and Reinquin, 2017; Sun et al., 2016), three oblateness values of the Earth (Cheng et al., 2013; Lemoine and Reinquin, 2017; Loomis et al., 2019), and two GIA corrections (Peltier et al., 2018, Caron et al., 2018). In order to reduce the anisotropic noise, DDK filters are applied to the L2 solutions, including DDK3 and DDK6 (Kusche et al., 2009). Solid Earth displacement due to the largest earthquakes (Sumatra 2004 and 2012, Tohoku 2010, and Chile 2010) is corrected following Tang et al., (2020). To reduce leakage and Gibbs effects, the spherical harmonics solutions are separated in the a priori part using external data such as land–ocean masks, glacier mass trends (Hugonnet et al., 2021), and lake volume change (Crétaux et al., 2016) and the residual part, which contains the signal to be filtered. In the final solutions, the a priori and the filtered residuals are added back together.

The GRACE LEGOS MAGELLIUM MANOMETRIC V2.0 product contains the ensemble mean of the 140 solutions and their uncertainties estimated as the square root of the diagonal terms of the covariance matrix of the full ensemble at each geographical point.

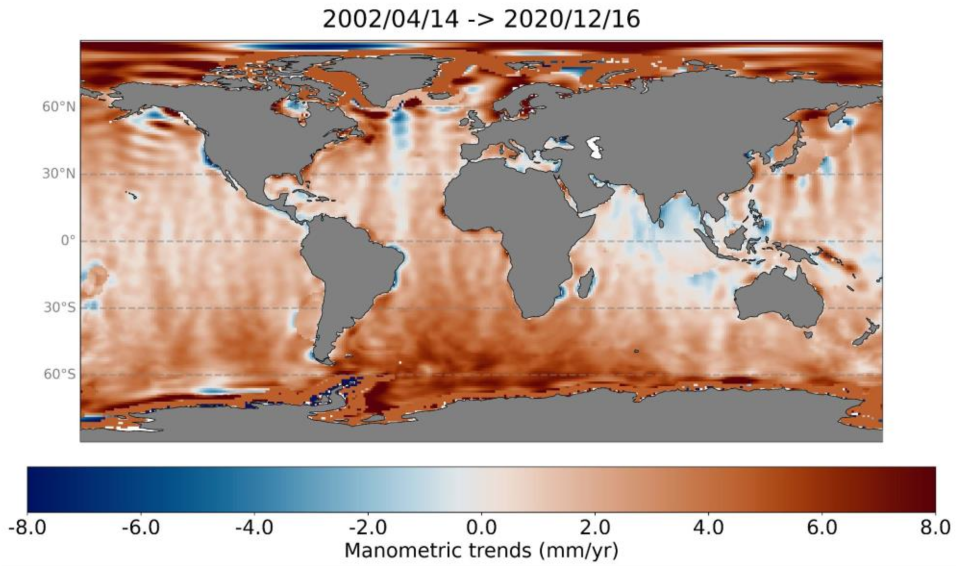

Figure 1: Manometric sea level trends estimated from April 2002 until December 2020 with GRACE and GRACE-FO ensemble V2.0.

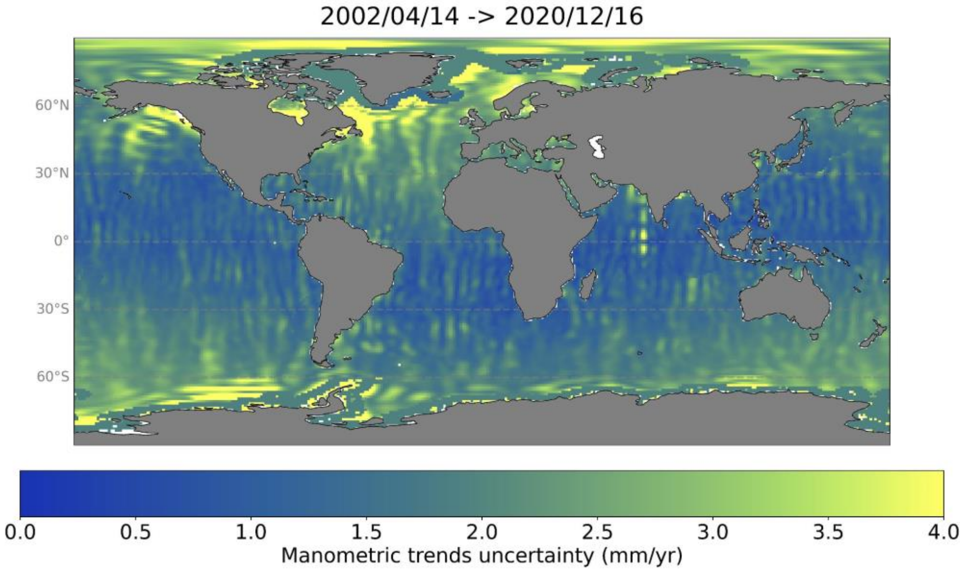

Figure 2: Uncertainty on manometric sea level trends estimated from April 2002 until December 2020 with GRACE and GRACE-FO ensemble V2.0.

2.1.2 Barystatic sea level changes

The GRACE LEGOS MAGELLIUM BARYSTATIC V2.0 product contains the monthly barystatic sea level changes and their uncertainties from April 2002 to August 2022.

The barystatic sea level changes are calculated as the global average of the manometric sea level anomalies weighted according to the surface area of each grid cell. The GRACE LEGOS MAGELLIUM BARYSTATIC V2.0 product contains the ensemble mean of the 140 barystatic solutions and their uncertainties estimated as the square root of the diagonal terms of the covariance matrix of the full ensemble, also provided.

Two estimates of the barystatic sea level changes are provided corresponding to two different geographical masks, including (i) the ocean surface covered by GRACE and GRACE-FO, (ii) the ocean surface covered by satellite altimetry and in situ measurements of the seawater temperature and salinity. The barystatic sea level changes calculated with the second mask can directly be compared with the barystatic estimates derived from the sea level budget approach.

2.2 SEA LEVEL BUDGET DATASETS

The estimation of barystatic and manometric sea level anomalies is extended to the altimetry era (January 1993 - December 2020) using the sea level budget approach. The sea level budget approach takes advantage of the redundant ocean monitoring systems, measuring geocentric sea level changes with satellite radar altimetry, barystatic and manometric sea level changes with satellite gravimetry and steric sea level changes with in-situ temperature and salinity estimates. Any of the three components may be estimated based on the two others. As a consequence, barystatic and manometric sea level changes may be estimated as the difference between altimetry-based sea level changes and in-situ estimates of steric sea level changes.

2.3 Manometric sea level changes

The SLB LEGOS MAGELLIUM MANOMETRIC V2.0 contains the monthly manometric sea level changes and their associated uncertainties on a regular 1x1° grid covering the January 1993 - December 2020 time period.

The manometric sea level changes are calculated as the difference between the geocentric sea level changes based on satellite altimetry and steric sea level changes based on in situ measurements of the seawater temperature and salinity.

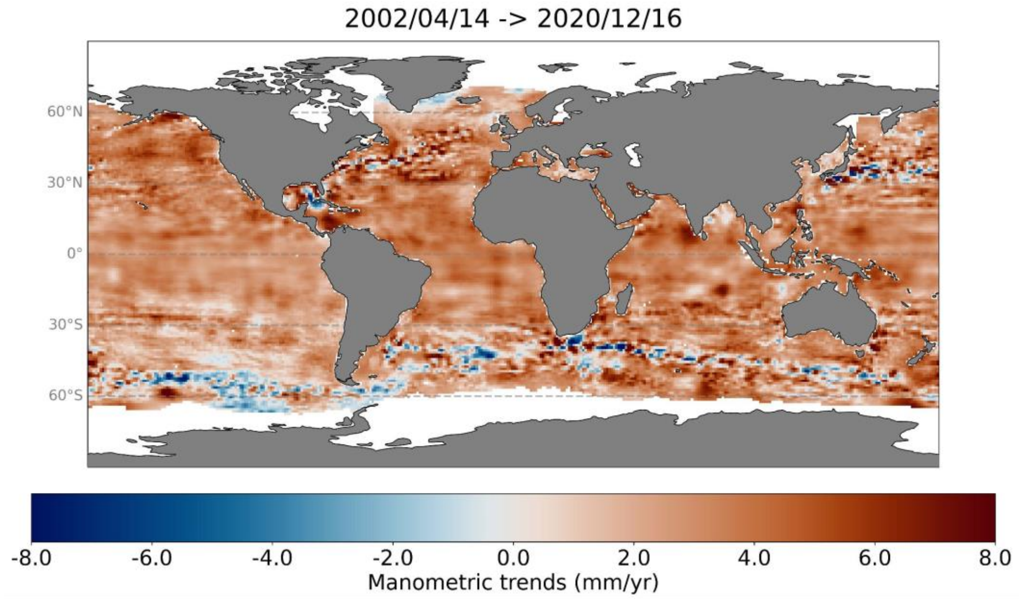

Figure 3: Manometric sea level trends estimated from April 2002 until December 2020 with the sea level budget product V2.0.

- Geocentric sea level changes are estimated using the vDT2021 sea level product operationally generated by the Copernicus Climate Change Service (C3S), dedicated for climate studies (Legeais et al., 2021). Geocentric sea level changes are corrected for the drifts evidenced in TOPEX A altimeter (Ablain, 2017) and Jason 3 wet tropospheric correction (Barnoud et al., 2023). Geocentric sea level changes are also corrected for GIA, using the ensemble mean of 27 GIA models (Prandi et al., 2021) centered on ICE5G-VM2 (Peltier et al., 2004) , and for the elastic deformation of the solid Earth due to present-day ice melting (Frederikse et al., 2017). The uncertainty on the geocentric sea level changes is calculated with the error budget method detailed in Prandi et al., (2021).

- Steric sea level changes are estimated as the sum of the thermosteric and halosteric sea level changes calculated from gridded temperature and salinity estimates from three different centers including EN4 (Good et al., 2013), IAP (Cheng et al., 2017, 2020) and Ishii et al., (2017). Four different corrections for XBT and MBT measurements are applied on the EN4 dataset, leading to an ensemble of 6 temperature and salinity datasets. From these datasets, we compute the thermosteric and halosteric sea level changes due to temperature and salinity variations between 0 and 2000 m depth. A linear trend of 0.12 ± 0.03 mm/yr is added to take into account the contribution of the deep ocean to thermosteric sea level changes (Chang et al., 2019). Steric sea level changes are estimated as the ensemble mean of the 6 solutions and their uncertainty is estimated with the covariance matrix of the ensemble, once the timewise mean of every ensemble element has been removed.

The uncertainties on manometric sea level changes are calculated as the square root of the diagonal term of the manometric covariance matrix. The manometric covariance matrix is calculated as the sum of the covariances matrices of the geocentric sea level changes, estimated with a budget error approach (Prandi et al., 2021), and the steric sea level changes, estimated as the covariance matrix of 6 steric solutions at each geographical point.

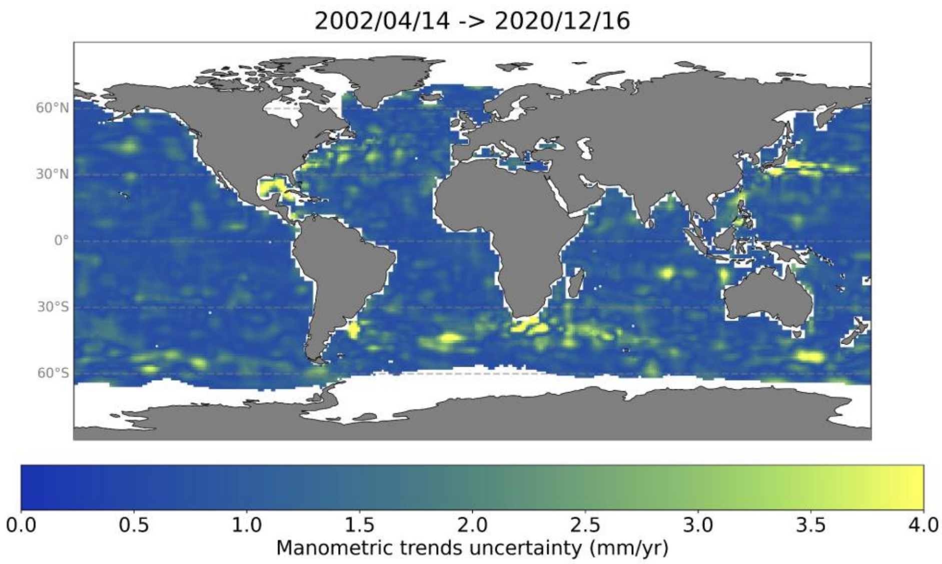

Figure 4: Uncertainties on manometric sea level trends estimated from April 2004 until December 2020 with the sea level budget product V2.0

2.4 Barystatic sea level changes

The SLB LEGOS MAGELLIUM BARYSTATIC V2.0 product contains the monthly barystatic sea level changes and their uncertainties from January 1993 to December 2020.

The barystatic sea level changes are calculated as the difference between the global mean sea level changes from satellite altimetry and the global mean thermosteric sea level changes. This approach relies on the assumption that the halosteric component cancels out on global average. This allows to avoid the propagation of errors in the halosteric component in the budget approach (Barnoud et al., 2021) and provides a more robust estimation of the barystatic component than the global mean of the manometric changes. The uncertainty on the barystatic component is estimated as the square root of the diagonal terms of the barystatic covariance matrix. The barystatic covariance matrix is estimated as the sum of the covariance matrix of the global mean sea level (Ablain et al., 2019) and global mean thermosteric sea level (see section 2.3). The same centers and corrections are used for the manometric and barystatic components estimated with the sea level budget approach.

Note: the deep ocean correction was not properly applied in the SLB BARYSTATIC V1.0 product, it has been corrected in the V2.0.

3 PRODUCT DESCRIPTION

3.1 Spatial information

The two (GRACE & SLB) manometric products are provided on a regular 1x1° grid on the WGS84 ellipsoid. GRACE data are defined on the global ocean (Fig. 1 and 2), and SLB data are defined on the global ocean except marginal seas and high latitudes (≳ 60°) (Fig. 3 and 4).

3.2 Temporal information

All 4 products are provided at the same dates, i.e. the 15th of each month between January 1993 and August 2022. Data gaps are filled with non defined values (NaN).

- GRACE data are only provided from April 2002 until August 2022, with several data gaps including a gap of 12 months between the last data from GRACE (June 2017) and the first from GRACE-FO (June 2018).
- SLB data are provided from January 1993 to December 2020.

3.3 File format

The product is delivered as a set of Network Common Data Form version 4 (netCDF4) files. Metadata attributes are compliant with version 1.7 of the Climate & Forecast conventions (https://cfconventions.org/Data/cf-conventions/cf-conventions-1.7/cf-conventions.html)

3.4 File naming convention

The product follows the naming standard:

<METHOD>_<CENTERS>_<VARIABLE>_<VERSION><_OPT>.nc

where:

- <METHOD> indicates the method used to generate the products. Here, we provide two different methods GRACE and SLB.
- <CENTERS> indicates the centers that generated the data. Here, both the LEGOS and MAGELLIUM were involved in the generation of the data.
- <VARIABLE> indicates the variable estimated in the product. Here we provide estimates of the manometric and barystatic sea level changes.
- <VERSION> is the version number, here 'V1-0' for the first major version. The first digit changes each time a major version is released ('V2-0', 'V3-0'), while changes in the second digit indicate reprocessing versions or minor versions ('V1-2', 'V1-3').
- <_OPT> is optionally included to add information. Covariances matrices are provided in option.
- .nc: standard NetCDF filename extension.

Example: GRACE_LEGOS_MAGELLIUM_MANOMETRIC_V2-0.nc

3.5 Product content

3.5.1 Dimensions

There are 4 dimensions are present in every netCDF:

- latitude: size 180, dimension corresponding to latitudes
- longitude: size 360, dimension corresponding to longitudes
- time: size 345, dimension corresponding to decimal years

One additional dimension is present in barystatic netCDF:

- id_mask: size 1 or 2, dimension corresponding to the number of masks used to compute the global means

3.5.2 Variables

The variables defined in the files referring to manometric measurements are the following:

Variables(dimensions)	Description	Units	Data Type	Scale factor

time(time)	Time	decimal years	float	none
latitude(latitude)	Latitude	degrees_north	float	none
longitude(longitude)	Longitude	degrees_east	float	none
manometric(time,latitude,longitude)	Manometric sea level anomalies	meters	float	none
manometric_standard_error(time,latitude,longitude)	One sigma uncertainty on manometric sea level anomalies	meters	float	none

The variables defined in the files referring to barystatic measurements are the following:

Variables(dimensions)	**Description**	**Units**	**Data Type**	**Scale factor**
time (time)	Time	decimal years	float	none
latitude (latitude)	Latitude	degrees_north	float	none
longitude (longitude)	Longitude	degrees_east	float	none
barystatic(time,id_mask)	Barystatic sea level anomalies calculated with the SLB mask (id_mask=0) and the global ocean (id_mask=1)	meters	float	none
barystatic_standard_error(time,id_mask)	One sigma uncertainty on barystatic sea level anomalies calculated with the SLB mask (id_mask=0) and the global ocean (id_mask=1	meters	float	none
ponderation_masks(latitude,longitude,id_mask)	Ponderation factors applied to manometric sea level anomalies to obtain the barystatic sea level anomalies	no unit	float between 0 and 1	none
ponderation_masks_names(id_mask)	names associated with ponderation masks, ie “SLB mask” and “Open Ocean mask”	no unit	string	none

3.5.3 Metadata

Users will find a number of metadata attributes in the NetCDF file, at the file-level, at the layer-level and at the level of the dimension variables.

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