SAGSA

TERRESTRIAL WATER STORAGE ENSEMBLE PRODUCT USER MANUAL

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Document reference:	SAGSA-DT-028-MAG_PUM_LWSE
Edition.Revision:	V2.0
Date Issued:	18/06/2026
Customer:	CNES
Ref. Market, consultation:	MARCHÉ N° 241698/00

Document evolution sheet

Ed.	Rev.	Date	Purpose evolution	Comments
1	0	08/12/2025	Initial document and release of products V2.1	
1	1	26/02/2026	Correction of the product user manual Products remain unchanged	The anomalies are referenced to the temporal mean over the period January 2005 to December 2014 (instead of April 2002 to August 2025 as written in the PUM V1.0). The CNES SAGSA Terrestrial Water Storage product presented here is of Level-3 (instead of Level-4). All monthly products are provided at each mid-month time step (it doesn't always fall on the 15th as it was written in the PUM V1.0).
2	0	18/06/2026	Release of new products V2.2	**The hydrological datasets V2.2 are calculated based on the GRACE ensemble L3 V2.2 produced by Magellium and the CNES**. • The GRACE ensemble L3 V2.2 was generated using PANIS v1.2.0. • Leakage was corrected zonally using the mean_mass_model method. • The C00 coefficient of GAA was set to zero. • The GRACE ensemble L3 V2.2 was extended until February 2026. The hydrological products are **expressed in EWH** instead of water volumes (V1.0).

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1 INTRODUCTION

The Product User Manual (PUM) describes the Level-3 CNES SAGSA Terrestrial Water Storage (TWS) product. Terrestrial Water Storage represents the total amount of water contained on land, spanning natural and artificial reservoirs alike, including groundwater, soil moisture, rivers, lakes, snowpack, glaciers, land ice, and water stored in biomass. Variations in TWS, expressed as anomalies relative to a long-term mean, reflect shifts in available freshwater resources and can significantly influence both natural ecosystems and human activities. TWS anomalies are also sometimes referred to as land water storage anomalies, total land water storage anomalies or total terrestrial water storage anomalies, and always refer to changes in the total amount of water integrated from the surface to deep aquifers.

The GRACE (Gravity Recovery and Climate Experiment; (Tapley et al., 2004, 2019)) and GRACE-FO (Follow-On; (Chen et al., 2022; Landerer et al., 2020)) satellite gravity missions have provided the first direct, global observations of TWS variability at continental scales since 2002. By measuring subtle changes in Earth's gravity field caused by mass redistribution across the land, ocean, and atmosphere, these missions established satellite gravimetry as a key tool for monitoring the hydrological cycle. Deriving quantitative estimates of water-mass variations from the gravity measurements requires substantial processing and post-processing informed by multiple geophysical models, analysis centers, and auxiliary datasets. A review of hydrological applications of satellite gravimetry can be found in (Humphrey et al., 2023), providing concrete usage guidelines of TWS data derived from satellite gravimetry.

The L3 SAGSA TWS V2.2 product is derived from the L3 SAGSA ENSEMBLE V2.2 dataset, incorporating all necessary corrections and offering systematic estimates of the uncertainties associated with GRACE/GRACE-FO processing and post-processing choices (Blazquez et al., 2018). Although TWS anomalies are provided on a regular 1° × 1° geographic grid, the effective spatial resolution of satellite-gravity observations is on the order of a few hundred kilometers (~300 km). All anomalies are referenced to the temporal mean over the period January 2005 to December 2014. Monthly TWS anomaly data are available for all continental land areas worldwide for the period April 2002–February 2026.

1 METHODOLOGY

1.1 L3 SAGSA Ensemble

The Level-3 SAGSA TWS V2.2 product is based on the L3 SAGSA ENSEMBLE V2.2 dataset (Table 1) providing monthly estimates of surface mass anomalies, expressed as Equivalent Water Heights (EWH), in the hydrosphere, ocean, and cryosphere, along with a robust estimation of their uncertainty.

The L3 SAGSA ensemble combines gravitational potential data from five processing centers—JPL, CSR, GFZ, ITSG, and CNES—allowing robust evaluation of uncertainties associated with the processing of GRACE and GRACE-FO calibrated measurements (L1B). Systematic spatial noise in the gravitational potential, typically observed as North-South stripes, is mitigated using Decorrelation and Denoising Kernel (DDK) filters at two levels (DDK3 and DDK6).

GRACE and GRACE-FO satellites, which detect variations in Earth's gravity, are insensitive to geocenter motion and have limited sensitivity to large-scale deformations represented by low-degree coefficients (C20, C30). These coefficients are corrected using three geocenter models and precise SLR(SatelliteLaser Ranging)-based C20 and C30 estimates from three independent centers. To isolate mass changes associated with water redistribution, corrections for Glacial Isostatic Adjustment (GIA) are applied using two models.

The combination of five processing centers, three geocenter models, three oblateness corrections, two GIA models, and two filtering levels results in an ensemble of 180 solutions. All ensemble members are further corrected for major earthquakes, coastal leakage, and high-frequency atmospheric and oceanic mass variations.

Additional details on the processing of the L3 SAGSA ENSEMBLE V2.2 dataset are provided in the PANIS ATBD (Boughanemi et al., 2026, in preparation).

Version	Publication date	Input data	Temporal coverage	DOI
V2.1	March 2026	ensemble L3 V2.1	April 2002- August 2025	10.24400/329360/SAGSA_TWSA_ENS_1MONTH_V2.1

V2.2	August 2026	ensemble L3 V2.2	April 2002- Février 2026	10.24400/329360/SAGSA_TWSA_ENS_1MONTH_V2.2

Table 1 : Table of versions of Level-3 SAGSA TWS products

1.2 L3 SAGSA Terrestrial Water Storage

The Level-3 TWS product is generated by applying a land mask on the EWH from the L3 ensemble .

$$\Delta TWS_i = \Delta H_i * 10^{-3} * L_i$$

Where:

- ΔTWS_i is the terrestrial water storage anomaly for grid cell i expressed in mm
- ΔH_i is the equivalent water heights anomaly for grid cell i expressed in m, from the L3 ensemble
- Li is the land mask that equals 1 if grid cell i is on land and 0 if grid cell i is on the oceans. A cell is defined as a land cell if at least 30% of its surface is covered by land.

TWS anomalies are calculated only over the land mask; grid cells outside the land mask are excluded.

To produce a representative product, ensemble statistics are computed across all 180 ensemble members[1] for each time step and grid point as follows.

- The Ensemble Mean ($\overline{\Delta TWS}$) is computed as the average TWS anomaly.

$$\overline{\Delta TWS_i} = \frac{1}{180}\sum_{j=1}^{180} \Delta TWS_{i,j}$$

- The Ensemble Uncertainty ($\sigma_{\Delta TWS}$) is computed as the Standard Deviation of the TWS anomalies. It represents the spread due to different processing and post-processing choices.

$$\sigma_{\Delta TWS_i} = \sqrt{\frac{(\sum_{j=1}^{180}(\Delta TWS_{i,j} - \overline{\Delta TWS_i}))^2}{180-1}}$$

[1] The L3 ensemble is composed of 180 members. One ensemble member is defined as the result of one processing center, one geocenter model, one oblateness correction, one GIA model and one filtering level. There are 180 possible combinations.

The resulting mean and standard deviation grids are then disseminated as TWS products from April 2002 to February 2026 at a monthly timescale and with a spatial resolution of 1 degree.

The trend of TWS anomalies is computed for each member of the ensemble over 04/2002 - 02/2026. The mean trend and the uncertainty of the ensemble trend are then calculated and represented in Figure 1 and 2.

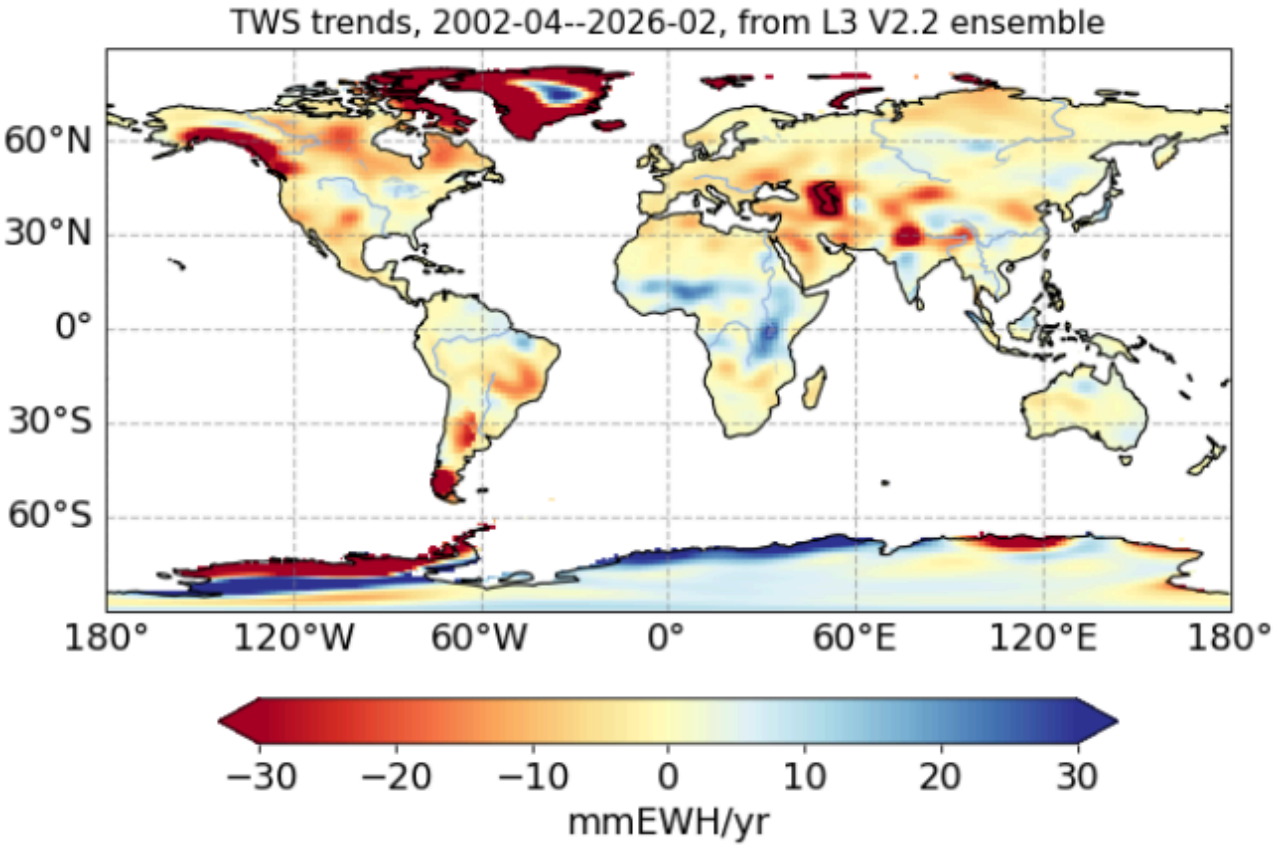


Figure 1: Terrestrial water storage anomalies trends estimated from April 2002 until February 2026 with GRACE and GRACE-FO ensemble V2.2.

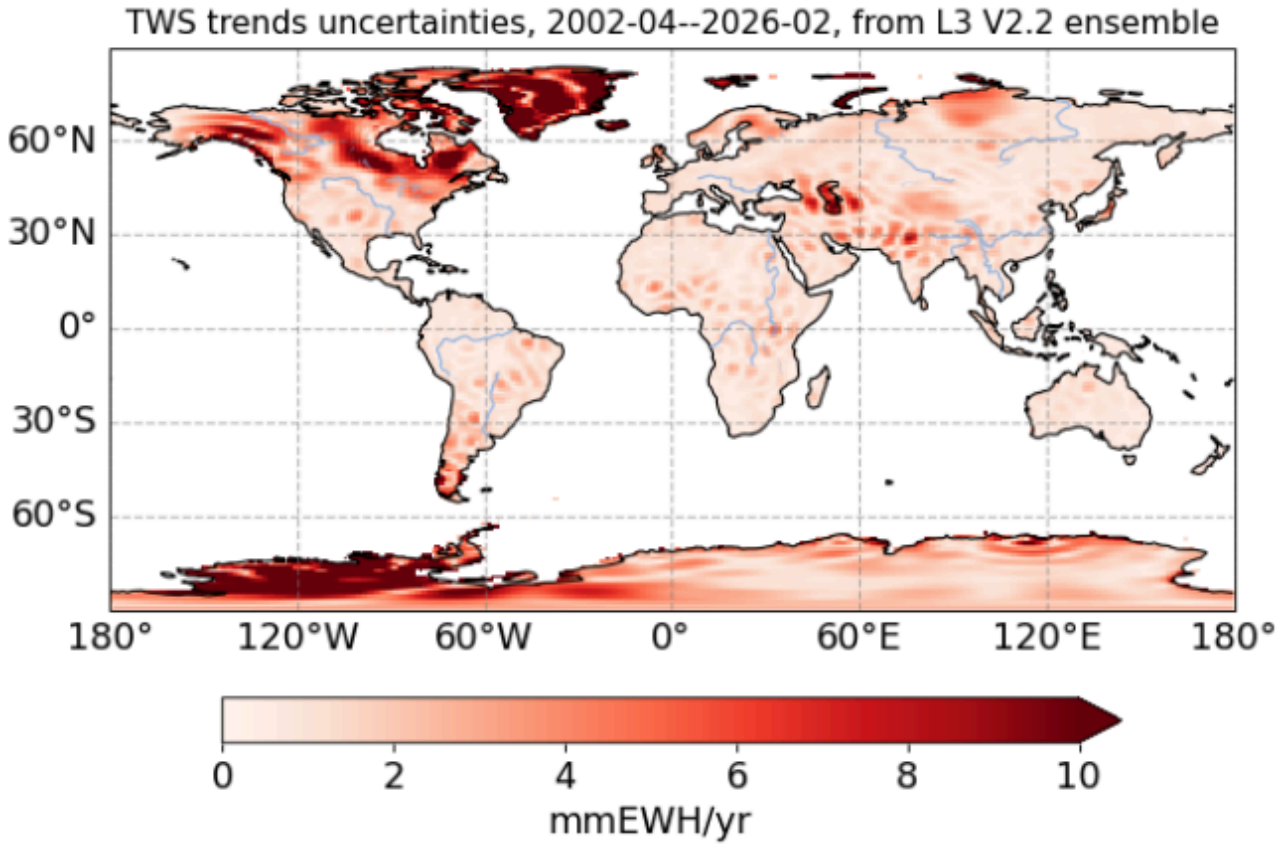


Figure 2: Terrestrial water storage anomalies trends uncertainties estimated from April 2002 until February 2026 with GRACE and GRACE-FO ensemble V2.2.

2 PRODUCT DESCRIPTION

2.1 Spatial information

The TWS products are provided on a regular 1x1° grid projected on a sphere. The land mask used for the generation of the product is also provided and covers all five continents including all islands.

2.2 Temporal information

2.2.1 Temporal resolution

All GRACE based products are provided at each mid-month time step between April 2002 and February 2026. Each file provides the average and standard deviation of the 180 L3 solutions for the given month.

2.2.1 Temporal latency

The TWS products are delivered every six months with a 4 to 6 month data latency (for example, the August release covers data up to February) and are based on various corrections that have delivery delays ranging from 6 to 12 weeks.

2.2 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)

2.3 File naming convention

The product follows the naming standard:

<VARIABLE>_<VERSION>_<DATE>.nc

where:

- <VARIABLE> indicates the variable estimated in the product. Here we provide estimates of the Total Water Height Anomaly.
- <VERSION> is the version number. 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').
- .nc: standard NetCDF filename extension.

Example: Total_Water_Height_Anomaly_V2.2_2025-07.nc

2.4 Product content

2.4.1 Dimensions

There are 3 dimensions present in every netCDF file:

- latitude: size 180, dimension corresponding to degrees north
- longitude: size 360, dimension corresponding to degrees east
- time: size 1, dimension corresponding to hours since the first date of the product, using the Gregorian proleptic calendar. The user can concatenate all files together along the 'time' dimension.

2.4.2 Variables

The variables defined in each netCDF file are the following:

Variables(dimensions)	Description	Units	Data Type
time(time)	Time	hours since 2002-04-16	datetime64
latitude(latitude)	Latitude	degrees_north	float
longitude(longitude)	Longitude	degrees_east	float
ewh_mean(time,latitude,longitude)	Total land EWH anomalies	mm	float
ewh_std(time,latitude,longitude)	One sigma uncertainty on the total land EWH anomalies	mm	float
surface(latitude, longitude)	Surface of land pixels	m^2	float
land_mask(latitude,longitude)	Mask of the continents used	No unit	boolean

2.4.3 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.

3 REFERENCES

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4 ACRONYMS

Acronym	Description
ATBD	Algorithm Theoretical Basis Document
CNES	Centre National d'Études Spatiales
DDK	Decorrelation and Denoising Kernel
EWH	Equivalent Water Height
GIA	Glacial isostatic adjustment
GRACE	Gravity Recovery And Climate Experiment
GRACE-FO	Gravity Recovery And Climate Experiment Follow-On
ITSG	Institute of Geodesy at Graz University of Technology
JPL	Jet Propulsion Laboratory
L1B	Level 1B
L3	Level 3
PUM	Product User Manual

SAGSA	Service d'Activités en Gravimétrie Spatiale et Applications
SLR	Satellite Laser Ranging
TWS	Terrestrial Water Storage