SAGSA

LAND WATER STORAGE ENSEMBLE PRODUCT USER MANUAL

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Document evolution sheet

Ed.	Rev.	Date	Purpose evolution	Comments
1	0	08/12/2025	Initial document and release of products V1.0	
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 Land 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).

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1 INTRODUCTION

The Product User Manual (PUM) describes the Level-3 CNES SAGSA Land Water Storage (LWS) product. Land 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 LWS, 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. LWS anomalies are also sometimes referred to as total land water storage anomalies, terrestrial 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 LWS 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 LWS product is derived from the L3 SAGSA ENSEMBLE V2.1 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 LWS 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.

1 METHODOLOGY

1.1 L3 SAGSA Ensemble

The Level-3 SAGSA Land Water Storage (LWS) product is based on the L3 SAGSA ENSEMBLE V2.1 dataset providing monthly estimates of surface mass anomalies, expressed as equivalent water heights, 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 L1B measurements. Systematic spatial noise in the gravitational potential, typically observed as North-South stripes, is mitigated using DDK decorrelation 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 gaps are addressed using three geocenter models and precise SLR-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 V2.1 dataset are provided in the PANIS ATBD (Boughanemi et al., 2025, in preparation).

2.2 L3 SAGSA Land Water Storage

The first step in generating the Level-3 Land Water Storage (LWS) product is to convert the column-averaged Equivalent Water Heights (EWH) from the L3 ensemble into integrated water volumes over continental grid cells:

$$\Delta LWS_i = \Delta H_i \times a_i \times 10^{-9} \quad (1)$$

Where:

- ΔLWS_i are the land water storage anomaly for grid cell i expressed in km^3
- ΔH_i are the equivalent water heights for grid cell i expressed in m
- a_i is the area of grid cell i in m^2

LWS anomalies are calculated only over the land mask; grid cells outside the land mask (i.e. ocean) are excluded.

To produce a representative product, ensemble statistics are computed across all 180 ensemble members.

- Ensemble Mean

$$\overline{LWS} = \frac{1}{N}\sum_{j=1}^{N} LWS_j \tag{2}$$

The average LWS anomaly is computed across all 180 members of the ensemble for each time step and grid point.

- Ensemble Standard Deviation

$$\sigma_{LWS} = \sqrt{\frac{\left(\sum_{j=1}^{N} \Delta_{LWS_j} - \overline{\Delta_{LWS}}\right)^2}{N-1}} \tag{3}$$

The uncertainty is characterized by the ensemble standard deviation of the LWS anomalies across the 180 ensemble members, representing the spread due to different processing and post-processing choices.

The resulting mean and standard deviation grids are then disseminated as monthly LWS products from April 2002 to August 2025 at a monthly timescale and with a spatial resolution of 1 degree. The trend in LWS anomalies and its uncertainty are represented in Figure 1 and 2.

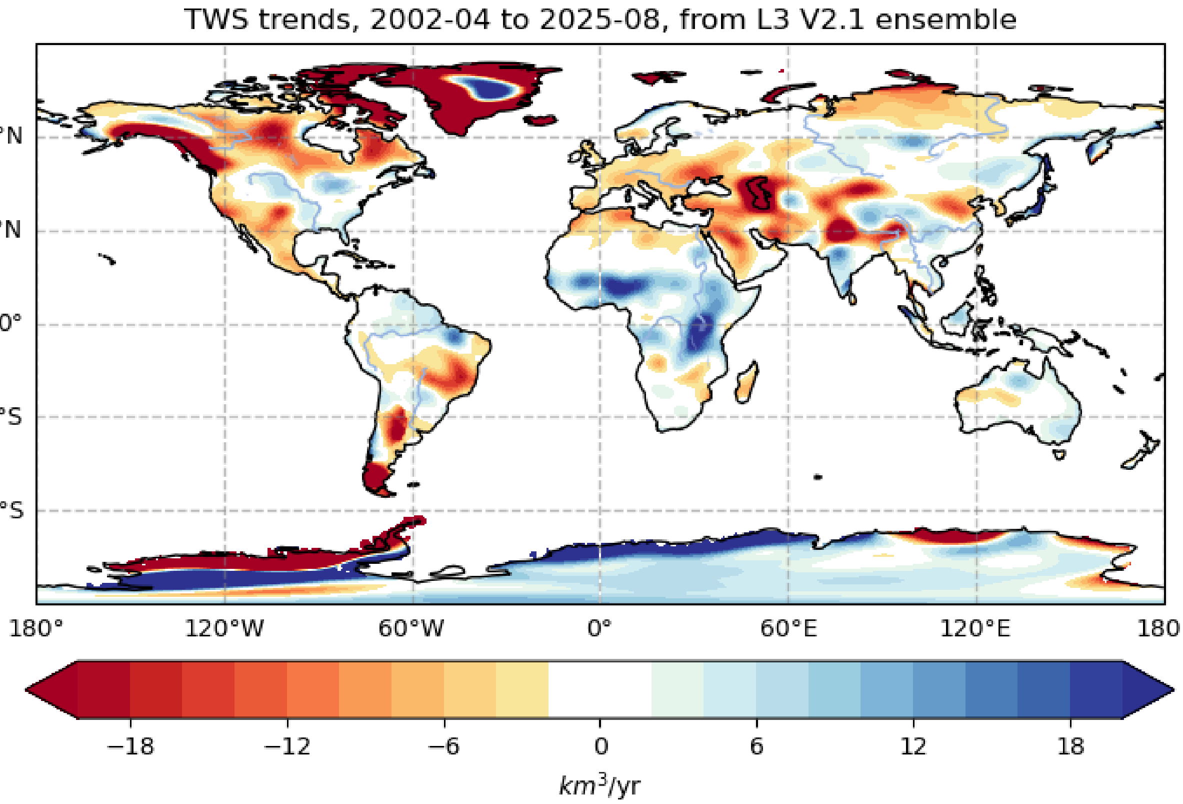

Figure 1: Total land water anomalies trends estimated from April 2002 until August 2025 with GRACE and GRACE-FO ensemble V2.1.

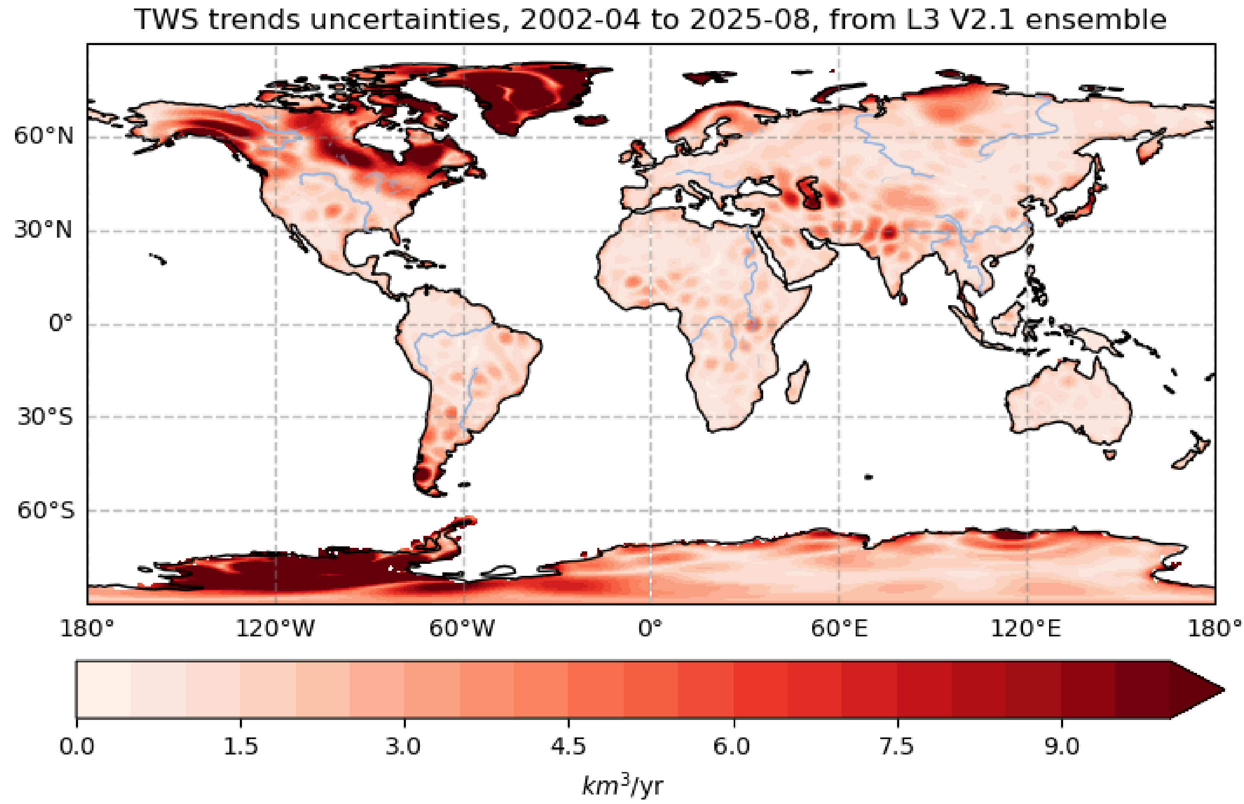

Figure 2: Total land water anomalies trends uncertainties estimated from April 2002 until August 2025 with GRACE and GRACE-FO ensemble V2.1.

2 PRODUCT DESCRIPTION

2.1 Spatial information

The Total Land Water Anomalies 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.

2.2 Temporal information

All GRACE based products are provided at each mid-month time step between April 2002 and August 2025. Each file represents the average and standard deviation of the 180 L3 solutions for the given month.

2.3 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)

2.4 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 Land Water Anomalies.
- <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’).
- .nc: standard NetCDF filename extension.

Example: Total_Water_Storage_V2.1_2025-07.nc

2.5 Product content

2.5.1 Dimensions

There are 3 dimensions present in every netCDF:

- 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 time dimension is present in each file to make their concatenation easier for the user.

2.5.2 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	hours since 2002-04-16	datetime64	none

latitude(latitude)	Latitude	degrees_north	float	none
longitude(longitude)	Longitude	degrees_east	float	none
total_water(time,latitude,longitude)	Total Land Water Anomalies	Km³	float	none
total_water_std(time,latitude,longitude)	One sigma uncertainty on the total land water anomalies	Km³	float	none
land_mask(latitude,longitude)	Mask of the continents used	No unit	boolean	none

2.5.3 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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