**Technical Note**

# GravIS Terrestrial Water Storage Anomaly Level-3 Products

**for**

**GFZ GravIS RL06 (V. 0006)**

**COST-G GravIS RL01 (V. 0005)**

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## 1. Introduction

This Technical Note describes the processing scheme and product details of the Terrestrial Water Storage (TWS) Anomaly Level-3 products that are visualized at the GFZ web portal GravIS (https://gravis.gfz.de) and provided at GFZ's data archive ISDC.

## 2. Data Product Details

### *2.1 Gridded Products*

The TWS product based on GFZ GRACE/GRACE-FO monthly gravity field models contains the complete available time series, whereas the TWS products based on COST-G GRACE/GRACE-FO monthly gravity field models are divided into yearly batches.

*Filenames:* GFZ: **GRAVIS-3_ccccc_rrrr_TWS_GRID_GFZ_vvvv.nc**

COST-G: **GRAVIS-3_YYYY-----------_ccccc_rrrr_TWS_GRID_GFZ_vvvv.nc**

where:

YYYY is the corresponding year (note that files may contain partial years)

ccccc is either GFZOP if the product is based on GFZ GRACE/GRACE-FO monthly gravity field models, or COSTG if the product is based on combined GRACE/GRACE-FO monthly gravity field models from COST-G rrrr is the corresponding 4-digit release number of the underlying monthly gravity field models (either 0600 for GFZ or 0100 for COST-G)

vvvv is the 4-digit version number of the most recent product release

*Format:* **NetCDF**

*Product links:* GFZ: **ftp://isdcftp.gfz-potsdam.de/grace/GravIS/GFZ/Level-3/TWS**

COST-G: **ftp://isdcftp.gfz-potsdam.de/grace/GravIS/COST-G/Level-3/TWS**

### *2.2 Regional Average Products*

Spatially averaged products over predefined regions can be downloaded directly from the dedicated TWS subpage at the GravIS web portal. Here, these products are offered via the download button above the time series plot in terms of two zip archives (one for products based on GFZ, the other for products based on COST-G) which each contain several ASCII files in csv format for different available TWS product variables and types of regions.

*Filenames:* **TWS_ccccc_rrrr_<layer>_<region>_vvvv.csv**

where:

ccccc is either GFZOP if the product is based on GFZ GRACE/GRACE-FO monthly gravity field models, or COSTG if the product is based on combined GRACE/GRACE-FO monthly gravity field models from COST-G

rrrr is the corresponding 4-digit release number of the underlying monthly gravity field models (either 0600 for GFZ or 0100 for COST-G)

<layer> is the name of the specific variable, i.e. either 'tws', 'leakage', or 'model_atmosphere' (see Section 3.1 below for further details about the content of these variables)

<region> indicates the type of predefined regions, i.e. either 'clireg' for climatically similar regions or 'rivbas' for river basins (see Section 3.2 below for further details about the predefined regions)

vvvv is the 4-digit version number of the most recent product release

*Format:* **csv**

*Product links:* **https://gravis.gfz.de/tws** (via download button above time series plot)

## 3. Processing Details

### *3.1 Gridded Products*

TWS estimates obtained from GRACE and GRACE-FO are provided at 1° latitude-longitude grids as defined over all land regions except Greenland and Antarctica. The reference surface for the spherical harmonic synthesis to the 1° grid is the reference ellipsoid as defined in the IERS Conventions (2010) Tab 1.1.

The files each contain four different variables (see variable names of the NetCDF files marked in **bold** below) providing

1) gravity-based TWS (**tws**);
2) gravity-based TWS uncertainties (**std_tws**);
3) spatial leakage contained in TWS (**leakage**); and
4) background model atmospheric mass (**model_atmosphere**).

**Layer “tws”:**

Temporal changes in the Earth's gravity field over the continents are interpreted in terms of changes in the terrestrially stored water masses. We use GravIS Level-2B coefficients (https://gravis.gfz.de/corrections), either for GFZ RL06 (Dahle & Murböck, 2019) or COST-G RL01 (Dahle & Murböck, 2020), filtered with VDK5 and VDK3 and estimate trend as well as annual and semi-annual harmonics for both filter versions. In view of the lower noise level of the seasonal components, we subsequently combine the deterministic components from VDK5 with residual month-to-month and inter-annual variations from VDK3. In months, where the standard deviation of the residuals (see layer “std_tws”) are larger than two times the mean of the monthly standard deviation, the residual variations are taken from the VDK2 filtered fields. As an additional correction which is not part of the Level-2B processing, co- and post-seismic deformations from megathrust earthquakes (magnitude > 8.8) are removed. Thus, the seismic events (i) Sumatra-Andaman 2004, (ii) Chile 2010, and (iii) Tohoku-Oki 2011 are taken into account. The empirical correction is based on a step function which is fitted to all available monthly solutions in a spherical cap with a radius of 1000 km centered at the epicenter and an exponential decay function which is fitted over two years following the main event (note that solutions from subsequent epochs are no longer statistically independent as soon as earthquake signals were empirically estimated and removed). Mass anomalies are unambiguously inverted from the Stokes coefficients by utilizing the thin layer approximation (Wahr et al., 1998). The TWS data is not corrected for spatial leakage.

**Layer “std_tws”:**

The signal estimates are accompanied by associated uncertainties that take into account the varying noise level from month-to-month associated with (i) the amount of available sensor data in a certain month which might be limited due to, e.g., satellite maneuvers; (ii) the actual ground track pattern which might be sparse during periods of occasional short repeat orbits; and (iii) the condition of the satellites’ on-board batteries which impacts the maintenance of thermal stability and thereby the noise level of the science instruments. For each monthly TWS field this layer consists of the standard deviation of the TWS residuals (after removal of trend, annual and semi-annual signal) over the open ocean, i.e., all ocean points with a distance of at least 1000 km to the coast. These standard deviations are further used in the uncertainty modeling provided for the basins. The uncertainty modeling is based on a spatial covariance model which takes the non-homogeneous and anisotropic structure of spatial correlations as well as non-stationarity into account. The uncertainties are not based on formal uncertainties provided with the Stokes coefficients, but are estimated from empirical covariances of the TWS fields. Further details can be found in Boergens et al. (2020) and Boergens et al. (2022).

**Layer "leakage":**

This additional layer is provided to enable the correction for spatial leakage of the TWS data if needed. The spatial leakage is estimated from differences of a combination of VDK filters with different filter strengths. The spatial leakage estimation is separated into spatial leakage of the deterministic signals (VDK5) and interannual variability (VDK3). The spatial leakage of VDK5 is estimated from scaled differences between VDK6 and VDK4, likewise for VDK3 the differences between VDK4 and VDK2 are used. Further details are reported in Dobslaw et al. (2020).

The following scaling factors are used:

| | |
|---|---|
| **GFZ GravIS RL06** | |
| Leakage VDK3 | 3.9 |
| Leakage VDK5 | 4.0 |
| **COST-G GravIS RL01** | |
| Leakage VDK3 | 2.2 |
| Leakage VDK5 | 1.4 |

**Layer "model_atmosphere":**

It should be noted that a certain fraction of the time-variable gravity signal picked up by a satellite gravimetry mission is caused by atmospheric mass variability. The non-tidal de-aliasing product AOD1B RL06 (Dobslaw et al., 2017) has been used to subtract the atmospheric contribution already during the processing of the Level-2 monthly gravity fields. In order to provide users with some flexibility to restore the atmospheric signals, the monthly mean estimate of the atmospheric background model is provided as well.

### *3.2 Regional Average Products*

Two different types of predefined regions can be selected via drop-down menu at the GravIS TWS subpage (located in the top left corner of the spatial plot): (1) the world's 100 largest river basins, or (2) climatically similar regions (i.e., regions with similar precipitation properties, see Appendix A in Dahle et al. (2024) for further details).

The regional average products are provided separately for the layers 'tws', 'leakage', and 'model_atmosphere'.

In case of the layer 'tws', each value is accompanied by its uncertainty. Uncertainties are computed according to the method described by Boergens et al. (2022).

## 4. Citation

The GravIS TWS Level-3 products are published as data publication via GFZ Data Services and should be cited as follows:

*GFZ RL06 products:*
Boergens, E., Dobslaw, H., Dill, R. (2019): GFZ GravIS RL06 Continental Water Storage Anomalies. V. 0006. GFZ Data Services. https://doi.org/10.5880/GFZ.GRAVIS_06_L3_TWS

*COST-G RL01 products:*
Boergens, E., Dobslaw, H., Dill, R. (2020): COST-G GravIS RL01 Continental Water Storage Anomalies. V. 0005. GFZ Data Services. https://doi.org/10.5880/COST-G.GRAVIS_01_L3_TWS

## 5. References

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Dobslaw, H., Bergmann-Wolf, I., Dill, R., Poropat, L., Thomas, M., Dahle, C., Esselborn, S., König, R., Flechtner, F. (2017): A new high-resolution model of non-tidal atmosphere and ocean mass variability for de-aliasing of satellite gravity observations: AOD1B RL06. Geophysical Journal International, 211, 1, pp. 263-269. https://doi.org/10.1093/gji/ggx302

Dobslaw, H., Dill, R., Bagge, M., Klemann, V., Boergens, E., Thomas, M., Dahle, C., Flechtner, F. (2020): Gravitationally Consistent Mean Barystatic Sea Level Rise From Leakage-Corrected Monthly GRACE Data. J. Geophys. Res.: Solid Earth, 125, e2020JB020923. https://doi.org/10.1029/2020JB020923

Wahr, J. M., Molenaar, M., & Bryan, F. (1998): Time variability of the Earth's gravity field: Hydrological and oceanic effects and their possible detection using GRACE. J. Geophys. Res., 103, 30205-30229. http://doi.org/10.1029/98JB02844

IERS Conventions (2010). Gérard Petit and Brian Luzum (eds.). (IERS Technical Note ; 36) Frankfurt am Main: Verlag des Bundesamts für Kartographie und Geodäsie, 2010. 179 pp., ISBN 3-89888-989-6