**GRACE Total Water Storage (TWS) Anomaly**

This Factsheet provides a detailed technical description of the indicator Total Water Storage (TWS) Anomaly, which is implemented in the Copernicus Global Drought Observatory (GDO), and used for detecting and monitoring long-term hydrological drought conditions. The variable of the hydrological cycle upon which the TWS Anomaly indicator in GDO is based, as well as the indicator’s temporal and spatial scales and geographic coverage, are summarized below. Examples of the TWS Anomaly indicator are shown in Figure 1.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Temporal scale</th>
<th>Spatial scale</th>
<th>Coverage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Water Storage</td>
<td>monthly</td>
<td>1 degree</td>
<td>Global</td>
</tr>
</tbody>
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*Figure 1:* Examples of the Total Water Storage (TWS) Anomaly in GDO, highlighting the conditions of water stress (negative anomalies) in Australia at the end of winter / start of spring 2019.
1. Brief overview of the indicator

The Total Water Storage (TWS) Anomaly indicator that is implemented in the Copernicus Global Drought Observatory (GDO) is used for determining the occurrence of long-term hydrological drought conditions, which arise when the TWS reaches values lower than usual. This quantity is often used as a proxy of groundwater drought. The TWS Anomaly indicator in GDO is computed as anomalies of GRACE-derived TWS data - which are produced by the Center for Space Research (CSR) at the University of Texas at Austin, as scaled by the NASA Jet Propulsion Laboratory (JPL) (available at: https://podaac-tools.jpl.nasa.gov/drive/files/allData/tellus/L3/gracefo/land_mass/RL06/).
Details on the comparison between this dataset and multiple timescale SPI can be find in Cammalleri et al. (2019).

2. What the indicator shows

The Total Water Storage (TWS) is the sum of all above and below surface water storages, including canopy water, rivers and lakes, soil moisture and groundwater, and it represents a synthetic proxy of the dynamic of slow-responding hydrological quantities. The TWS remote estimates from the GRACE-FO pair of satellites are used to compute the anomaly from the climatological reference period (2002-2018), and it is updated monthly, with a latency of about 45 days. The TWS Anomaly indicator is used to detect and monitor long-term hydrological drought, which complements more fast-responding indicators, such as soil moisture and streamflow droughts.

3. How the indicator is calculated

The Gravity Recovery and Climate Experiment (GRACE) mission was launched in March 2002 with the goal to measure variations in the terrestrial gravity field (Tapley et al., 2004). The GRACE mission consisted of a pair of identical satellites, both orbiting at an altitude of about 450–500 km and around 200 km apart. Precise variations in the distance between the two satellites were measured by means of a microwave ranging system, and successively converted into temporal variations in Earth’s gravity field. A follow-on mission (GRACE-FO) was successfully launched in May 2018, and its currently operational.
For land hydrological applications, the terrestrial water storage (TWS) change is derived from the surface mass change after removing the atmospheric and oceanic contributions, which are better constrained and easier to reconstruct (Wahr et al., 2004).
This land product is derived from a gravity field composed of a set of spherical harmonic coefficients (up to a maximum order/degree of 60) after a series of post-processing procedures (see for details Landerer and Swenson, 2012), which include smoothing, destriping and glacial isostatic adjustment. In addition, grid-based scaling is introduced in order to restore the signal amplitude lost due to the application of smoothing and destriping filters, and TWS data are finally reported not as absolute values, but as deviations from the long-term 2004–2009 mean value.

TWS Anomaly indicator implemented in GDO is computed monthly as follows:

\[ TWS \text{ Anomaly}_t = \frac{TWS_t - \bar{X}}{\delta} \]

where \( TWS_t \) is the TWS value of the month \( t \) of the current year, \( \bar{X} \) is the long-term average TWS and \( \delta \) is the standard deviation, both calculated for the same month \( t \) using the available time series.
4. How to use the indicator

The GDO MapViewer allows visualizing the last available TWS Anomaly map, as well as the past archive (see Figure 2). These maps provide information on the spatial distribution of the long-term hydrological droughts, and their evolution over time.

As detailed in Cammalleri et al. (2019), the TWS Anomaly is well correlated with long-term SPI (12, 24 and 48 months), with SPI-12 representing a global-average optimal solution. This suggests that the TWS Anomaly can be used as proxy of the long-term hydrological drought, such as the ones observable in groundwater storage.

The maps of TWS anomalies can be used as a “proxy” for the presence of potential long-term hydrological drought conditions. However, given the complex nature of TWS, which summarizes numerous hydrological quantities and complex interactions, it is not surprising that a combination of several factors may be needed to explain its spatio-temporal dynamics.

Figure 2: Maps of Total Water Storage (TWS) Anomaly for the month of September 2019, produced by the processing chain in the Copernicus Global Drought Observatory (GDO).
5. Strengths and weaknesses of the indicator

Strengths:

- GRACE and GRACE-FO satellite represent a unique source of data for monitoring long-term drought at global scale.
- The combination of the data from two pairs of satellites allows retrieving TWS anomalies for a relatively robust baseline of almost 20 years.

Weaknesses:

- The latency of the TWS data provided by the NASA JPL (45 days) is sub-optimal for a near-real time monitoring.
- The spatial resolution of the TWS product, 1 decimal degree, is often too coarse, especially for analyses at sub-continental spatial scale.
- The relationship between TWS Anomaly and groundwater drought can be weak under some circumstances.

References