GLOBAL CLIMATE OBSERVING SYSTEM

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GCOS SC-28

Doc. 6.1b

(10.XI.2020)

Item 6.1

GCOS STEERING COMMITTEE

TWENTY-EIGHTH SESSION

GCOS SC-28, 24–26 November 2020

Virtual Session

Total Water Storage as an ECV

Total Water Storage as a new ECV The Steering Committee is asked to decide that Total Water Storage will be an ECV.

DRAFT DECISION (2) The Steering Committee decides that Total Water Storage (TWS) should be and ECV and asks TOPC to include it and its requirements in the next revision of the GCOS Implementation Plan.

Summary: Total Water Storage as a new ECV

1. In the course of the Public Review of GCOS Requirements for Essential Climate Variables by the end of the year 2017, a group of about 20 scientists from Germany, U.S., France, Switzerland and Austria representing a large user community from geodesy, hydrology, oceanography and glaciology proposed establishing Total Water Storage (TWS) as a new ECV. A completed proposal was presented by Andreas Güntner at the 22nd Session of the GCOS/WCRP Terrestrial Observation Panel for Climate (TOPC-22) on March 20, 2020.
2. TOPC agreed with the proposal and has forwarded this proposal to the steering committee for their consideration. The complete proposal including the TWS scope and relevance is included in the Annex to this document
3. TWS comprises all the water storage on the Earth's continental areas in frozen and liquid state, including ice caps, glaciers, snow cover, soil moisture, groundwater and surface water bodies such as lakes, man-made reservoirs, rivers, wetlands, and flooded areas. TWS change is

the only variable that allows for comprehensively closing the terrestrial water budget, balancing precipitation, runoff and evapotranspiration.

4. TWS can be observed through satellite observations of the temporal and spatial changes in the Earth's gravity field. Gravity data have been provided by the GRACE satellite mission (2002-2017) and are continued by the GRACE-Follow-On mission (GRACE-FO, launched in 05/2018). The observed gravity variations are converted to TWS change after the reduction of non-hydrological mass variations such as in the atmosphere, in the oceans, by tides and other geophysical or geodynamic processes (e.g., earthquakes and glacial isostatic adjustment). The standard temporal resolution of the GRACE/GRACE-FO based TWS change record is monthly, while higher-resolved products with down to daily resolution have recently become available for studying short-term processes such as floods or atmospheric mass variations.
5. TWS change has many uses including:

- Quantifying the net effect of changes in the climate, human water use and other hydrological effects on the continental water budget;
- Closing the terrestrial water balance;
- Identifying hot spots of changes in the water cycle assessing the severity of droughts, contributing to flood prediction by measuring the wetness status of river basins, monitoring the ice mass loss of glaciers and ice caps, quantifying the contribution of TWS to sea level rise;
- Improving the predictive skill of Earth system models through validation and calibration.

Proposed ECV

The requirements for the proposed ECV are given in Table 1.

Table 1 ECV product requirements for proposed new ECV - Thresholds*

ECV	Product	Temporal resolution	Latency	Spatial resolution	Required measurement uncertainty	Stability (per decade)
Terrestrial Water Storage (TWS)	TWS anomaly	monthly	monthly	300 km	10-20 mm, Trend 10 mm/a	No drift

*GCOS ECV guidelines: The threshold defines the minimum requirement, i.e., the value that has to be met to ensure that data are useful

Table 3 ECV product requirements for proposed new ECV – Goals+

ECV	Product	Temporal resolution	Latency	Spatial resolution	Required measurement uncertainty	Stability (per decade)
Terrestrial Water Storage (TWS)	TWS anomaly	daily	2-3 days	50 km	10-20 mm, Trend 10 mm/a	No drift

+GCOS ECV guidelines: The goals define the ideal requirements above which further improvements are not necessary. This is likely to evolve as applications and technologies progress

Further details (extracted from document prepared for TOPC)

6. As noted above, total terrestrial water storage (TWS) comprises all the water storage on the Earth's continental areas in frozen and liquid state, including ice caps, glaciers, snow cover, soil moisture, groundwater and the storage in surface water bodies such as lakes, man-made reservoirs, rivers, wetlands, and inundation areas. TWS change is the only variable that allows for comprehensively closing the terrestrial water budget, balancing precipitation, runoff and evapotranspiration. Notably, while the latter are flux variables, TWS is a state variable. As such, only TWS variations provide the full picture of hydrological changes on the continents as a consequence of climate change, climate variability, human-induced changes on Earth surface characteristics and human modifications of the water cycle such as by water withdrawals, water diversions, or irrigation. TWS changes are also an expression of coupled processes in the Earth system that are only partly understood such as biological and geological controls on the water cycle. In addition to its fundamental relevance for continental water budgets and resources, TWS change on the continents directly influences the global sea level budget.

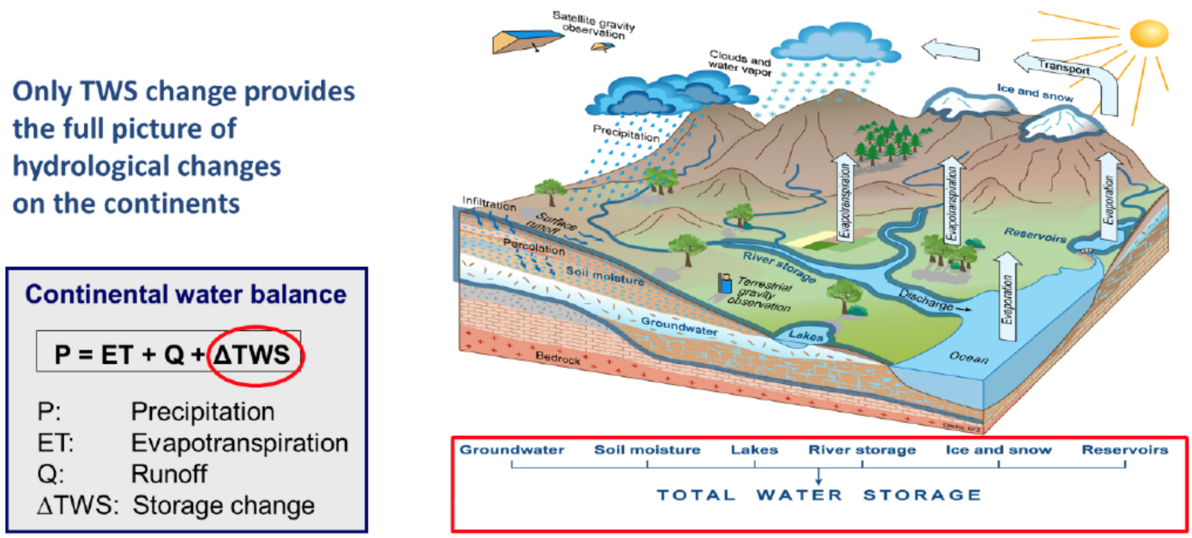

Figure 1: Total terrestrial water storage and its change as part of the continental water cycle

7. TWS change is relevant for:

- Quantifying the net effect of climatic and hydrological change on the continental water budget with TWS as a comprehensive state variable;
- Closing the terrestrial water balance;
- Revealing hot spots of climate change and human change impacts on the water cycle;
- Quantifying the impact of climate variability and climate change on water storage from sub-monthly to decadal time scales;
- Demonstrating the impact of human water use on water resources, including the unsustainable depletion of groundwater storage;
- Assessing the severity of droughts;
- Predicting the hazard of flood generation by providing a measure of the wetness status of river basins;
- Monitoring the ice mass loss of glaciers and ice caps;

- Quantifying the contribution of terrestrial water storage change to global and regional sea level rise;
- Indicating and deciphering processes of cross-cutting changes of the atmosphere, hydrosphere, the biosphere, the cryosphere, and the anthroposphere;
- Improving the predictive skill of Earth system models by validating and calibrating with TWS and by TWS data assimilation;
- Assessing climate model and re-analyses products with an independent observable;
- Evaluate seasonal to decadal climate predictions and assess long-term climate model projections.

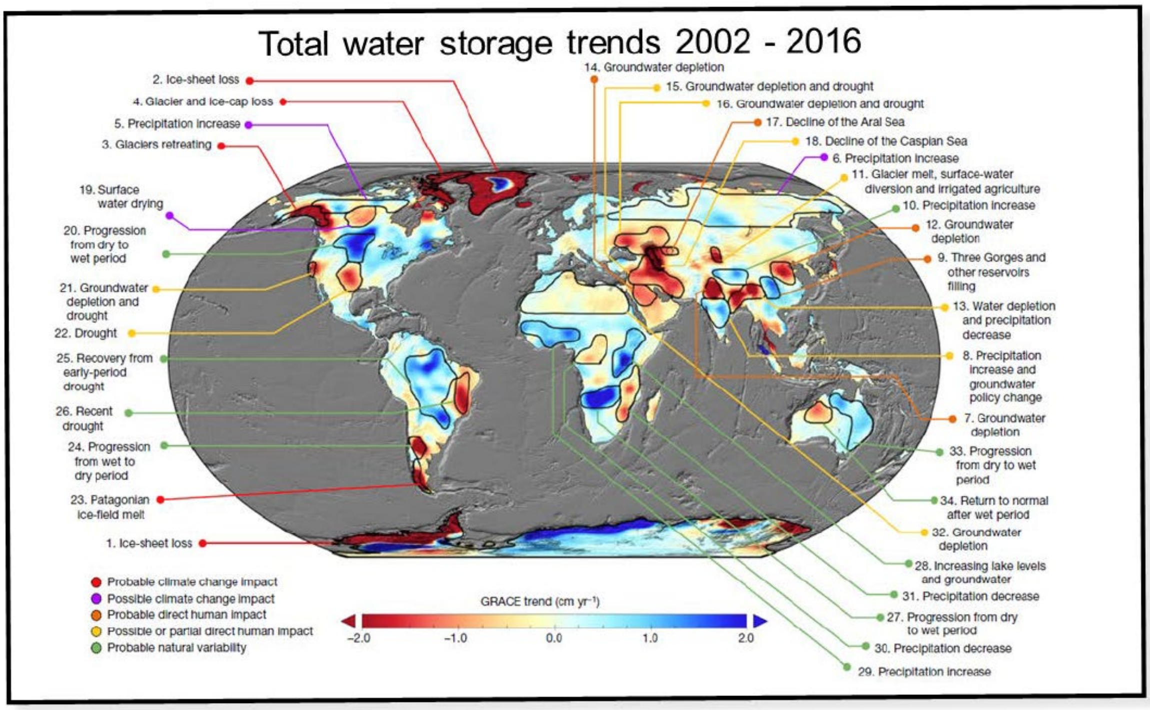

Figure 2: TWS trends from GRACE time-variable gravity data (Rodell et al., 2018)

8. Satellite observations of the Earth's time-variable gravity field provide global-scale information on mass changes on and below the Earth surface. Gravity data have been provided by the GRACE satellite mission (2002-2017) and are continued by the GRACE-Follow-On mission (GRACE-FO, launched in 05/2018). The observed gravity variations are converted to TWS change after the reduction of non-hydrological mass variations such as in the atmosphere, in the oceans, by tides and other geophysical or geodynamic processes (e.g., earthquakes and glacial isostatic adjustment). In this way, time-variable gravity data provide a unique observable of changes in the full terrestrial water column, including all aforementioned water storage compartments. The standard temporal resolution of the GRACE/GRACE-FO based TWS change record is monthly, while higher-resolved products with down to daily resolution have recently become available for studying short-term processes such as floods or atmospheric mass variations. TWS products from satellite gravimetry exhibit a trade-off between temporal and spatial resolution, though.

9. GRACE-FO data have been confirmed to consistently extend the GRACE time series with no intermission biases (Landerer et al. 2020). The combined GRACE and GRACE-FO data record of TWS anomalies thus approaches two decades. The nominal mission lifetime of GRACE-FO is 5 years. Next generation satellite gravity missions are proposed to guarantee continuation of global TWS climate data records. Most notably, NASA’s 2018 Decadal Survey defined mass change (of which TWS water mass change is a major constituent) as one of five designated observables, i.e., highest priority Earth observation needs, to guide the selection of satellite missions.

10. Processing of GRACE and GRACE-FO data to TWS products is carried out at several processing centers worldwide, following different processing strategies. GRACE and GRACE-FO Level-1 data, Level 2 spherical harmonic gravity coefficients and the Technical Notes TN-13 and TN-14 with processing standards are available at NASA's PO.DAAC (https://podaac.jpl.nasa.gov), and at the GFZ Potsdam GRACE archive ISDC (Information System and Data Center, https://isdc.gfz-potsdam.de/grace-fo-isdc/). Advances in instrument understanding and background models will allow for consistent re-processing and thus for further improving the releases of GRACE and GRACE-FO data in future. Global gridded TWS products for users with climate and hydrological applications are provided by several processing centers (e.g. the data hubs GRACE Tellus (NASA/JPL), GravIS (GFZ)) and allow for an inter-comparison and an assessment of uncertainties. Furthermore, the International Combination Service for Time-variable Gravity Fields (COST-G) is a product center of the International Gravity Field Service (IGFS) within the International Association of Geodesy (IAG) and is dedicated to the combination of monthly global gravity field models from different processing centers into a best-estimate combined product, including a regularly updated TWS product.

11. For the ECV TWS one product is proposed, which is TWS anomaly, i.e. the deviation of TWS at each time step relative to a long-term mean TWS. The rationale behind this product is that, firstly, TWS anomaly or its difference between one epoch and another (i.e., TWS change) represents the main variable for the relevant applications listed above, and, secondly, total TWS cannot be observed in absolute but just in relative values.

12. In Pail et al. (2015) (“Science and User Needs for Observing Global Mass Transport to Understand Global Change and to Benefit Society"), an international IUGG expert panel defined user requirements for TWS products from satellite gravity data. Partly based on this survey and later input from the community, threshold and goal requirements for a new ECV TWS have been defined. Threshold requirements as listed below are met by the current GRACE/GRACE-FO TWS data sets. Goal requirements are considered for the design of follow-on satellite gravity missions under consideration, and may also be approached in future by combination of satellite gravimetry with other observation techniques such as terrestrial gravimetry.
   - Spatial resolution: the length scale of TWS observations must allow for assessing climate change and human impacts on the water cycle for the major hydrological units worldwide e.g., river (sub-)basins or aquifers;
   - Spatial coverage: TWS anomaly data from satellite gravimetry have full global coverage;
   - Temporal resolution: Major TWS changes occur at (sub-)seasonal or longer time scales so that a monthly resolution is sufficient. However, for certain applications such as hydrological extremes, in particular heavy rainfall and floods, a daily resolution of TWS is required to capture the major event dynamics;

- Accuracy: the required accuracy of TWS data varies markedly with the TWS amplitude of the process / application of interest. For TWS derived from satellite gravimetry, the accuracy largely diminishes with increasing spatial and temporal resolution;
- Latency: In the case of management and early-warning applications for meteorological and hydrological extreme events such as floods and droughts, TWS data are required in near-real time. For analyzing long-term changes on the water cycle, data provision with longer latency is sufficient.

References

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