



## **Estimating the global terrestrial hydrologic cycle through modeling, remote sensing, and data assimilation**

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Documentation of the water cycle and its evolution over time is a primary scientific goal of the Global Energy and Water Cycle Experiment (GEWEX) and fundamental to assessing global change impacts. In developed countries, observation systems that include in-situ, remote sensing and modeled data can provide long-term, consistent and generally high quality datasets of water cycle variables. The export of these technologies to less developed regions has been rare, but it is these regions where information on water availability and change is probably most needed in the face of regional environmental change due to climate, land use and water management. In these data sparse regions, in situ data alone are insufficient to develop a comprehensive picture of how the water cycle is changing, and strategies that merge in-situ, model and satellite observations within a framework that results in consistent water cycle records is essential. Such an approach is envisaged by the Global Earth Observing System of Systems (GOESS), but has yet to be applied.

The goal of this study is to quantify the variation and changes in the global water cycle over the past 50 years. We evaluate the global water cycle using a variety of independent large-scale datasets of hydrologic variables that are used to bridge the gap between sparse in-situ observations, including remote-sensing based retrievals, observation-forced hydrologic modeling, and weather model reanalyses. A data assimilation framework that blends these disparate sources of information together in a consistent fashion with attention to budget closure is applied to make best estimates of the global water cycle and its variation. The framework consists of a constrained Kalman filter applied to the water budget equation. With imperfect estimates of the water budget components, the equation additionally has an error residual term that is redistributed across the budget components using error statistics, which are estimated from the uncertainties among data products. The constrained Kalman filter treats the budget closure constraint as a perfect observation within the assimilation framework.

Precipitation is estimated using gauge observations, reanalysis products, and remote sensing products for below 50°N. Evapotranspiration is estimated in a number of ways: from the VIC land surface hydrologic model forced with a hybrid reanalysis-observation global forcing dataset, from remote sensing retrievals based on a suite of energy balance and process based models, and from an atmospheric water budget approach using reanalysis products for the atmospheric convergence and storage terms and our best estimate for precipitation. Terrestrial water storage changes, including surface and subsurface changes, are estimated using estimates from both VIC and the GRACE remote sensing retrievals. From these components, discharge can then be calculated as a residual of the water budget and compared with gauge observations to evaluate the closure of the water budget. Through the use of these largely independent data products, we estimate both the mean seasonal cycle of the water budget components and their uncertainties for a set of 20 large river basins across the globe. We particularly focus on three regions of interest in global changes studies: the Northern Eurasian region which is experiencing rapid change in terrestrial processes; the Amazon which is a central part of the global water, energy and carbon budgets; and Africa, which is predicted to face some of the most critical challenges for water and food security in the coming decades.