Geophysical Research Abstracts, Vol. 8, 08045, 2006
SRef-ID:
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Global Water Cycle Variability and Change

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Earth is a unique, living planet due to the abundance and vigorous cycling and replenishing of water throughout the global environment. The water cycle operates on a continuum of time and space scales and exchanges large amounts of energy as water undergoes phase changes and is moved from one part of the Earth system to another. Water is essential to life and is central to society's welfare, progress, and sustainable economic growth. However, global water cycle variability which regulates flood, drought, and disease hazards is being continuously transformed by climate change, erosion, pollution, salinization, and agriculture and civil engineering practices. Among the most compelling global climate-change manifestations would be an intensification of the global water cycle, characterized by increased global precipitation, evaporation, river discharge, and exacerbations of extreme hydrologic regimes, such as floods and droughts. The underpinning question is to what extent global climate change (anthropogenic or natural) entails an associated water cycle response, which is fundamentally a manifestation of changes in event-based characteristics (i.e. storms and dry periods) and process-level biogeophysics (i.e. evapotranspiration). To address this question there is an unambiguous requirement for climate-quality, globally complete observations of the key water-cycle rates (i.e. precipitation and evaporation) and storages (e.g. water vapor). Regardless of the extent to which multiple sources of data (i.e. in-situ or remotely-sensed) will be used to construct these fields, it is practical to expect satellite-based measurements to provide a substantial portion of the information, particularly in areas where on-site measurements are sparse or impractical. However, a key issue that remains is an assessment of the degree to which our satellite-based observational capabilities provide a balanced, consistent global water cycle depiction.

In this study, we assess the capability of a global data compilation, largely satellite based, to faithfully depict global, vertical water fluxes, and the extent to which their spatiotemporal variations are consistent to each other and to complementary water storage variations. Global satellite-based, in-situ, and modeled precipitation, evaporation, and total precipitable water are used to update and assess our ability to characterize the global water cycle's mean state and variability. We find that the averaged annual global precipitation (P) and evaporation (E) estimates are out of balance by approximately 5% or 24,000 (metric) gigatons of water, and the imbalance exceeds the estimated uncertainty of global mean annual precipitation ($\sim \pm 1\%$). Moreover, for any given year, the annual mean flux imbalance can be on the order of $\sim$10% or about 48,000 gigatons of water. However, the interannual global precipitable water variations suggest that the imbalance should be on the order of 0.01% or about 48 gigatons of water - a finding that is consistent with results from a general circulation model (GCM) simulation. The year-to-year budgets show a substantial degree of inconsistency, with multiple years of sufficient balance preceded and/or followed by a comparable number of large, erroneous imbalances.

In light of (potential) global water cycle changes shown in GCM simulations, our ability to consistently detect or verify these changes in nature rests upon one or more of the following: quantification of global evaporation observational uncertainty, at least a two-fold increase in the consistency between the observationally based global precipitation and evaporation variations, a two-order of magnitude rectification between annual variations of E-P and precipitable water as well as substantial improvements in the consistency of their seasonal cycles, and a critical reevaluation of inter-satellite calibration for the relevant geophysical quantities used for ocean evaporation estimates – as well as the continuation of a dedicated calibration in this regard for future satellite transitions.