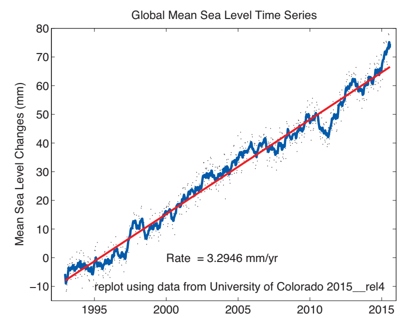
A decade of sea level rise slowed by climate-driven hydrology

Rising sea level is a threat to people living in and near coastal regions. Therefore, accurately predicting and understanding changes in sea level are critical, especially in the face of climate change. However, because of a lack of knowledge regarding the mechanisms that govern the water exchange between the land and the ocean, the fraction of global total water storage on land that contributes to changes in sea level remains unclear.

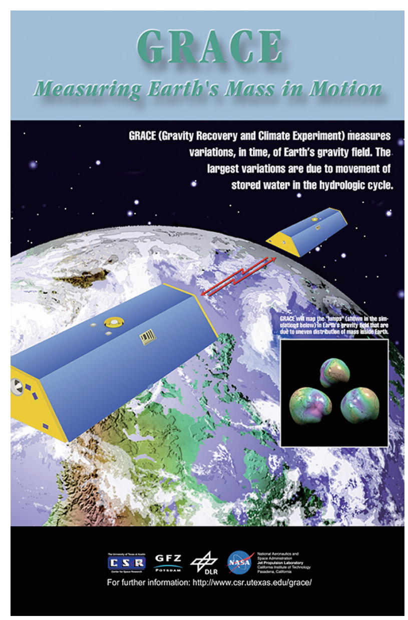
Between 2003 and 2011, mass loss from glaciers and ice sheets continuously increased, whereas the rate of sea level rise decreased to 2.4 mm/year (from approximately 3.3 mm/year between 1993 and 2002). Climate-driven changes in land water storage have been suggested to contribute to this decrease in the rate of sea level rise, but direct observations have not been available to verify this speculation. In a recent study, we found that while the ice sheets and mountain glaciers continue melting, changes in climate between 2003 and 2014 have caused continental land areas such as soils, lakes, and groundwater aquifers to store extra water (approximately 3.2 trillion tons). This storage temporarily decreased the rate of sea level rise by approximately 20% and can be considered a "climate-driven sea level change".

Because of the lack of observations, the effects of climate-driven sea level rise have not been given sufficient attention in Intergovernmental Panel on Climate Change (IPCC) sea level budgets. Recent satellite measurements collected during a time-variable gravity mission, GRACE (Gravity Recovery and Climate Experiment, launched in 2002), have enabled us to estimate the water storage changes at the continental scale and to quantify climate-driven sea level rise. Our results show that from 2003 to 2014, climate-driven land water storage was of opposite sign and similar magnitude as ice losses from glaciers and ice sheets, and was nearly twice as large as mass losses from direct human-driven changes (groundwater withdrawal and dams) in land water storage. Between 2002 and 2014, climate variability resulted in an additional 3200 ± 900 gigatons of water storage on land. This gain partially offset water losses from ice sheets, glaciers, and groundwater pumping and slowed the rate of sea level rise by 0.71 ± 0.20 mm per year. However, such contributions from land water storage are not permanent—they are a form of climate variability and may change in the future. Thus, land-based hydrology has masked the true rate of sea level rise and may also exaggerate the rate of sea level rise in the future.

Our results show that climate-driven changes in land water storage are now observable on a global scale, and these changes are large and necessary for the closure of decadal-scale sea level budgets. The findings



Global mean sea level changes from 1993 to 2015. Data are from Nerem, R. S., D. Chambers, C. Choe, and G. T. Mitchum. "Estimating Mean Sea Level Change from the TOPEX and Jason Altimeter Missions." *Marine Geodesy* 33, no. 1 supp 1 (2010): 435.



Gravity Recovery and Climate Experiment (GRACE) mission. This figure was prepared by The University of Texas Center for Space Research as part of a collaborative effort with the NASA Jet Propulsion Laboratory and the GeoForschungsZentrum Potsdam.

improve upon previous estimates by accounting for feedback between the land, ocean, and atmosphere, and highlight the importance of the land-hydrological cycle and its interactions with climate when assigning contributions to changes in sea level.

Reference
John T. Reager, Alex S. Gardner, James S. Famiglietti, David N. Wiese, Annette Eicker, Min-Hui Lo. (2016) A decade of sea level rise slowed by climate-driven hydrology. *Science*, 351(6274), 699-703. DOI: 10.1126/science.aad8386

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Recent increases in extreme rainfall during typhoons in Taiwan

Role of global warming questionable

Taiwan, which is situated in one of the main paths of western North Pacific tropical cyclones (TCs), has experienced a series of TCs with an extraordinary amount of rainfall since the late 1990s. As of 2015, 11 of the top 15 typhoons based on total rainfall since hourly rainfall observations began in 1960 have occurred in the 21st century. The most extreme case was the record-breaking Typhoon Morakot in 2009. This eventcaused considerable economic losses and casualties and became the first natural disaster in Taiwan to trigger the resignation of the Premier. Some scientists have warned that because of anthropogenic global warming, this large increasing trend in extreme rainfall will continue into the future with dire consequences,as has been widely reported in the media.

The assertion that global warming will cause a dramatic increase in rainfall in Taiwan is based on the fact that as the temperature rises, the capacity of water vapor in the air expands. The thermodynamic law governing this relationship predicts that for every 1 °C of warming, the water vapor capacity increases by 7%. Therefore, the probability and amount of extreme rainfall will increase, and dynamic storm processes can further increase these effects through feedback mechanisms.

A team of researchers from the National Taiwan University (NTU) Department of Atmospheric Sciences led by Professor Hung-Chi Kuo and including doctoral students Yi-Ting Yang (now a postdoctoral researcher) and Li-Huang Hsu collaborated with Distinguished Professor Chih-Pei Chang (visiting from the U.S. Naval Postgraduate School) to tackle this problem. They found that while the increase in rainfall in recent decades is a manifestation of climate change, it would be a mistake to attribute the apparently large increasing trend of typhoon rainfall to anthropogenic global warming[1,2].

The research team usedhourly rainfall data averaged over 21 stations in Taiwan (Fig. 1a) and collected during the 91 typhoons that made landfall from 1960-2015. When all typhoons are considered together, the rainfall intensity exhibitsa large increasing trend over the period. To look for the possible cause of this trend, they separated the typhoons according to the track type of each storm, as defined by the Central Weather Bureau, and focused on the three leading track types that directly cross Taiwan:the Northern type (N, Fig. 1b), Central type (C, Fig. 1c), and Southern type (S, Fig. 1d). The average separation between adjacent track types is approximately 110 km, which is about half of the length of the Central Mountain Range (CMR) shown in Fig. 1a.

An important factor that affects the amount of typhoon rainfall is the terrain effect of the