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Remote Sensing Of Total Water Storage Variability During Extreme Heat Waves

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REMOTE SENSING OF TOTAL WATER STORAGE VARIABILITY DURING EXTREME HEAT WAVES

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ABSTRACT

Droughts and heat waves are a major hazard for food & water security, economic development, and human & ecosystem health, among others. Over the last decade, short-term but exceptional heat waves have been observed across different regions of the world, with several locations experiencing all-time maximum temperature records and soil moisture deficits. While many studies have suggested that the extreme intensity of such recent events can be attributed to a changing climate, little attention has been given to the impacts on the terrestrial water balance. This work assesses the impact of total water storage to the 2010 Northern Hemisphere extreme heat wave in the Middle East, Russia and Sahel. The main objective is to infer the response of extreme dry spells to total water storage decline using water storage deficit indicators. The methodology used in this study is based on satellite remote sensing of terrestrial water storage variations obtained from the Gravity Recovery and Climate Experiment (GRACE) mission. The results suggest that extreme heat waves do not always enhance depletion of total water storage, mainly, its groundwater component.

INTRODUCTION AND OBJECTIVES

The intensification of extreme climate events and their impacts on the human environment and its physical infrastructure have been steadily increasing over the last decade (Rahmstorf and Coumou, [1]). The implications and economic costs of such natural catastrophes on water, food and human security have become a major concern and for such reasons it is necessary to improve the characterization of those events (Houbourg et al., [2]).

Natural hazards associated with extended periods of high temperatures and low precipitation, such as droughts and heat waves, enhance groundwater resources depletion after surface water reservoirs have are diminished during the early stages of extreme dry events. Droughts and heat waves have increased substantially over the last years across the world with recent research suggesting the link between climate change and an increase in the severity of such anomalies (Prudhomme et al., [3]). Most of such recent studies have focused in evaluating the magnitude, duration and severity from a meteorological perspective, leaving aside the impacts of those events on the terrestrial hydrological cycle. Monitoring such impacts on surface water and groundwater can be quite difficult mainly due to the lack of reliable information on quantitative groundwater changes, especially in remote areas with limited information on spatial and temporal variability of groundwater levels.

Satellite based remote sensing tools such as the Gravity Recovery and Climate Experiment (GRACE) have the potential to overcome the observational gap of monitoring terrestrial water storage changes. The GRACE satellite provides monthly changes in total water storage on the basis of fluctuations of the Earth's gravity field. Total water storage as inferred from the GRACE mission, represents vertical estimates of water storage that includes groundwater, soil moisture, surface water, snow and ice, and biomass (Tapley et al., [4]). Large scale hydrological studies using GRACE data have been aimed at the assessment of aquifer storage changes, drought characterization, and flood risk variability, among others. Despite its wide range of applications, the impact of extreme dry spells on terrestrial water storage has rarely been monitored with few exceptions (Andersen et al., [5]). The aim of this work is to detect the sensitivity of terrestrial water storage to intense heat waves across different hydroclimatic regimes.

METHODS AND DATA

The study area involves three rectangular domains located in Western Russia, the Central region of the Middle East and Eastern Sahel (Figure 1). These regions were severely affected during the 2010 Northern Hemisphere summer heat wave, which caused economic damages worth 500 billion USD, almost 18,000 deaths and millions of hectares of forest and cropland destroyed. Although the heat wave onset and end, occurred from April to October 2010, it is between the month of June and August that maximum temperature records, sometimes exceeding 50°C, were established across many locations in those regions. Due to data availability and control quality reasons, GRACE data were used instead of direct observations in rivers, reservoirs and aquifers of the three regions. Processed and quality-controlled estimates of total water storage anomalies from the GRACE satellite CSR-RL05 version (Landerer and Swenson, [6]) were obtained during 125 months from March 2003 to July 2013. This gridded product consisted of monthly land water thickness equivalent with 1 x 1 degree resolution, expressed in mm month^{-1}. The water storage anomalies were estimated as the variation between monthly water storage values and the five-year average from January 2004 to December 2009. A total of 6 monthly anomalies values that were not available in the post-processed grid were estimated as the average from the previous and subsequent month. Errors due to leakage after filtering and rescaling and, due to measurements from the sensors were computed. GRACE cells with an error higher than 50 mm were removed. Water storage deficits (Thomas et al., [7]) were computed by subtracting mean monthly water storage anomalies from the time series.

RESULTS

Monthly time series show a contrasting response of terrestrial water storage during the peak of the heat wave (Figure 2). For example, Western Russia was the most affected region (Figure 2, top, blue line) followed by the Middle East and Sahel. While the Middle East region was already feeling the impacts of the on-going drought that started in 2008, the heat wave broke temperature records in Bahrain, Iraq, Jordan, Kuwait and Qatar during June, July and August. Such extreme period of high temperature and air dryness, however, was not reflected in the depletion of water storage (Figure 2, top, green line), especially in the Southern part of the Arabian Peninsula (not shown). The Eastern Sahel region was characterized by low amplitude signals compared to the other 2 study regions with the southern part showing the largest variations, probably caused by the rapid depletion of surface water storage, notably the Lake Chad, to extreme aridity conditions. Spatial variability of total water storage was however larger in Middle East than in Russia (Figure 2, bottom). A possible explanation is that total storage in the Northern countries of the Middle East domain (Turkey, Syria, Iraq) is strongly dependent on surface water reservoirs for irrigation and hydropower purposes, mainly. Over the last 10 years, storage water deficits have dominated the Middle East region, in terms of duration and intensity, when compared to Russia, with a short duration but intense deficit and, the Sahel, characterized by its long duration but low to moderate storage deficit (Figure 3).

Total water storage in Russia and the Middle East not only experienced a strong decline during the summer-autumn of 2010 but also a lag time, ranging from 1 to 3 months, between the peak of the meteorological and hydrological drought. This suggested that the subsurface water storage components have multi-week response times when severe declines in precipitation and atmospheric evaporative demand occur. For those regions where water storage anomalies were not affected during the heat wave period and surface water sources were scarce (Northern Sahel, Arabian Peninsula), it is likely that summer precipitation rarely affects the deep subsurface storage component, even during normal conditions. Also, such lack of hydrological response implies that the subsurface water storage in semi-arid and arid environments can be remarkably resilient to climate extremes.

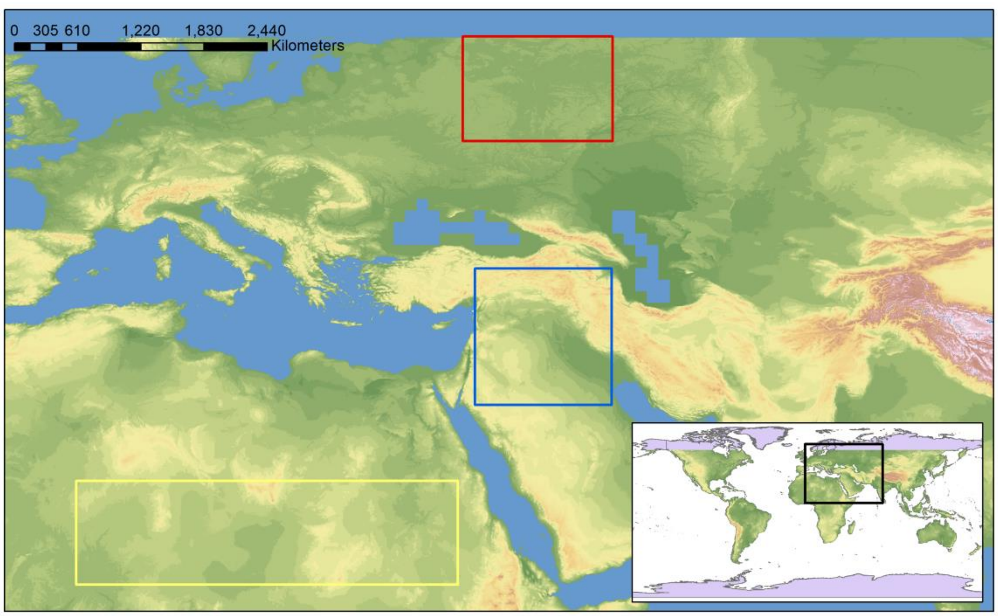

Figure 1: Location of the study regions: Western Russia (red box), Central Middle East (blue box) and Eastern Sahel (yellow box).

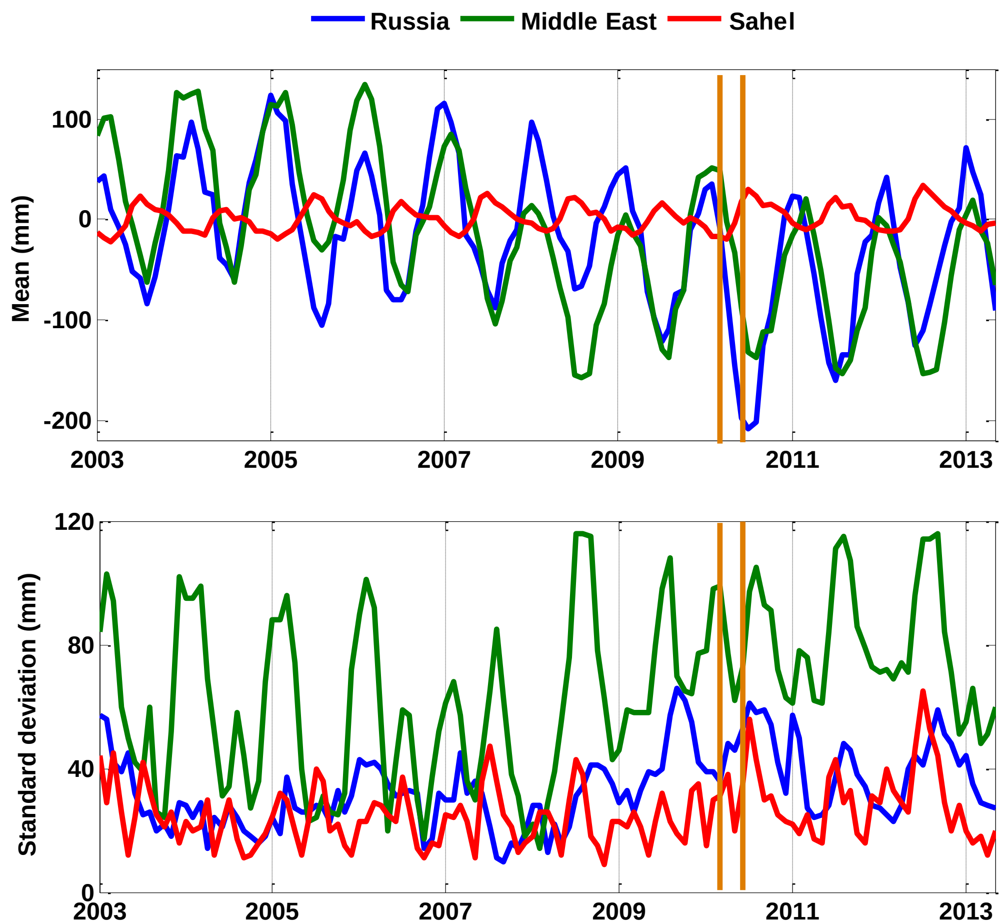

Figure 2: Spatial averaged water storage anomalies time series from 2003 until 2013 (top) and its standard deviation (bottom) for Western Russia (Blue), Central Middle East (Green) and Eastern Sahel (Red). Orange vertical bars denote the foremost period (May-August) of the 2010 Northern Hemisphere summer heat waves. GRACE errors for Russia, Middle-East and Sahel are 36, 49 and 20 mm, respectively.

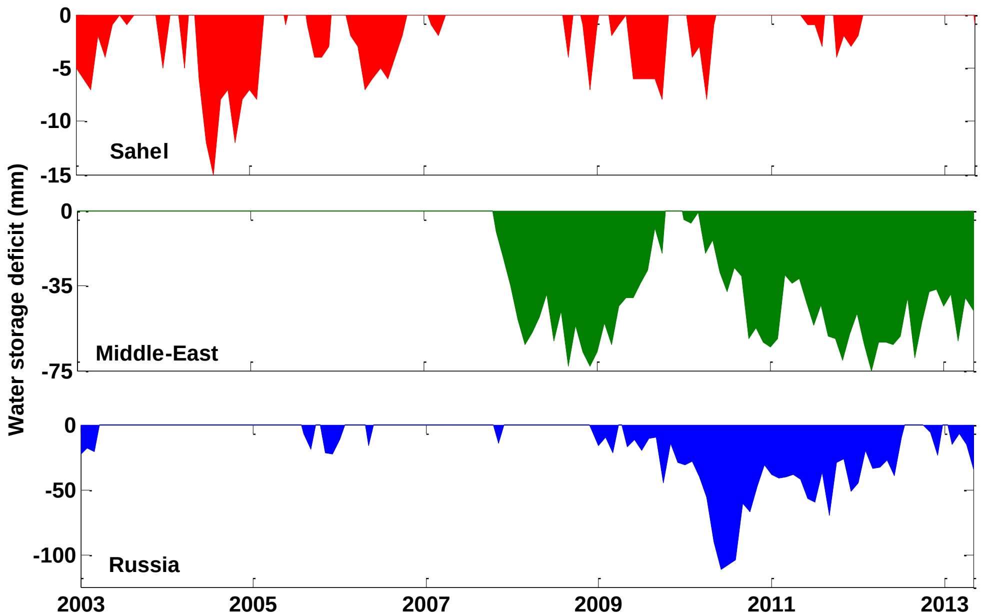

Figure 3: Water storage deficits between 2003 and 2013 for Eastern Sahel (top), Central Middle-East (middle) and Western Russia (bottom)

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