Groundwater Depletion in the Mississippi Delta as Observed by the Gravity Recovery and Climate Experiment (GRACE) Satellite System

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The Gravity Recovery and Climate Experiment (GRACE), launched in early 2002, is a satellite mission jointly managed by the US National Aeronautics and Space Administration (NASA) and the German Aerospace Center (DLR). Its goal is to map Earth's gravity field with high precision, approximately on a monthly basis. Global representations of Earth's gravity field are produced based on a K-band microwave system, which measures the distance (loosely controlled at about 220 km) between two identical satellites nearly continuously as they revolve in a tandem, near polar orbit, at an initial 485 km altitude. The gravitational effects of changes in atmospheric surface pressure and ocean bottom pressure are removed using numerical model analyses, such that the remaining variability can be attributed primarily to the redistribution of terrestrial water storage, thus provide measurements of column integrated terrestrial water storage (TWS) for the entire globe. Several recent studies clearly demonstrated that GRACE-derived estimates of variations of total water storage (all of the snow, ice, surface water, soil water and groundwater in a region), when combined with auxiliary hydrological datasets, can provide groundwater storage change estimates of sufficient accuracy to benefit water management. This paper summarizes the recent studies that conducted to investigate the groundwater depletion in the Mississippi Delta using GRACE data. This paper also presents the results obtained from the analysis of last ten years monthly GRACE Level 3 data for the Mississippi Delta areas.

Introduction

GRACE is a satellite mission jointly managed by the US National Aeronautics and Space Administration (NASA) and the German Aerospace Center (DLR). This mission is dedicated to map Earth's gravity field with high precision, approximately on a monthly basis (Tapley et al. 2004). The mission was launched in March 2002 and is continued providing high quality data. It's operation is based on a K-band microwave system, which measures, nearly continuously, the range (maintained at about 220 km) between two identical satellites as they revolve in a tandem, near polar orbit, at an initial altitude of 485 km. It produces global representations of Earth's gravity field on a near-monthly basis as sets of spherical harmonic coefficients up to degree and order 120, based on highly precise K-band microwave measurements of the distance between two identical satellites orbiting Earth in tandem (Tapley et al. 2004). The process is based on the technique that analyzes the variance spectrum of GRACE spherical harmonic coefficients as a function of degree and order, and compare it with an analogous variance spectrum derived from modeled water storage fields, with the goal of maximizing the signal-to noise ratio in the GRACE retrievals.

The non-hydrological gravitational contributions are removed from GRACE level 2 data products based on numerical models of the underlying processes, including atmospheric and oceanic circulation and solid Earth tides. That means, the gravitational effects of changes in atmospheric surface pressure and ocean bottom pressure are removed using numerical model analyses, such that the remaining variability can be attributed primarily to the redistribution of terrestrial water storage. Therefore, measurements of column integrated terrestrial water storage (TWS) for the entire globe are obtained.

The horizontal resolution of GRACE is limited to about 150 000 km^2 (Rowlands et al. 2005; Yeh et al. 2006).

Vertically, the GRACE TWS observation is a single number that integrates changes in groundwater, soil moisture, vegetation, surface water, snow, and ice. To realize the full potential of GRACE for hydrology, the derived regional-scale column-integrated monthly water storage anomalies must be disaggregated horizontally, vertically, and in time. Therefore, skillful disaggregation of GRACE terrestrial water storage anomalies into changes in these individual components would greatly improve their value for hydrological research and applications.

One approach for vertical disaggregation of GRACE data is to use auxiliary information to isolate individual components. Rodell et al. (2007) computed groundwater storage variations averaged over the Mississippi River basin and its four major sub-basins by using soil moisture and snow water equivalent output from the Global Land Data Assimilation System (GLDAS)(Rodell et al. 2004) to estimate and remove those components from GRACE TWS, assuming vegetation and surface water contributions to be negligible.

Another approach is based on a more sophisticated disaggregation method to merge GRACE-derived TWS with the one simulated by a land surface model (LSM) via data assimilation. This approach has a number of advantages. First, despite coarser spatial resolution, the GRACE observations yield reasonably reliable estimates of TWS anomalies (Swenson et al. 2006). Therefore, assimilation of these data into an LSM has the potential to improve the accuracy of TWS in LSM simulations (Ellett et al. 2006), much as assimilation of remotely sensed snow cover (Clark et al. 2006; Rodell and Houser 2004), snow water equivalent (Slater and Clark 2006), soil moisture (Reichle et al. 2007), and skin temperature (Bosilovich et al. 2007) have had a positive impact on LSM simulations. Second, our current understanding of hydrological processes, as captured by the model, is used to enhance the satellite observations, and provide downscaling and quality control of GRACE observations while enabling the synthesis of multiple observation types in a physically consistent manner. Third, an assimilated observation of TWS influences a number of processes within an LSM in addition to water storage.

GRACE Level 3 Data

GRACE Level 3 data provides monthly land mass grids that contain terrestrial water storage anomalies (in aquifers, river basins, etc.) from GRACE time-variable gravity data relative to a time-mean. Each monthly grid represents the difference in the masses for that month, and the average over Jan 2004 to Dec 2009. The data covers entire globe from July 31, 2002 to present time. The spatial resolution of the data is 1 degree (Latitude) x 1 degree (Longitude). It is in Geographic projection with WGS 84 Ellipsoid. The data can be obtained in NETCDF format (release 5.0) from http://podaac.jpl.nasa.gov/dataset/TELLUS_LAND_NC_RL05. Figure 1 and Figure 2 show the processed GRACE Level 3 data for the entire globe and the US respectively.

Ground Water Depletion in MS Delta

In Mississippi ground water constitutes 80% of all the freshwater used and serves the water-supply needs for the majority of the population. The demand for freshwater supplies is expected to increase due to increasing population and the accompanying economic growth. The Mississippi River Valley alluvial aquifer is the most heavily pumped aquifer in Mississippi. It supplies about 2 billion gallons per day of water for agricultural and industrial use in the Mississippi Delta.

In the Mississippi embayment area water resources have a profound effect on the economy, which is based largely on agriculture. Mississippi ranks first for aquaculture and fourth for cotton in 2007 with a total value of over $600 million (U.S. Department of Agriculture, 2010).

Ground water depletion in the Mississippi embayment area including Mississippi Delta is a major concern. Konikow (2013) reported that the total net volumetric ground water depletion in the Mississippi embayment area during the period of 1900-2000 and 1900-2008 are 117.6 km^3 and 182.0 km^3 respectively.

MS Delta ground water study using GRACE Level 3 data

The need for the ability of the techniques to monitor ground water depletion regularly in the Mississippi Delta is very important. This study attempted to explore the potential of GRACE Level 3 data to study the Mississippi Delta GW depletion.

Methods

The GRACE Level 3 gridded data were obtained from NASA Jet Propulsion Laboratory (JPL) (http://podaac.jpl.nasa.gov/dataset/TELLUS_LAND_NC_RL05) for the period July 2002 to October 2013. The data were received in NETCDF format. The NETCDF dataset was processed in Arc GIS 10.2 software to produce global gridded data in geographic coordinate system (using WGS 84 datum). In this research only one month from each yearly dataset was processed (Figure 1).

The monthly ground water depletion data for the United States as shown in Figure 2 were acquired by clipping the global gridded data using the administrative GIS data of the United States. This obtained gridded GRACE data provides ground water depletion information in cm at every 100 km X 100 km areas. This grid data was converted to point coverage so that the ground water depletion information for the Mississippi Delta can be acquired using spatial analysis technique.

The boundary of Mississippi Delta area was obtained from the physiographic map of Mississippi as shown in Figure 3. The Mississippi Delta bounding polygon was used to extract the ground water depletion data within the delta areas. It was found that only two measurements were available from GRACE data for using in the delta area, one in the northern side and other in the southern side. Figure 4 shows the Mississippi Delta boundary and the GRACE data points available to study the ground water depletion in the delta. The points corresponding to these two measurements were extracted from the GRACE data point coverage. These two point locations were used to extract ground water depletion data for the month of January for each year from 2003 to 2010 and 2013. Ground water depletion data were also extracted from 2002 and 2011 for the months of August and February respectively.

Results and Analysis

The obtained monthly ground water depletion data were analyzed in Microsoft Excel to study the trend of ground water depletion in the delta areas. Figure 5 shows the trend of the ground water depletion from the scatter plots for the period between 2002 and 2013 in the northern side of the Mississippi Delta. Figure 6 shows the trend of the ground water depletion from the scatter plots for the period between 2002 and 2013 in the southern side of the Mississippi Delta. This analysis shows that although the amount of ground water recharge and depletion in each year was different the overall trend indicates ground water depletion in the delta. The trend is similar in both northern and southern parts of the delta.

Conclusions and Discussion

Ground water depletion in the Mississippi Delta is one of the most important issues in this region. It would be very useful to have the capability to monitor the ground water level changes all over the delta at regular basis. This study explored the potential of the Gravity Recovery and Climate Experiment (GRACE) Satellite System derived ground water level changes estimation data to study the ground depletion in the Mississippi Delta. The results of the analysis using a 13 year period time series of GRACE Level 3 data indicate that GRACE can be used to study and monitor ground water depletion in the Mississippi Delta at regional scale. However, appropriate downscaling technique using in situ microgravity measurements can be useful to make the GRACE data applicable to study ground water depletion in the Mississippi Delta at more local scale. Future research is needed in this direction.

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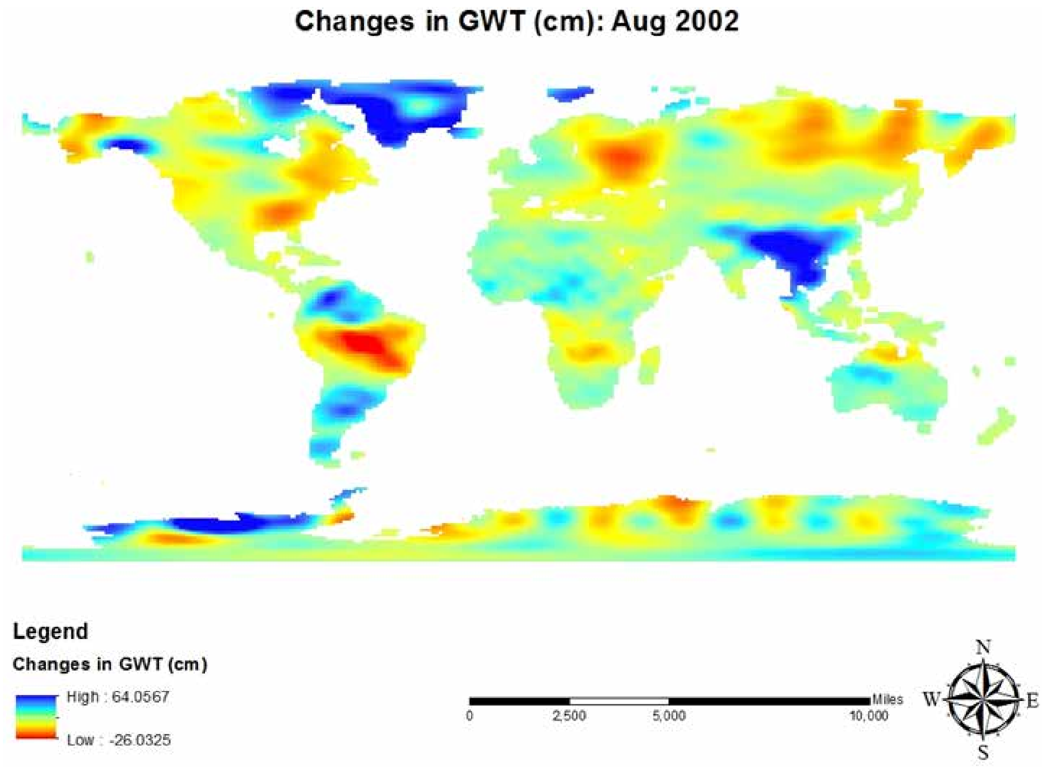

Figure 1. Processed GRACE Level 3 data for the entire globe

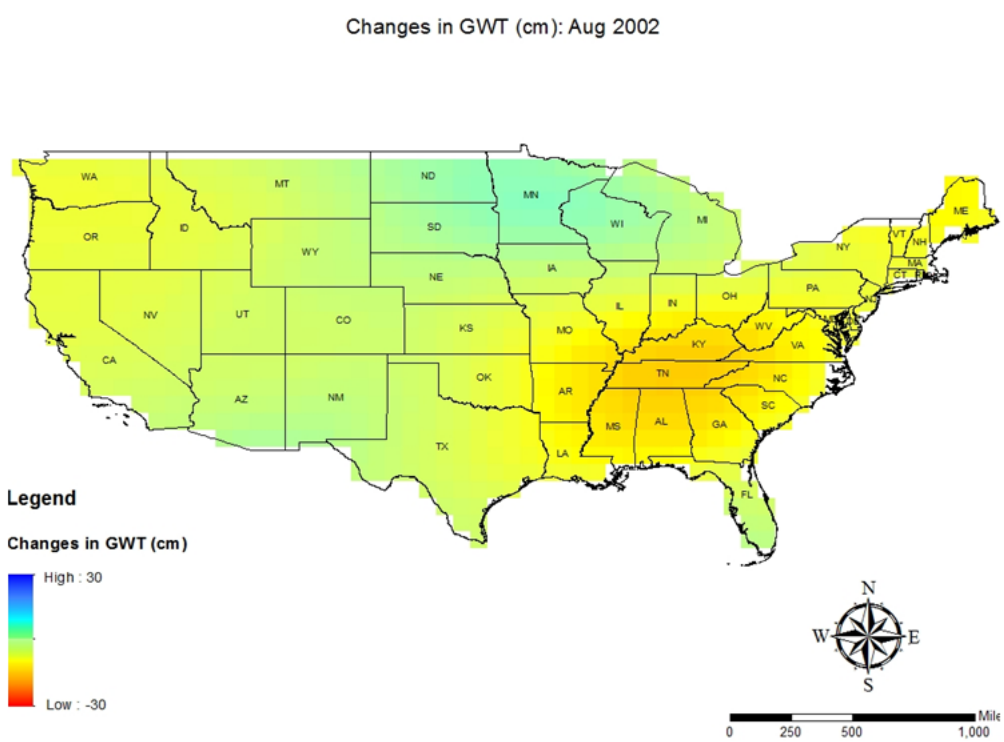

Figure 2. Processed GRACE Level 3 data for the United States

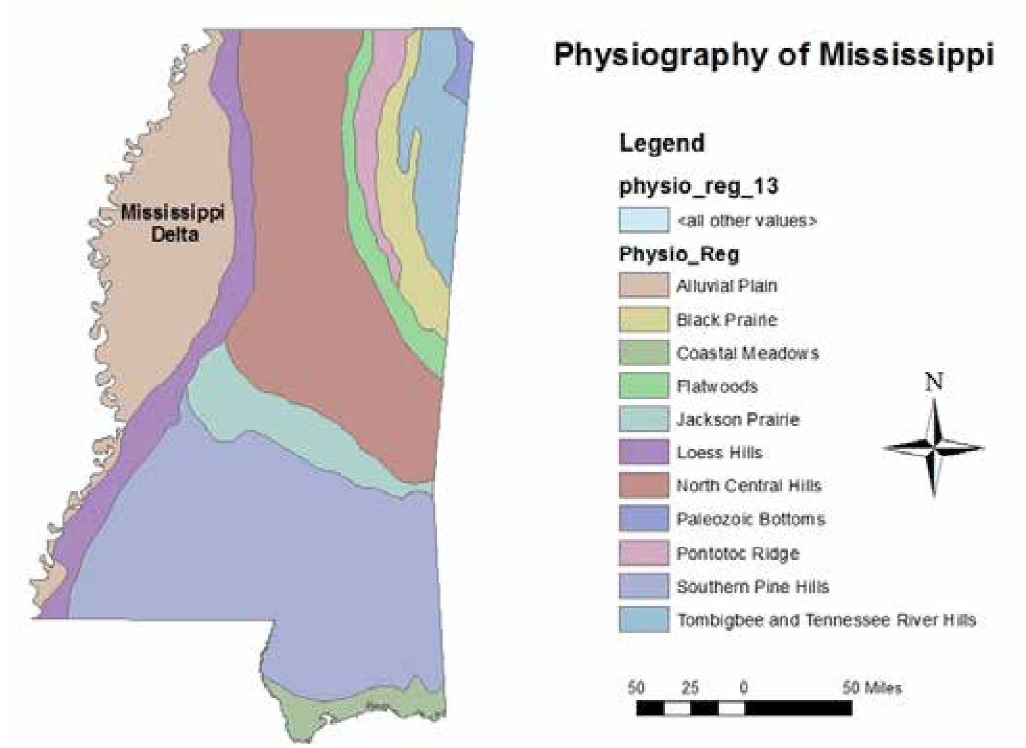

Figure 3. Physiographic map of Mississippi showing the delta region

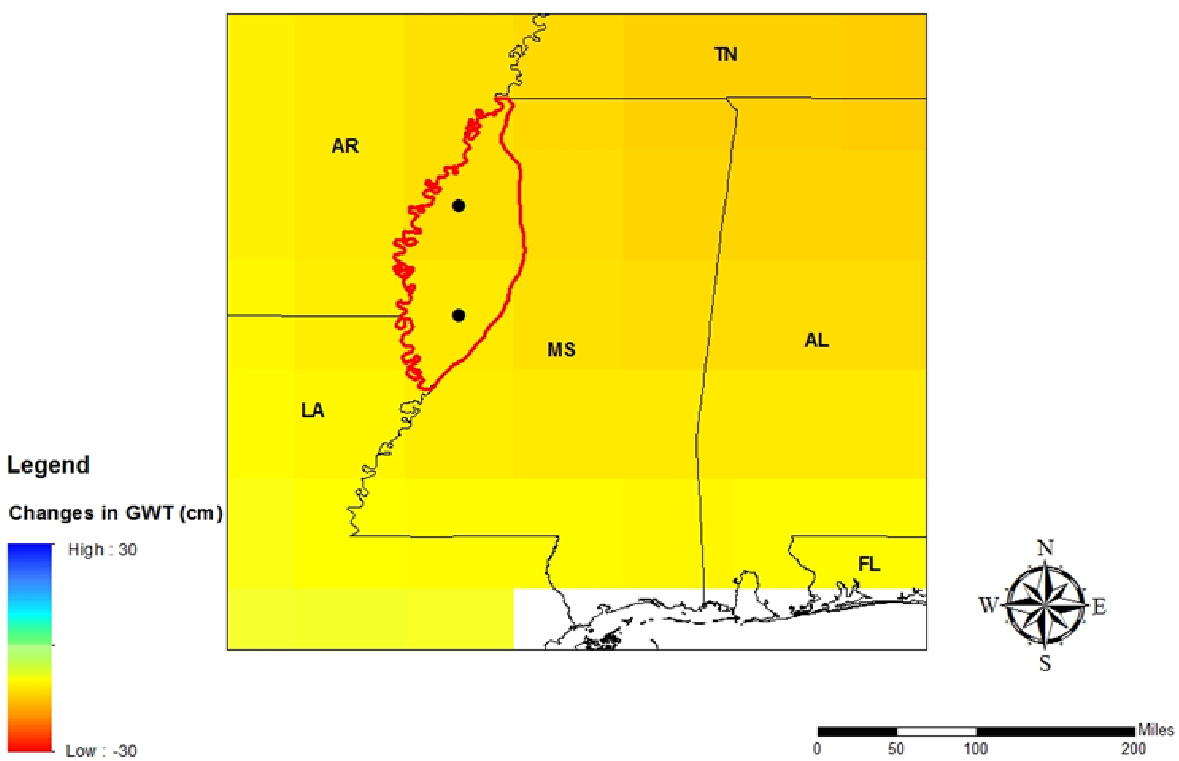

Figure 4. Mississippi Delta boundary and the GRACE data points available to study the ground water depletion in the delta region

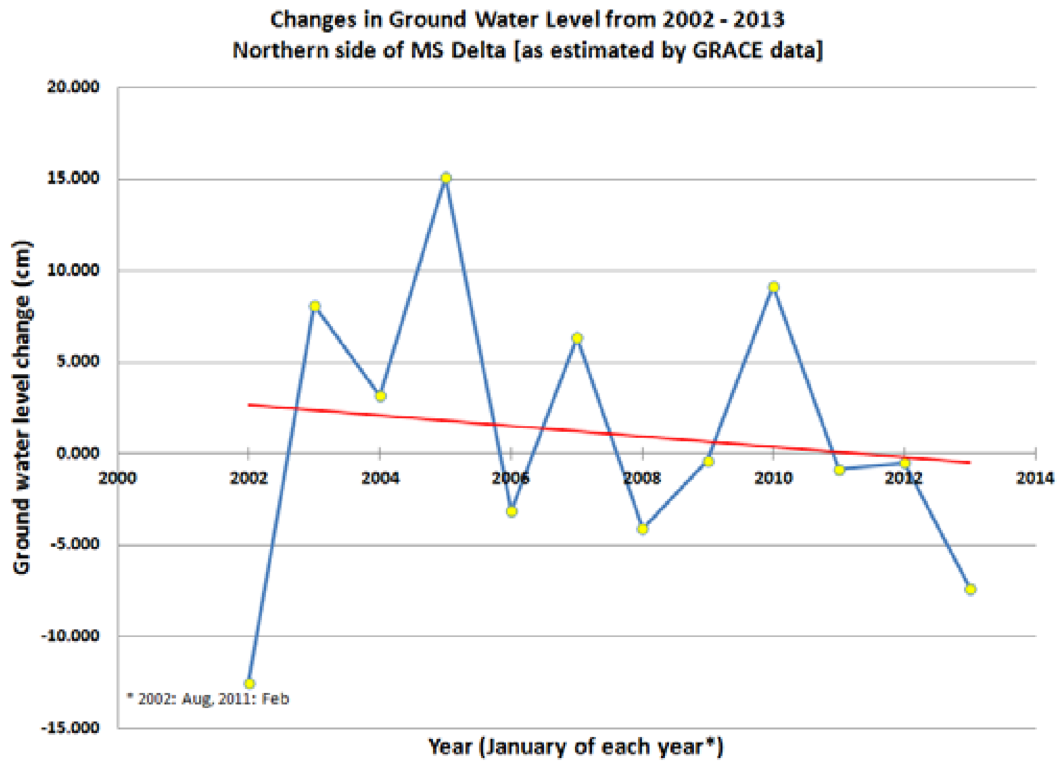

Figure 5. The trend of the ground water depletion in the northern side of the Mississippi Delta for the period between 2002 and 2013

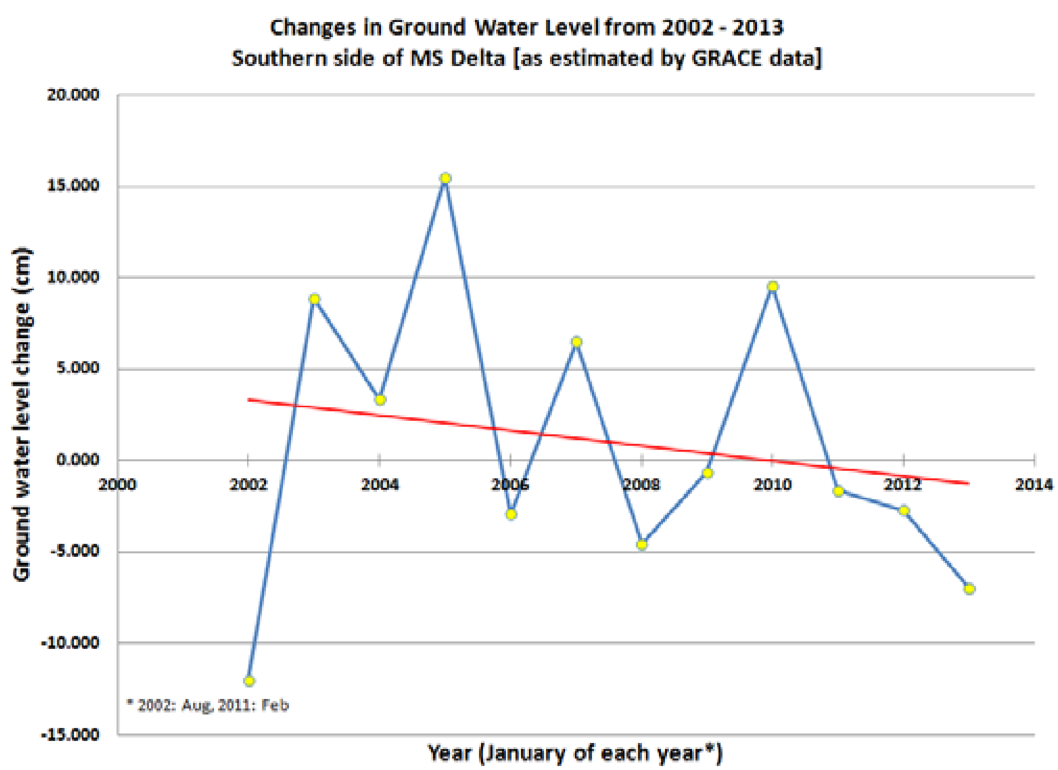

Figure 6. The trend of the ground water depletion in the southern side of the Mississippi Delta for the period between 2002 and 2013