

Studying the Potential Impact of Groundwater Depletion on Surface Vegetation in the Mississippi Delta Using Remote Sensing

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ABSTRACT:

The fertile soils of the Mississippi Delta physiographic province allow for the region to be a large producer of cotton, soy, rice, and other crops for commercial use. However, the extensive use of groundwater for irrigation raised concerns about the possible depletion of groundwater in this region. Therefore, it is important to understand the potential impact of groundwater depletion on surface vegetation in the Mississippi Delta region. The Gravity Recovery and Climate Experiment (GRACE) satellite data provides the opportunity to monitor the changes in the groundwater surface through recording gravity fluctuations over the entire planet, with data released every month. Pairing information provided by GRACE with the Moderate Resolution Imaging Spectroradiometer (MODIS) Normalized Difference Vegetation Index (NDVI) data, it is possible to see if there is a correlation between the changes in the groundwater levels over a period from 2011 to 2020, and the overall vegetative health of the region. This paper presents the obtained preliminary results of this study.

INTRODUCTION

The fertile soils of the Mississippi Delta physiographic province allow for the region to be a large producer of cotton, soy, rice, and other crops for commercial use. However, the extensive use of groundwater for irrigation raised concerns about the possible depletion of groundwater in this region. Therefore, it is important to understand the potential impact of groundwater depletion on surface vegetation in the Mississippi Delta region. The Gravity Recovery and Climate Experiment (GRACE) satellite data provides the opportunity to monitor the changes in the groundwater surface through recording gravity fluctuations over the entire planet, with data released every month. Pairing information provided by GRACE with the Moderate Resolution Imaging Spectroradiometer (MODIS) Normalized Difference Vegetation Index (NDVI) data, it is possible to see if there is a correlation between the changes in the groundwater levels over a period from 2011 to 2020, and the overall vegetative health of the region. This research is a continuation of GRACE research that was performed in the Mississippi Delta by Hossain (2014).

Gravity Recovery and Climate Experiment (GRACE)

GRACE and GRACE Follow On (FO) are a pair of satellites in low earth orbit that measure changes in gravity over the surface of the earth. The pair of satellites measures these fluctuations by monitoring the distance between the two satellites as they orbit in near polar orbit. The first of the two satellites will be “pulled” toward a larger mass and increase the distance between it and the trailing satellite. As the trailing satellite approaches the same mass, it will also be pulled toward the mass and bridge the distance between the two satellites. These changes in the distance between the satellites is measured by a precise k/ka-band ranging assembly, that can detect a change in distance of 1 micron (NASA, 2018).

The pair of satellites are used to measure the fluctuation in Ground Water Height (GWH) over the respective area when compared to an average of the GWH over previous measurements (Anapalli, 2022). This approach allows the observer to detect fluctuations in the GWH over the same month, which outside of some potential outliers, should have similar weather and natural processes occurring during that month over time.

Moderate Resolution Imaging Spectroradiometer (MODIS)

MODIS NDVI is readily available for download from NASA and the USGS. Due to the demand and many applications of NDVI imagery, these agencies have provided files where the calculations have already been performed, and the imagery is ready for observation or application upon receiving the file. NDVI pixel values range from -1 to 1, and the higher the value is to one the higher the chance of vegetation being present. NDVI pixel values that are closer to 1 are often thought of being representative of healthier vegetation, being that they are absorbing more of the red of the electromagnetic spectrum and reflecting more of the Near Infrared of the spectrum.

Methods

GRACE global data was obtained for the period of 2011 to 2020 and processed in ArcMap 10.8.1. Each set of data was clipped to a smaller area that was comprised of Mississippi, Arkansas, and Louisiana. A shapefile of the Mississippi Delta physiographic region was acquired from the Mississippi Department of Environmental Quality and placed over the processed imagery (Figure 1). Due to the large size of the GRACE pixels, 12,100 km², any pixels that were in contact with the delta boundary were captured and included in the sample size. This application led to a total of eight GRACE pixels that were either located in or tangential to the Mississippi

Grace Boundary. MODIS NDVI data were obtained for the same time and clipped to the same area as the GRACE pixels. After processing the entirety of GRACE and MODIS data, both sets of data were converted from raster to point (Figure 2). The spatial join geoprocessing tool was utilized to join the both the GRACE and MODIS point values for each month of data. Each NDVI MODIS point that was located within a 0.5° radius of each of the GRACE pixels was averaged and assigned to the initial GRACE point. This allowed for an easier comparison of both sets of data and different ways to look at the provided values.

The data from each of the monthly sets were exported from ArcMap into individual Microsoft excel files, and then compiled into a master file with all data present. Columns were added to the excel file for different methods of organization such as month/monitoring point/year, year/month/monitoring point, and point/month/monitoring point. Adding these columns allowed for a closer observation of the data through different parameters.

Results and Analysis

The eight points for each month of GRACE and MODIS NDVI values were averaged and plotted on a line graph by sensor from 2011 to 2020. The GRACE points averaged line graph exhibited an upward trend from 2011 to 2020 (Figure 3) with an increased variation between the local maximum and minimum of the line graph from October 2018 to September 2020. The averaged graphed MODIS data showed a downward trend in the NDVI values and a slightly increased variation of local maximum and local minimum of the line graph from October 2018 to September 2020 (Figure 4).

Conclusions and Discussions

The information that was provided by the graphical analysis of the GRACE and GRACE-FO was unexpected and led to more questions. It should be noted that from 2011 to 2018, the initial GRACE mission was reaching the end of its operations, and although there is accurate data available for every year of that range, it was not available for every month due to technical problems and the age of the satellite. GRACE-FO has been functioning properly since the beginning of its mission in 2018 and is regularly providing monthly data. Although there are gaps in several years of the initial GRACE mission's data, we were still able to plot and observe seasonal trends from 2011 to 2020 using both GRACE and GRACE-FO data.

The MODIS NDVI data showed a downward trend from 2011 to 2020 which would be expected with the increased amount of extreme weather conditions that have been present not only in the Mississippi Delta, but in the Southern United States as a whole.

The upward trend in GWH observed from the GRACE satellite missions may be due to the eight points that were averaged together for each month. This approach is a good indicator of the GWH of the Mississippi Delta and the surrounding area but may not be the most accurate method for analysis of what is taking place within the boundaries of the delta itself. The initial method of including pixels that were tangential to the boundary of the delta was due to large resolution of GRACE and to start

with a more conservative approach. The upward trend in the GWH may also be a result of the increased amount of precipitation in the Mississippi Delta region, and the proximal tributaries of the Mississippi River. Mississippi experienced its record precipitation each year from 2016 to 2020, and several states in the immediate area experienced higher levels of precipitation in their respective river valleys during the same period.

For future research, GRACE and MODIS NDVI data will be attained from 2002 to 2011 and the same eight points will be extracted via the same methods and compared to the present set of information. This will also allow for analysis of the GWH and NDVI values and to deduce if there are trends or changes at different temporal ranges.

In addition to the data from 2002 to 2011, GRACE-FO and MODIS data will be gathered for the remainder of 2020 to December of 2021 to have data for a total of approximately 19 years. Pixels will be extracted from both the MODIS and GRACE – FO by the same methods as the previous sets, but solely within the confines of the Mississippi Delta Physiographic boundary to attain a more precise understanding of the variation of GWH and NDVI in that region. This will lead to a lower number of pixels for processing, but they all will be representative of the characteristics of the Mississippi Delta Boundary.

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References

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NDVI False Color Image of Mississippi MODIS-Terra August, 2011

MODIS-Terra Normalized Difference Vegetation Index (NDVI)
 This false color image shows areas that have a higher vegetative indices (More Green) and areas that have lower vegetative indices (Less Green/White). This approach or process can be used to estimate vegetation health. Normal NDVI ranges are between 1 and -1. MODIS provides NDVI images at the 250m resolution level, the pixel values that are provided by Modis can be converted by multiplying the MODIS pixel value by 0.0001. For example the max value of 9992 when multiplies by 0.0001 will provide an NDVI value of 0.9992.

Legend

Mississippi Delta
 Physiographic Delta Boundary

MODIS NDVI Values

Value
 High : 9992
 Low : -2000

MODIS NDVI IMAGE AUGUST 2011
 Source: USGS, NASA, MDEQ
 WGS 1984
 Author: Sean M. Jones
 University of Tennessee at Chattanooga

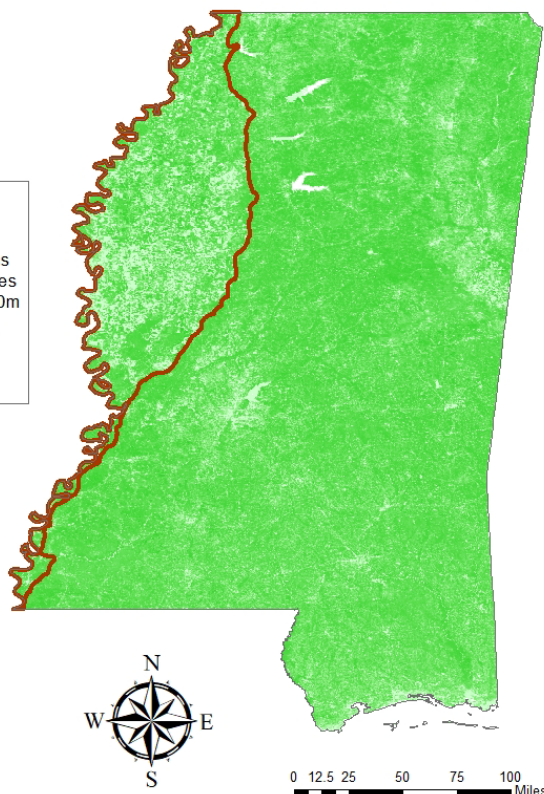


Figure 1. Processed MODIS NDVI data for the state of Mississippi and the Mississippi Delta Physiographic region.

Gravity Recovery and Climate Experiment Observations over the Mississippi Delta

GRACE satellite data measures the distance between two satellites in tandem in LEO (Low Earth Orbit) as they travel across the earth. As the first satellite is pulled toward an area with a higher gravity it accelerates toward the mass (Gravity) it increases its distance from the trailing satellite. The second satellite will accelerate toward the same mass as it approaches it, and bridge the distance between the two satellites, bringing it back to its "regular" position. These changes are carefully documented, and then converted to show gravity maps of the earth. This data shows the ground water height in centimeters, and can be used to observe departures from a "normal" calibrated water table value for that respective area or pixel.

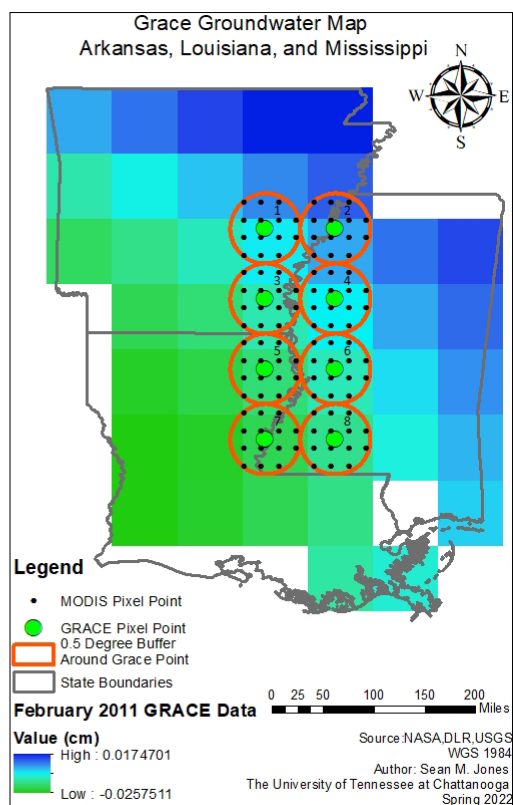
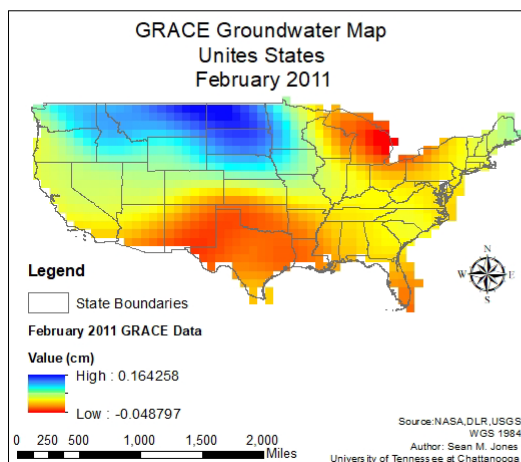


Figure 2. Processed GRACE data for the United States (Left), and Processed GRACE and MODIS data for the Mississippi Delta Physiographic region and surrounding states (Right).

This contribution has been peer-reviewed.

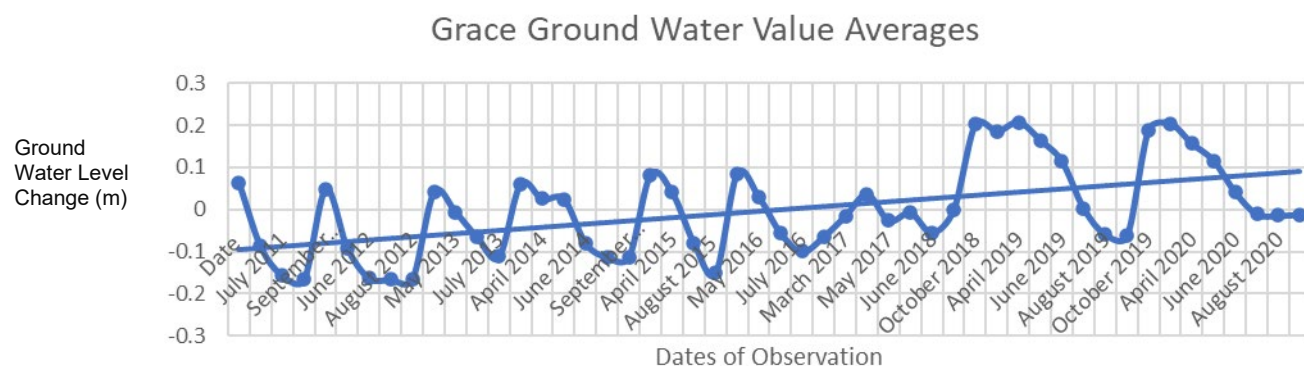


Figure 3. Line graph of average of eight GRACE pixels/point values within and tangential to the Mississippi Delta Physiographic region from 2011 to 2020.

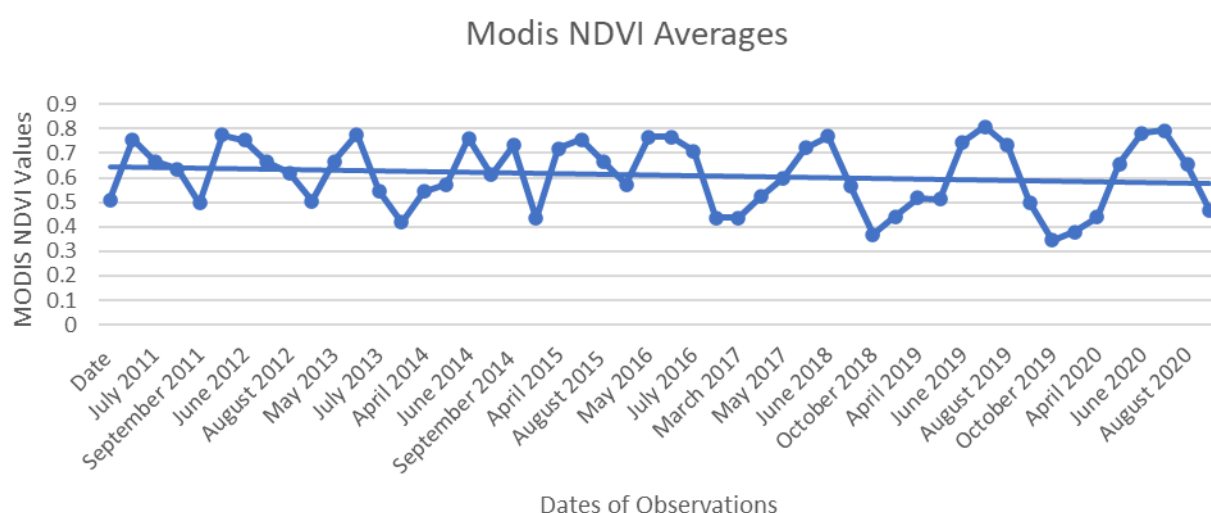


Figure 4. line graph of average of the eight MODIS point values that were within 0.5° of each GRACE point in and tangential to the Mississippi Delta from 2011 to 2020.