GIS, GRACE, and the Texas Drought of 2011

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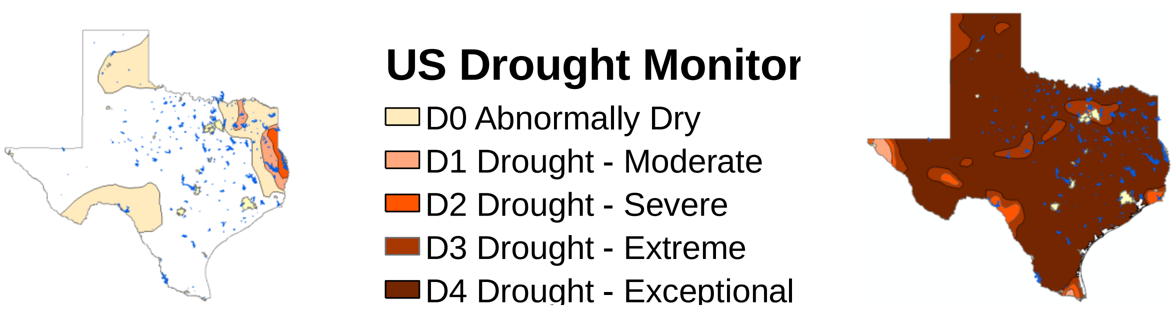
Project Objective

The Texas drought of 2011 has been described as, "the worst single-year drought in Texas' recorded history" (TAMEST, 2012). Archives from The US Drought Monitor indicate that while in September 2010 the state was relatively drought free, by the end of September 2011, approximately 90% of the state was in "exceptional drought"; the most extreme category of drought on the rating scale.



September 2010 **September 2011**

Figure 1

Remotely sensed data provide vast amounts of information about our planet for analysis; and what is more, the data is available fast (NASA, 2012). So much data is available, in fact, that the analysis can appear daunting at times. ArcGIS provides user friendly and powerful tools for the analysis of this data, and has the capability to produce quality exhibits for conveyance of information to stakeholders and other interested parties. The purpose of this paper is to explore and present some of the means by which ArcGIS can be used in conjunction with remotely sensed data to provide information about our planet. Specifically, data from the

Gravity and Climate Experiment (GRACE) satellite mission will be analyzed using ArcGIS 10.1, to present exhibits relevant to understanding the Texas Drought of 2011.

Background

GRACE was launched in March 2002, as a joint project between the National Aeronautics and Space Administration (NASA) and the German Aerospace Center (DLR). The mission includes twin satellites in polar orbit about the earth separated along track by 220 km at an altitude of 500 km. Components include a K-band microwave ranging system accurate to within 10 um, accelerometers, and various positioning systems (NASA, 2002). Analysis of data provided by these systems makes it possible to determine variations in the earth's gravitational field. Of the total mass of the earth, water makes up 0.02% of that mass, and as the water moves about the planet, this mass variation is picked up by GRACE; making it possible to determine variations in the equivalent water thickness on a gridded map of the earth. ArcGIS is an excellent tool for analyzing gridded maps of the earth.

Drought has been defined as, "Dryness; want of rain or of water; especially, such dryness of the weather as affects the earth, and prevents the growth of plants; aridity" (Hyperdictionary 2012). The Palmer Drought Severity Index combines information on temperature and rainfall for a given area to determine relative dryness (NOAA, 2012). Another source of information on drought, The U.S. Drought Monitor, "is produced in partnership between the National Drought Mitigation Center [NDMS] at the University of Nebraska-Lincoln, the United States Department of Agriculture, and the National Oceanic and Atmospheric Administration". According to the National Drought Mitigation Center, the maps and data concerning drought on the US Drought Monitor website are, "a synthesis of multiple indices and impacts, that represents a consensus of federal and academic scientists" (NDMS, 2012). These maps and data show that on September 13, 2011, 88% of the state of Texas was in Exceptional Drought. After this peak, the drought diminished through to June 2012, at which time only 26% of the state was in severe drought or above, and 0% of the state was in exceptional drought. Between June and September of 2012, drought conditions deteriorated somewhat.

Methods and Data

The functionality of ArcGIS 10.1 was used as the primary method of data analysis, with inputs from a variety of sources. Firstly, drought maps were generated from NDMC data to gain an understanding of the scope of the drought. Secondly, maps of equivalent water thickness variation were generated from GRACE data obtained from NASA for each month for the period of interest. Thirdly, maps of rainfall over the state were generated for the same period, from gridded data provided by the Prism Climate Group at Oregon State University. Finally, the data were interpreted using a variety of maps and shapefiles available through the Texas Water Development Board (TWDB).

Drought Monitor Data are provided by NDMC as ArcGIS shapefiles for the period of 2000 through 2012 at http://www.droughtmonitor.unl.edu/dmshps_archive.htm. The Texas state line was used to clip the maps to size, and the color scaling of drought zones was set to resemble the color gradations utilized by the NDMC. Examples of the maps generated are shown in Figure 1, above.

GRACE Data are available at a variety of processing levels. Level 1 data include range measurements, accelerometer readings, and other raw data provided from the satellites. Level 2 data, which include spherical harmonic and associated dealiasing fields, are provided by the three GRACE ground centers; namely University of Texas at Austin Center for Space Research (CSR), GeoForschungsZentrum Potsdam (GFZ), and the NASA Jet Propulsion Laboratory (JPL). The Level 2 data are considered the "official" data releases for the mission (NASA Overview, 2012). Level 3 data were used for this paper, and include additional post processing which includes the application of a destriping filter, a 200km gaussian filter, and a high degree spherical harmonic filter, as well as the removal of a post-glacial rebound signal. Specifically, "GRACE land data were processed by Sean Swenson, supported by the NASA MEaSUREs Program, and are available at http://grace.jpl.nasa.gov" (NASA Land, 2012). (Landerer and Swenson, 2012) describe that this post processing removes much of the signal of interest, and hence in order to effectively close the water balance for a region, the data should be rescaled to add back energy lost from the unfiltered signal. Consequently, the data provided includes scaling factors along with the Level 3 dataset, and includes the instructions that "THE USER SHOULD MULTIPLY THE LAND GRACE DATA PROVIDED HERE BY THE SCALING GRID also provided here" (NASA Land, 2012).

Processing of the GRACE data as performed as part of this report also involved many steps. Once the 1 degree by 1 degree land grids and associated scale factors were downloaded, the grid needed to be reduced from a 360 degree x 360 degree grid extent to a smaller size, so that the files would be manageable in ArcGIS. After this reduction was accomplished in Microsoft Excel, the data were then added to the ArcMap base maps as XY data, into a WGS 1984 geographic coordinate system. Next, scale factors were joined to the GRACE thickness data table, and the field calculator was used to obtain the scaled data. The dataset was then further reduced by eliminating data points in the Gulf of Mexico, but leaving several hundred kilometers of data points around the state, so as to be able to have a buffer for spatial interpolation. The next step was to create a raster of the featureset using the kriging tool. After then clipping the raster to the state of Texas, the interpolated raster image for the state could then be used to calculate statistics for the state as a whole, as well as for various regions of the state, using the zonal statistics table tool. These GRACE rasters were generated for each month of the drought, from September 2010 through December 2011, as well as for June 2012 (the most drought free period from 2011 to date, and September 2012 (the most recent data available). The two rasters from September 2010 and September 2011 are shown below in Figure 2.

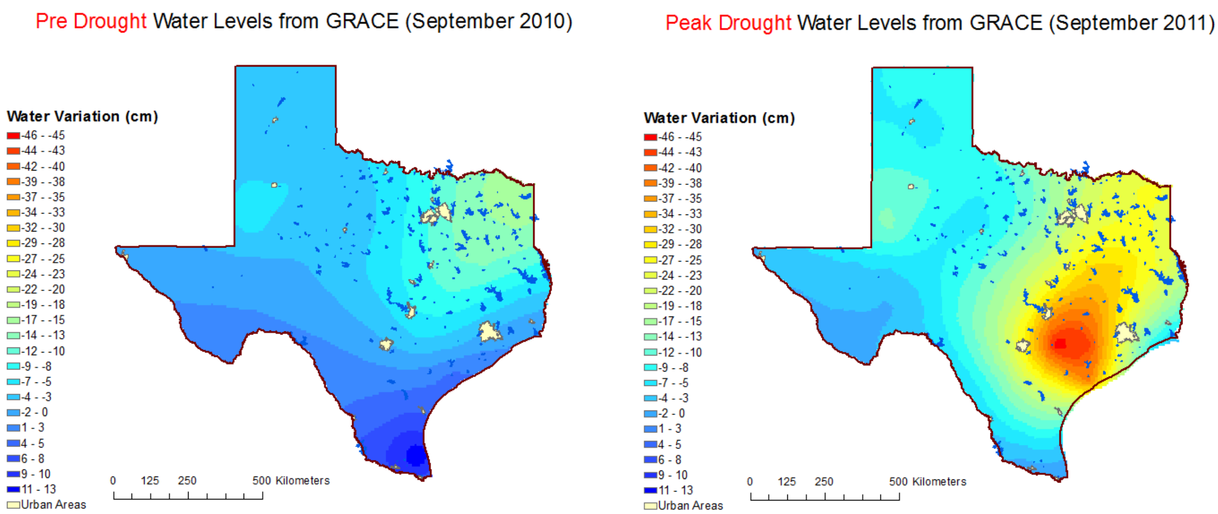


Figure 2

Precipitation Data was obtained from the Prism Climate Group at Oregon State University (PRISM, 2012). The data are available as monthly grids of 2.5 arcminutes (4km), referenced to the World Geodetic Spheroid 1972 (WGS 1972) datum. The ascii to raster tool was used to import the data into ArcGIS. One intent of including the precipitation data was to obtain a monthly precipitation value for the entire state. Consequently, the precipitation data was next projected onto the USA Contiguous Albers Equal Area Conic spatial reference, so as to allow accurate calculations of spatial statistics.

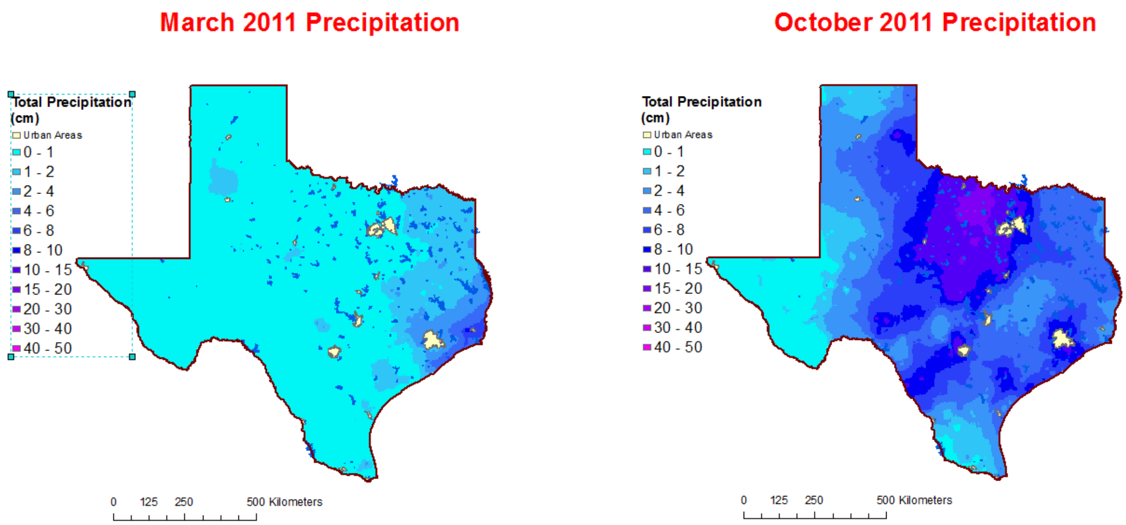


Figure 3

Results and Discussion

The incorporation of scale factors into the GRACE data added back detail to the water anomaly grids that was lost during the filtering and smoothing associated with the generation of the Level three data.

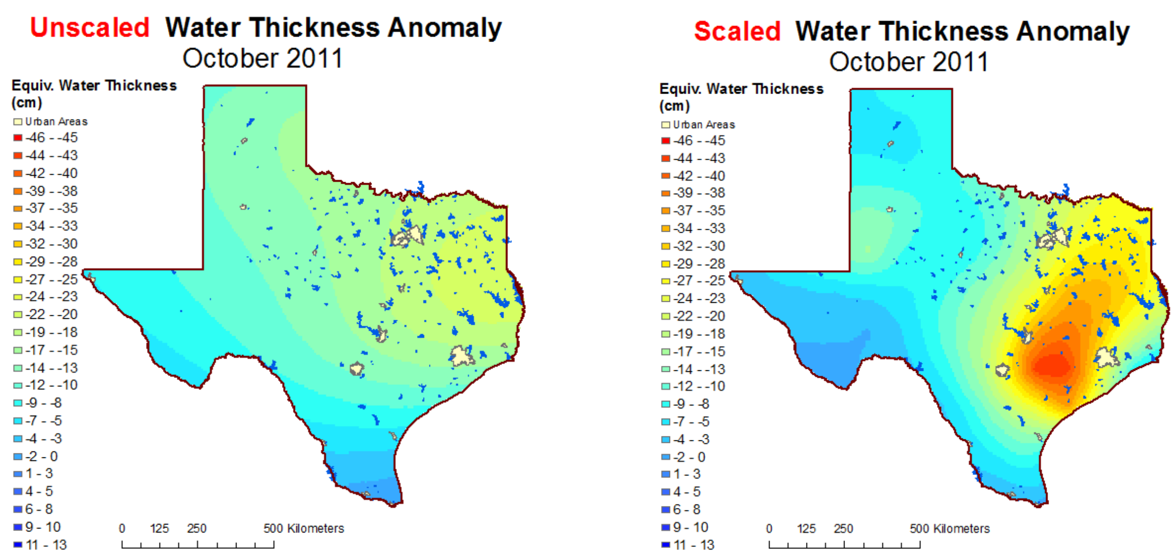


Figure 4

SCALING	MEAN	ST. DEV.
Unscaled	-13.6 cm	4.4
Scaled	-15.4 cm	10.5

With detailed information regarding anomaly location, it was possible to compare the location of these anomalies with the location of administrative boundaries and natural features, as shown in the figures on the following pages:

Drought Water Thickness Change by Groundwater Management Unit

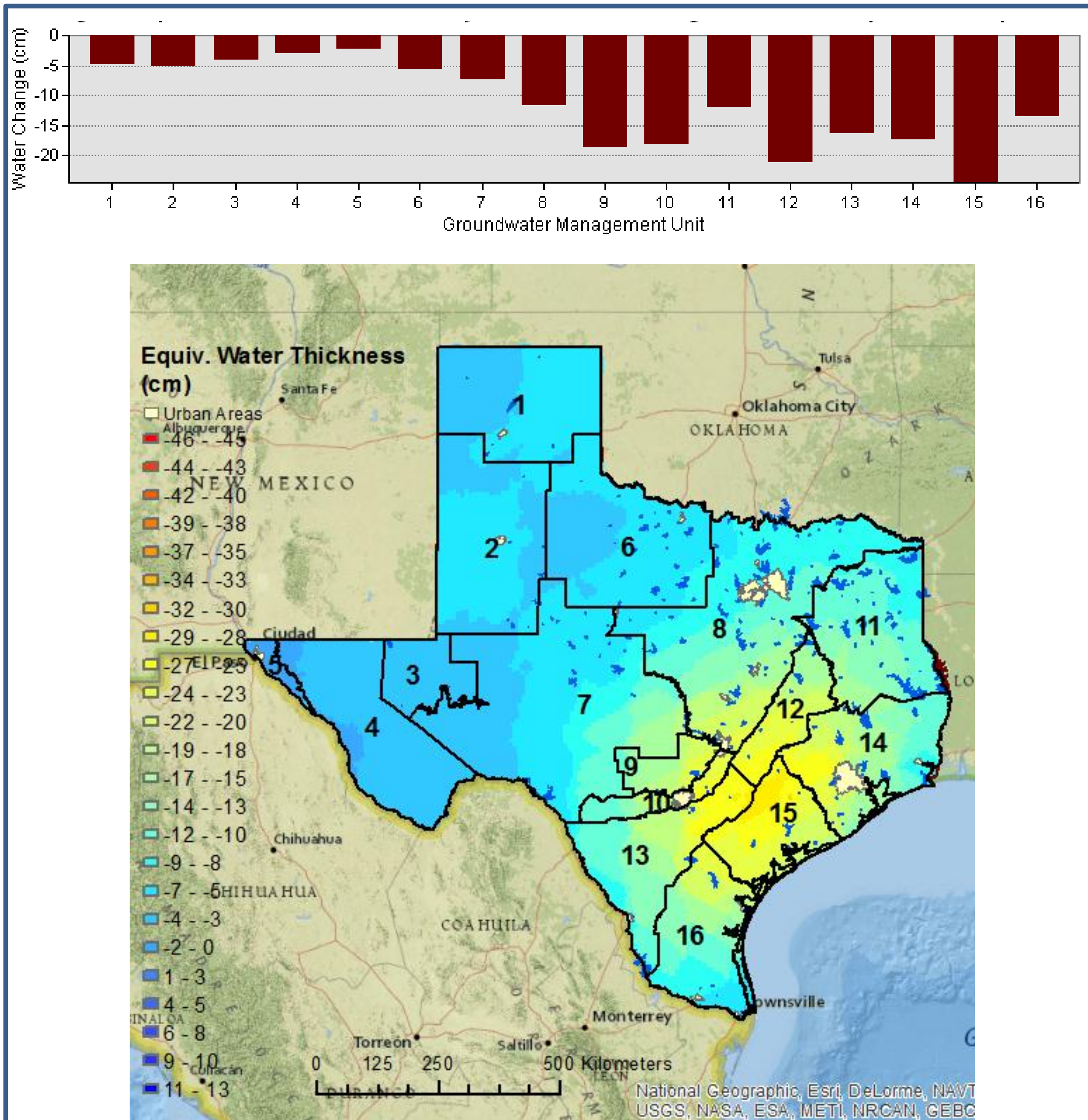


Figure 5

Drought Water Thickness Change by Regional Water Planning Area

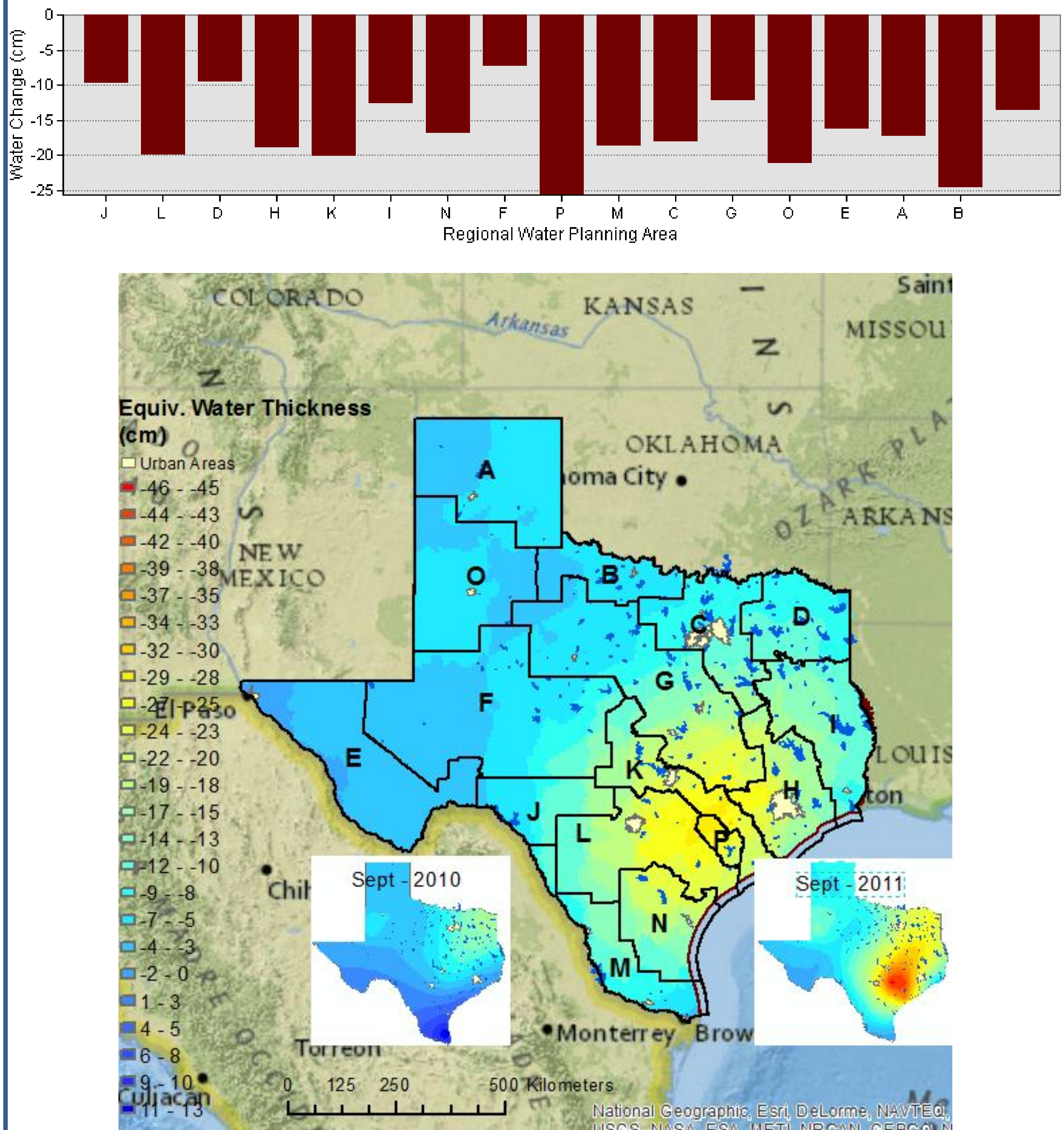
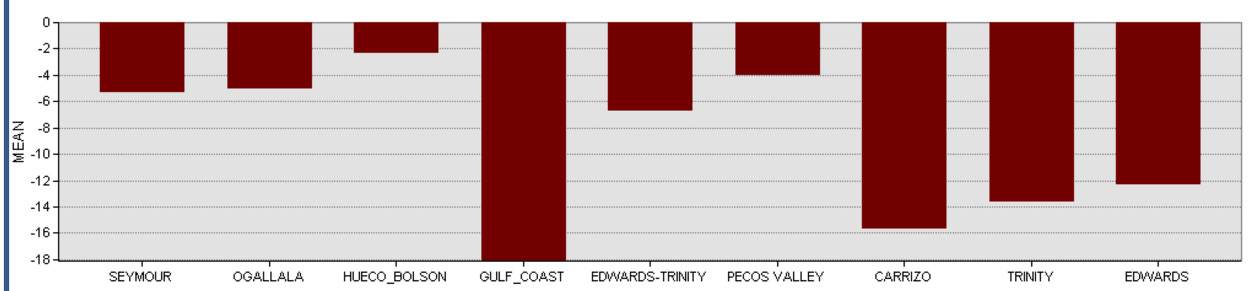


Figure 6

Drought Water Thickness Change by Underlying Aquifer



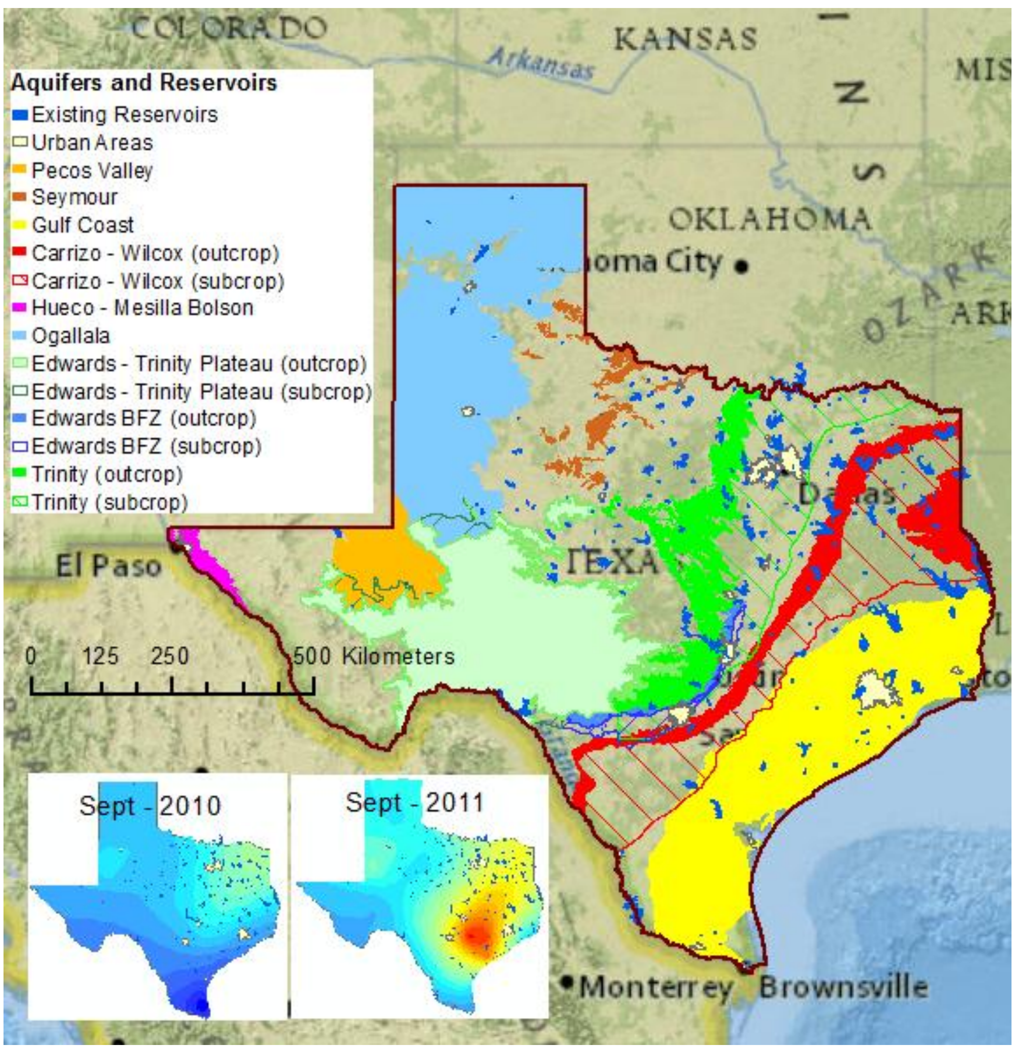


Figure 7

The figures above show some of the spatial relations between the terrestrial water storage change as detected by GRACE and potentially related features. Many of the shapefiles were obtained from the Texas Water Development Board website (TWDB, 2012). The graphical representation afforded by ArcGIS allows qualitative as well as quantitative exploration of how features may be related. For example, of the approximately 100 cubic kilometers of water that GRACE shows left the state during the drought, approximately 9 cubic kilometers was depleted from reservoirs (TAMEST, 2012). The water thickness change data above were obtained by subtracting the monthly water thickness anomaly grid from September 2011 (Peak Drought) from the corresponding grid from September 2011 (Pre Drought). This data was then projected into the USA Contiguous Albers Equal Area Conic spatial reference. Use of the Zonal Statistics Table allowed for calculation of mean values for the state, which enabled calculation of volumetric water changes. A similar procedure was followed for precipitation, the results of which are summarized in the following chart.

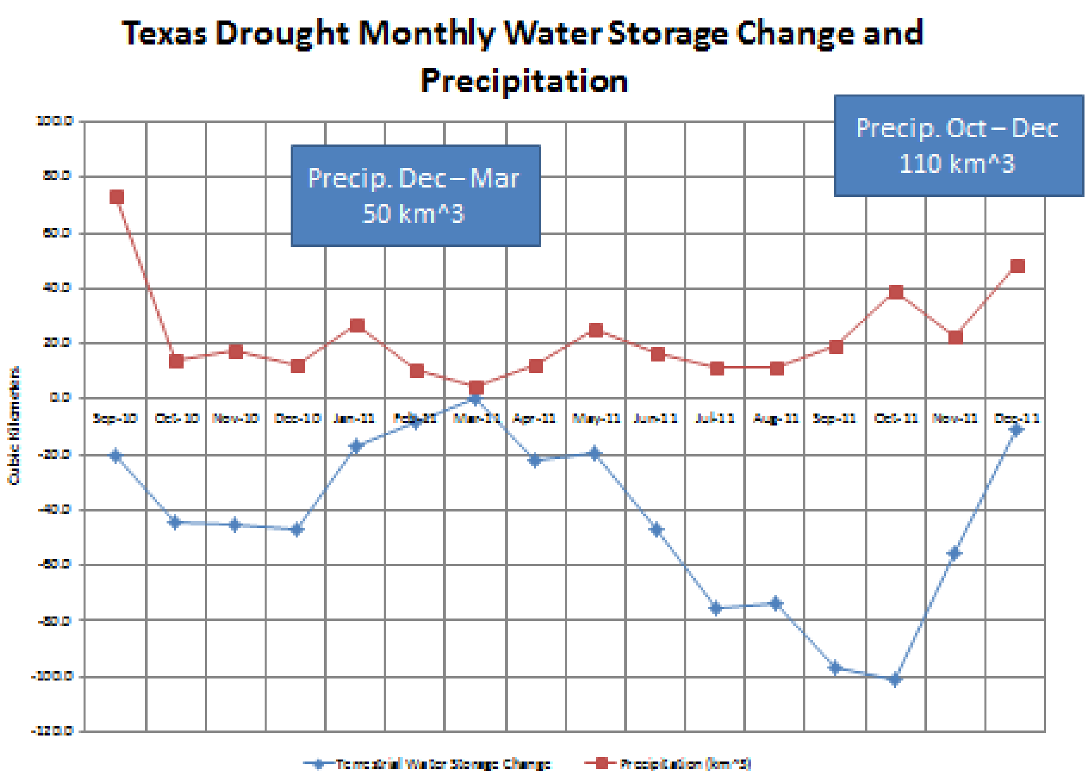


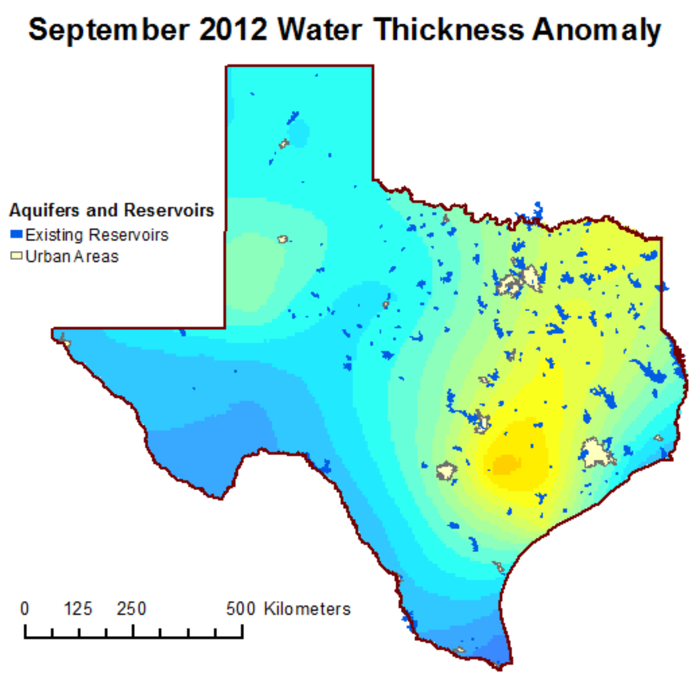
Figure 8

Conclusions

The analysis presented in the preceding pages highlights some of the uses of ArcGIS and GRACE in exploring features of the earth. While such data do not establish cause and effect, or rigorously prove any relations, they do suggest possible avenues of investigation for further exploration. This is perhaps one of the most useful aspects of ArcGIS; the program allows the user to see data in new ways.

The more robust data that can be added to such a Geographical Information System, the more complete the picture that is formed. A fuller understanding of the above data could include more components of the hydrologic cycle, as well as statistical and error analyses. In particular, it would be of benefit to explore the possibility of periodic relations in data such as that presented above. Are these anomalies something new, or are they just part of a larger cycle? Are they statistically significant? These are some of the questions that would need to be answered before one could establish cause and effect relationships.

At present, GRACE is operating well beyond its design life of five years. At some point, however, the satellites will be unable to operate, as the batteries do not hold charge as they once did, and the orbits themselves are slowly decaying. Fortunately, as of November 29th, 2012, an agreement has been signed between the space technology company Astrium and NASA to construct two new satellites, which are expected to become operational in 2017 (Astrium, 2017).



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