Report

TWS capacity variation using GRACE

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Introduction:

Terrestrial water storage (TWS) is defined as all forms of water stored above and underneath the surface of the Earth. Its estimation, monitoring, and analysis carry great importance since it is the support system of all kinds of life on earth. From agriculture to drinking water, we depend on TWS. Being the principal component of the hydrological cycle, it is important to study changes in TWS capacity due to human activities and other natural phenomenon.

In 2002, the Gravity Recovery and Climate Experiment (GRACE) satellite Mission was launched by NASA and the German Aerospace Centre (DLR) to collect direct observations of large scale TWS estimates. It was a twin satellite mission in which the satellites were launched at an altitude of about 400 km from Earth’s surface. The two satellites were separated by a distance of about 225 kilometres (137 miles). The two GRACE satellites (i.e. GRACE 1 and GRACE 2) should remain functional to accurately measure the distance between them by using a microwave ranging system. It was originally intended for five years of operations but went on to work for 15 years till 27 October 2017. It turned out to be a huge scientific success and data gathered by this program was used by people from more than 100 countries.

GRACE works by measuring mass variations at the Earth’s surface by interpreting temporal variations in the global gravity field. The variations in gravity mainly include variations due to Deep Ocean as well as surface ocean currents, groundwater storage, runoff, exchanges between glaciers and the ocean. GRACE satellite data is provided in the form of spherical harmonic (SH) coefficient data products, also called as GRACE level-2 data, by Jet Propulsion Lab (JPL), Center for Space Research (CSR) at the University of Texas at Austin and others. For processing the SH data tools like GRACE MATLAB Toolbox (GRAMAT) are used.

Objectives:

To get the total terrestrial water storage change data from GRACE satellite and plot the anomalies of Terrestrial water storage (TWS) with time of the region comprising of Rajasthan, Punjab, Delhi and Haryana.

Data and Methods:

The Earth Gravity Spherical Harmonic Model Format data file consists of the following variables: spherical harmonic degree l and m, Clm coefficient (cosine coefficient for degree l and order m), Slm coefficient (sine coefficient for degree l and order m) and standard deviation of Clm and Slm. Here l and m are both less than or equal to 60.

Equivalent water thickness: The monthly changes in mass cause the changes in the observed monthly variations in gravity. This mass variations near the Earth's surface can be seen as very narrow layers of water (these layers can extend up to several kilometres thick). In actuality, the changes in water storage in hydrologic reservoirs, atmospheric and land ice masses and moving oceans cause the majority of monthly gravity values. The equivalent water thickness are measured in centimetres which are much diminutive when compared to the horizontals ones which are usually measured in kilometres. The other reasons for the change in gravity values include the ones caused by mass redistribution in the Earth which happens after huge earthquakes or due to Glacial Isostatic Adjustment (GIA, the rising of land post to the ice age due to the melting of the ice, it can also be defined as the reaction of land to the ice age burden). In this particular case, the changes in gravity shouldn't be measured in terms of equivalent water thickness.

The atmospheric mass variability over ice areas in continents or land is not included in the mass grids of GRACE data as the mass of the atmosphere is already pulled out during the processing of the European Centre for Medium-Range Weather Forecasts (ECMWF) atmospheric pressure fields excluding for the errors. The disturbing high-frequency winds and ocean motions that are driven by pressure are removed using the ocean model. Hence, the ideal results don't include ocean variability in the model. In order to use these models over the oceans, we have to add back the monthly averaged ocean bottom pressure fields to the model.

Spherical Harmonic data versions: The revisions in the data are more frequent when compared to other stable satellites as GRACE is the first of its kind. GRACE ground system has three centers namely CSR (Center for Space Research); GFZ (Geo Forschungs Zentrum Potsdam); and JPL (Jet Propulsion Laboratory) which generates Level -2 spherical harmonic field data. The output files contain the spherical harmonic coefficients of the gravity field and the fields that are used to de-alias them.

Degree 2 / order 0 coefficients: It is represented by the symbol – C (2, 0). Its technical name is 'Earth's dynamic oblateness'. It is representative of flattening of the earth. Since 1979, a steady decrease in the C (2, 0) value has been observed, and it is mainly due to glacial isotopic adjustment (GIA). The changes in GRACE data due to GIA has already been modified using satisfactory models. The time series data (for the time period - 2002 to present) show variation of degree two coefficients.

Destriping and spatial smoothing: The obtained data from the GRACE has noises in the form of north-south (N-S) stripes. The short wavelengths undergo higher degree of attenuation as compared to the long wavelengths. This attenuation mainly happens due to the presence of GRACE satellite at a distance of 400 kilometres from the earth's surface. To minimize the noise, Gaussian function is used for spatial averaging. The Gaussian weighting function is calculated based on equation (34) of Chambers et al. JGR, 2006, Observing seasonal steric sea level variations with GRACE and satellite altimetry. Exact radius(r) = 0 km, a_E = 6371, degree (l) is used for Gaussian weighting function. The following function is:

$$W_l = \exp\left[-\frac{(lr/a_E)^2}{4\ln(2)}\right]$$

Data gaps since 2011 and months with lower data accuracy: Due to battery management issues (after 2011), mainly because of aging of batteries, there was a problem in data collection for four to five consecutive weeks. There was also a data gap that occurred for four to five weeks, generally after a period of five to six months. During July to December 2004, and January to February near-exact repetition of the orbit took place and this led to large errors.

Spectral leakage: It happens due to finite widening of the grace data. The data is then passed through FFT (fast Fourier transform) / DFT (discrete Fourier transform) algorithm, so as to eliminate the spectral leakage.

C_{20} estimated from Satellite Laser Ranging (SLR): SLR is a technique used to determine Earth satellite's geocentric location. C_{20} estimates were obtained from the analysis of Satellite Laser Ranging (SLR) data to five geodetic satellites: LAGEOS-1 and 2, Starlette, Stella and Ajisai. The background gravity model used in the SLR analysis is consistent with the GRACE Release-05 processing, including the use of the same Atmosphere-Ocean De-aliasing product.

Steps:

- We have downloaded the data generated by CSR from the website: https://podaac.jpl.nasa.gov/GRACE of 146 months level-2 processed GRACE data or Earth Gravity Spherical Harmonic Model Format. It represents an estimate of the mean gravity field of Earth during the specified timespan derived from GRACE mission measurements.

- The Degree 2 / order 0 coefficients (C_{20}) coefficients were replaced by values from satellite laser ranging for better accuracy. This was done with the help of a code written in MATLAB.
- After this, the Gaussian function was used for the smoothing of spherical harmonic coefficients.
- The spherical harmonic coefficients were converted into grids of 1^o latitude by 1^o longitude.
- To restrict ourselves to the north-western part of India (mainly Rajasthan, Punjab, Haryana, and Delhi), we extracted the data from latitudes ranging from 69^o to 75^o and longitudes ranging from 23^o to 32.5^0. Then a 2D matrix was created to make a polygon by joining the points of latitudes and longitudes to create the required area of study.
- The mean of extracted TWS data was calculated and then subtracted from the same data to obtain TWS anomalies.
- After this, the TWS anomalies were plotted against time in months to understand the variation of TWS in this area. We also plotted a regression line to understand the trend of TWS.

Results:

1]

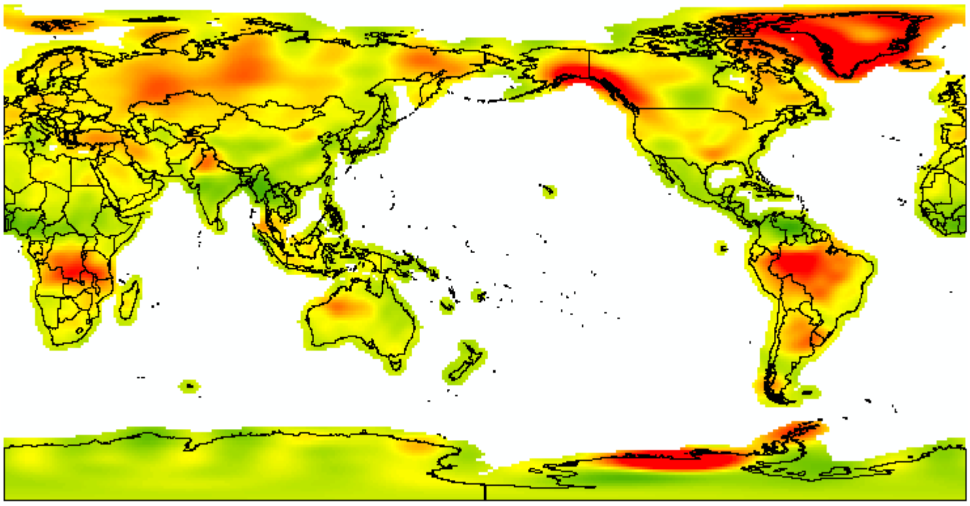
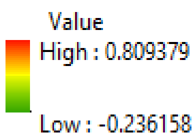


Fig. 1: Color ramp on raster layer of water equivalent thickness (m) of world of Apr-2002



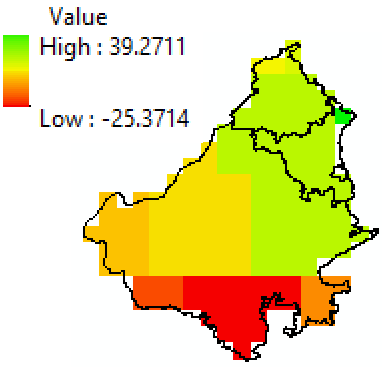


Fig. 2: Color ramp on raster layer of water equivalent thickness (cm) of north-west India region of Apr-2002.

We downloaded GRACE data in NETCDF file and plotted the raster layer of color ramp from range 0.809379 (Red, High) to -0.236158 (Green, Low) of TWS data variation on world map, which is Fig-1. Our research interest area was Rajasthan, Punjab, Haryana and Delhi in India. We extracted the specific region data by creating a mask of required region and then clip that region specific data from the original raster layer, and got a new raster layer of region of interest, which is Fig. 2. The color ramp of the raster layer has range from 38.7271 (Green, High) to -41.0855 (Red, Low).

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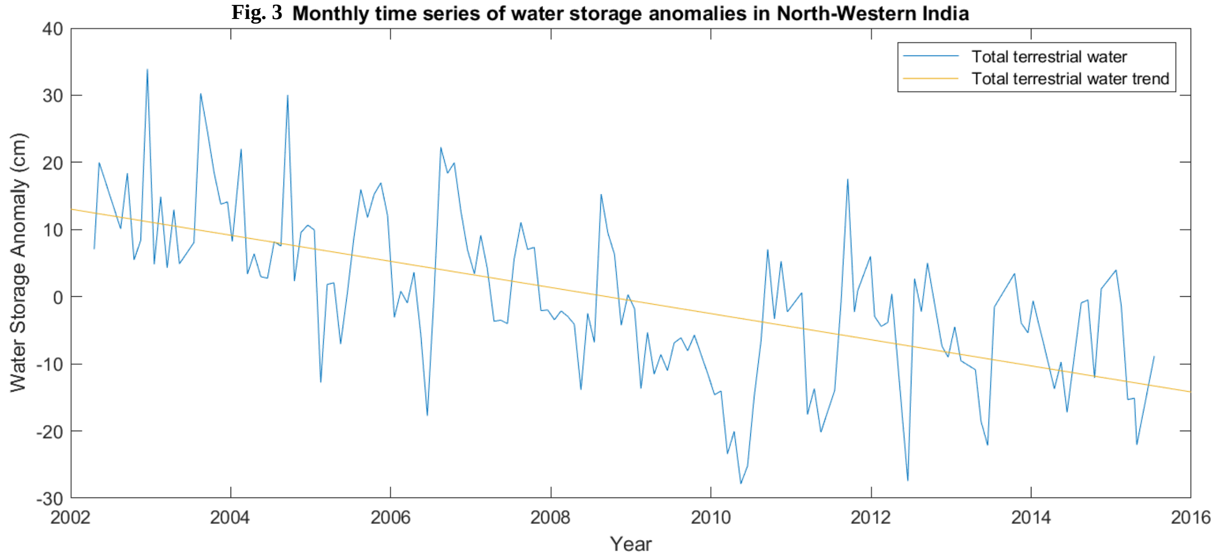
Fig. 3 **Monthly time series of water storage anomalies in North-Western India**



We have plotted in Fig.3, the total terrestrial water storage anomaly vs time (in months). We can observe in the graph that terrestrial water storage anomaly line (blue line) is oscillating with change in months. The mean peak to peak amplitude of water storage anomaly is about 15 cm. We can see the terrestrial water storage trend (Yellow line) in Fig.3, which is strictly decreasing with respect to time and this is because of the green revolution (an increase of groundwater irrigated areas), increased runoff due to urbanization and population growth.

Challenges faced:

- To interpret the NetCDF file, containing gridded data in time dimensions.
- To learn ArcGIS software for extracting the data of the required regions.
- To learn MATLAB software for interpretation of spherical harmonic coefficients.
- To write functions in MATLAB for processing data.
- To work with 3D matrices, string and vector files in MATLAB.

References:

- Wenjie Yin, Litang Hu, Shin-Chan Han, Menglin Zhang, and Yanguo Teng, "Reconstructing Terrestrial Water Storage Variations from 1980 to 2015 in the Beishan Area of China," Geofluids, vol. 2019, Article ID 3874742, 13 pages, 2019. https://doi.org/10.1155/2019/3874742.
- Cheng, M. K. & Tapley, B. D. Variations in the Earth's oblateness during the past 28 years. J. Geophys. Res. 109, B09402 (2004).
- Syed, Tajdarul & Famiglietti, James & Rodell, Matthew & Chen, Jianli & Wilson, Clark. (2008). Analysis of terrestrial water storage changes from GRACE and GLDAS. Water Resources Research. 44. 10.1029/2006WR005779.
- Gravity field determination and characteristics: Retrospective and prospective R. S. Nerem C. Jekeli W. M. Kaula.
- Rodell, Matthew & Velicogna, Isabella & Famiglietti, James. (2009). Satellite Based Estimates of Groundwater Depletion in India. Nature. 460. 999-1002. 10.1038/nature08238.
- The grace data for this was downloaded from https://grace.jpl.nasa.gov/data/get-data/.
- Functions used in the code were from GRAMAT can be downloaded from the website https://github.com/fengweiigg/GRACE_Matlab_Toolbox.
- Feng, Wei. (2018). GRAMAT: a comprehensive Matlab toolbox for estimating global mass variations from GRACE satellite data. Earth Science Informatics. 10.1007/s12145-018-0368-0.
- MATLAB code: https://github.com/Ashwanis31/GRACE-TWS-CALCULATION