Journal of Geodynamics 67 (2013) 106–110

Contents lists available at SciVerse ScienceDirect

Journal of Geodynamics

journal homepage: http://www.elsevier.com/locate/jog

Satellite based estimates of terrestrial water storage variations in Turkey

Onur Lenk*

General Command of Mapping, Tip Fakultesi Caddesi, TR-06100, Dikimevi, Ankara, Turkey

ARTICLE INFO

Article history:
Received 15 October 2011
Received in revised form 11 April 2012
Accepted 13 April 2012
Available online 25 April 2012

Keywords:
GRACE satellites
Temporal gravity field
Terrestrial water storage
Groundwater storage

ABSTRACT

In recent years, the Gravity Recovery and Climate Experiment (GRACE) has provided a new tool to study terrestrial water storage variations (TWS) at medium and large spatial scales, providing quantitative measures of TWS change. Linear trends in TWS variations in Turkey were estimated using GRACE observations for the period March 2003 to March 2009. GRACE showed a significant decrease in TWS in the southern part of the central Anatolian region up to a rate of 4 cm/year. The Global Land Data Assimilation System (GLDAS) model also captured this TWS decrease event but with underestimated trend values. The GLDAS model represents only a part of the total TWS variations, the sum of soil moisture (2 m column depth) and snow water equivalent, ignoring groundwater variations. Therefore, GLDAS model derived TWS variations were subtracted from GRACE derived TWS variations to estimate groundwater storage variations. Results revealed that decreasing trends of TWS observed by GRACE in the southern part of central Anatolia were largely explained by the decreasing trends of groundwater variations which were confirmed by the limited available well groundwater level data in the region.

1. Introduction

The Gravity Recovery and Climate Experiment (GRACE) satellite gravity mission, launched by National Aeronautics and Space Administration (NASA) and the German Aerospace Center (DLR) in March 2002 measures temporal variations in the gravity field, which can be used to estimate changes in terrestrial water storage (TWS). The GRACE satellite gravity mission is one of the major advancements in geodesy. It is regarded as one of the most efficient, economical, and promising techniques for accurately estimating the gravity field of Earth, the distribution and transport of TWS and ocean water mass variations.

Various studies applied early GRACE results to a variety of problems including TWS change (e.g., Wahr et al., 2004), polar ice sheets mass balance (e.g., Velicogna and Wahr, 2006; Chen et al., 2006), oceanic mass change (e.g., Chambers et al., 2004; Lombard et al., 2007) and gravity variations due to earthquakes (Chen et al., 2007).

TWS change is the most important component of the global water cycle comprising changes in water stored in soil, as snow over land, and in groundwater storage (Chen et al., 2009). TWS change reflects accumulated precipitation, evapotranspiration and surface and subsurface runoff within a given area or basin. Moreover, TWS change provides a good measure of climate change. TWS is one of the crucial resources related to economic and society development. Accurate estimation of TWS change is valuable for the investigation and forecast of flood and other natural disasters such as drought, agriculture and for other water uses. However, TWS variations are difficult to quantify due to limited networks for observations such as ground water, soil moisture, precipitation, evapotranspiration, snow water equivalent, and others at basin or smaller scales (Chen et al., 2009). Remote sensing data such as precipitation data from satellites and in situ measurements such as river level gauge stations are valuable assets in estimating TWS changes. However, remote sensing measurements can only provide TWS variations within several centimeters depth below the Earth surface and in situ measurements are point measurements and can only cover small regions close to the gauge stations.

For medium and large-spatial scales, GRACE can overcome the short-comings of the remote sensing and ground-based gauge station measurements and has the major advantage that it senses water stored at all levels, including groundwater.

On the other hand, groundwater storage variations can be isolated from GRACE data given auxiliary information on the other components of TWS, from either in situ observations (Yeh et al., 2006) or land-surface models (Rodell et al., 2007, 2009; Tiwari et al., 2009). The second approach is used to produce time series of groundwater storage variations in Turkey. The groundwater variations are isolated by subtracting the Global Land Data Assimilation System (GLDAS) (Rodell et al., 2004) derived TWS variations (soil moisture and snow) from GRACE derived total TWS variation time series. Consequently, linear trends of large-scale TWS and groundwater storage variations in Turkey during the period from March 2003 to March 2009 are determined.

---

* Tel.: +90 312 5952018; fax: +90 312 3201495.
E-mail address: onur.lenk@hgk.msb.gov.tr

0264-3707/$ – see front matter © 2012 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.jog.2012.04.010

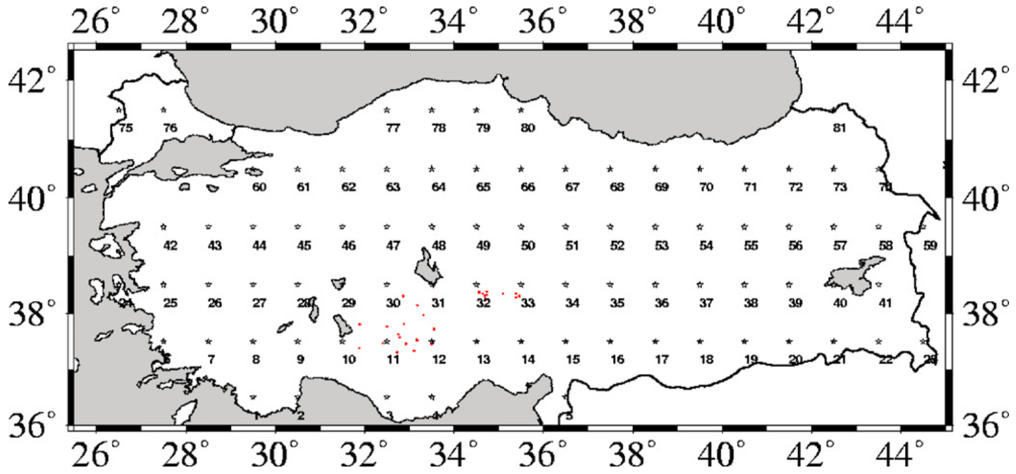

Fig. 1. 1° × 1° grid points where the TWS and groundwater variations are estimated. The red dots indicate 31 well locations. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of the article.)

2. Data and processing

2.1. TWS variations from GRACE

GRACE gravity field solutions used are the Release-02 (RL02) of the Center National d'Ètudes Spatiales and Groupe de Recherche en Géodesie Spatiale (CNES/GRGS) time-variable gravity field models supplied as 1° × 1° grid files of equivalent water mass (WM) variations. These solutions are obtained from normalized spherical harmonic (SH) geopotential coefficients (from degree 2 up to degree and order 50) (Lemoine et al., 2007). CNES/GRGS RL02 WM variations provided every 10 days are based on 10-day data. The solutions are stabilized towards the EIGEN-GRGS.RL02.MEAN-FIELD (EIGEN = European Improved Gravity model of the Earth by New techniques) at each given epoch, with a constraint law that depends on the degree and order of each coefficient (http://bgi.cnes.fr:8110/geoid-variations/README.html). Monthly means from the 10-day solutions are derived to be consistent with the temporal resolution of the GLDAS hydrological model and data for 72 months from March 2003 to March 2009. As no 10-day solutions have been released for the months of January and February for 2003, the WM time series started from March 2003. In order to minimize the effect of annual signal on the linear trend estimates the WM time series ended in March 2009.

Atmospheric pressure variations, ocean tides and barotropic ocean signals have been removed using the European Centre for Meteorological Weather Forecasting (ECMWF) model (http://www.ecmwf.int), the Finite Element Solution 2004 (FES2004) (Lyard et al., 2006) and the MOG2D-G barotropic (Carrère and Lyard, 2003) model, respectively. Therefore, over land areas CNES/GRGS GRACE solutions reflects the TWS variations.

2.2. TWS variations from GLDAS land surface model

GLDAS model was developed jointly at the National Aeronautics and Space Administration Goddard Space Flight Center and NOAA NCEP (Rodell et al., 2004). GLDAS parameterizes, forces, and constrains sophisticated land surface models with ground and satellite products with the goal of estimating land surface states (e.g., soil moisture and temperature) and fluxes (e.g., evapotranspiration). In this particular simulation, GLDAS drove the Noah land surface model (Ek et al., 2003), with observed precipitation and solar radiation included as inputs. Monthly averaged TWS variation from GLDAS model at each grid point is sum of the soil moisture (2 m column depth) and snow water equivalent. Groundwater is not modeled by GLDAS (Chen et al., 2009).

A fair comparison with GRACE observations requires that GLDAS fields be spatially filtered in a consistent way. To accomplish this, GLDAS gridded fields were represented in a SH expansion to degree and order 50. Additionally SH coefficients for degree 0 and degree 1 were set to zero. Finally, GLDAS SH representations were evaluated on a global 1° × 1° grids.

2.3. Estimation of groundwater variations using GRACE and GLDAS

In this study, the major sources of TWS variability are assumed to be groundwater, soil moisture, and snow. Therefore, given GRACE-based estimates of terrestrial water storage variations (ΔTWS) and numerically modeled changes in soil moisture (ΔSM) and snow water equivalent (ΔSWE) through the GLDAS model (Rodell et al., 2004), groundwater storage variations (ΔGW) are computed as:

$$\Delta \mathrm{GW} = \Delta \mathrm{TWS} - (\Delta \mathrm{SM} + \Delta \mathrm{SWE}) \tag{1}$$

This approach has been previously used by Rodell et al. (2009) and Tiwari et al. (2009) in order to estimate groundwater depletion in India using GRACE data. The groundwater variations are isolated by subtracting GLDAS anomalies from the GRACE TWS anomalies at each grid point shown in Fig. 1. These are named as GRACE–GLDAS time series.

2.4. Groundwater level data

Currently groundwater level data from the wells are not available for all of Turkey. Only limited groundwater level data are available in a small area in the southern part of central Anatolia. A total of 31 groundwater level data from wells (indicated by red dots in Fig. 1) operated by the Turkish General Directorate of State Hydraulic Works are used. For each well, monthly water level data are transformed into equivalent water layer by multiplying by a uniform specific yield (Swenson et al., 2006; Johnson, 1967). However, as the specific yield values for the wells were not available, A mean value of uniform specific yield (effective porosity) value of 1.2% were determined by comparing the averaged GRACE–GLDAS derived water storage variations with the averaged groundwater level data. The adopted value of the specific yield is very small. The geology of the central Anatolia justify such a low value as most of the surface of the region is sedimentary (Aydemir and Ates, 2006).