ANALYSIS OF DE-CORRELATION FILTERS PERFORMANCE FOR ESTIMATING TEMPORAL MASS VARIATIONS DETERMINED FROM GRACE-BASED GGMS OVER KONYA BASIN

Emel ZERAY ÖZTÜRK (Turkey), Walyeldeen GODAH (Poland), R. Alpay ABBAK (Turkey)

Key words: de-correlation filters, GGM, GRACE, Temporal mass variations

SUMMARY

Since the launch of GRACE (Gravity Recovery And Climate Experiment) satellite gravimetry mission in 2002, a great progress has been made in the monitoring of temporal mass variations within the Earth system. The main objective of this study is to investigate the performance of de-correlation filters (DDK1—DDK8) applied to reduce the noise included in the latest release (i.e. release 5) GRACE-based GGMs for the estimation of temporal mass variations within the Earth system in a local scale.
Konya basin has been chosen as study area because of its serious groundwater variations according to earlier studies. Temporal variations of equivalent water thickness were determined from release 5 GRACE-based GGMs. Thereafter, they were compared with the corresponding ones obtained from WaterGAP (Water Global Assessment and Prognosis) Global Hydrology Models (WGHMs). The obtained results were analyzed and discussed. Finally, the most convenient De-correlation filter for the estimation of temporal mass variations over the Konya basin was specified.

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1. INTRODUCTION

With the partnership of NASA (National Aeronautics and Space Administration) and DLR (German Aerospace Center) centers, a great improvement has been made in the area of geodesy with the GRACE (Gravity Recovery and Climate Experiment) satellite mission, which was launched in March of 2002. As a result of the GRACE mission, obtaining temporal variations in the gravity field has become much more accurate and practical from monthly solutions. GRACE satellite mission ended in October of 2017, after providing 15 years of unprecedented insights into how Earth's masses is changing.

In order to investigate temporal mass variations, there are many research papers using GRACE data (e.g. Tapley et al., 2004; Swenson and Wahr, 2007; Luthcke et al., 2013; Krynski et al., 2014; Wu and Helfin, 2015). GRACE gravitational field solutions are used in different areas such as studying tectonic motions (e.g. Mikhailov et al., 2004; Choi et al., 2006; Han and Simons 2008),studies involving mass transports such as ocean mass variations (Chambers, 2009), glacier melting (e.g. Slobbe et al., 2009), level changes in groundwater sources (e.g. Swenson and Wahr 2003; Schmidt et al., 2006; Chen et al., 2008; Cazenave and Chen, 2010) and etc. GRACE gravitational field solutions are often used to estimate the equivalent water thickness (*EWT*) because of their high sensitivity to hydrological changes at the global and regional level (Wahr et al., 2006, Cazenave and Chen 2010).

In GRACE research, several solutions, i.e. Release 1, Release 2, Release 3, Release 4, and Release 5 (RL05), of GRACE-based GGMs have been developed. These solutions generated by data centers are gradually getting better results (Dahle et al., 2014). GRACE-based GGMs are highly affected by the noise caused by various reasons during the acquisition of data. Especially, the orbital plane followed by GRACE satellites (Tapley et al., 2004) is one of the most common causes of the noise. An appropriate filtering method is chosen to reduce these errors to the minimum level (Ditmar et al., 2012). By applying a filter, the corresponding errors are eliminated, but on the other hand, the losses of the signal and the spatial resolution decreases depending on the filter. The Gaussian filtering method is generally preferred because of its practical usage (Wahr et al., 1998). However, recent studies (e.g. Kusche et al., 2009; Godah et al., 2015) proved the suitability of de-correlation filters to reduce the noise included in GRACE solutions. The idea behind the de-correlation method is to identify and remove error correlation in the sets of spherical harmonic coefficients using an a priori synthetic model of the observation geometry (Kusche et al., 2009).

The main aim of this study is to performance of de-correlation filters (DDK1—DDK8) applied to reduce the noise in RL05 GRACE-based GGMs as well as to select the most suitable GRACE-based GGM time series to estimate mass variations in Konya basin where mass variations are mostly seen.

2. DATA USED AND STUDY AREA

Konya basin bounded by meridians of 37°E and 40°E and parallels of 31°N and 35°N was chosen as the main study area (Fig. 1). The basin spreads over an area of almost 5 million hectares, is one of the regions where mass variations are most intense. Many studies were carried out in the field of surface deformation in this area (for more details, see Üstün et al., 2015). In the study area, there are two points at which the estimation of mass variations was made in the Earth system.

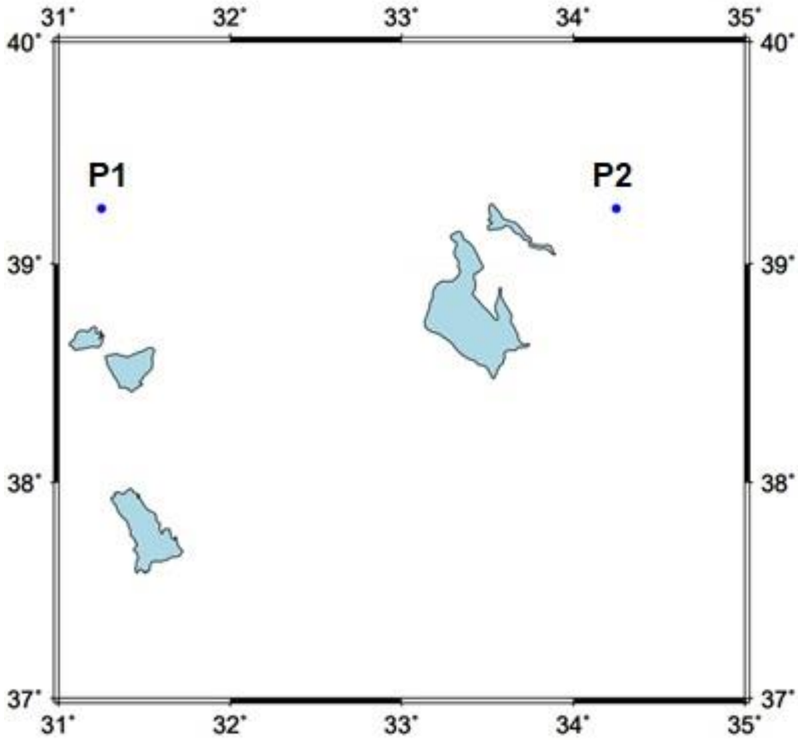

Fig. 1. Study area and two points where GGMs tested at

In the current study, the latest release RL05 GRACE-based GGMs developed by the GFZ (GeoForschungsZentrum), JPL (Jet Propulsion Laboratory) and CSR (Center for Space Research at University of Texas, Austin) centres filtered with the use of the decorrelation (DDK1, DDK2, DDK3, DDK4, DDK5, DDK6, DDK7, DDK8) filters (Kusche 2007) was utilized. These centers are regarded as official data centers of the GRACE mission (Bettadpur, 2012). The GGMs are released on the ICGEM (International Centre for Global Earth Models) website (http://icgem.gfz-potsdam.de/home).

The attainability of GGMs is shown in Figure 2. It indicates that gaps in the GGM time series are mostly similar for the three data centers. The resolution of GFZ GGMs is 90 degree/order (d/o) while the resolution of CSR GGMs is 96 d/o. The resolution of JPL GGMs changes between 60 and 90 d/o. In this study, the coefficients of all data centers were cut at 60 d/o.

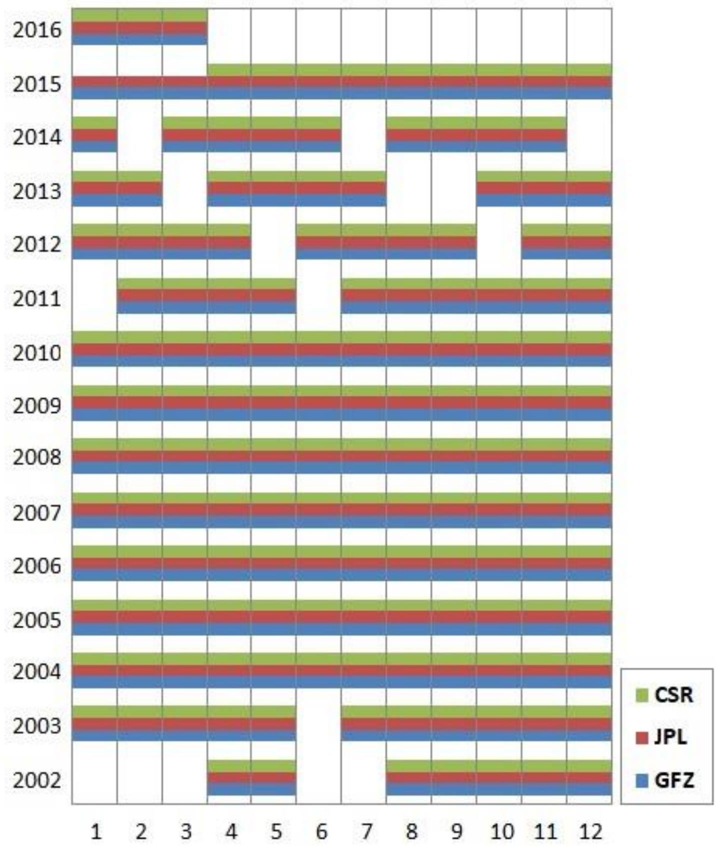

Fig. 2. Attainability of RL05 GRACE-based GGMs from the CSR, GFZ, and JPL centers (Godah et al., 2015)

WaterGAP (Water Global Assesment and Prognosis) Global Hydrological Model (WGHM), a joint product of Kassel University and Frankfurt University, was used to compare GRACE-based GGMs in the study. WGHM, produced at 0.5° × 0.5° spatial resolution and monthly runoff and river discharge, is based on meteorological and hydrological datasets (Müller et al., 2014; Müller et al., 2016; Müller 2017, Döll et al., 2014).

In addition to the WGHM data, the JPL mascon (mass concentration) solutions produced by JPL were used as a second control data (Watkins et al., 2015). This control data is mascon number #:803, which covers the study area. Figure 3 shows the JPL mascon grid.

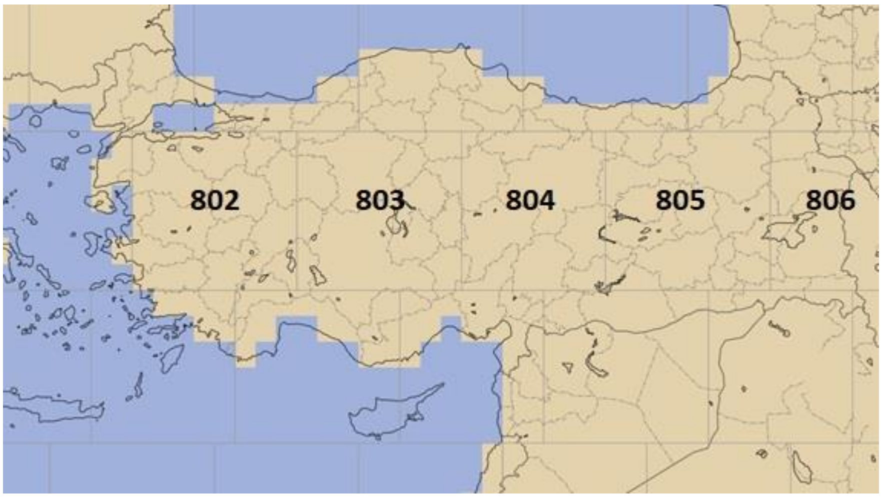

Fig. 3. JPL mascons

3. METHODOLOGY

In the first part of the study, the effect of de-correlation filters (DDK1–DDK8) applied to reduce the noise contained in RL05 GRACE-based GGMs were examined (Wahr et al., 1998; Kusche, 2007; Kusche et al., 2009). The equivalent water thickness (*EWT*) values were computed at monthly intervals using those GGMs as follows:

$$EWT^{(GRACE)} = \frac{R \times \rho_{av}}{3} \sum_{n=0}^{N_{max}} \left(\frac{2n+1}{1+k_n}\right) \sum_{m=0}^{n} \bar{Y}_m(\varphi, \lambda) \qquad (1)$$

with

$$\bar{Y}_{nm}(\varphi, \lambda) = (C_{nm} cosm\lambda + S_{nm} Sinm\lambda) \bar{P}_{nm}(sin\varphi) \qquad (2)$$

where $N_{\max}$ is the applied maximum degree of the GRACE-based GGM, φ, λ are the latitude and the longitude, respectively, of the computation point P, ρ_{av} is the average density of the Earth, R is the Earth's mean radius, k_n are load Love numbers, C_{nm}, S_{nm} are dimensionless coefficients of degree n and order m, $\bar{P}_{nm}(\sin\varphi)$ are fully normalized associated Legendre functions.

The temporal variations of the equivalent water thickness $\Delta EWT^{(GRACE)}$ from RL05 GRACE-based GGMs were computed as follows:

$$\Delta EWT_i^{(GRACE)} = EWT_i^{(GRACE)} - EWT^{(GRACE)}{}_{mean} \quad (3)$$

where $EWT_i^{(GRACE)}$ detones the equivalent water thickness obtained from RL05 GRACE-based GGMs, i symbolizes the month, $EWT^{(GRACE)}{}_{mean}$ is the mean value obtained from the time series of $EWT_i^{(GRACE)}$.

The accuracy of these GGMs was evaluated by using independent datasets. For this purpose, the temporal variations of the equivalent water thickness were computed from the WGHM as follows:

$$\Delta EWT_i^{(WGHM)} = EWT_i^{(WGHM)} - EWT^{(WGHM)}{}_{mean} \quad (4)$$

where $EWT_i^{(WGHM)}$ represents the equivalent water thickness obtained from the WGHM monthly grids, $EWT^{(WGHM)}{}_{mean}$ is the mean value obtained from time series of $EWT_i^{(WGHM)}$. These $\Delta EWT_i^{(WGHM)}$ were compared with the corresponding $\Delta EWT_i^{(GRACE)}$ obtained from RL05 GRACE-based GGMs. The differences $d\Delta EWT_i$ between those equivalent water thickness variations are obtained as follows:

$$d\Delta EWT_i = \Delta EWT_i^{(WGHM)} - \Delta EWT_i^{(GRACE)} \quad (5)$$

4. RESULTS

Firstly, the performances of the de-correlation filters (DDK1-DDK8) were examined at the local scale. The results were obtained with Eq. (1) and Matlab codes developed within this study. Performances of DDK filters' statistics are given in Table 1 for P_1 and P_2.

Table 1. Statistics of the differences between the corresponding equivalent water thickness variations $\Delta EWT^{(WGHM)}$ and $\Delta EWT^{(GRACE)}$ for P_1 and P_2 in Konya closed basin

Statistics[m] (P_1)	**Min**	**Max**	**Mean**	**Std**	**Max-min**
DDK1	-0.0965	0.0977	-0.0036	**0.0453**	0.1943
DDK2	-0.1393	0.0805	-0.0248	0.0513	0.2199
DDK3	-0.1623	0.0979	-0.0374	0.0612	0.2603
DDK4	-0.1648	0.1183	-0.0330	0.0649	0.2831
DDK5	-0.1999	0.1898	-0.0089	0.0794	0.3897
DDK6	-0.2213	0.2272	0.0062	0.0893	0.4484
DDK7	-0.2928	0.2987	0.0448	0.1296	0.5915
DDK8	-0.3503	0.3575	0.0465	0.1565	0.7079
(P_2)	**Min**	**Max**	**Mean**	**Std**	**Max-min**
DDK1	-0.1226	0.1251	0.0043	**0.0537**	0.2478
DDK2	-0.0932	0.1637	0.0319	0.0554	0.2569
DDK3	-0.0918	0.2104	0.0492	0.0630	0.3022

DDK4	-0.0960	0.2067	0.0490	0.0658	0.3027
DDK5	-0.0966	0.2741	0.0585	0.0765	0.3707
DDK6	-0.1136	0.3371	0.0773	0.0849	0.4506
DDK7	-0.1773	0.5066	0.1325	0.1281	0.6839
DDK8	-0.2281	0.5558	0.1454	0.1623	0.7839

According to statistics presented in Table 1, the DDK1 filter with smaller amplitude is more successful at reducing noise than the others and reflected the changes more clearly, for both points. These results are also consistent with the results of the study of Godah et al. (2015). Global maps of equivalent water thickness variations, produced by Godah et al. (2015) are presented in Figure 4.

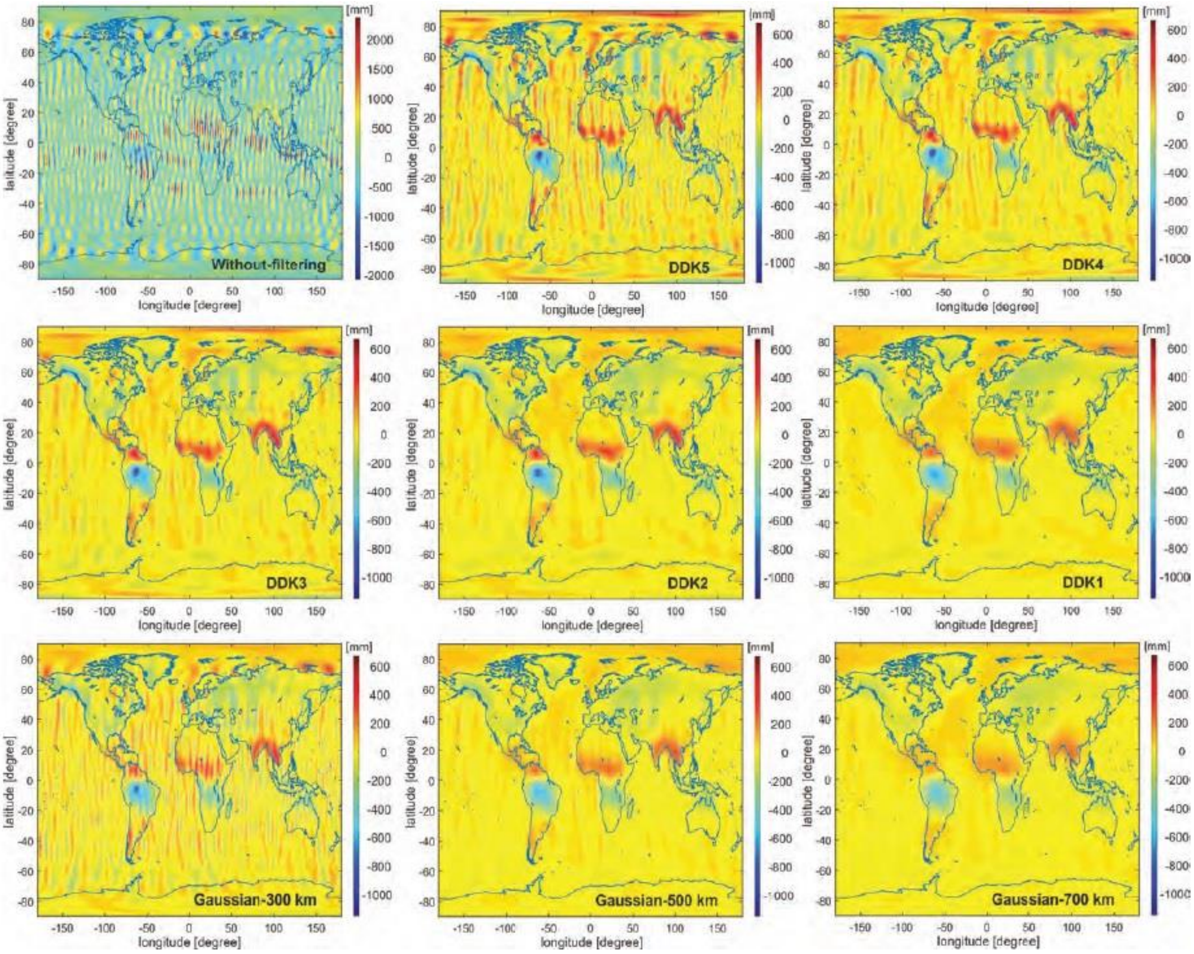

Fig. 4. The equivalent water thickness variations between March 2005 and September 2005 obtained from RL05 GRACE-based GGMs computed by the JPL centre (Godah et al. 2015).

ΔEWT values of P_1 and P_2 are shown in Figures 5, 6, 7 and 8 as $\Delta EWT^{(GRACE)}$ time series. According to these Figures, JPL, CSR and GFZ data reveal a good agreement with each other when applying DDK1 and DDK2 filters. Moreover, in terms of seasonal mass changes, Figure 5 demonstrates a clear seasonal pattern of water mass variations, with the maximum values in April-May and minimum values in August–September. The time-dependent mass variation pattern clearly shows that the decreases/increases in water masses over the area investigated are by the reason of water evaporation during dry months in the summer season, and the melting of snow that was accumulated in the winter season. On the other hand, the difference between the DDK1, DDK2, DDK3, DDK4, DDK5 DDK6, DDK7 and DDK8 filtered RL05 based-GGMs produced in the GFZ, CSR and JPL centers is visualized. It is quite obvious that $\Delta EWT^{(GRACE)}$ water mass changes are not clearly observable, especially when applying DDK3, DDK4, DDK5, DDK6, DDK7 and DDK8 filters. This can be explained by the fact that the noise in the DDK3, DDK4, DDK5, DDK6, DDK7 and DDK8 dominate the signal and lead to a lot of stripes. Thus, DDK1 filter recommended reducing the noise contained in RL05 GRACE-based GGMs, when estimating mass variations in the Earth system over Konya basin.

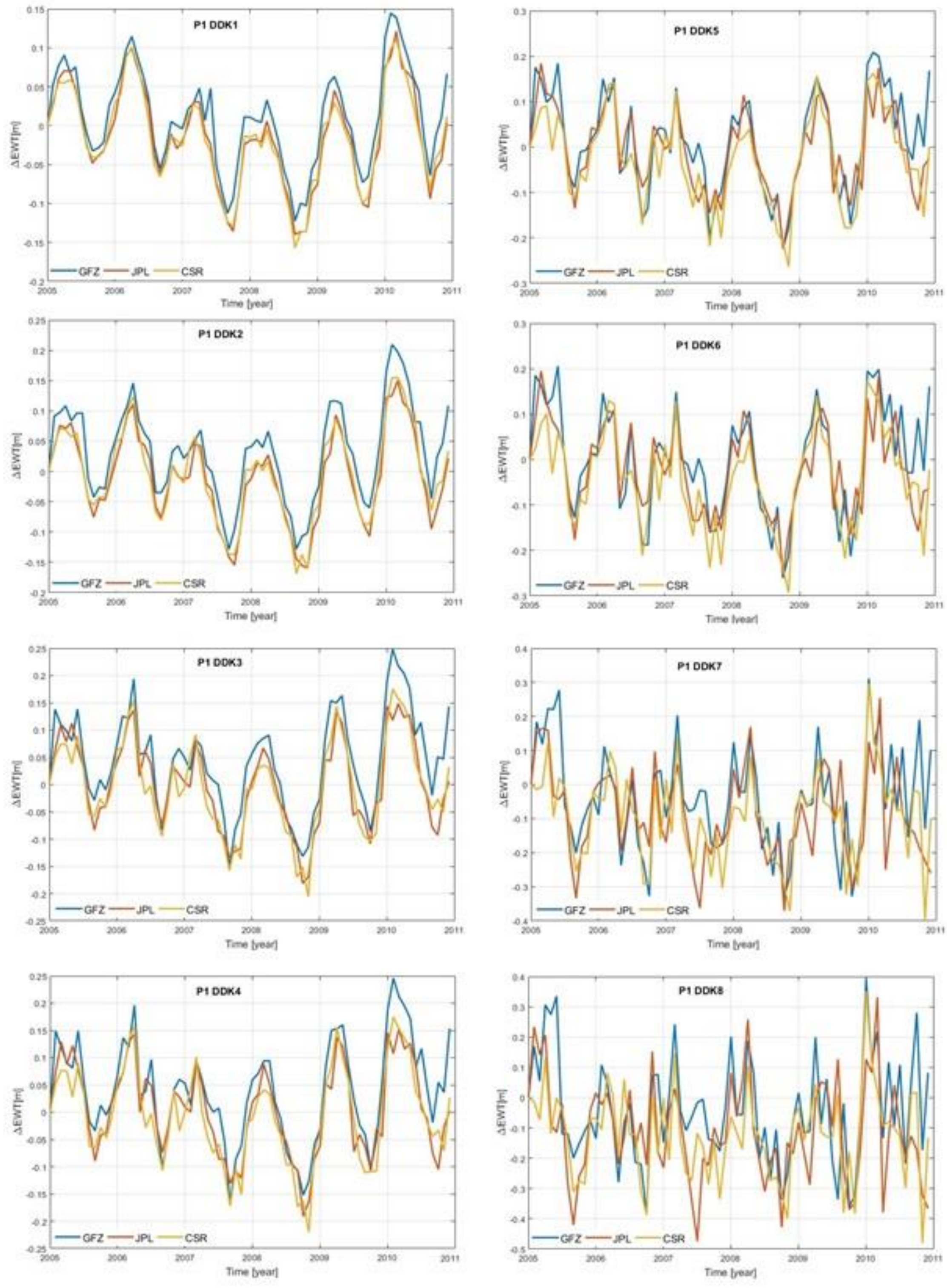

Fig. 5. Time series of $\Delta EWT^{(\mathrm{GRACE})}$ for P_1 using DDK1, DDK2, DDK3, DDK4, DDK5, DDK6, DDK7 and DDK8 filters

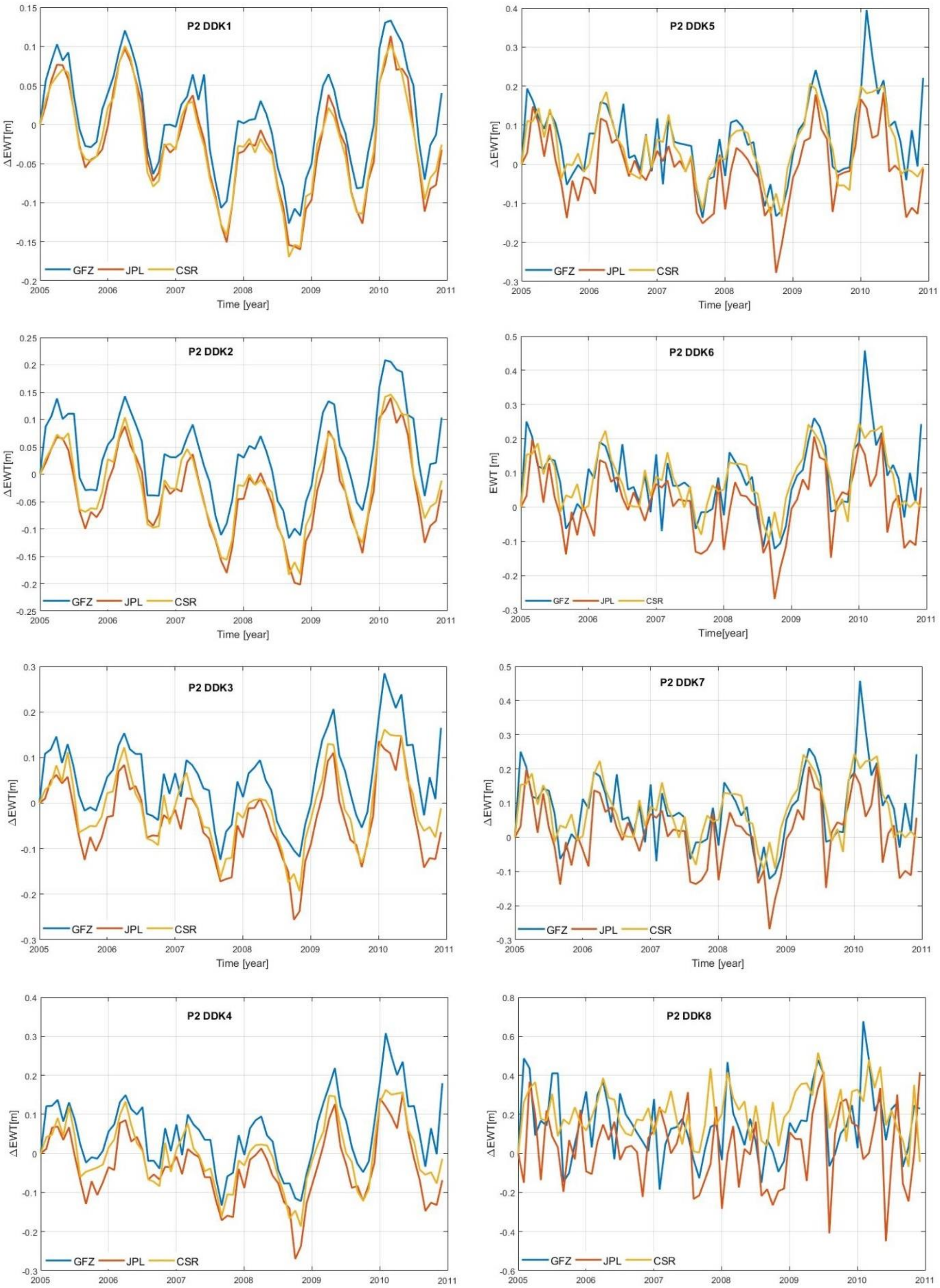

Fig. 6. Time series of $\Delta EWT^{(\mathrm{GRACE})}$ for P_2 using DDK1, DDK2, DDK3, DDK4, DDK5, DDK6, DDK7 and DDK8 filters.

Temporal variations of *TWS* (Total water storage) and temporal variations of *EWT* were also obtained from the JPL mascon solutions using the Mascon Visualization Tool (https://ccar.colorado.edu/grace/jpl.html) as a second control data. In this contribution, *EWT* and *TWS* were obtained from the mascon number #:803 that covers the area of Konya closed basin. The resulting temporal variations of $\Delta EWT^{(GRACE)}$, $\Delta EWT^{(WGHM)}$ and temporal variations of *TWS* are shown in Fig. 7.

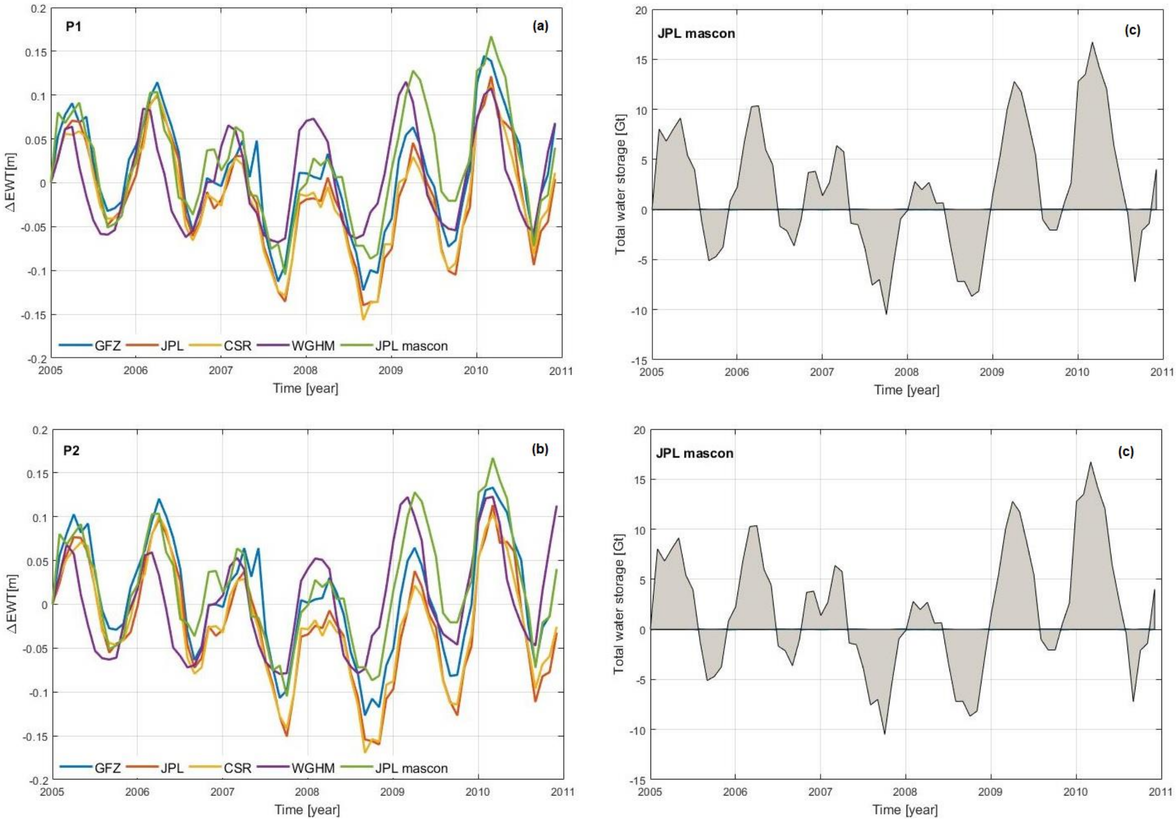

Fig. 7. Temporal variations of water mass over Konya basin: (**a**) temporal variations of equivalent water thickness obtained from GFZ, JPL and CSR GRACE-based GGMs, JPL mascon solutions and the WGHM, and (**b**) temporal variations of equivalent water thickness obtained from JPL mascon solutions

From the results in Figure 7, it can be clearly seen that the mass variations are at the highest levels in spring in April and May, and at the lowest levels in August and September. These results show that the mass variations (Figures 5 and 6) in the study area are also confirmed by the control data. In other words, RL05 GRACE-based GGMs are found to be sufficient for the investigation of equivalent water thickness obtained in the estimation of the temporal mass variation in Turkey.

The differences between $\Delta EWT^{(WGHM)}$ and $\Delta EWT^{(GRACE)}$ were computed using Eq. (5). Their statistics are given in Table 2.

Table 2. Statistics of the differences between the corresponding equivalent water thickness variations $\Delta EWT^{(WGHM)}$ and $\Delta EWT^{(GRACE)}$ for P_1 and P_2

Statistics[m]		**Min**	**Max**	**Mean**	**Std**	**Max-min**
P_1	**CSR**	-0.1270	0.0793	-0.0222	0.0469	0.2063
	GFZ	-0.0977	0.0965	0.0036	**0.0453**	0.1943
	JPL	-0.1321	0.0838	-0.0209	0.0504	0.2159
P_2	**CSR**	-0.1599	0.1003	-0.0280	0.0572	0.2602
	GFZ	-0.1226	0.1251	0.0043	**0.0537**	0.2478
	JPL	-0.1686	0.1040	-0.0278	0.0610	0.2726

As it can be seen in the statistics in Table 2, RL05 GRACE-based GGMs obtained from GFZ center are more convenient than the RL05 GRACE-based GGMs obtained from other JPL and CSR Centers. In this case, it can be highly recommended to utilize RL05 GRACE-based GGMs developed by GFZ center in order to determine the mass changes in Konya basin compared to other CSR and JPL-based GGMs.

5. CONCLUSIONS

In this study, the filters applied to reduce the noise including in the latest release of GRACE-based GGMs as well as the most suitable GRACE-based GGM time series for estimating mass variations over Konya basin were investigated.

The results show that DDK1 and DDK2 filters are more suitable to reduce the noise contained in RL05 GRACE-based GGMs than DDK3, DDK4, DDK5, DDK6, DDK7 and DDK8 filters as well as more effective at revealing mass variations in the study area.

The results of the comparison between equivalent water thickness variations obtained from RL05 GRACE-based GGMs and the corresponding ones obtained from the WGHM and JPL mascon demonstrate that the advantage of RL05 GRACE-based GGMs developed by GFZ center to estimate temporal mass variations, over other GGM time series analyzed.

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BIOGRAPHICAL NOTES

Emel Zeray Öztürk
She has been working as a research assistant at Selcuk University in Geomatics Engineering Department since April 2014.
Papers: Ustun A., Abbak, R.A., Zeray Ozturk E., (2016). Height biases of SRTM DEM related to EGM96: From a global perspective to regional practice, Survey Review, 50:358, 26-35.
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CONTACTS

Emel Zeray Öztürk
Selçuk University, Geomatics Engineering Department, Geodesy Division
42100-Konya-TURKEY
Tel. +90332 223 1930
Fax +90 332 241 06 35
Email: emelzeray@selcuk.edu.tr
Web site: galileo.selcuk.edu.tr/~ezeray

Walyeldeen Godah
Institute of Geodesy and Cartography
27 Jacka Kaczmarskiego St., 02-679
Warsaw
POLAND
Tel. +48 22 3291903
Fax +48 22 3291950
Email: walyeldeen.godah @igik.ed.pl

Ramazan Alpay Abbak
Selçuk University, Geomatics Engineering Department, Geodesy Division
42100-Konya-TURKEY
Tel. +90332 223 1898
Fax +90 332 241 06 35
Email: aabbak@selcuk.edu.tr
Web site: galileo.selcuk.edu.tr/~aabbak