EGSIEM

European Gravity Service for Improved Emergency Management

HORIZON 2020

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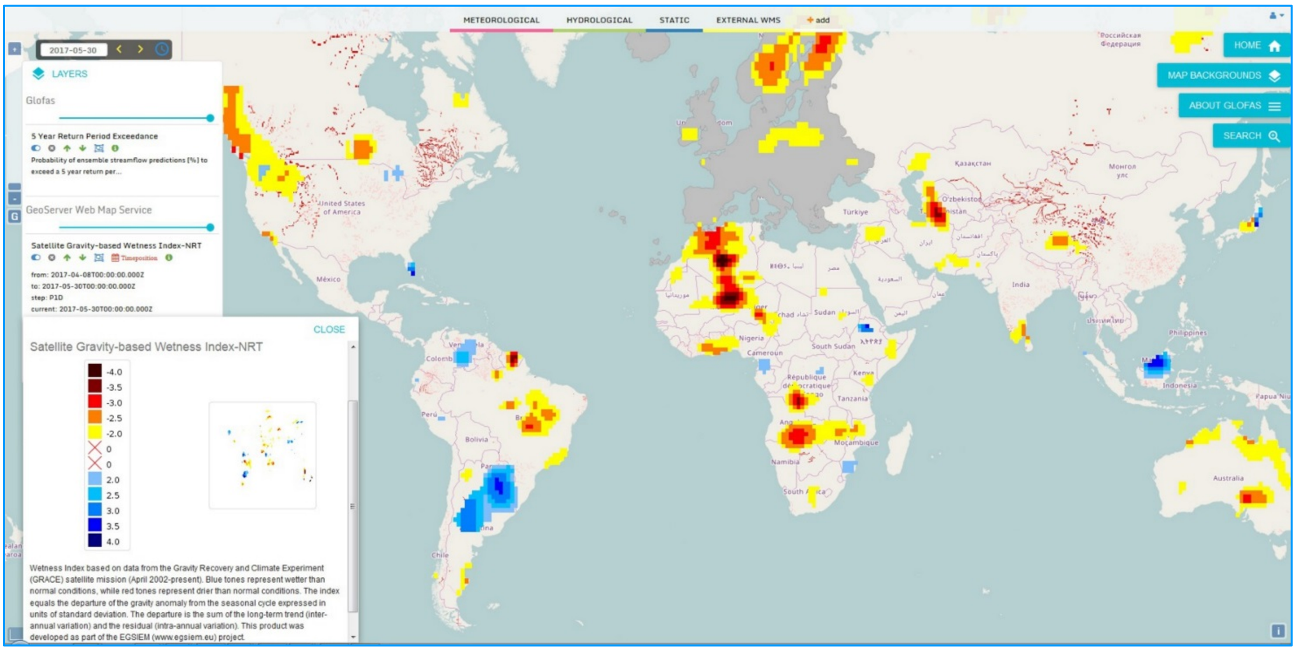

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1.Change Record

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Release 1	Gouweleeuw, Zwenzner, Güntner	31.12.2017	

2. Terms

This document provides the product report of the Operational Hydrological Service of EGSIEM (Work Package 6). It describes the activities in this work package on the validation of new gravity products provided by the NRT Service (Work Package 5) for flood events and on the development of a main product of the Hydrological Service, i.e. a flood and drought indicator. This indicator has been incorporated in the near-real time (NRT) Operational Hydrological Service for a test run of 3 months duration, in the period of 04.01.2017-30.06.2017. Details on the NRT Operational Hydrological Service are provided in this final WP6 deliverable.

3. Overview and Summary

This document provides the product report of the Operational Hydrological Service of EGSIEM (Work Package 6). It describes the activities in this work package on the validation of new gravity products provided by the NRT Service (Work Package 5) for flood events and on the development of a main product of the Hydrological Service, i.e. a flood and drought indicator.

Section 4 gives a short overview on the daily gravity products developed in EGSIEM by the German Research Centre for Geosciences (GFZ) and the Graz University of Technology (TUG) in the NRT Service and used for the Operational Hydrological Service. Details on the evaluation of these daily gravity products for major flood events were given earlier in the Deliverable No. 6.1 (Hydrological Service Product Report).

Section 5 presents the technical details of the method for deriving global wetness indices from the daily gravity-based products of water storage anomalies. Both the GFZ and TUG products are used for a combined Wetness Index. Evaluation for the example of the Danube basin over the entire GRACE operation period demonstrates the capacity of the wetness index to trace the major flood events in the river basin, but even more importantly, to indicate flood-prone above average wetness conditions in the river basin already ahead of the flood event itself. This chapter is an extended update of an earlier version presented in Deliverable No. 6.1 (Hydrological Service Product Report).

Section 6 describes the workflow of the near-real time (NRT) Operational Hydrological Service that has been implemented in a fully operational manner for a test run of 3 months duration, in the period of 04.01.2017-30.06.2017. The ways of integrating EGSIEM-based wetness indicators as a data layer into the European Commission's Copernicus Global Flood Awareness System (GloFAS) platform and into the DLR/ZKI Center for Satellite-based Crisis Information workflow for improved satellite tasking and acquisition planning for disaster monitoring and management are detailed.

Section 7 illustrates in a retrospective analysis of a historical flood event in the Danube basin in 2006 what the benefit would have been if a gravity-based early warning was available for the acquisition of additional satellite observations during a major flood event for which the International Charter Space & Major Disasters had been activated.

4. Evaluation of daily gravity products

Since the satellite data coverage within one day does not allow for a gravity field solution based on GRACE data alone, the computation of daily gravity maps employs a prediction – correction principle. Information obtained from geophysical models on the temporal behavior of the gravity field are used to predict the following day, which is subsequently improved with the available GRACE observations in a Kalman filter approach. Daily gravity field solutions are made available by the German Research Centre for Geosciences (GFZ) and the Graz University of Technology (TUG), with each analysis center providing an independent solution. TUG focuses on improving global gravity field solutions, whereas GFZ implements tailored regional representations of the gravity field. Details are specified in the EGSIEM NRT Service Product Report. Both approaches provide global coverage. Additional processing converts the resulting gravity field solutions, expressed in terms of spherical harmonics coefficients, into global 1^o x 1^o gridded map of total water storage anomaly (TWSA) in Equivalent Water Height (EWH) (Figure 1).

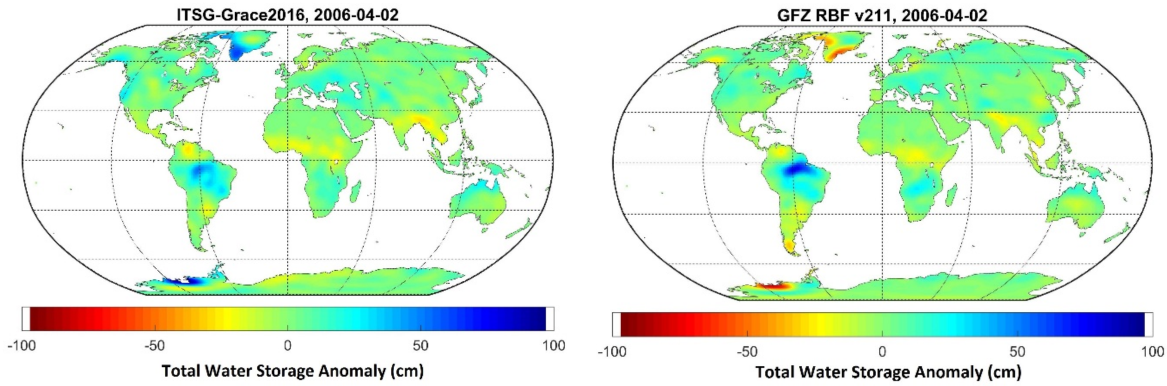


Figure 1: TUG (left) and GFZ (right) daily GRACE gravity solution converted into water storage anomalies, for the example of 2 April 2006.

5.Global satellite gravity-based wetness index: Method and Evaluation

Contrary to other Earth observation data, satellite-based measurements of gravity represent total water storage variations (i.e., variations of all surface and subsurface water storage compartments). As such, it provides unique information on the wetness state of a river basin with regard to its actual flood generation potential or its susceptibility to a drought. Reager and Famiglietti (2009) estimated flood potential at the regional scale by means of determining repeated maxima in water storage anomaly, which suggest an effective storage capacity in a region, beyond which additional precipitation must be met by increases in runoff or evaporation. Thomas *et al.* (2014) presented a quantitative approach for measuring hydrological drought occurrence and severity based on GRACE data by calculating the magnitude of the deviation of regional, monthly total water storage anomalies from the time series' monthly climatology. Humphrey *et al*. (2016) surveyed key features of temporal variability in the GRACE record by decomposing gridded times series of monthly equivalent water height into linear trends, inter-annual, seasonal and intra-annual components, with an additional focus on extreme dry anomalies and their relation to documented drought events. Here, for the development and testing of daily indicators of hydrological extreme events, we evaluate how large-scale water storage anomalies derived by the NRT, daily and regional GRACE products of the EGSIEM project can be used as early warning indicators in flood and drought monitoring and alerting services.

The Wetness Index (*WI*) developed here represents the departure (*D*) of the GRACE-derived total water storage anomaly (*Xtot*) from the mean seasonal cycle (*Xseas*) after removing the long-term trend (*Xlong*). *WI* is expressed in dimensionless units, normalized by an overall measure of the variation of *D* over the considered time series, i.e., its standard deviation (*S*). *Xtot* is the total daily change of mass, expressed in centimeters of equivalent water thickness, relative to a time-base line over the daily GRACE record considered (April 2002- December 2015). *Xtot* can be decomposed as follows:

$$Xtot = Xlong\ (= Xinter + Xlin) + Xseas + Xres \qquad (1)$$

The long-term component (*Xlong*) is computed by applying a 365-day low-pass filter and, as such, is considered to contain periodicities larger than 12 months only. The inter-annual variation is calculated as the deviation from the linear trend (*Xinter = Xlong – Xlin*). The mean seasonal component is taken as the daily average over the full GRACE life time after removing the long-term trend (*Xtot – Xlong*). *Xres* is then the residual or irregular component. *D* is then the sum of the inter-annual variation (*Xinter*) and the intra-annual variation or residual (*Xres*):

$$WI = \frac{D}{S} = (Xinter + Xres)/S \qquad (2)$$

In an effort to eliminate smaller gravity signals or noise, which are considered not to reflect a hydrological basin response, threshold values (THs) are set equal to the formal error of the respective gravity solution (i.e., 1.57 (cm) and 3.41 (cm) for ITSG-Grace2016 and GFZ RBF v211, respectively (Kvas, Gruber, pers.comm.)). Each day-to-day change of the gravity signal smaller than the noise level is considered hydrologically insignificant. With extreme hydrological events in focus, the most extreme absolute value of either WI, after outlier elimination, is selected for a combined WI.

Figure 2 shows an example of the Wetness Index derived from the TUG (left) and GFZ (right) daily gravity solutions for 2 April 2006. Blue tones represent wetter than normal conditions, while red tones represent drier than normal conditions. Similarities between the two patterns exist for instance for unusual wet conditions in the Danube Basin, and for marked below average water storage conditions, e.g. SE Africa. Differences between the two Wetness Indices based on the two daily gravity solutions may be regarded as an indication of the uncertainty of the methods, both in the daily gravity field solutions as well as in the index calculation.

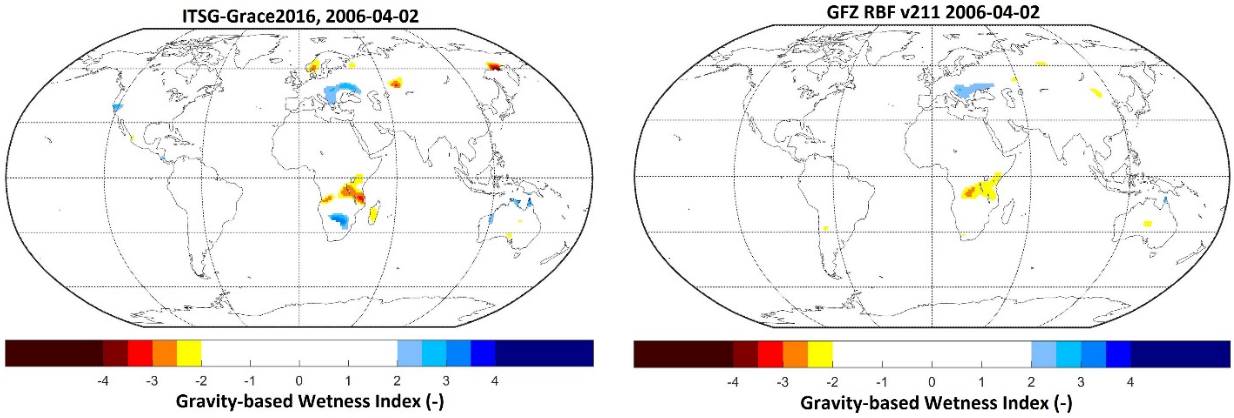


Figure 2: TUG (left) and GFZ (right) daily satellite gravity-derived Wetness Index for 10 June 2017.

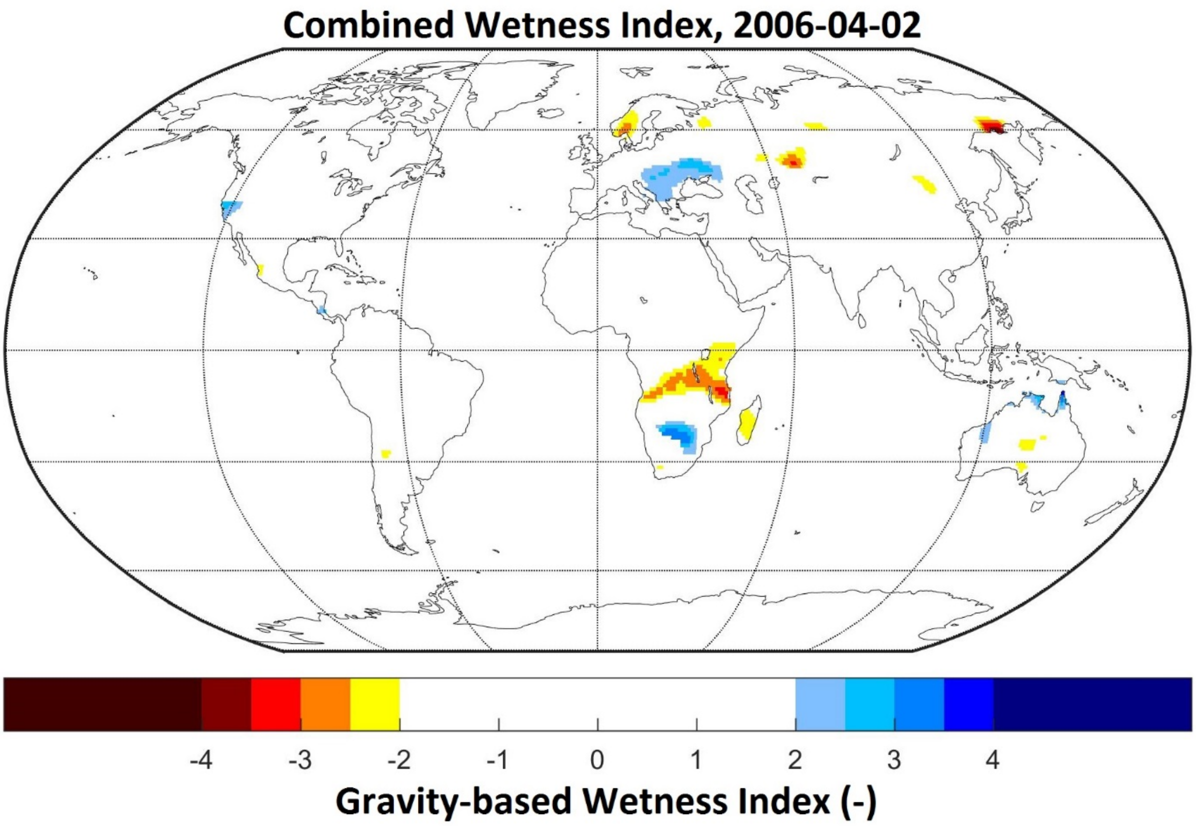


Figure 3: Combined daily satellite gravity-derived Wetness Index for 2 April 2006.

With extreme hydrological events in focus, a combined Wetness Index is derived by selecting the most extreme absolute values of either index in the combination product. For the example of 10 June 2017, the combined index is shown in Figure 3. The different Wetness Indices are calculated for the most recent daily gravity products provided by the Near-Real Time Service, but also in a retrospective analysis for the historical period of GRACE operation.

In a regional context, Figure 4 shows a retrospective analysis of daily global gravity solutions for the years 2002-2015 for the Danube basin. Both the gravity solutions (ITSG-Grace2016 and GFZ RBF v211) and the WIs derived from these solutions indicate increased values during widespread flooding in the Danube basin in 2002, 2006, 2010 (cyan dashed vertical lines), respectively, and for smaller floods in 2005, 2009, 2013 and 2014 (cyan solid vertical lines). Particularly relevant with respect to early flood warning is the build-up of basin-wide water storage of several weeks duration prior to the larger flood events of 2006 and 2010, which were triggered by a combination of (early season) snowmelt (resulting from unusual early high temperature peaks in 2006) and intense (2006) or excessive (2010) rainfall (ICPDR, 2007; ICPDR, 2012).

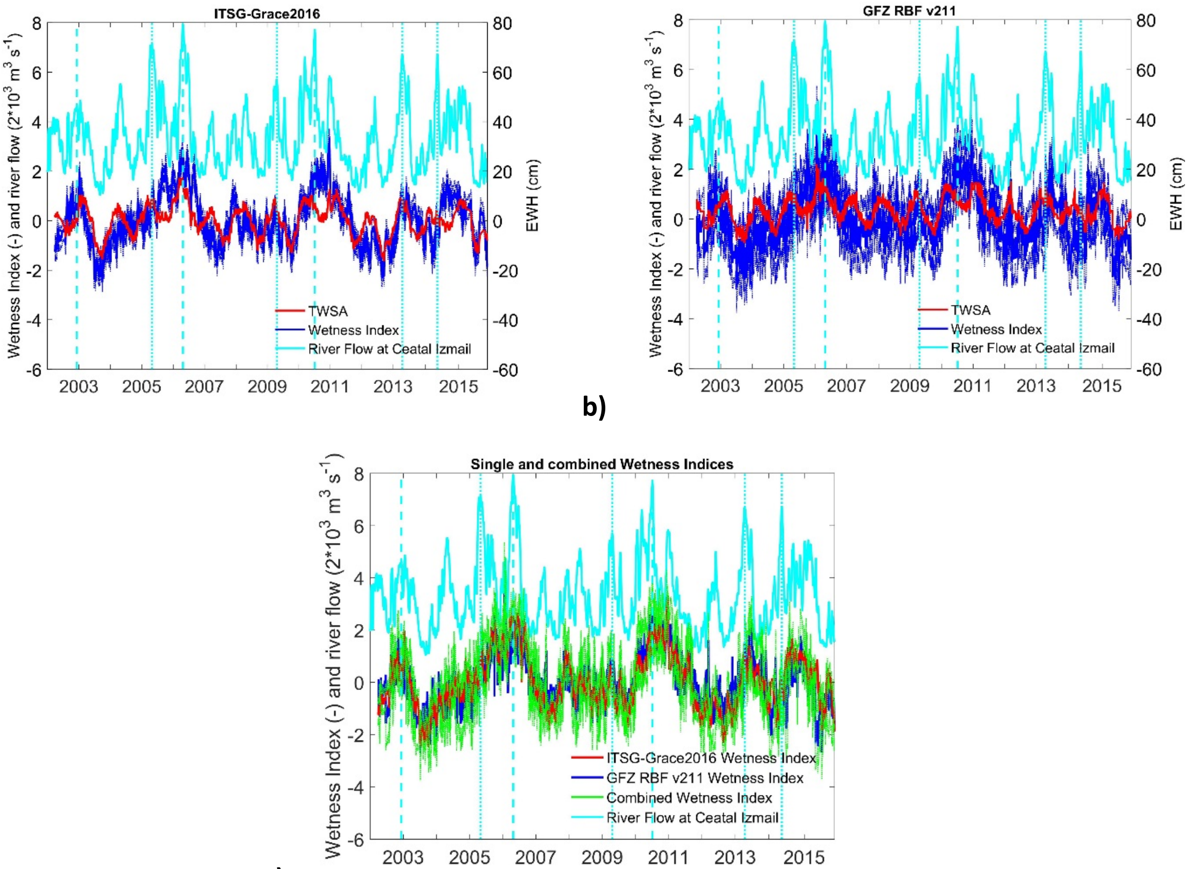


Figure 4: Total water storage anomalies (in equivalent water height (EWH)) from daily gravity solutions and gravity-derived Wetness Indices (WI) for the Danube basin (2002-2015) for a) TUG ITSG-Grace2016 and b) GFZ RBF v211 as well as c) for both Wetness Indices.

Figures 5 and 6 illustrate the flood and WI dynamics in more detail for the 2006 and 2010 events. River flow at Ceatal Izmail station at the outlet of the Danube Basin peaks on 26 April 2006. Elevated WI values of around 2 are recorded from early March onward and tend to increase close to 3 about 1 week before the peak discharge (at the basin outlet on 20 April). Although an early indication of elevated water storage that may lead to flood generation is evident, the selection of an exact point of time of early warning, however, is ambiguous. As an early choice, the date of 7 March could be considered, when WI peaks close to 2, which appears to reflect a level of basin storage saturation.

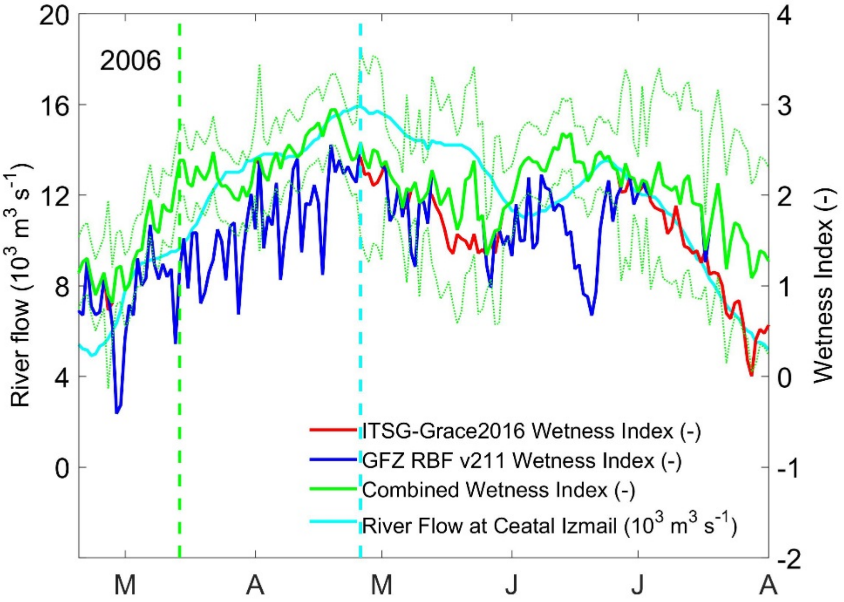


Figure 5: Gravity-derived Wetness Index (WI) for the Danube basin for the 2006 flood, together with discharge at the basin outlet, gauging station Ceatal Izmal. Light green lines indicate WI uncertainty ranges. Vertical dashed lines indicate time of peak flow (cyan) and early flood warning (green), here selected as the first peak over a presumed WI threshold value of 2, yielding a flood warning lead-time before peak discharge of 43 days.

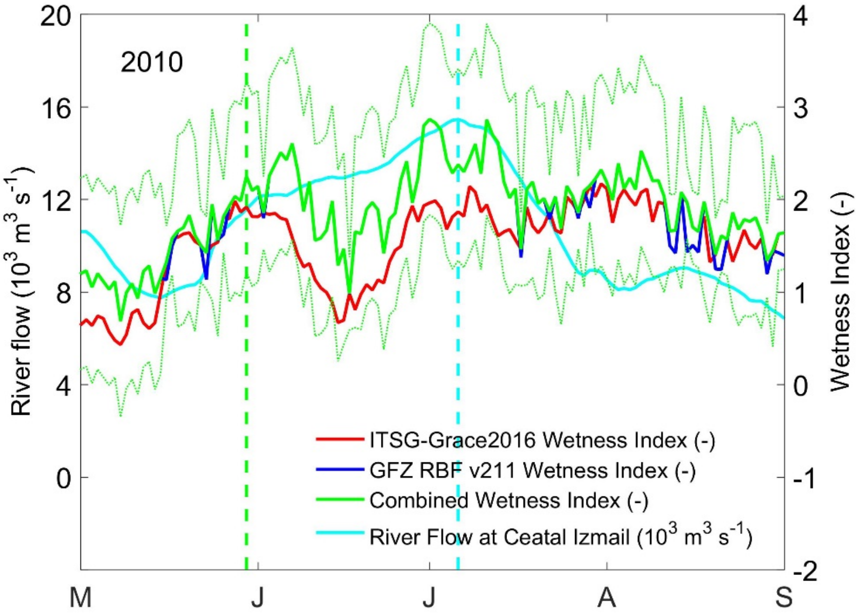


Figure 6: Gravity-derived Wetness Index (WI) for the Danube basin for the 2010 flood, together with discharge at the basin outlet. Light green lines indicate WI uncertainty ranges. Vertical dashed lines indicate time of peak flow (cyan) and early flood warning (green), here arbitrary selected as the first peak over a presumed WI threshold value of 2, yielding a flood warning lead-time before peak discharge of 37 days.

Alternatively, a first WI peak over the presumed threshold of 2 could be selected on 14 March, marked as a (green) vertical line in Figure 2. The arguably arbitrarily selected date of 14 March in Figure 2 would provide a lead-time to river peak flow at the basin outlet of 43 days (or over 6 weeks).

Figure 6 illustrates the setting for the 2010 Danube flood. River discharge at the basin outlet peaks on 6 July (vertical dashed cyan line). The first WI value (clearly) over the indicative threshold of 2 is recorded on 30 May. Slightly earlier, WI only just exceeds this threshold on 28 May, and earlier (local) peaks just short of it are registered on 24 May and, still earlier, 20 May. The first (clear) WI peak over threshold on 30 May results in a flood warning lead-time prior to peak flow at the basin outlet of 37 days (or over 5 weeks). This earliest possible indication of 20 May yields a lead-time of 47 days or just under 7 weeks.

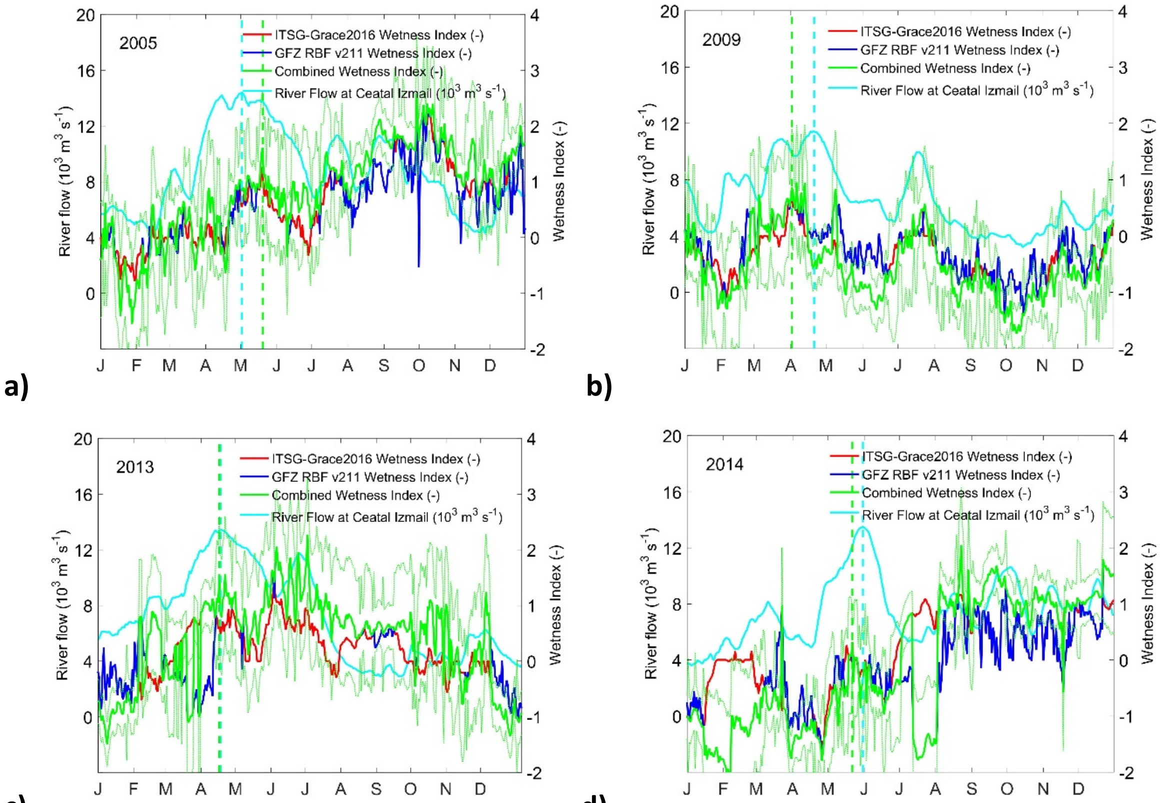


Figure 7: Gravity-derived Wetness Indices for the Danube basin for the a) 2005 b) 2009 c) 2013 and d) 2014 smaller, regional floods, together with discharge at the basin outlet. Light green lines indicate WI uncertainty ranges. Vertical dashed lines indicate time of peak flow (cyan) and early flood warning (green), here selected as the first peak over a WI threshold value of 2, yielding no (negative) or short flood warning lead-time before peak discharge.

A closer look at the figures discussed above reveals different dynamics with respect to the two WIs derived from the individual daily gravity solutions. While the ITSG-derived WI dominates (i.e., generates the more extreme WI values) for the 2006 flood (Figure 5), the GFZ-derived WI does so for the 2010 flood (Figure 6). This tentatively points to a strength of the combined WI, which selects the most extreme absolute value. Interestingly, on the longer-term perspective (2002-2015) the similarity of the two WIs, despite differences in dynamics and/or noise levels of the individual daily gravity solutions they are derived from, is striking (Fig. 4c). Here, apart from the larger floods in 2006 and 2010 (exceeding the indicative WI threshold of 2), smaller and shorter duration floods in 2005, 2009, 2013 and 2014 are detected with shorter lead times (Figure 7, Table 1), possibly indicating a different flood triggering mechanism with less water storage accumulation. Lead time for the 2002 flood is also relatively short (Table 1), possibly due to technical initialization issues of the GRACE twin-satellite mission (launch date: March 2002) at the time. A low of the wetness index reflects dry conditions during the 2003 and 2015 European heatwaves.

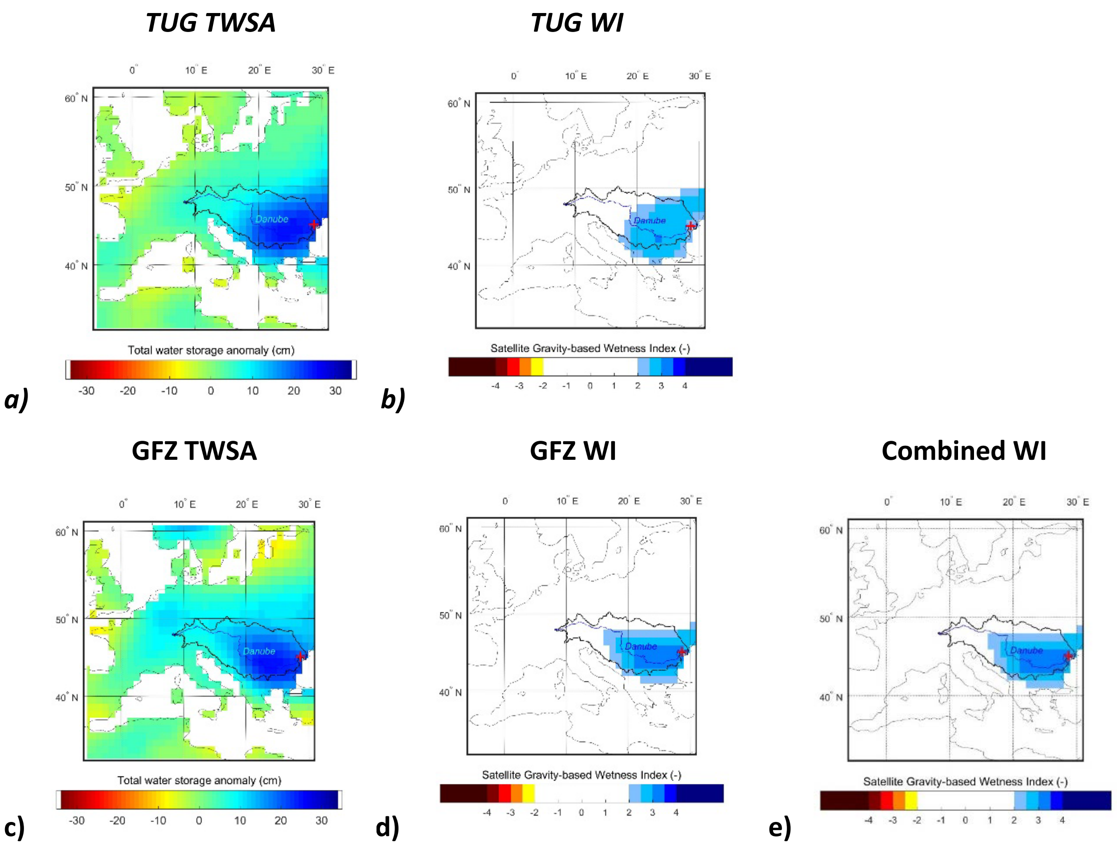
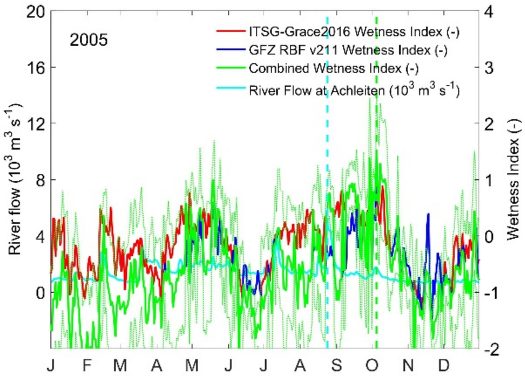
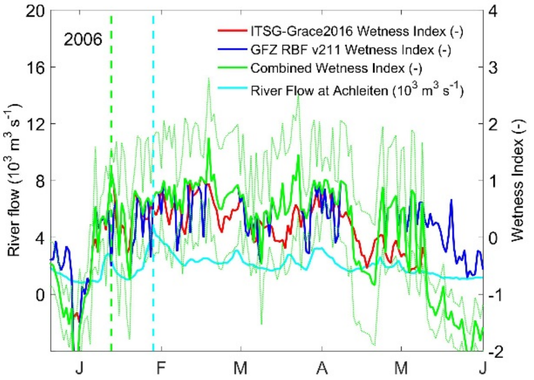


Figure 8: Daily gravity-based water storage anomlies (TWSA) and the gravity-based Wetness Indices (WI) for the Danube basin for 26 April 2006 based on the TUG ITSG-Grace2016 data (a, b) and the GFZ RBF v211 data (c,d,) as well as the combined index (e). Red cross indicates the location of the gauging station Isaccea.

Figure 8 shows maps of the daily gravity-based TWSA and WIs for the Danube basin on 26 April 2006, when flow peaks at Ceatal Izmail station at the basin outlet. Increased gravity TWSA values (dark blue) in both gravity solutions are reflected in elevated WI values, in particular in the lower parts of the river basin, with a spatially more focused pattern of high WI along the downstream reaches of the Danube where major flooding occurred by GFZ RBF gravity solution.



a)



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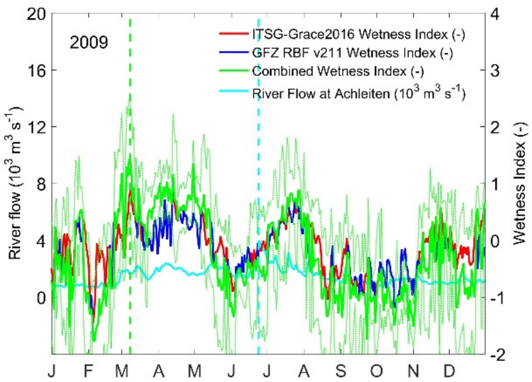

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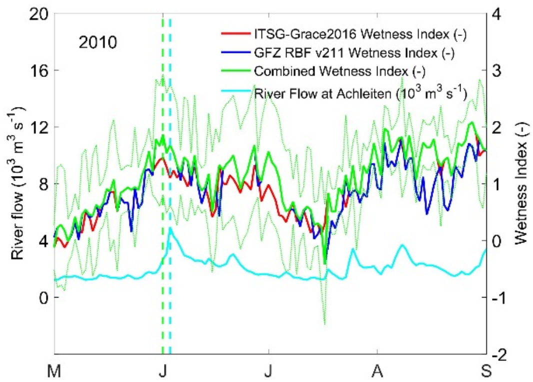

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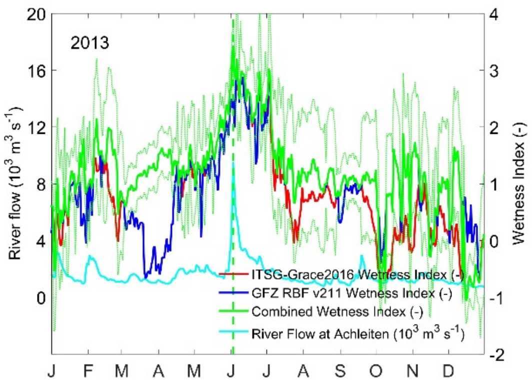
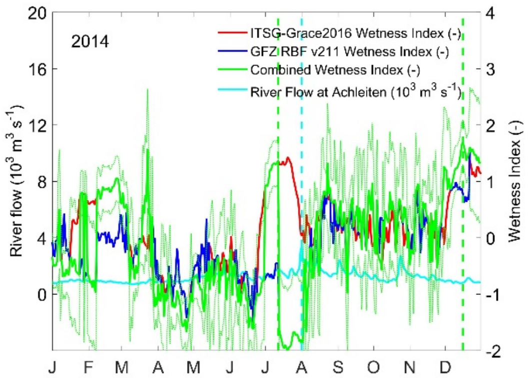


e)



f)

Figure 9: Gravity-derived Wetness Indices (WI) for the Upper Danube basin upstream gauging station Achleiten for the a) 2005 b) 2006 c) 2009 d) 2010 e) 2013 and f) 2014 Danube flood years, together with discharge at station Achleiten. Vertical dashed lines indicate time of peak flow (cyan) and early flood warning (green), here selected as the peak WI value, yielding no (negative) or short flood warning lead-time before peak discharge.

Further, in an attempt to look at flooding taken place earlier in time for the basin-wide flood events, e.g. of 2006 and 2010, the upper reach of the Danube Basin is analyzed in more detail, taking into account river flow observed at Achleiten station at the German-Austrian border (Figure 9).

Both the magnitude of river flow and of storage anomalies is values observed for the entire Danube Basin, due to the smaller catchment size. In fact, the Upper Danube sub-basin size of just under 80.000 km2 borders on what is a physically detectable gravity signal for the GRACE twin-satellite constellation. Further, only minor flooding occurred in the upper reaches of the Danube in 2006 and 2010 (no DLR/ZKI activations). Figure 9 shows lead-times prior to peak flow in the Upper Danube are critically reduced for 2006, 2010, and 2013 or even negative (2005). Lead-times for 2009 and 2014, on the other hand, do give longer lead-times. The peaks in flow and WI, however, do not appear to be connected. Table 1 summarizes early flood warning times stamps for both the Upper and the entire Danube basin, together with the respective peak flood occurrences during the GRACE period considered here (2002-2015).

Table 1: Gravity-based Wetness Index (WI) based early flood warning time stamps versus peak flow (Q)occurrences in the Danube Basin, for the Upper basin (station Achleiten) and the entire basin (station Ceatal Izmal) (WI is dimensionless, Q is give in 10^3 m^3s^{-1}).

	WI Flood Warning Upper Danube		Peak flow at Achleiten		WI Flood Warning Danube Basin		Peak Flow at Ceatal Izmal	
	Date	WI	Date	Q	Date	WI	Date	Q
2002 Flood	17.08	3.2	13.08	7.3	17.08	1.1	02.09	17.4
2003	06.01	3.6	05.01	3.3	12.01	2.0	20.01	19.5
2004	16.07	1.3	14.01	3.3	16.05	0.4	29.04	22.2
2005	05.10	1.4	24.08	5.3	20.05	1.6	02.05	28.8
2006 Flood	13.03	1.2	29.03	4.7	14.03	2.4	26.04	31.8
2007	29.06	0.6	07.09	4.0	19.11	1.4	12.14	17.2
2008	11.05	1.5	03.03	1.9	20.04	0.1	28.04	20.6
2009	08.03	1.4	24.06	3.9	02.04	0.9	21.04	22.8
2010 Flood	01.06	1.9	03.06	4.9	30.05	2.3	06.07	30.9
2011	18.01	2.2	14.01	5.3	26.01	2.2	04.01	23.1
2012	30.05	2.9	13.06	3.5	30.05	-0.4	03.06	20.1
2013 Flood	03.06	3.4	03.06	9.5	17.04	1.6	18.04	26.8
2014 Flood	12.07	1.4	01.08	3.4	22.05	0.3	09.06	27.0
2015	01.06	1.5	24.05	3.0	22.02	1.4	18.03	21.7

6.Operational Hydrological Service implementation

The NRT Operational Hydrological Service was established in a test run period between April 1 to June 30 2017, ending with the regular availabily of GRACE data due to approaching the end of the satellite mission. During this time span, the processing chain (Figure 10) was operated in a fully operational manner. The processing chain includes the calculation of daily gravity fields at TU Graz and GFZ, their transformation into water storage anolamies in equivalent water heights at a 1 degree global grid, the derivation of the wetness indices as flood indicators by the Hydrological Service run at GFZ, and their transfer to DLR's Center for Satellite-based Crisis Information (ZKI). In addition, towards the integration of Hydrological Service Produts into Operational Flood and Drought Mapping and Forecasting Services, the EGSIEM gravity-based Wetness Index has been integrated into the European Commission's Copernicus Global Flood Awareness System (GloFAS) platform. The Operational Hydrological Service has been implemented with providing the gravity-based flood information to the ZKI and GloFAS services with a latency of two to three days, well below the five day latency defined as target for the EGSIEM project.

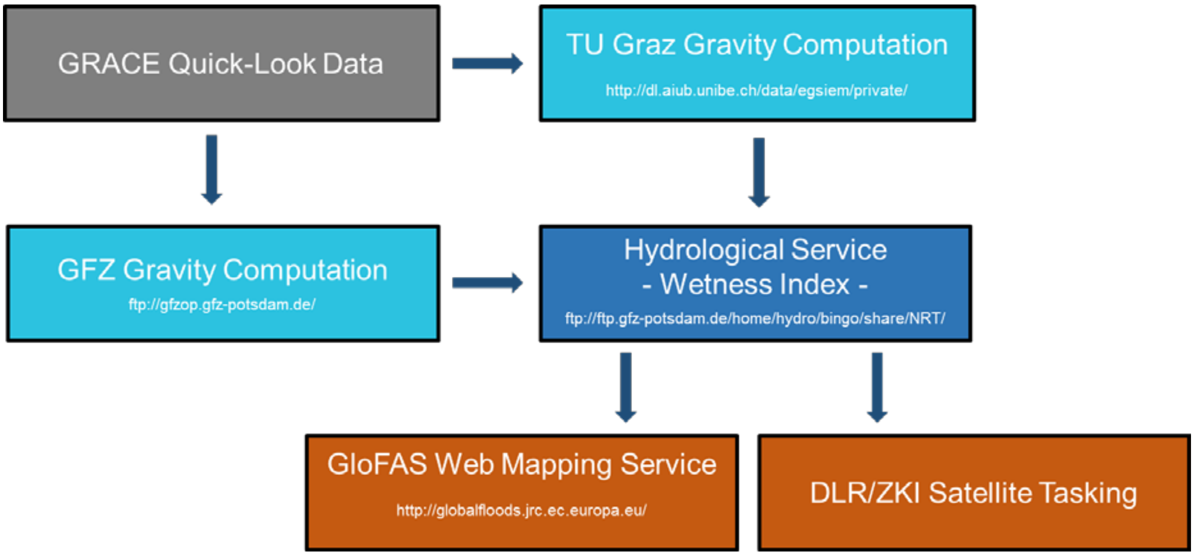


Figure 10: Flow chart of the NRT Operational Hydrological Service during the test run period in 2017

Hydrological Service integration into GloFAS

The EGSIEM gravity-based Wetness Index has been integrated into the Global Flood Awareness System (GloFAS) by adding an information layer to the Web Mapping Service of the GloFAS platform. The wetness index can be visualized in GLOFAS. It is accessible on the GloFAS WMS (Web Mapping Service) at http://globalfloods.jrc.ec.europa.eu/ by selecting (1) "Hydrological", (2) clicking "add layer", (3) writing "gravity" in the search box, and (4) choosing "Satellite Gravity-based Wetness Index-NRT". As an example, Figure 11 shows the combined Wetness

Index in the GloFAS platform, for the example of 31 May 2017. Wetter than normal conditions (2.5-3 times the standard deviation) are indicated for parts in Latin America, signaling ‘El Niño` conditions and causing flooding in southern Columbia and Uruguay, as also reported in the International Charter of natural and man-made disasters (https://disasterscharter.org). Hotspots of considerably drier than normal conditions indicate ongoing drought-related humanitarian crises in Africa (Zambia, Angola, North-Eastern Africa). The Wetness Index can currently be compared in the GloFAS platform with other global data layers that characterize the preconditions and the event characteristics of flood events worldwide.

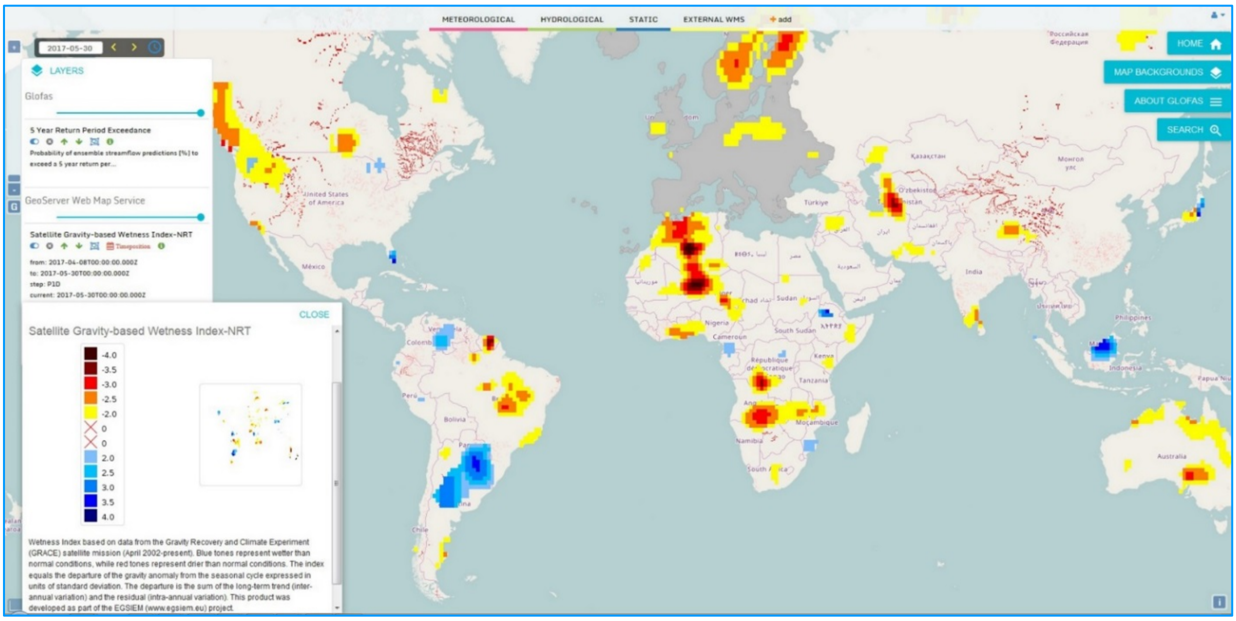


Figure 11: EGSIEM combined daily satellite gravity-derived Wetness Index of 31 May 2017, visualized within the GloFAS platform.

Hydrological Service integration into DLR/ZKI disaster management service

Early warning by the wetness index presented here is expected to improve the programming and the efficient use of high resolution satellites that are used for disaster management activities. The International Charter Space & Major Disasters run by the Center for Satellite Based Crisis Information (DLR/ZKI) is a major international activity in this respect. Generally, the Charter mechanism is activated upon user request (Voigt *et al.,* 2016). Its rapid mapping concept has been developed and refined over the years based on experiences made in rapid mapping activities for national, European as well as international users in the domain of disaster relief and civil protection.
The EGSIEM wetness index, being an indicator for flood forecasting and drought monitoring, can facilitate an early warning component and thus improve the first two steps of the rapid mapping workflow: the mobilization and data acquisition. Requirements expressed by DLR/ZKI users focus on timely and high frequency flood monitoring from the onset of a flood event with

a special focus on mapping the flood extent at peak level until water levels have receded to near normal stages. For this task, a number of SAR and optical satellites have to be tasked, as it is done within mechanisms such as the International Charter or the European Copernicus Emergency Management Service (EMS). Both mechanisms are activated upon user request, which means that satellite tasking does not start before a user request has been received. In some cases, i.e., when a large flood evolves quickly or has not been considered as evolving into a major flood event, user requests came in relatively late and satellite tasking could not be put into effect until the flood peak had already passed the area of interest.
For such cases, a proactive satellite tasking based on external information such as the gravity based wetness indicators are of key importance. In order to enhance the rapid mapping service with such indicators, an interactive web viewer has been developed (see Figure 12) to visualise the daily gravity based wetness indicator provided by the EGSIEM NRT Service and the Operational Hydrological Service together with other DLR/ZKI data sources such as the operational Sentinel-1 and TerraSAR-X flood services during the EGSIEM operational NRT test phase from April to June 2017.

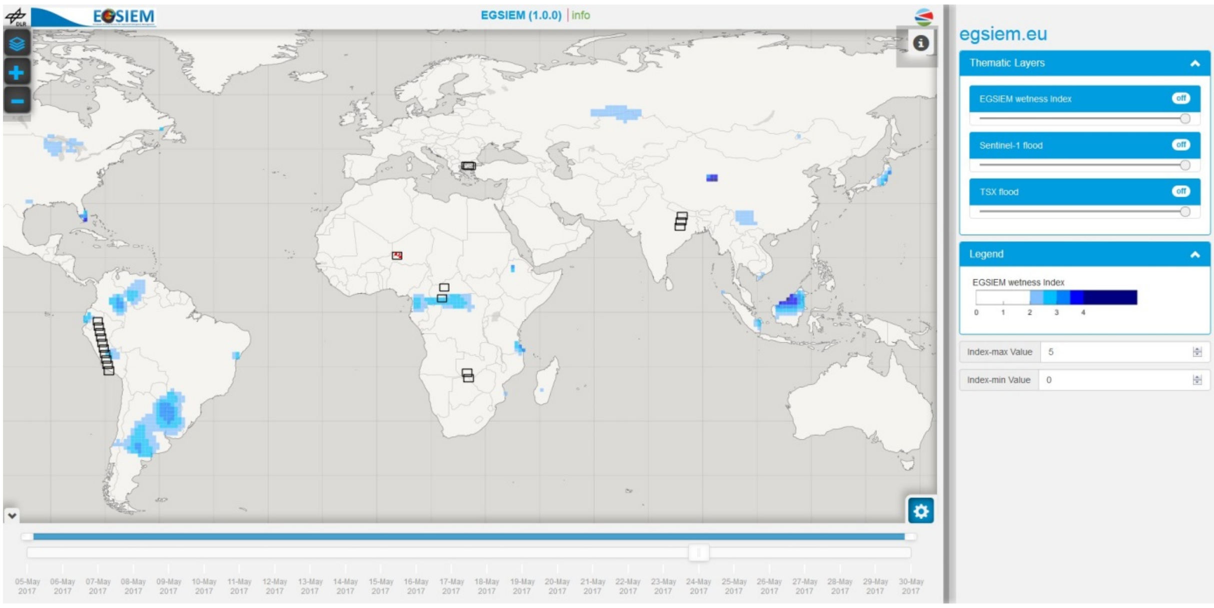


Figure 12: DLR EGSIEM Viewer showing daily gravity based wetness indicator and the operational Sentinel-1 and TerraSAR-X flood service

With the help of this tool, operational workflows for improved on demand programming of high and medium resolution satellite data can be realized. This includes establishing a detailed acquisition plan for all relevant earth observation satellites (e.g. from the Charter) by selecting the optimal orbits and satellite overpasses with the help of the software tool “Savoir Acquisition planner” (Figure 13).

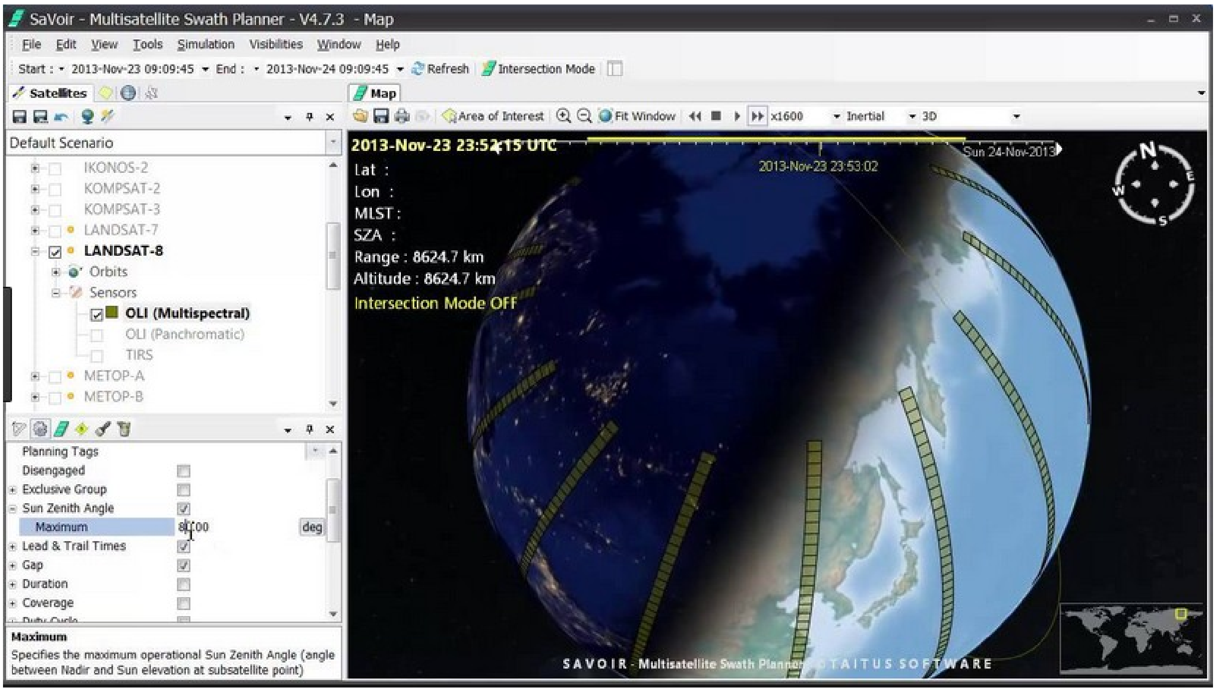


Figure 13: User interface of the Savoir Multi-satellite Swath Acquisition Planner at DLR/ZKI (software from TAITUS)

7.Retrospective evaluation of the DLR/ZKI satellite tasking for flood events

For the example of the Danube flood in 2006, the value of early proactive satellite tasking before the actual activation of the Charter, based on gravity-based wetness indicators as given by the Operation Hydrological Service, is assesed in a retrospective way below.

Figure 14 shows a map of flooded areas in the delta region of the river Danube in eastern Romania, derived from MODIS (Moderate Resolution Imaging Spectroradiometer) data acquired on April 26th, 2006. This corresponds to the time of the flood peak at Ceatal Izmail station at the outlet of the Danube basin (see Figure 5). MODIS is a medium resolution optical satellite sensor with 250 m pixel size used for large-scale environmental monitoring. MODIS acquires images of the Earth’s surface continuously every 1-2 days, provided that there are no clouds. Higher resolution satellites (particularly SAR satellites), which are more suitable for flood delineation even for cloudy conditions, need to be programmed prior to the flood peak in order to acquire up-to-date high resolution images of the flood affected regions to be used for disaster management activities. For the 2006 flood, the International Charter has been activated for Romania on April 18th, 2006 (Call #121). The area affected in the Danube delta shown in Figure 14 was one of the two areas of interest (AOI) of the Charter call for which a number of rapid mapping products were produced (Table 2).

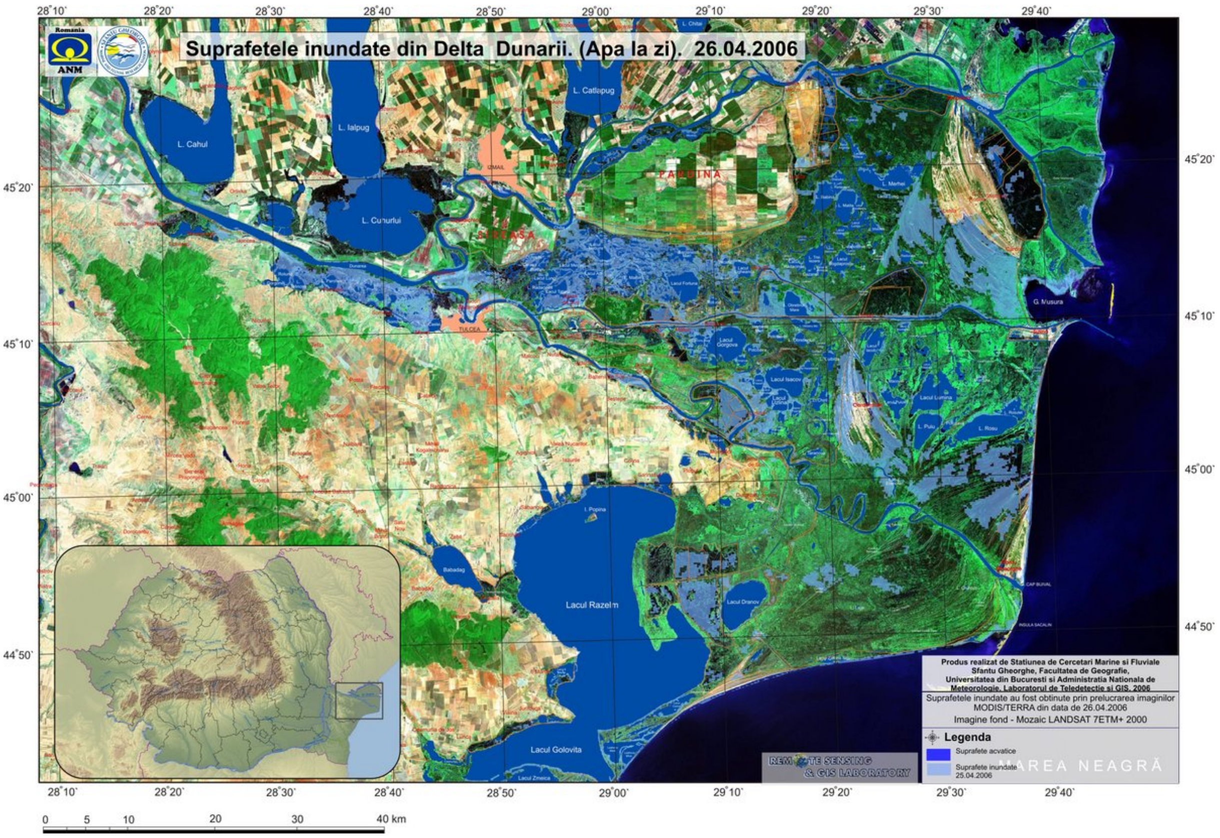


Figure 14. Map of flooded areas in the Danube delta based on MODIS data acquired 26th April 2006.

Table 2: Satellite data acquisitions for the Danube delta in Romania during Charter Call #121

Satellite	Sensor / Mode	Spatial Resolution	Date
SPOT-4	optical	10 m	23.04.2006
ERS-2	SAR	30 m	23.04.2006
Radarsat-1	SAR	30 m	25.04.2006
ENVISAT-ASAR	SAR	30 m	28.04.2006

Figure 15 shows for three of the above mentioned satellites which acquisitions would have been possible for the Danube delta area based on the available overpasses during April 2006. This analysis has been carried out with the “SaVoir Charter - Swath Acquisition Planner” – V4.5.4.0 (© Taitus Software) (Figure 13).

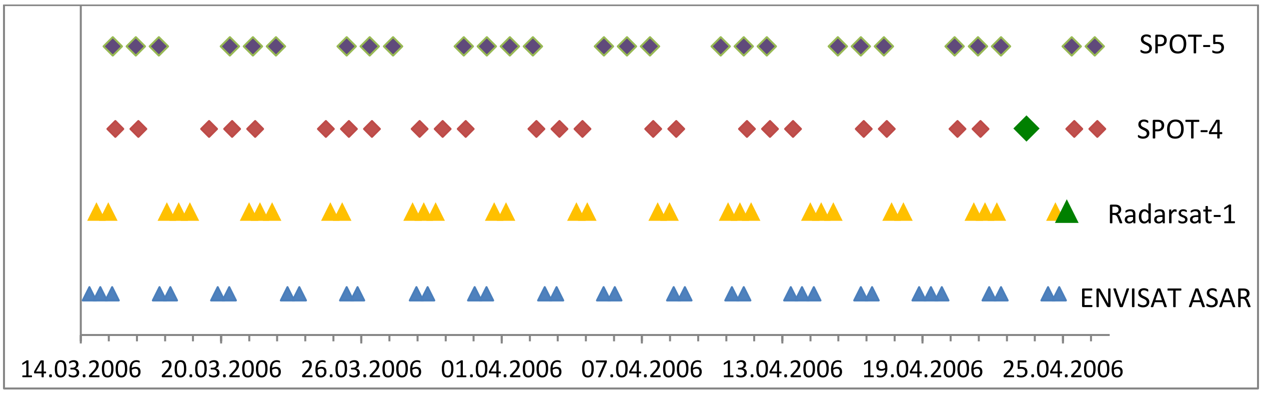


Figure 15: Possible overpasses and acquisitions of ENVISAT ASAR (wide swath mode with 150 m spatial resolution), Radarsat-1 (standard mode with 30 m spatial resolution), SPOT-4 (HRVIR sensor with 10 m spatial resolution) and SPOT-5 satellite (HRG sensor with 10 m spatial resolution) for the Danube delta region shown in Figure 5. Acquisitions that have been realized during Charter Call #121 are marked with dark green symbols.

Taking into account the lead time of the gravity-based wetness index of 43 days prior to the flood peak at Ceatal Izmail station at the outlet of the Danube basin (see Figure 5), a large number of additional satellite overpasses (35 for ENVISAT-ASAR, 32 for Radarsat-1, 26 for SPOT-4 and 27 for SPOT-5) could have been acquired for flood monitoring and emergency mapping if the wetness indices were available at that time.

For the Danube flood 2006 the Charter was activated four times (Czech Republic/Slovakia: 1 April; Austria: 7 April; Hungary: 14 April; Romania: 18 April). According to Table 1 the WI Early flood warning time stamp of the Upper Danube was 13 March 2006. Regarding the time when the Charter was first activated for the Danube flood on 1 April for the Czech Republic & Slovakia being the point in time when it was considered as a major disaster, an early flood warning lead time of 18 days can be determined in this case.

Requirements expressed by the users of satellite rapid mapping products focus on timely and high frequency flood monitoring from the onset of a flood event with a special focus on mapping the flood extent at peak level until water levels have receded to near normal stages. Based on the example of the Danube flood 2006 it could be demonstrated that gravity-based early-warning indicators for total water storage anomalies can improve the programming and the efficient use of EO satellites for rapid flood mapping tremendously. For the case of widespread flooding along the Danube in southern Romania after a dam break close to the village of Bistret on April 17, 2006 (not shown in detail here), proactive early satellite tasking would have offered the possibility to have satellite data available for disaster response teams a few hours after the dam break instead of a few days.

8.Acknowledgements

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10. Glossary

DEM	Digital Elevation Model
DLR	German Aerospace Center
EMS	Copernicus Emergency Management Service
GFZ	German Research Centre for Geosciences Potsdam
GloFAS	Global Flood Awareness System
NRT	Near Real Time
RBF	Radial Basis Function
SAR	Synthetic Aperture Radar
SRTM	Shuttle Radar Topography Mission
TUG	Technical University of Graz
TWSA	Total Water Storage Anomaly
WI	Wetness Index
ZKI	Center for Satellite Based Crisis Information at DLR