EGSIEM

European Gravity Service for Improved Emergency Management

EGSIEM's Near Realtime Mass Transport Products For Monitoring Of Hydrological Extreme Events

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GRACE Science Team Meeting

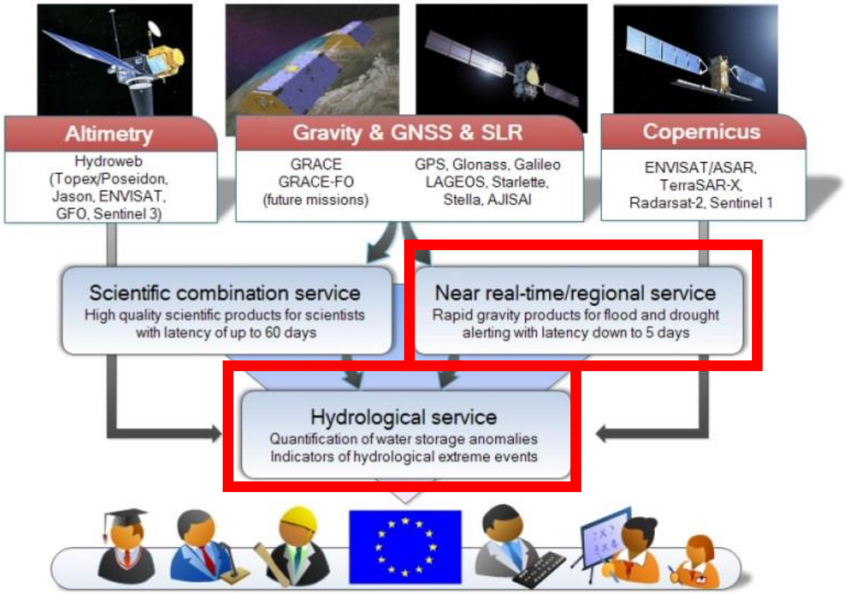
Austin, TX, 12.10.2017

Background

- **The nominal time delay of GRACE** Level-1 instrument data (11 days) and of the derived monthly global Level-2 **gravity field products** (60 days) **makes the application of GRACE for monitoring of e.g. hydrological extremes difficult.**

- On the other side **flood forecast models need, e.g. near-real time (NRT) information** to estimate the probable development of the event in terms of flood stage or river discharge with typical lead times of a few days for larger river basins.

- To enable the application of mass redistribution data for rapid monitoring of hydrological extreme events, the EU funded project EGSIEM (European Gravity Service for Improved Emergency Management) has established a **NRT and Regional Gravity** as well as a **Hydrological Service,** jointly developed by GFZ, TU Graz and DLR.



Background (2)

- The **NRT Service aims** to
  - **reduce the latency** of mass transport products **to less than 5 days**, and
  - **increase the temporal resolution** from one month **to one day**.

- **NRT flood indicators based on NRT gravity solutions will be used within DLR´s Center for Satellite-based Crisis Information** starting on April 1 in an **operational test run** for up to 6 months (in fact only 3 months due to GRACE health status).

- **Todays' talk**
  - focuses on the proof of concept of the NRT Gravity Service for historical GRACE data (2002-2015, 2004-2010),
  - will show some results for historical flood events and
  - will summarize results gained throughout the operational test run.

Part 1:
Comparison of Historical (2002-2015) TUG and GFZ NRT Gravity Time Series

Concept TU Graz NRT Daily Gravity Solutions

- Kalman filtered solutions following the **approach of Kurtenbach et al. (2012)**

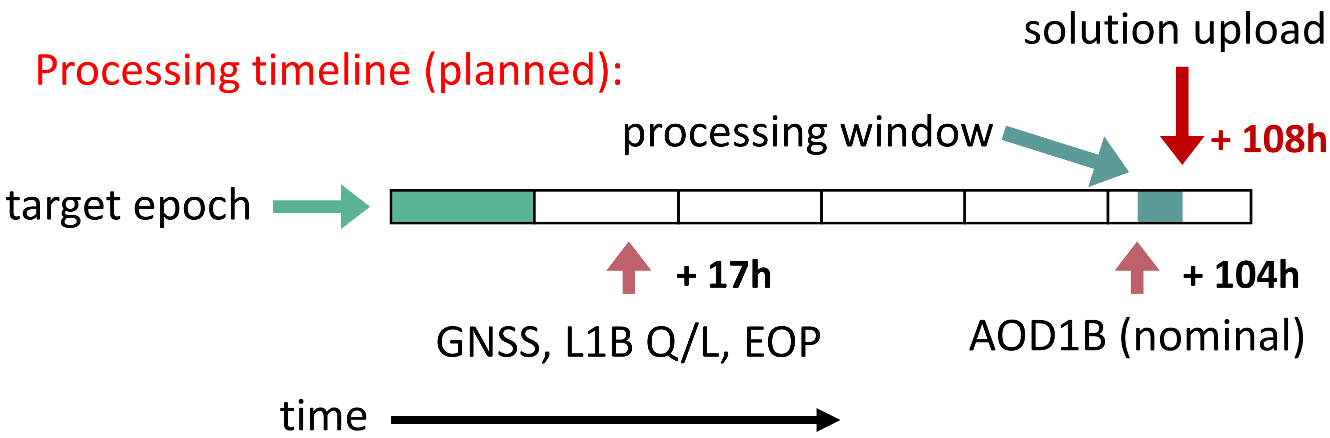
- Required **input data**:
  - GRACE Quick-Look data (L1B Q/L, JPL)
  - Atmosphere and ocean dealiasing (AOD1B RL06, GFZ)
  - CODE Rapid GNSS orbits and clocks
  - IERS rapid Earth orientation parameters

- GRACE data processing follows **processing strategy of ITSG-Grace2016**
  - Kinematic orbits based on the raw observation approach (Zehentner and Mayer-Gürr, 2015)
  - Smoothed star camera product by fusion with accelerometer data (Klinger and Mayer-Gürr, 2014)

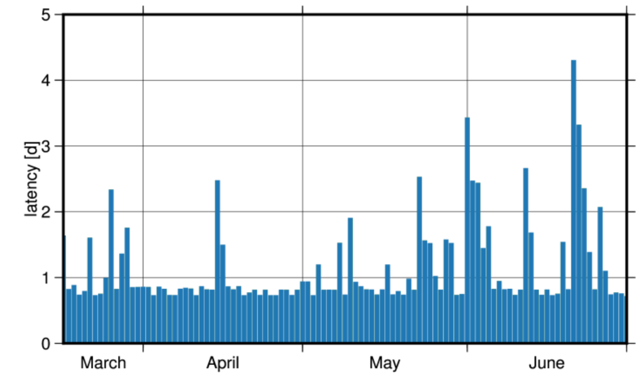
- Necessary **adaptions** (selected):
  - Outlier detection in Kalman update step using variance component estimation
  - Bi-monthly update of background models (annual and secular variations) to ensure stationarity for the residual gravity field.

Timeline and Steps TU Graz NRT Daily Gravity Solutions

- Processing timeline (planned):



During NRT Test



Timeline and Steps TU Graz NRT Daily Gravity Solutions

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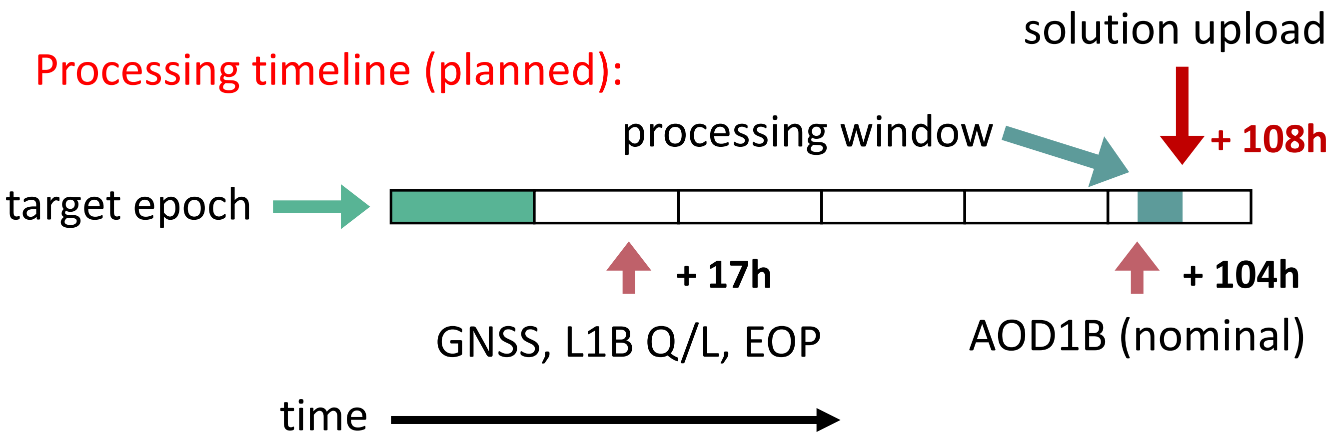
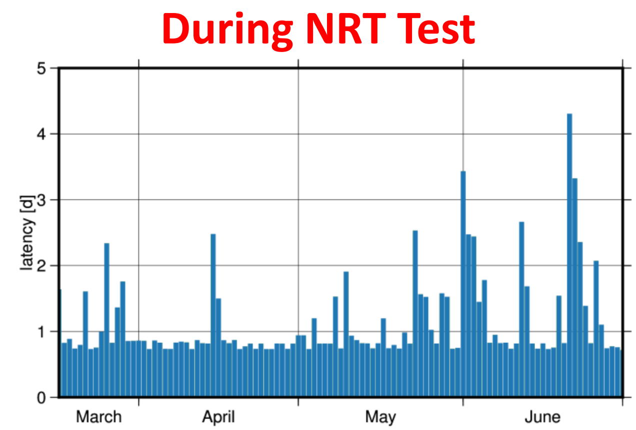
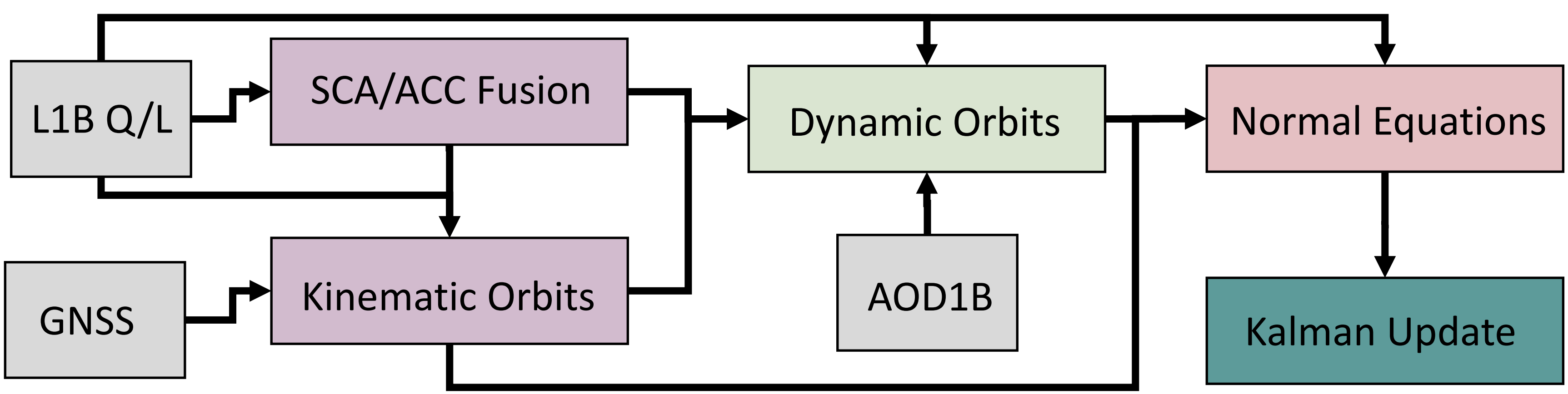




- Processing steps from raw data to final solution:



Concept GFZ NRT Daily Gravity Solutions

- Kalman filtered solutions using **acceleration approach** and **surface integral equations.**

- Required **input data**: as TU Graz

- GRACE data processing follows **2-step processing strategy** (Gruber (2014), Gruber (2017, submitted):
  - Reduced dynamic LEO orbits (reduction of empirical parameters per revolution), constraint by K-Band ranging
  - Conversion to gradient differences in line-of-sight

- Processing details:
  - Use seasonally dependent stochastic process model
  - Background model derivation (annual and secular variations) from monthly fields
  - Integration on 2x2 arc degree areal surface tiles
  - Details described in Gruber, C.: Short latency monitoring of continental, oceanic and atmosphere mass variations using GRACE inter-satellite accelerations (in review).

- Three versions derived with EGSIEM: V201, V211, V221
  - V211 used in the following

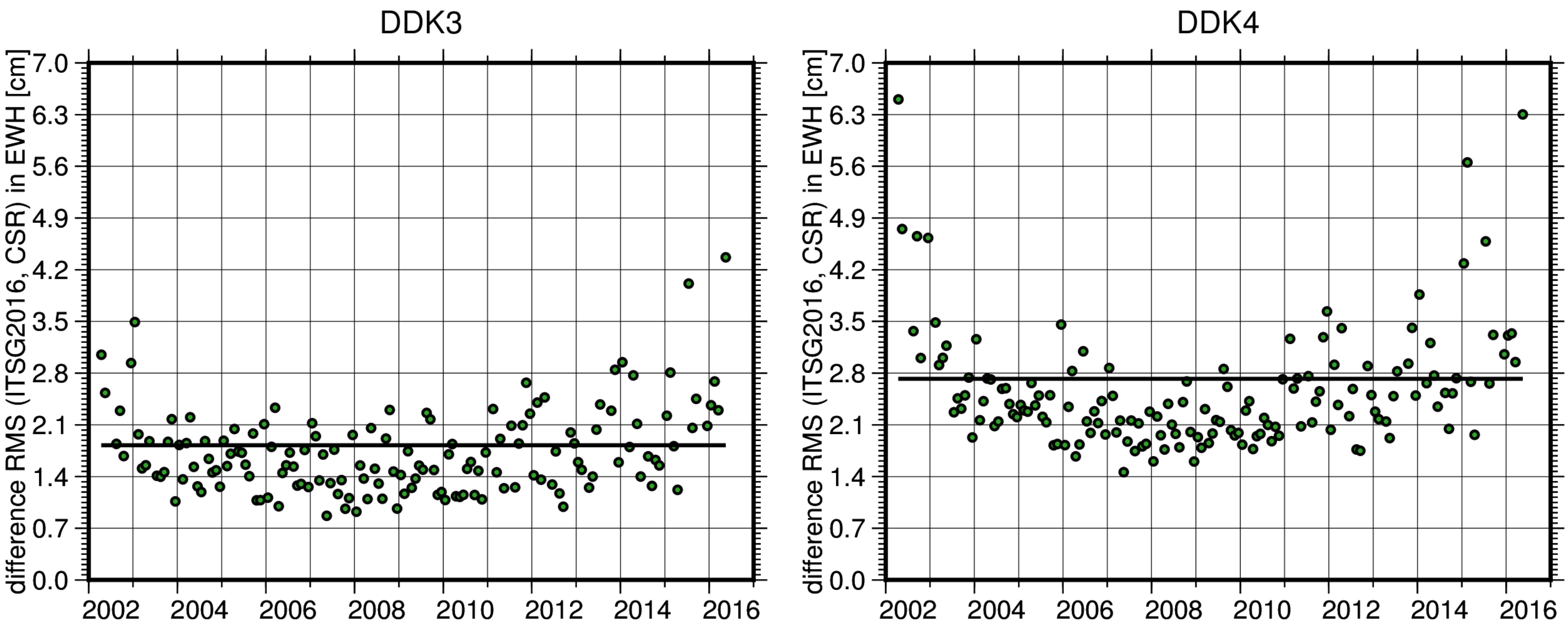
Intercomparison of Historical (2002-2015) Time Series

- Input data
  - TUG: ITSG-Grace2016 (spherical harmonics)
  - GFZ: v211 (gridded)

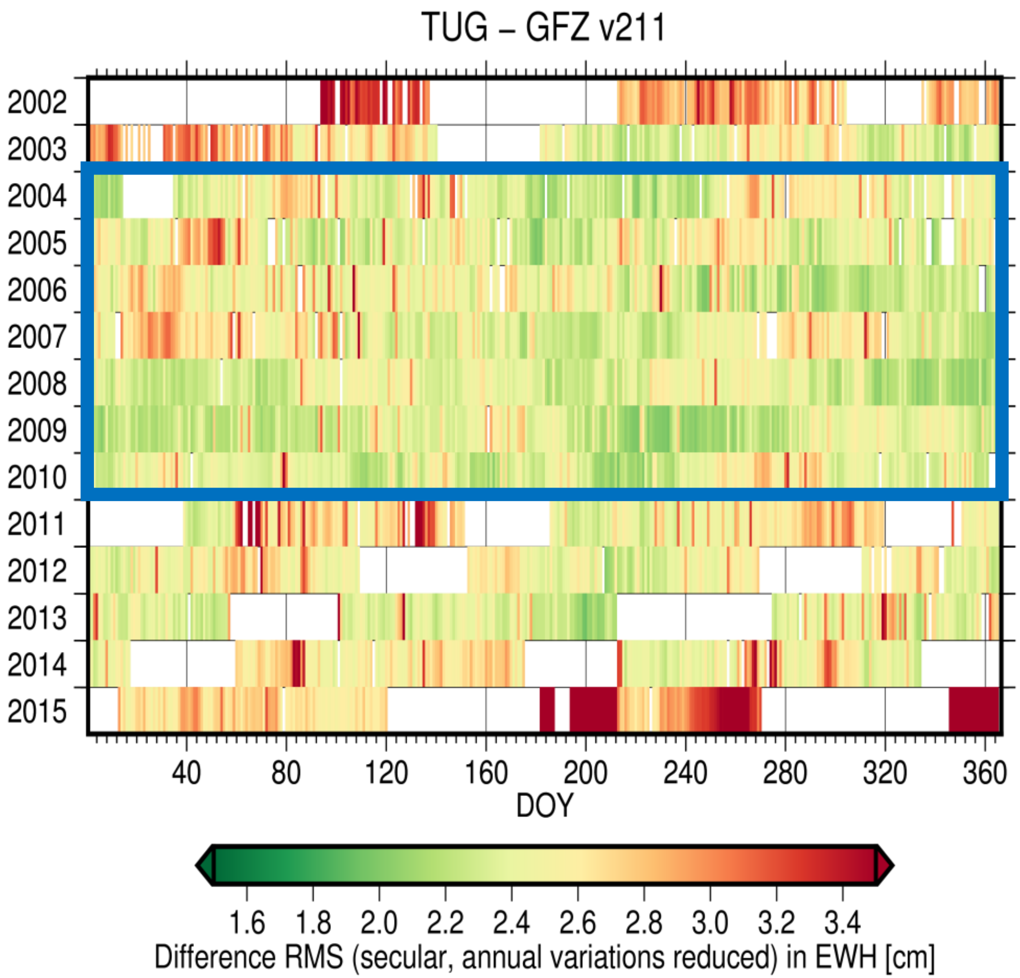
- Methodology
  - GFZ Water storage grids are converted to potential coefficients
  - Multiyear mean is removed from all time series
  - Only epochs where both time series have GRACE contribution are considered
  - Comparisons based on spatial frequency band up to degree 40

Intercomparison of Historical Time Series

- **Benchmark: Difference RMS of two monthly time series** (ITSG-Grace2016, CSR RL05)
  - Heavily depends on spatial filter: **1.9-2.8 cm**



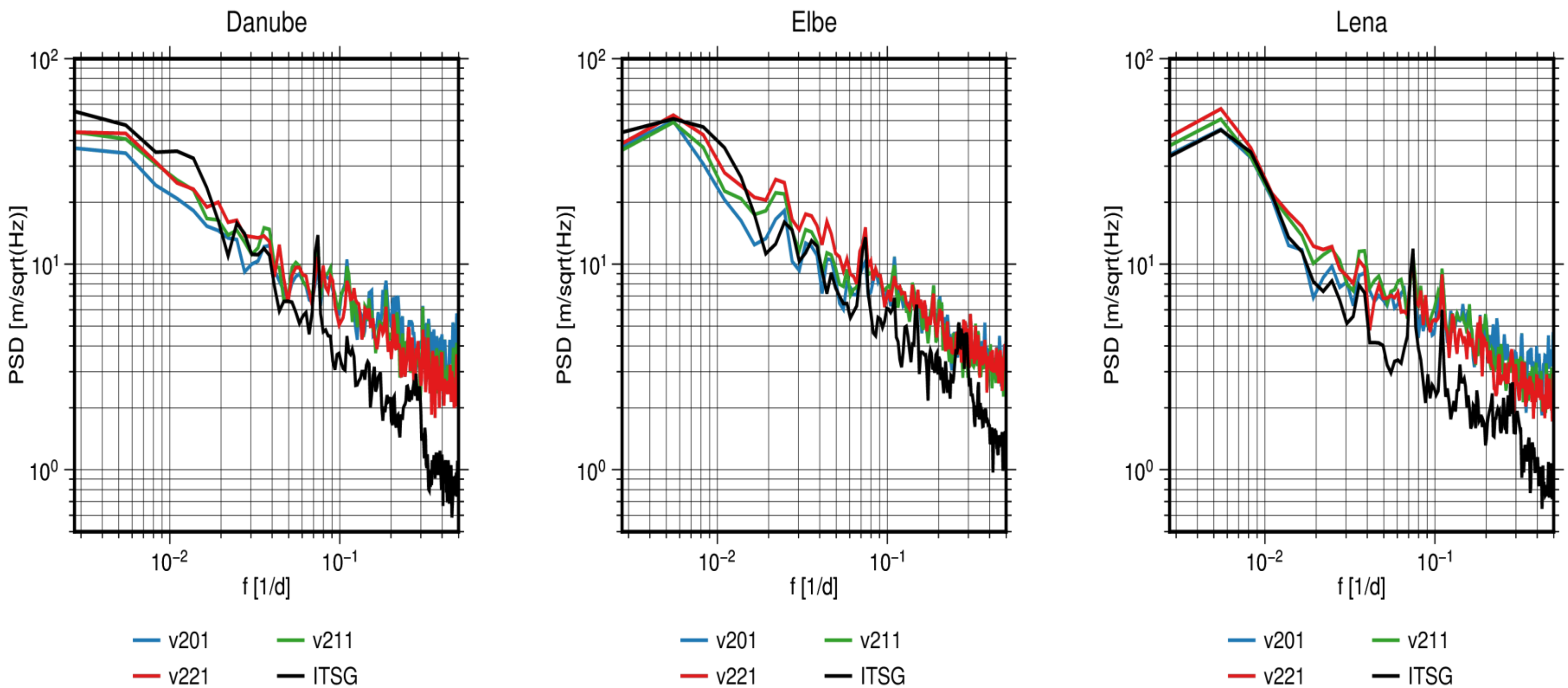
Intercomparison of Historical Time Series



EWH RMS [cm]	2002-2015	2004-2010
TUG-GFZ	2.53	2.43

Intercomparison of Historical Time Series

- Power spectral density for selected basins
  - Annual/secular variations removed
  - **GFZ generally has more high frequency content → more signal, more noise**



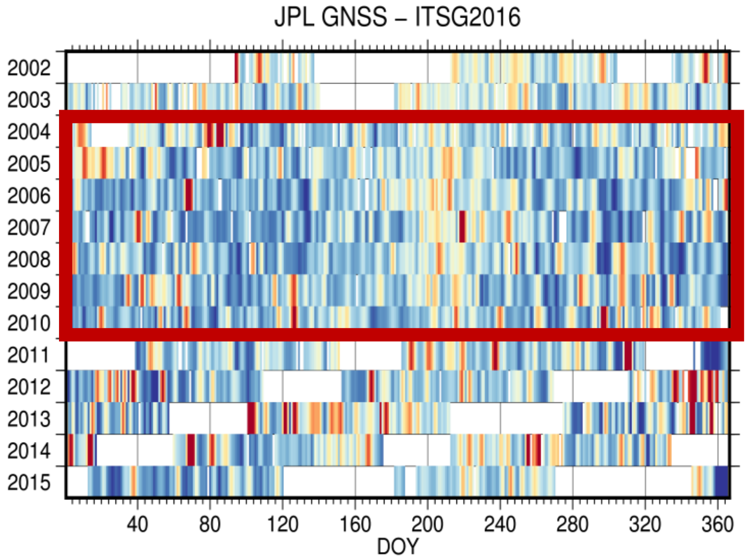
Comparison of Historical Time Series with GNSS Displacements

- Input data
  - TUG: ITSG-Grace2016
  - GFZ: v211

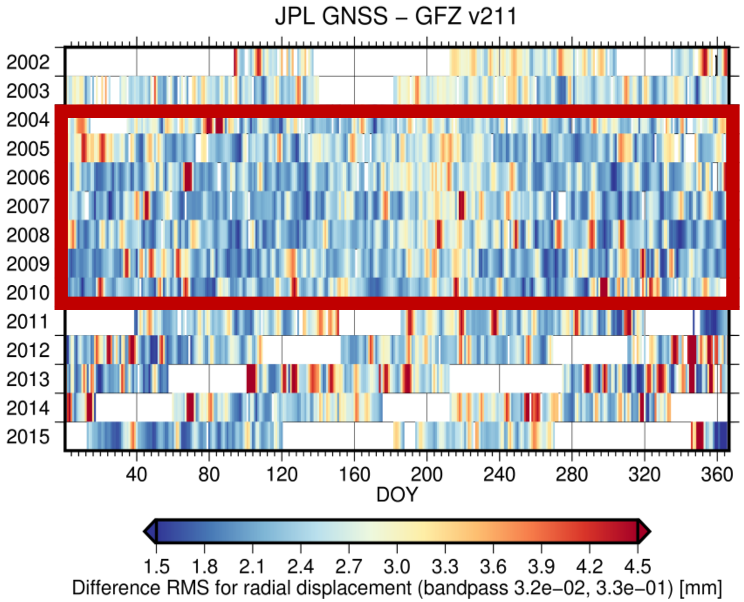
- JPL GPS time series (cleaned)
  - Annual, secular variations are removed
  - AOD1B RL06 is reduced from the displacements
  - Stations with large gaps or short observation time spans are discarded
    → 257 remain for comparison

- Methodology
  - Contiguous segments are band-pass filtered (band considered: 2 months – 6 days)
  - Only epochs where both time series have GRACE contribution are considered

Comparison of Historical Time Series with GNSS Displacements



Radial Displacement RMS [mm]	2002-2015	2004-2010
v211	2.67	2.57
ITSG2016	2.59	2.51
CSR RL05 Monthly (w/o annual, secular) – DDK3 applied	2.49	2.32



- Consistent behavior of ITG and GFZ
  - RMS differences < 8%
- Both solutions very similar to monthly CSR!
- Largest deviations around data gaps
  - Probably caused by Kalman filter warmup

Part 2: Comparison of Daily Time Series **during NRT Test Run** **(1.4.2017-29.6.2017)**

Intercomparison of NRT Time Series

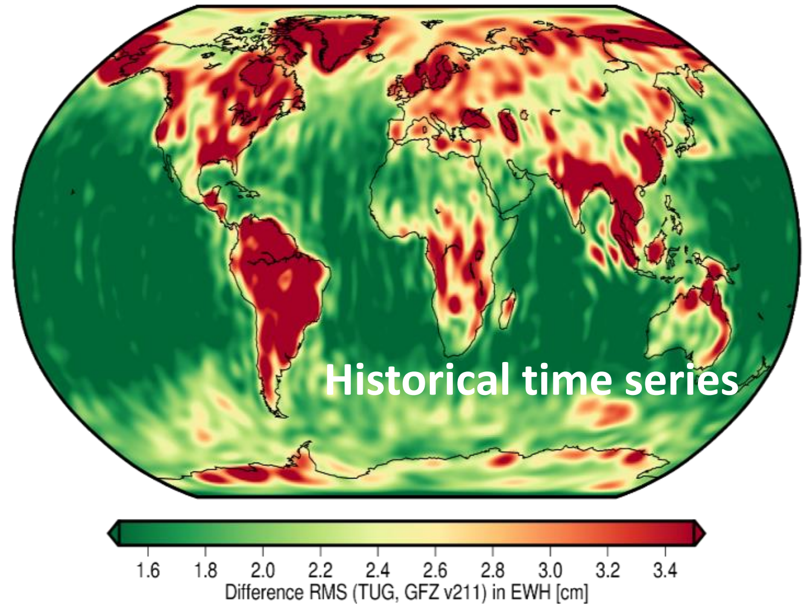
- Input data (April to June 2017)
  - TUG: EGSIEM-NRT
  - GFZ: v221

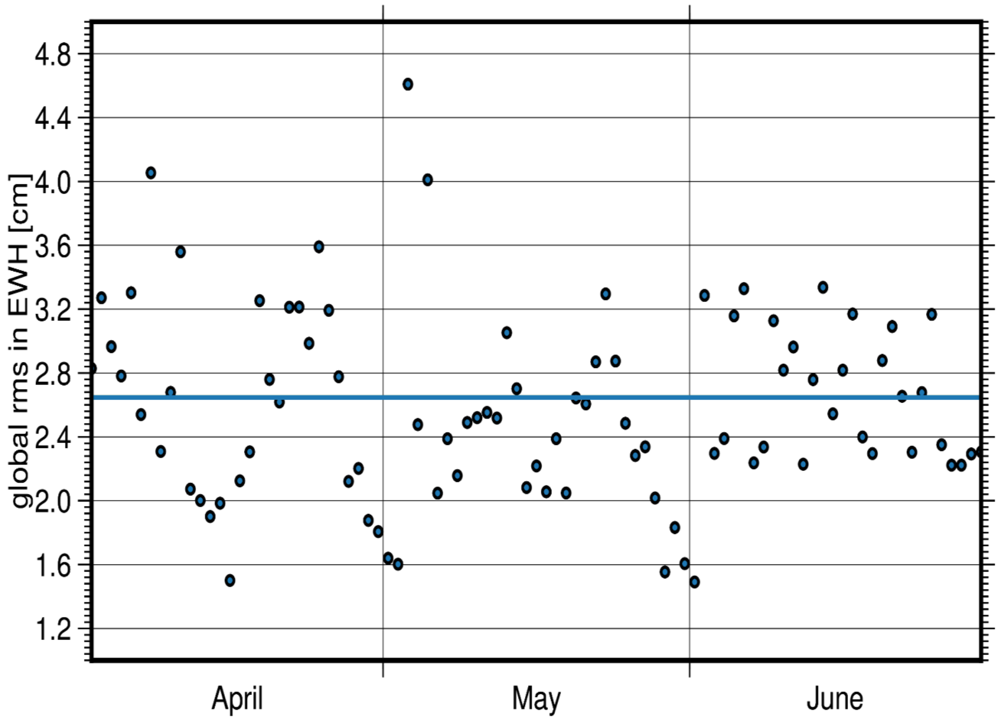
- Methodology (slightly different than for historical data)
  - Computations based on GSM like signal (i.e. with annual and trend component)
  - Degree one: Swenson/Chambers (TUG estimate)
  - Three month average removed from both time series
  - Output: Daily spatial difference wRMS from a 1x1 degree grid

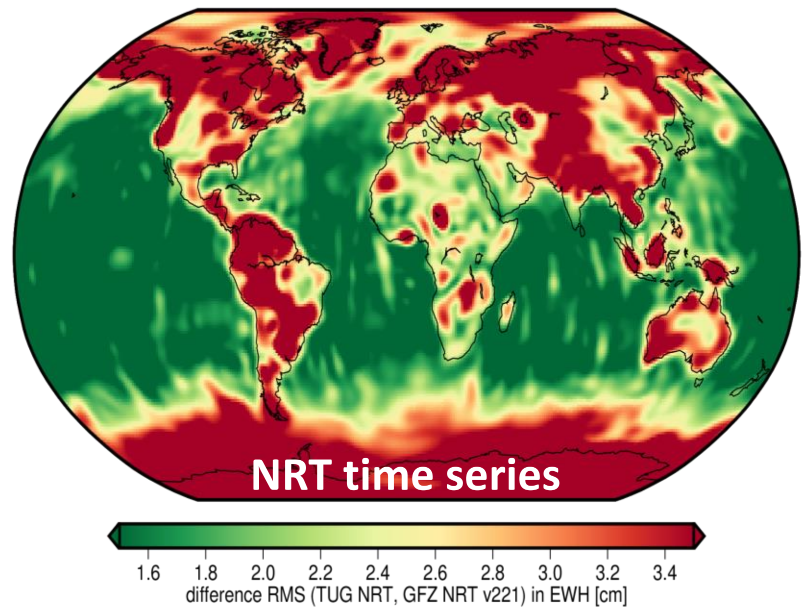
- **Results are impacted by pitch bias change introduced March 29 and KBR data gaps**

Intercomparison of NRT Time Series

- Global difference RMS
  - Overall 2.64 cm EWH (2.43 cm for 2004-2010)
  - Large deviations around Antarctica not visible in historical time series







Comparison of NRT Time Series with GNSS Displacements

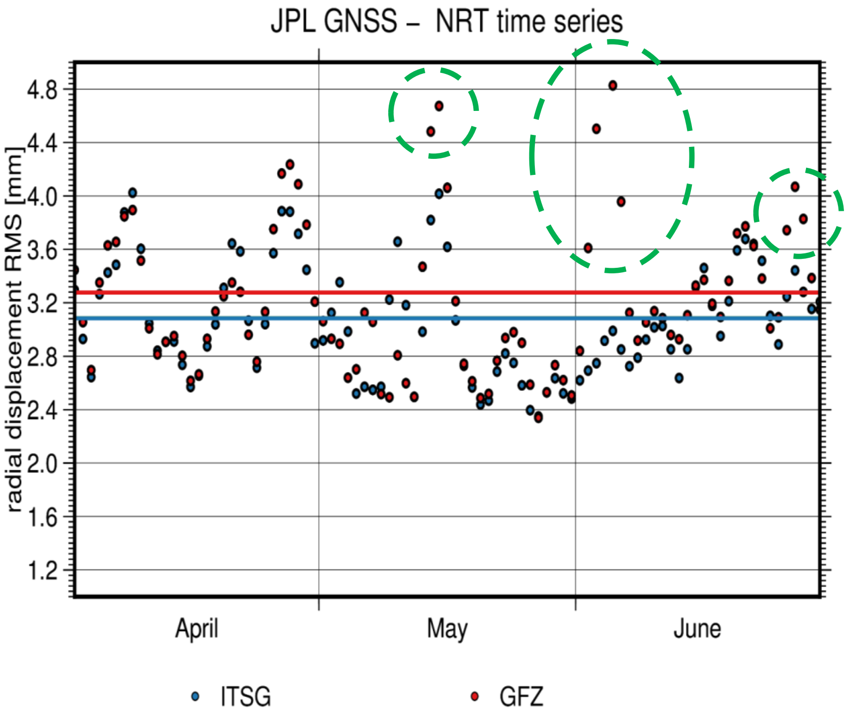
- Input data (April to June 2017)
  - TUG: EGSIEM-NRT
  - GFZ: v221

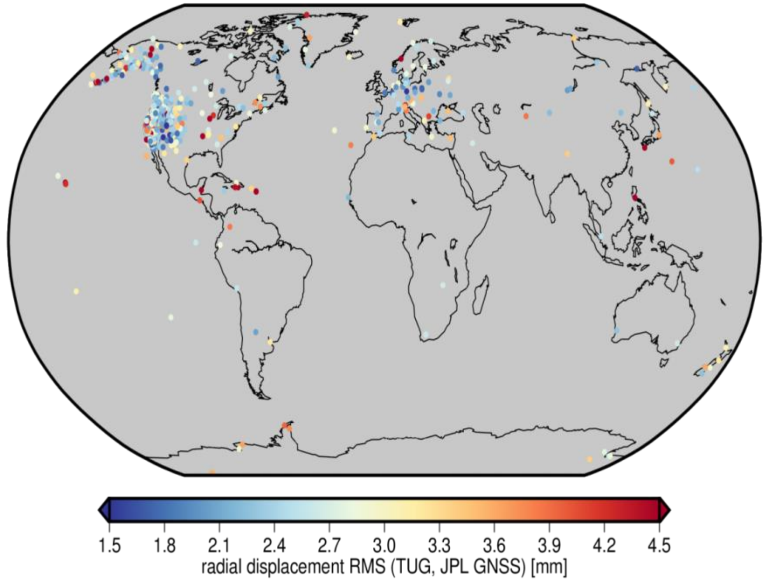
- JPL GPS time series (cleaned) (similar to comparison of historical data)
  - Three month mean is reduced (instead annual, secular variations for historical data)
  - AOD1B RL06 is reduced from the displacements
  - Stations with large gaps or short observation time spans are discarded → 992 remain for comparison
  - Inhomogeneous distribution: primarily Europe and North America

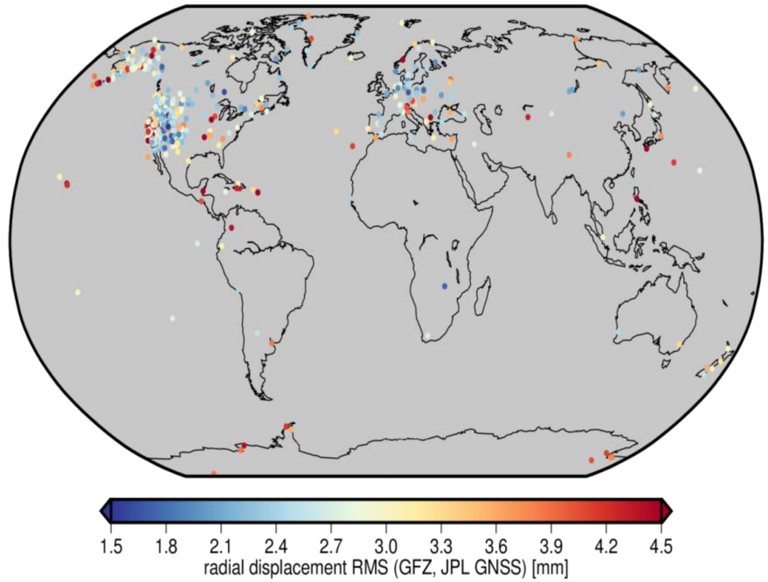
- Methodology
  - Contiguous segments are low-pass filtered (cut off 6 days)

Comparison of NRT Time Series with GNSS Displacements

- Similar pattern for TUG and GFZ
  - TUG 3.0 mm vs 2.5 mm (historic, 2004-2010)
  - GFZ 3.3 mm vs. 2.6 mm (historic, 20014-2010)
  - Some outliers increase GFZ RMS (to be investigated)
  - Time series length of GNSS displacements has to be kept in mind (91 epochs)







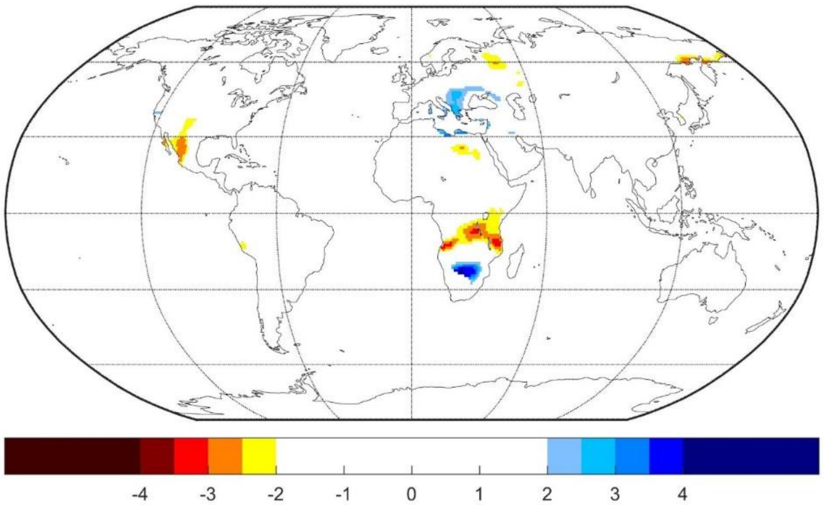
Part 3:

Application of TUG and GFZ NRT Gravity Time Series within historical flood events

Gravity Based Wetness Index

- Based on the daily gravity field solutions (GFZ V211 and ITSG-Grace2016)
- Input: gridded (1°x1°) total water storage anomaly, GIA reduced
- For each pixel
  - Correct seasonal cycle and secular variations
  - Remaining deviation (D) is the sum of the inter-annual variation plus the residual (intra-annual variation)
  - Divide pixel by standard deviation (S)
- Result: unit-less index for each pixel

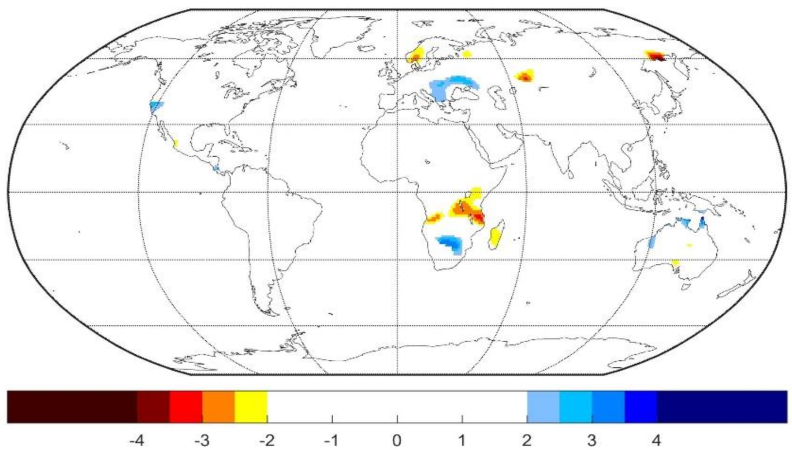
EGSIEM Wetness Index, 19 March 2006



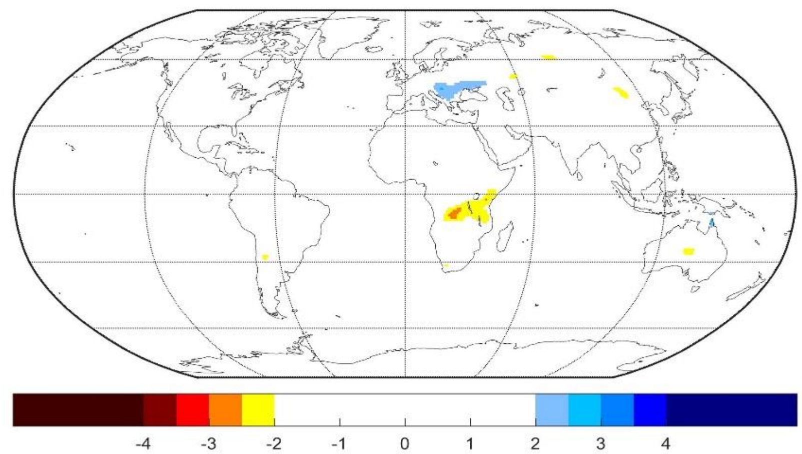
Wetness Index = (X_inter_annual + X_residual) / Standard Deviation = D/S

Gravity Based Wetness Index (2)

TUG Wetness Index, 2 April 2006

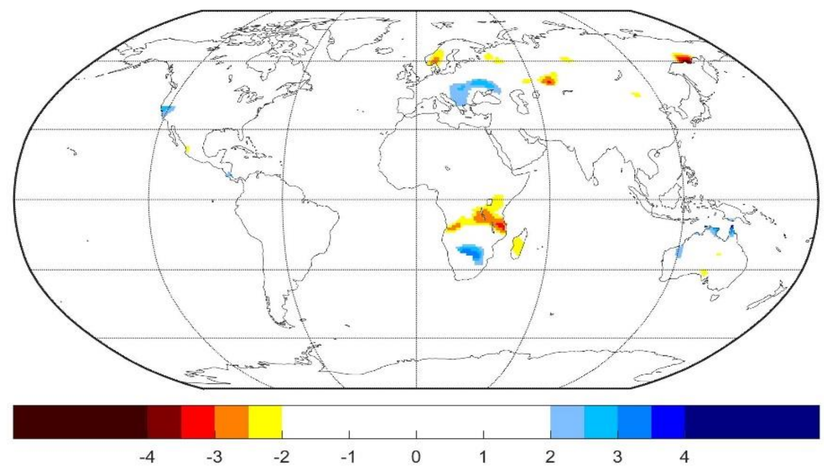


GFZ Wetness Index, 2 April 2006



The combined Index takes the most extreme index value of either index

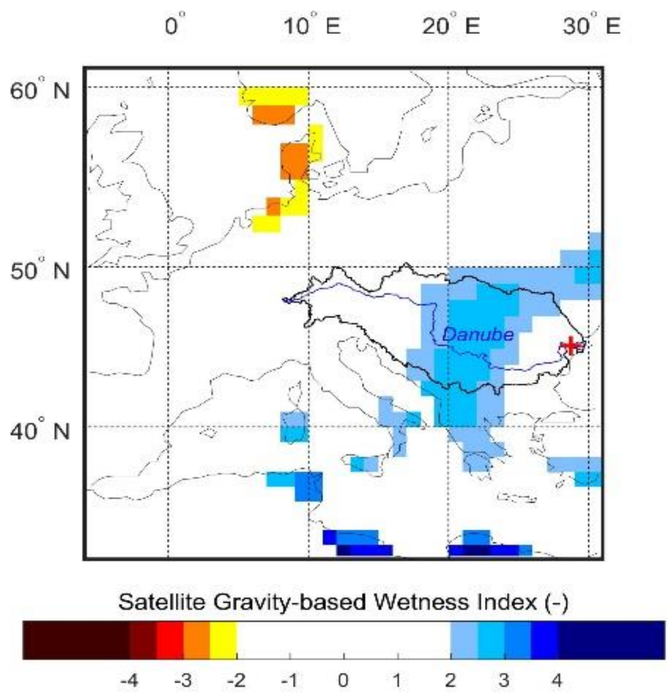
EGSIEM Wetness Index, 2 April 2006



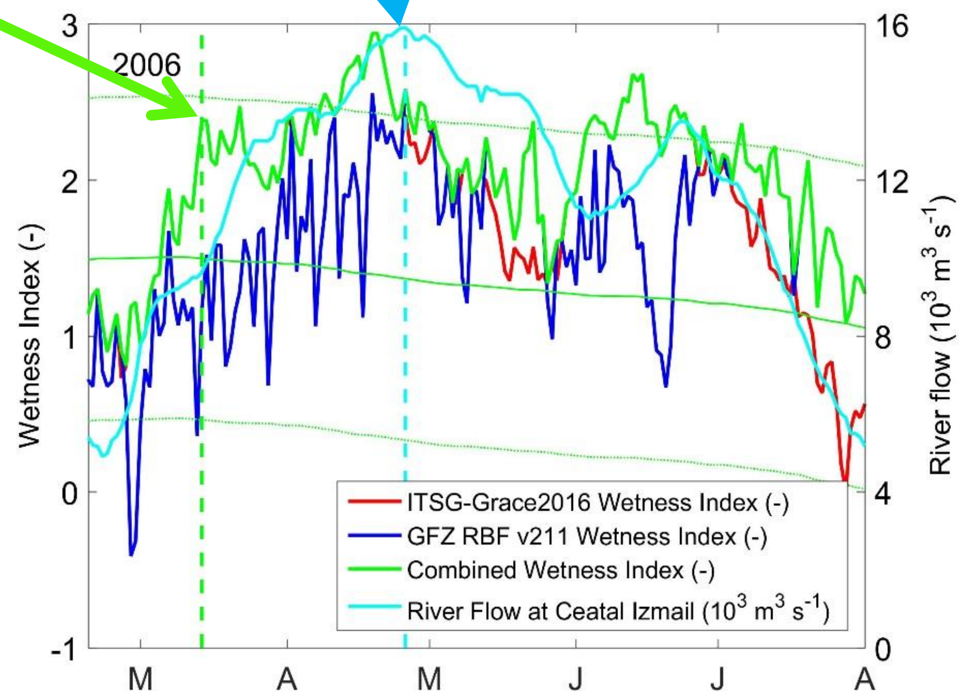
Example: Danube Flood 2006

A first WI peak over the presumed threshold of 2 could be selected on 14 March, marked as a (green) vertical line.
Leadtime of 43 days

River flow at Ceatal Izmail station at the outlet of the Danube Basin peaks on 26 April 2006.



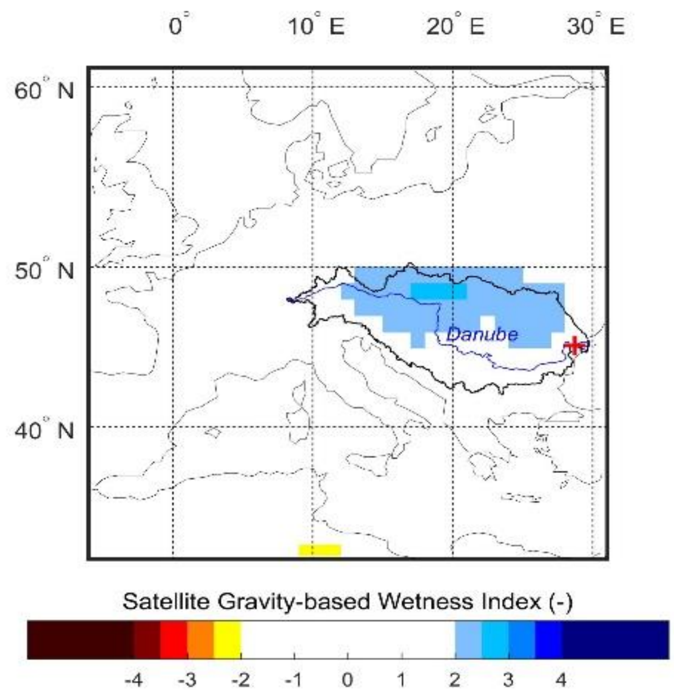
14 March 2006



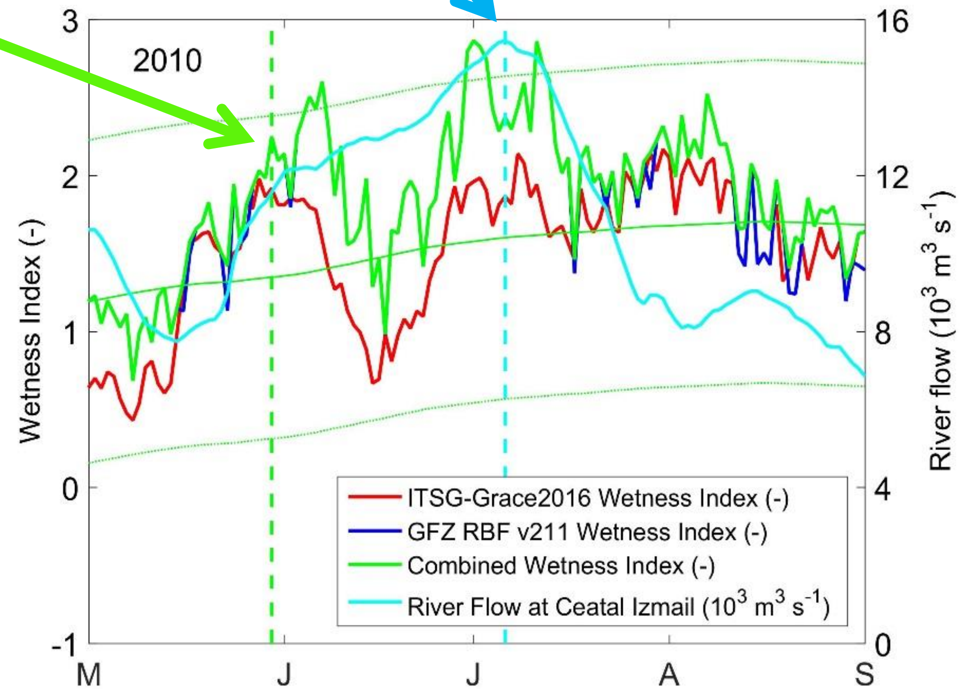
Example: Danube Flood 2010

A first WI peak over the presumed threshold of 2 could be selected on 30 May, marked as a (green) vertical line.
Leadtime of 37 days

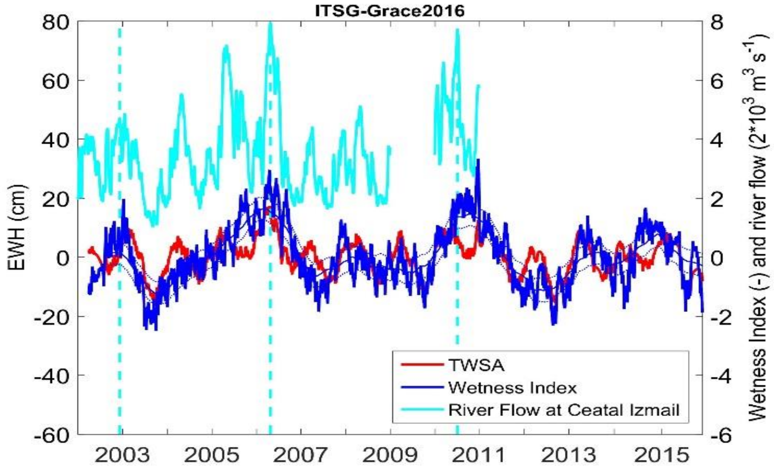
River flow at Ceatal Izmail station at the outlet of the Danube Basin peaks on 6 July 2010.

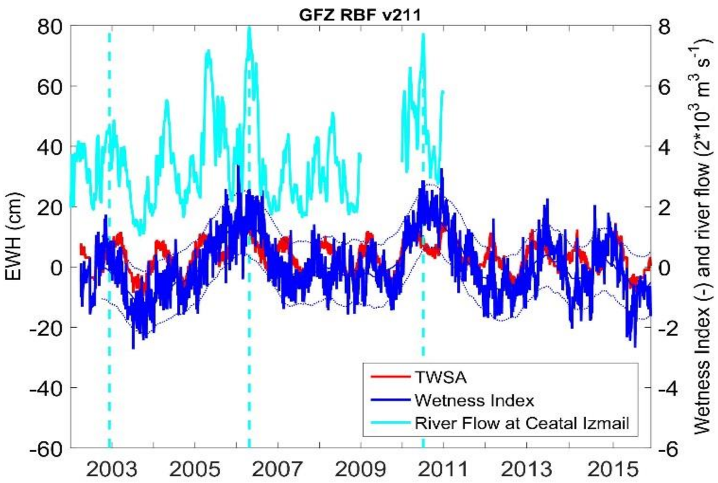


30 May 2010



Example: Danube Floods 2002-2016



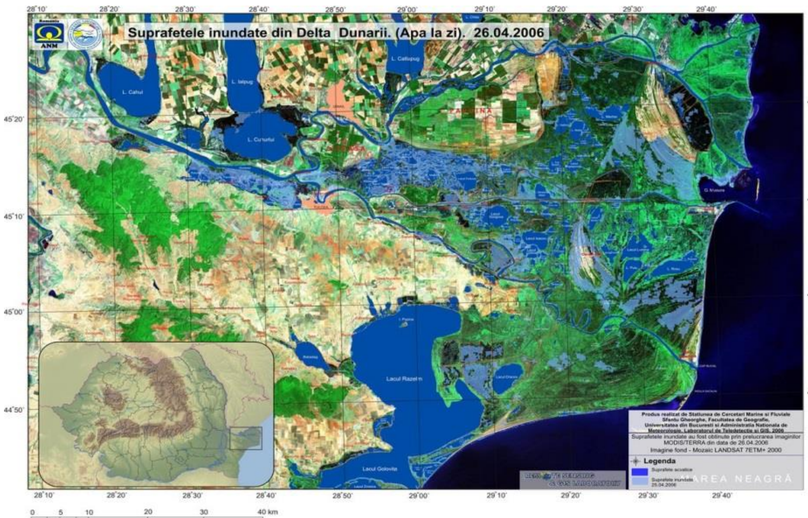


Complete historic time series (April 2002-Dec 2015):

- The larger, 2006 and 2010 basin-wide floods, which have a water storage related trigger (snow melt) are picked up well by the 2 gravity solutions and WIs.
- The smaller, sub-basin floods in 2005 and 2009 (triggered by rainfall only) are not or to a lesser degree detected by GRACE.

Application of GRACE-derived Flood Indicators at DLR ZKI

- The **International Charter 'Space and Major Disasters',** which is an agreement of space agencies and satellite operators worldwide (incl. ZKI) has the aim to provide a uniform system for the quick acquisition and delivery of EO data in case of disasters.
- Acquisitions that have been realized in 2006 for Danube Delta Basin (Charter Call #121) are marked with **dark green symbols**.
- A large number (26-35 for each satellite) additional satellite overpasses could have been acquired for flood monitoring and emergency mapping if the GRACE-based wetness indices of March 14 were available at that time (**43 days before flood peak in Romania**).
- Lead time before flood peak in **Czech Republic on April 1 still 17 days** .



MODIS image Dnube Delta Basin on April 26, 2006

Summary of EGSIEM NRT and Hydrological Service

- Daily and NRT (< 1-2 days) GFZ and TUG gravity time series agree very well (~2.5 cm EWH)
- Similar values of 1.9 cm (DDK3) and 2.8 cm (DDK4) for filtered monthly fields (CSR-TUG)
- GFZ time series exhibit higher frequency content → more noise but also more signal
- Comparison with GNSS vertical displacements 2.6 mm (monthly CSR 2.5 mm)
- Hydrological Service established at GFZ and applied at DLR/ZKI
  - Wetness Index has been derived; final definition still under discussion
  - Potential of GRACE to detect large flood events with lead times of up to several weeks (depending on applied threshold values) demonstrated for various historical flood events (Danube, Ganges-Brahmaputra (not shown), ...); NRT run in 2017 ´complicated´ due to GRACE health status
  - Usefulness of GRACE-based WI for International Charter ‘Space and Major Disasters’ demonstrated
  - More floods presently evaluated till project end on December 31 based on Dartmouth Flood Observatory or JRC’s daily global run-off center data (also to detect ´false alarms´!)
- Looking forward to get “fresh data” from GRACE-FO (and to acquire Third Party Funding to continue EGSIEM work)!