EGSIEM

European Gravity Service for Improved Emergency Management

WP6 - Hydrological Service

The value of daily total water storage anomalies from GRACE for observing and indicating large-scale flood events

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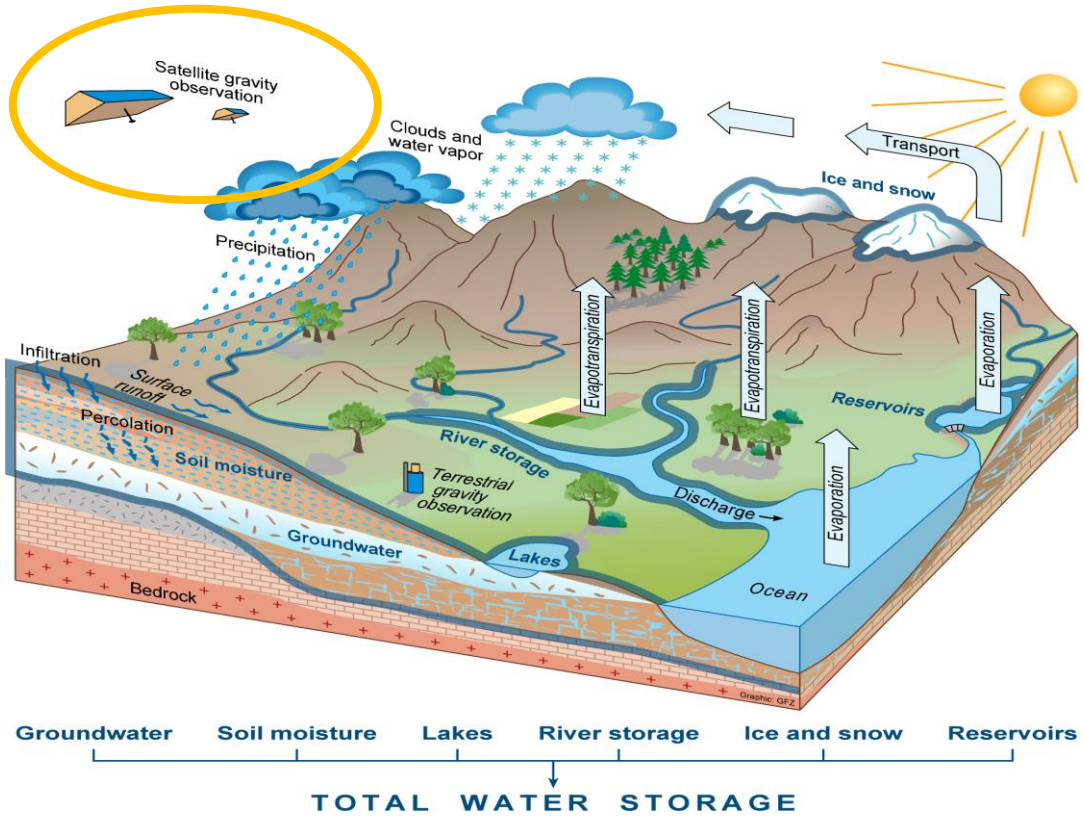
Final Meeting,

Bern, February 09, 2018

HORIZON 2020

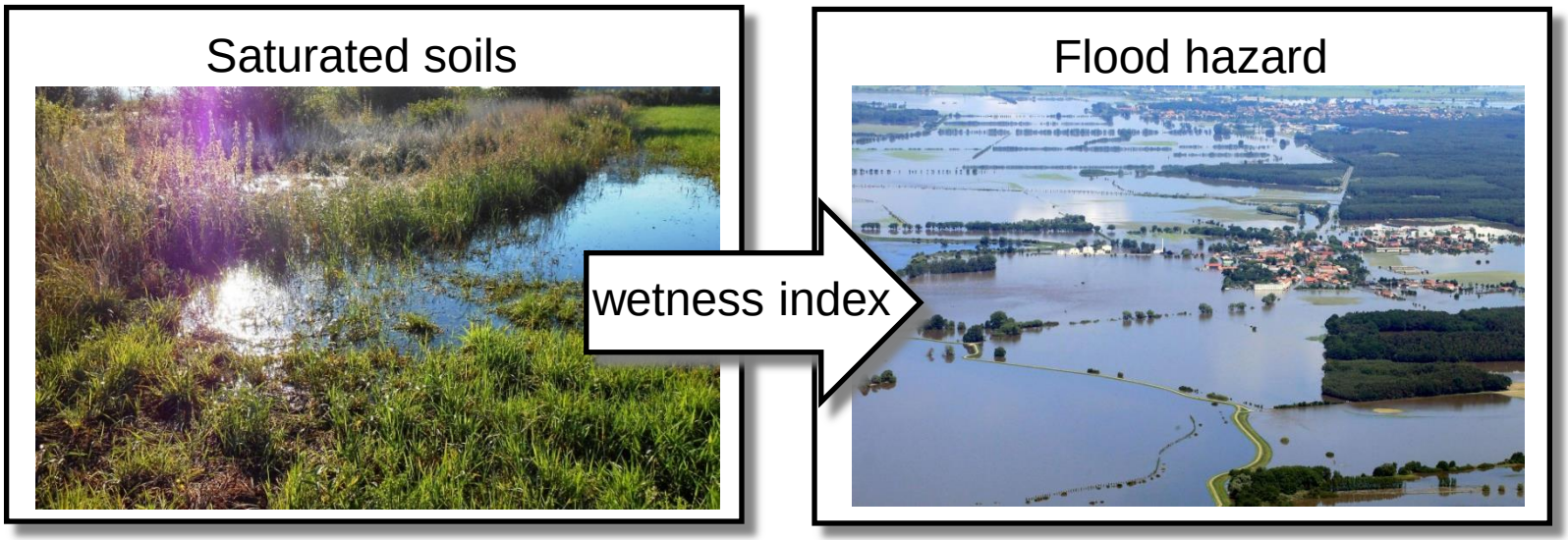
WP6 Motivation

- Gravity-based time series of ***total*** water storage anomalies are an integral descriptor of the wetness status of river basins



WP6 Motivation

- Gravity-based time series of ***total*** water storage anomalies are an integral descriptor of the wetness status of river basins
- ***Hypothesis***: added value for monitoring and forecasting hydrological extreme events (floods and droughts)
  as compared to standard indices based on precipitation or soil moisture



WP6 Objectives

Task 6.1

Validation of new gravity products for historical flood events (M07-M30)

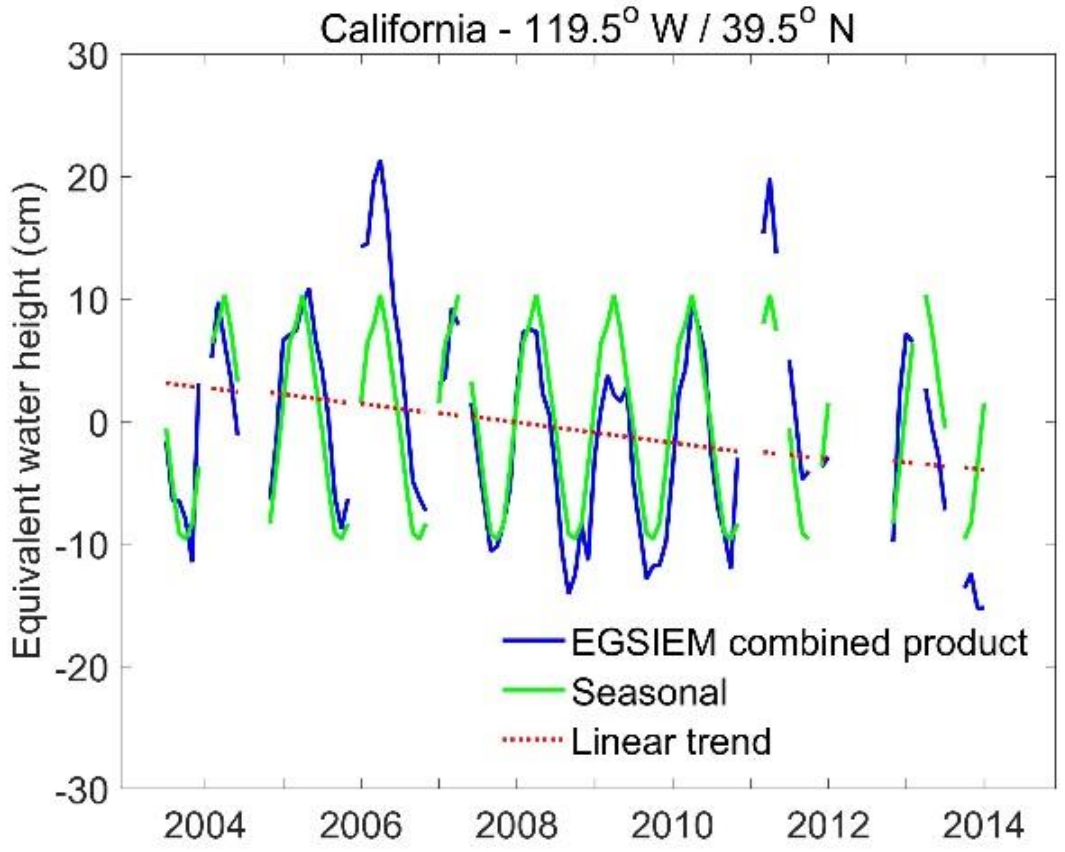
Task 6.2

Provision of gravity-based indicators for forecasting of hydrological extreme events with lead times of several months up to near real time (M01-M36)

Task 6.3

Improved mechanisms for automatic satellite-based flood services (M07-M36)

Analysis of the monthly EGSIEM combination product - drought indicators -



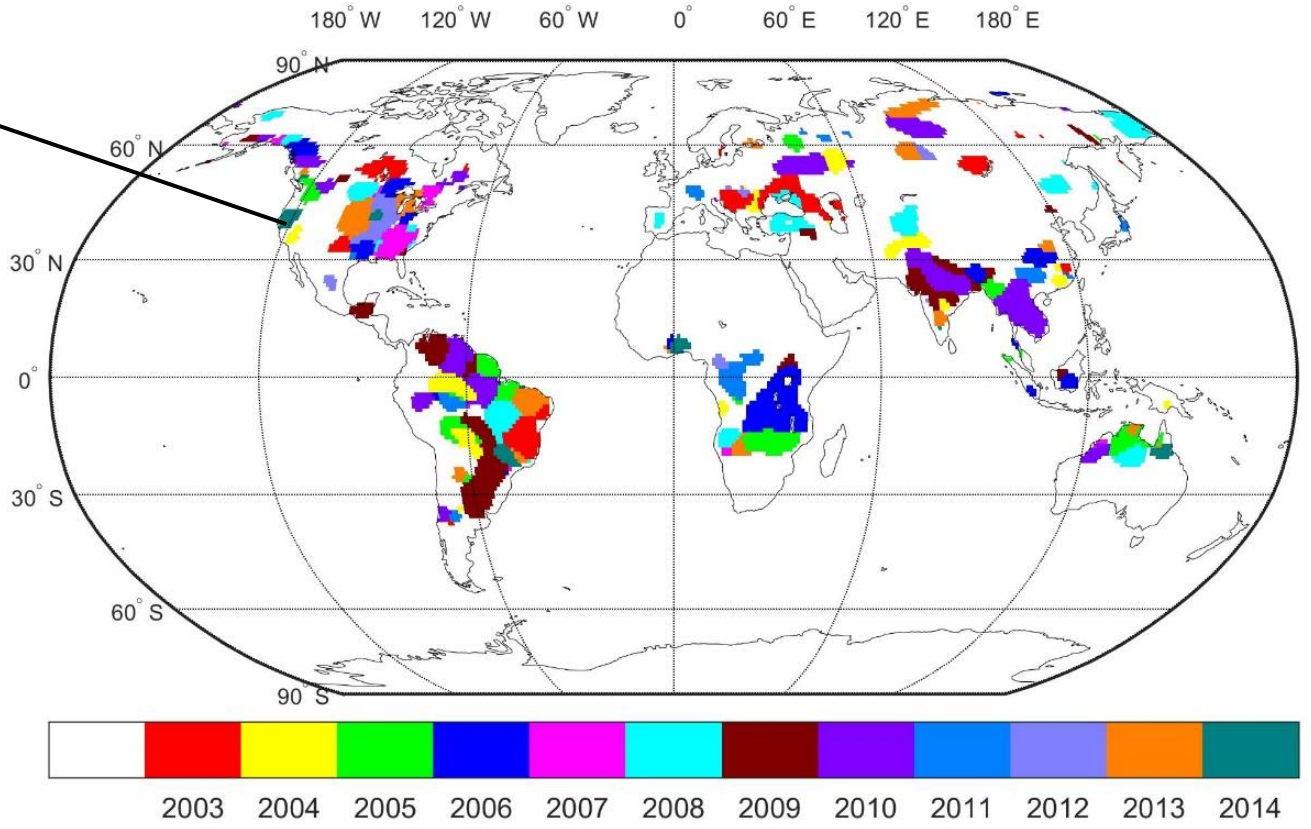
- Water storage deficit as the negative residual of the de-seasonalized GRACE time series

Drought indicators

Drought events (3 months and longer), 2003-2014

Year of maximum TWS deficit of the EGSIEM combined product (threshold -10 cm)

2014: Continuing extreme drought in California



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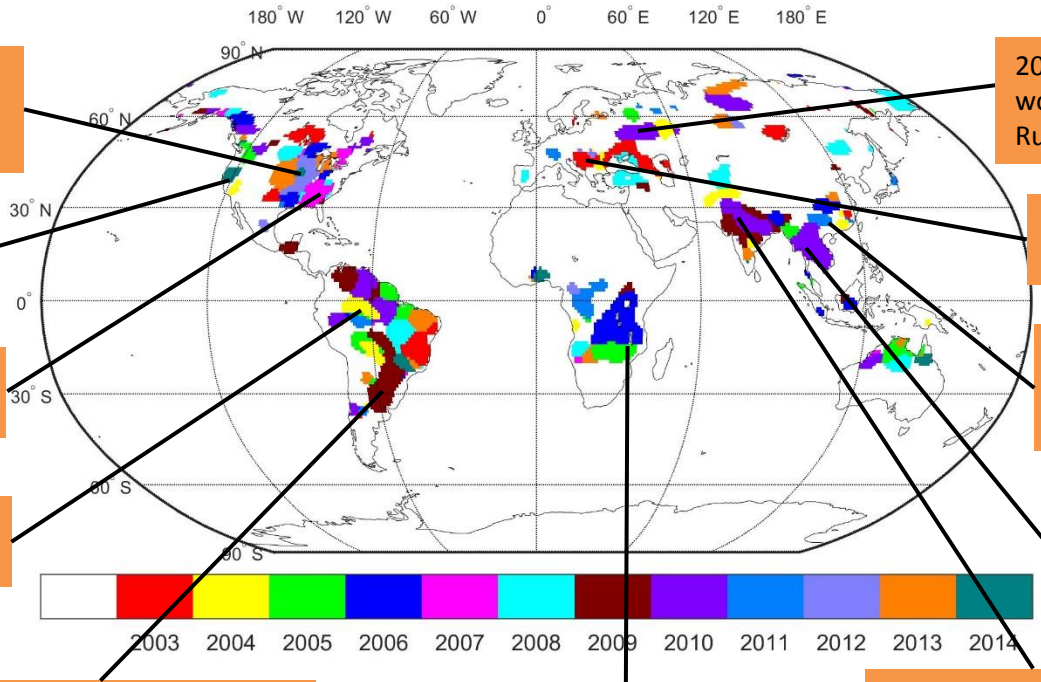


2012: Widespread drought grips the U.S. and persists in Central U.S. in 2013

2014: Continuing extreme drought in California

2007: Severe drought in Southern and Eastern U.S.

2004: Drought in western Amazonia

2010: Record heat exacerbates worst drought since 1972 in Russia

2003: Heatwave and dry conditions in Europe

2004: Worst drought in 50 years threatens drinking water supplies in SE China

2010: Drought in SE Asia prior to onset of heavy monsoon rains

2008-2009: Drought in the La Plata basin, Argentina

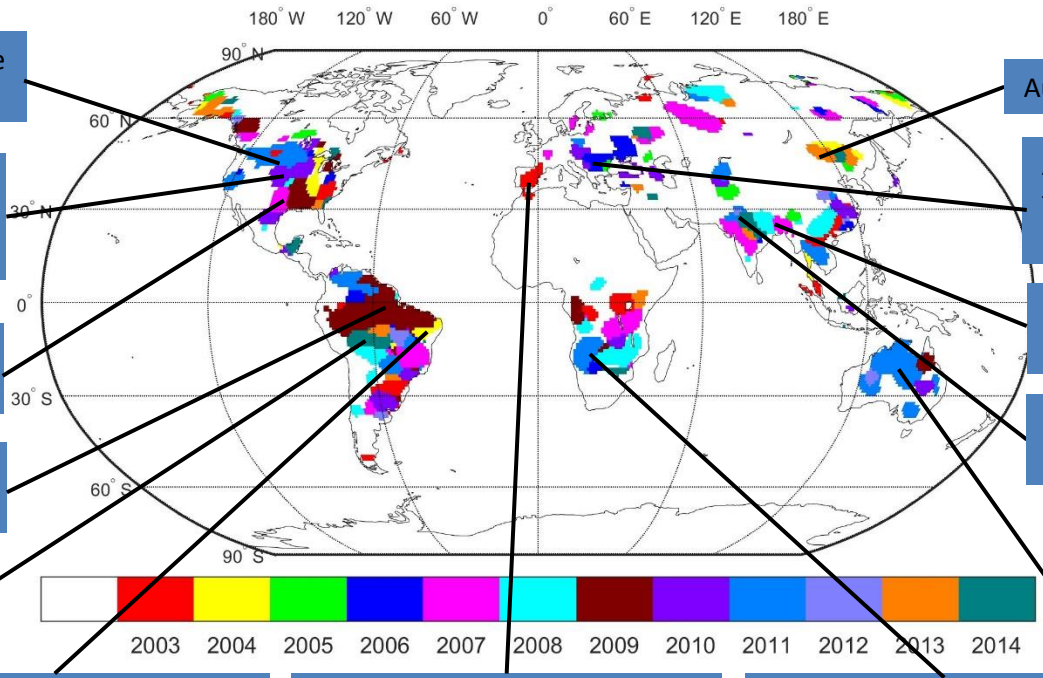
2005-2006: Near end of long term drought in East Central Africa

2009-2010: Drought conditions in northern India

Flood indicators

Wettest month on record, 2003-2014 (threshold > 10 cm)

Year of maximum monthly TWS of the EGSIEM combined product, linear trend and seasonal cycle removed



2011: Record flooding across the U.S. Northern Plains

March 2010: Heavy rain and snowmelt cause flooding in Upper Mid-West U.S.

June-Aug 2007: Heavy rain and flooding in Texas

2009: Devastating floods in NE Brazil

Jan-May 2014: Torrential rain and floods in Bolivia

2004: Major flooding in Eastern Brazil in Jan-Feb

2003: Flooding in Ebro river basin (March) and heavy rain in southern Spain (Nov)

March-April 2011: Severe flooding in Namibia and Angola

Aug 2013: Flooding in NE China

April 2006 and May 2010: Major flooding in central and lower Danube river basin

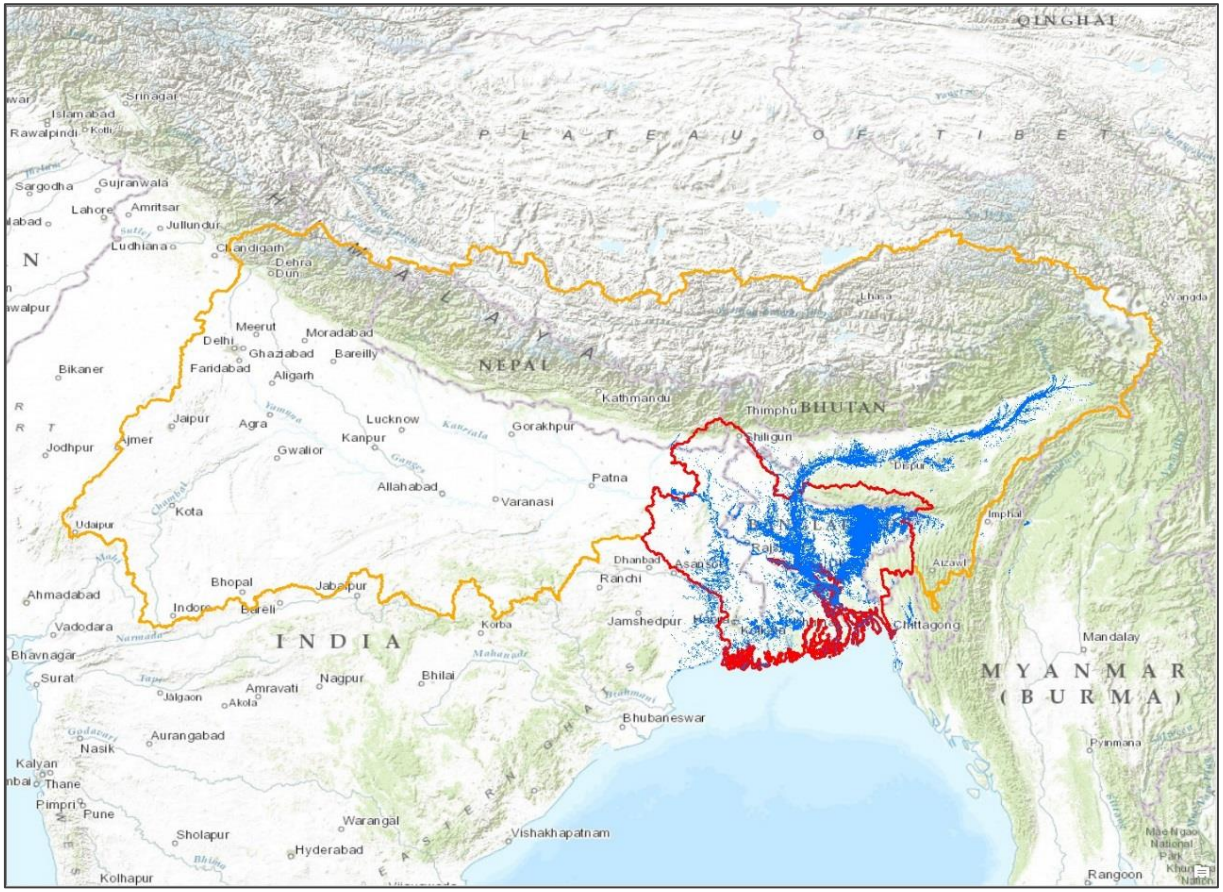
Aug-Sept 2007: Major flooding in Ganges-Brahmaputra Delta

August 2014: Widespread flooding in northern India

2011: Summer 2010-2011 second wettest on record across Australia

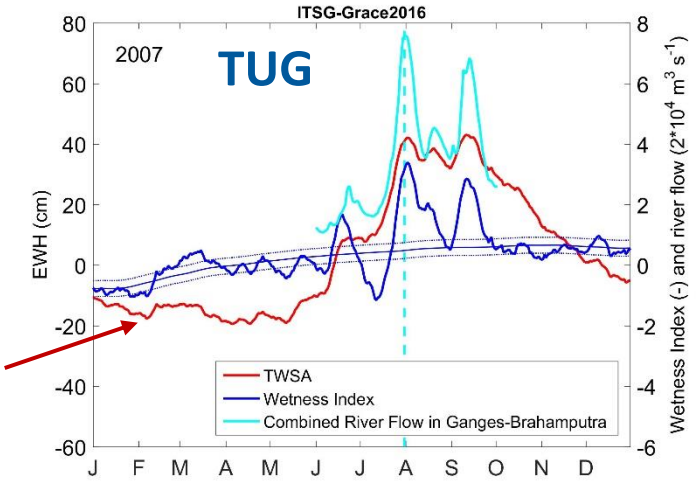
Evaluation of daily EGSIEM gravity products

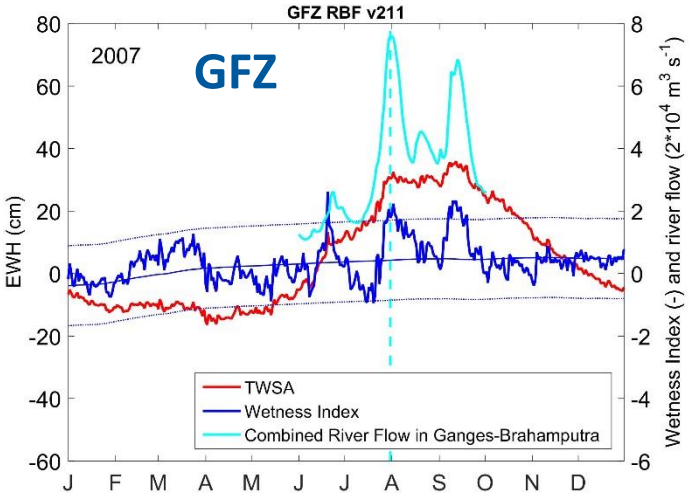
Floods in the Ganges-Brahmaputra Delta region

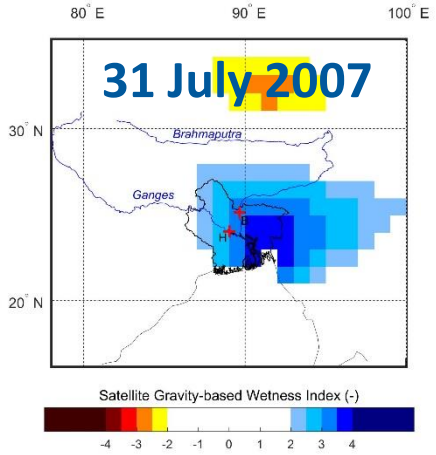


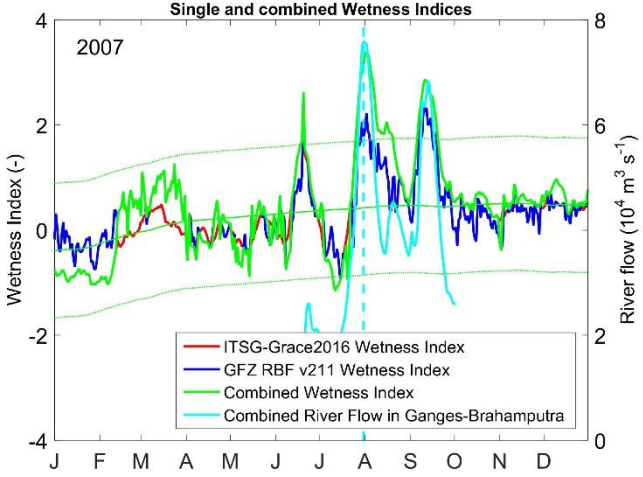
Daily GRACE gravity solutions track major flood events in the Ganges-Brahmaputra Delta, example 2007 flood

Total water storage anomaly (TWSA)









Gouweleeuw et al. (2017) in: Hydrology and Earth System Science Discussion (HESSD)

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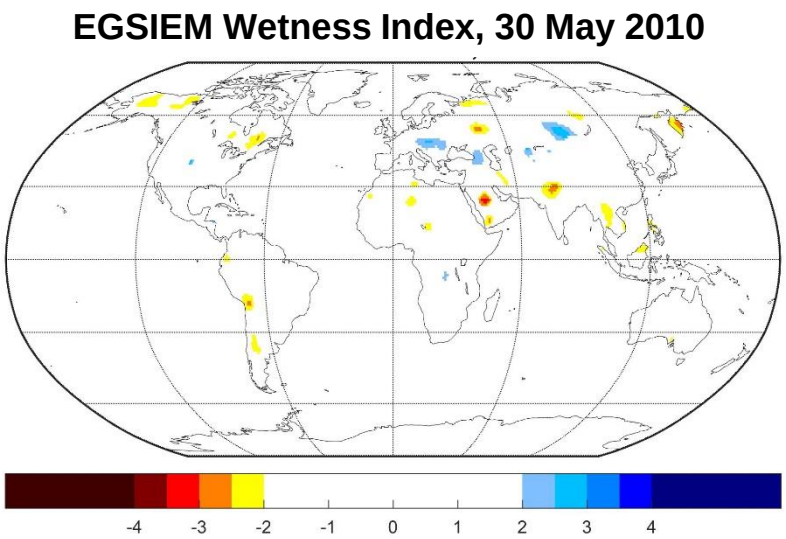
Gravity-based wetness index

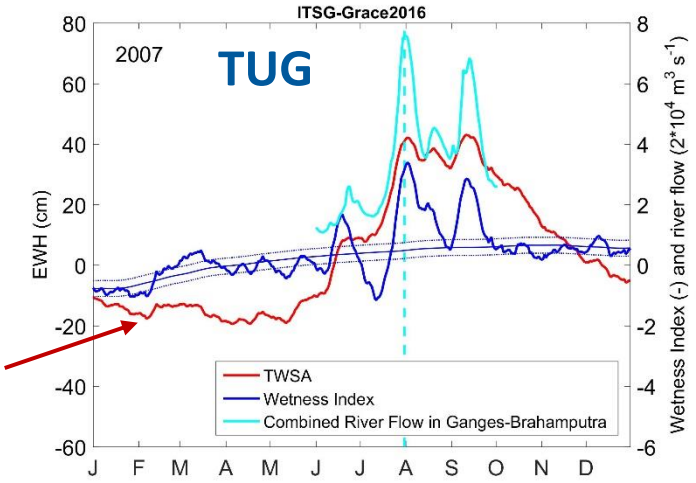
- Based on the daily gravity field solutions (GFZ RBF V211 and TUG ITSG-Grace2016)
- Input: gridded (1x1 degree) total water storage (TWS) anomalies, GIA reduced
- For each grid cell:
  - Reduce long-term trend and mean seasonal variations
  - Normalize by standard deviation of TWS over entire time period
- Result: unit-less wetness index for each grid cell describing the inter- and intra-annual storage anomaly as a deviation from the seasonal cycle

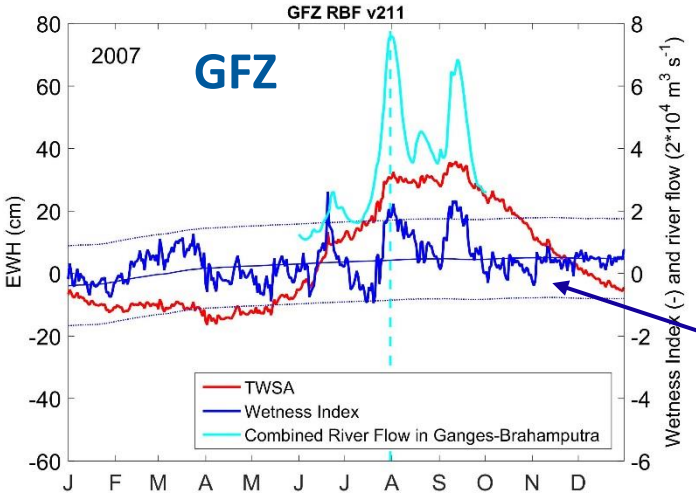


- Combined wetness index as the maximum of GFZ and TUG indices on each day

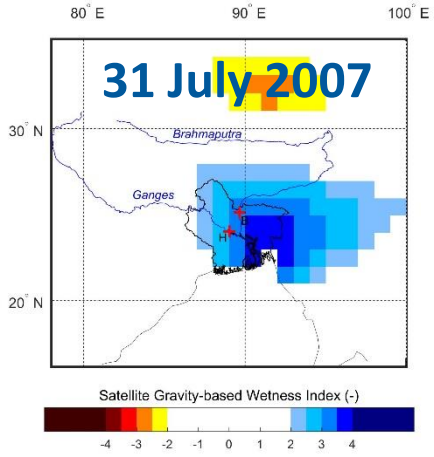
Daily GRACE gravity solutions track major flood events in the Ganges-Brahmaputra Delta, example 2007 flood

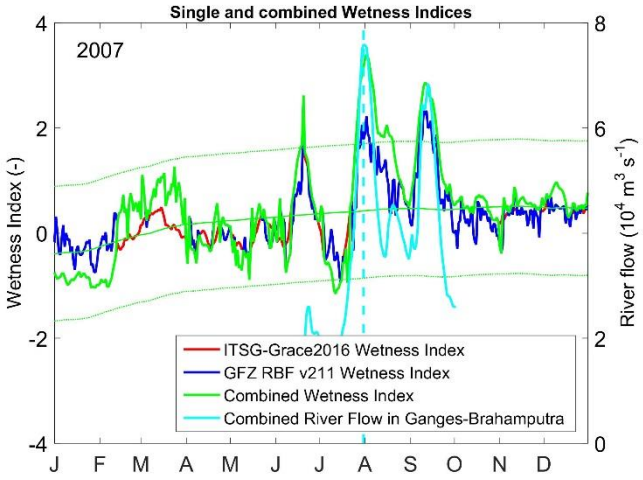
Total water storage anomaly (TWSA)





Wetness Index (WI)





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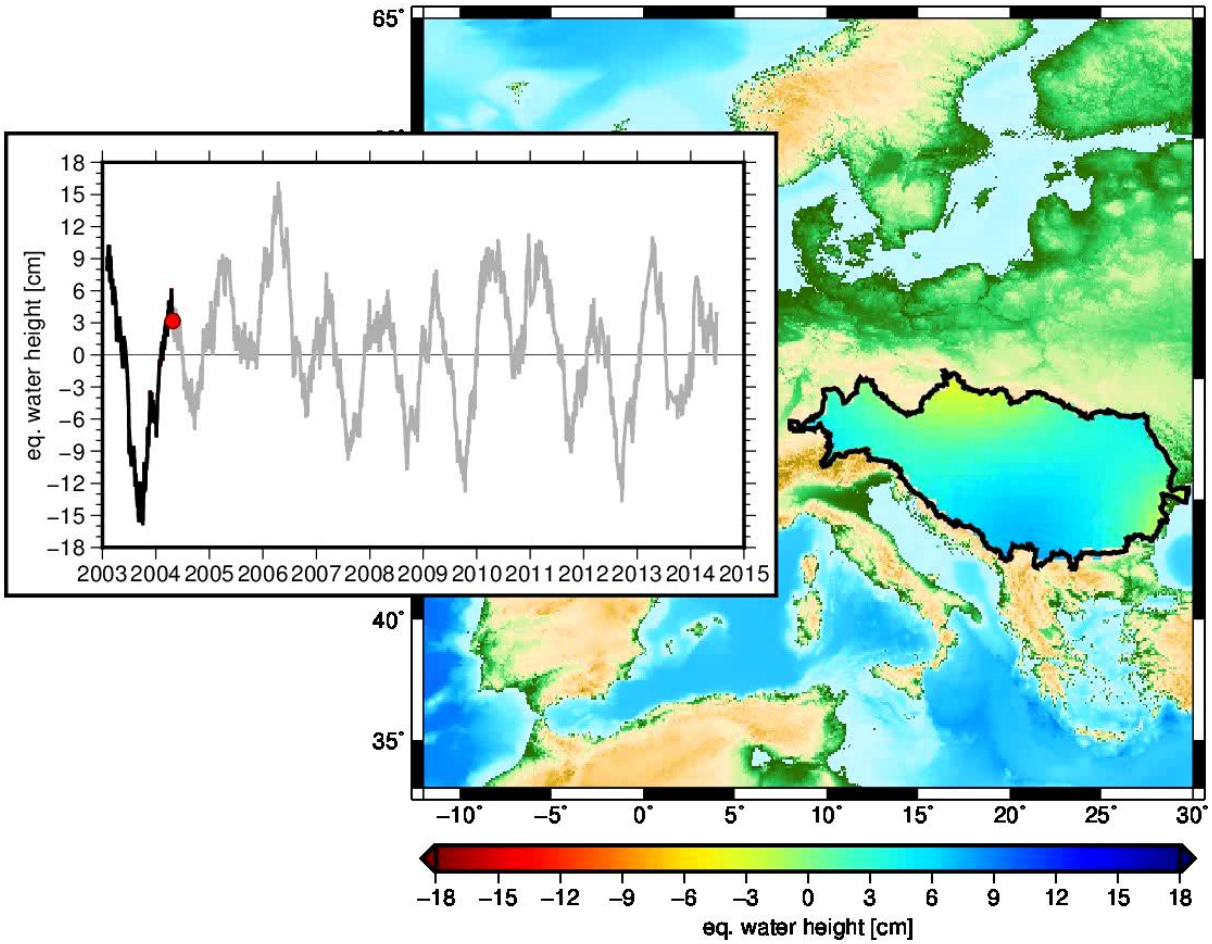
Daily total water storage in the danube basin from ITSG-Grace2014



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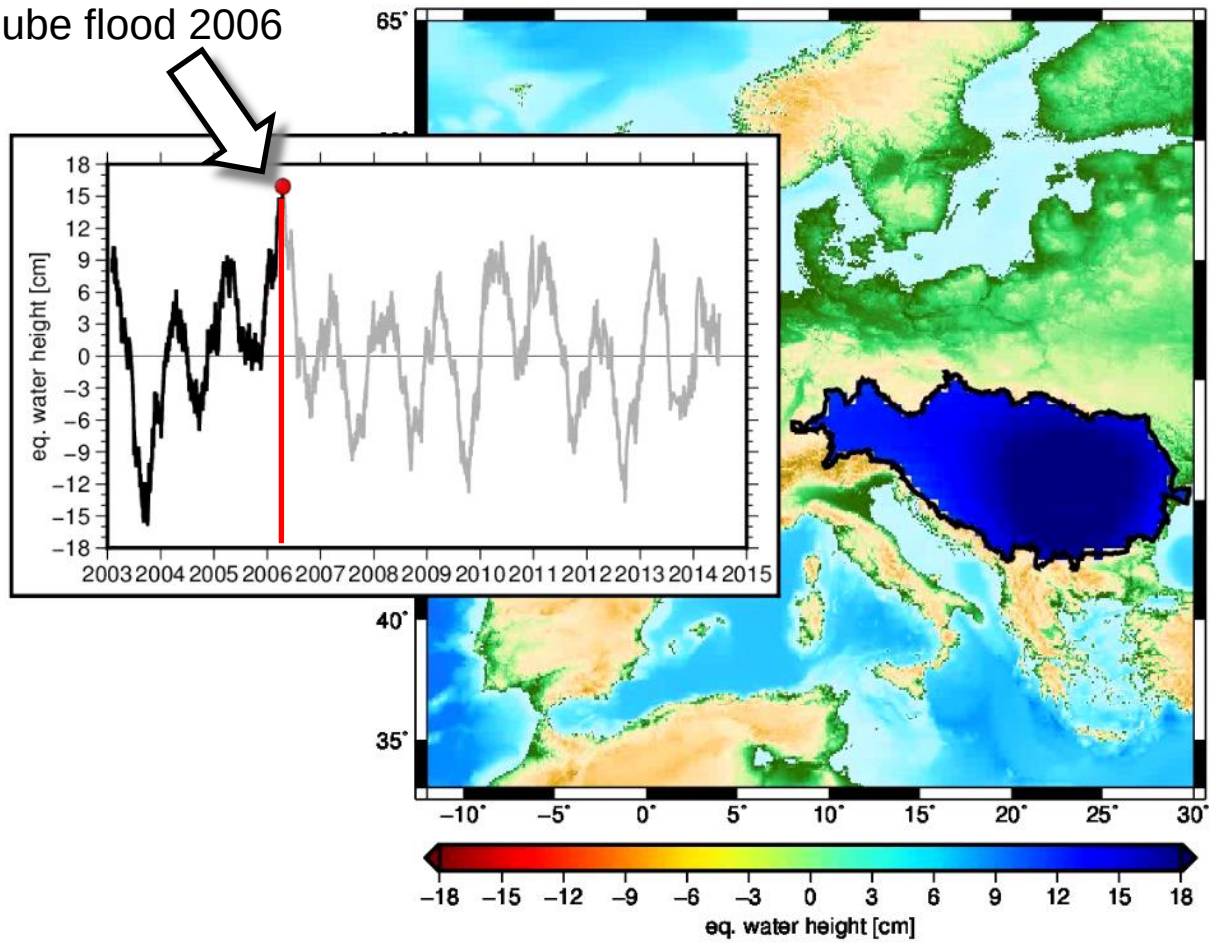
Daily total water storage in the danube basin from ITSG-Grace2014

Danube flood 2006



Wetness index for early flood warning

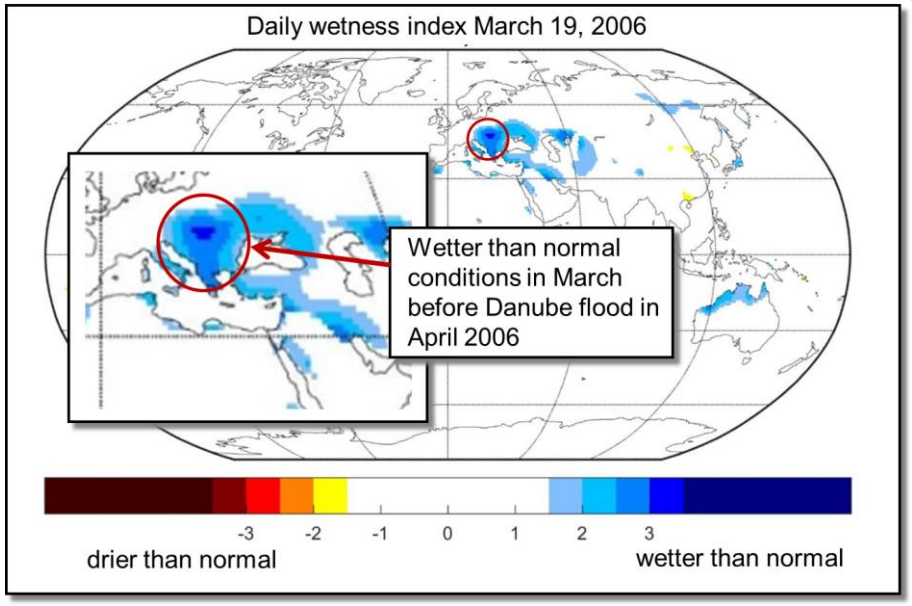
Example Danube river basin – 2006 Flood

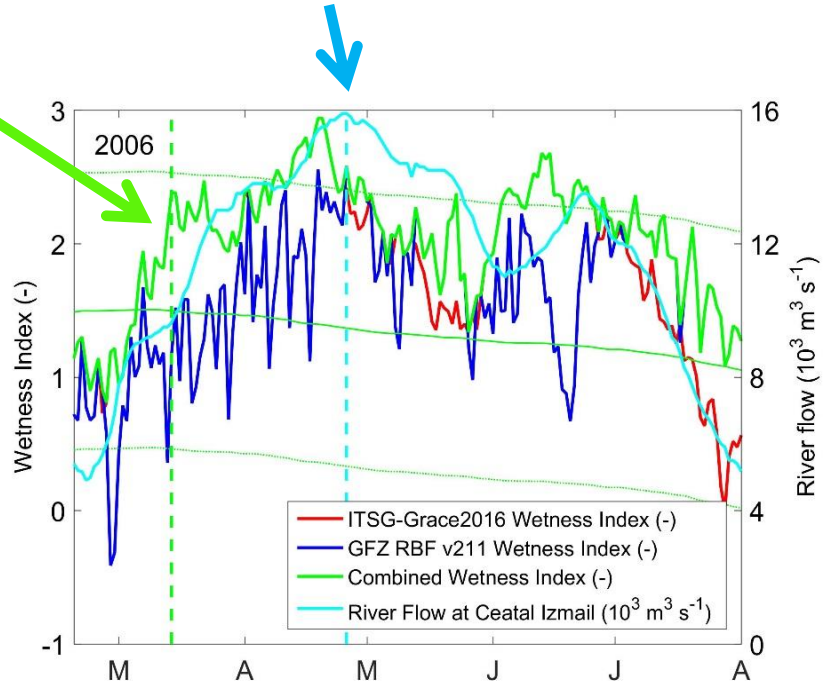
First Peak of Wetness Index on 14 March 2006

Lead time: 43 days

River discharge at Ceatal Izmail (outlet of the Danube Basin)

Flood peak on 26 April 2006



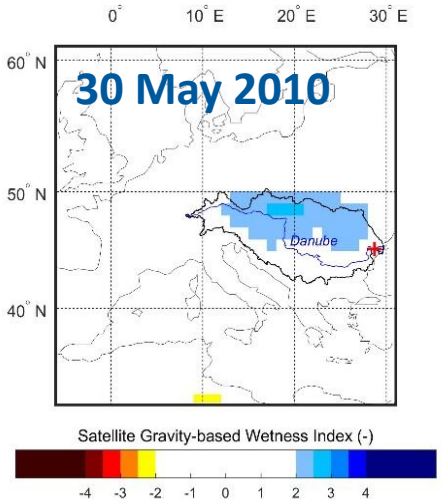


Wetness index for early flood warning

Example Danube river basin – 2010 Flood

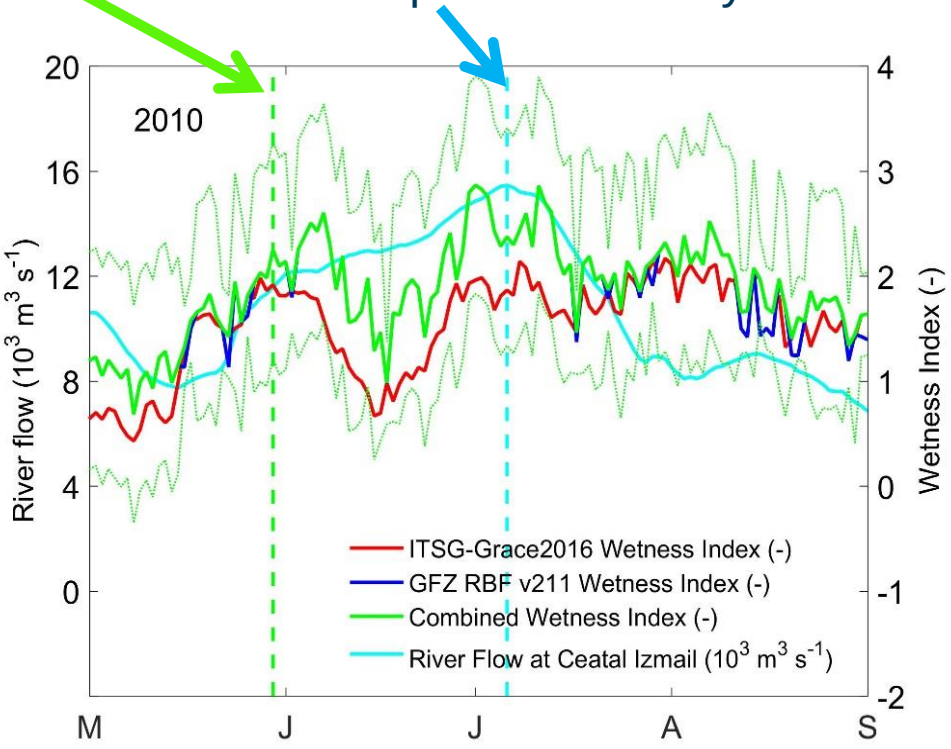
Empirical threshold of Wetness Index of 2 exceeded on 30 June 2010

Lead time: 37 days



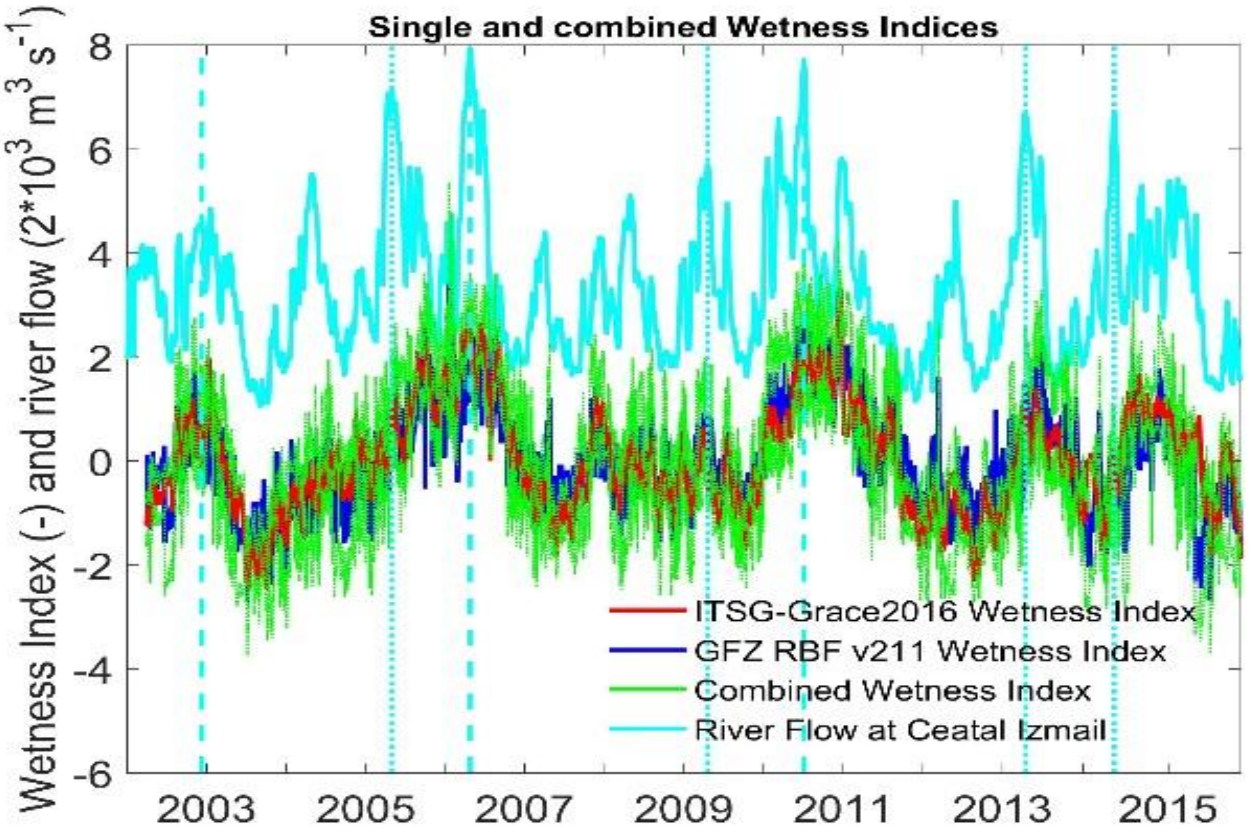
River discharge at Ceatal Izmail (outlet of the Danube Basin)

Flood peak on 06 July 2010



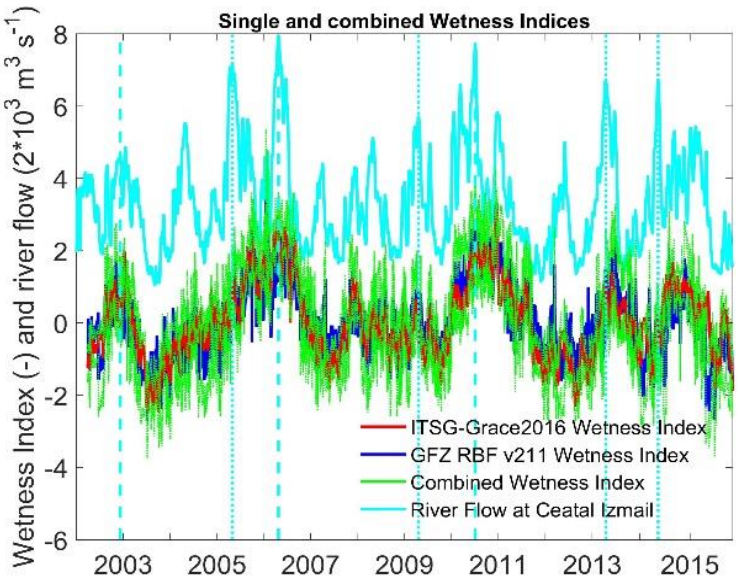
Wetness index for early flood warning

Example Danube river basin (Ceatal Izmail, 807000 km²) – Annual flood maxima



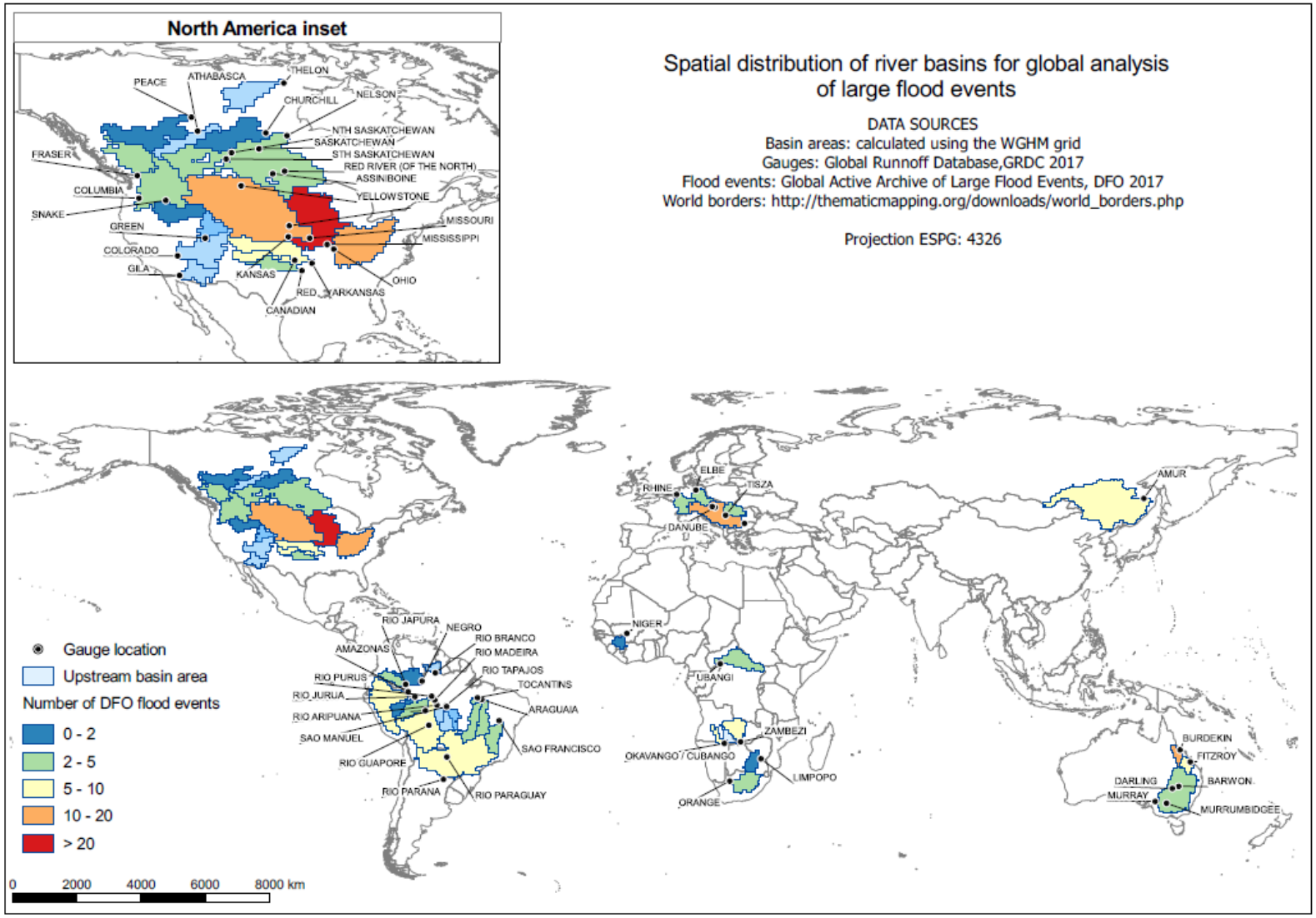
Wetness index for early flood warning

Example Danube river basin (Ceatal Izmail, 807000 km²) – Annual flood maxima



Year	Major flood event in the basin	Peak Flow at Ceatal Izmal		Flood Warning if WI > 2		Lead time (days)	Comment
		Date	Qmax (10^3 m^3/s)	Date	WI		
2002	x	02.09.	17.4	-			False negative
2003	x	20.01.	19.5	12.01.	2.0	8	Correct positive
2004		29.04.	22.2	-			Correct negative
2005	x	02.05.	28.8	-			False negative
2006	x	26.04.	31.8	14.03.	2.4	43	Correct positive
2007		14.12.	17.2	-			Correct negative
2008		28.04.	20.6	-			Correct negative
2009	x	21.04.	22.8	02.03.	(0.9)	42	False negative
2010	x	06.07.	30.9	30.05.	2.3	37	Correct positive
2011		04.01.	23.1	26.01.	2.2	-12	False positive
2012		03.06.	20.1	-			Correct negative
2013	x	18.04.	26.8	02.04.	(1.2)	16	False negative
2014	x	09.06.	27.0	-			False negative
2015		18.03.	21.7	-			Correct negative

Pre-event wetness indices – global-scale analysis



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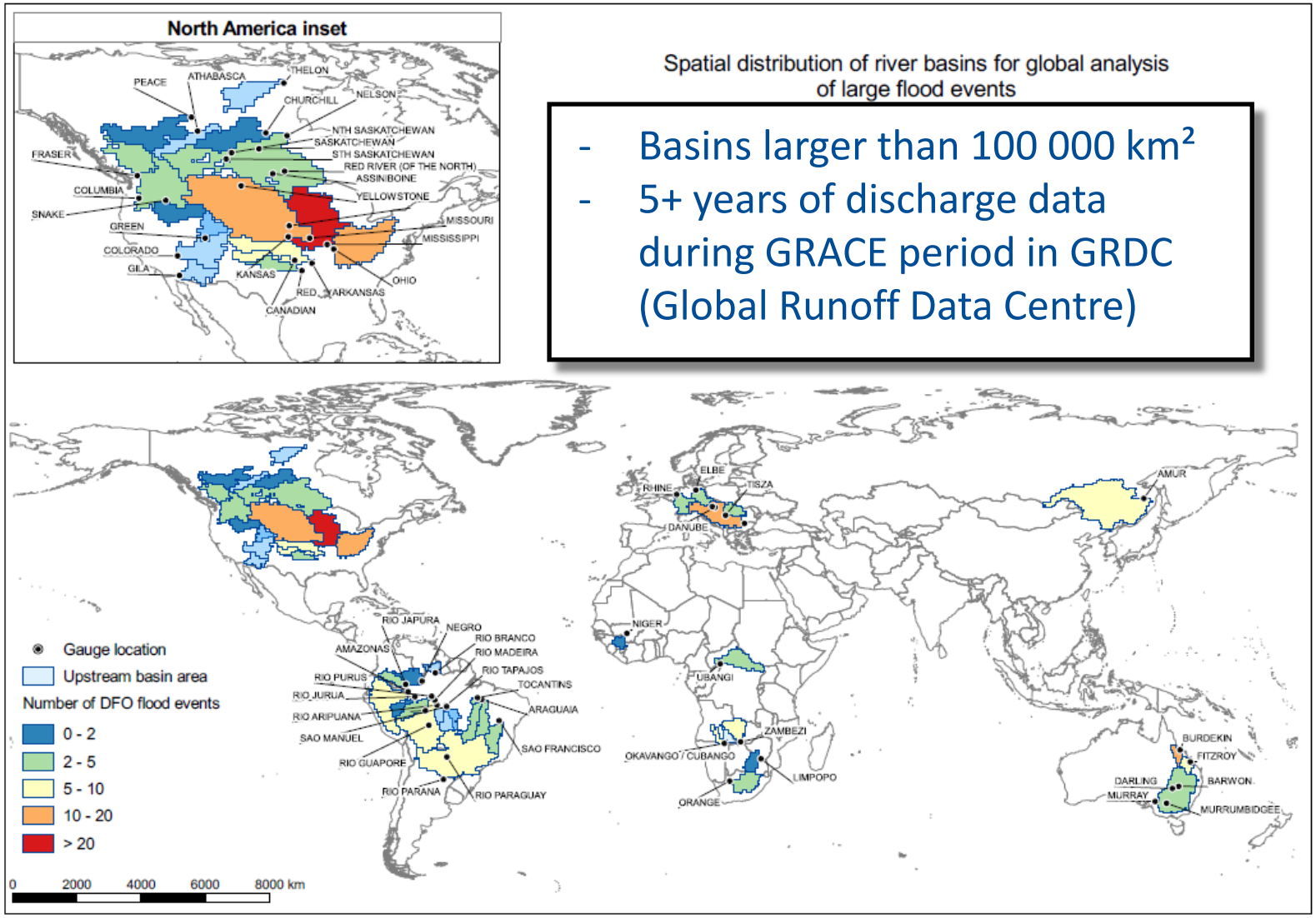


Pre-event wetness indices – global-scale analysis

Basic idea:

Assess the information content of daily gravity data and of wetness indices (classical indices included) just before the onset of a flood event for explaining flood characteristics

Flood characteristics:

- Peak discharge
- Flood volume
- Runoff ratio (ratio between total runoff and total precipitation of flood event)

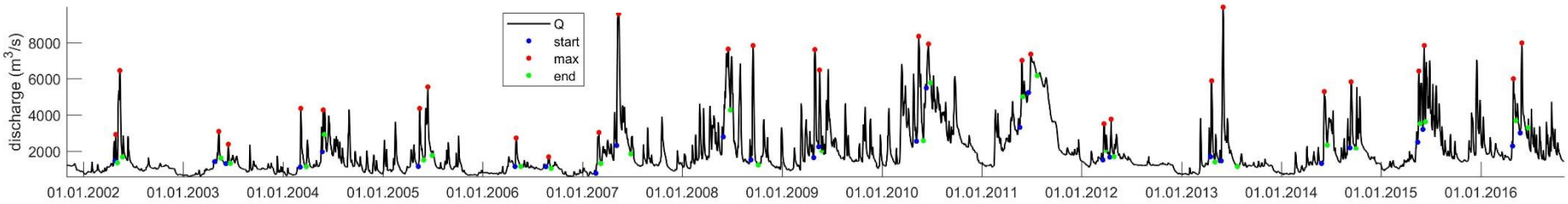
Approach:

- Selection of 2 high flow or flood events per year
- Correlation analysis

Pre-event wetness indices – global-scale analysis

Example:

Daily river discharge time series at gauging station Boonville, Missouri River (basin area 1,296,000 km²)



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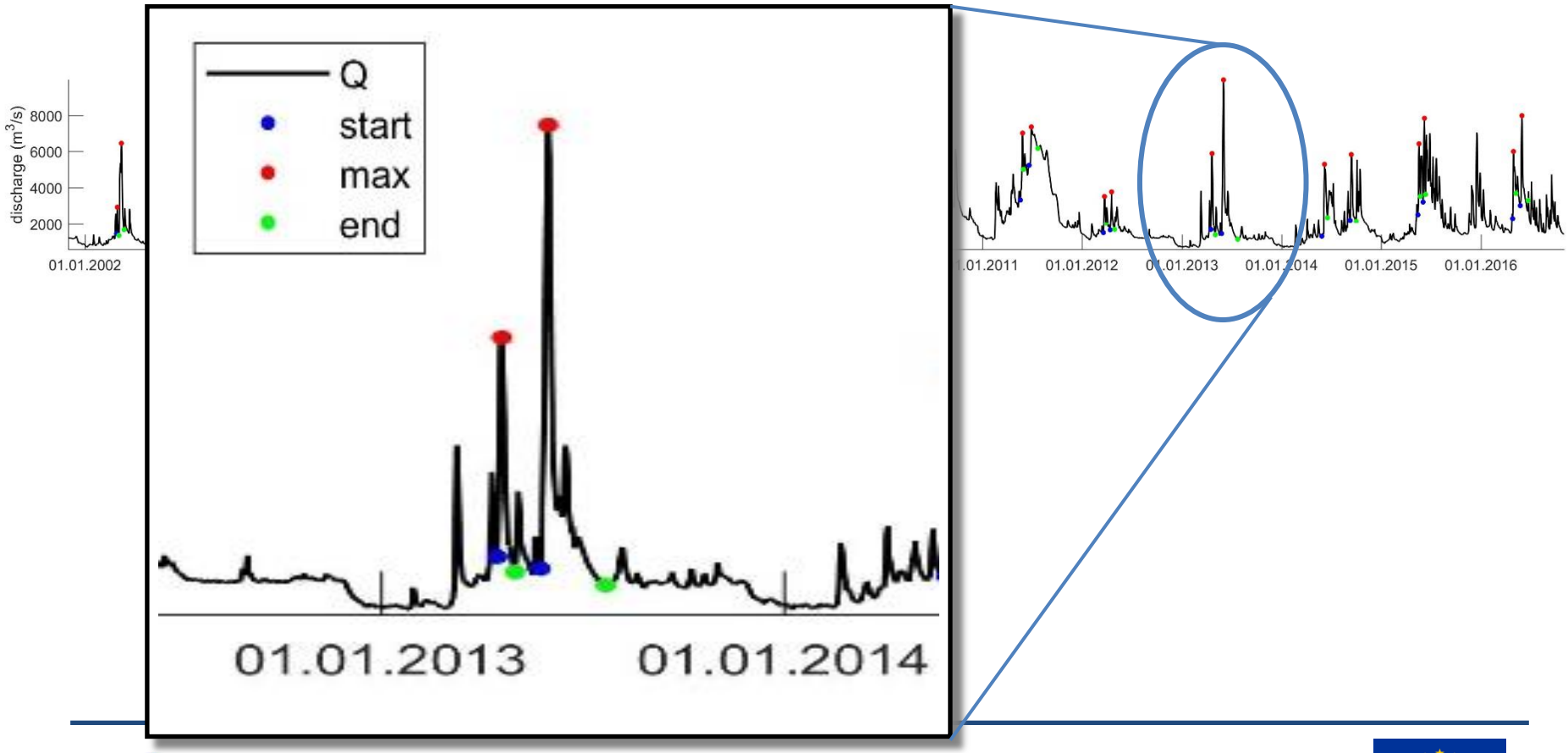

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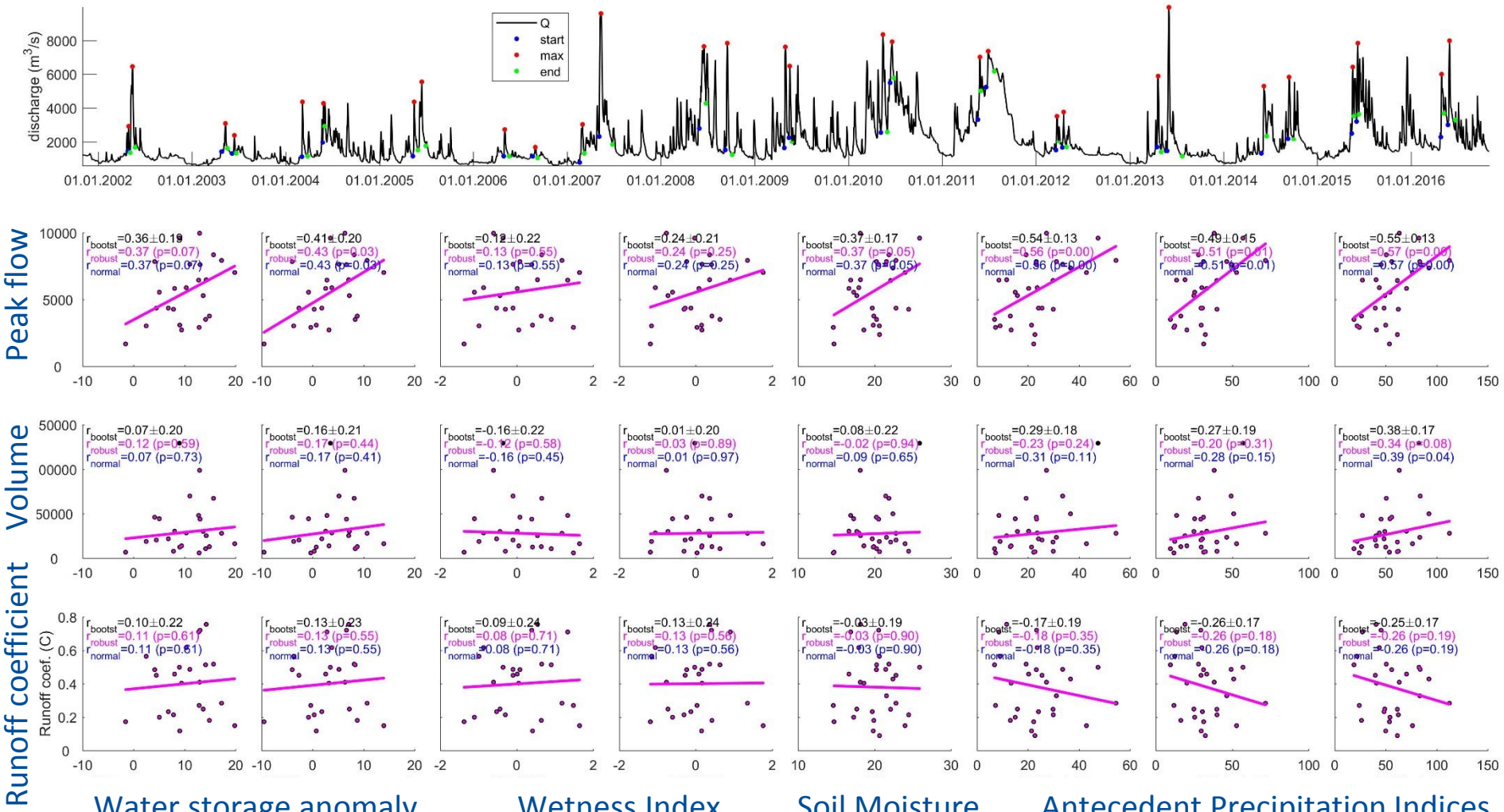

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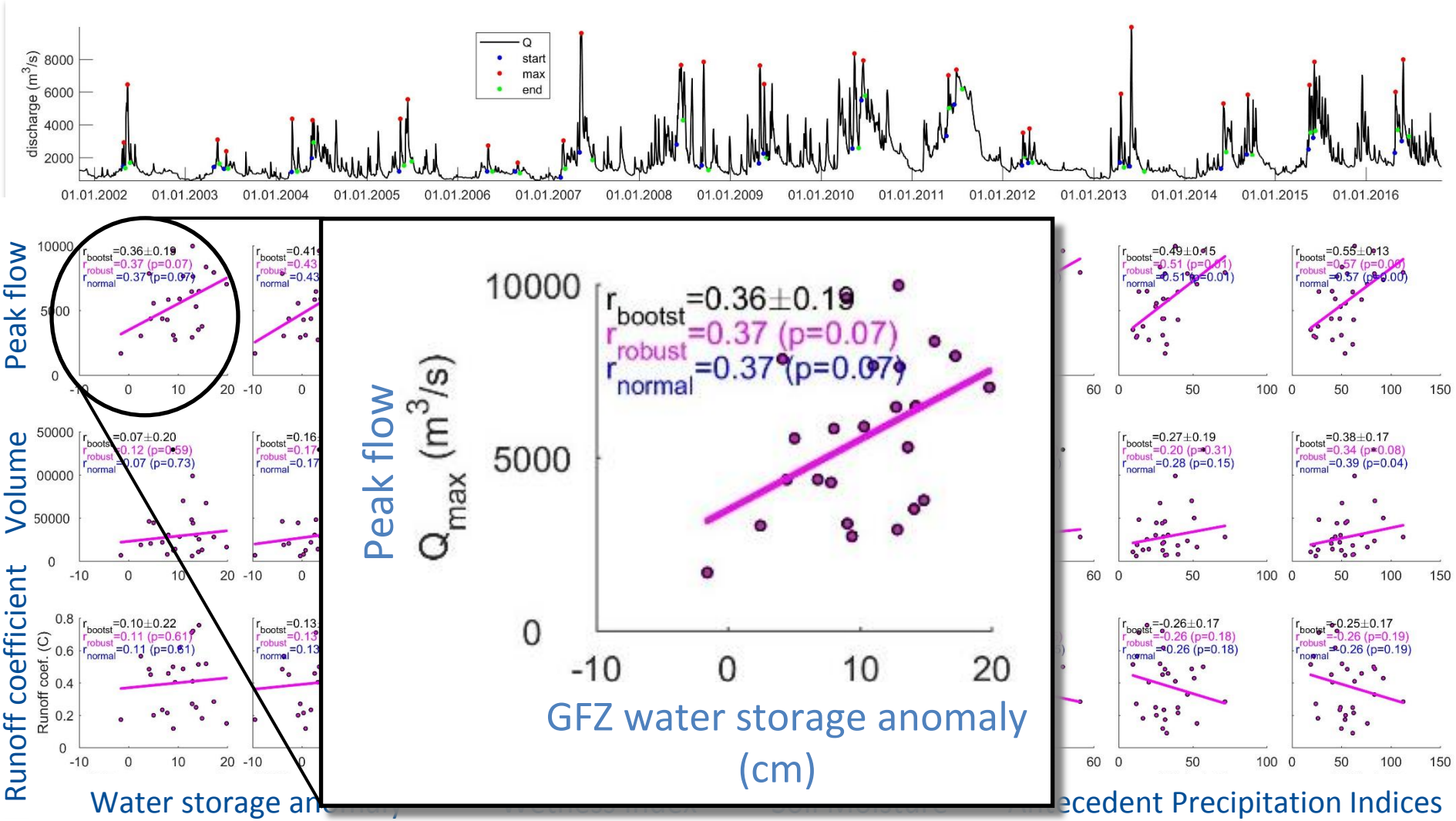

Pre-event wetness indices – global-scale analysis

Correlations between flood peak discharge and gravity-based indicators

Storage anomaly (GFZ)			***Storage anomaly (TUG)***			***Wetness index (GFZ)***			***Wetness index (TUG)***		
Basin ID	*corr*	*±*	*Basin ID*	*corr*	*±*	*Basin ID*	*corr*	*±*	*Basin ID*	*corr*	*±*
4213440	0.81	0.08	4213550	0.79	0.08	4214262	0.79	0.11	4208450	0.65	0.13
6742500a	0.69	0.21	4213440	0.74	0.10	4213440	0.73	0.09	4213440	0.62	0.16
4214051	0.66	0.27	6742500	0.73	0.17	4208450	0.57	0.17	4122600	0.58	0.16
6742500	0.66	0.14	6742500a	0.63	0.18	6742900	0.56	0.16	6544100	0.54	0.21
4213550	0.64	0.12	4214051	0.55	0.23	4125804	0.54	0.15	6742500a	0.52	0.21
4214262	0.62	0.17	6544100	0.54	0.24	6742500	0.54	0.25	6742900	0.47	0.19
4213573	0.59	0.19	Danube	0.51	0.07	4214051	0.52	0.33	4213550	0.46	0.16
4207900	0.58	0.19	4213573	0.51	0.20	4213573	0.52	0.20	6742500	0.45	0.24
4127502	0.55	0.16	4207900	0.49	0.21	4152550	0.51	0.13	4214051	0.44	0.28
4152550	0.52	0.17	4122600	0.46	0.18	4207900	0.43	0.20	4125804	0.42	0.17
4123050	0.51	0.19	4127502	0.43	0.17	6742500a	0.41	0.22	6340150	0.41	0.17
6742900	0.48	0.18	4122901	0.39	0.20	6342900	0.35	0.23	4214262	0.41	0.21
Danube	0.47	0.08	4208450	0.35	0.21	4213550	0.35	0.17	4208730	0.40	0.19
4122901	0.37	0.19	4125804	0.34	0.21	4127502	0.32	0.21	4207900	0.39	0.20
6342900	0.30	0.24	6742900	0.32	0.22	4208730	0.31	0.21	4213573	0.37	0.23
Snow	0.30	0.06	4214262	0.31	0.21	6340150	0.29	0.20	Danube	0.35	0.09
6340150	0.28	0.21	6342900	0.29	0.24	Danube	0.29	0.10	4152550	0.34	0.21
4122600	0.26	0.23	4152550	0.29	0.20	6242501	0.29	0.21	6242501	0.29	0.22
4125804	0.25	0.23	Snow	0.28	0.07	4213681	0.26	0.32	6142200	0.29	0.30
4208730	0.24	0.22	4123050	0.27	0.23	4123050	0.25	0.19	6342900	0.26	0.24
6142200	0.23	0.28	4208730	0.27	0.21	Snow	0.25	0.07	Snow	0.23	0.07
4208450	0.22	0.23	Temperate	0.23	0.06	4122600	0.24	0.22	4122901	0.21	0.21
6544100	0.20	0.28	6340150	0.21	0.23	6335020	0.19	0.22	4127502	0.15	0.22
4213681	0.14	0.34	4213681	0.20	0.35	6544100	0.12	0.26	4213681	0.13	0.39
6242501	0.14	0.23	6242501	0.19	0.26	6142200	0.11	0.30	4123050	0.13	0.21
Temperate	-0.13	0.07	6142200	-0.01	0.37	4122901	0.10	0.21	Temperate	0.08	0.07
6335020	-0.18	0.22	6335020	-0.13	0.26	Temperate	0.09	0.06	6335020	0.03	0.26
Mean	**0.38**			**0.38**			**0.37**			**0.36**	

Basin in snow-dominated climate

Basin in temperate climate

Basin group

Pre-event wetness indices – global-scale analysis

Correlations between flood peak discharge and gravity-based indicators

Storage anomaly (GFZ)			*Storage anomaly (TUG)*			*Wetness index (GFZ)*			*Wetness index (TUG)*		
Basin ID	*corr*	*±*	*Basin ID*	*corr*	*±*	*Basin ID*	*corr*	*±*	*Basin ID*	*corr*	*±*
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4214051	0.66	0.27	6742500	0.73	0.17	4208450	0.57	0.17	4122600	0.58	0.16
6742500	0.66	0.14	6742500a	0.63	0.18	6742900	0.56	0.16	6544100	0.54	0.21
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4213573	0.59	0.19	Danube	0.51	0.07	4214051	0.52	0.33	4213550	0.46	0.16
4207900	0.58	0.19	4213573	0.51	0.20	4213573	0.52	0.20	6742500	0.45	0.24
4127502	0.55	0.16	4207900	0.49	0.21	4152550	0.51	0.13	4214051	0.44	0.28
4152550	0.52	0.17	4122600	0.46	0.18	4207900	0.43	0.20	4125804	0.42	0.17
4123050	0.51	0.19	4127502	0.43	0.17	6742500a	0.41	0.22	6340150	0.41	0.17
6742900	0.48	0.18	4122								
Danube	0.47	0.08	4208								
4122901	0.37	0.19	4125								
6342900	0.30	0.24	6742								
Snow	0.30	0.06	4214								
6340150	0.28	0.21	6342								
4122600	0.26	0.23	4152								
4125804	0.25	0.23	Sno								
4208730	0.24	0.22	4123								
6142200	0.23	0.28	4208								
4208450	0.22	0.23	Temp								
6544100	0.20	0.28	6340								
4213681	0.14	0.34	4213								
6242501	0.14	0.23	6242501	0.19	0.26	6142200	0.11	0.30	4123050	0.13	0.21
Temperate	-0.13	0.07	6142200	-0.01	0.37	4122901	0.10	0.21	Temperate	0.08	0.07
6335020	-0.18	0.22	6335020	-0.13	0.26	Temperate	0.09	0.06	6335020	0.03	0.26
Mean	**0.38**			**0.38**			**0.37**			**0.36**	

Basin in snow-dominated climate

Basin in temperate climate

Basin group

- Correlations vary markedly among river basins and with respect to the rank order
- In snow-dominated basins, correlations tend to be higher (more value of gravity-based pre-event indices)
- Global differences among the products (GFZ vs. TUG, Storage Anomaly vs. Wetness Index) are marginal

Pre-event wetness indices – global-scale analysis

Average correlations between flood characteristics and pre-event flood indicators

Basins in temperate climate zone

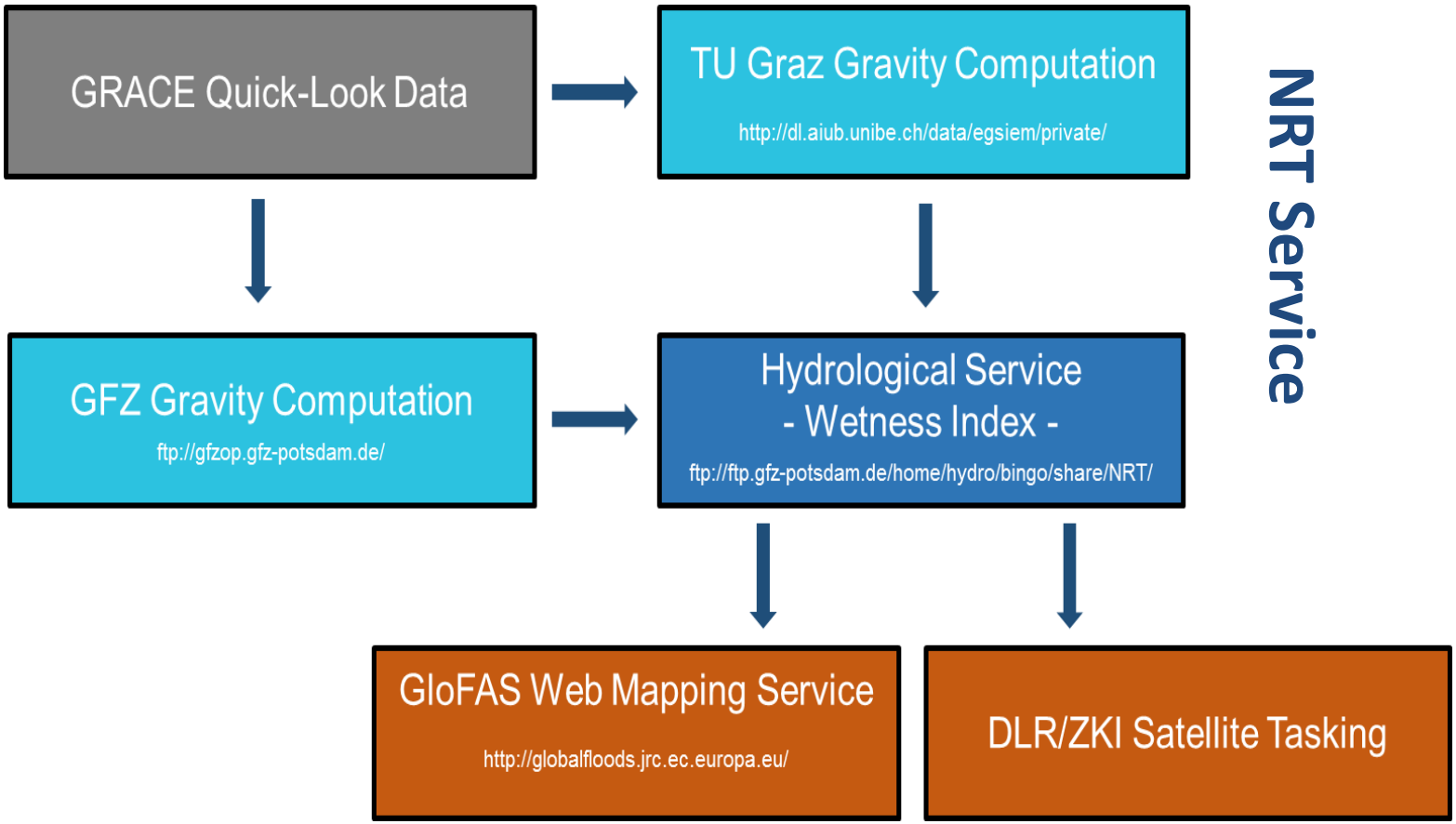
	Storage anomaly		Wetness Index		Soil moisture	Antecedent Precip Index	
	GFZ	TUG	GFZ	TUG		k=0.85	k=0.95
Peak discharge	0.34	0.33	0.32	0.31	0.13	0.11	0.19
Volume	0.16	0.16	0.14	0.17	0.05	0.08	0.07
Runoff coefficient	0.27	0.27	0.18	0.27	0.11	-0.13	-0.07

Basins in snow-dominated climate zone

	Storage anomaly		Wetness Index		Soil moisture	Antecedent Precip Index	
	GFZ	TUG	GFZ	TUG		k=0.85	k=0.95
Peak discharge	0.29	0.29	0.19	0.23	0.03	0.10	0.05
Volume	0.29	0.25	0.16	0.17	-0.11	-0.12	-0.16
Runoff coefficient	0.45	0.43	0.45	0.45	0.07	0.22	0.18

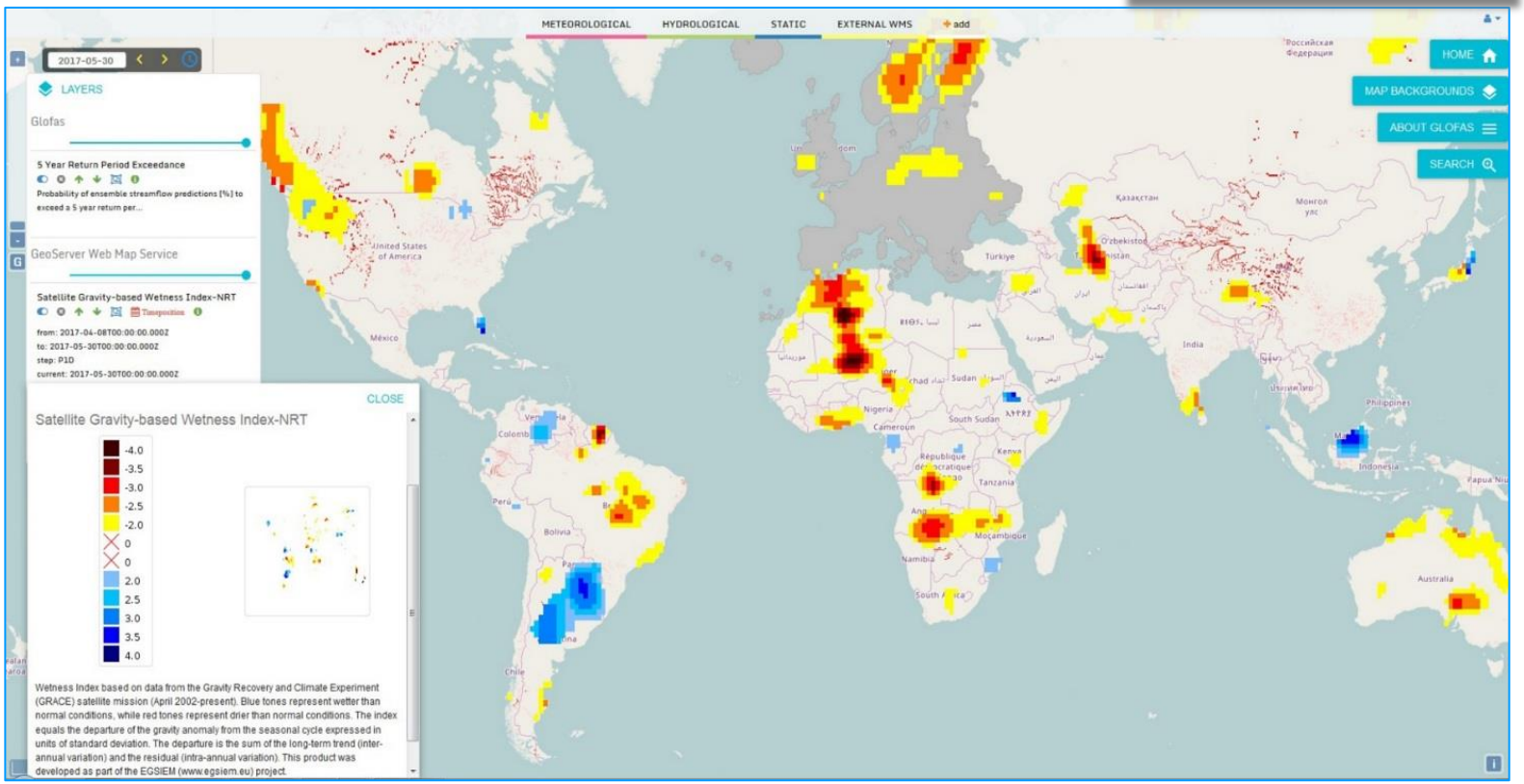
- Storage anomalies correlate higher than wetness index in snow basins
- Gravity-based indices result in higher correlations than classical indices

Operational Hydrological Service Implementation



Operational Hydrological Service Implementation

Gravity-based wetness index included in NRT in the GloFAS Forecast Viewer with latency of about 2 days



Operational for April 1 to June 30, 2017

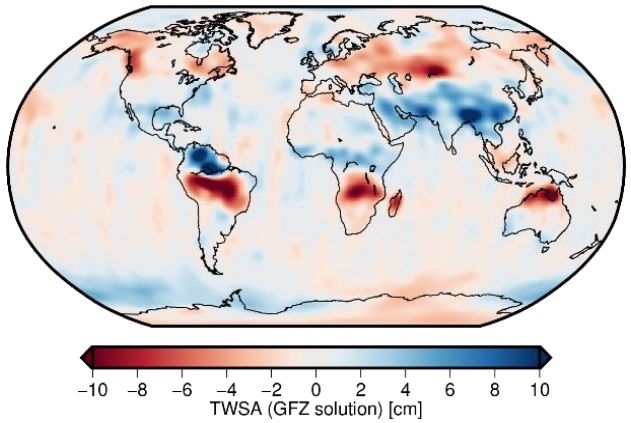
Operational Hydrological Service Implementation

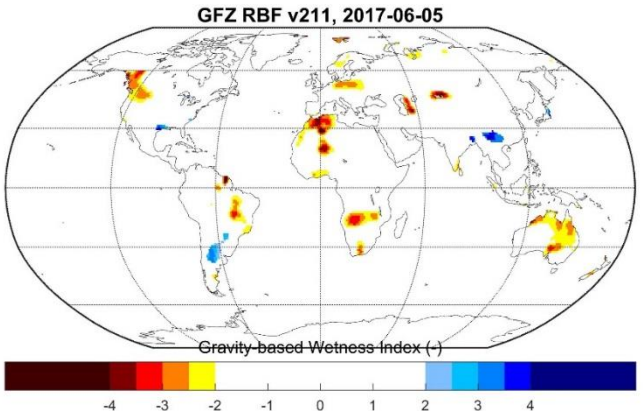
Example 05 June 2017

Water storage anomaly

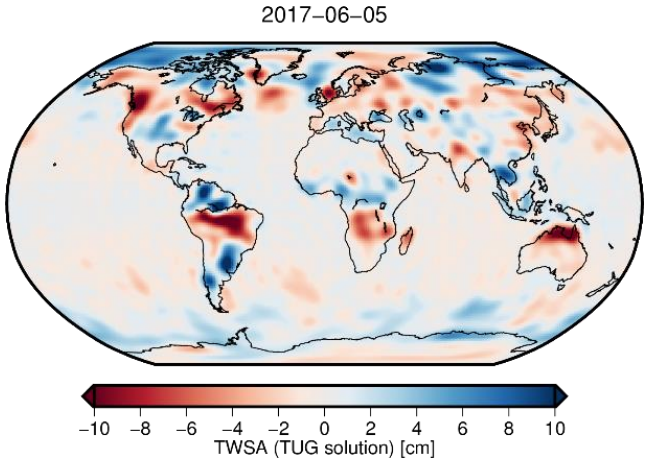
Wetness index

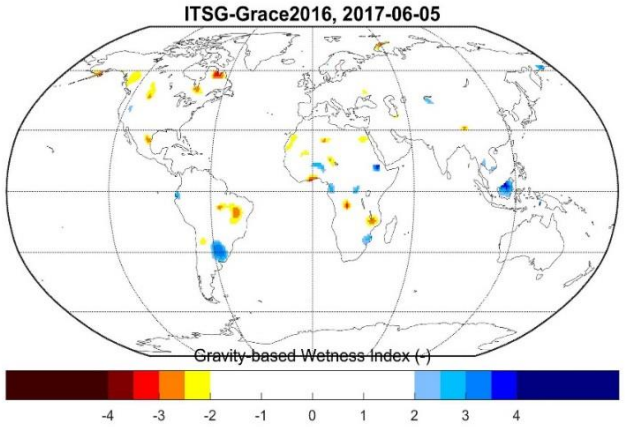
GFZ





TUG





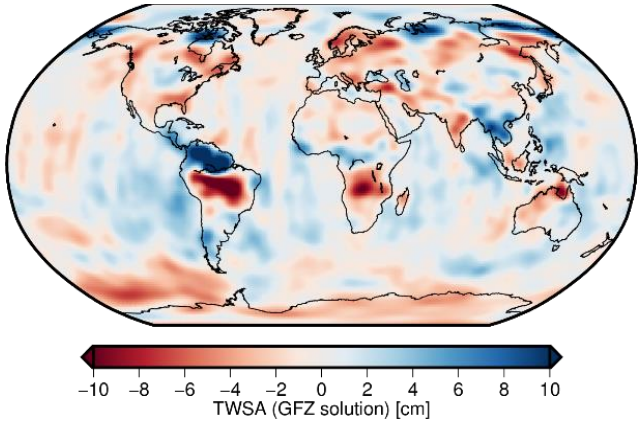
Operational Hydrological Service Implementation

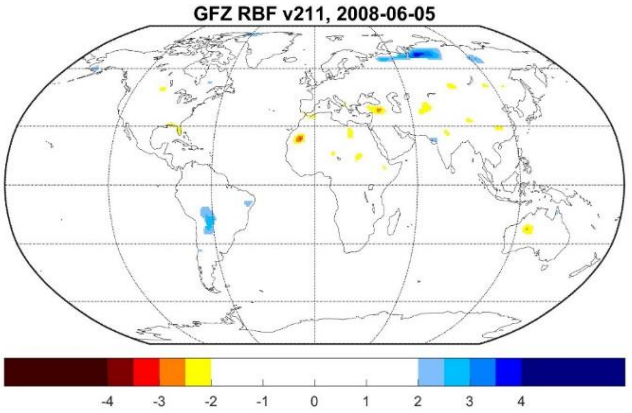
Example 05 June 2008

Water storage anomaly

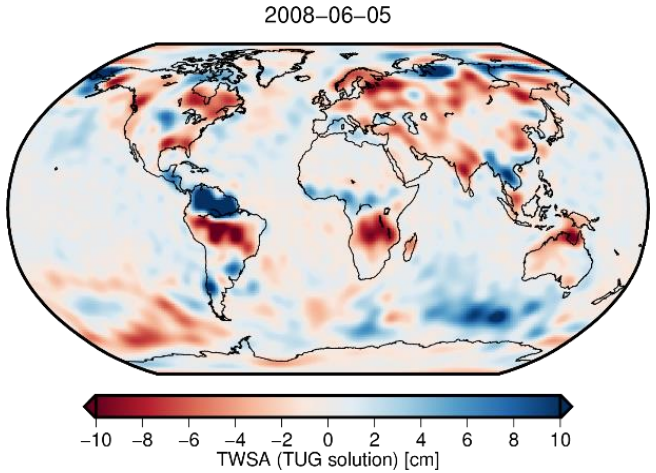
Wetness index

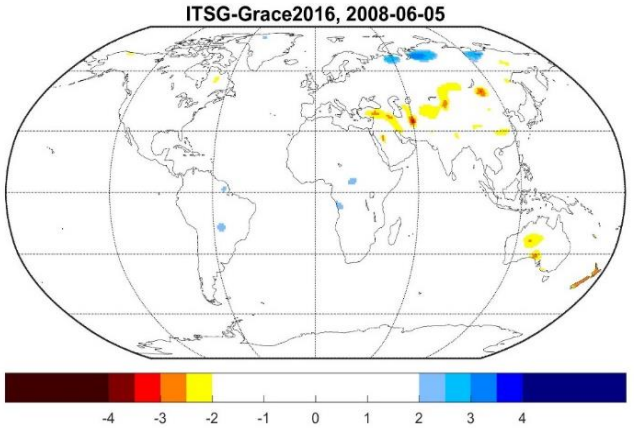
GFZ



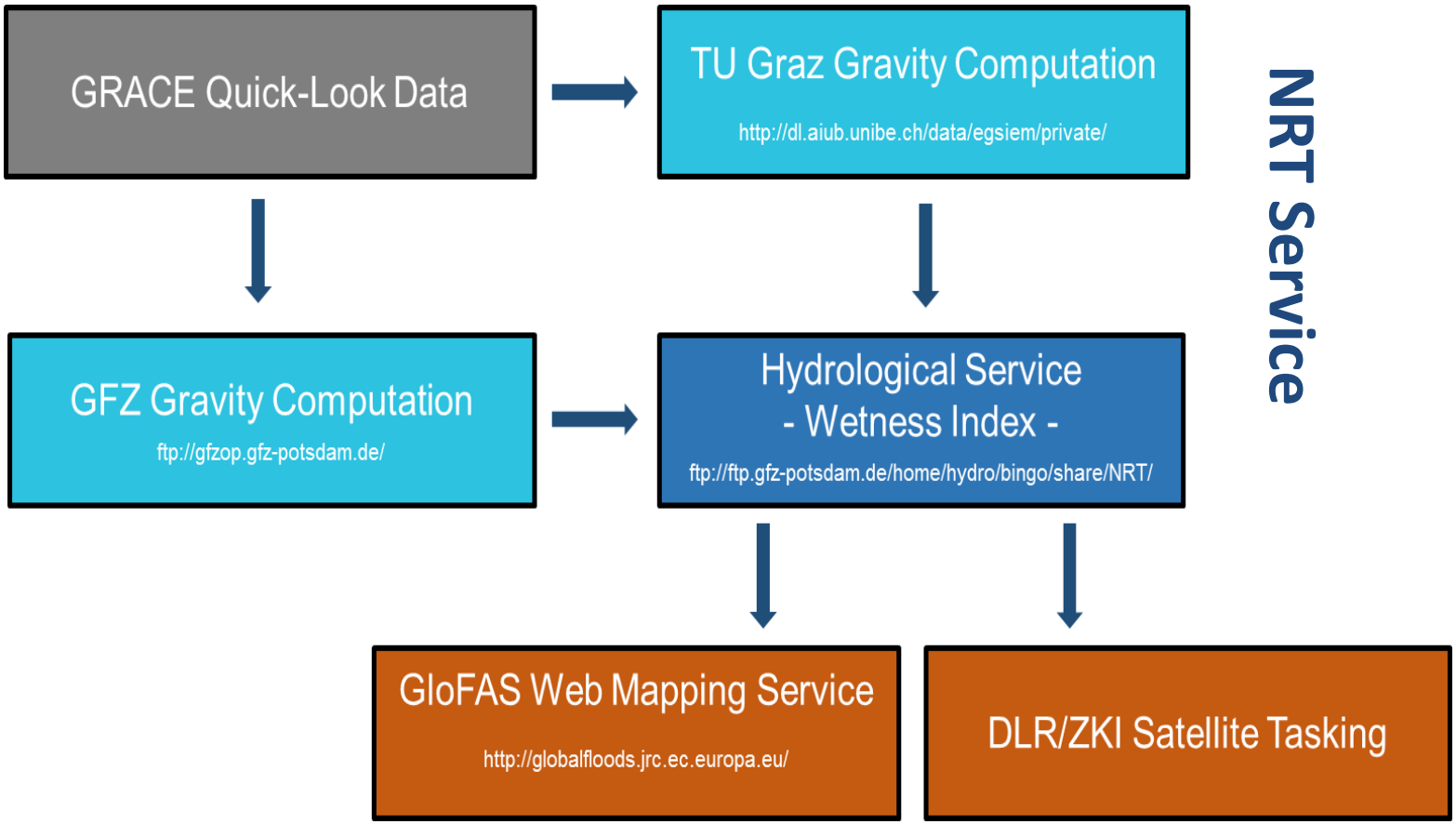


TUG





Operational Hydrological Service Implementation



Operational for April 1 to June 30, 2017

Seasonal streamflow forecast

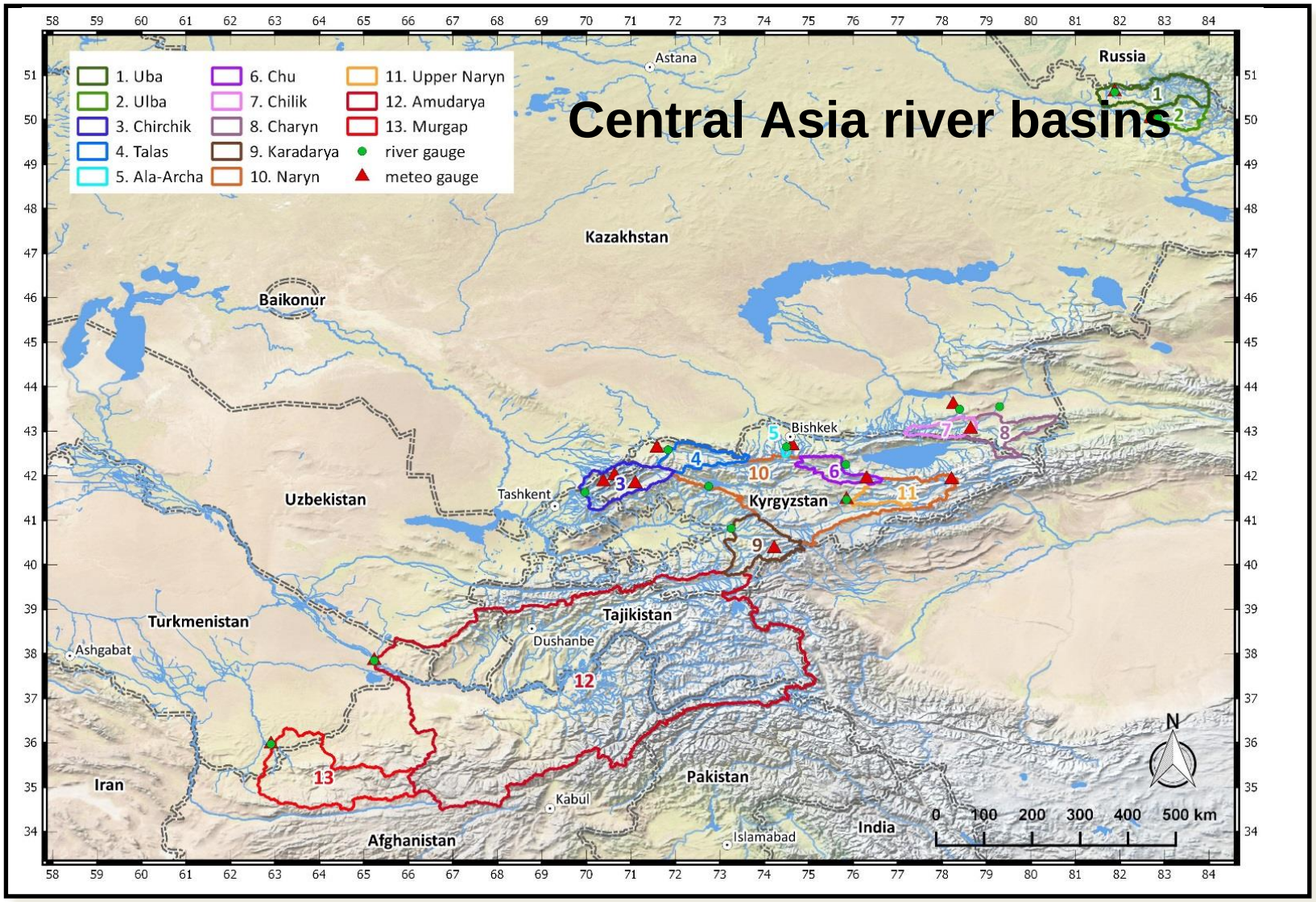
How much water will be available in summer (vegetation period)?

How much snow is stored in the mountains during winter?

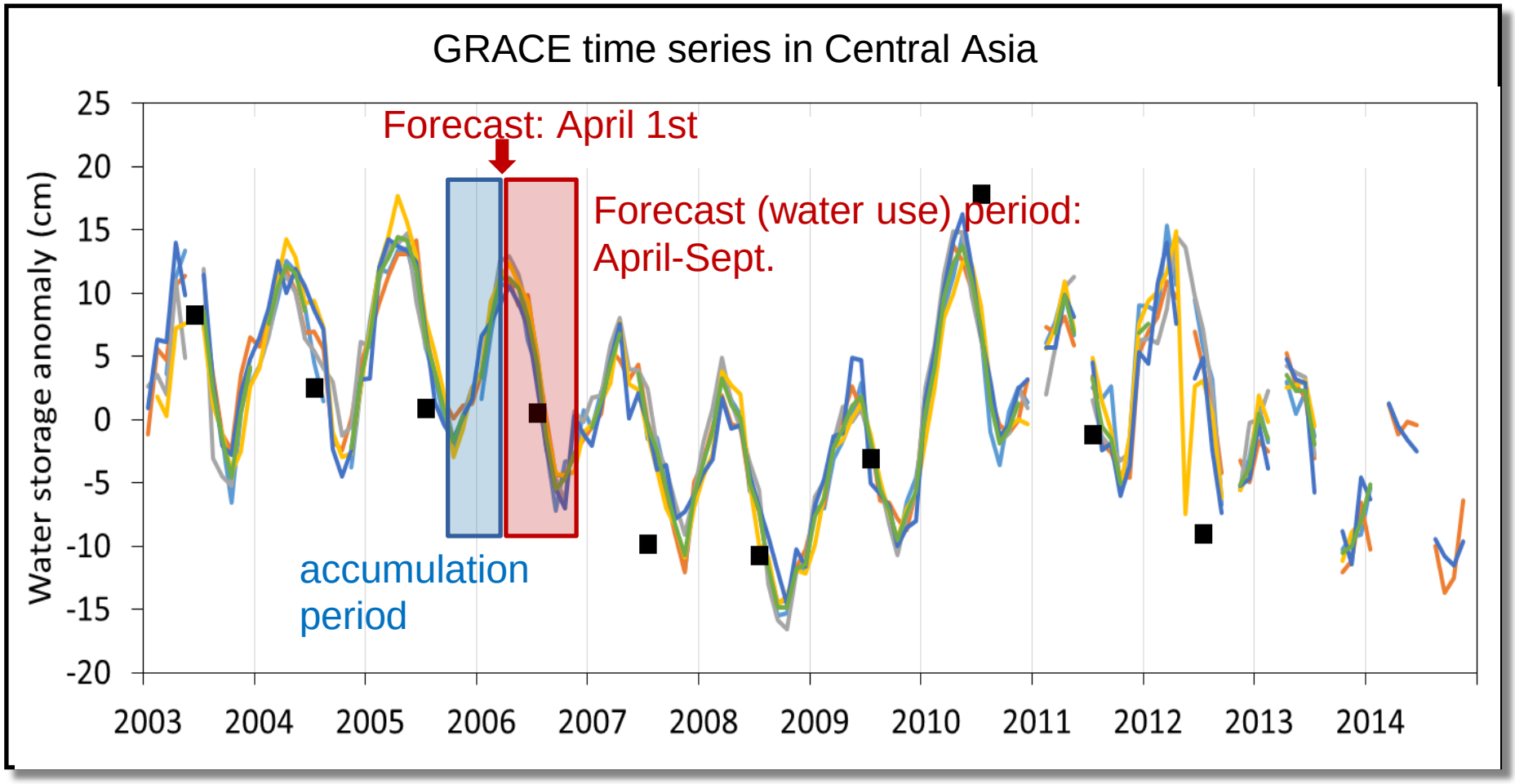
Streamflow forecast

Management / allocation of water resources
=> irrigation and hydropower generation

Seasonal streamflow forecast



Seasonal streamflow forecast

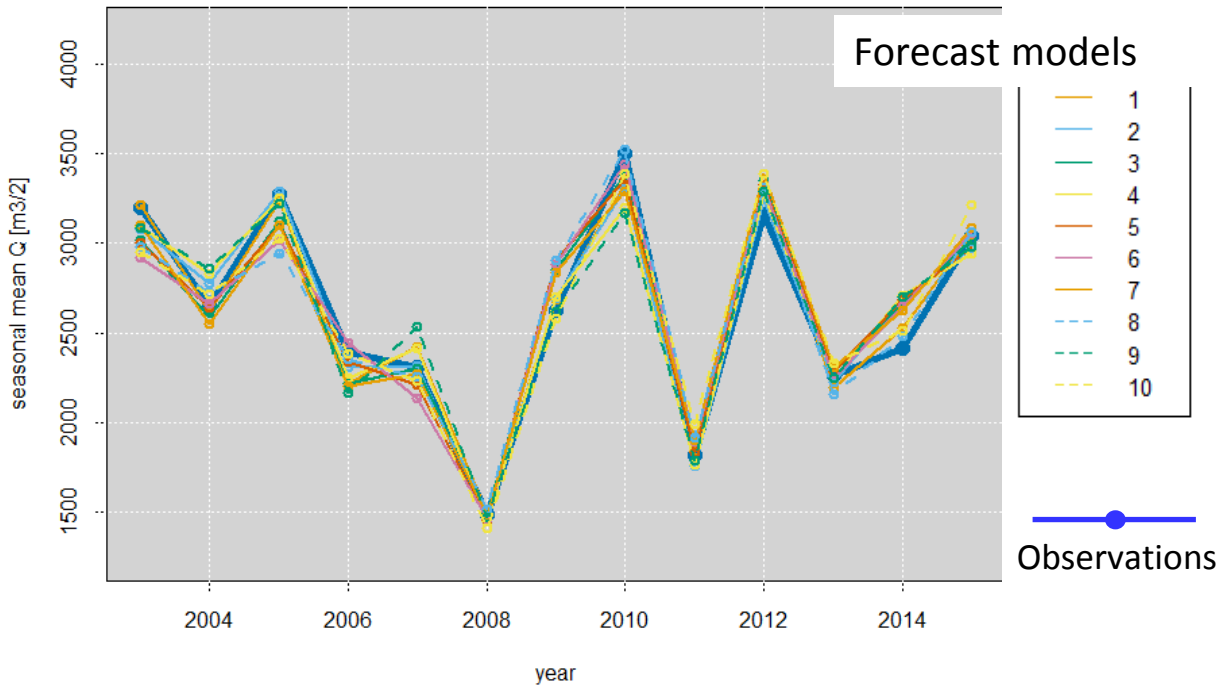


Seasonal streamflow forecast

Predictors

SC	Fractional snow cover
TWS	GRACE-based water storage (TUG daily)
P	Precipitation

Linear forecast model (3 predictors) (2003-2015) for summer streamflow in the Amudarya basin



Best forecast model

TWS (March)	0.63
SC (Jan)	0.30
P (Dec)	0.04

Predictor (Month)

Importance (partial R^2 explained by the predictor)

Apel et al. (2018): EGU abstract.
Manuscript in prepration.

HORIZON 2020

Summary

- Daily gravity field products can monitor the dynamics of large flood events
- Wetness index derived from daily gravity data shows early flood warning capacity for selected basins and flood types
- Seasonal streamflow forecasting benefits from gravity data in snow-dominated areas (example Central Asia)
- Operational Hydrological Service implemented globally, with near-real time delivery of gravity-based wetness indices