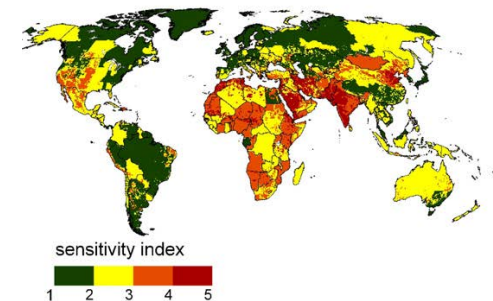


Impact of human water use on groundwater + Information content of GRACE for understanding groundwater dynamics



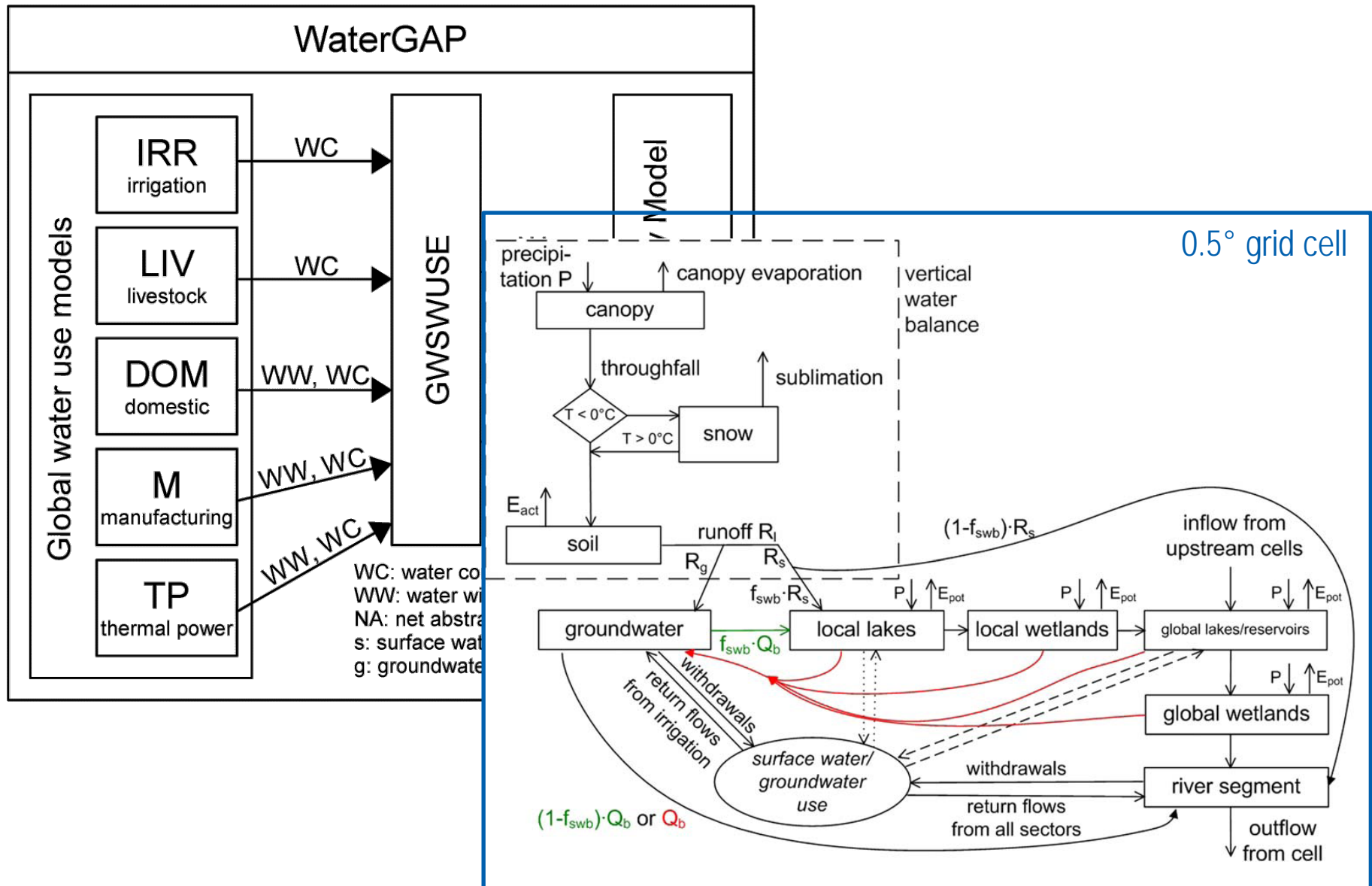
http://water.usgs.gov/ogw/gwrp/photo_gallery/



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Quantification of impact of water use on groundwater

Water use related flows

1. Consumptive water use of irrigated crops as well as other water users
2. Water abstractions
3. Source: from groundwater (gw) and from surface water (sw)
4. Return flows to gw and to sw
5. Net abstractions from gw =
gw abstractions (for all other sectors)
– return flows from irrigation with sw and gw

Water resources related flows

1. (Natural) gw recharge
2. gw discharge to swb (relevant for freshwater biota, affected by net abstractions)
3. *(Capillary rise, for vegetation)(affected by gw use)*

Water resources: storage

1. Volumetric storage anomalies
2. *gw table, hydraulic head*

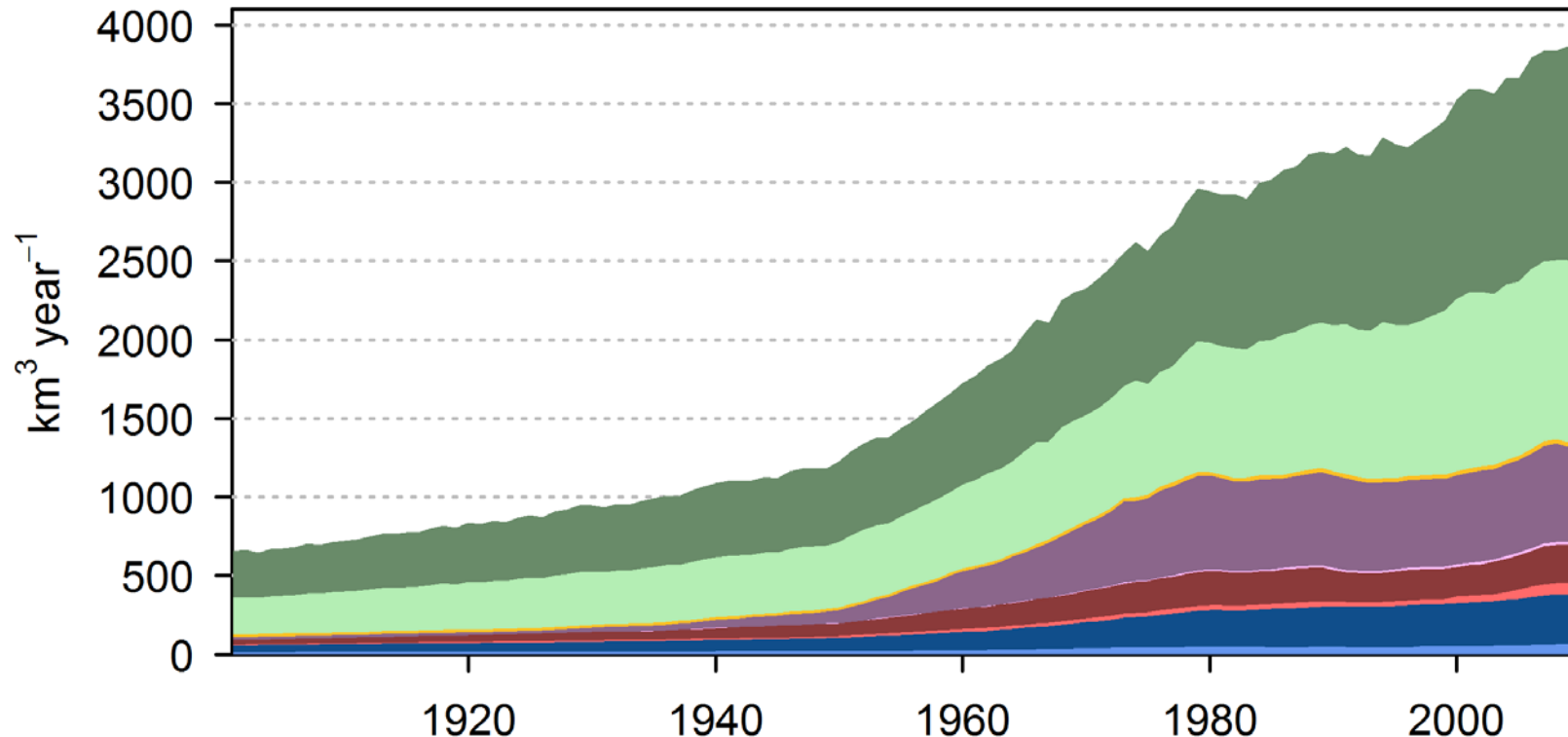
Uncertain data and assumptions used for computing water use components affecting groundwater

- Country values of domestic and manufacturing water withdrawals, modeling of temporal development and downscaling to grid cells
- Areas equipped for irrigation and areas actually irrigated (Global Map of Irrigation Areas GMIA v5.0, including spatial information on map quality, Siebert et al., with FAO)
- Areas equipped for irrigation with groundwater (Siebert et al. 2010 HESS)
- Irrigated crop calendars
- Climate data (WFDEI: reanalysis data that are bias-corrected with observations)
- Equation for computing potential evapotranspiration (Priestley-Taylor)
- Degree of deficit irrigation (70% in groundwater depletion areas, Döll et al. 2014 WRR)
- Ratio of consumption over abstraction (0.7 in case of groundwater use, otherwise country-specific)
- Fraction of return flows to gw ($= 0.95 - 0.75 \cdot f_{\text{drain}}$, with f_{drain} = fraction of grid cell that is artificially drained, Döll et al. 2014 WRR)

Uncertain data and assumptions used for computing gw resources

- Climate data
- Equation for computing potential evapotranspiration
- Equation for computing actual evapotranspiration and runoff (calibrated against observed streamflow at 1319 gauging stations world-wide, Müller Schmied et al. 2014 HESS)
- Algorithm for partitioning total runoff into groundwater recharge and fast surface and subsurface runoff (function of relief, soil texture, hydrogeology and glaciers/permafrost)
- gw-sw interactions (baseflow from gw to sw except lakes and wetlands in dry areas that are assumed to recharge gw)

Global human water use (no distinction gw/sw)



manufacturing industries

- return flows
- consumptive use

irrigation

- return flows
- consumptive use

livestock sector

- consumptive use

thermal power plant cooling

- return flows
- consumptive use

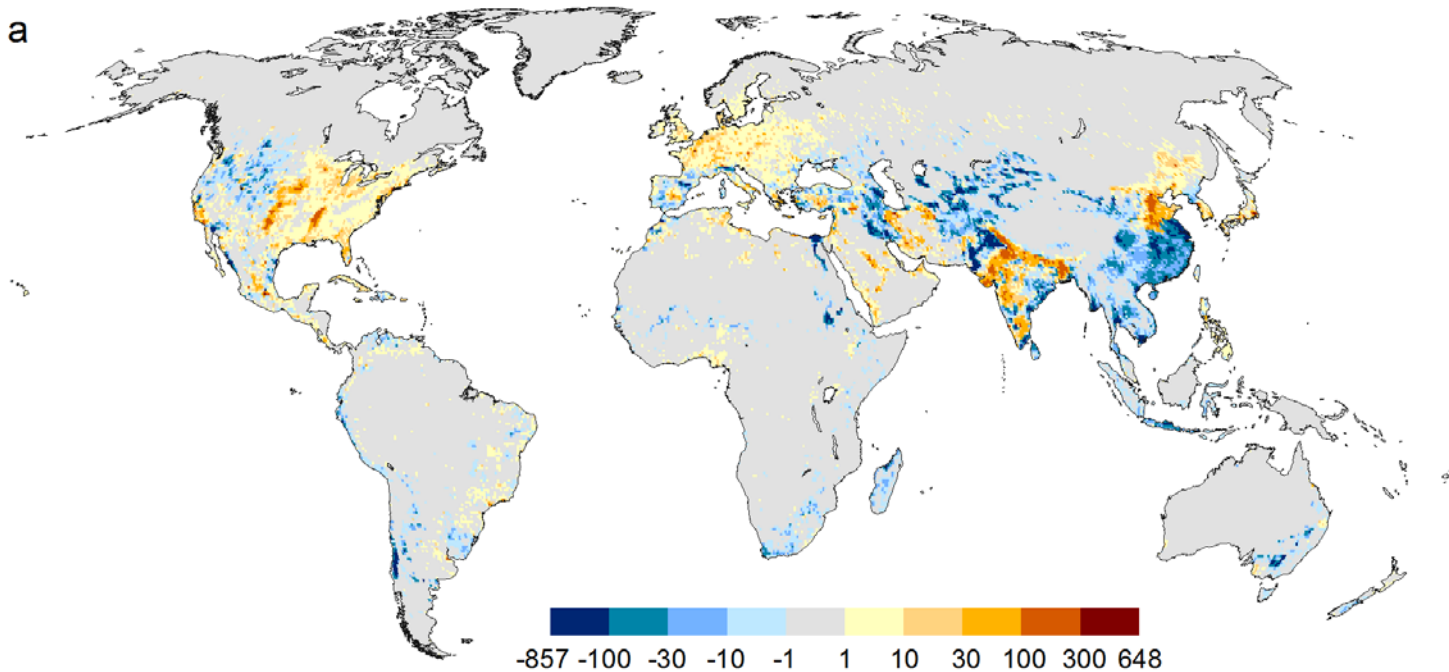
domestic sector

- return flows
- consumptive use

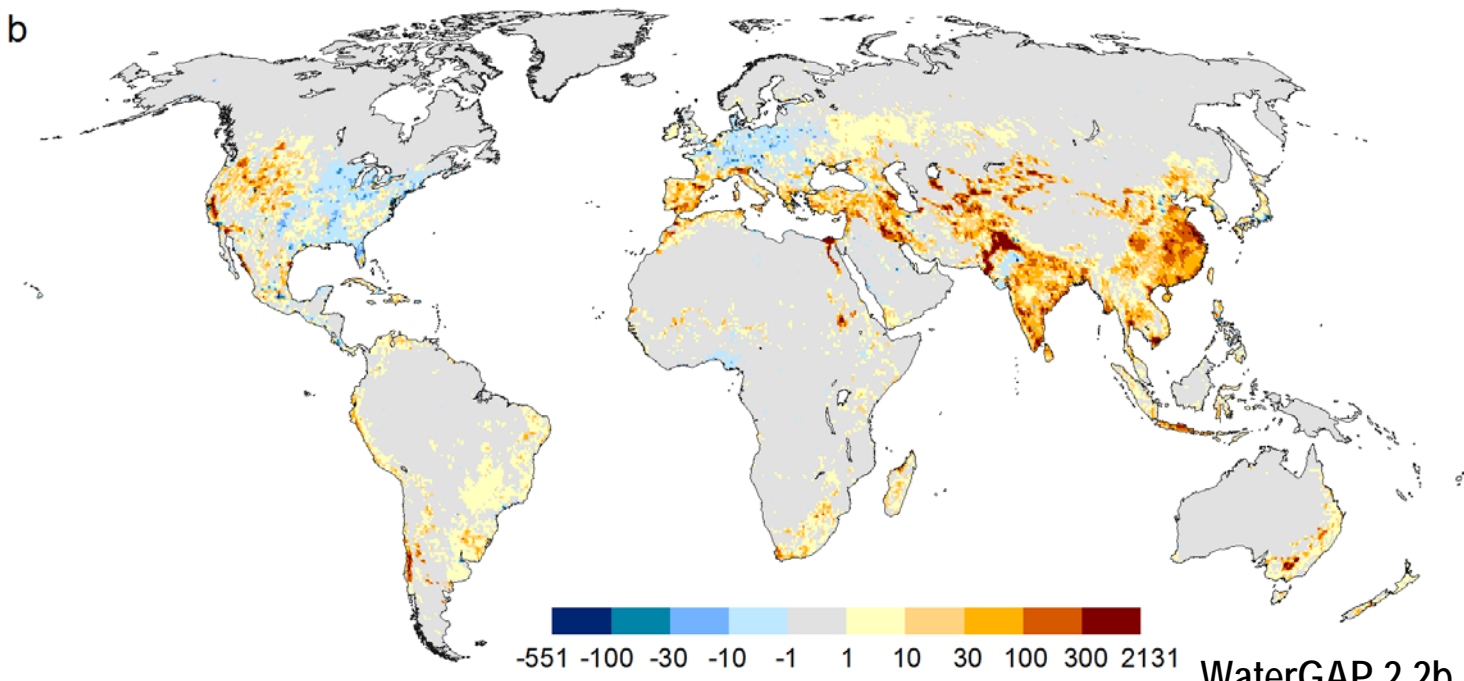
WaterGAP 2.2b

Net water
abstractions
2003-2009
(mm/yr)

from
groundwater

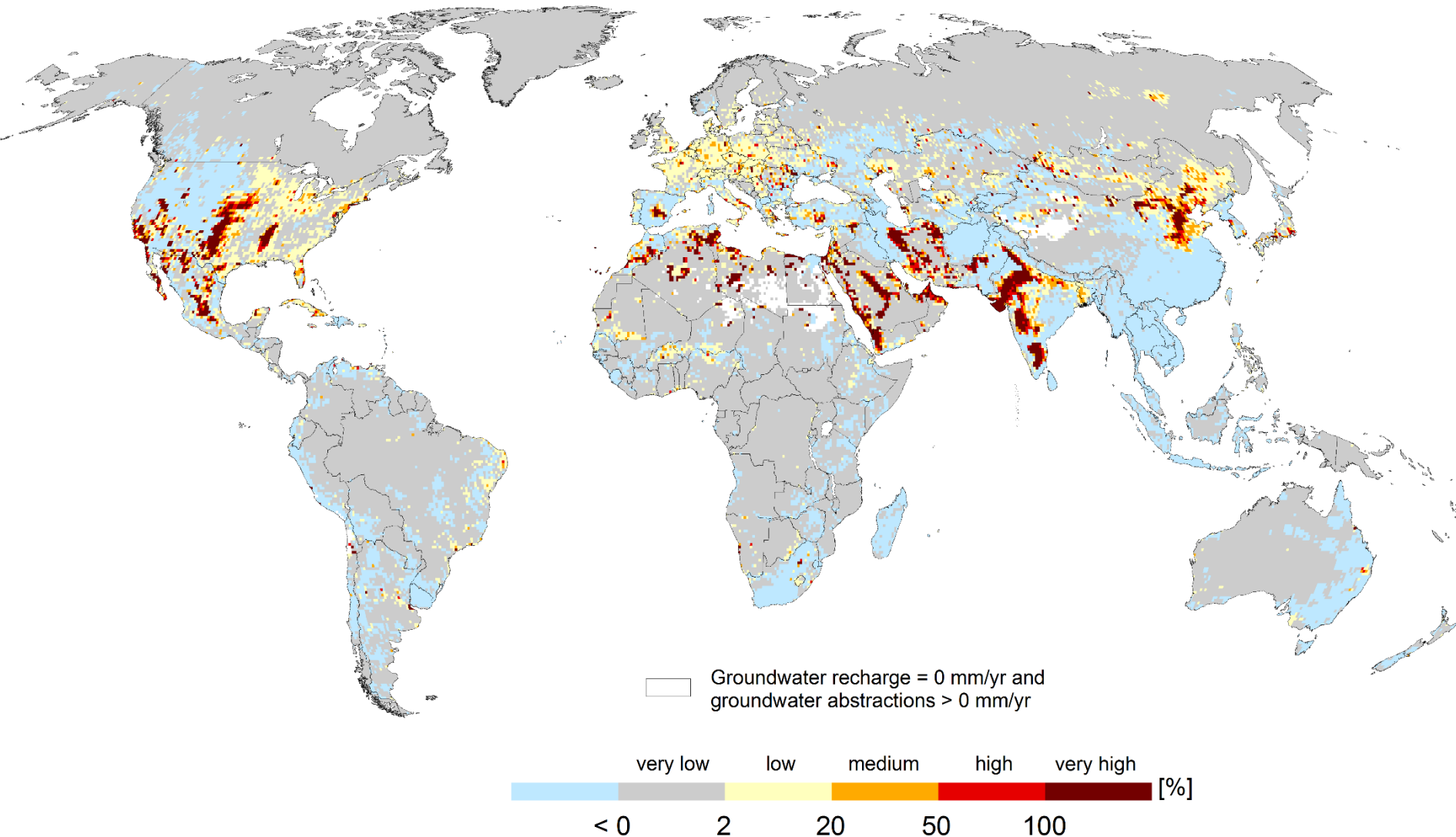


from surface
water bodies



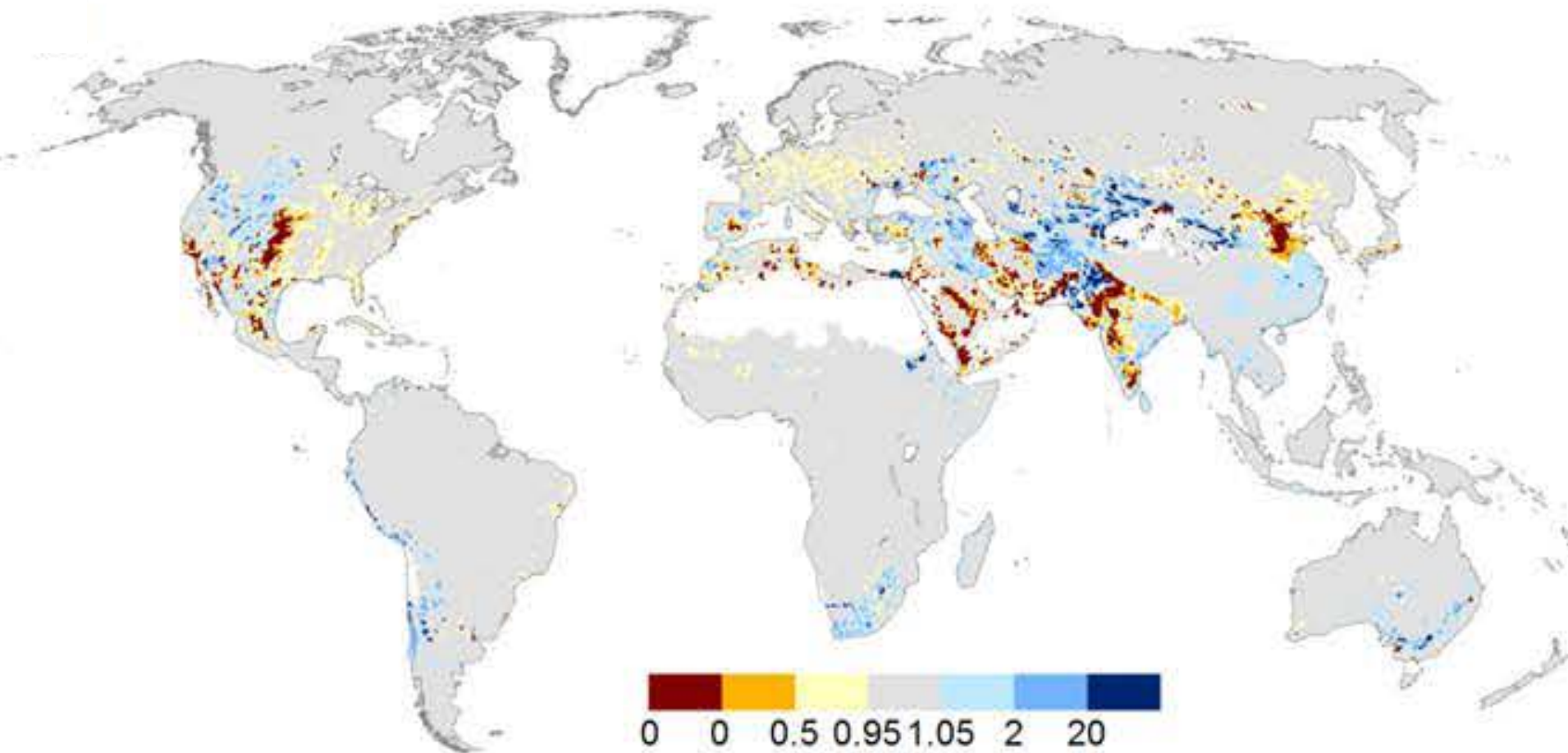
Groundwater development stress (1971-2000)

Mean annual net groundwater abstraction divided
by mean annual natural groundwater recharge in % per grid cell

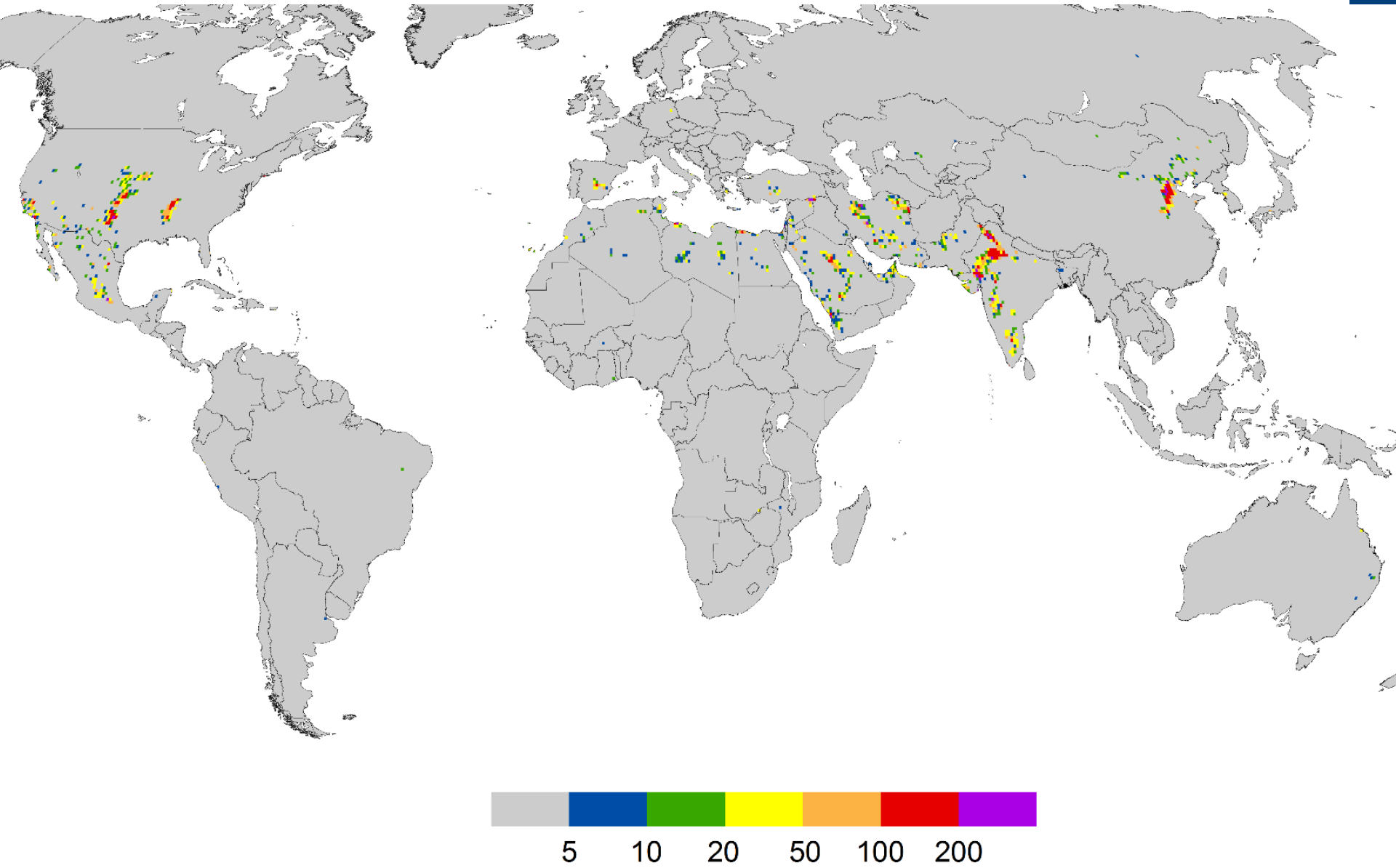


Impact of human water use on gw discharge to swb (1980–2009)

gw discharge as a fraction of natural gw discharge



Groundwater depletion by human water use 2000-2009, in mm/yr (impact of climate variability subtracted)



Information content of GRACE for understanding groundwater dynamics

1. as impacted by water use
2. as such

1 Impact of water use on seasonality of water storage cannot be detected by GRACE

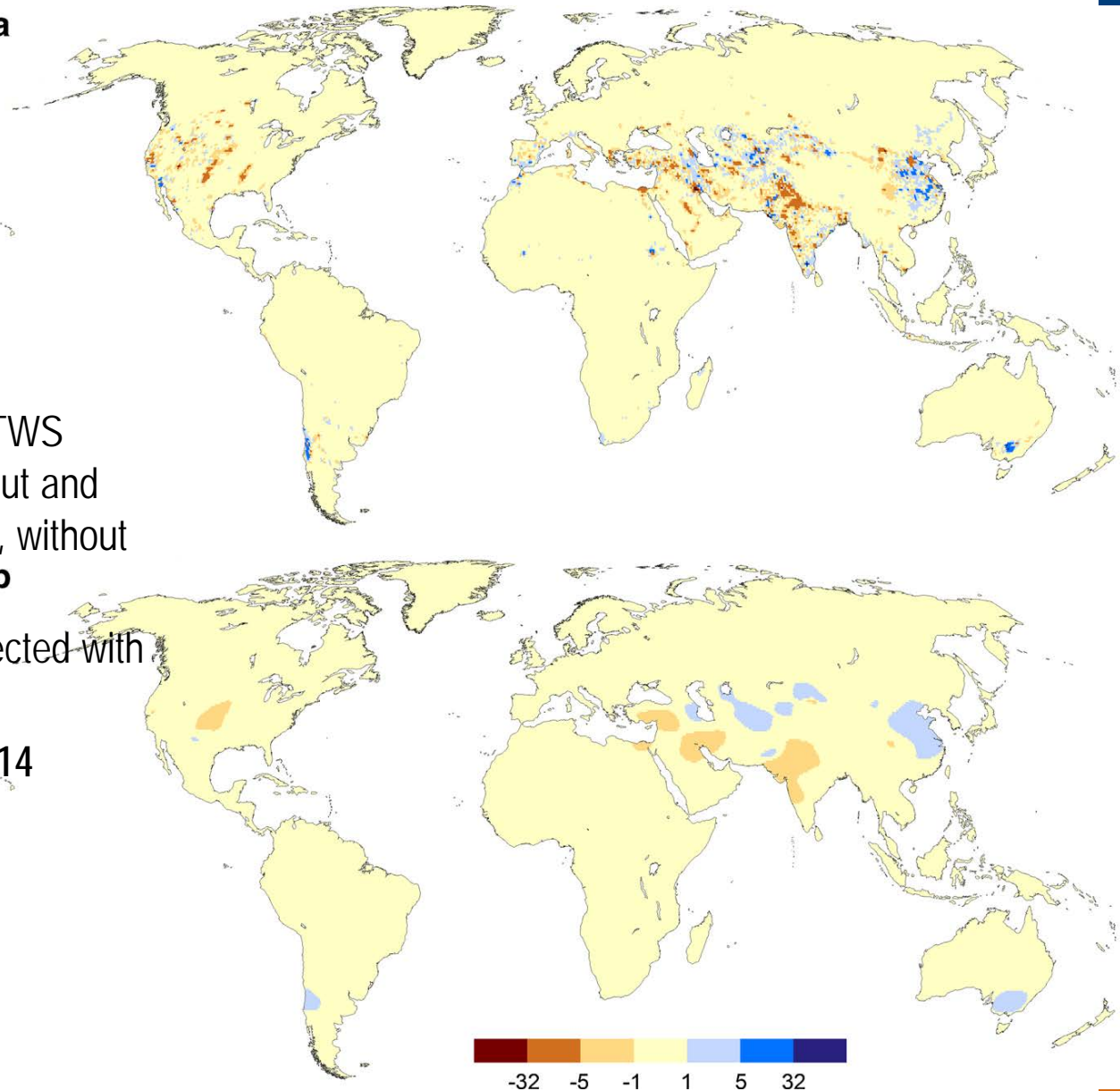
a

- due to attenuation of the TWSA differences between water abstraction variants due to the filtering required for GRACE TWS.

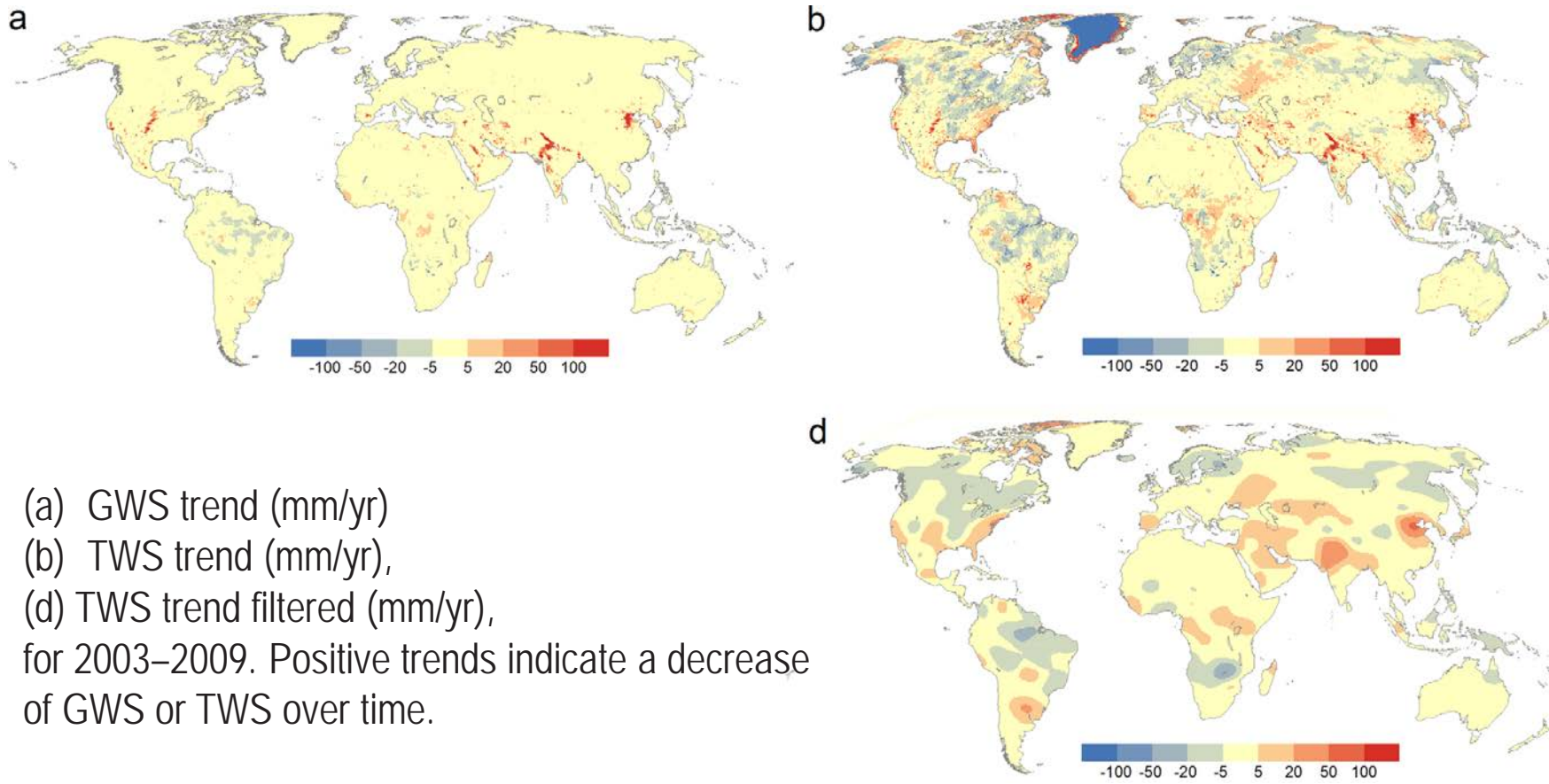
Difference between seasonal TWS amplitudes of WaterGAP without and with human water abstractions, without (top) and with filtering (bottom)^b

32 mm differences can be detected with high certainty.

Döll et al. Surv. Geophys. 2014



1 Impact of water use on storage trends may be detected if there is groundwater depletion (net abstraction larger than groundwater recharge plus reduction in baseflow) but longer time series required due to climate variability



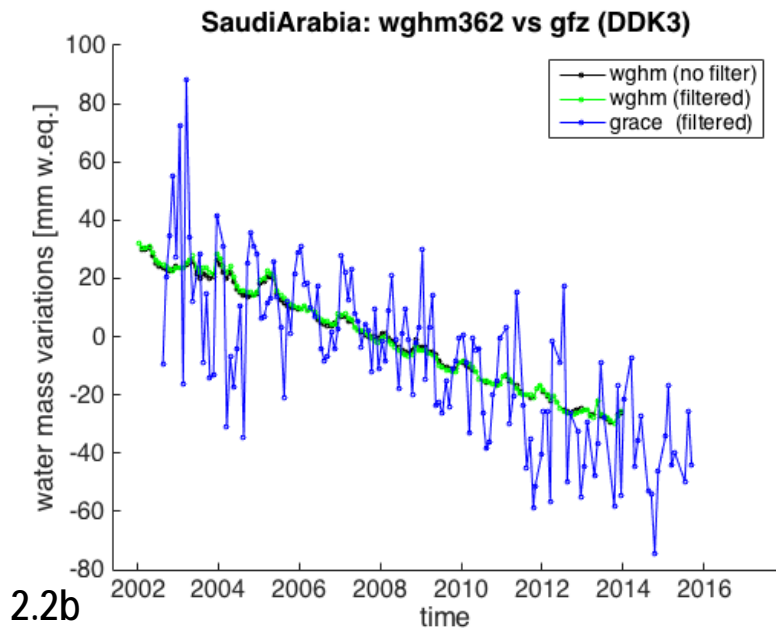
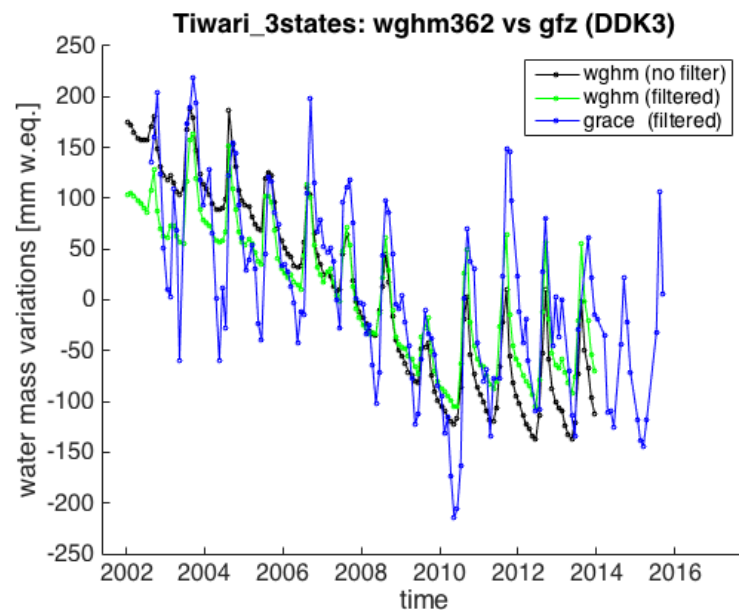
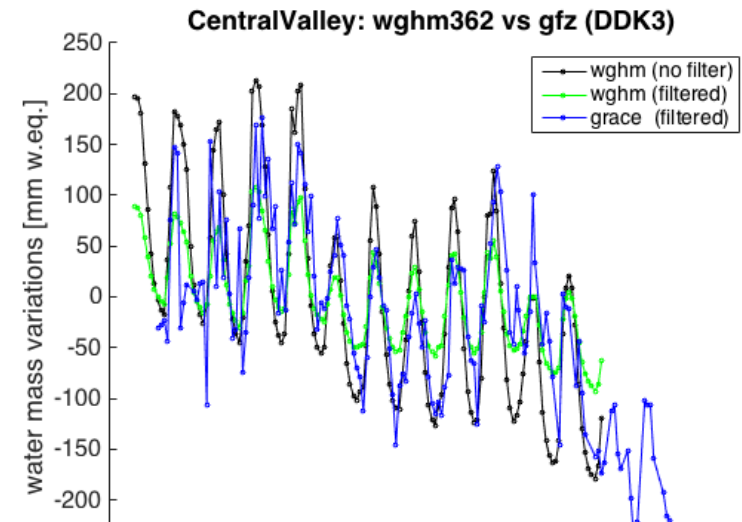
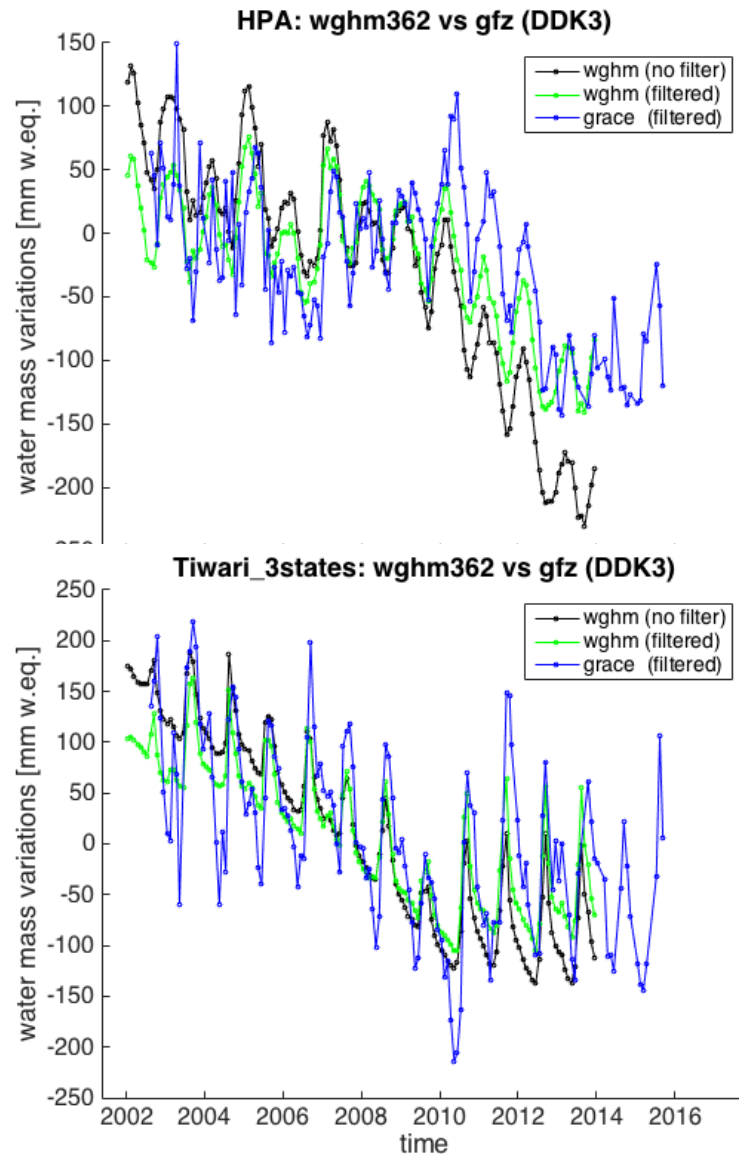
1 Comparison of WaterGAP and GRACE trends in groundwater depletion areas (2003-2009) suggested a 70% deficit irrigation in those areas (Döll et al. WRR 2014)

Table 5. Comparison of Trends in Simulated TWS in Main GWD Areas/Countries to Three Different (Filtered) GRACE Solutions, for 2003–2009 (mm/yr)^a

	WaterGAP IRR70_S Unfiltered	WaterGAP IRR70_S Filtered	WaterGAP IRR100_S Filtered	GRACE GFZ-RL05	GRACE CSR-RL05	GRACE ITG-Grace2010
High Plains aquifer	11.9	4.5	9.1	−0.2	−3.5	4.9
Hai river basin (Northeast China)	60.4	42.2	49.2	6.5	7.1	5.9
Three-states region (Northern India)	44.6	32.5	46.9	24.1	25.4	29.4
Tiwari study region	16.5	17.4	25.1	17.9	16.2	17.3
Saudi Arabia	5.3	5.5	7.2	6.2	3.2	−7.5
TEWI (2003–2009)	12.9	11.8	14.1	22.3	19.8	18.9
TEWI (2003–2006)	6.6	7.7	10.2	10.8	−3.8	−2.5
TEWI (2007–2009)	22.0	18.8	21.3	40.6	45.3	n.a.

^aPositive trends indicate a decrease of TWS over time. Location of the areas is shown in Figure 5c.

1 Comparison TWSA of WaterGAP and GRACE in ground-water depletion areas (pers. comm. Susanna Werth 2016)



WaterGAP 2.2b

2 Use of GRACE for validation of WaterGAP total water storage TWS and groundwater storage GWS dynamics

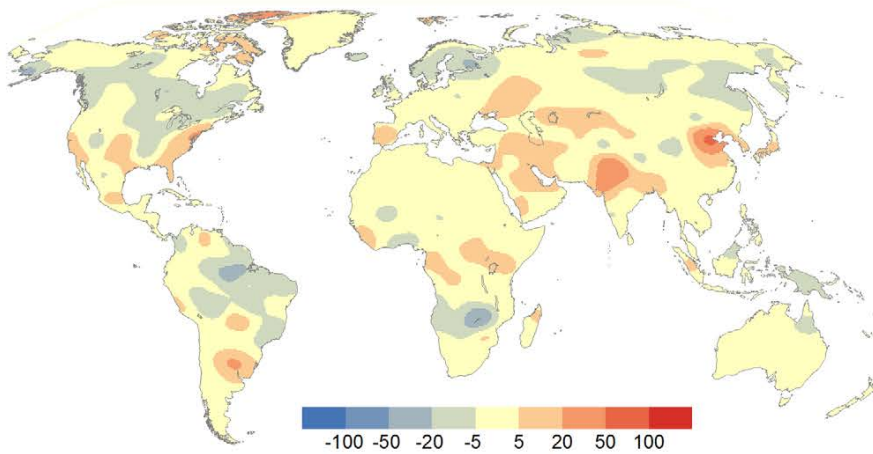
- In most areas of the globe, WaterGAP TWS **seasonal amplitudes** and **trends** are smaller than GRACE estimates (Döll Surv. Geophys 2014, Döll et al. WRR 2014)

2 Comparison of WaterGAP and GRACE TWS trends (2003-2009)

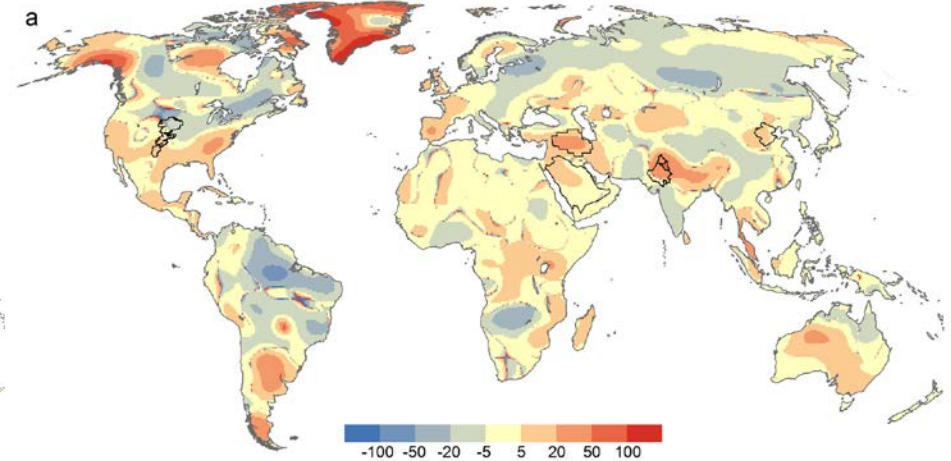
WaterGAP

GRACE

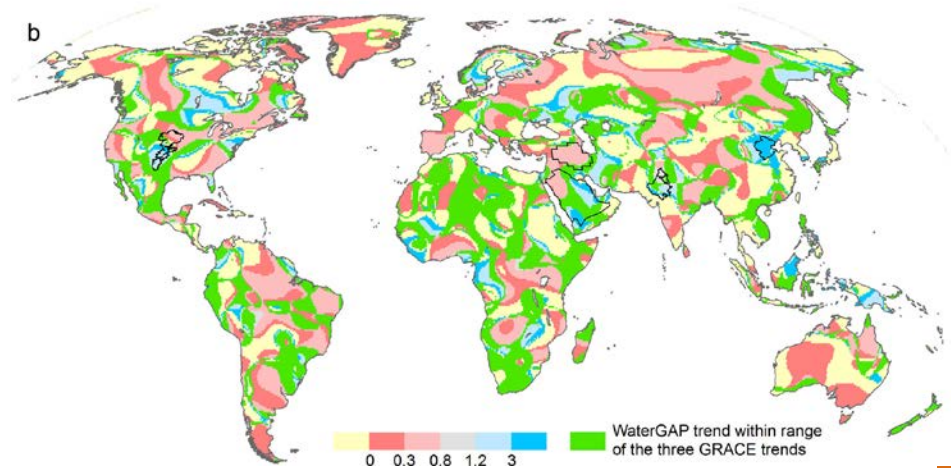
d



a



b



2 Use of GRACE for validation of WaterGAP TSW and GWS dynamics

- In most areas, seasonal WaterGAP TWS amplitudes and trends are smaller than GRACE estimates.
- **Amplitudes** are mostly dominated by soil moisture variations as well as variations in surface water body storage, and there is a phase lag between GWS and soil moisture. Difficult to discern GWS dynamics from GRACE.
- **Strong decreasing trends** in storage are likely due to GWS decrease. In case of discrepancy to WaterGAP, groundwater recharge or net abstraction of groundwater should be adjusted.

Information content of GRACE for understanding groundwater dynamics

- High information content only in areas with significant groundwater depletion
- First combined calibration and data assimilation efforts with an Ensemble Kalman Filter (University of Bonn) combining GRACE and WaterGAP show GRACE alone cannot constrain the multiple storages and parameter values in a reasonable manner,
- This should improve when adding river discharge observations (as Werth and Güntner 2010 did).