*Cold Atoms and Climate Change Workshop*

# Mapping groundwater storage change from space: how good is GRACE monitoring?


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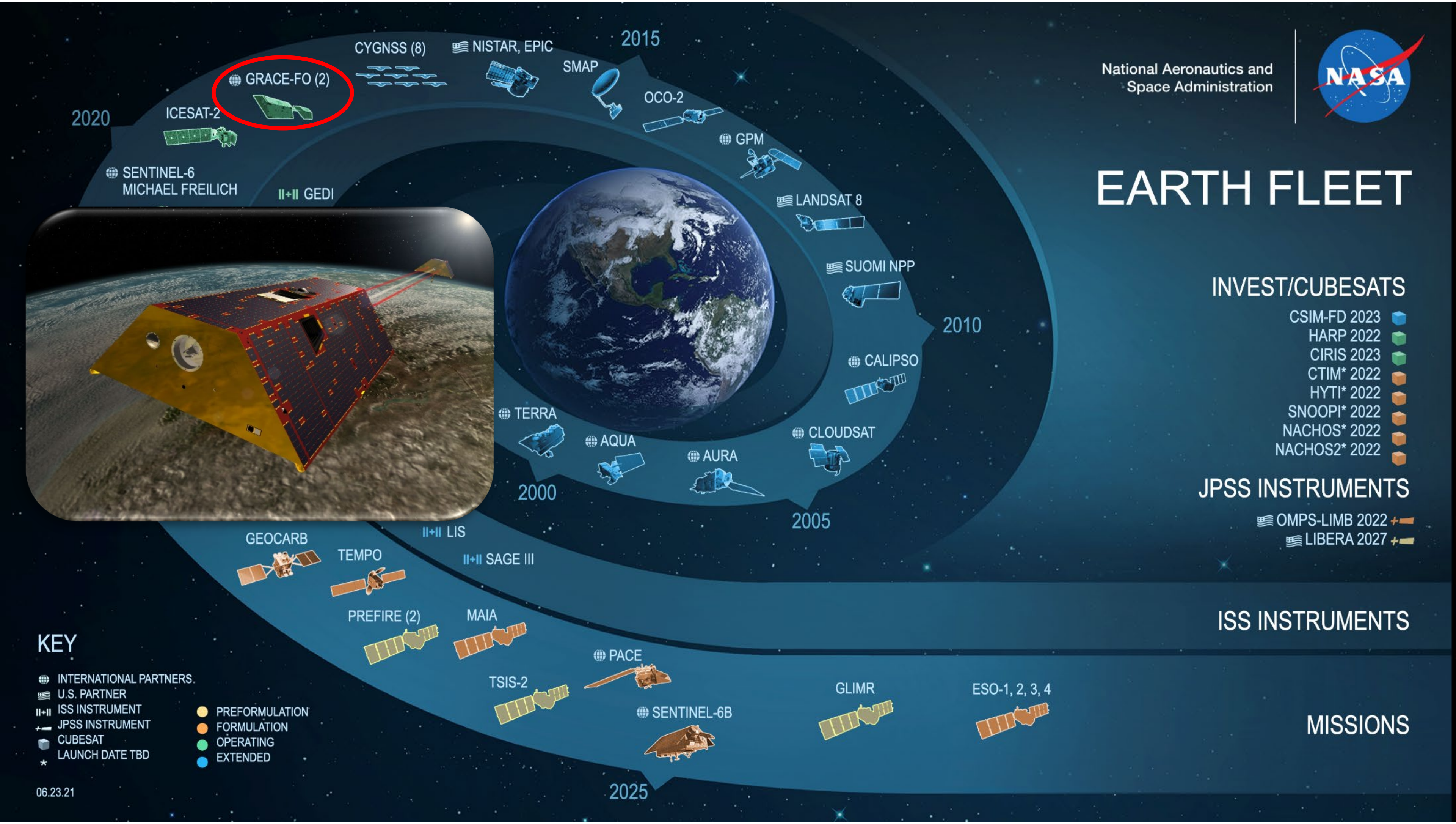
**King's College London**

14:00-14:40 | 22nd March 2022

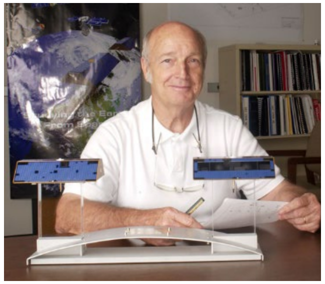
# Earth Observation Satellites and GRACE Mission




NASA Earth Observation Satellite Missions (October 2021)

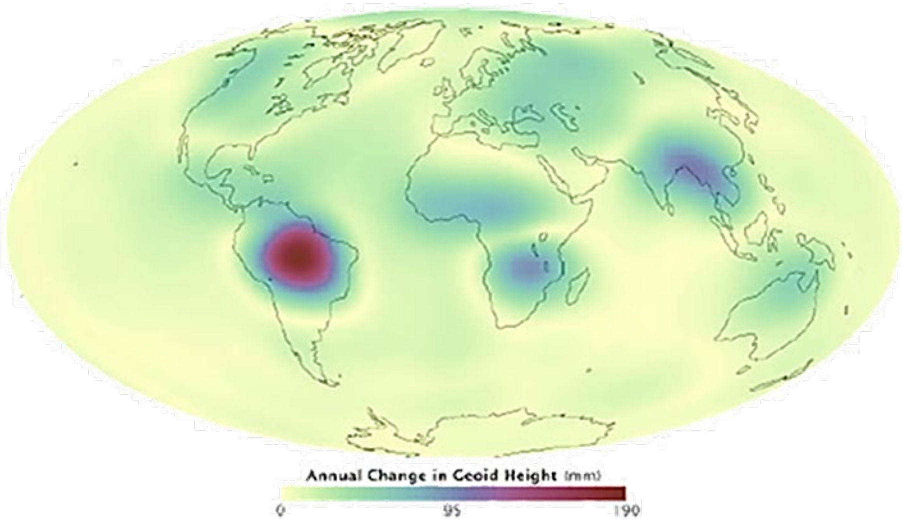
## The emergence of satellite gravimetry: GRACE

*"The first thing I tackled in the 1970s was the task of computing the orbits of satellites very accurately to support satellite altimetry missions. We reached the point that we could compute orbits that had an accuracy of a few centimeters"* – **Professor Byron Tapley**



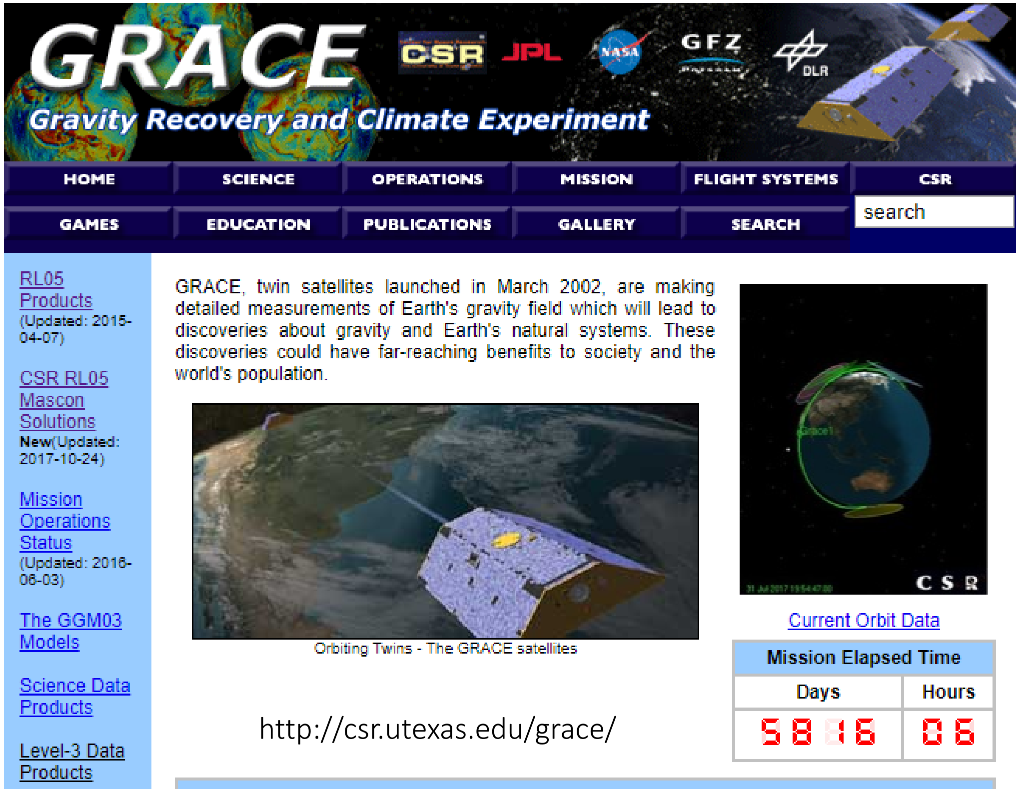
**Tapley's computations soon hit a glitch that he couldn't fix! He observed that the satellite orbits varied seasonally.**

- *These subtle shifts in Earth's gravity occur primarily due to movement of water mass from one place to another on and under land, in the ocean, and in the atmosphere*
- *Only satellite could measure these subtle, tiny shifts accurately enough to map Earth's gravity in fine detail*



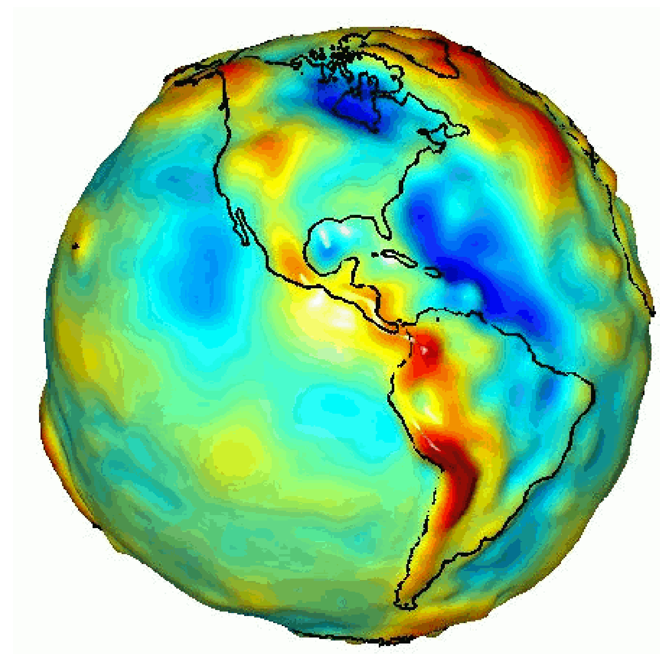

**The GRACE mission was led by Brian Tapley (PI) of the University of Texas at Austin (USA) and Frank Flechtner (Co-PI) of the German Research Centre for Geosciences (GFZ)**

# GRACE: Gravity Recovery and Climate Experiment

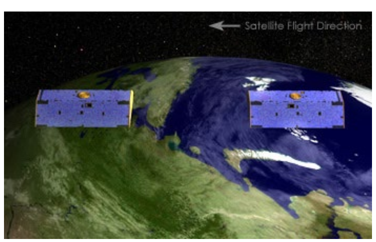



**~16 Years**

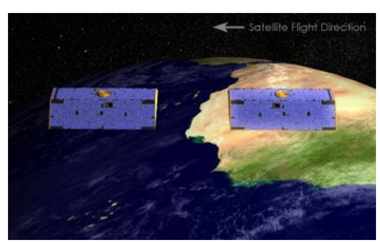
## Gravity model from GRACE satellites



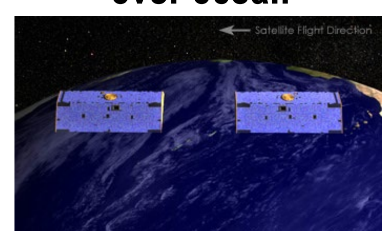
**approaching land**




**leaving land**

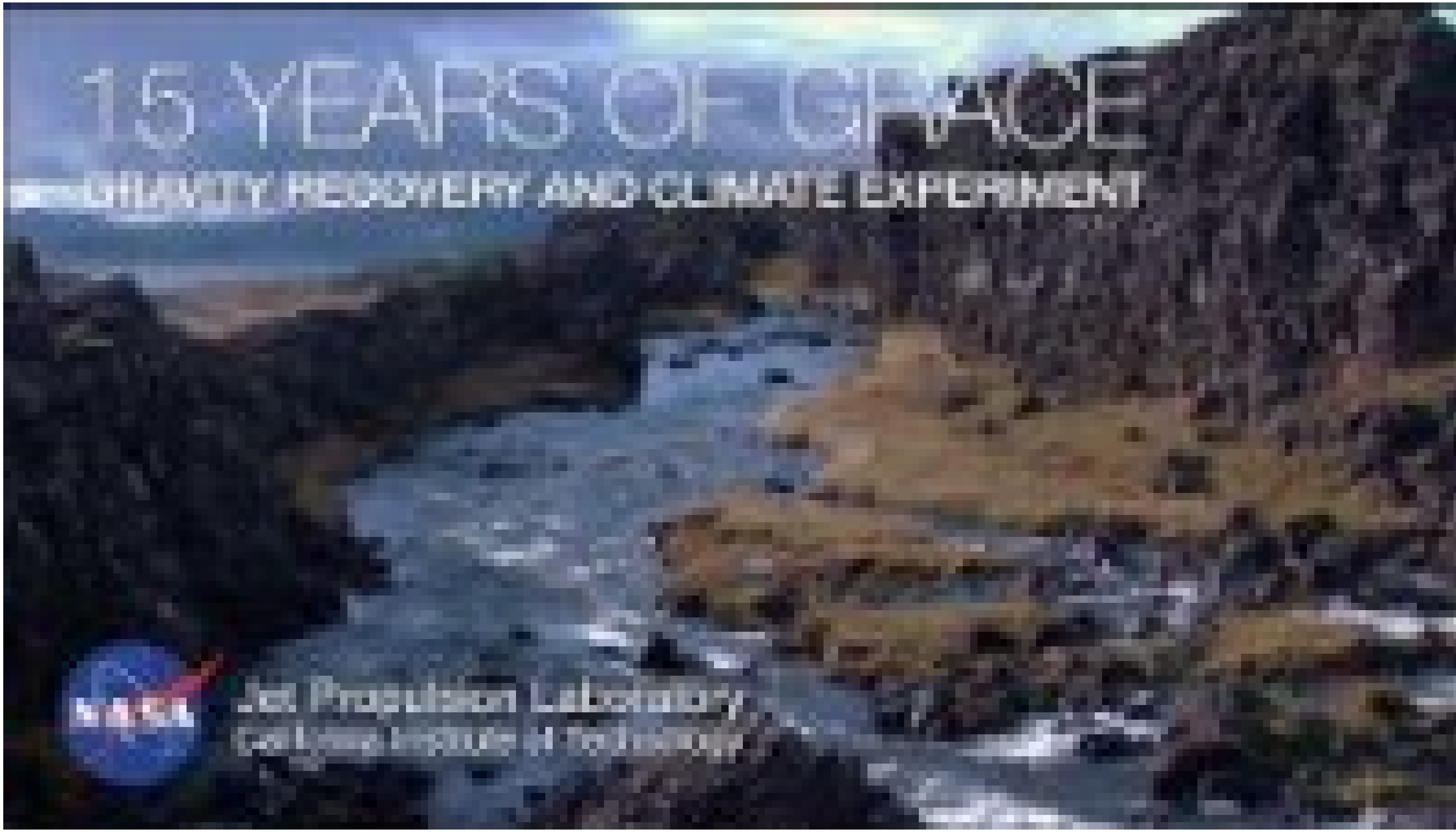



**over ocean**




http://earthobservatory.nasa.gov/

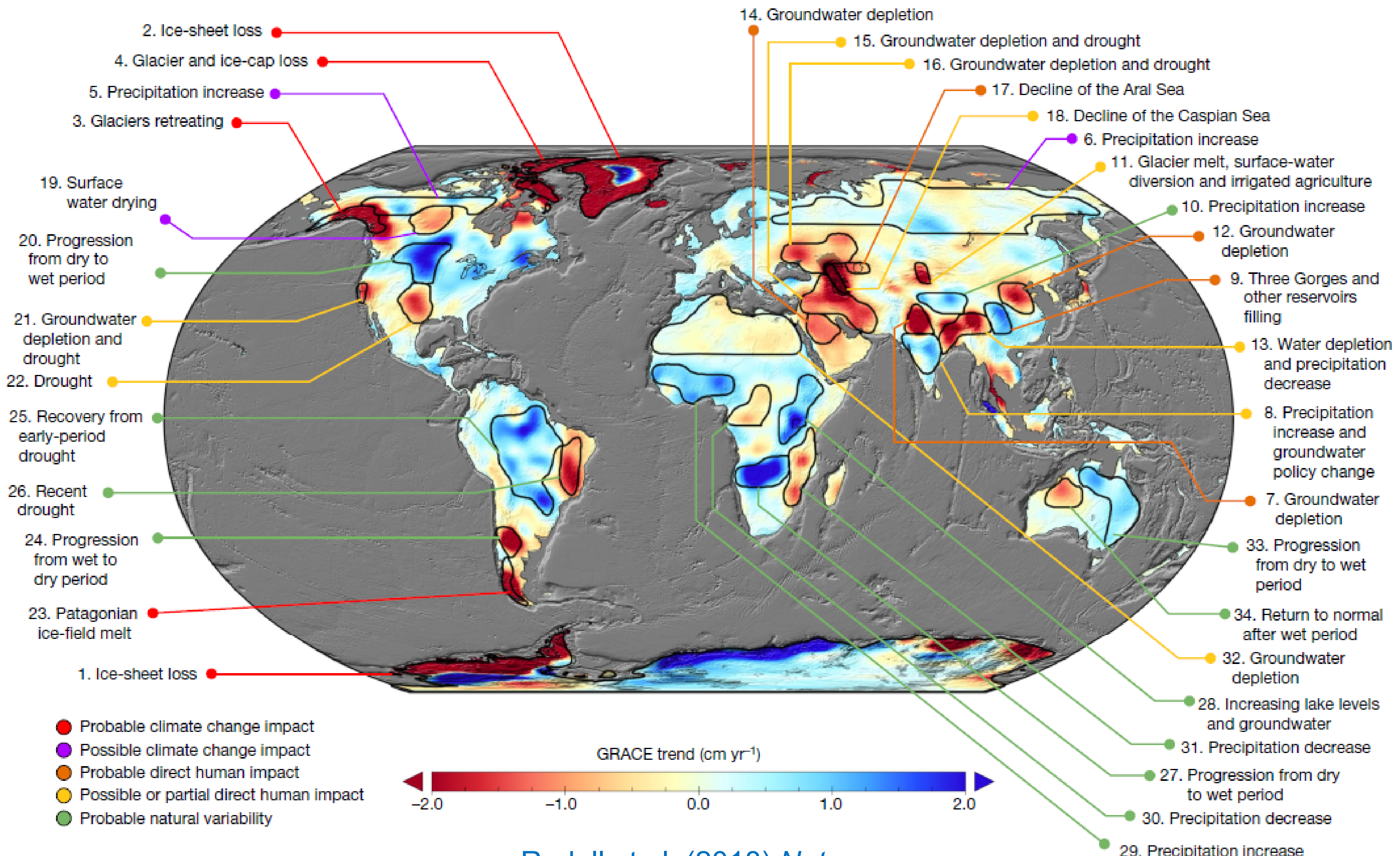
# GRACE: Gravity Recovery and Climate Experiment




https://www.youtube.com/embed/fKVPFyu_tHQ

# Trends in Global Terrestrial Water Storage

## Trends in total terrestrial water storage (TWS), including groundwater, soil water, lakes, snow, and ice, as observed by GRACE over 2002-2016

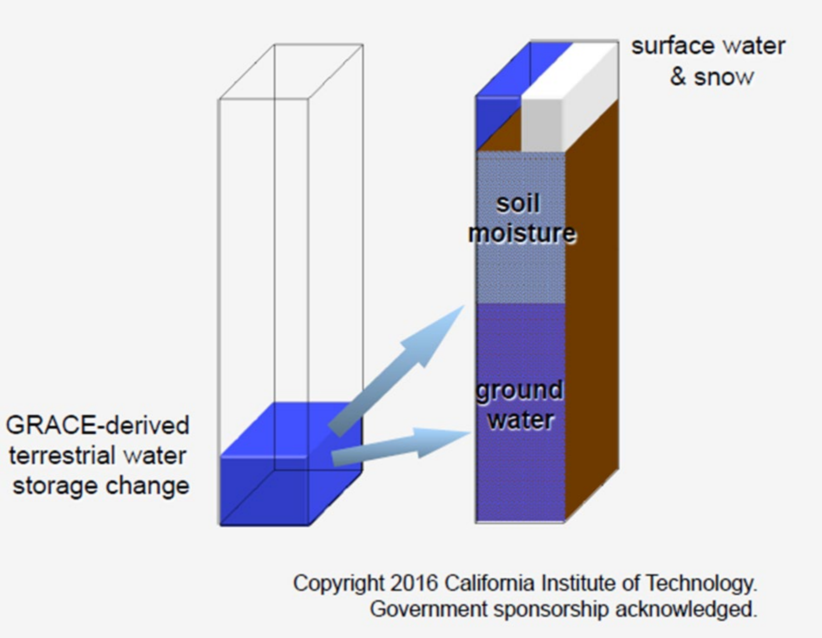



Rodell et al. (2018) *Nature*

# GRACE and groundwater storage change

$$\Delta TWS = \Delta ISS + \Delta SWS + \Delta SMS + \Delta GWS$$

- GRACE mass changes represent <u>total terrestrial water storage</u> changes <u>(ΔTWS)</u> after removing atmospheric mass variations and ocean tides




$$\Delta GWS = \Delta TWS - [\Delta ISS + \Delta SWS + \Delta SMS]$$

- **How good is the estimation of ΔGWS from GRACE measurements?**

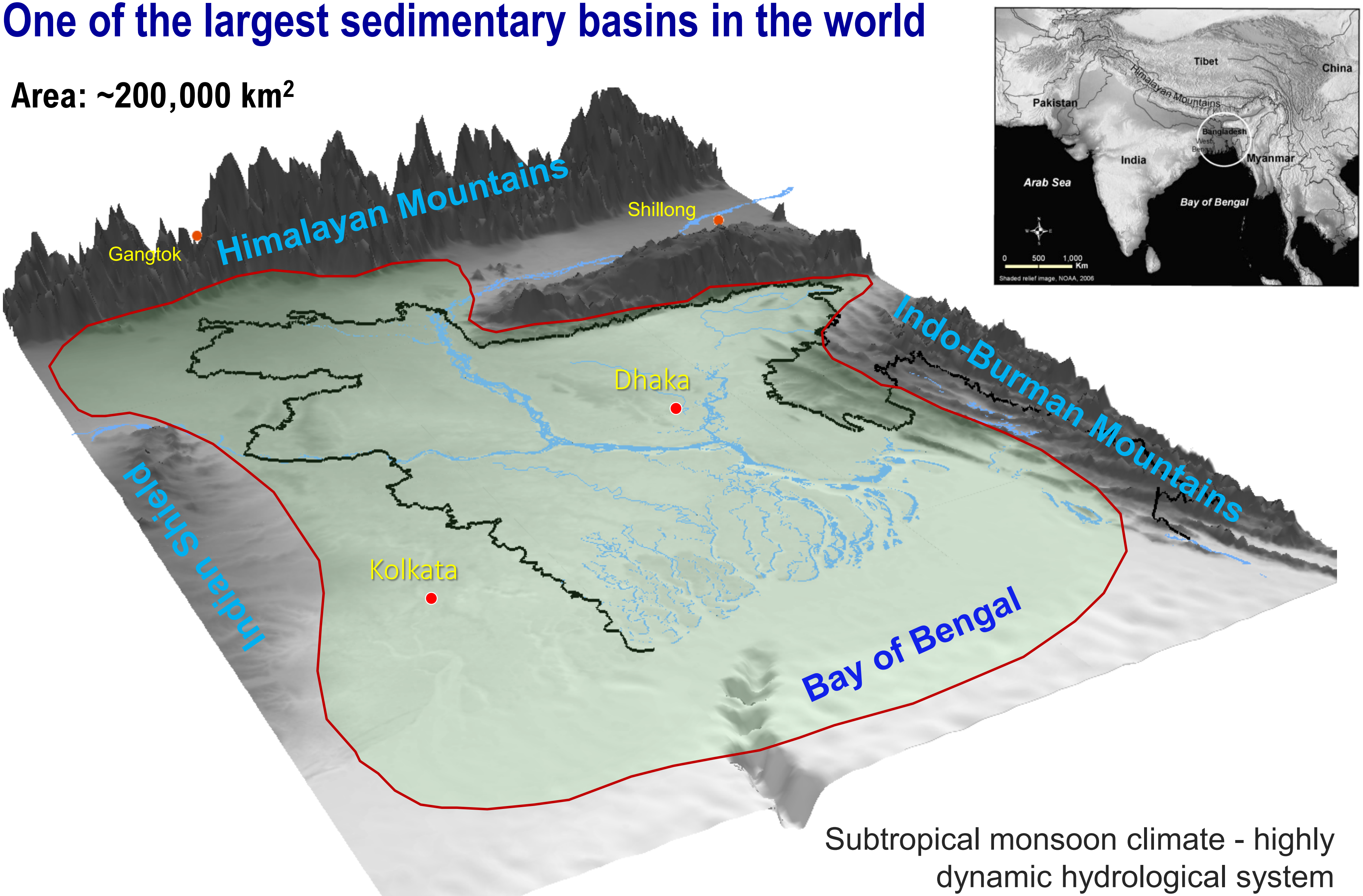

Monitoring groundwater storage changes in the highly seasonal humid tropics: Validation of GRACE measurements in the Bengal Basin

M. Shamsudduha, R. G. Taylor, L. Longuevergne

First published: 10 February 2012 | https://doi.org/10.1029/2011WR010993 | Citations: 131

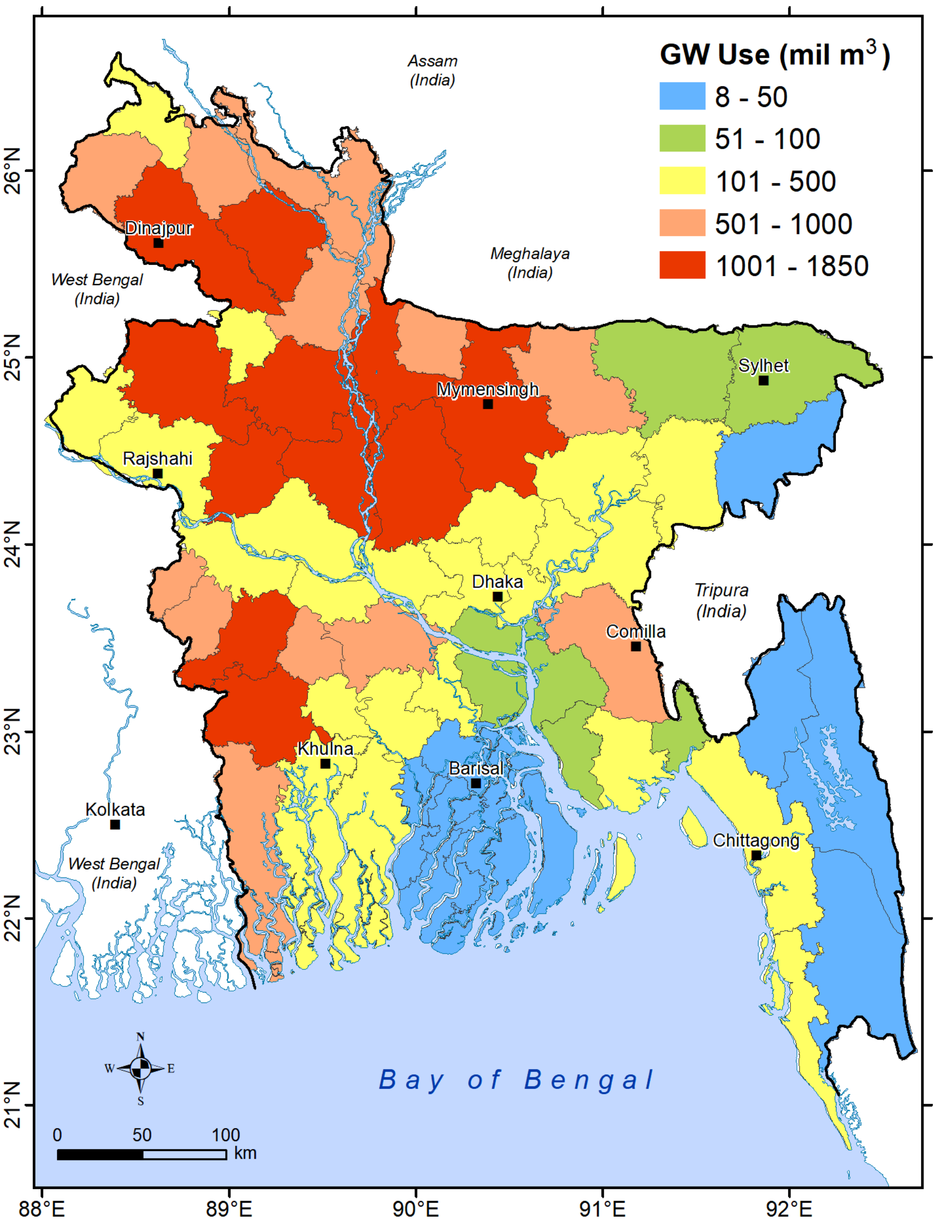
# One of the largest sedimentary basins in the world

**Area: ~200,000 km$^2$**




Subtropical monsoon climate - highly dynamic hydrological system

# Why is monitoring of groundwater so important?





## Bangladesh

**Population 160+ million**

**Groundwater-fed drinking water: 90%**

**Groundwater-fed irrigation: 80%**

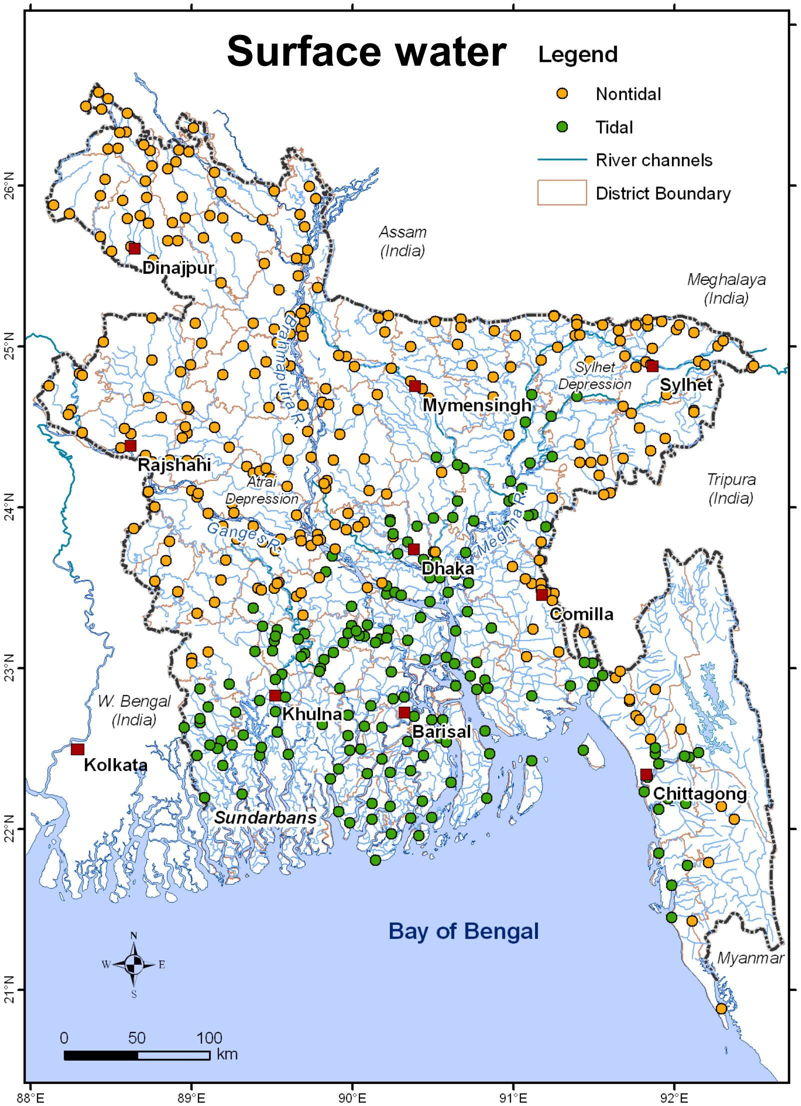
**Total Annual Groundwater Withdrawal: 32 km³**

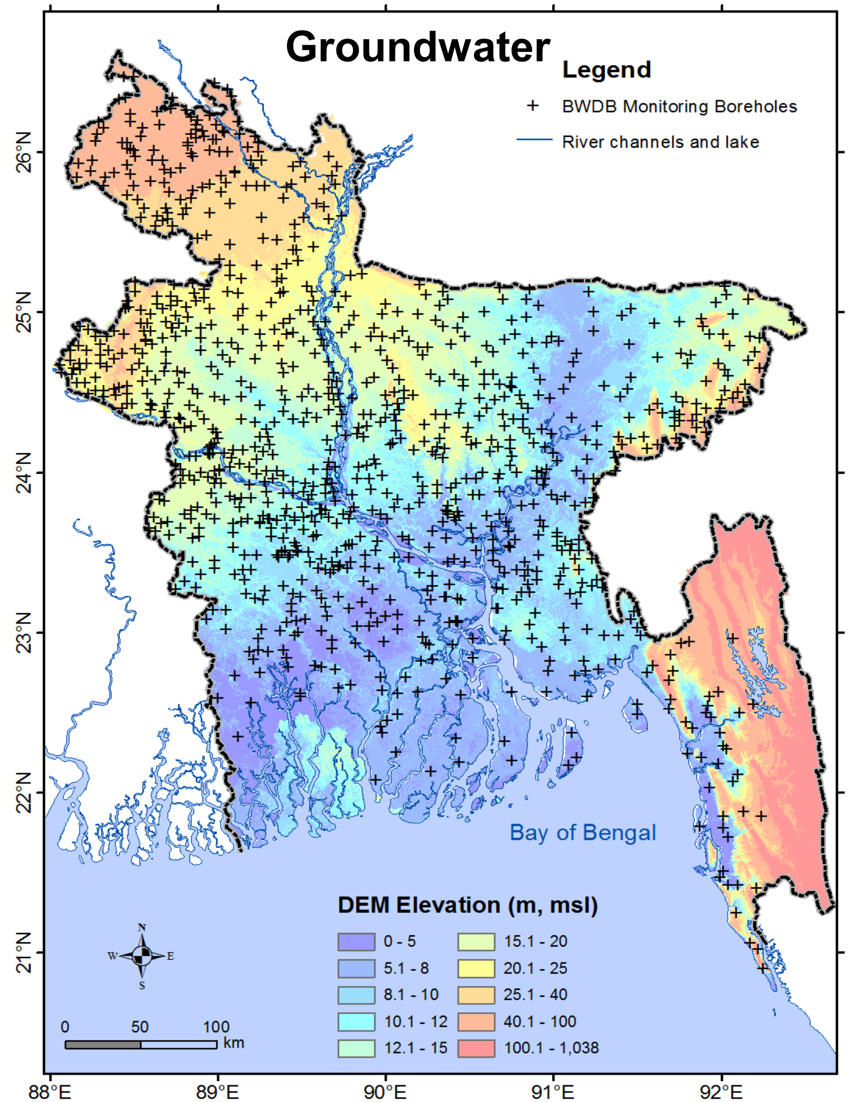
**Global GW use**
**600–800 km³ year⁻¹**

Shamsudduha et al. (2019)

# Bengal Basin of Bangladesh: a natural laboratory

## Dense networks of surface water and groundwater monitoring stations



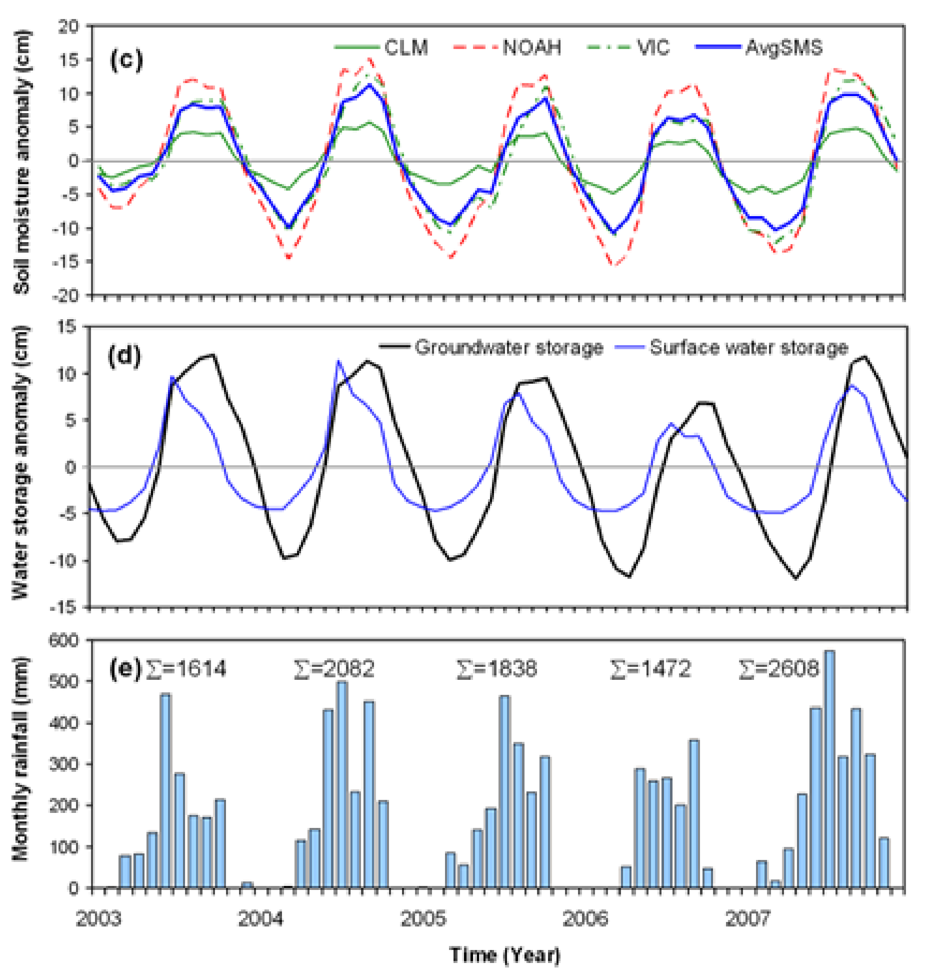



# GRACE $\Delta GWS = \Delta TWS - [\Delta ISS + \Delta SWS + \Delta SMS]$

## Datasets used in the study of ΔGWS in the Bengal Basin:

- ΔGWS & ΔSWS constrained by in-situ observations from 236 & 298 monitoring stations

- ΔSMS constrained by simulated soil moisture data from 3 LSMs: CLM, NOAH, VIC



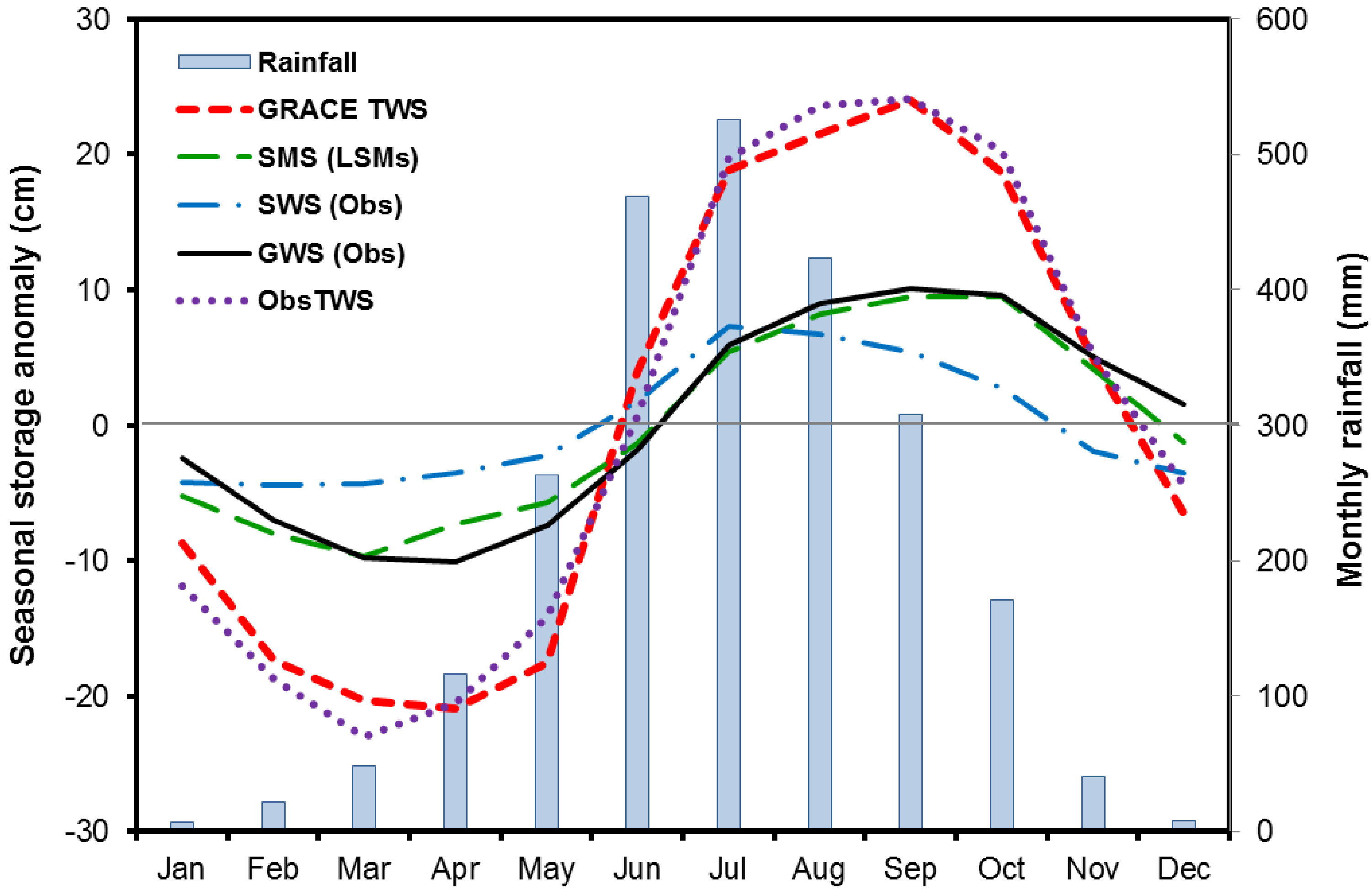

Shamsudduha et al. (2012)

Background picture shows irrigation of Boro rice in Bangladesh

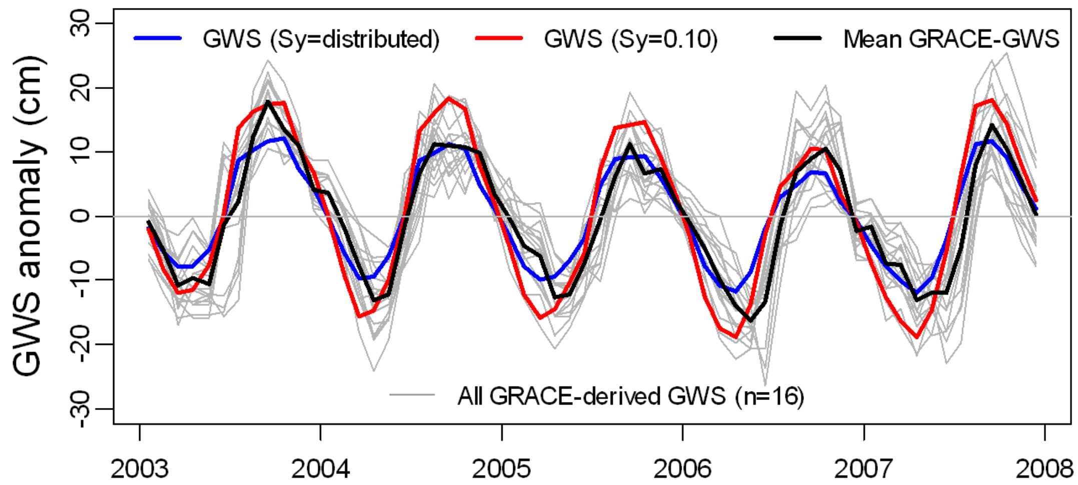
# Groundwater storage change in the Bengal Basin

$$\Delta GWS = \Delta TWS - (\Delta SWS + \Delta SMS + \Delta ISS)$$

Observed GRACE Observed LSMs (GLDAS) Nil



# Validation of GRACE-derived ΔGWS



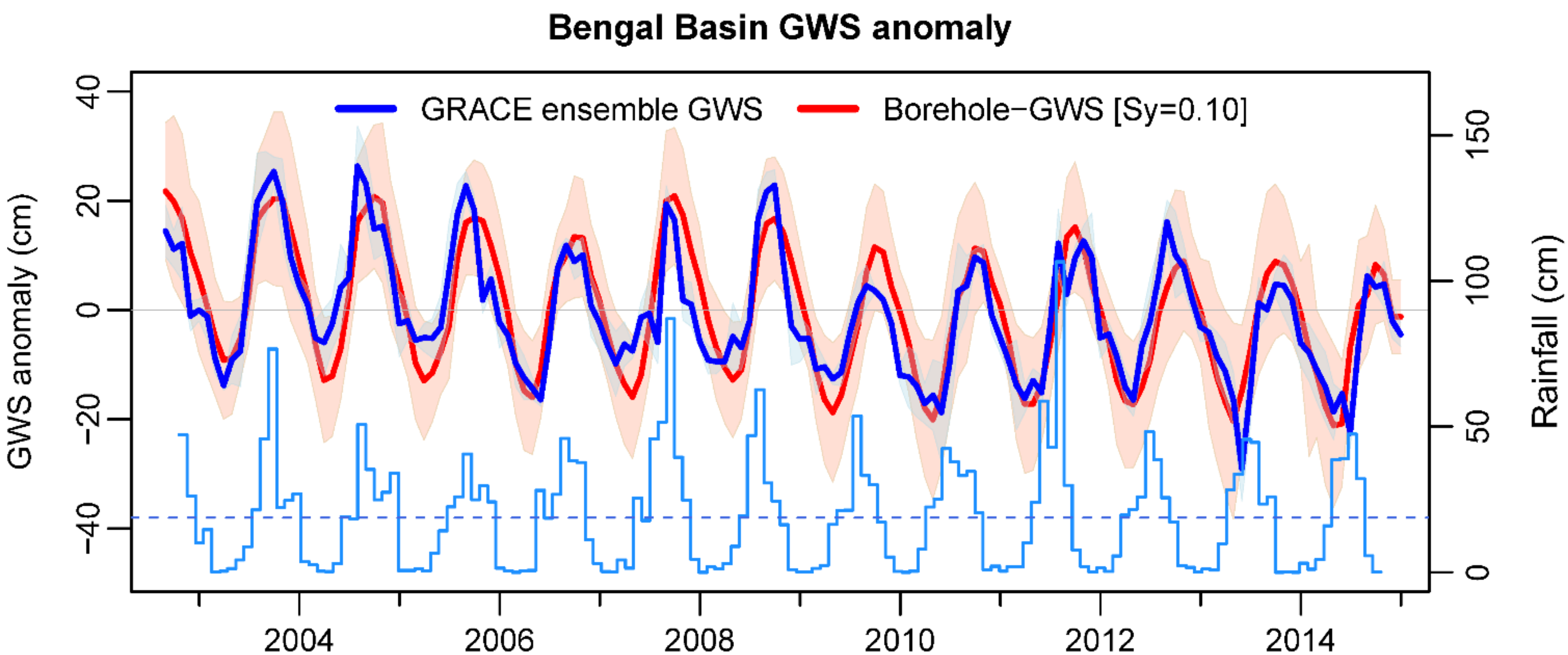

**GRACE data:** CSR and GRGS

**SMS data:** NOAH, VIC, CLM

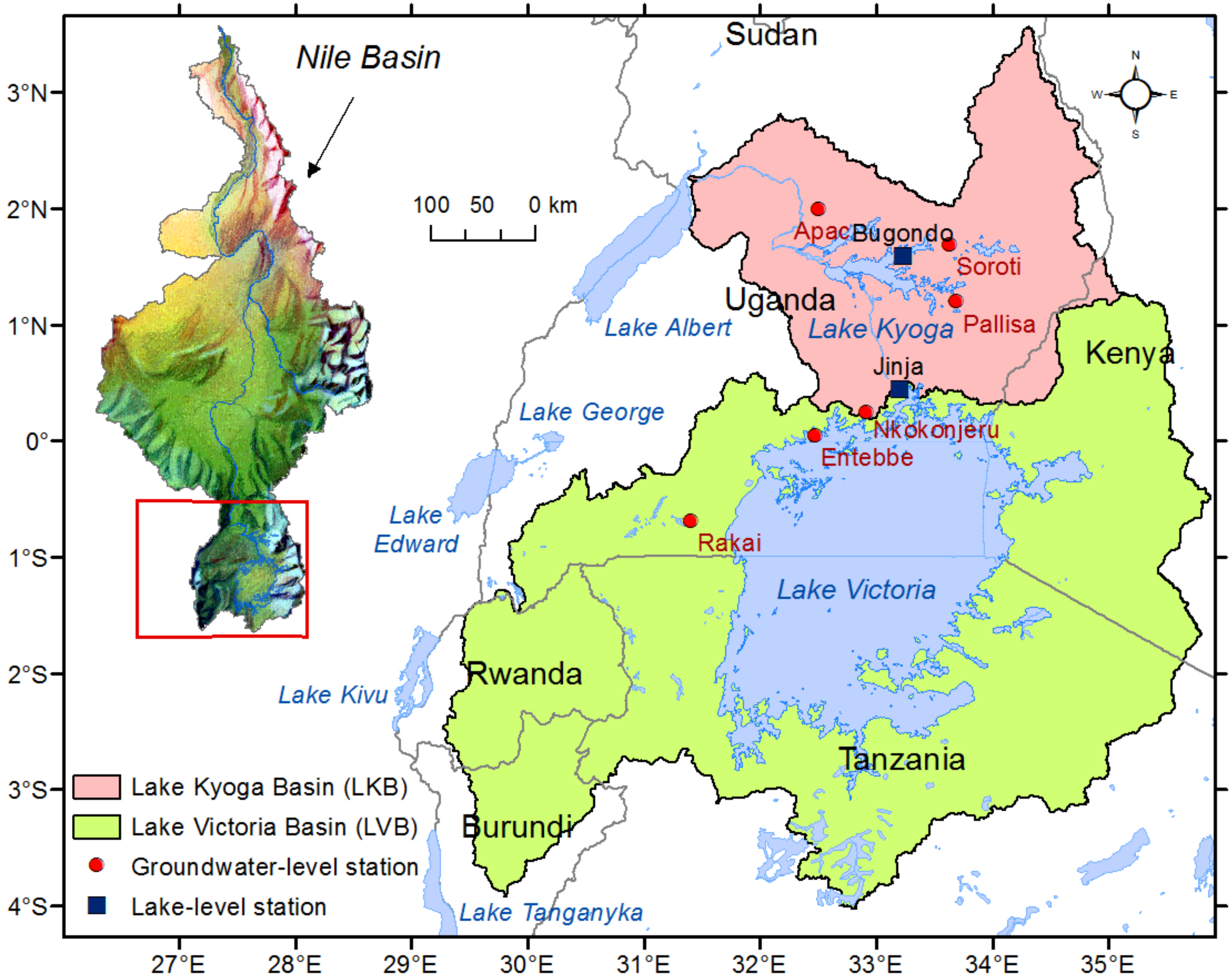
**SWS data:** observational

**GWS data:** observational

Shamsudduha et al. (2012)

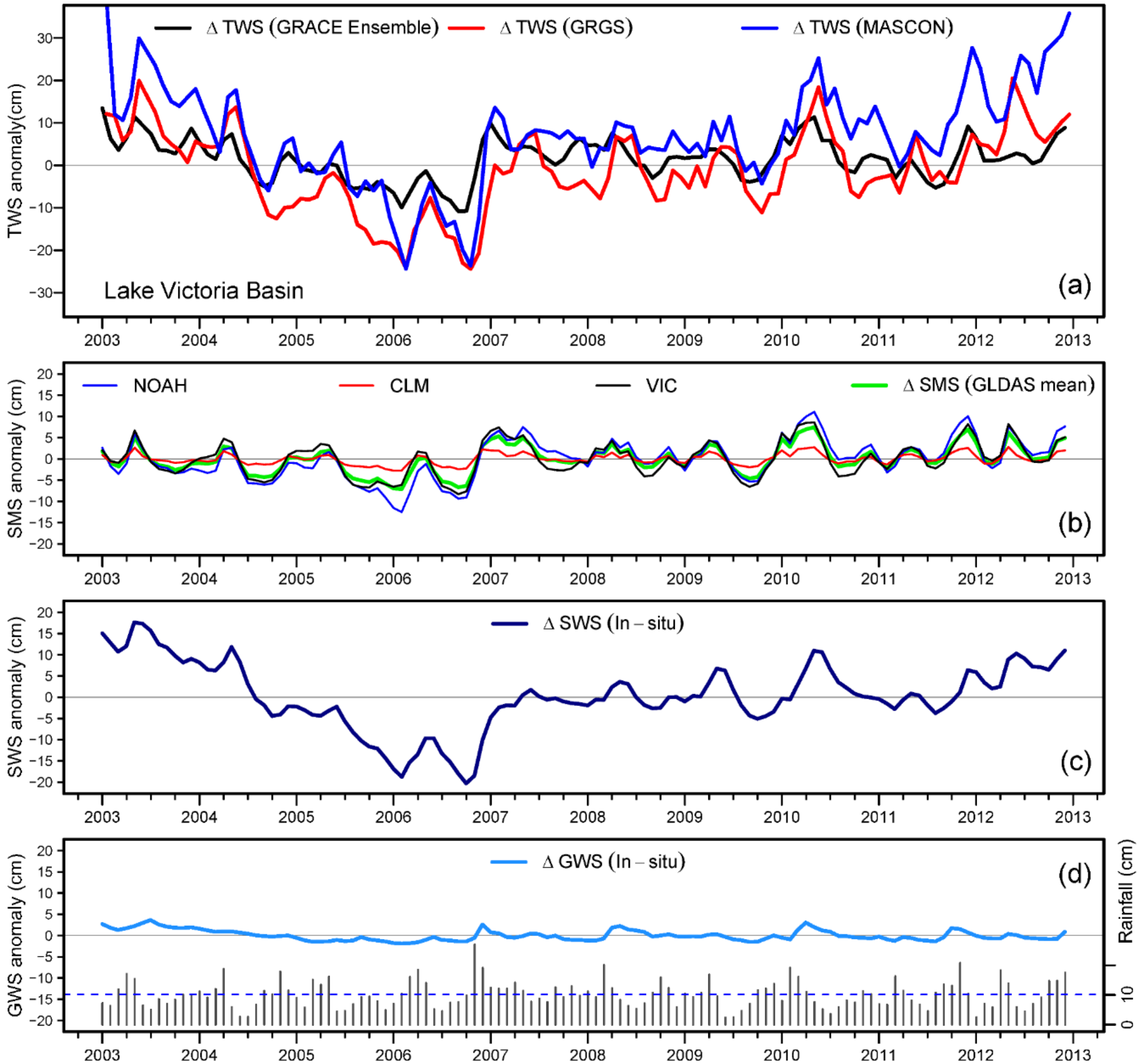


# Estimating GWS changes in Nile Basin from GRACE

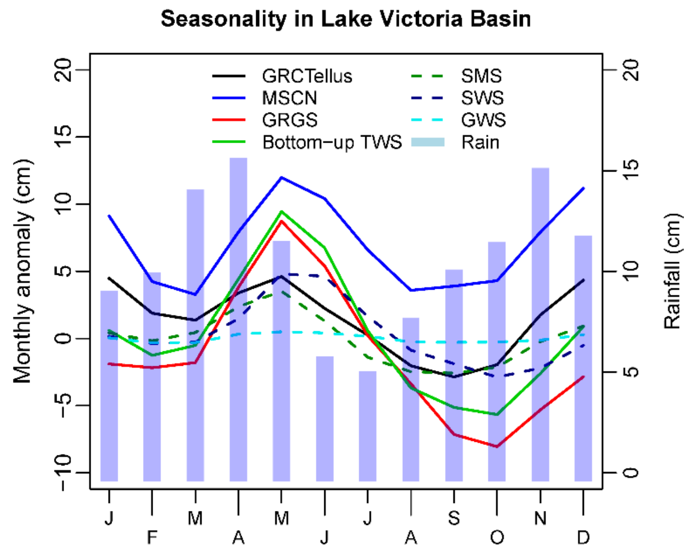



Shamsudduha et al. (2017)

# Estimating GWS changes in Nile Basin from GRACE



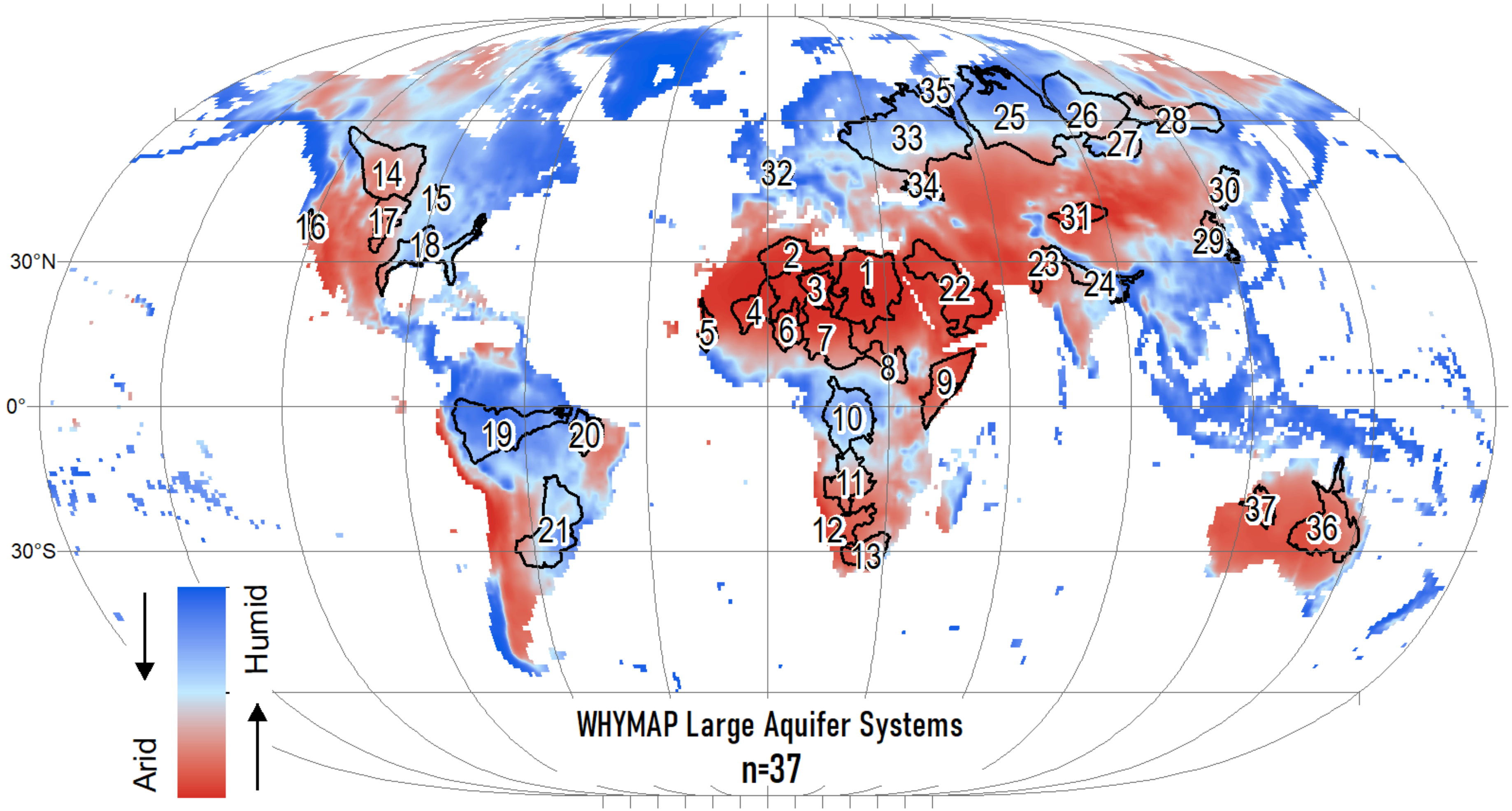

Shamsudduha et al. (2017)




- **Computed contributions of ΔGWS to ΔTWS in the Upper Nile Basin are low (<10%)**
- **GRACE-derived estimates of ΔGWS from all three products (GRCTellus, GRGS, and JPL-Mascons) correlate very weakly with in-situ ΔGWS in both the LVB and LKB**

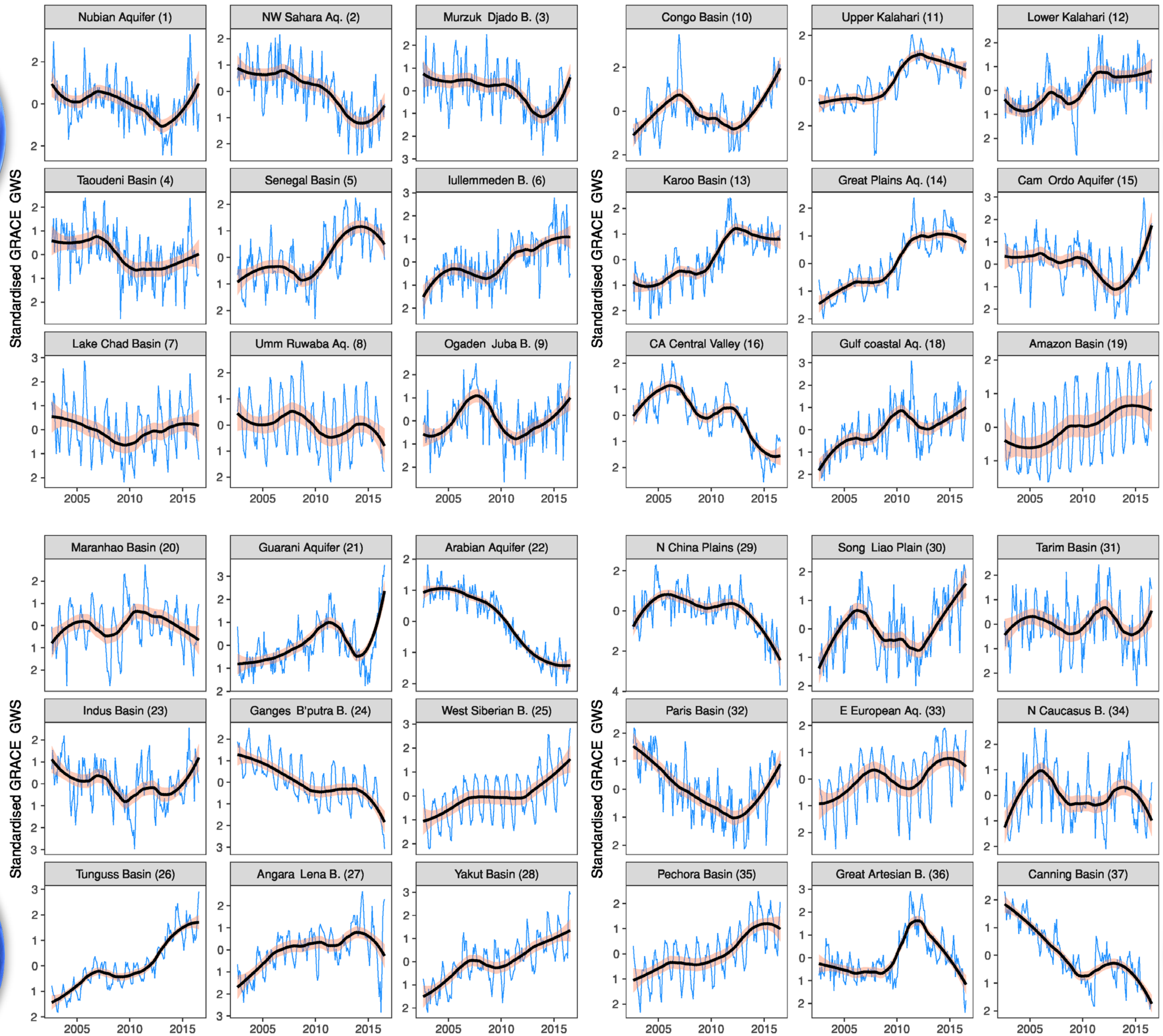
# GRACE-GWS in world's mega aquifer systems

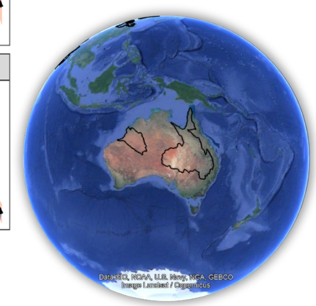
## GRACE-derived ΔGWS in 37 Mega Aquifer Systems




Shamsudduha and Taylor (2020)

# GRACE-GWS in world's mega aquifer systems

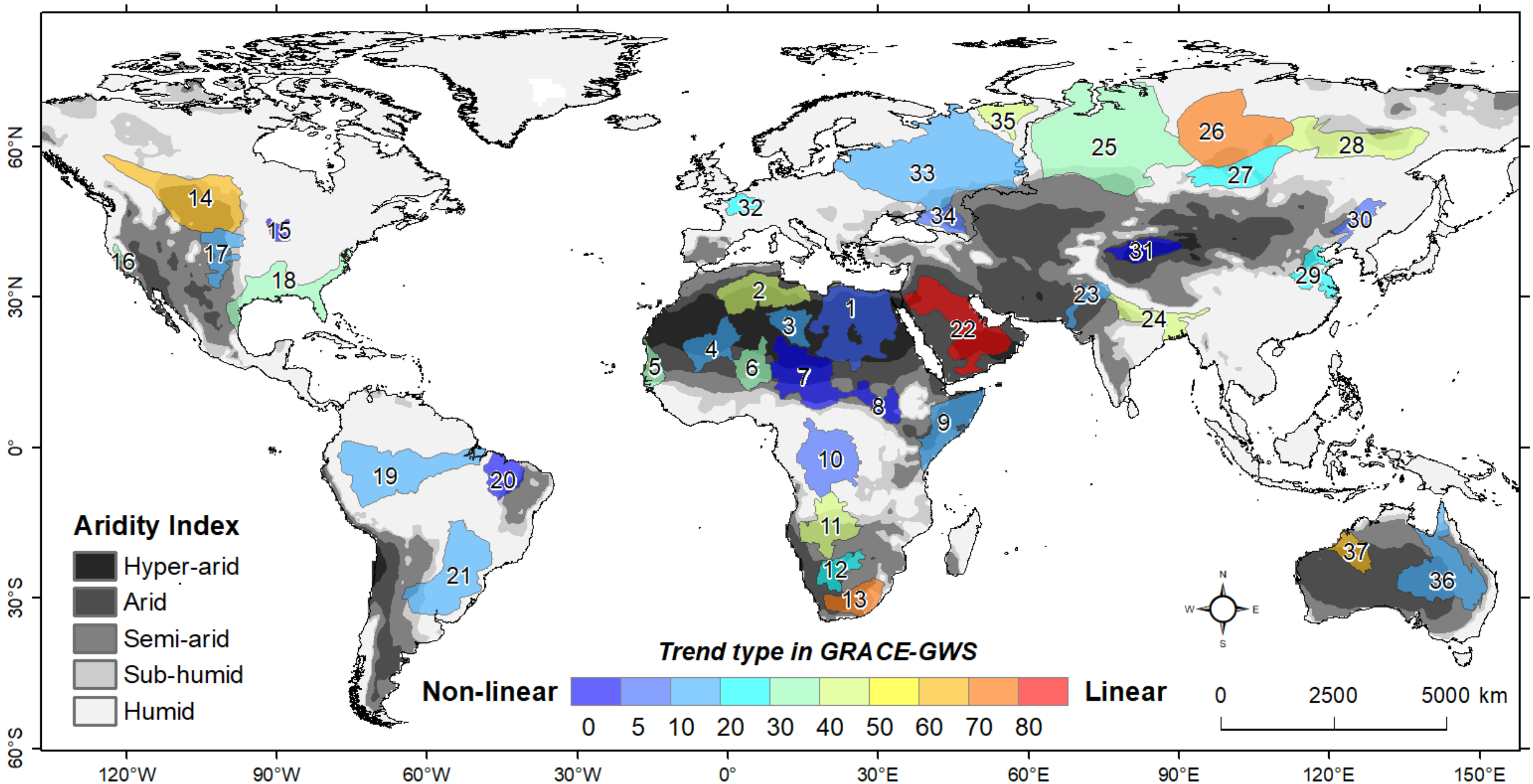


Shamsudduha and Taylor (2020)

# GRACE-GWS in world's mega aquifer systems

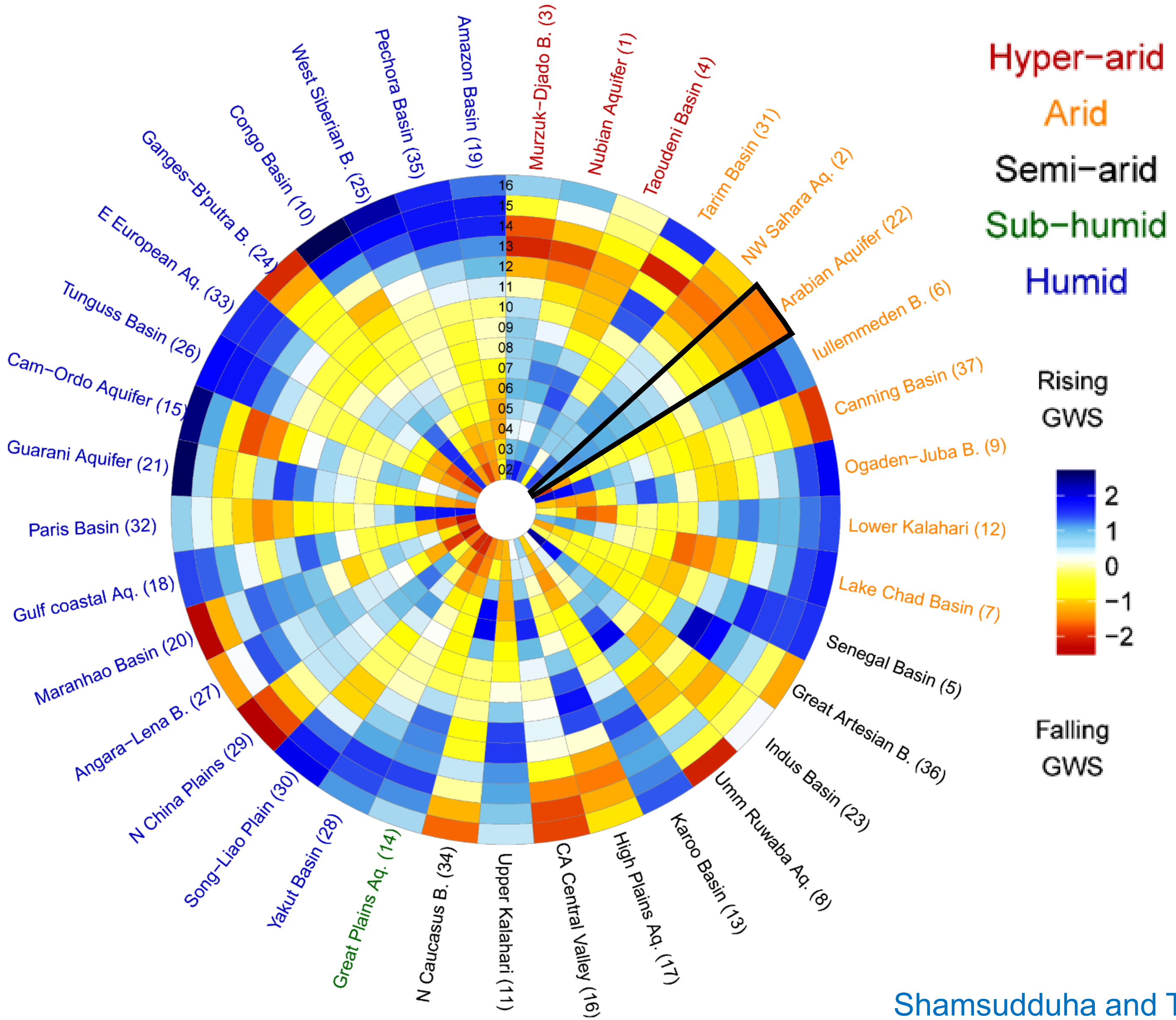
## Trends in GRACE-derived ΔGWS in 37 Mega aquifer systems




**Trends are predominantly non-linear**

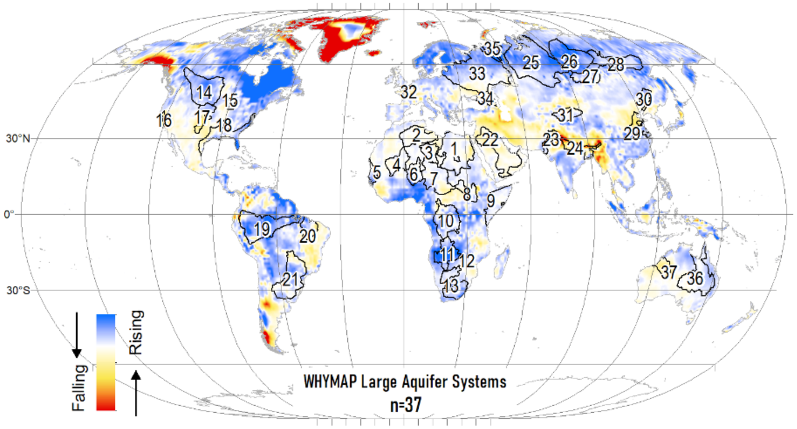
Shamsudduha and Taylor (2020)

# GRACE-GWS trends in the 37 mega aquifer systems



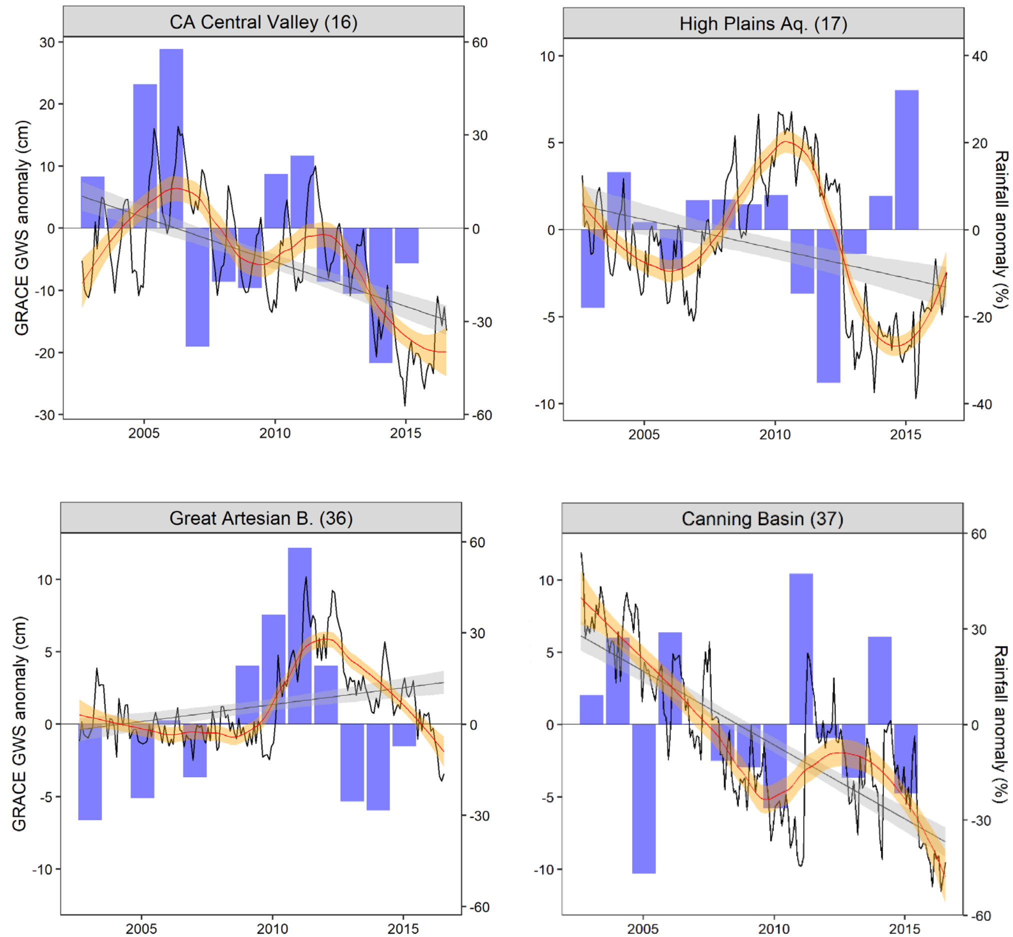

Shamsudduha and Taylor (2020)

# Extreme precipitation helps replenish groundwater systems




*GRACE-derived GWS trends (cm/year)*

**Period: Aug 2002 to Jul 2016**




- **GRACE-derived ∆GWS trends represent a reasonable picture of GWS dynamics across the globe – there are also areas of uncertainties**
- **GRACE-derived ∆GWS time-series data show that trends are not predominantly linear – extreme precipitation interrupts declining trends – thus raising question of GW sustainability based on linear trends**

Shamsudduha and Taylor (2020)

# How good are GRACE measurements for GWS mapping?

Decomposition of GRACE TWS signal into GWS is challenging as 'reliable' data on individual components (i.e., soil moisture and surface water storage) are not available – left with no option but to use uncalibrated/untested global land surface (i.e., GLDAS LSMs) or hydrological models

GRACE TWS signal (i.e., spherical harmonics) is often smoothed due to spatial filtering but subsequently amplified using 'scaling factors' that are primarily derived from unconstrained global-scale land-surface or hydrological models

In many areas around the world, there remains no dedicated monitoring network of groundwater, soil moisture and surface water storage changes – making it challenging to validate GRACE-derived estimates of GWS

One of the biggest limitations is the footprint or spatial scale – GRACE satellite footprint is ~100,000 $km^2$ and, thus, the application of GRACE measurements in smaller aquifer/basin is highly uncertain

GRACE provides basin-scale information – not appropriate or useful for groundwater management which is often done at localised/catchment scale

# GRACE footprint vs borehole-scale information/data