Satellite Observations and Modelling of Space Geodetic Data for Terrestrial Applications

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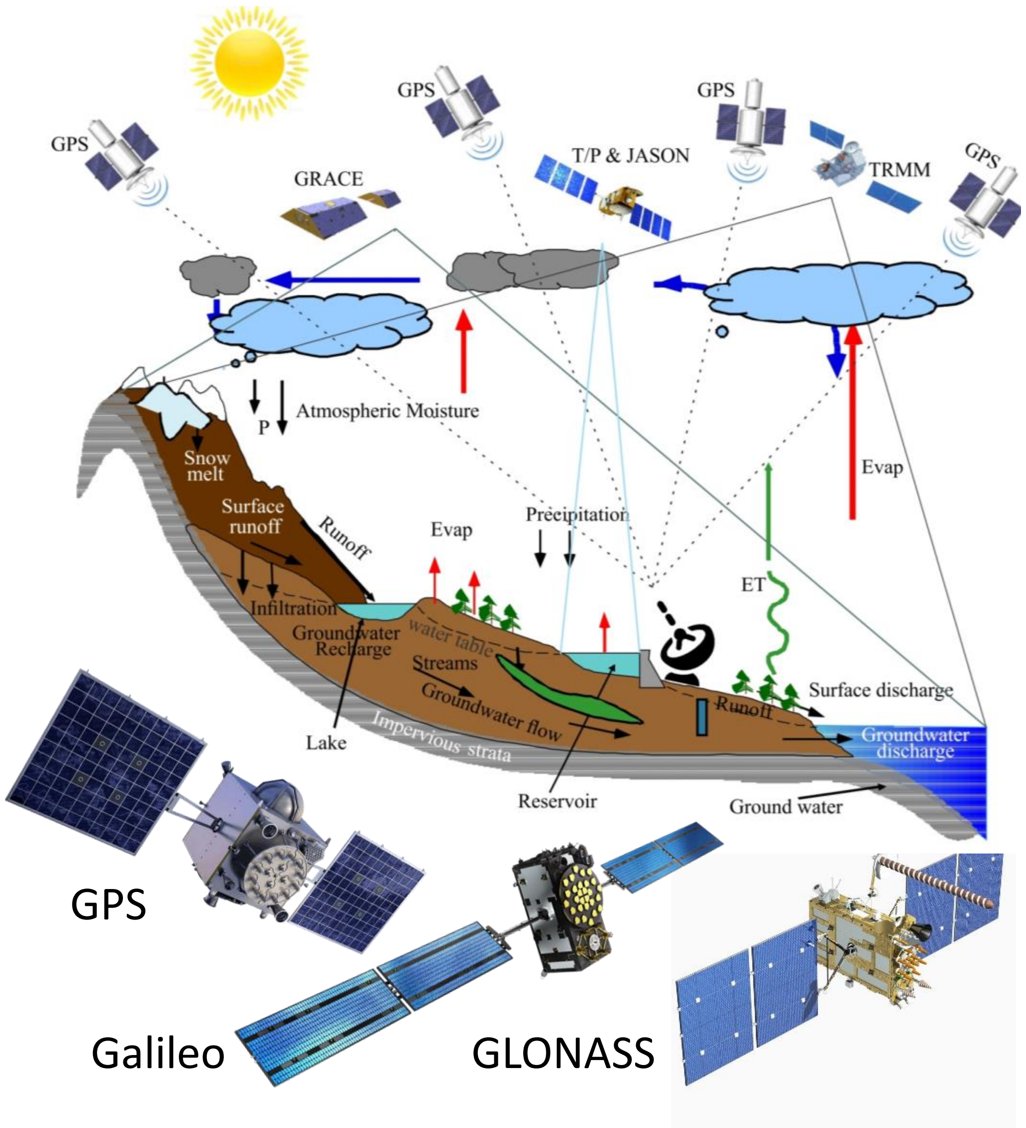
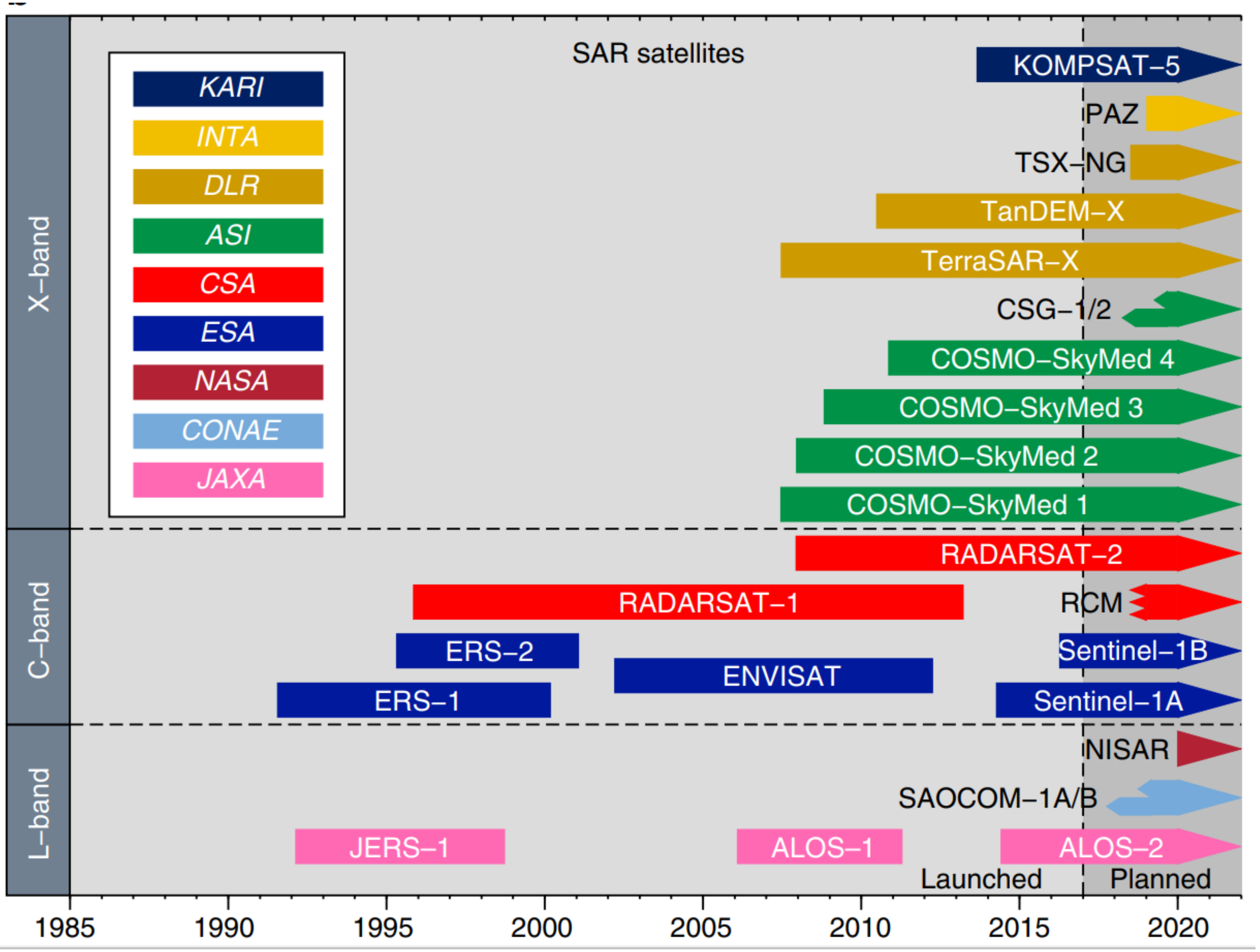
Satellite Geodetic Missions



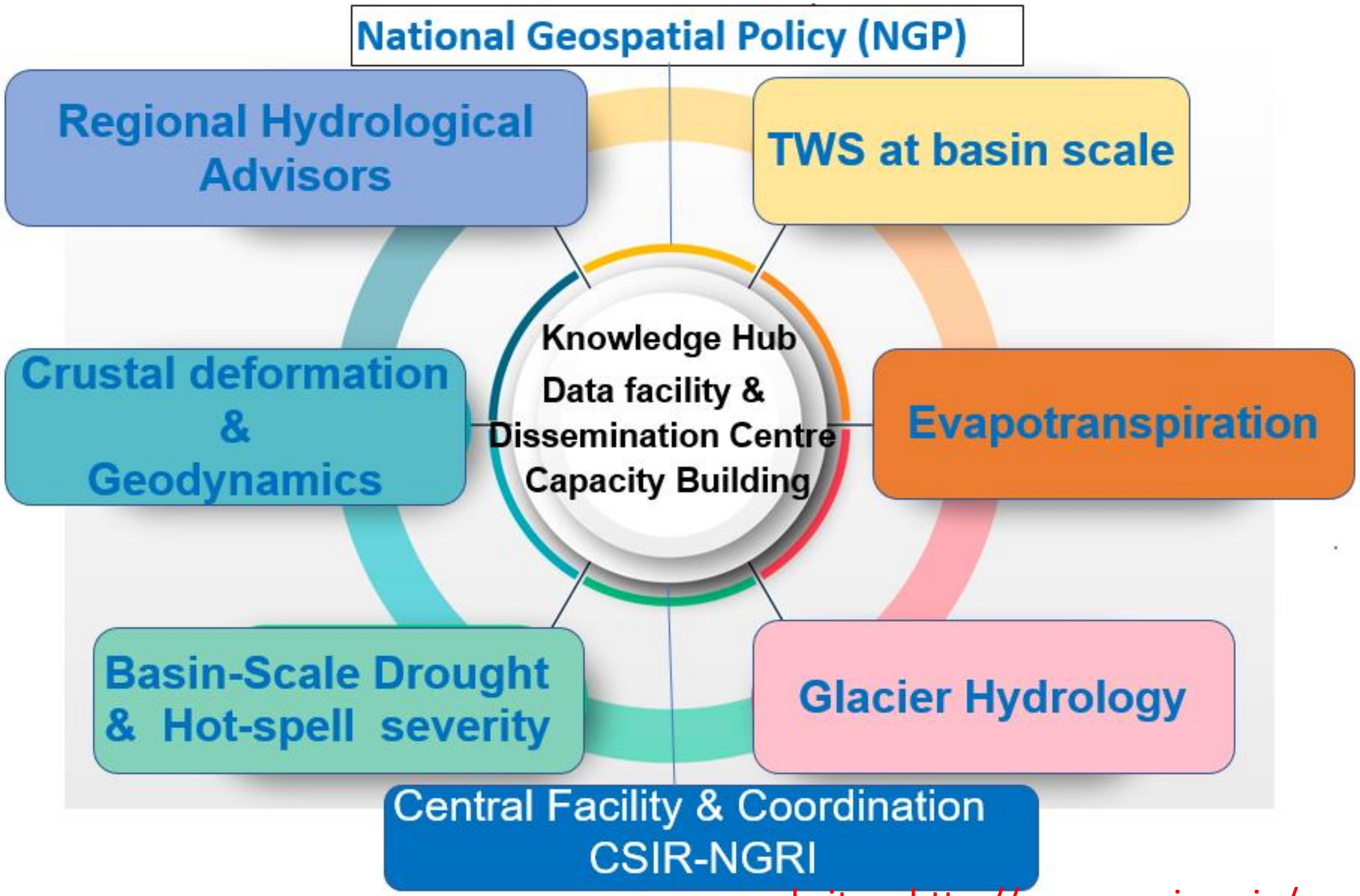


J.R. Elliott, 2016, Nature Communications

National Network Project

Assessment of Regional Hydrological Systems using Space Borne Gravity Observations

(Multi Disciplinary, Multi Institutional Research Project, As part of NGP,DST Govt. of India)



website : http://grace.ngri.res.in/

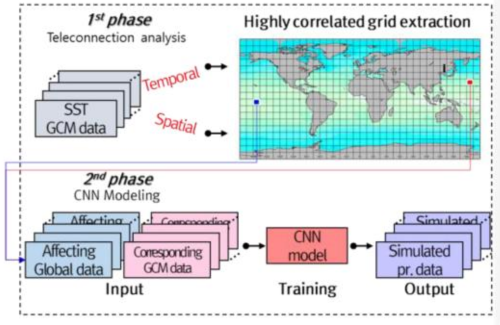
Uniqueness

- ❑ **Combination of the architecture and data framework and the capacity building strategy of GRACE Network project.**

- ❑ **A cooperative implementation body by linking science community, space agencies, and water-related decision makers.**

- ❑ **Strategic approaches by shifting scientific achievements to operational use dedicating to the societal benefits.**

- ❑ **Sharing advanced data infrastructure and downscaling methods for bridging between global data and local information.**

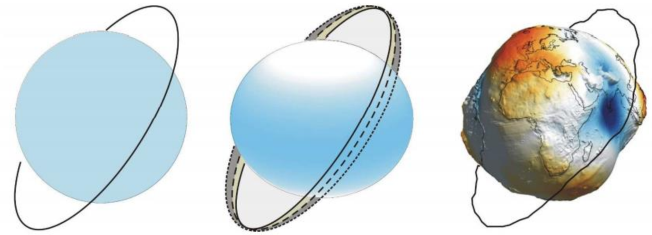


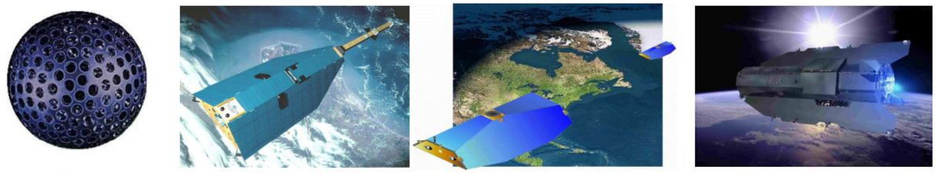
Satellite Geodetic Missions (Gravity)

➢ **Gravity satellites**

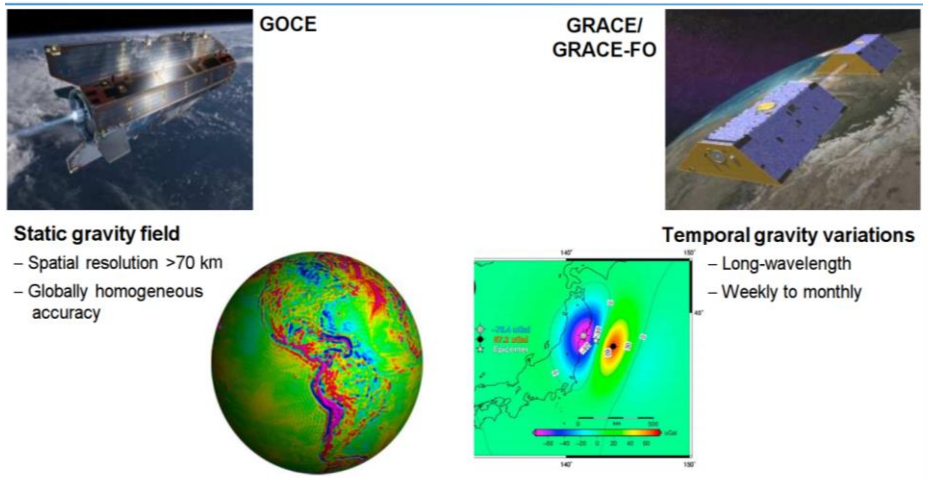
Gravity from:

- satellite orbits
- satellite orbit differences
- acceleration differences (direct gravity functional)





SLR CHAMP GRACE / GRACE-FO GOCE



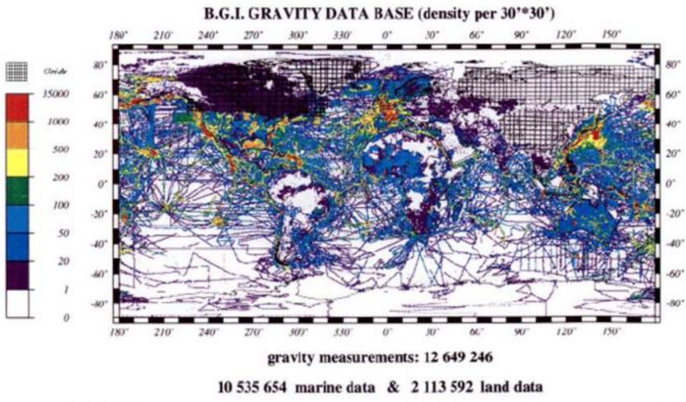
STATIC / TIME VARYING GRAVITY FIELD

➢ **Terrestrial data bases**

– Heterogeneous data distribution

– Heterogeneous accuracy

– Contains also high-frequency signal

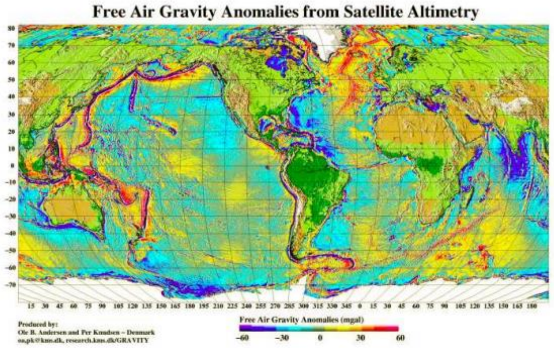


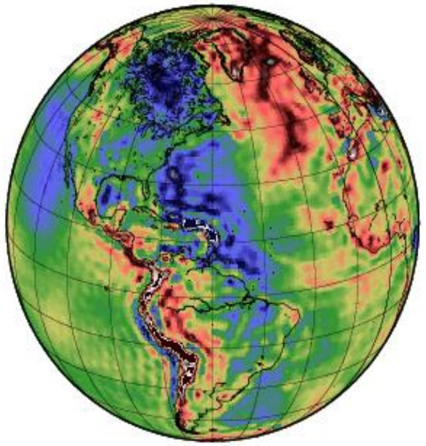
➢ **Altimetric gravity**

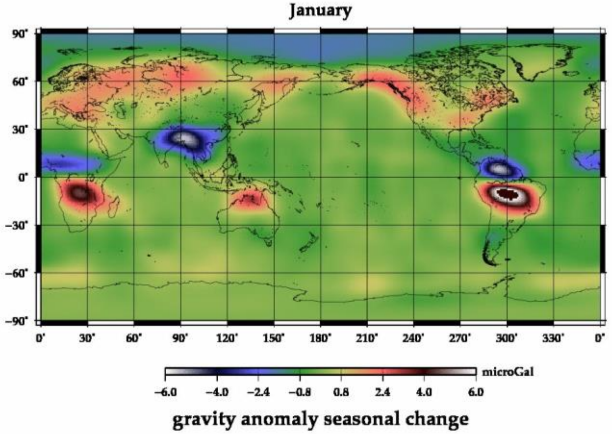
– Indirect method to derive gravity from Mean Sea surface with MDT corrections

– Covers oceans (problem: coastal areas)

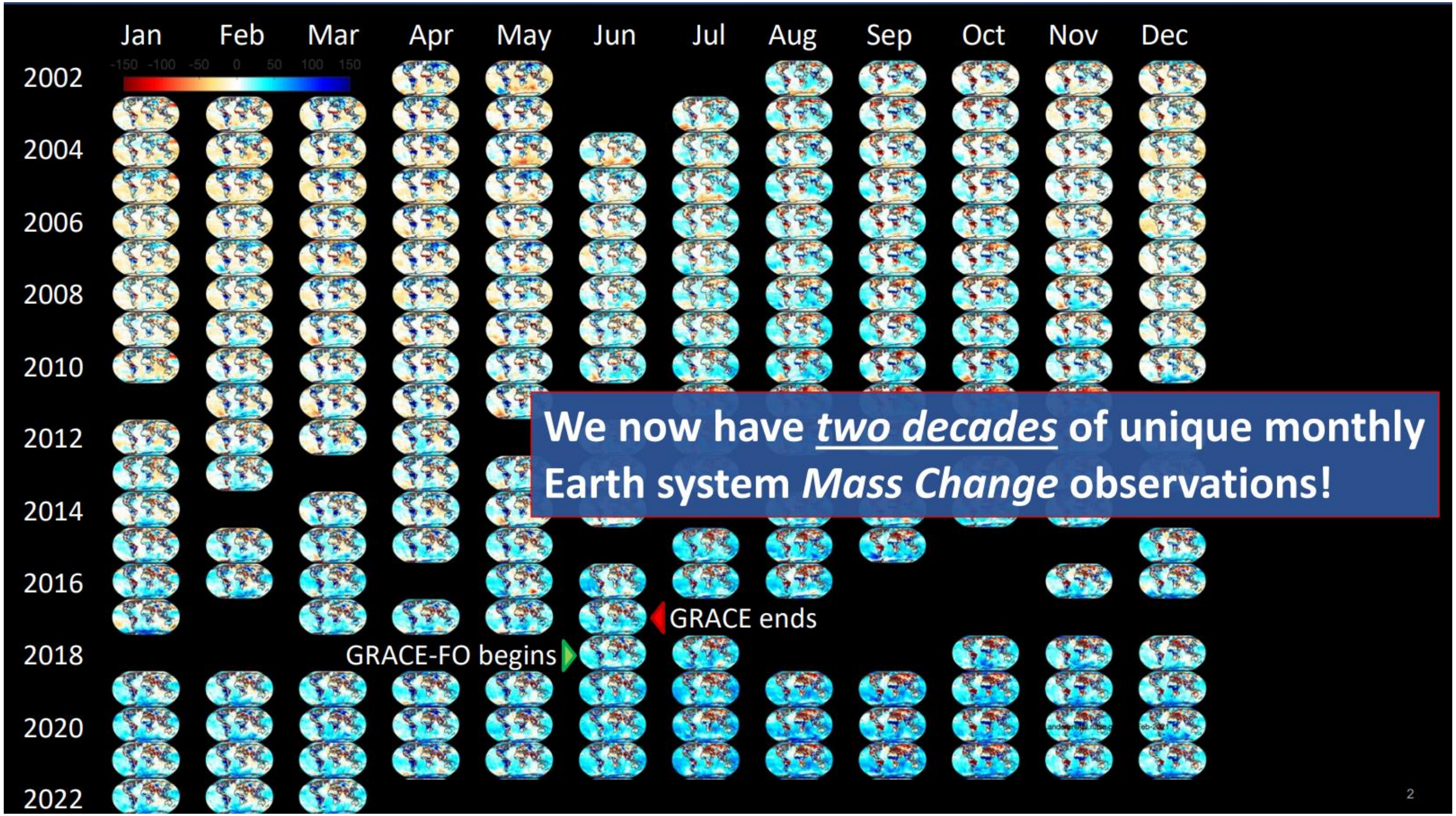
– Contains also high-frequency signal





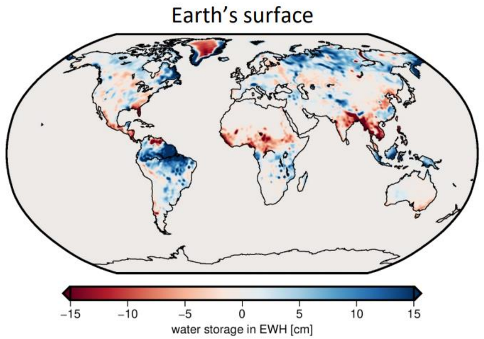


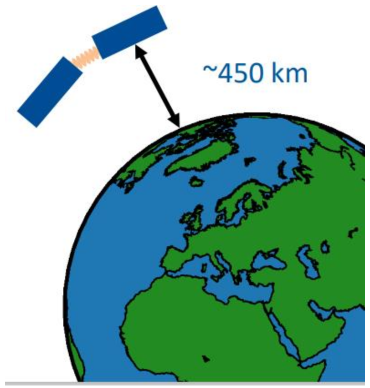
Gravity Recovery and Climate Experiment **(GRACE)**



Source: https://svs.gsfc.nasa.gov

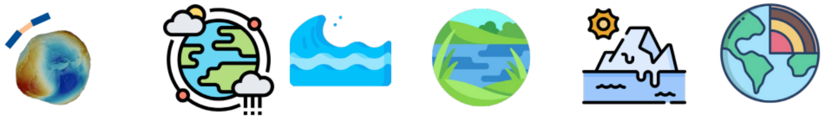
Resolution Problem and Signal separation **(GRACE)**



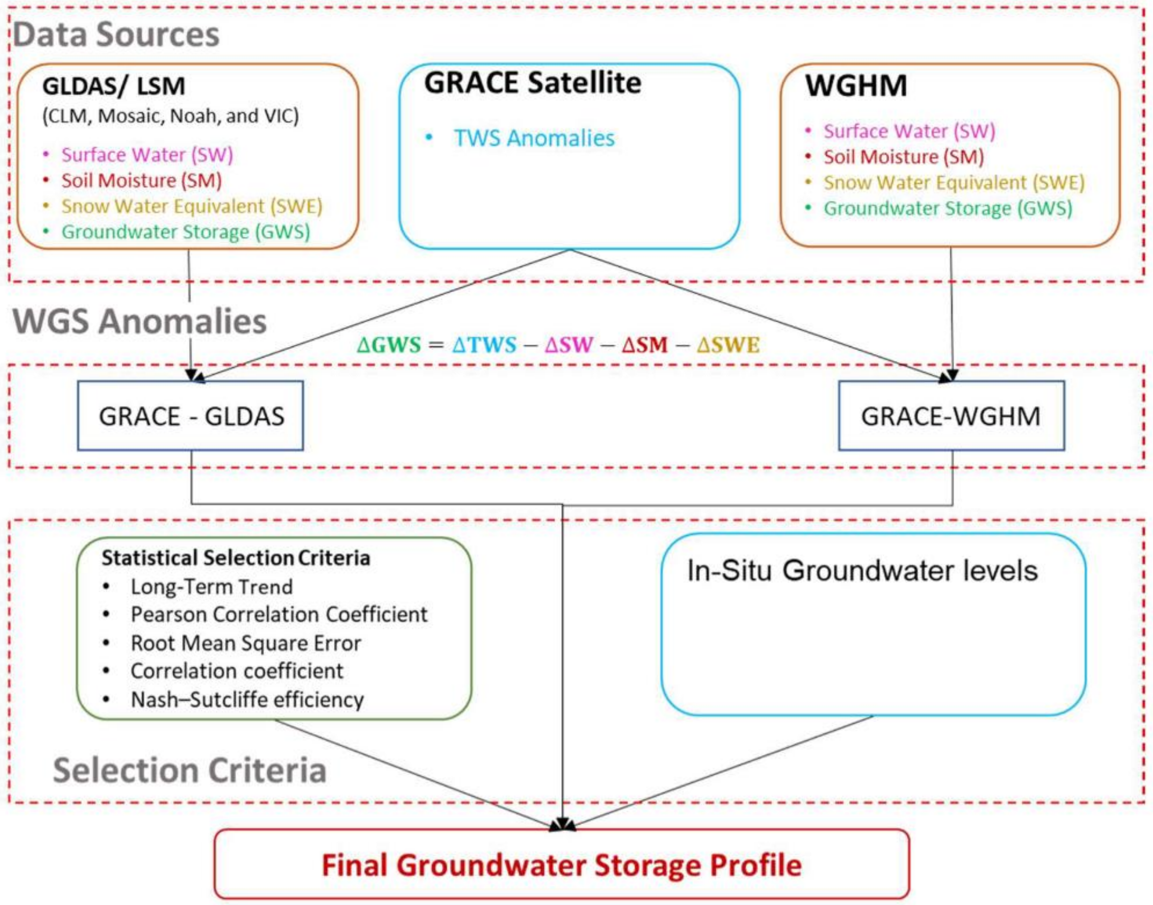


GRACE/GRACE-FO measure integrated mass transport

– We cannot distinguish between geophysical subsystems



GRACE = Atmosphere + Ocean + Hydrosphere + Ice Sheets + Solid Earth + ...



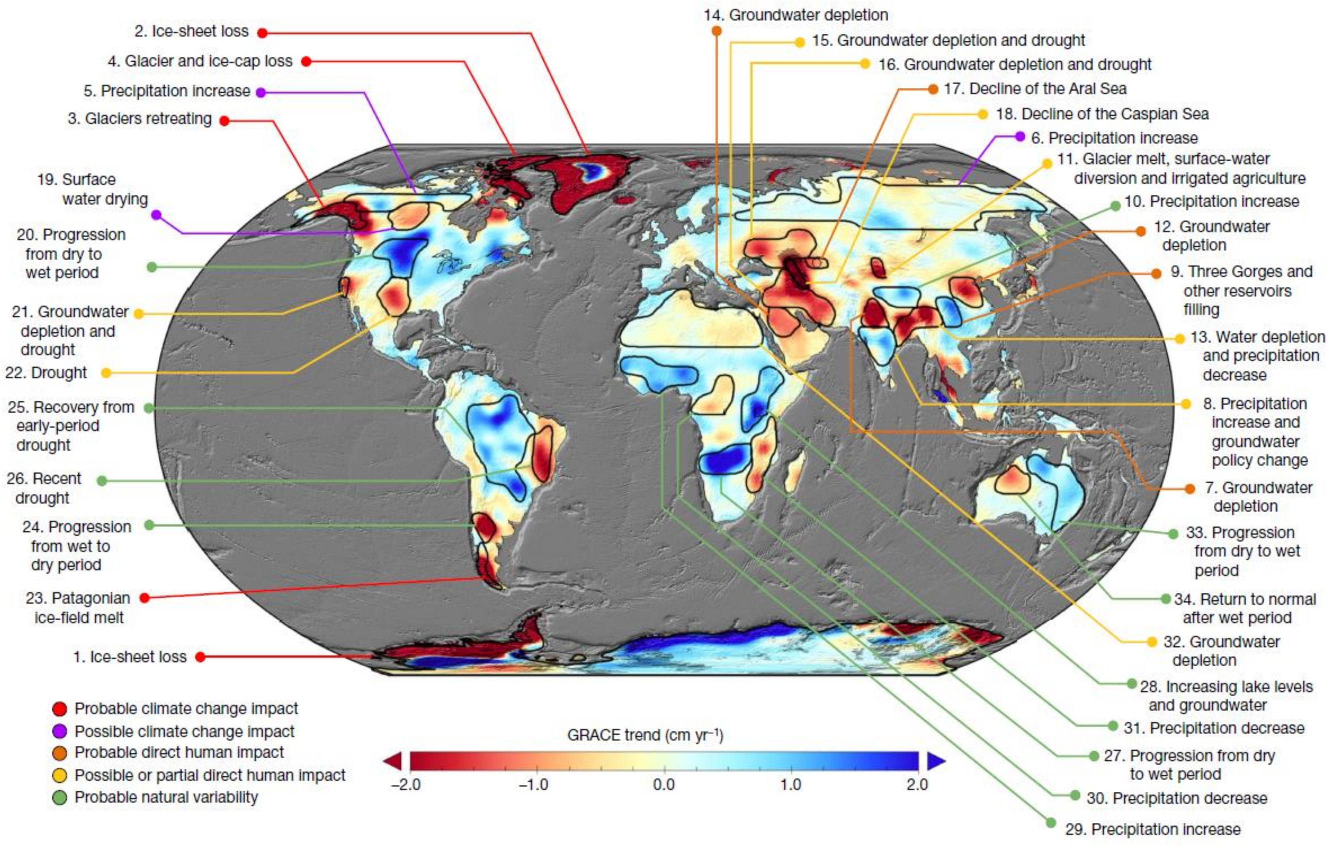
$$\Delta TWS_{GRACE} = \Delta S_{groundwater} + \Delta S_{canopy} + \Delta S_{snow} + \Delta S_{soil} + \Delta S_{lakes} + \Delta S_{wetlands} + \Delta S_{river}$$

$$\Delta S_{grounwater} = \Delta\, TW\, S_{GRACE} - \Delta S_{canopy} - \Delta S_{snow} - \Delta S_{soil} - \Delta S_{lakes} - \Delta S_{wetlands} - \Delta S_{river}$$

Limitations

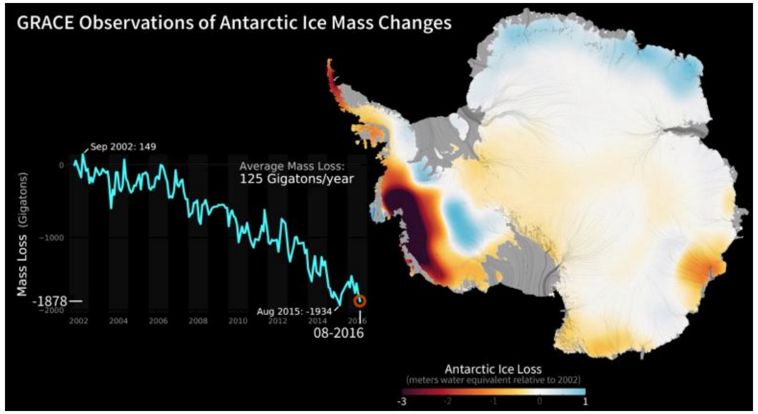
Gravity Recovery and Climate Experiment (GRACE)

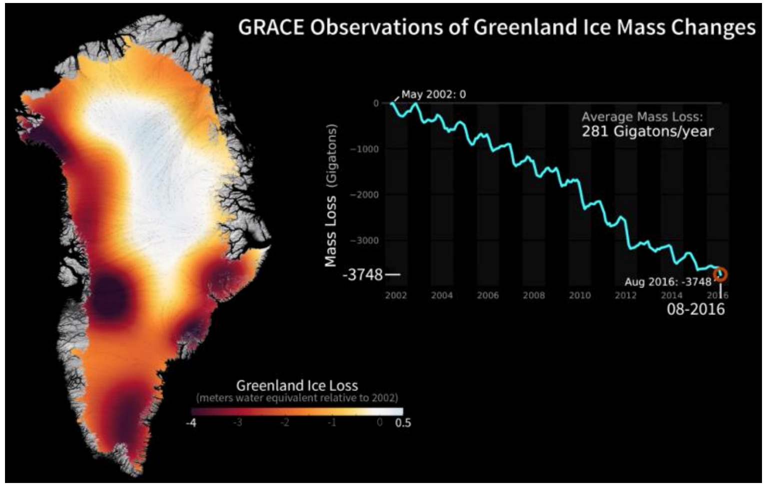
Contributions of GRACE: Applications (Global)



Rodell, M, 2018, Nature

Polar Ice Mass Loss from GRACE Satellite

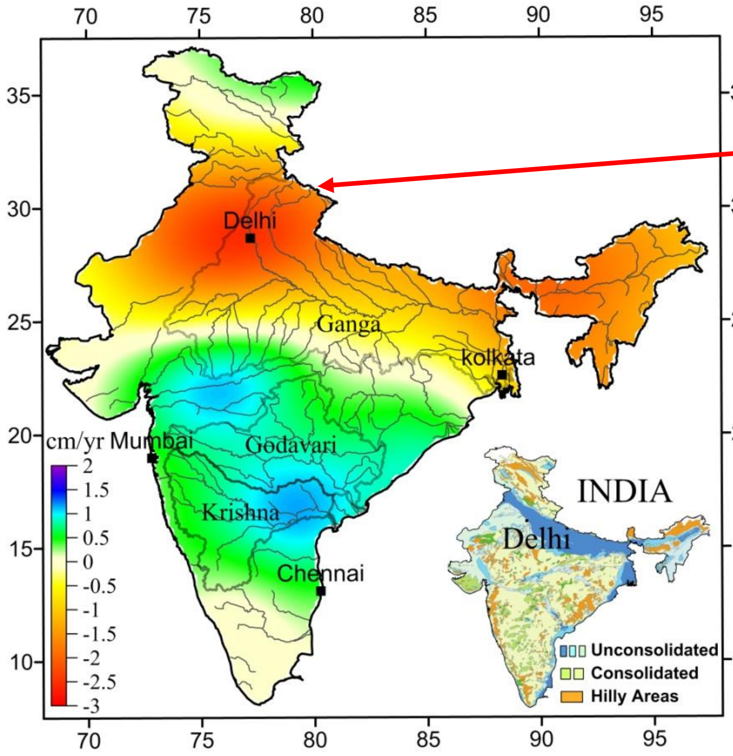




Source: https://svs.gsfc.nasa.gov/30879

SATELLITE BASED ESTIMATES OF WATER LOSS
FROM NORTHERN INDIAN REGION

GRACE Data

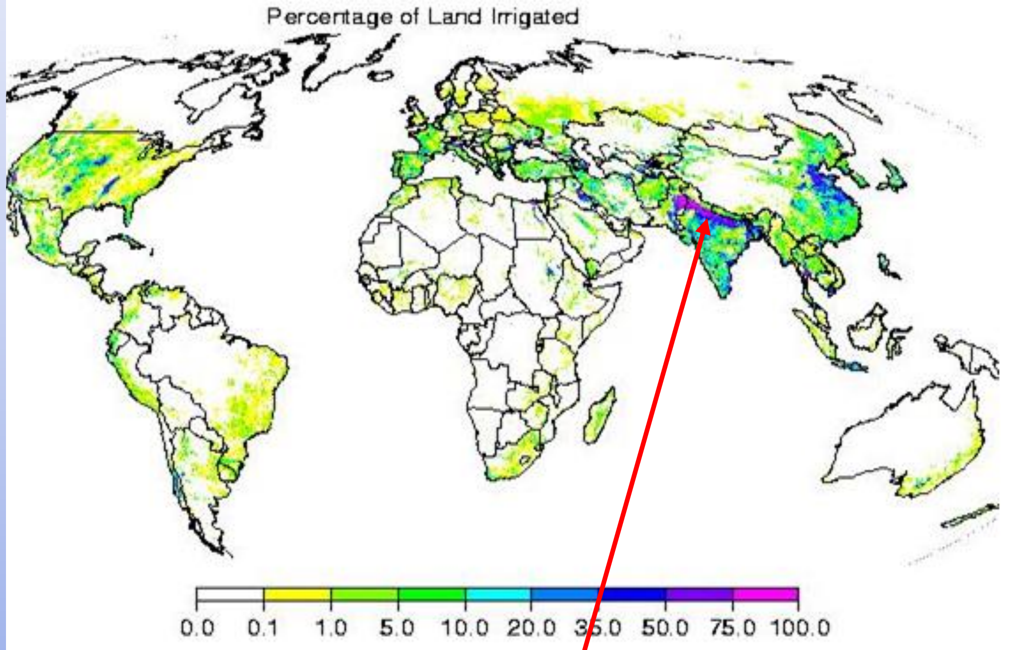


Trend of water storage 2002-2013 (ewh : cm)

Water mass loss from northern Indian Region about ~ 30 km^3/yr

*Largest Groundwater loss on the globe & provides new information for management of water resources

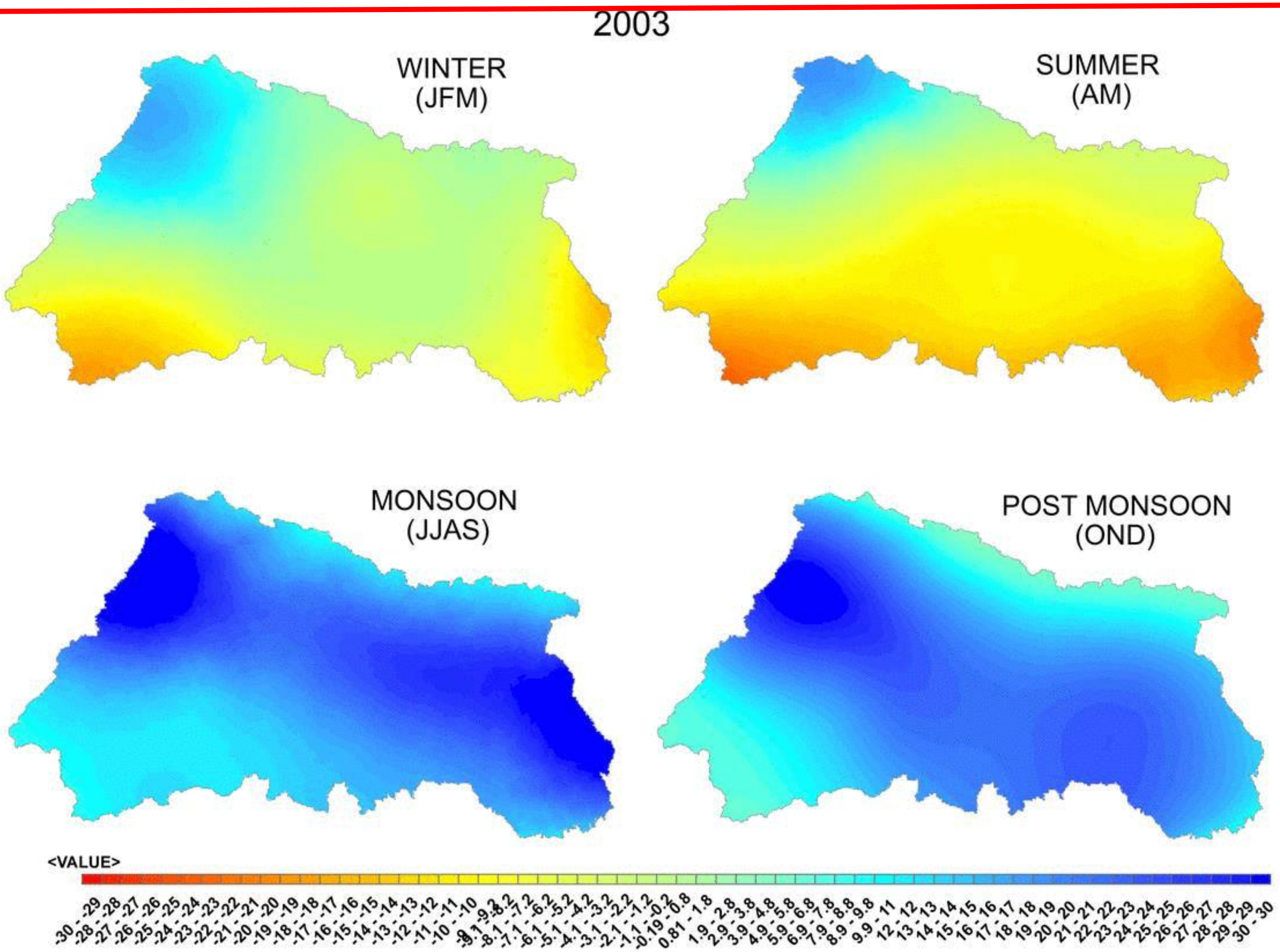
Data from the Food and Agriculture Organizations of the United Nations

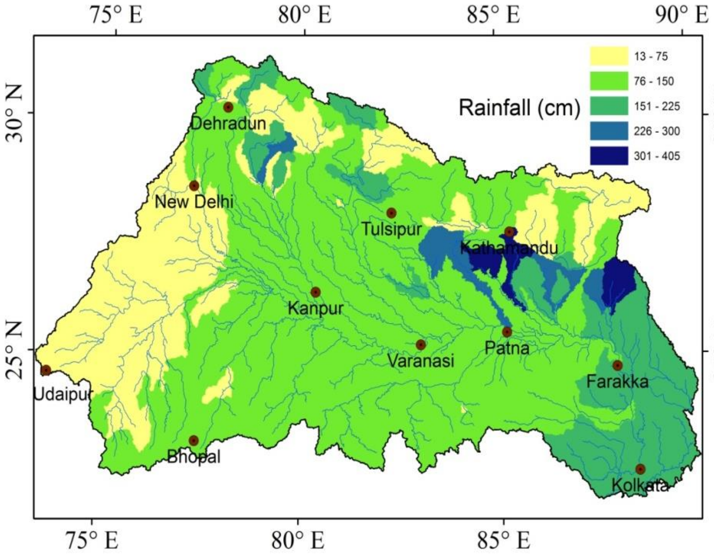


Northern India, Bangladesh, and Pakistan is the most heavily irrigated region on earth. Tiwari et al, 2009

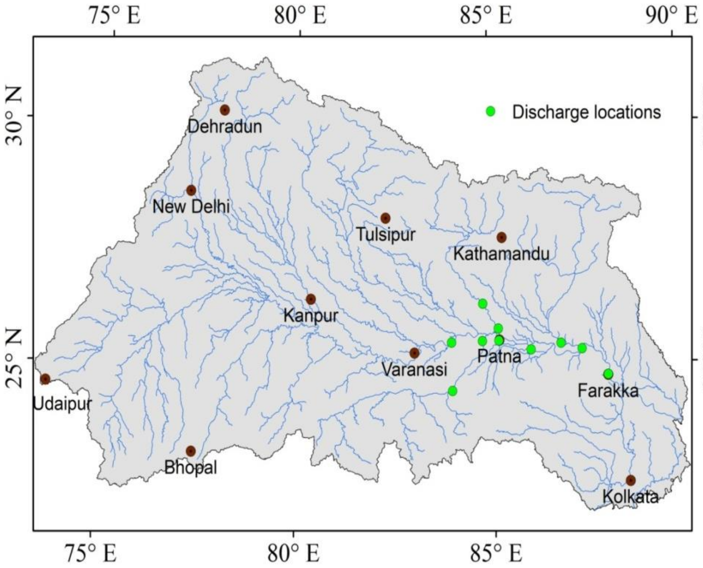
Water Budget of Ganga River Basin

Data Type	Source
DEM (Raster)	Shuttle Radar Topographic Mission (SRTM) 90m
Land Use (Raster)	USGS Global Land Cover(GLCC)
Soil (Raster)	Food and Agriculture Organization (FAO)
Drainage (Vector)	HydroSHEDS
Flow data (Point data)	Central Water Commission(CWC)
Weather (Raster)	Global Weather Data for SWAT

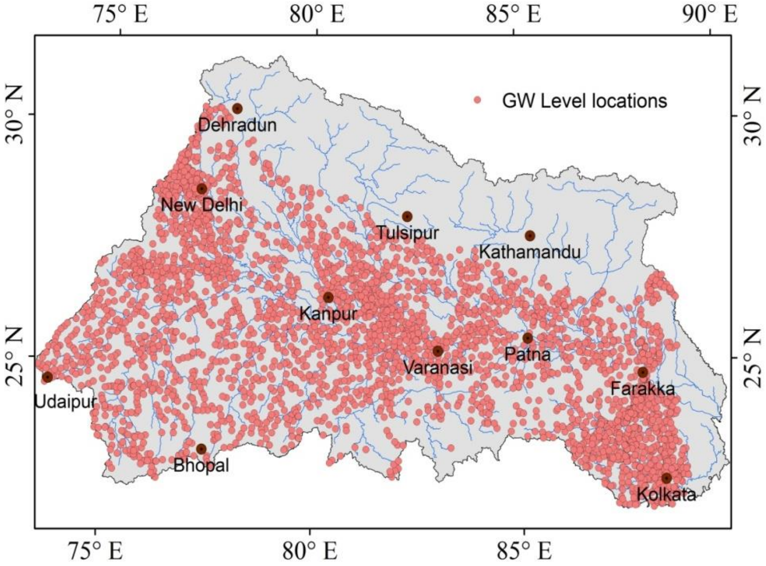




Rainfall



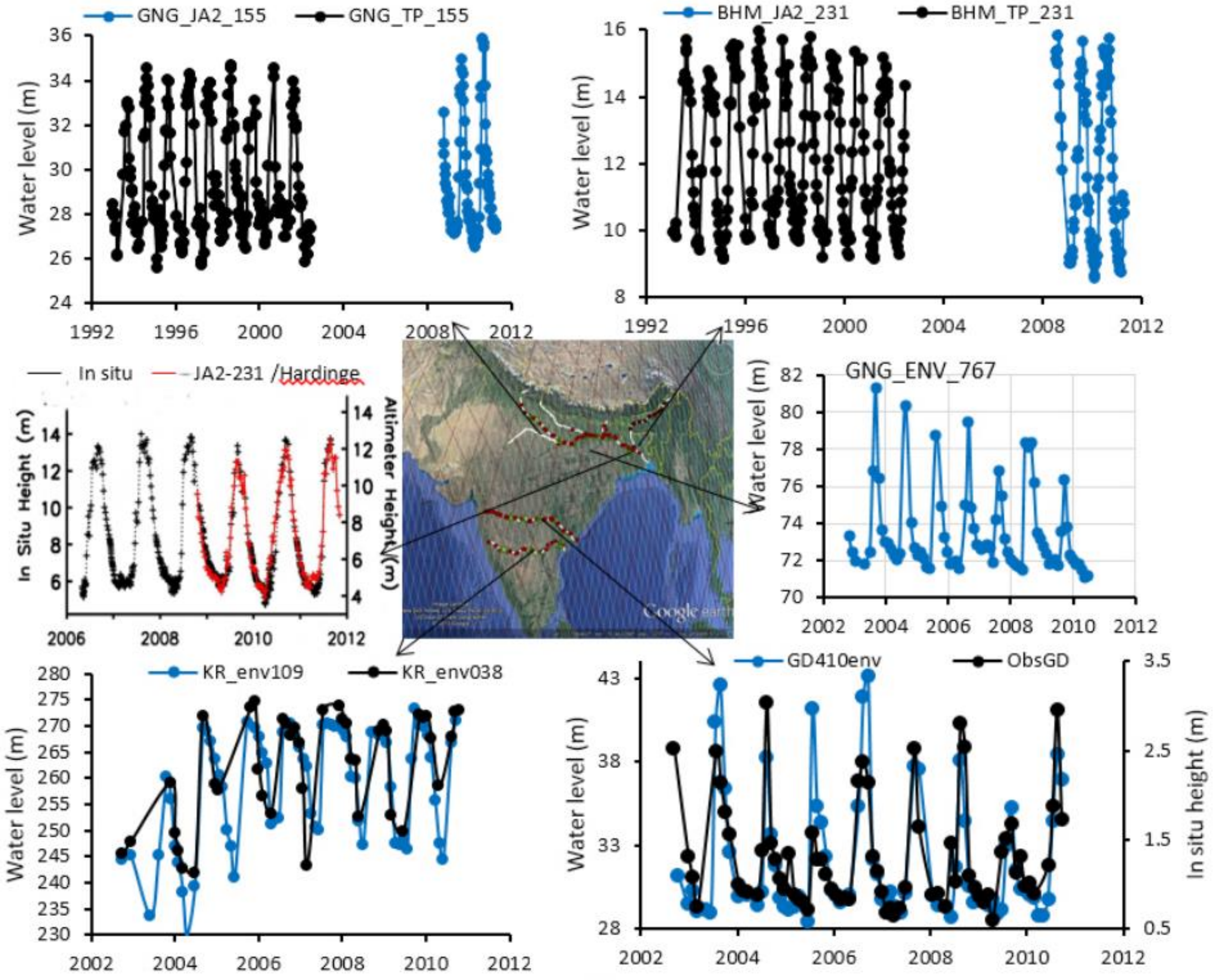
Gauge stations



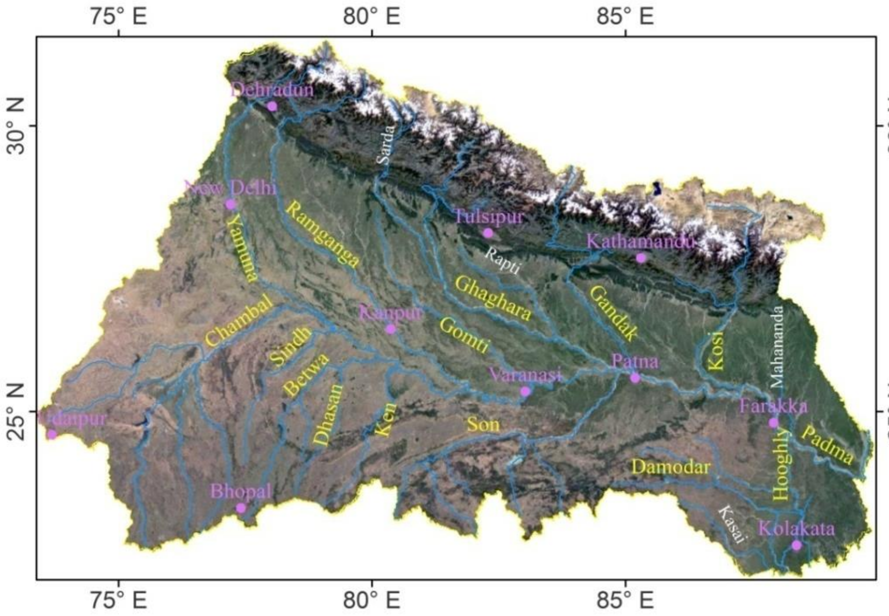
GW well location

Ganga River Basin

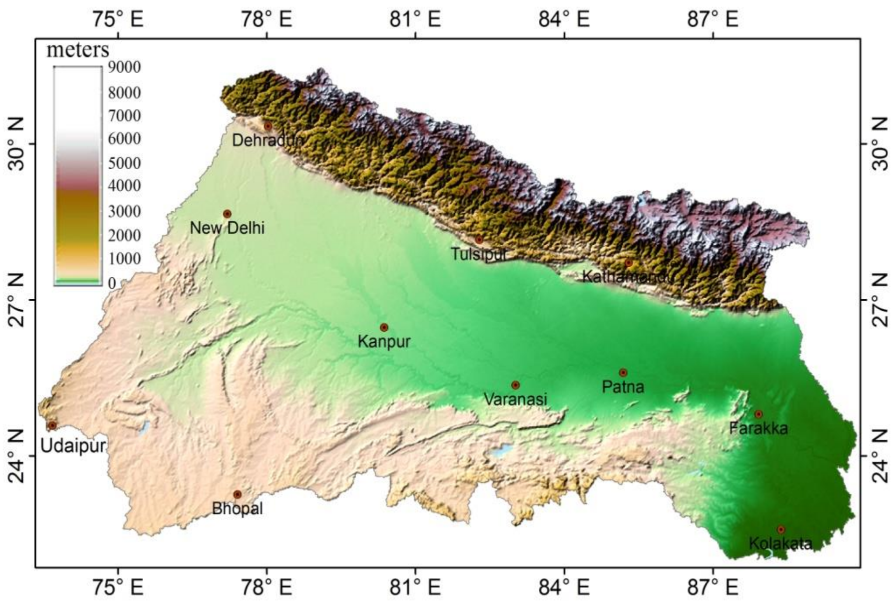
Satellite altimetry derived water levels



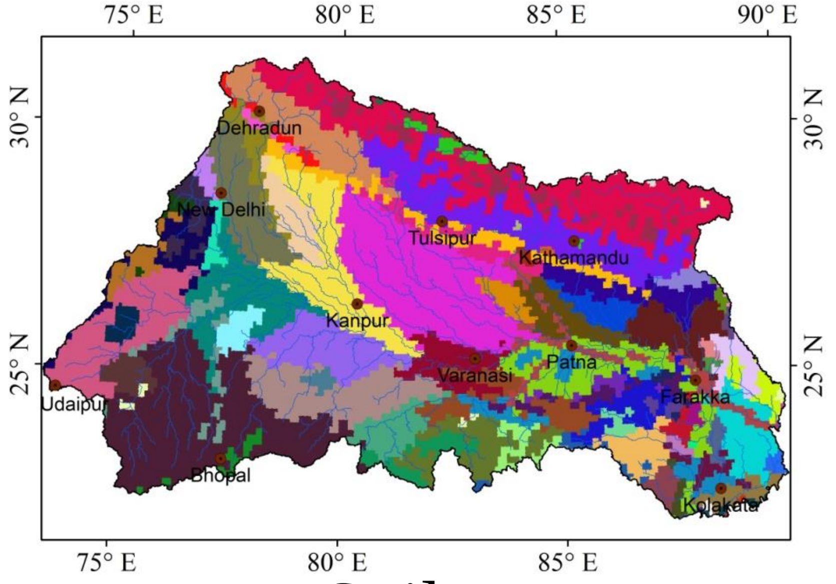
Tiwari et al, 2013



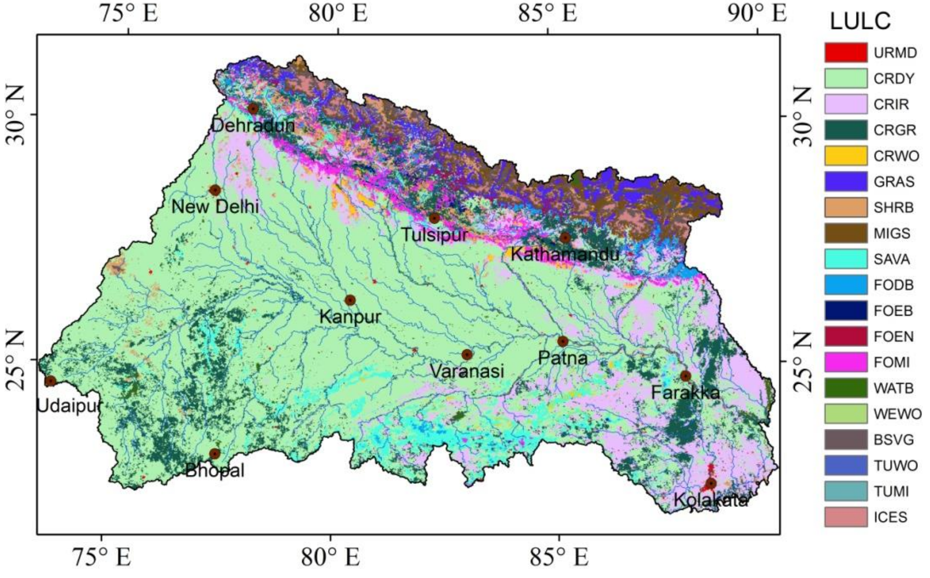
Ganga river and its tributaries



Topography

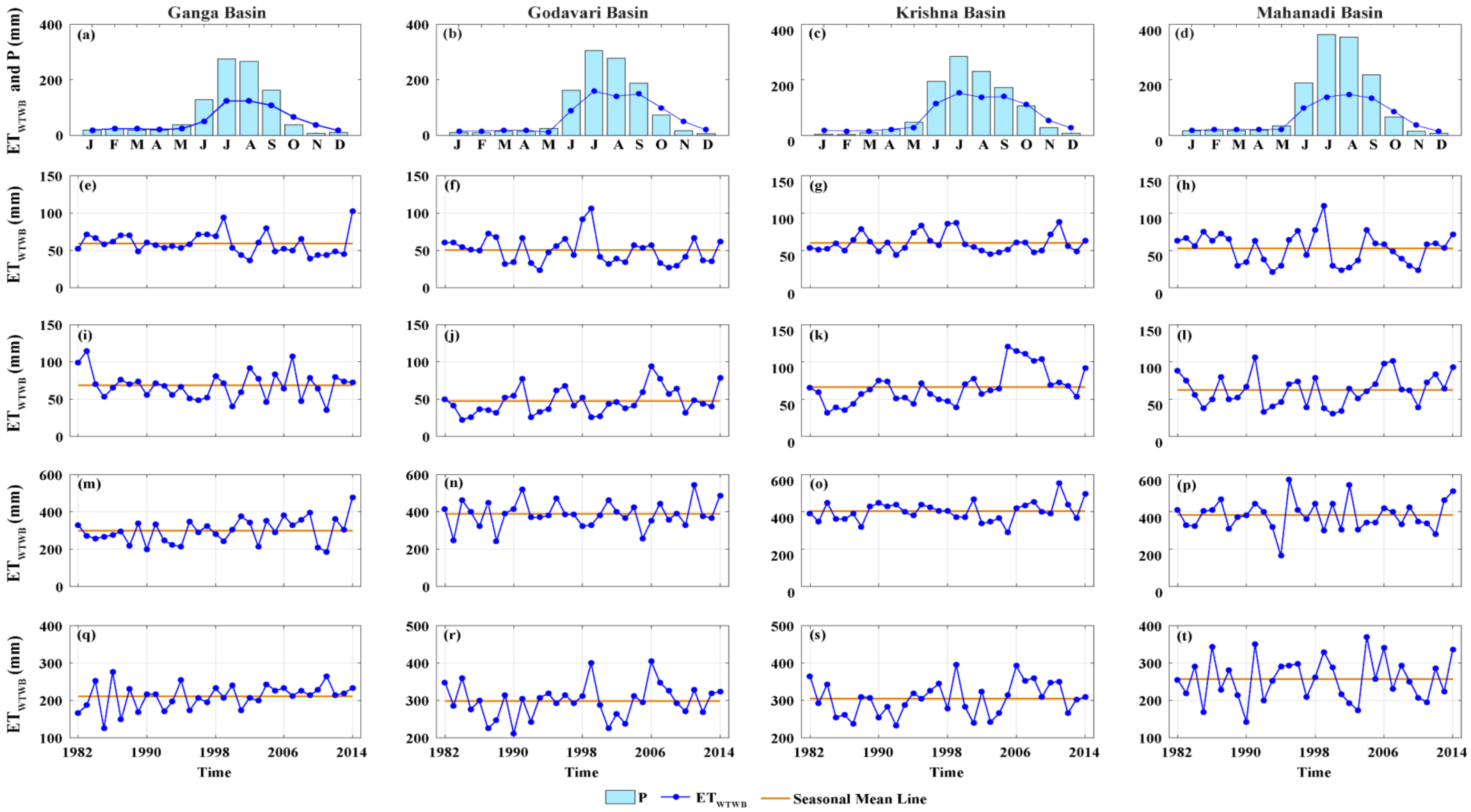


Soils



LULC

Seasonal Variations in GRACE-based ET over Indian River Basins



Winter (DJF)

Spring (MAM)

Summer (JJA)

Autumn (SON)

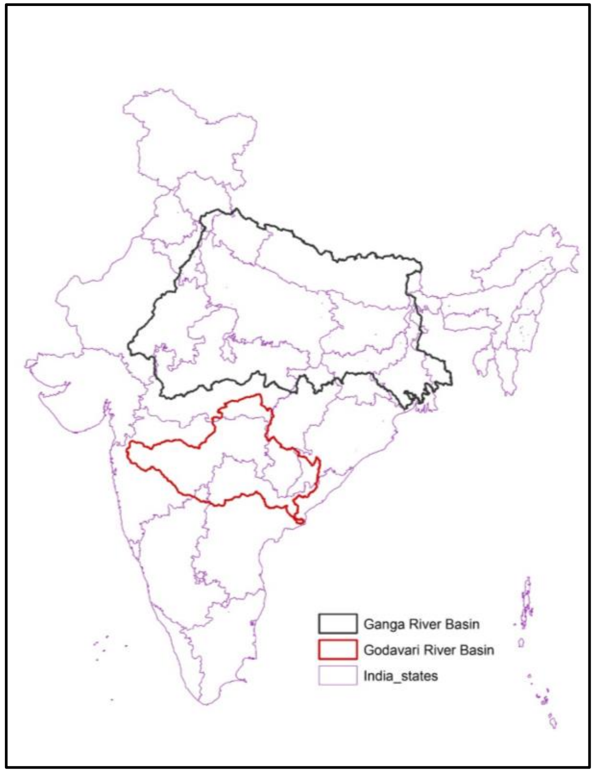
Winter account ~6-9%, Spring account~6-11%,

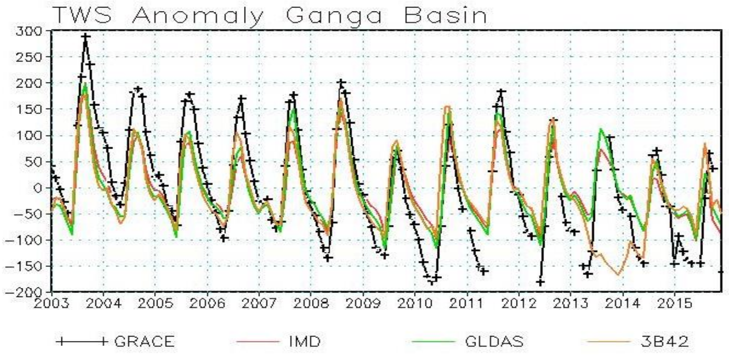
Summer account ~47-51%, Autumn accounts ~33-38% ET from total annual ET

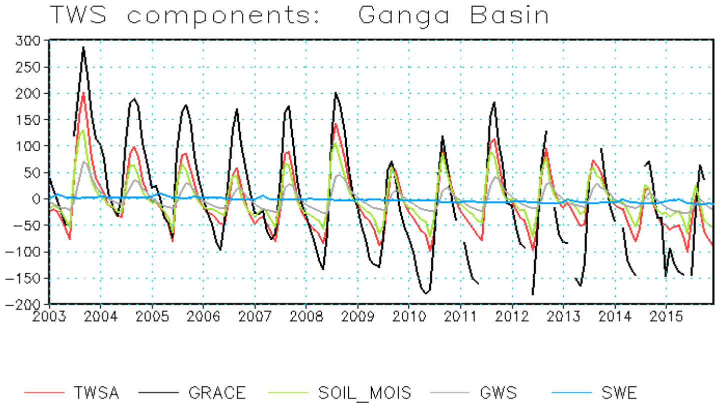
Source: Tajdarul H. Syed

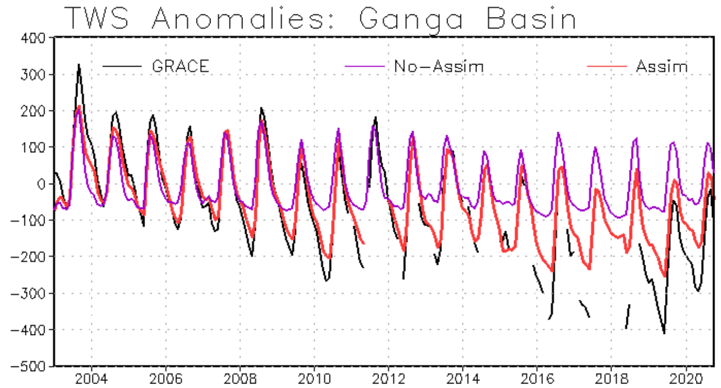
Assessment of Regional Hydrological Systems using Space Borne Gravity Observations(Data Assimilation)

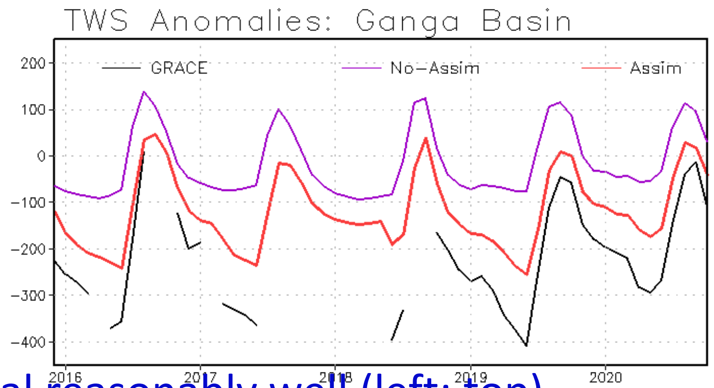
सत्यमेव जयते
Department of Science and Technology (DST)
DST





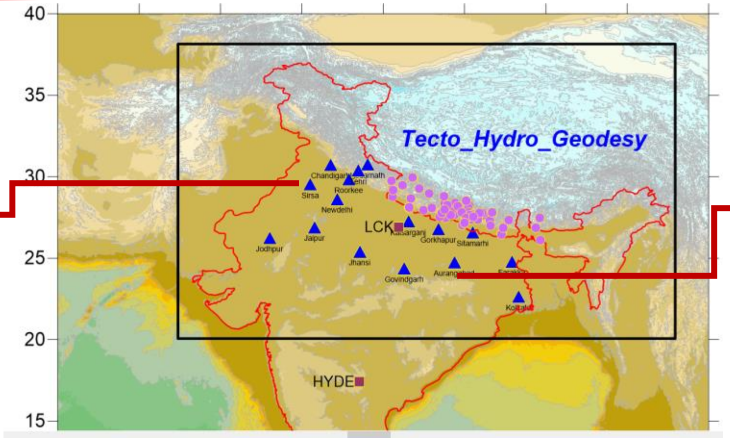


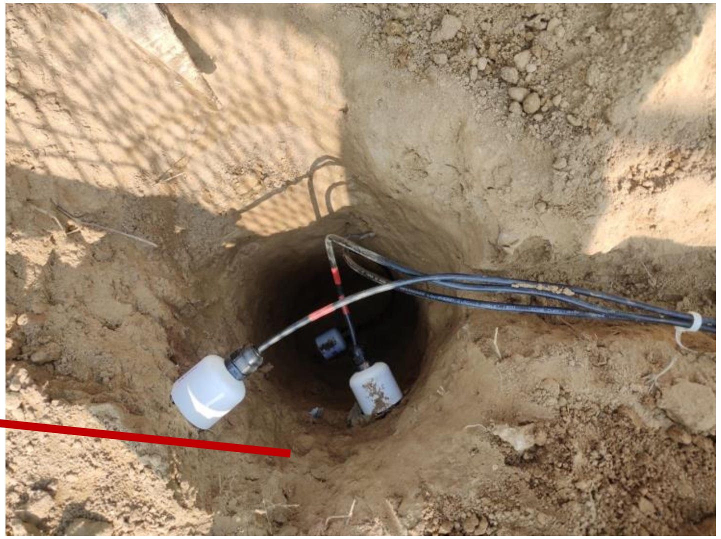




- The model simulated TWS anomalies capture the GRACE observed TWS anomaly signal reasonably well (left: top).
- Results indicate that Soil Moisture (4 layers) and Ground Water Storage contribute to the most of TWS values. Contribution of Snow is marginal (left:Right).
- As expected, the TWS after assimilation is between the observed values and the model TWS (without Assimilation). The Assimilation also provides consistent TWS anomalies in the months when there was no GRACE TWS data. Major impact of assimilation is noticed in drier months (Right top and Bottom are from 2003-2015 and 2016-2020 respectively).

GNSS- SOIL Moisture Observatories for Hydro Geodesy





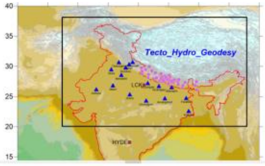
Ex. GNSS and Soil Moisture Probes Installed at JNV, Sirsa, Haryana.

Three Hydra Probe soil sensors installed 3 distinct soil horizons.

Ex. GNSS and Soil Moisture Probes Installed at JNV, Aurangabad, Bihar

Glimpses of GNSS – SOI observatories

GPS & Soil Moisture observatory
JNV-Sirsa, Haryana



Three Hydra Probe soil sensors installed 3 distinct soil horizons.

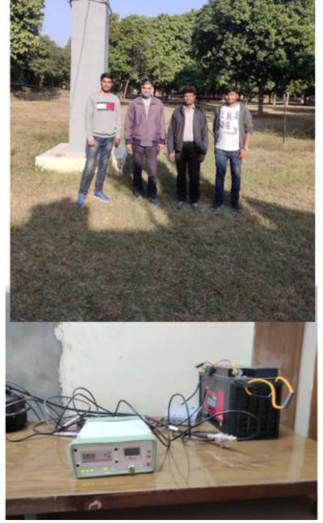
GPS & Soil Moisture observatory
JNV-Aurangabad, Bihar.

GPS observatory
JNV, Bahraich, UP

GPS & Soil Moisture observatory
Bundelkhand University, Jhansi

GPS & Soil Moisture observatory
JNV, Sitamarhi, Bihar.

Seismic observatory
CSIO- Chandigrh



GPS & Soil Moisture observatory
CSIR-CBRI, Roorkee, UK.

JNV, Govindgarh, MP

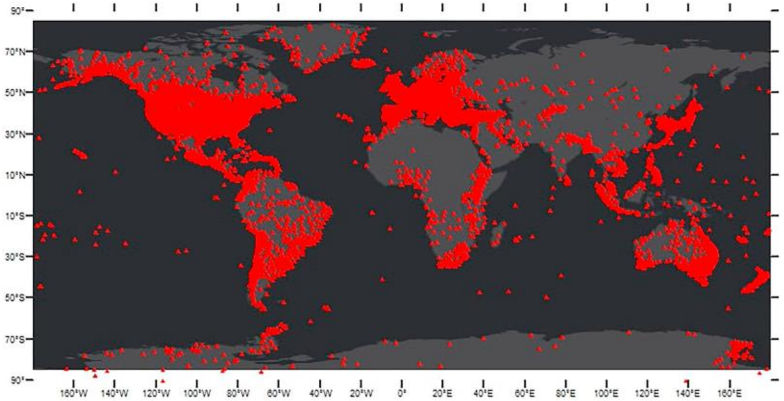
GPS & Soil Moisture observatory
JNV, Gorakhpur, UP.

Journey from WEST to EAST

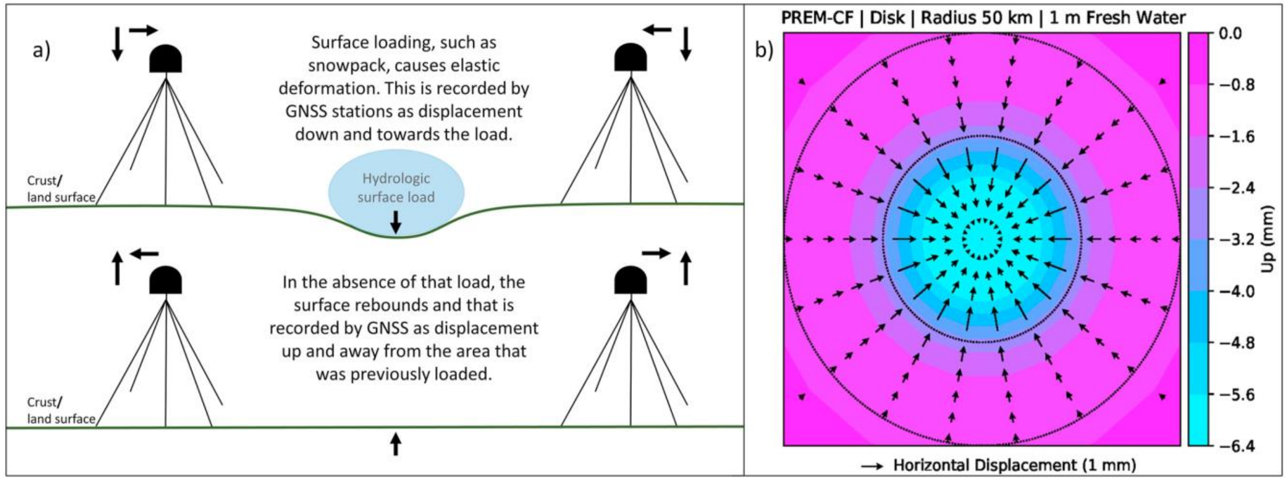
Department of Science and Technology (DST)
DST

Crustal Deformation due to Hydrological Loading

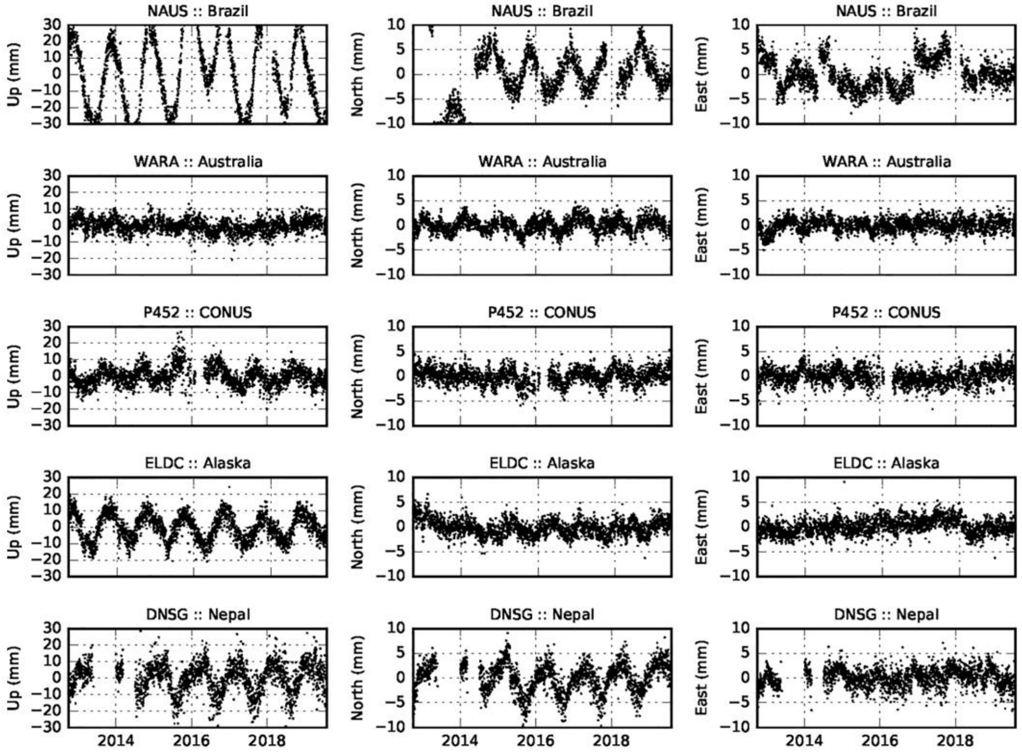
The use of GPS Horizontals and Vertical for loading



Global Navigation Satellite System stations (red triangles)



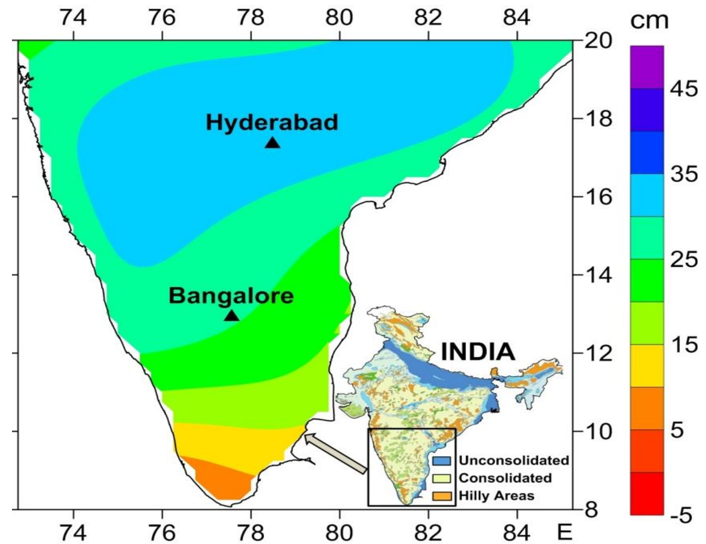
Conceptual model of how Earth's surface and attached Global Navigation Satellite System stations move in response to loading, assuming strictly elastic Earth rheology. Alissa M. White, 2022, WRR



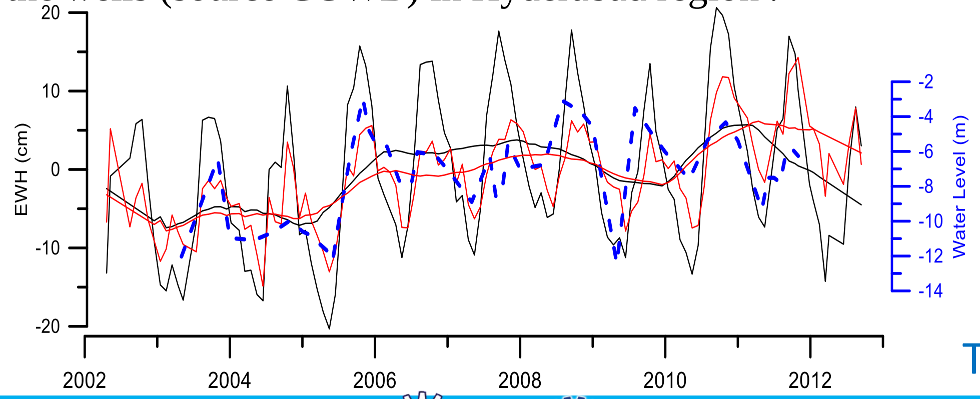
Time series of vertical and horizontal displacement (where positive displacement corresponds to up, north, and east movement, respectively)

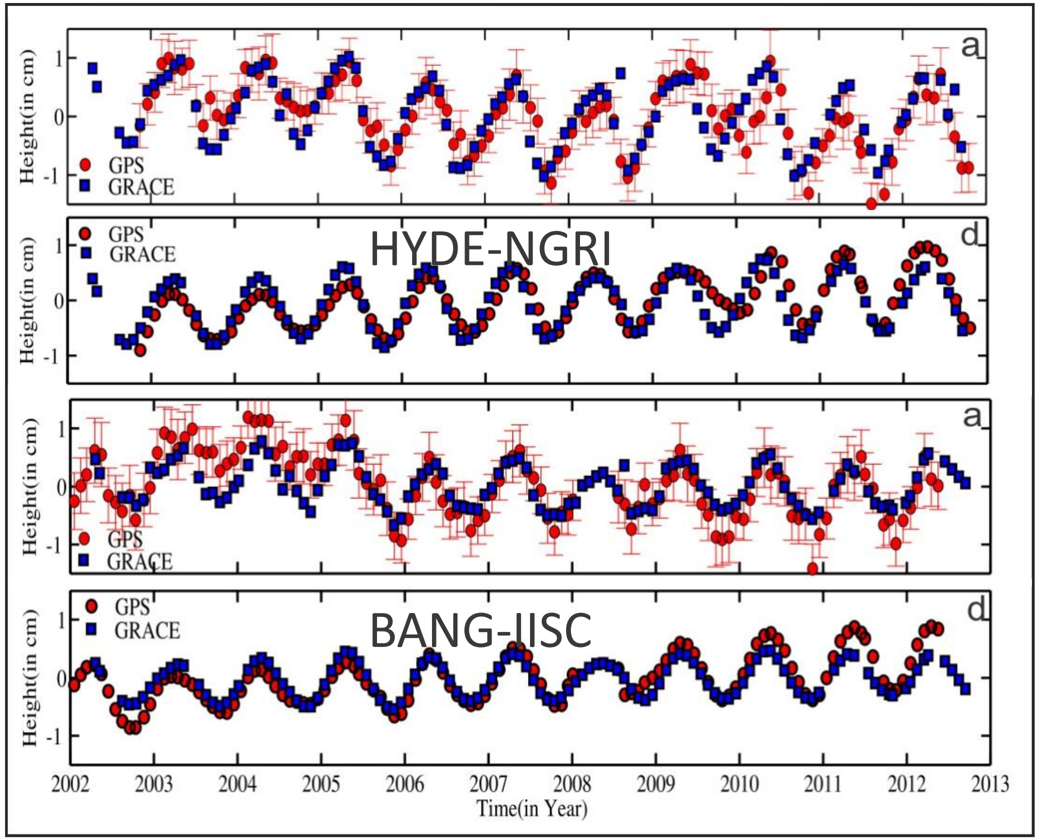
Crustal Deformation due to Hydrological Loading

The seasonal hydrological mass changes are in the range of 20–50 cm of equivalent water height over southern India, which causes vertical deformation of 1–2 cm.



Monthly and seasonal removed time series of **TWS**, **groundwater(GRACE-GLDAS)** and **average water level** variation from measured water level in the wells (source CGWB) in Hyderabad region .

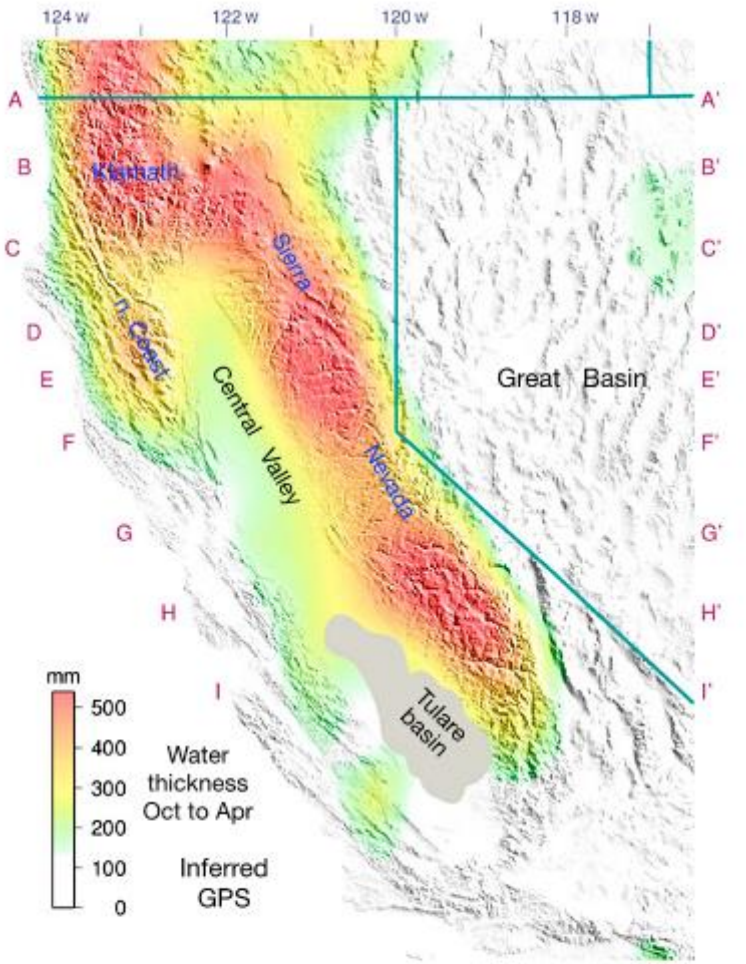




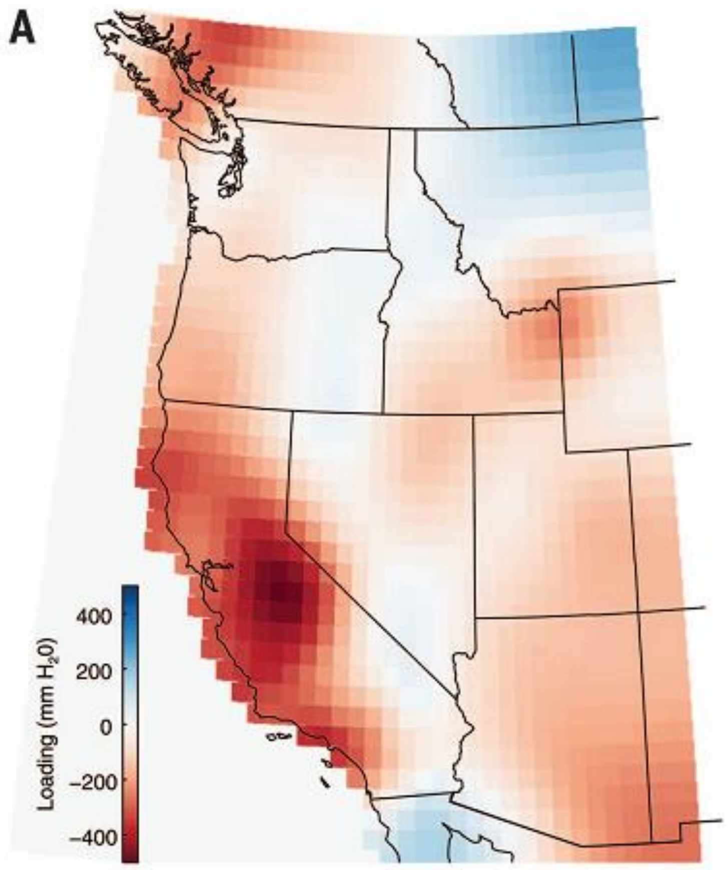
GPS VERTICAL COORDINATES AS HYDROLOGIC SENSORS

Tiwari et al., 2014.

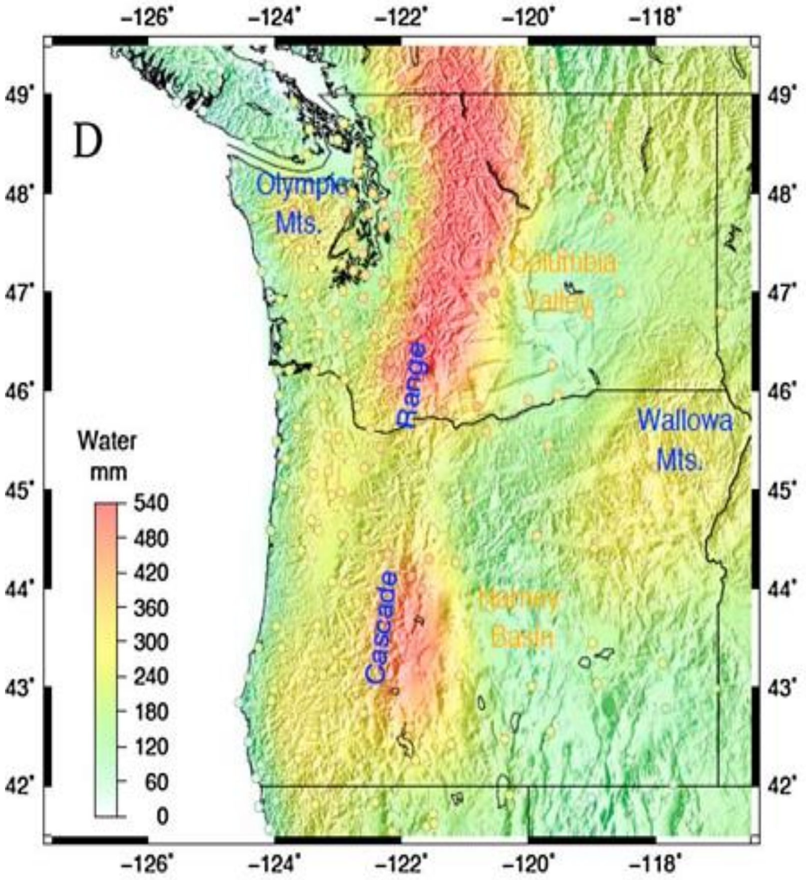
Terrestrial water storage change inverted from GPS loading deformations



Argus et al 2014



Borsa et al., Science; 2014

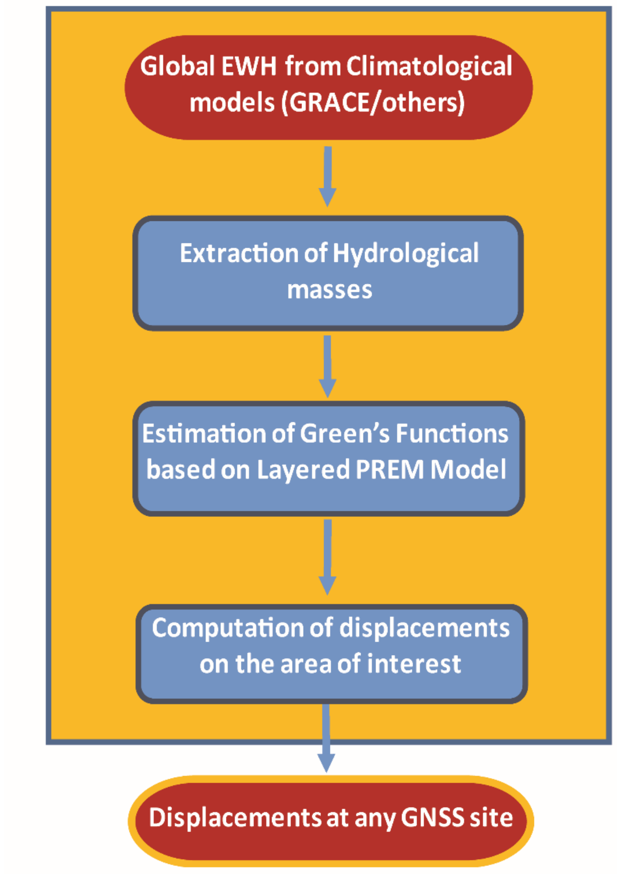


Fu et al 2015 JGR

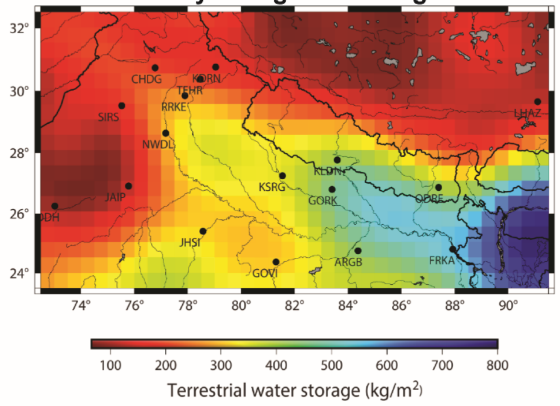
GPS VERTICAL COORDINATES AS HYDROLOGIC SENSORS

Deformation induced by seasonal variations of continental water

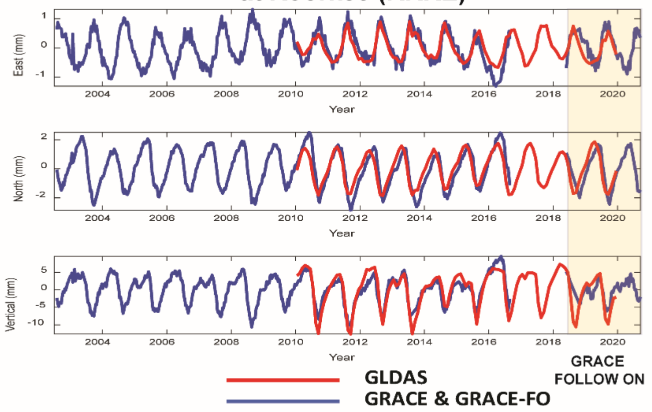
Global Hydrological Data Analysis



Average peak-to-peak annual variation in hydrological loading

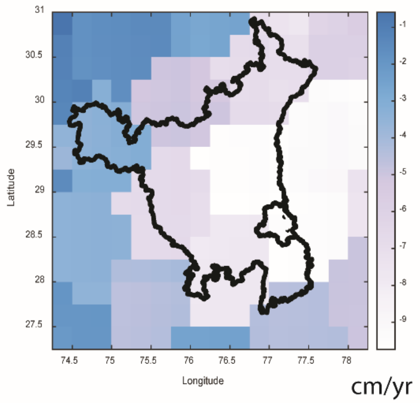


Elastic response due to hydrological loading at Roorkee (RRKE)

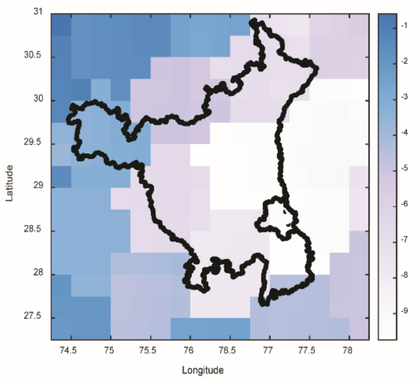


Ground water depletion in North India

GRACE TWS trend (2003-2016)



GRACE GWS trend (2003-2016)



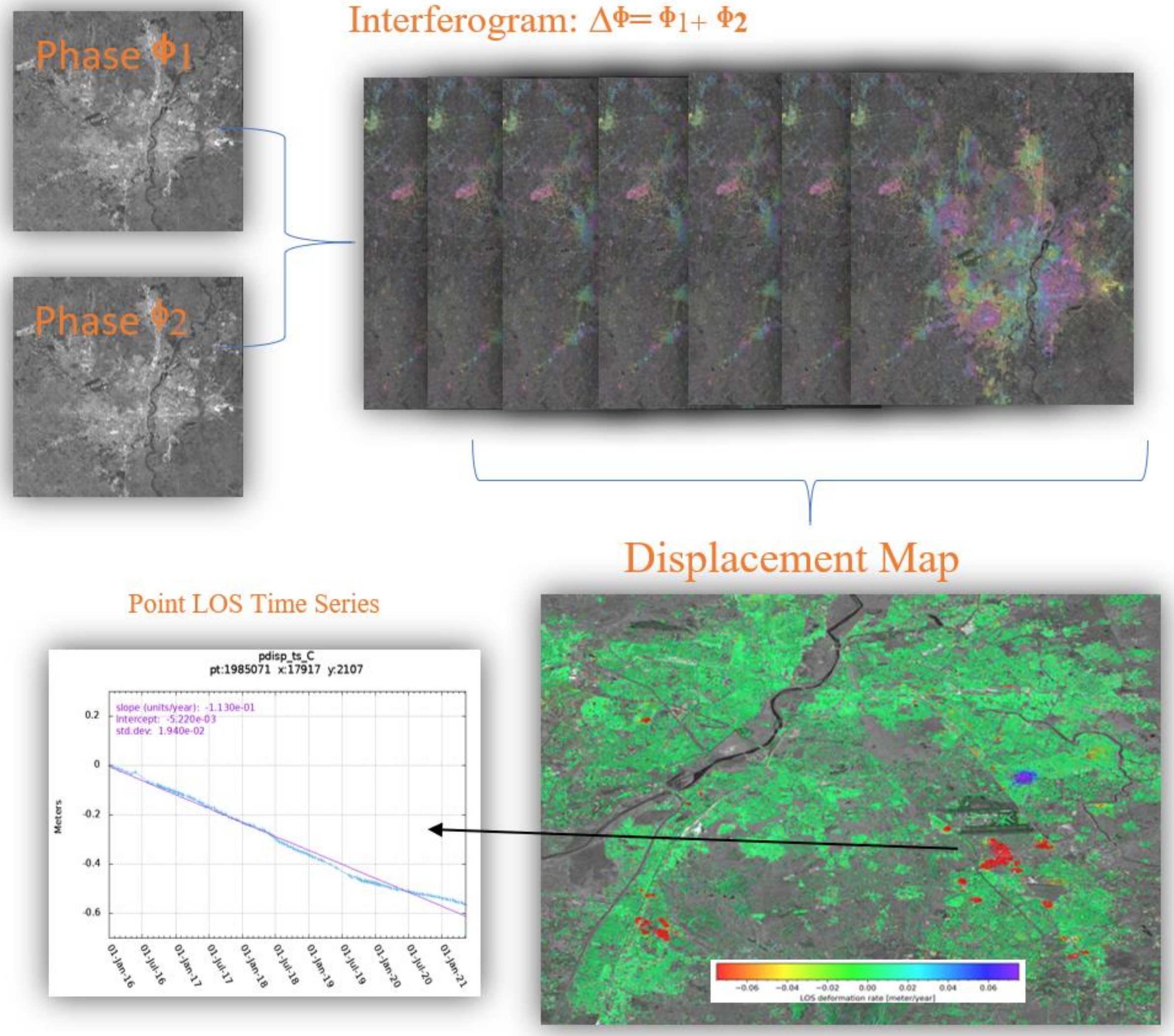
- North India shows significant variation in hydrological loads affecting the crustal deformation.
- The decline in GRACE-GWS anomaly is prominent in NCT-Delhi, Haryana, north Rajasthan, and western Uttar Pradesh.

Introduction: InSAR Principle and Mechanism

InSAR: Interferometric Synthetic Aperture RADAR

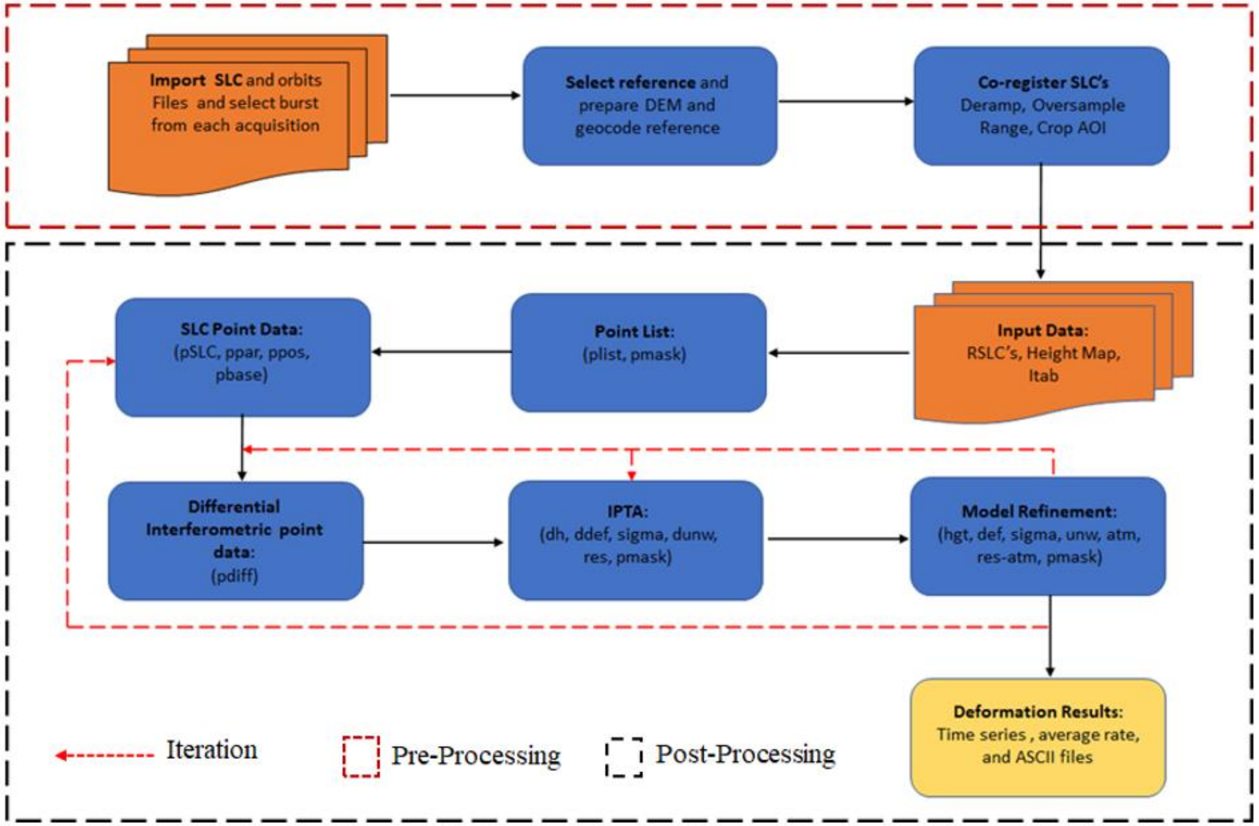
Active remote sensing technique

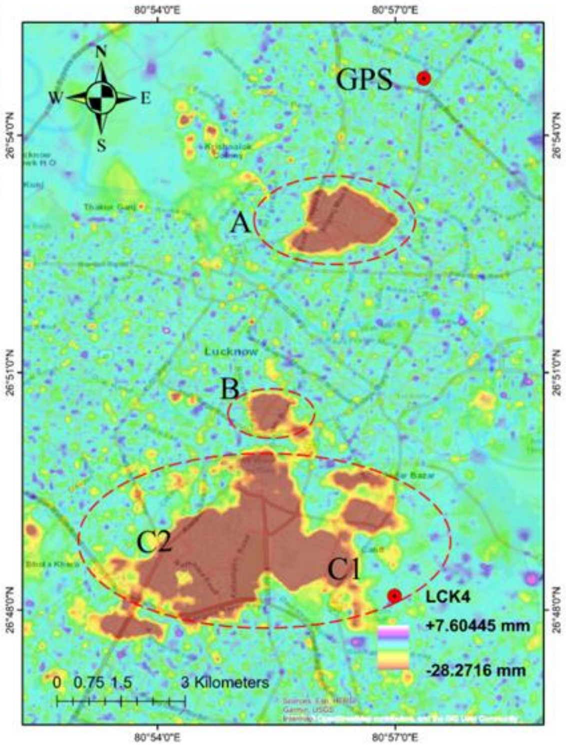
- Use microwave band from electromagnetic spectrum
- Measurement of phase delay of two SAR signal

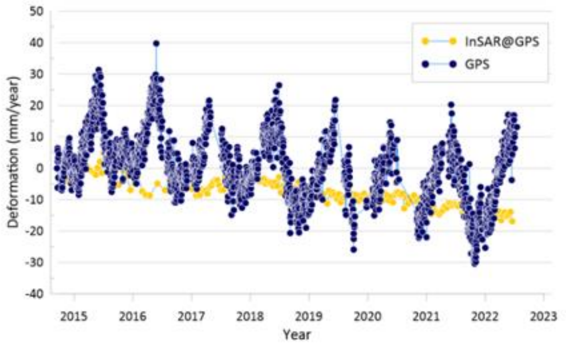


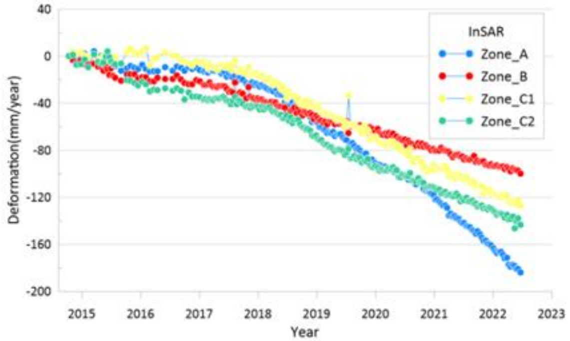
Source: GRACE Network Project CSIR-NGRI

Methodology of Time Series InSAR and Results



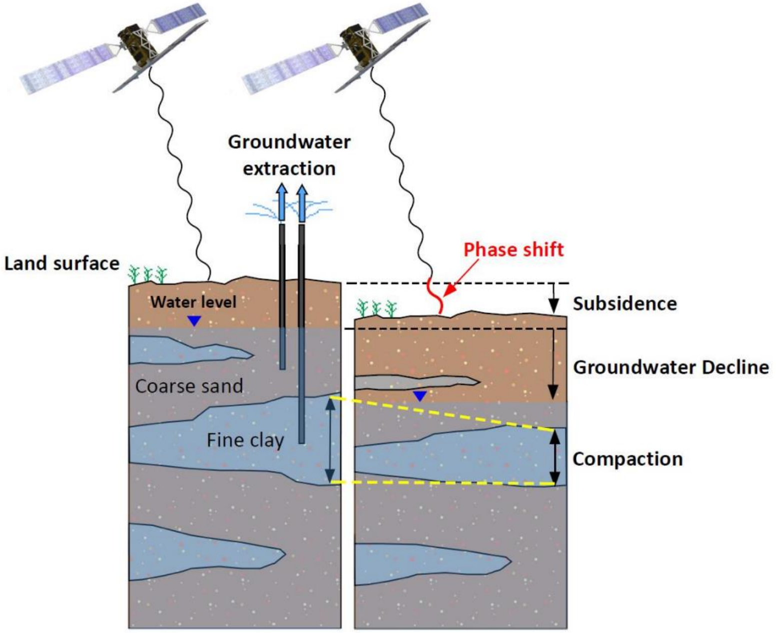






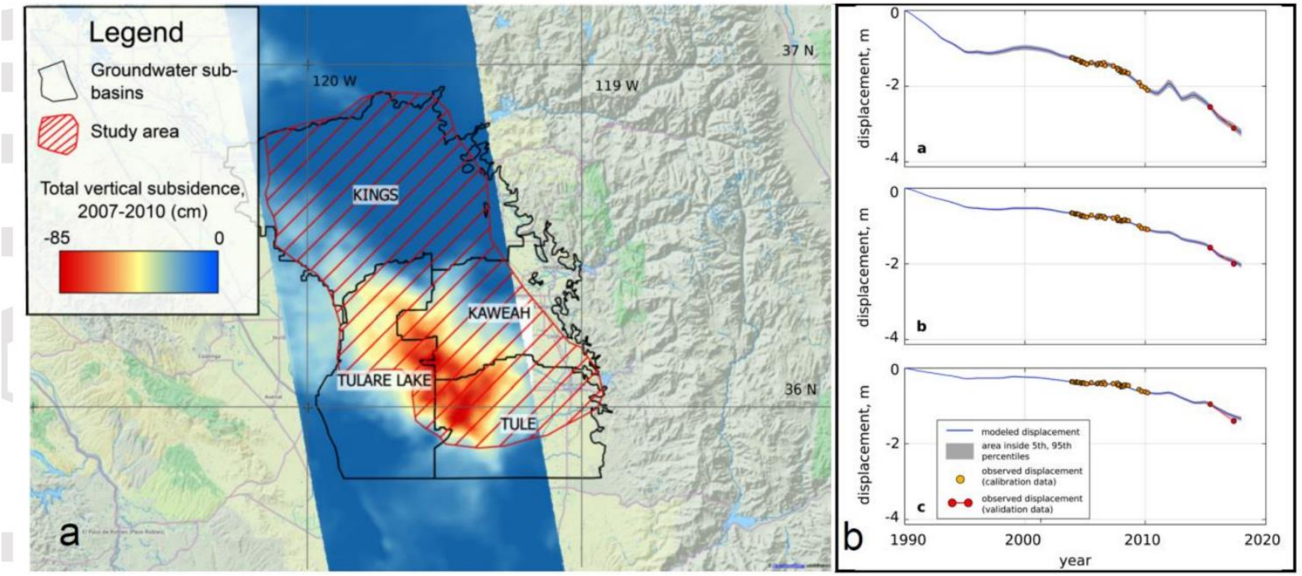
Lucknow Vertical Deformation from Ascending and Descending Datasets

Interferometric Synthetic Aperture Radar(InSAR)



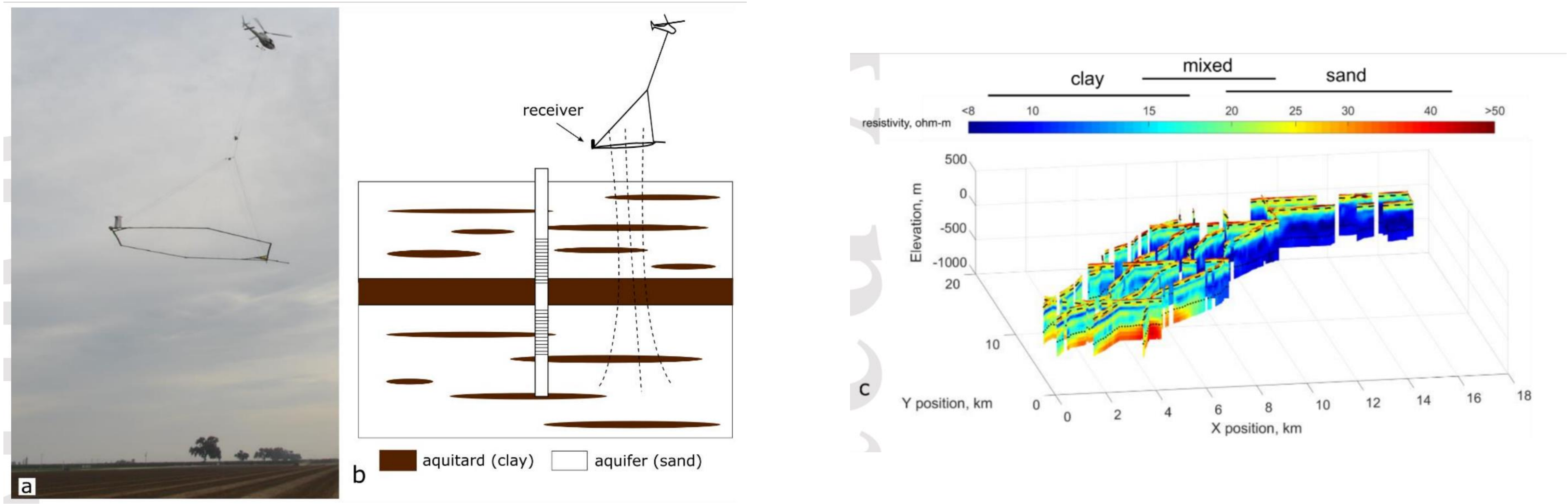
InSAR measures surface deformation by measuring the difference in the phase of the radar wave between the two passes if a point on the ground moves and the spacecraft is in the same position for both passes. Because changes to groundwater subsequently causes elastic or inelastic surface response, InSAR can be used to infer volumetric groundwater change by measuring surface deformation

Sub-basin Scale



[Modified from Smith et al., 2017 and Smith and Knight, 2019] a. Map of InSAR-derived total vertical subsidence from June 2007 to December 2010 across several groundwater sub-basins in Central Valley, California. b. Modeled and observed deformation data, with modeled subsidence (blue line), error (grey), InSAR-derived deformation from Envisat and ALOS (orange; used for calibration), and total displacement from Sentinel-1 (red; excluded from calibration, but used for validation) for three locations within the Kaweah sub-basin.

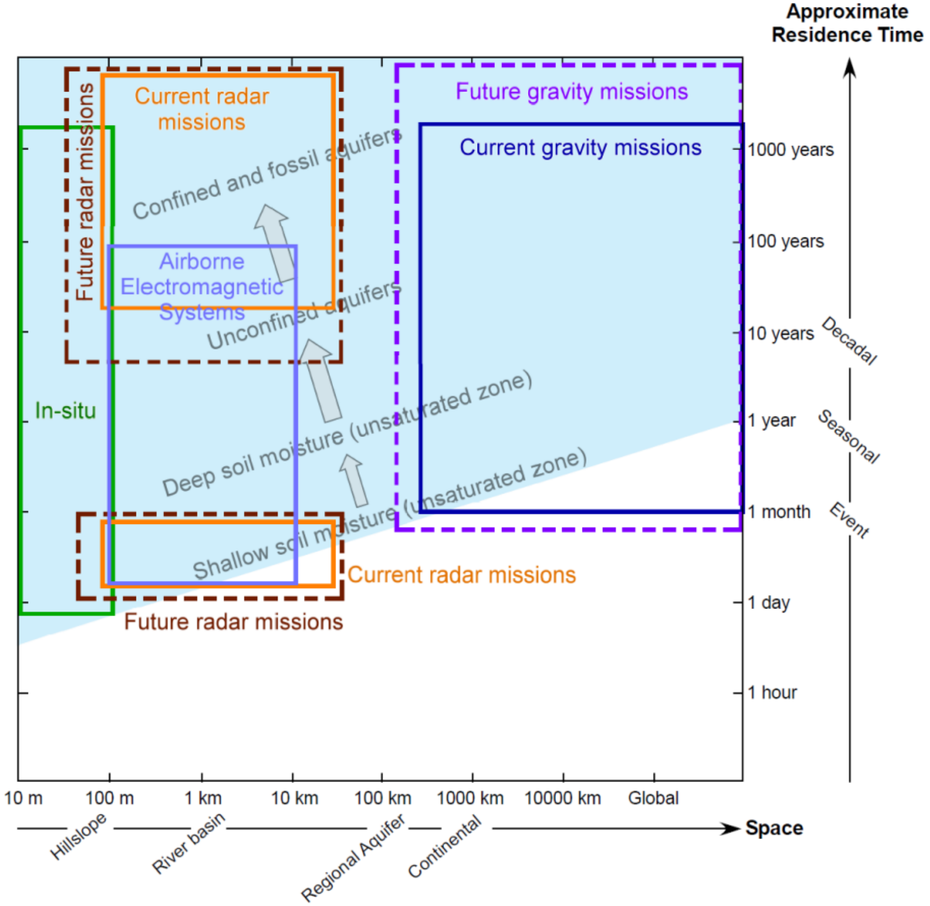
Airborne Electromagnetic Systems



AEM (SkyTEM) system acquiring data over the San Joaquin Valley, California, b. simplified schematic of AEM system, idealized magnetic fields shown as dashed lines, c inverted resistivity acquired with AEM modified from Knight et al. (2018), water table shown as a dashed line

Future Advances and Potential Directions

Unique advantage: GRACE, GNSS, InSAR and Heliborne with terrestrial measurements



Adams et al,2022

Spatial and temporal scales of groundwater variability and where the various observational approaches sample. Current monitoring capabilities (solid lines) and potential future capabilities (dashed lines) are indicated. Different methods and technologies can be integrated to synthesize a holistic groundwater measurement depending on the target research question

Gravity-based missions (limit the spatial resolution to ~100 km length scales)
InSAR: typical region of interest for studying aquifers is of order 100 km x 200 km

NASA-ISRO SAR (NISAR) mission will launch in the coming years and will provide global sampling every 12 days at L-band.

Conclusions:

- Geodetic science uses observations of the Earth's changing shape, rotation, and gravity field to inform us about the changing climate. Geodetic observations provide information on regional as well as global changes in the water cycle, the thickness and extent of ice cover, sea level, and other changes in ocean dynamics.
- Hydro-Geodetic studies: We aim to facilitate the use of GNSS/GPS, InSAR & GRACE (TWS)-observed surface deformation as an emerging tool for investigating and quantifying water resources.

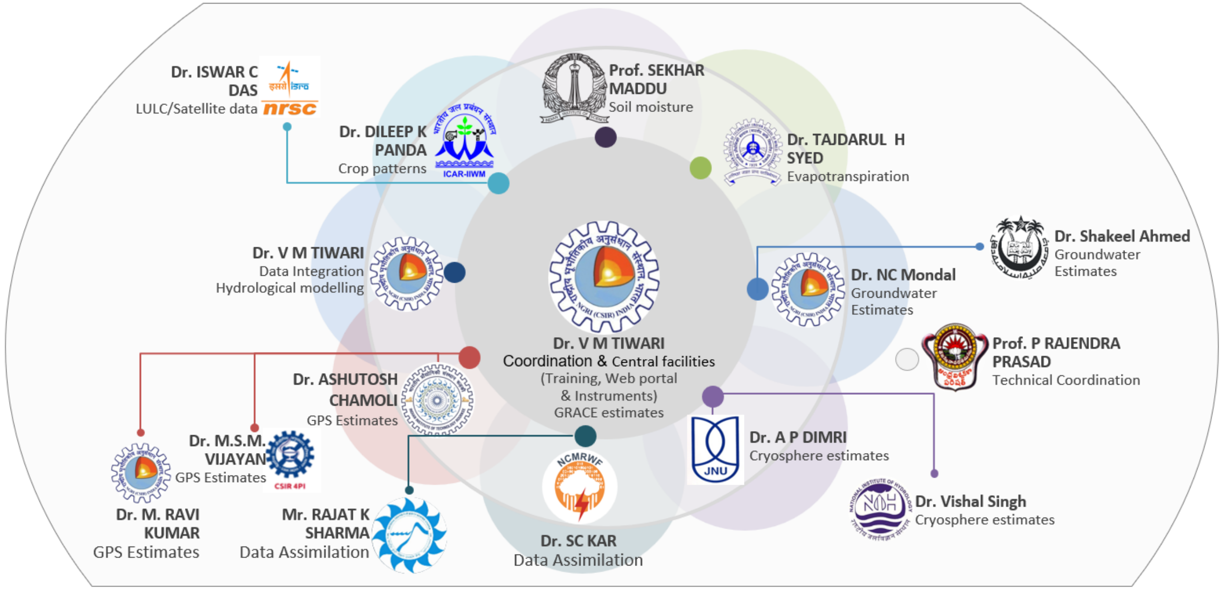
If you can **dream** it, you can **do** it

-Walt Disney

Thank you for your kind attention

Acknowledgement

सत्यमेव जयते
Department of Science and Technology (DST)
DST



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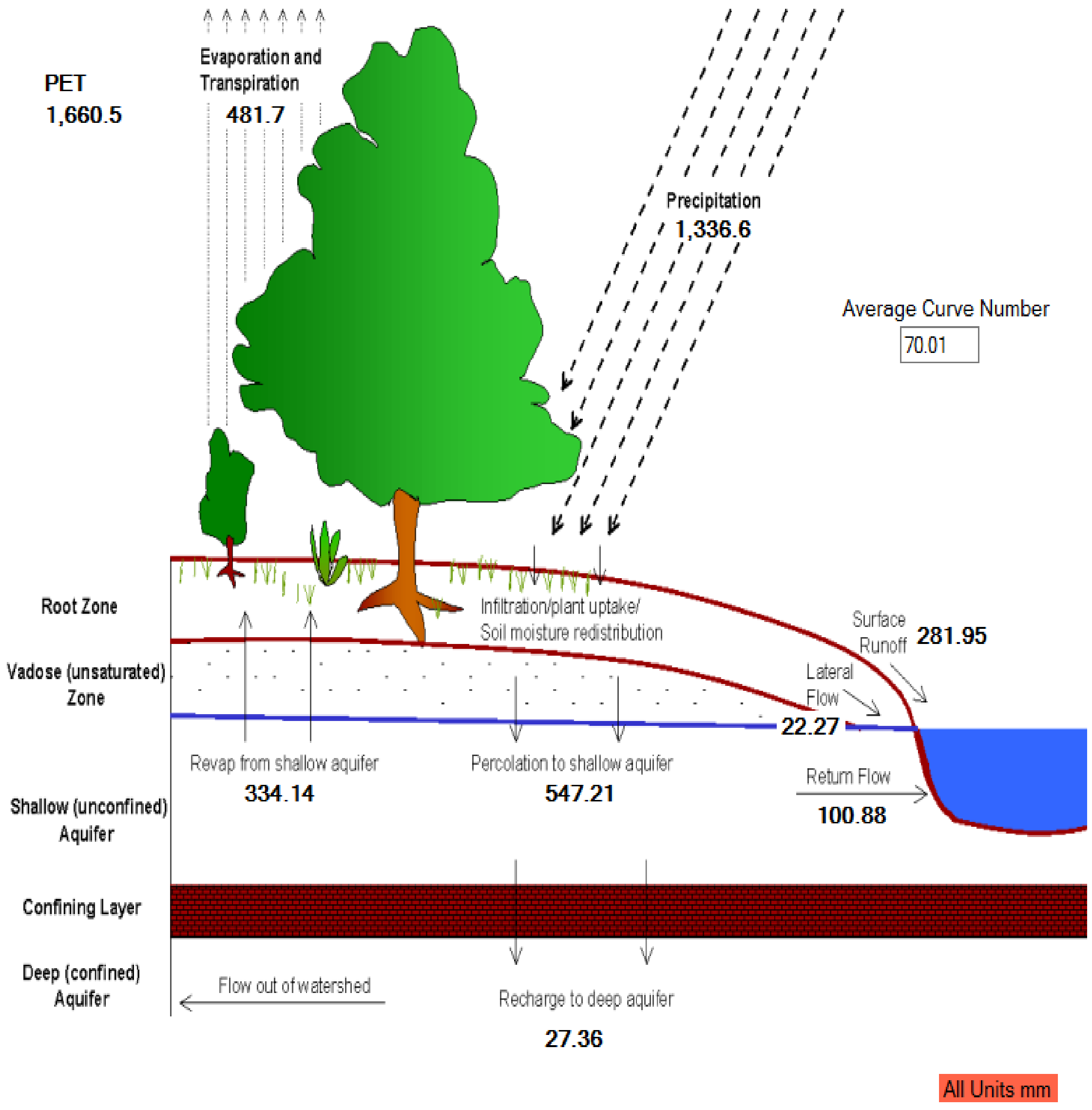
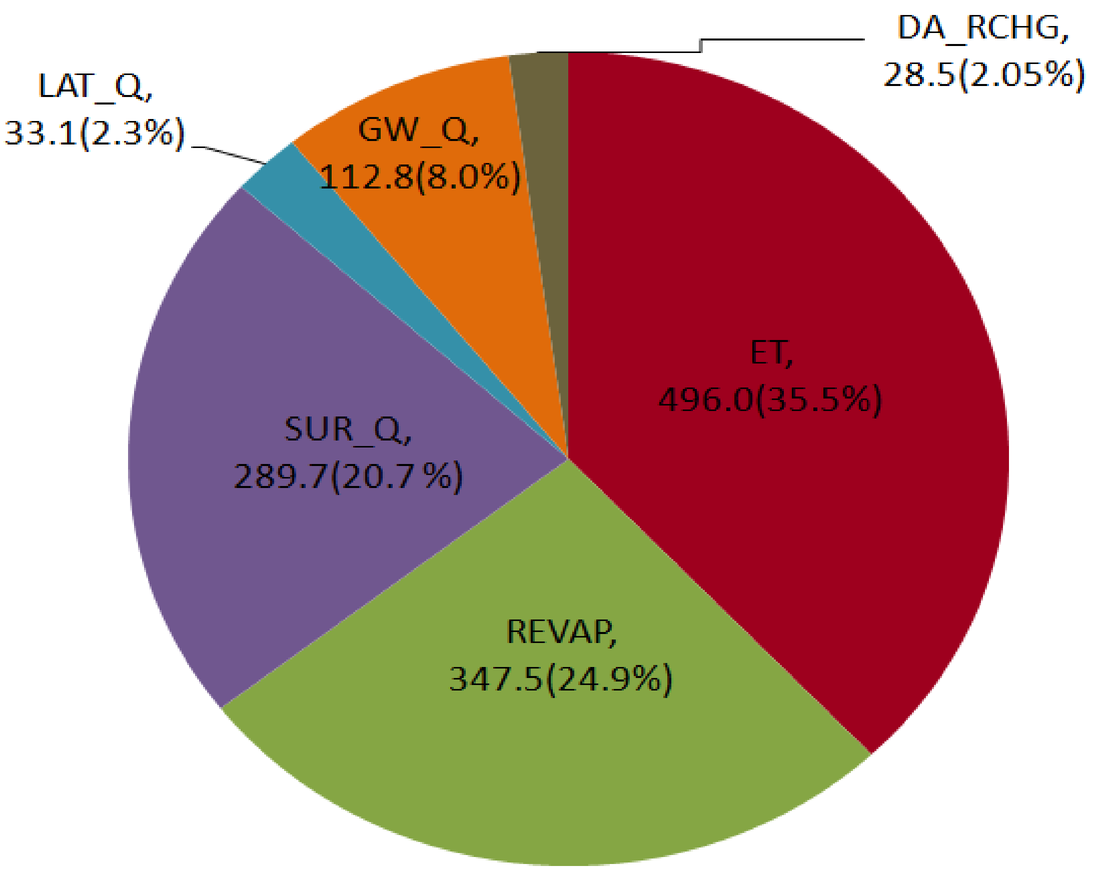
Thank you for your kind attention

Annual average





Annual averages of water balance components