Satellite Observations and Modelling of Space Geodetic Data for Terrestrial Applications

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Assessment of Regional Hydrological Systems using Space Borne Gravity Observations

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

[Diagram showing various project components and the central coordination facility]

National Network Project

National Geospatial Policy (NGP)
Regional Hydrological Advisors
TWS at basin scale
Evapotranspiration
Glacier Hydrology
Basin-Scale Drought & Hot-spell severity
Crustal deformation & Geodynamics
Knowledge Hub Data facility & Dissemination Centre Capacity Building
Central Facility & Coordination CSIR-NGRI

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.

website address: http://grace.ngri.res.in/
Satellite Geodetic Missions (Gravity)

- **Gravity satellites**
  - Gravity from:
    - satellite orbits
    - satellite orbit differences
    - acceleration differences (direct gravity functional)

- **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

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**STATIC / TIME VARYING GRAVITY FIELD**

- **Static gravity field**
  - Spatial resolution >70 km
  - Globally homogeneous accuracy

- **Temporal gravity variations**
  - Long-wavelength
  - Weekly to monthly
Gravity Recovery and Climate Experiment (GRACE)

We now have **two decades** of unique monthly Earth system **Mass Change** observations!

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

\[ \Delta TW S_{GRACE} = \Delta S_{groundwater} + \Delta S_{canopy} + \Delta S_{snow} + \Delta S_{soil} + \Delta S_{lakes} + \Delta S_{wetlands} + \Delta S_{river} \]

\[ \Delta S_{groundwater} = \Delta TW S_{GRACE} - \Delta S_{canopy} - \Delta S_{snow} - \Delta S_{soil} - \Delta S_{lakes} - \Delta S_{wetlands} - \Delta S_{river} \]

Limitations
Gravity Recovery and Climate Experiment (GRACE)

Contributions of GRACE: Applications (Global)  Polar Ice Mass Loss from GRACE Satellite

Rodell, M, 2018, Nature

Source: https://svs.gsfc.nasa.gov/30879
Northern India, Bangladesh, and Pakistan is the most heavily irrigated region on earth.

Data from the Food and Agriculture Organizations of the United Nations

Water mass loss from northern Indian Region about ~ 30 km³/yr

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

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

Northern India, Bangladesh, and Pakistan is the most heavily irrigated region on earth. Tiwari et al, 2009
# Water Budget of Ganga River Basin

<table>
<thead>
<tr>
<th>Data Type</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>DEM (Raster)</td>
<td>Shuttle Radar Topographic Mission (SRTM) 90m</td>
</tr>
<tr>
<td>Land Use (Raster)</td>
<td>USGS Global Land Cover (GLCC)</td>
</tr>
<tr>
<td>Soil (Raster)</td>
<td>Food and Agriculture Organization (FAO)</td>
</tr>
<tr>
<td>Drainage (Vector)</td>
<td>HydroSHEDS</td>
</tr>
<tr>
<td>Flow data (Point data)</td>
<td>Central Water Commission (CWC)</td>
</tr>
<tr>
<td>Weather (Raster)</td>
<td>Global Weather Data for SWAT</td>
</tr>
</tbody>
</table>
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 account ~6-9%, Spring account ~6-11%, Summer account ~47-51%, Autumn accounts ~33-38% ET from total annual ET

Source: Tajdarul H. Syed
▪ 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.

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

Three Hydra Probe soil sensors installed 3 distinct soil horizons.
Glimpses of GNSS – SOI observatories

Journey from WEST to EAST

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11-10-2022
The use of GPS Horizontals and Vertical for loading

Global Navigation Satellite System stations (red triangles)


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

Tiwari et al., 2014.
GPS VERTICAL COORDINATES AS HYDROLOGIC SENSORS

Terrestrial water storage change inverted from GPS loading deformations

Argus et al, 2014

Borsa et al., Science; 2014

Fu et al, 2015 JGR
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

Interferogram: $\Delta \phi = \phi_1 + \phi_2$

Source: GRACE Network Project CSIR-NGRI
Methodology of Time Series InSAR and Results

- Import SLC and orbits files and select burst from each acquisition
- Select reference and prepare DEM and geocode reference
- Co-register SLCs Deramp, Oversample Range, Crop AOI
- SLC Point Data (pSLC, pgar, ppox, phase)
- Point List (plist, pmask)
- Input Data: RSLC's, Height Map, tab
- Differential Interferometric point data (psdiff)
- IPTA: (dh, ddef, sigma, diam, res, pmask)
- Modal Refinement: (lgt, def, sigma, ums, atm, res-atm, pmask)
- Deformation Results: Time series, average rate, and ASCII files

Iteration
Pre-Processing
Post-Processing

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.

[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.
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

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.

Adams et al, 2022
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

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Virendra M. Tiwari

2nd UNWGIC-2022

11-10-2022

"Walt Disney"
Acknowledgement

If you can dream it, you can do it

Walt Disney

Thank you for your kind attention
Annual averages of water balance components

- **ET**: 496.0 (35.5%)
- **SUR_Q**: 289.7 (20.7%)
- **REVAP**: 347.5 (24.9%)
- **GW_Q**: 112.8 (8.0%)
- **LAT_Q**: 33.1 (2.3%)
- **DA_RCHG**: 28.5 (2.05%)

**Annual average**

- PET: 1,680.5
- Evaporation and Transpiration: 481.7
- Precipitation: 1,398.8
- Average Curve Number: 70.01

**Components**

- Root Zone
- Vadose (unsaturated) Zone
- Shallow (unconfined) Aquifer
- Confining Layer
- Deep (confined) Aquifer

**Flow**

- Flow out of watershed
- Recharge to deep aquifer
- Return Flow

**Units**: m

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