The hydrological links between groundwater dynamics and land-energy feedbacks in the Ganges basin

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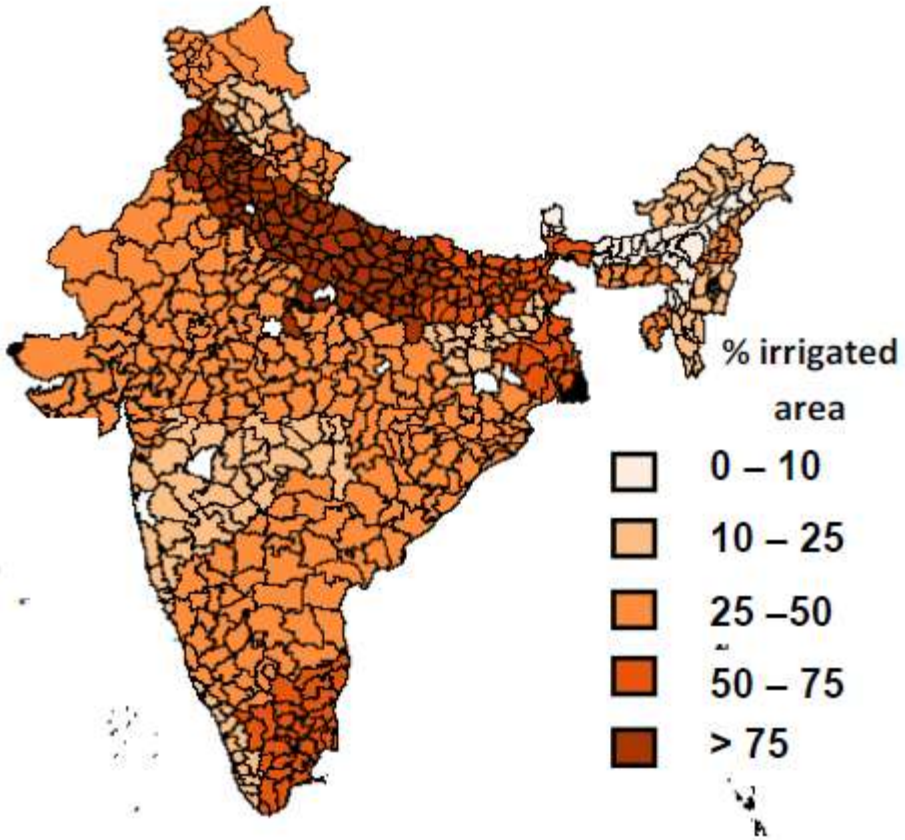
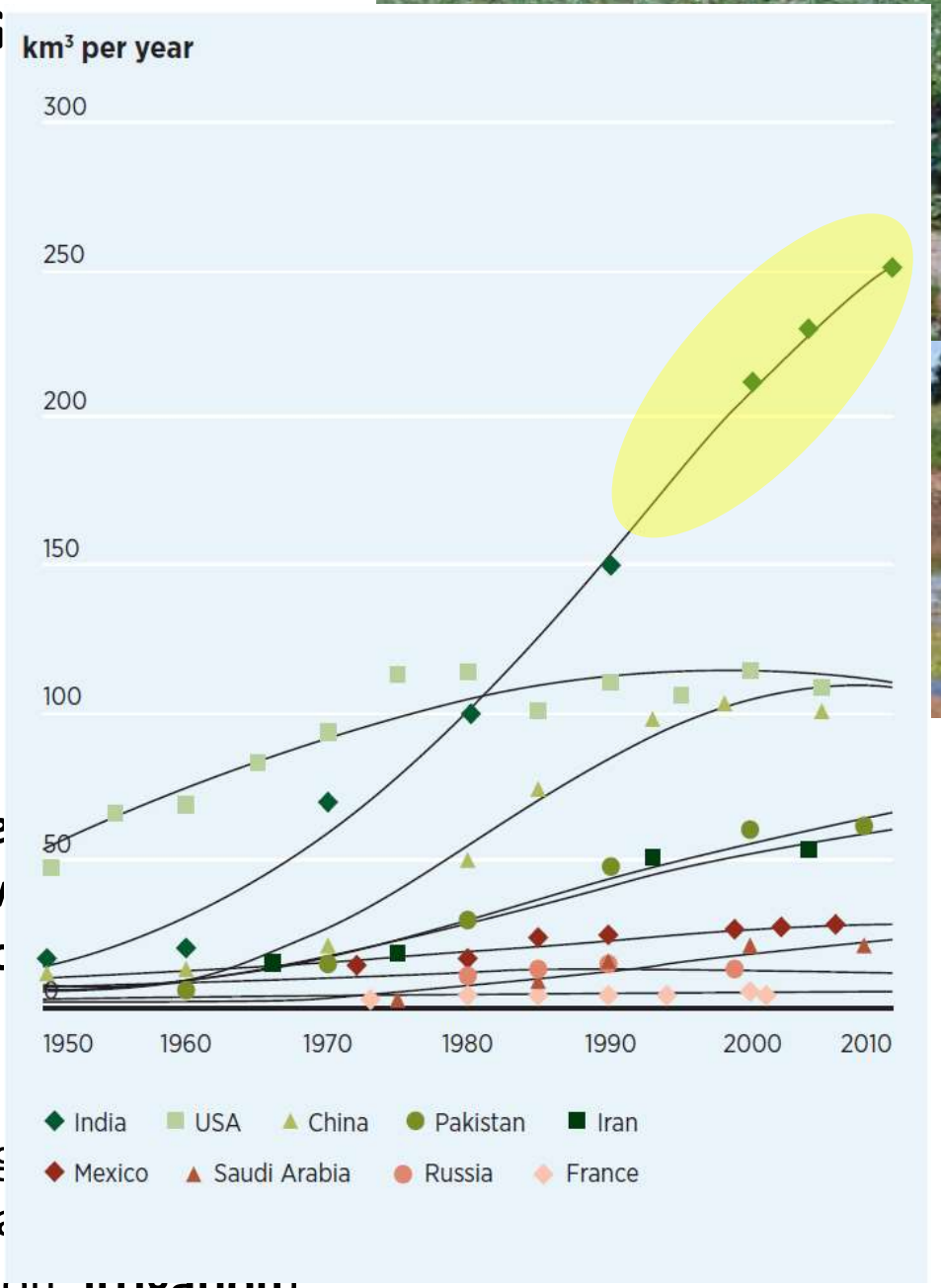
Indo-UK Workshop on Future Ganga: Science Needs for Water Security
3rd December 2015, New Delhi

General context : WATER and AG

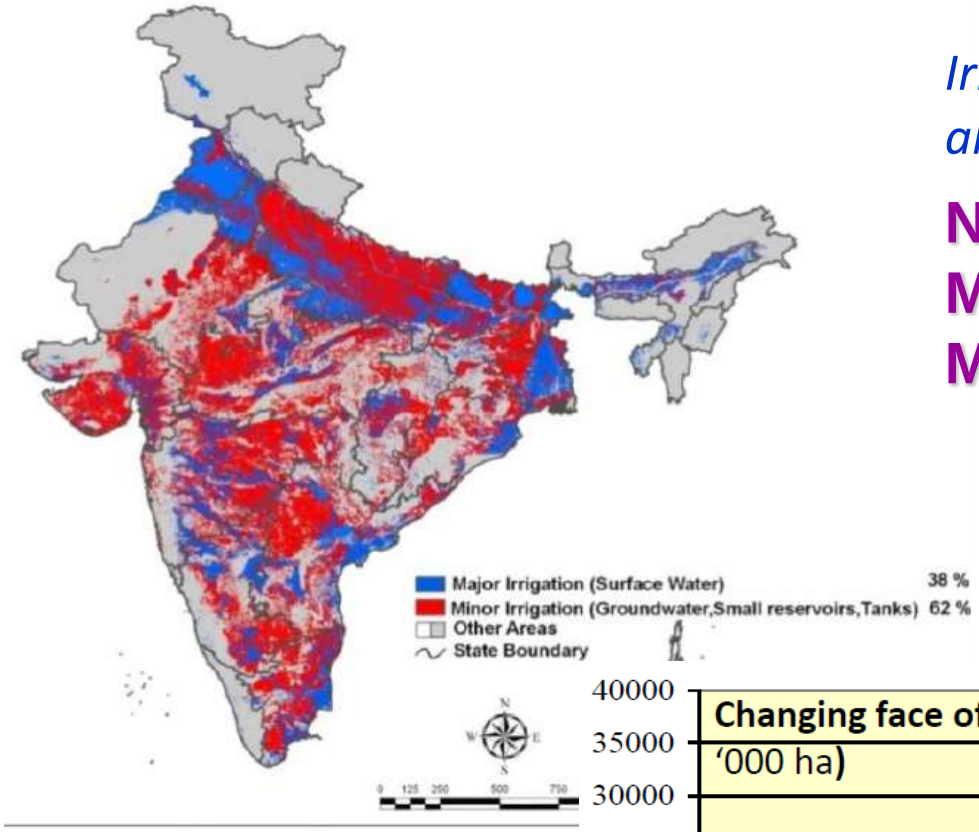




Through:

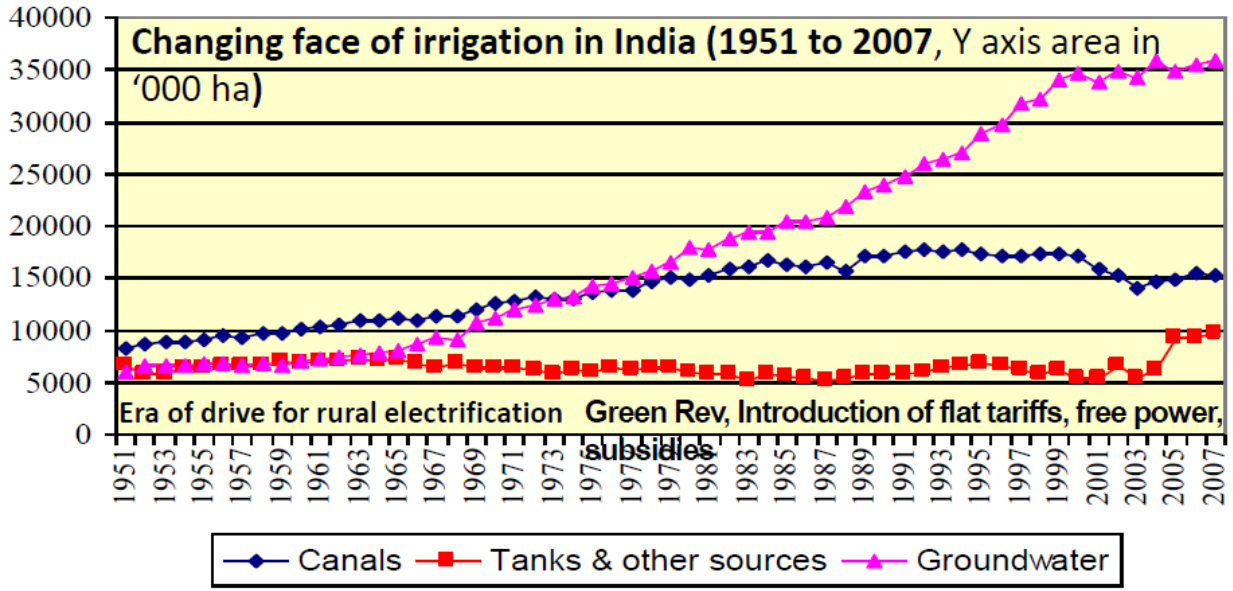
- Improved potential of crops through g
- **increased inputs** to reach that potentia
  (e.g. pesticides, fertilisers, mechanisation, irrigation)

Groundwater abstraction trends



Irrigated area Map using RS Thenkabail et al. (2010)

Net Irrigated area = 146 Mha
Major Irrigation = 55 Mha
Minor Irrigation = 91 Mha



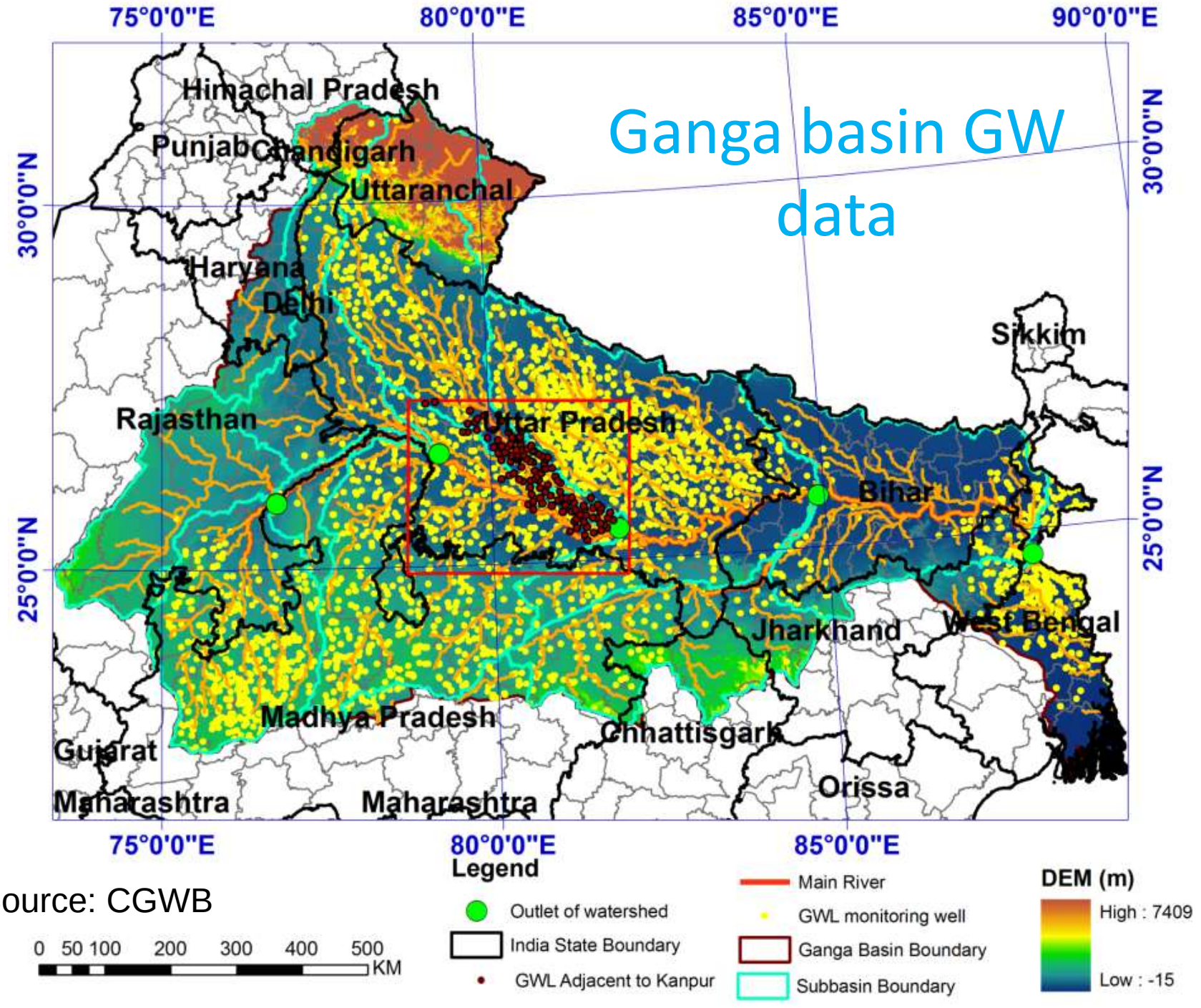
Agricultural Census, GOI

Groundwater pumping & ET – Ganges basin

Science Question

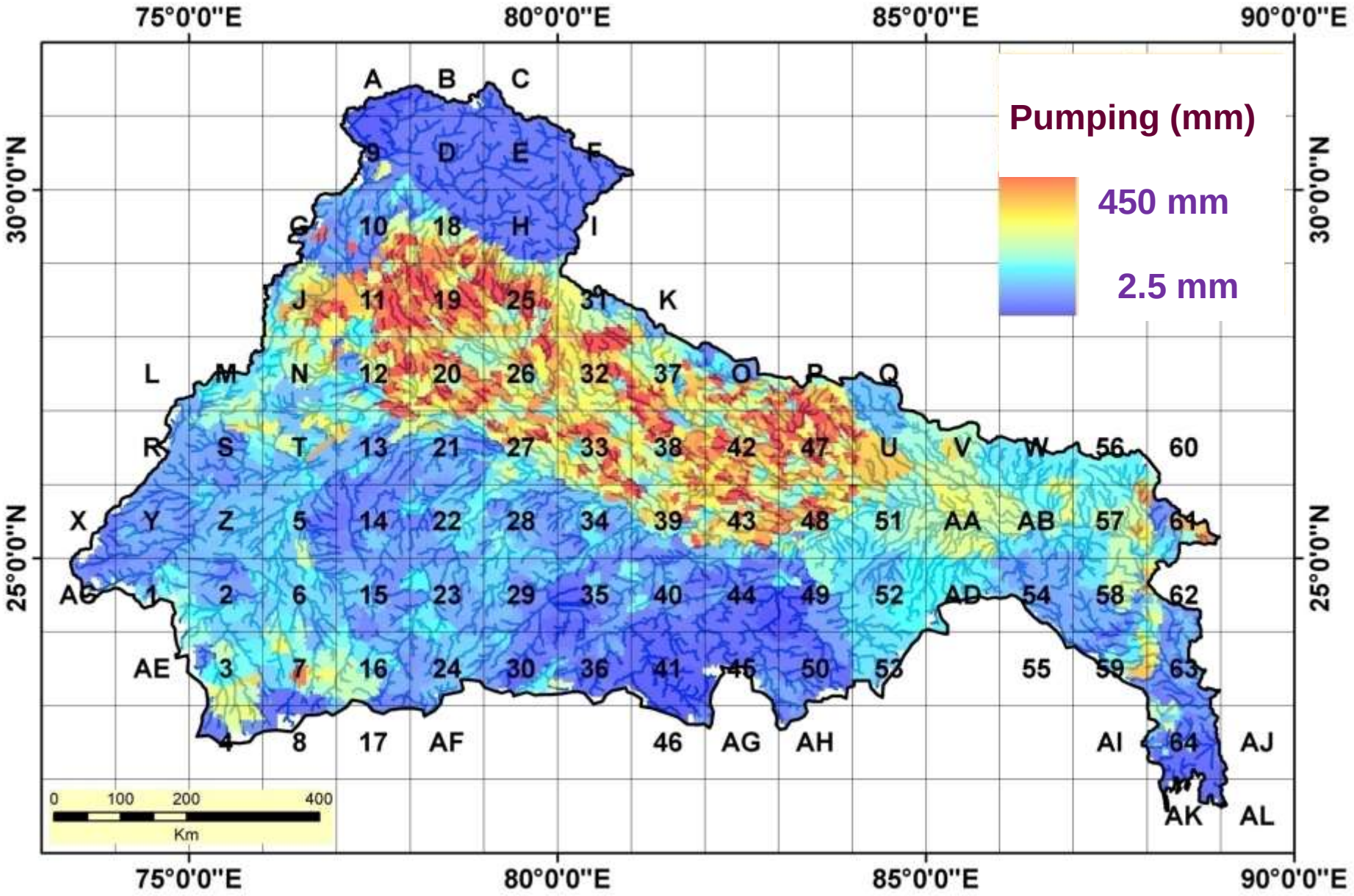
To what extent do the large-scale, human-induced land use changes and groundwater depletion that have taken place in India feed back to the hydrological and climate system at a basin scale?

MoES-NERC project: Hydrometeorological feedbacks and changes in water storage and fluxes in Northern India


Ganga basin GW data
75°0'0"E
80°0'0"E
85°0'0"E
90°0'0"E
30°0'0"N
25°0'0"N
Himachal Pradesh
Punjab
Chandigarh
Uttaranchal
Haryana
Delhi
Rajasthan
Uttar Pradesh
Sikkim
Bihar
Jharkhand
West Bengal
Madhya Pradesh
Chhattisgarh
Gujarat
Maharashtra
Maharashtra
Orissa
Legend
Outlet of watershed
India State Boundary
GWL Adjacent to Kanpur
Main River
GWL monitoring well
Ganga Basin Boundary
Subbasin Boundary
DEM (m)
High : 7409
Low : -15
0 50 100 200 300 400 500
KM

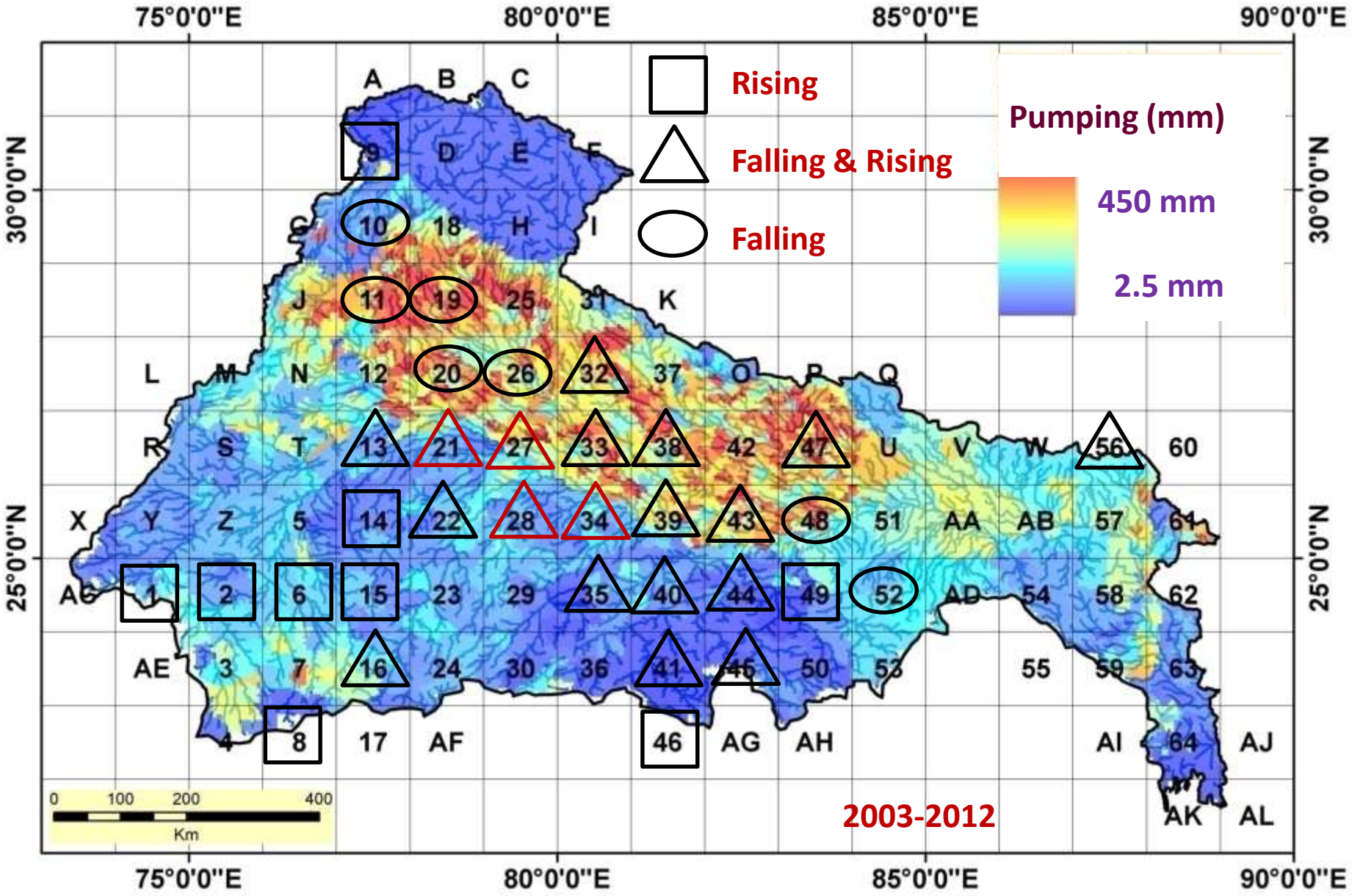
Source: CGWB

Groundwater Pumping



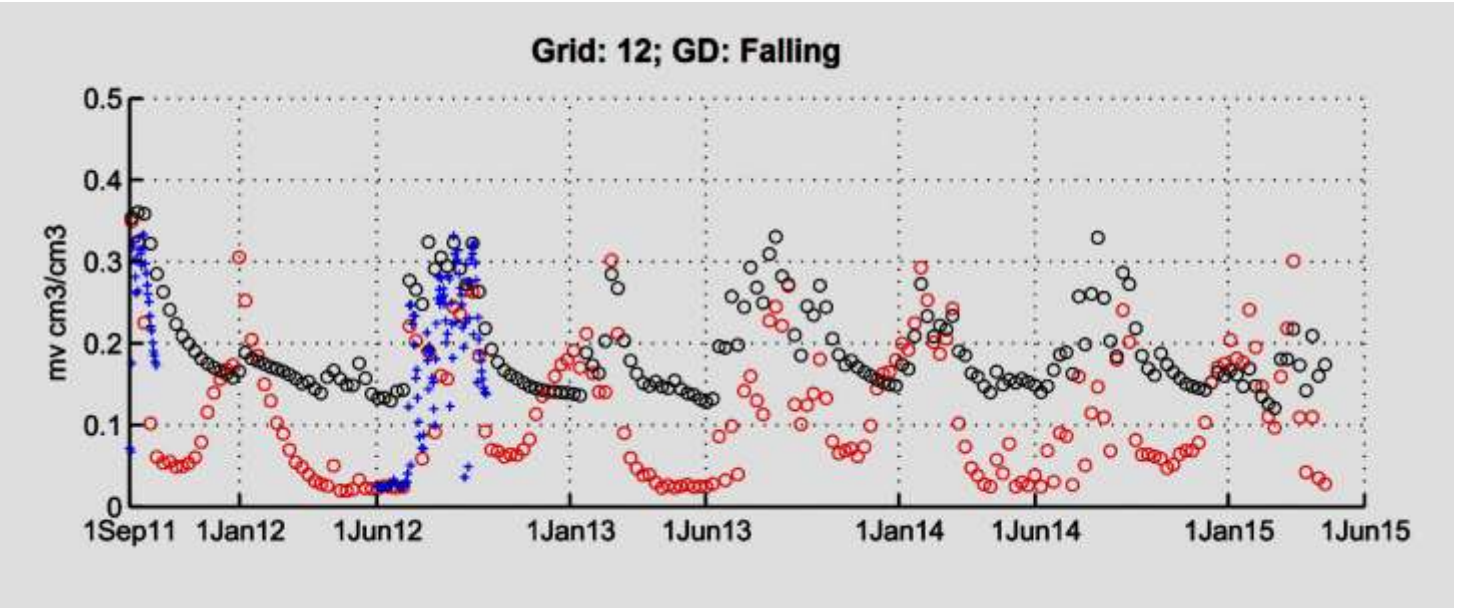
Source: CGWB

Groundwater System behavior

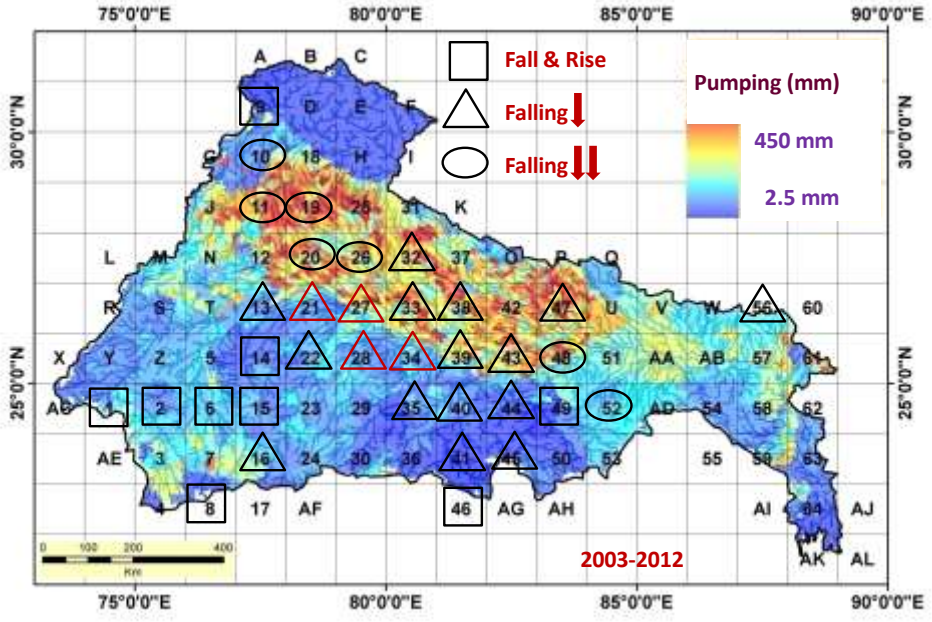


Source: CGWB

Aquarius Radar and CTCZ Soil Moisture Time Series

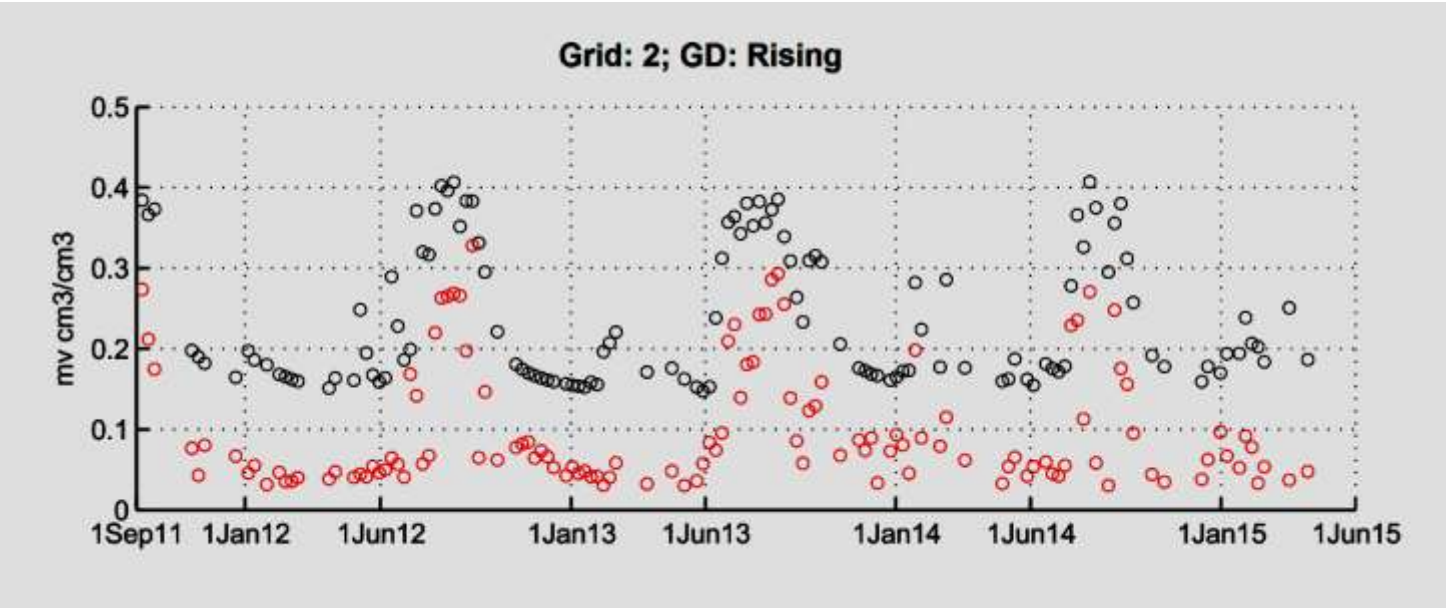


Aquarius: Red
NCEP: Black
CTCZ: Blue



During Jan-Feb, high soil moisture estimated from Aquarius satellite, (not estimated from NCEP), therefore indicator of high level irrigation activity.

Aquarius Radar and CTCZ Soil Moisture Time Series



Aquarius: Red
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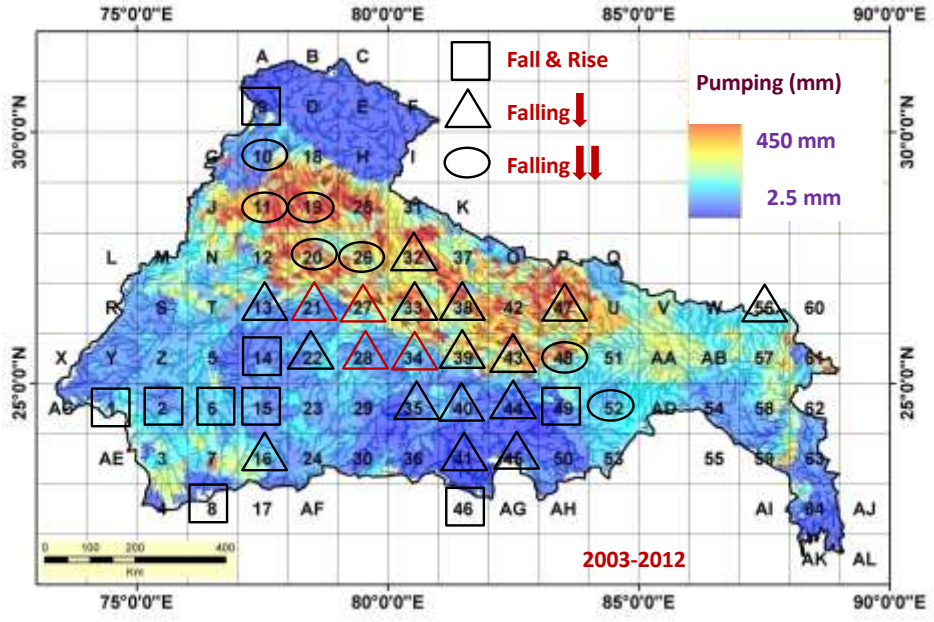
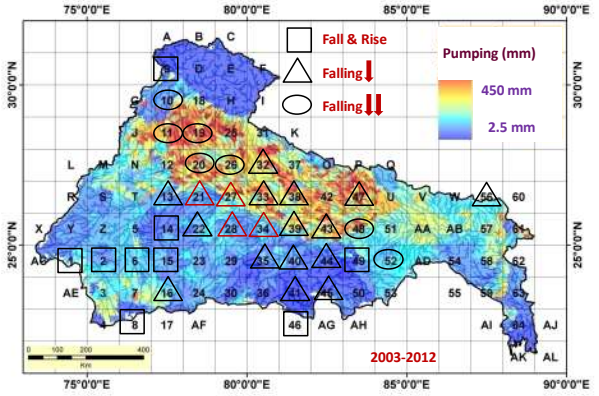
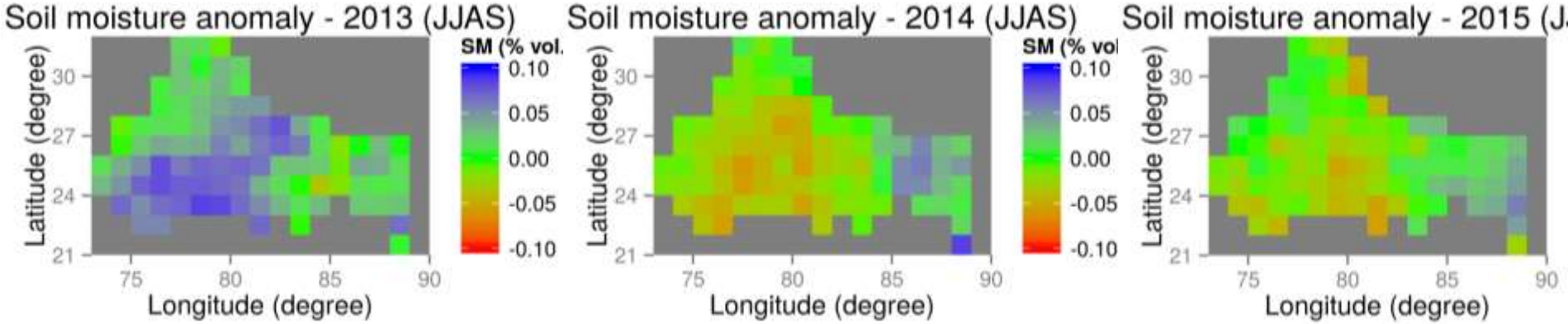
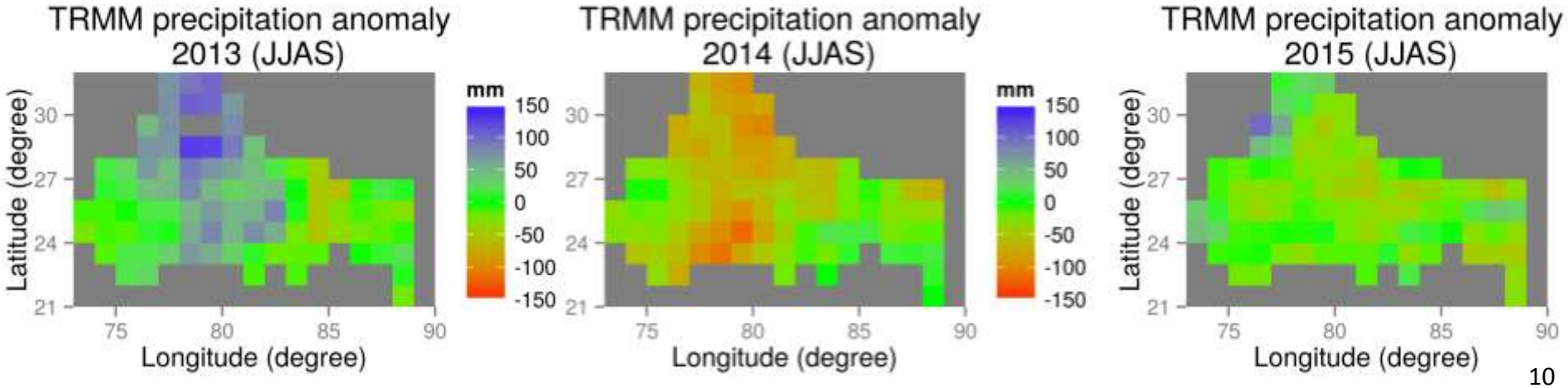


During Jan-Feb, no considerable high soil moisture events.

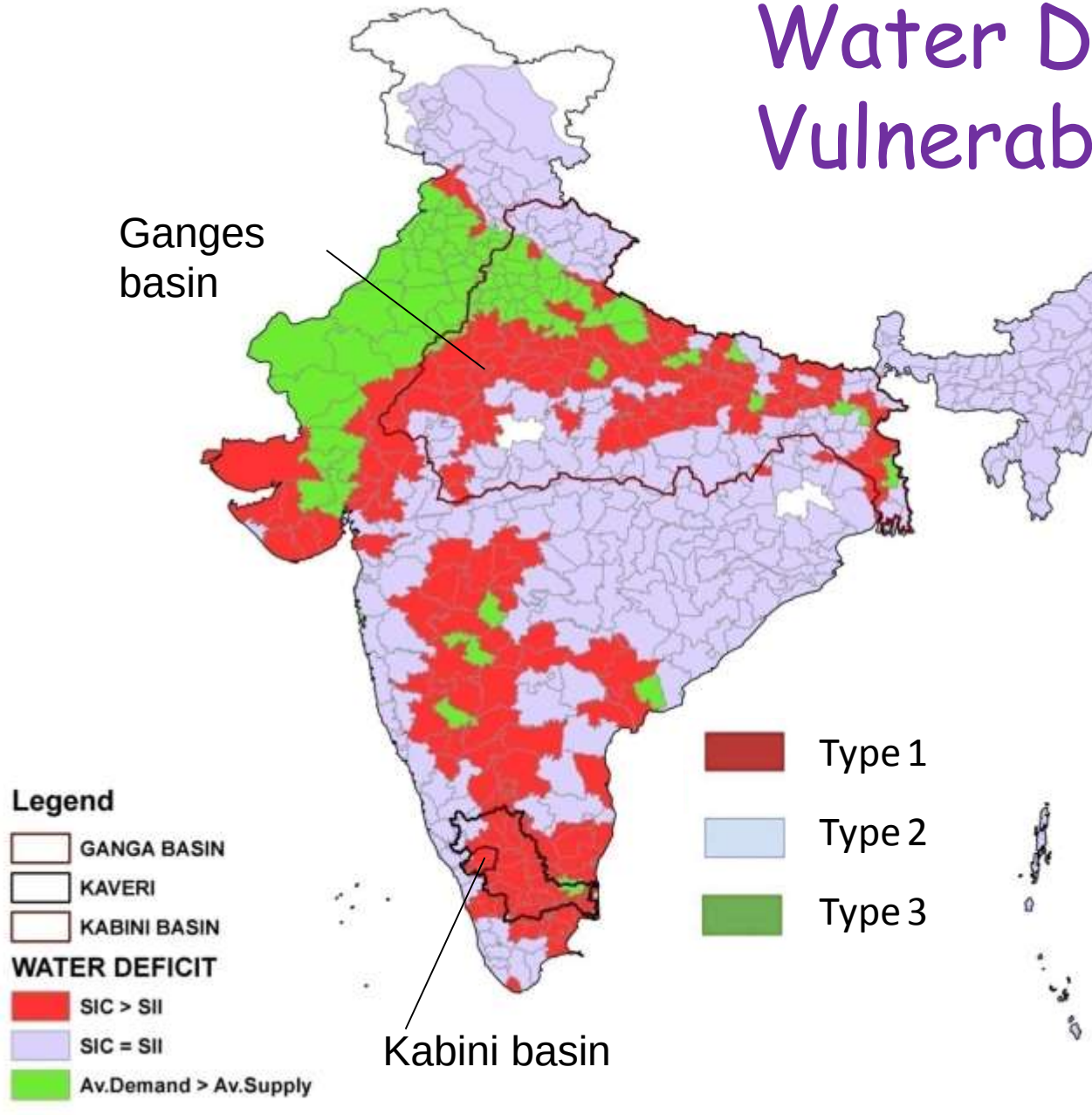
Soil Moisture Anomaly







Water Deficit and Vulnerability



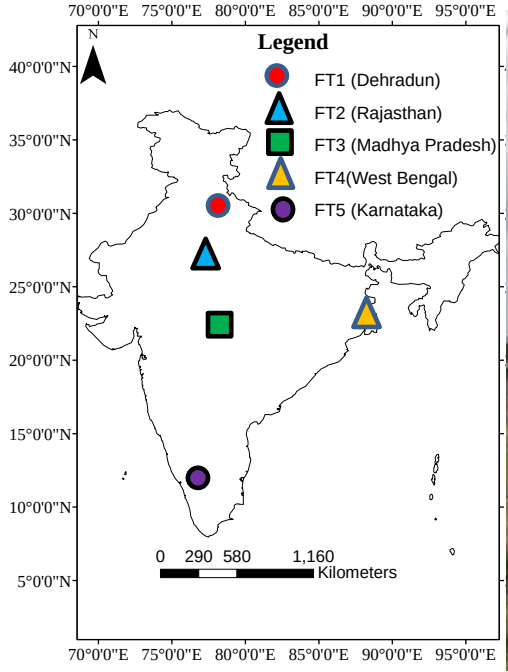
Type 2 – The deficit of water storage is filled up during each monsoon year.

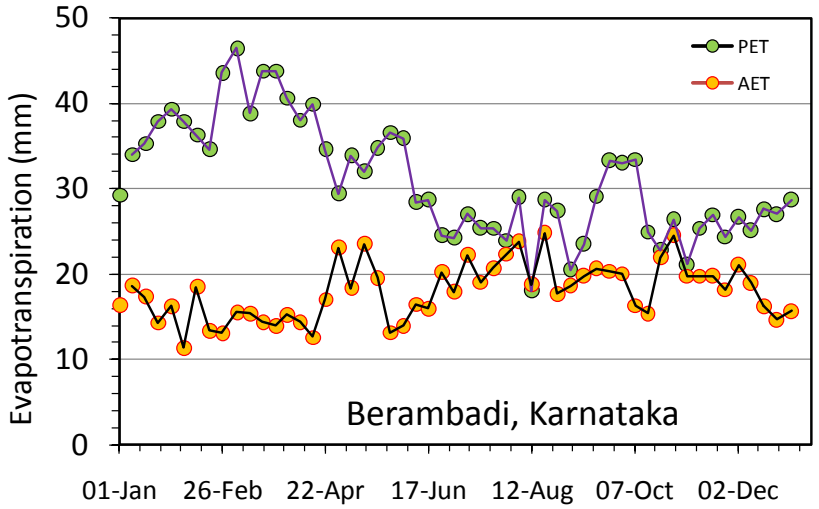
Type 1 – The water storage deficit is unlikely to be filled up during each monsoon year and would require a few monsoon years to overcome the deficit

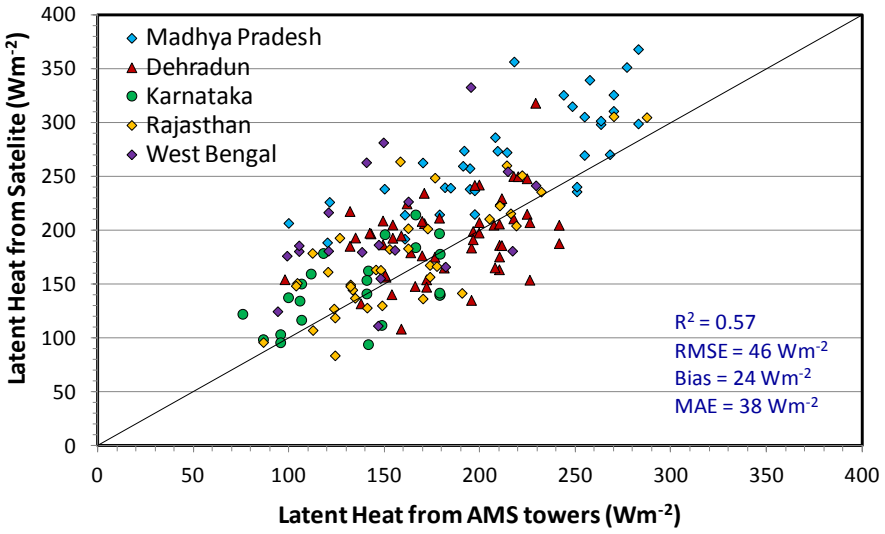
Type 3 – Average demand is in excess of supply so each year is deficit.

Source: Devineni et al. (2013) *WATER RESOURCES RESEARCH, VOL. 49, 2135–2145.*

Modeling Evapotranspiration from Remote Sensing







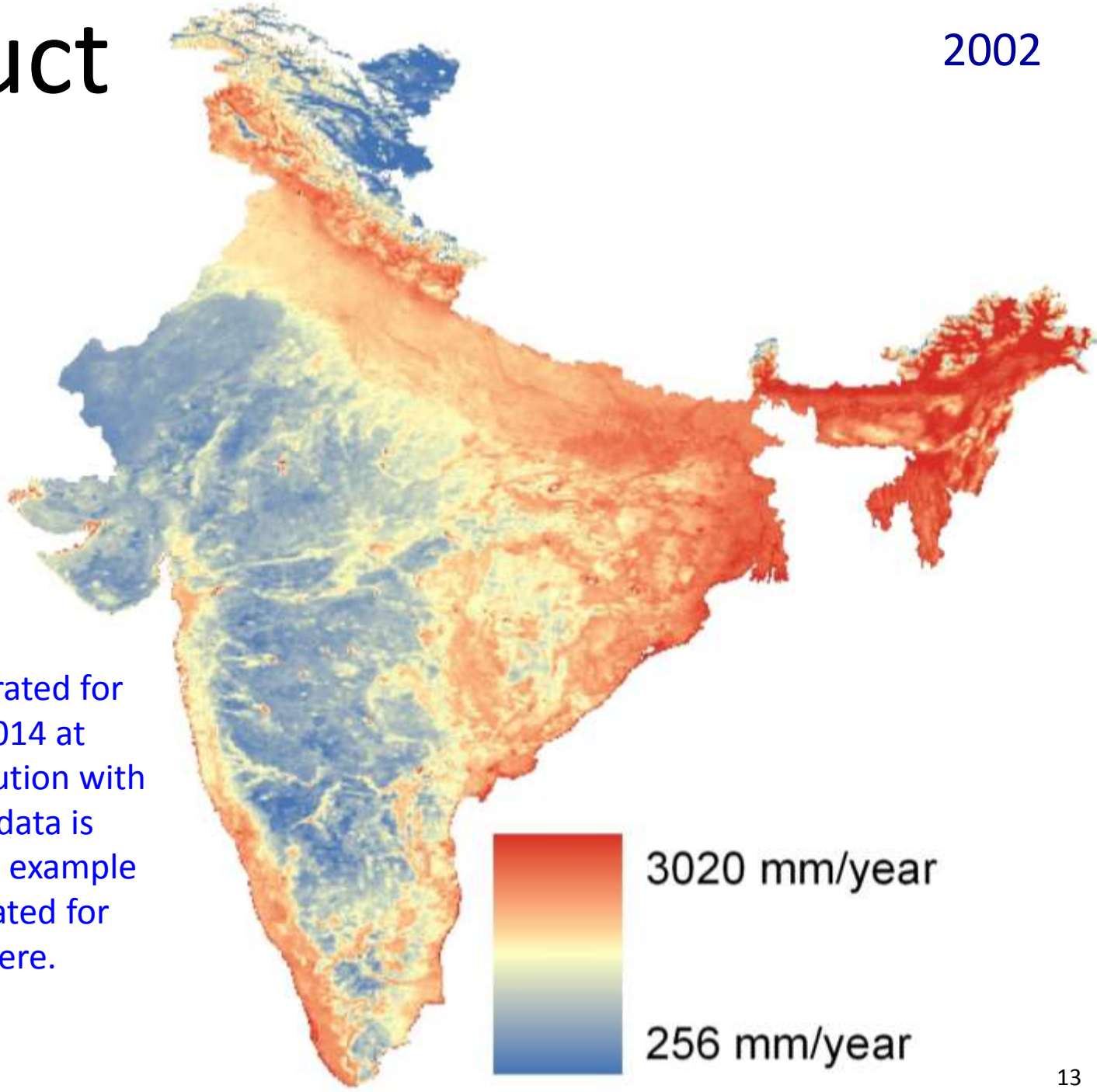
- The ET was estimated using **S-SEBI** and **Triangle** methods. Five sites with about 200 plus clear sky images from Terra and Aqua were used during 2009-12. It was observed that the **Triangle** method performed well with ground observations from the BREB towers of Energy, Mass Exchange project of SAC, ISRO.

Eswar, Sekhar, Bhattacharya (2013) Journal of Geophysical Res- Atmosphere

ET Product

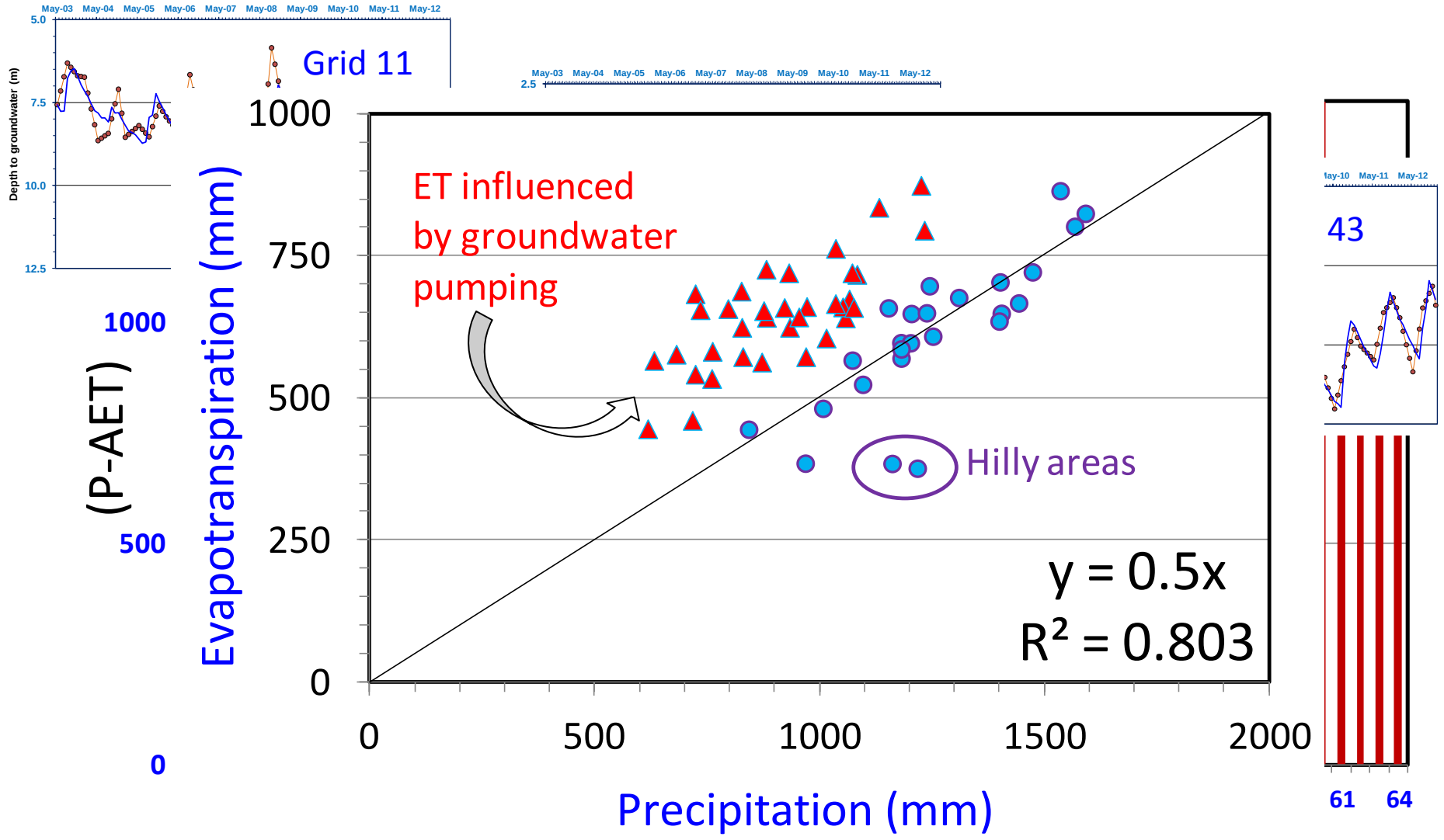
2001-2014

2002



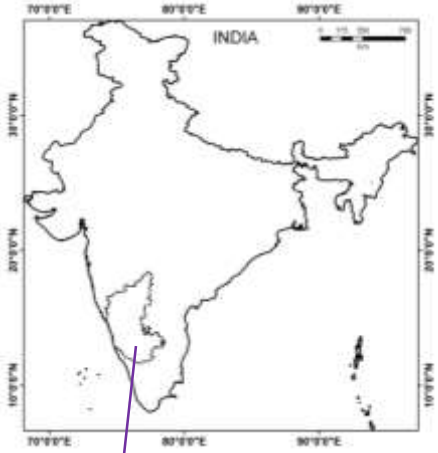
ET product is being generated for entire India from 2001-2014 at 0.05 degree spatial resolution with 8-day frequency. MODIS data is used for this purpose. An example of this ET product cumulated for the year 2002 is shown here.

Groundwater Pumping induced ET

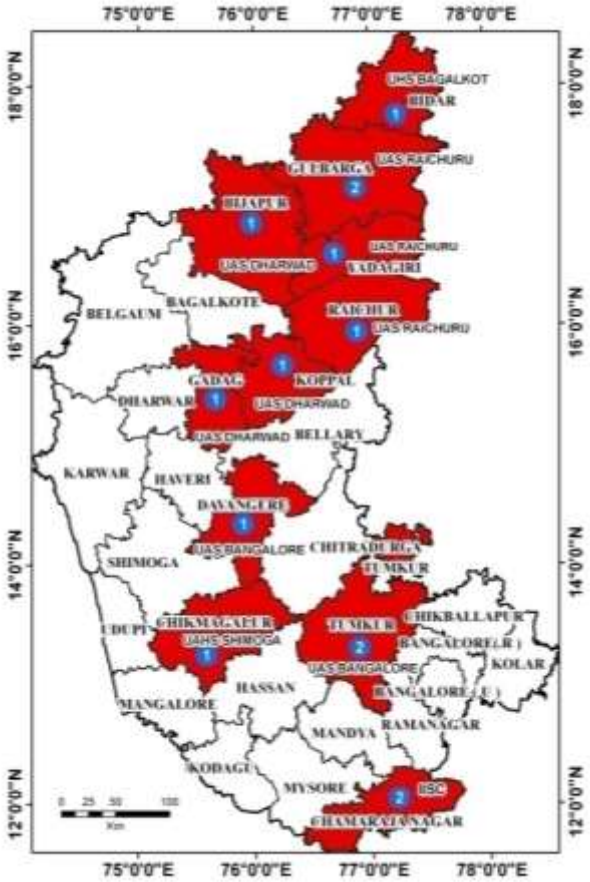


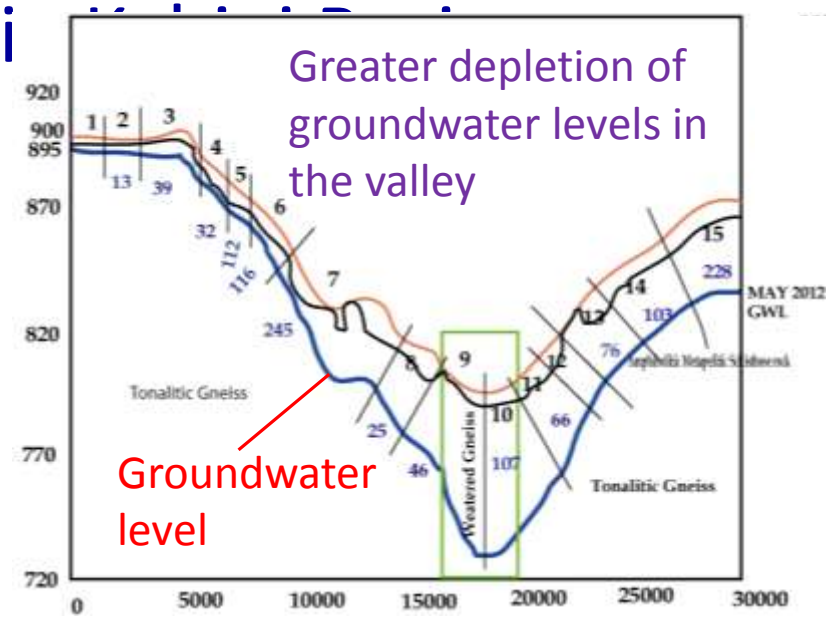
Evapotranspiration simulated is able to capture the trends induced by groundwater pumping

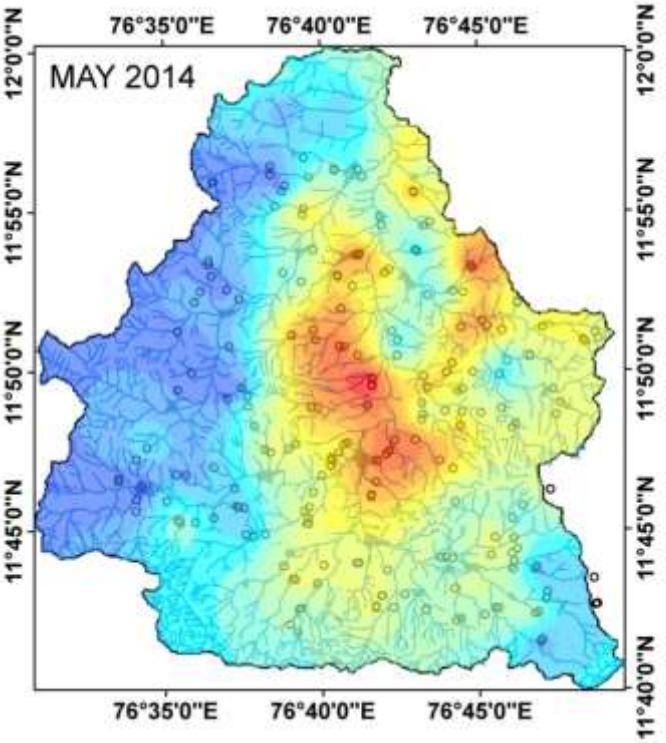
Data Centric Approach i



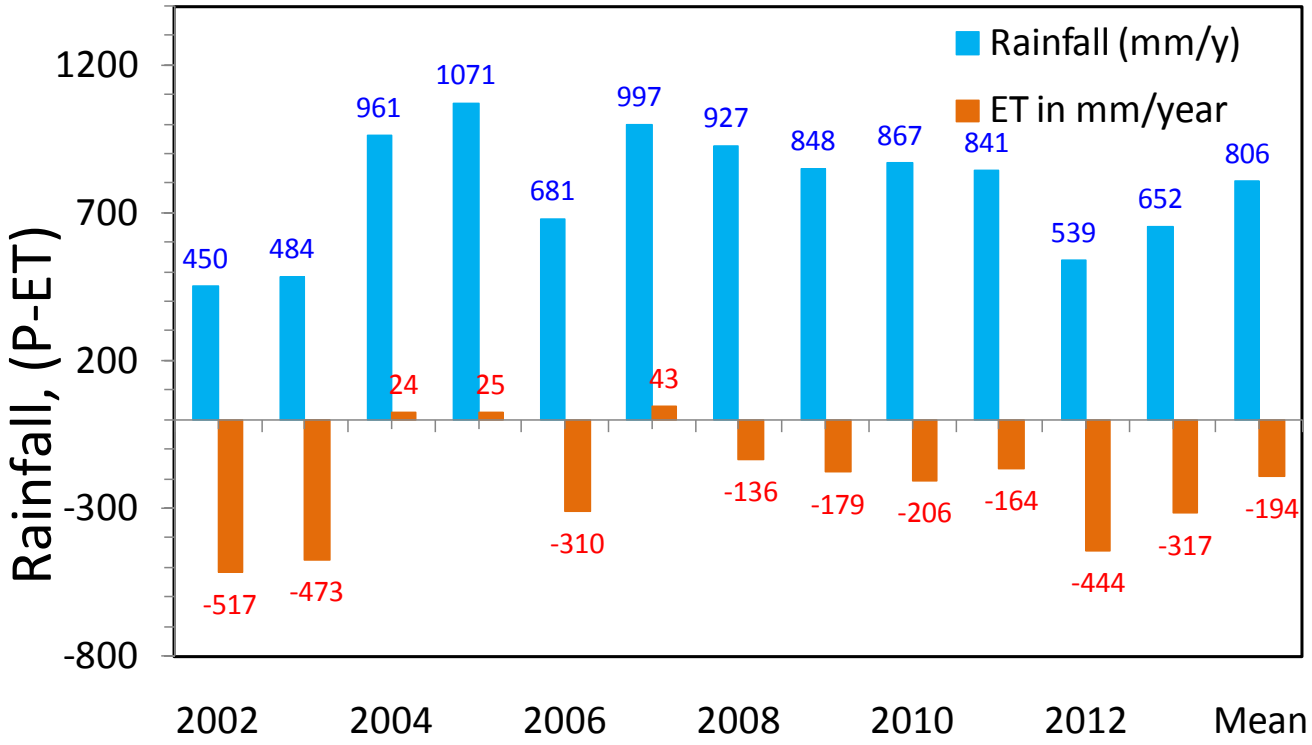
Karnataka State

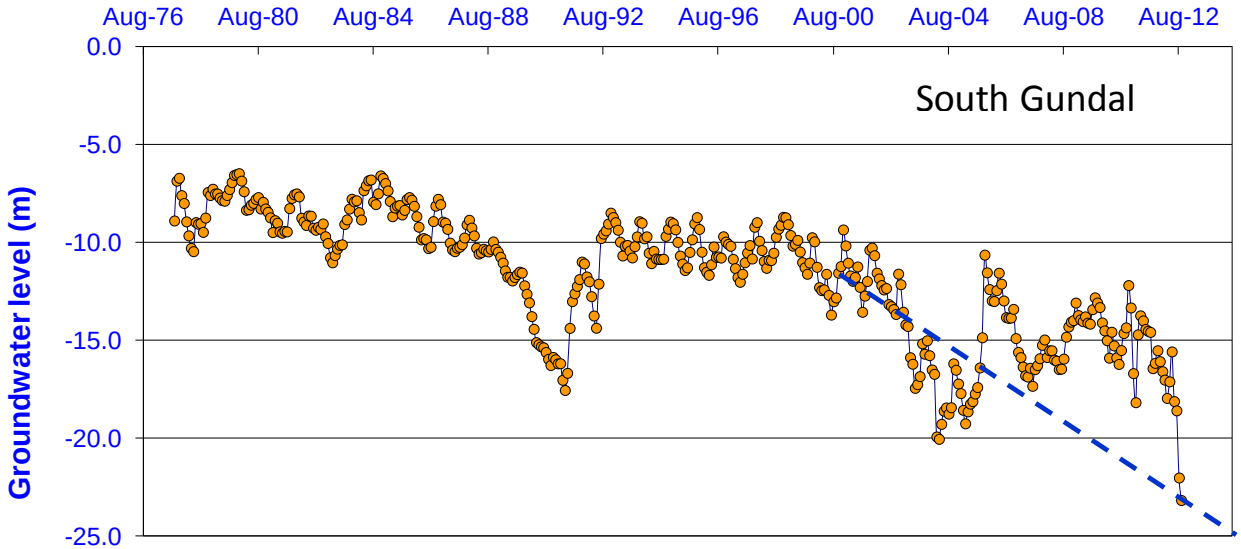






Precipitation – ET Trends



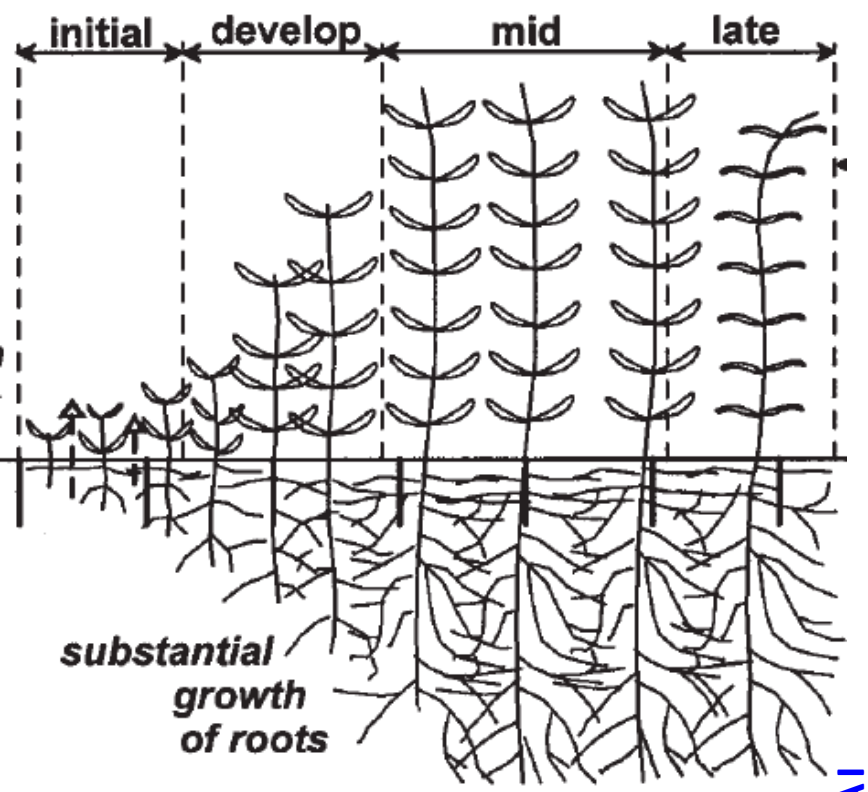


Mean (P-ET)
= 200 mm

For 10 years (2003-2013) (P-ET)
= 2000mm
= 2m

GWL change =
$2m / S_y$ =
20 m

Soil moisture & linkage to Crop Growth

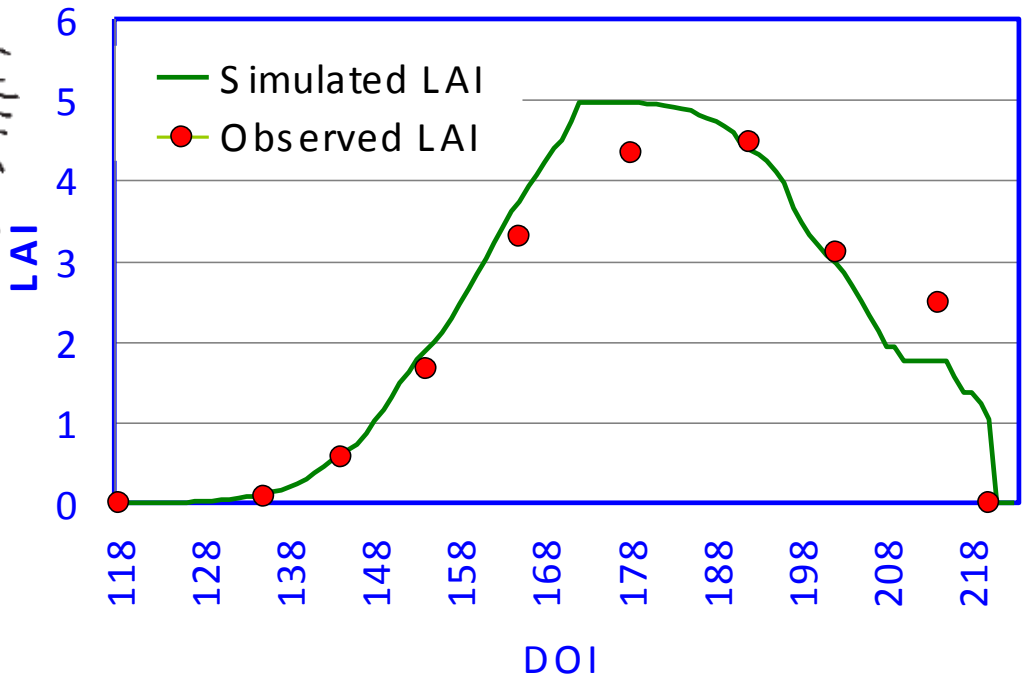


Function of -

- Climate Forcing
- Soil Properties

Moisture stress leads to poor growth of the crop & low yields

Sunflower – Kharif 2013

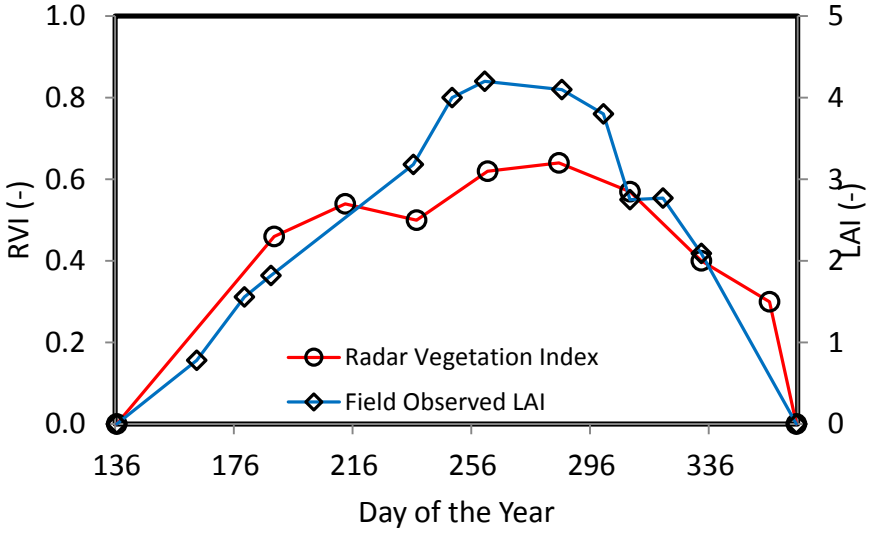


Irrigation Improvements & Efficiency

- Crop as a sensor to estimate the water stress.
- Integration of satellite and surface observations to support improvements in agricultural water resources management

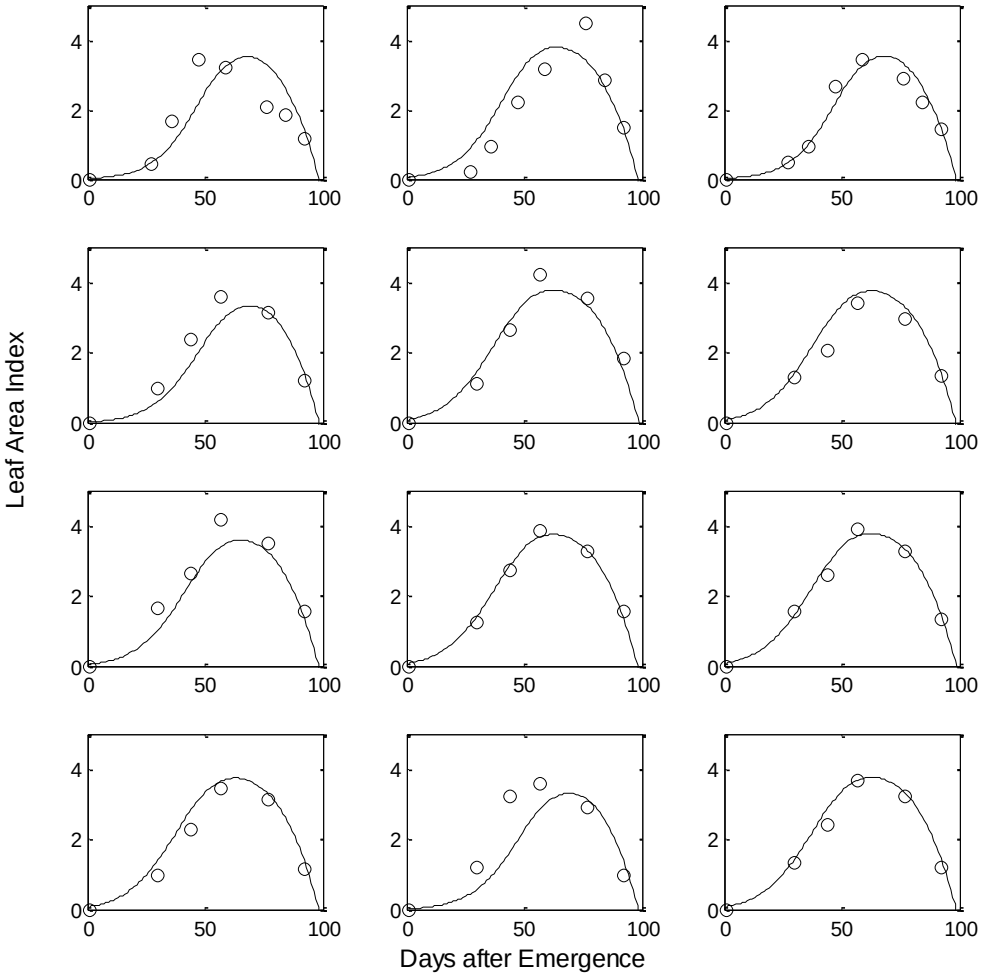
Characterization of Crop Canopies and Water Stress using Microwave Remote Sensing

Retrieval of LAI from RADARSAT-2



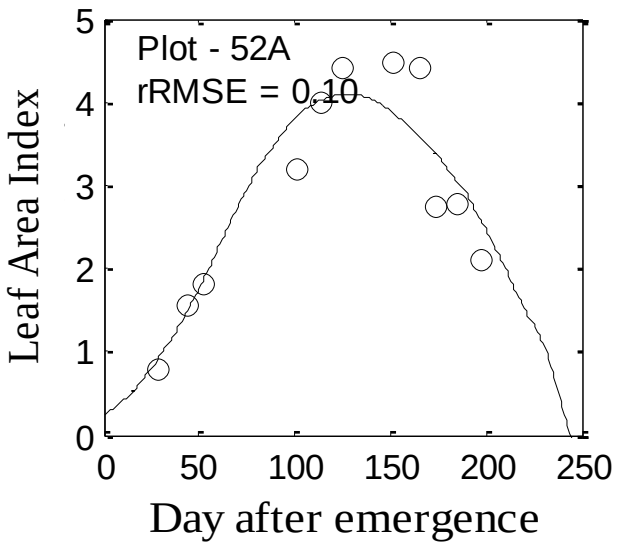
$$RVI = \frac{8\sigma^o{}_{HV}}{\sigma^o{}_{HH} + \sigma^o{}_{VV} + 2\sigma^o{}_{HV}}$$

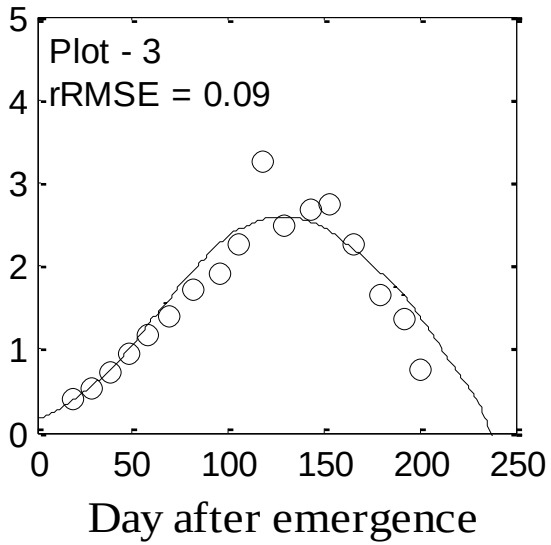
Crop: Marigold

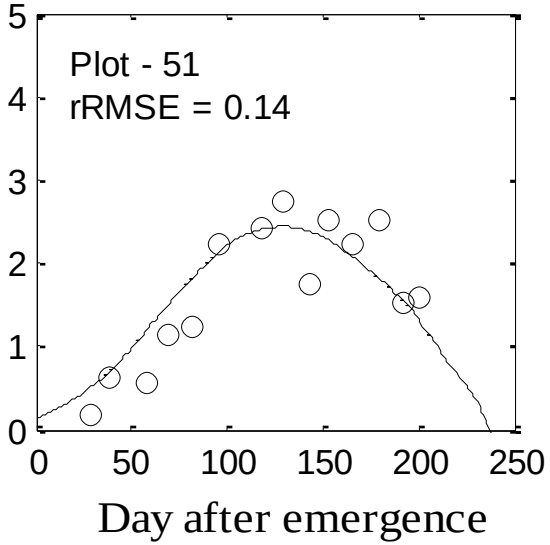


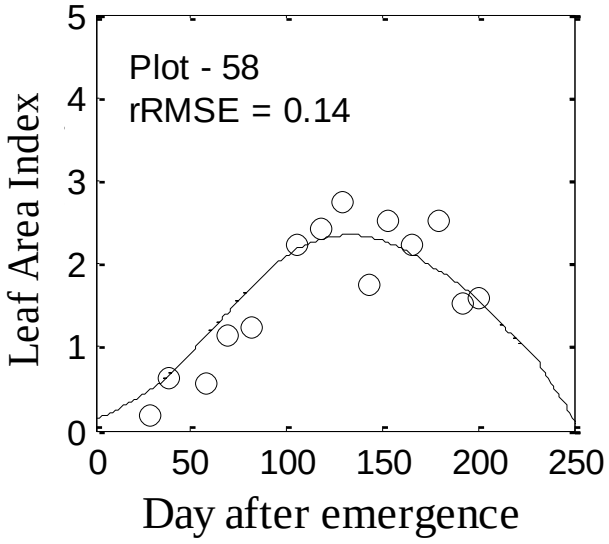
Sreelash et al., RSE (Under revison)

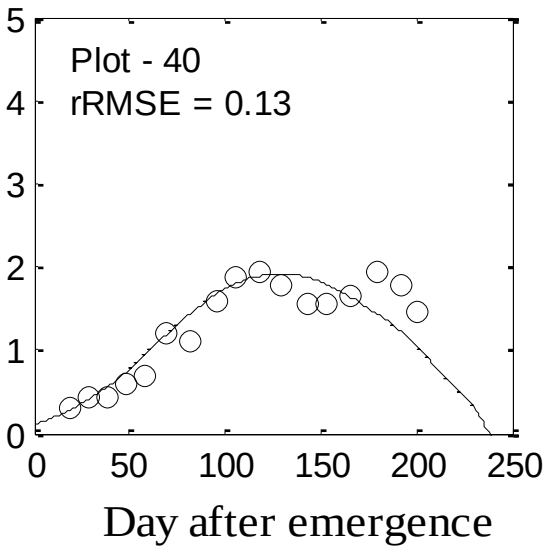
Retrieval of LAI of Turmeric from RADARSAT-2

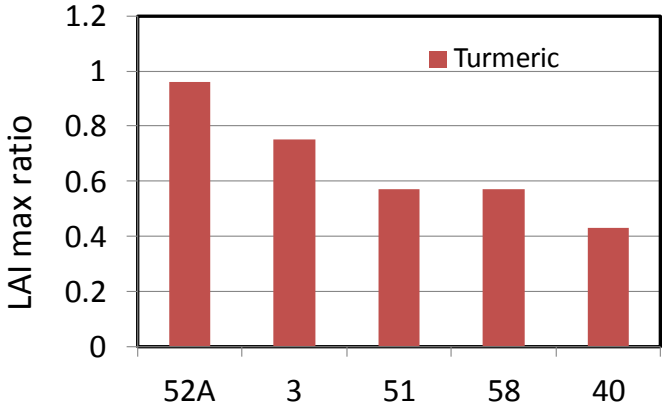






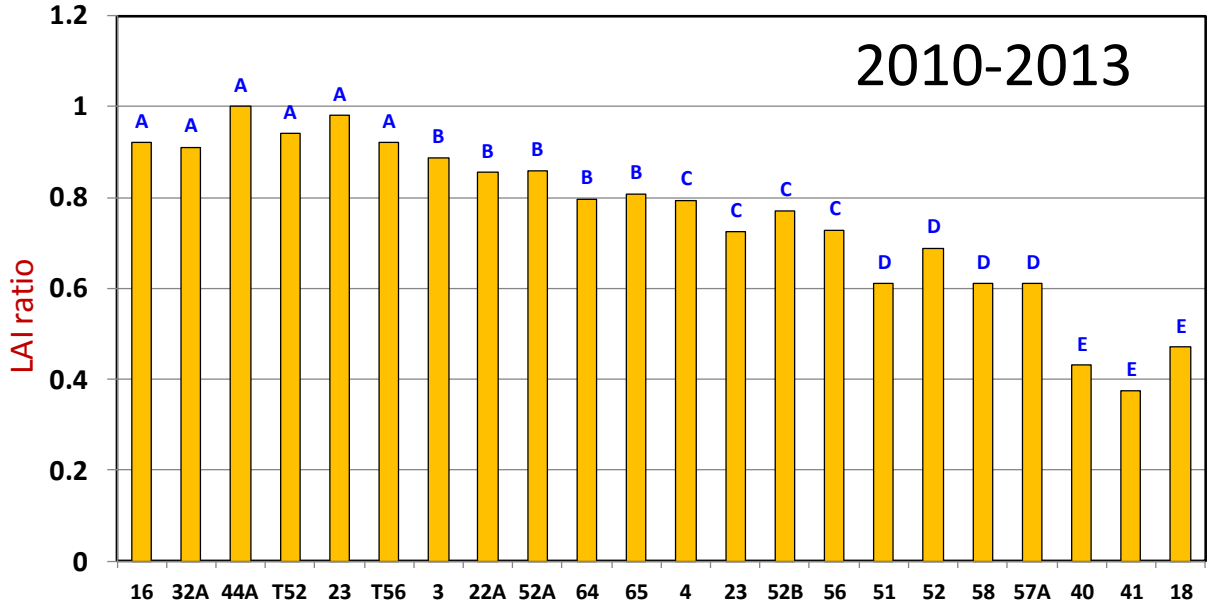




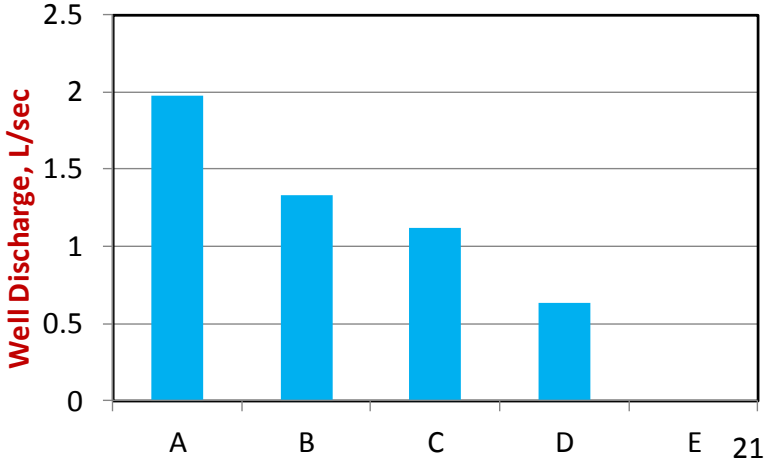


Crop growth in field vs Potential (STICS)

Crop growth and links with multiple factors

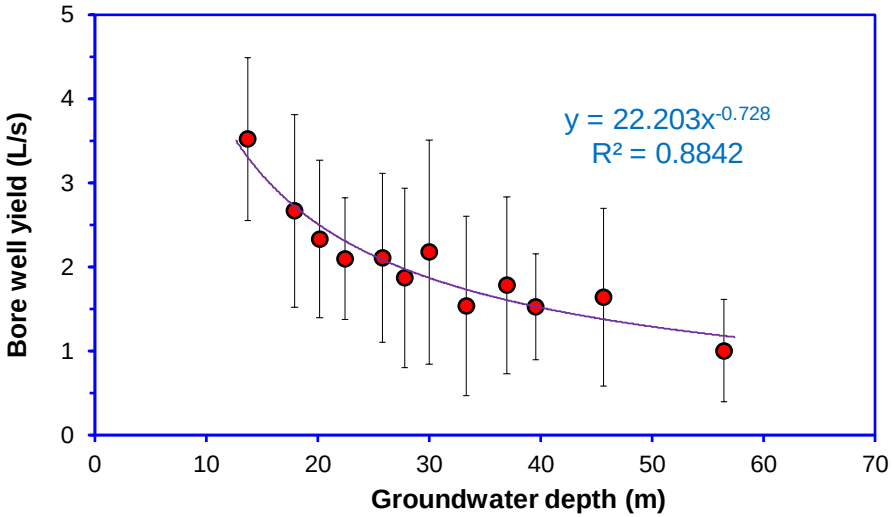


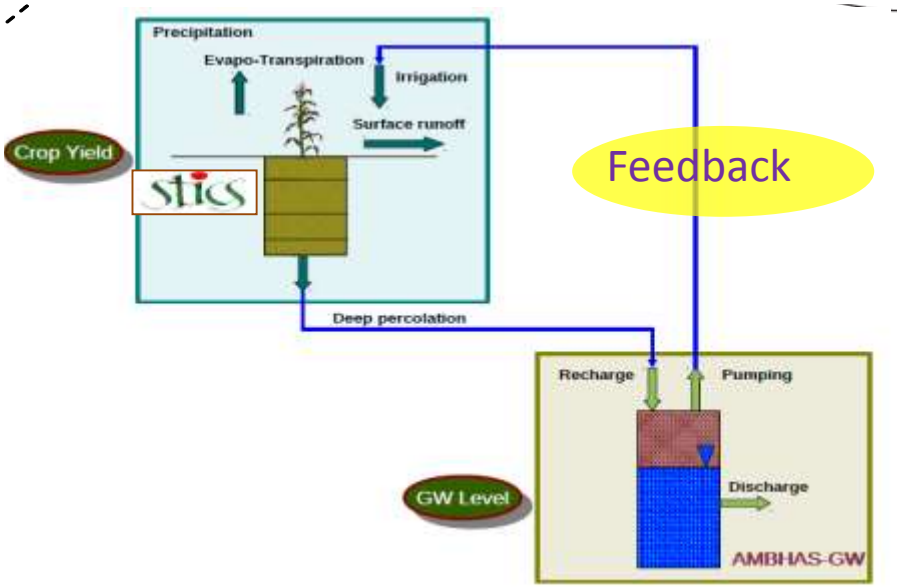
1. Water stress from irrigation
2. Soil characteristics (e.g. soil type, nutrient)
3. Seed characteristics
4. Pest impacts
5. Land operations (e.g. land levelling, plant spacing, uniformity of water application)



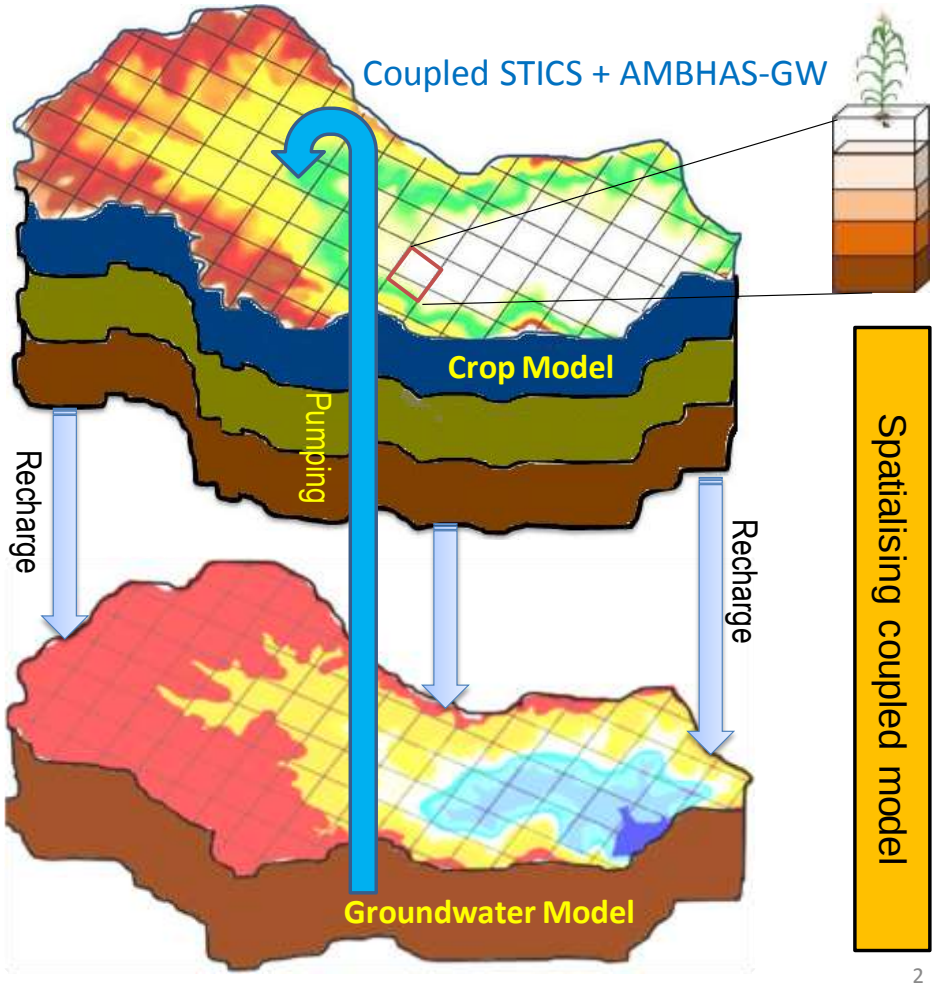
Agrohydrology models

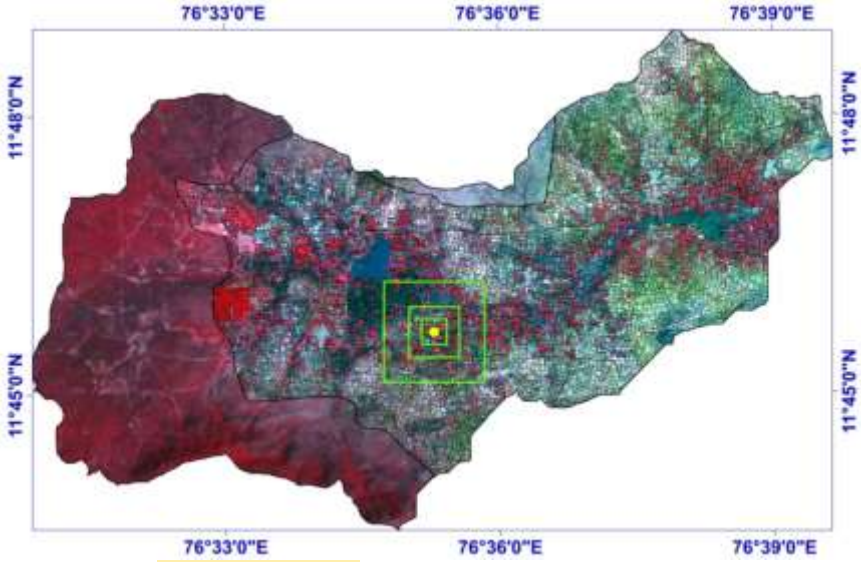
- To couple groundwater and crop models to understand the feedbacks/ interactions.
- To find the optimal irrigation which maximizes the crop yield while maintaining the sustainable groundwater level.

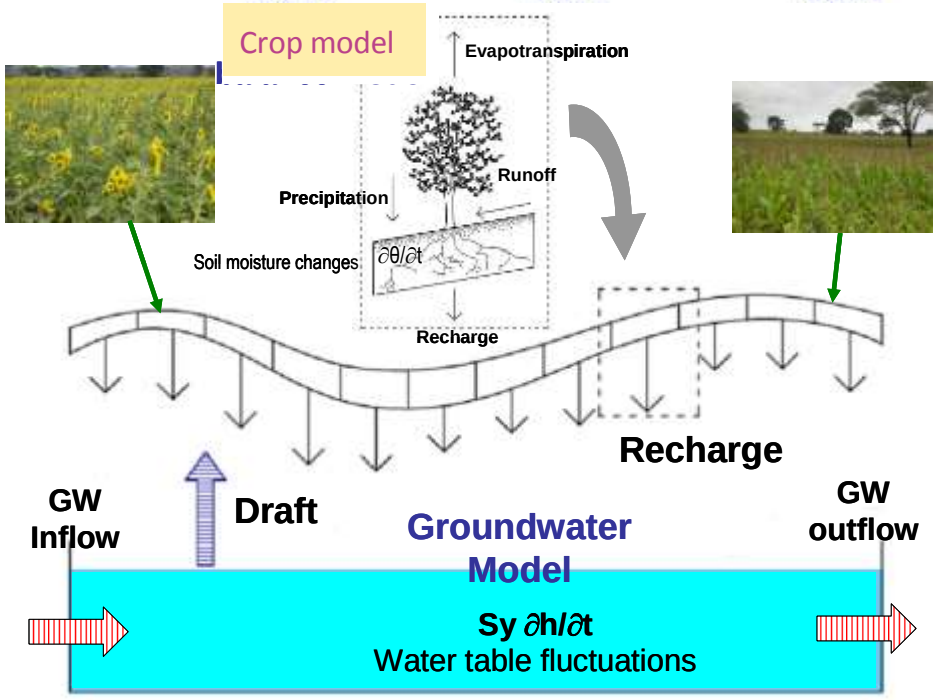




Parameterization of crop in DHMs





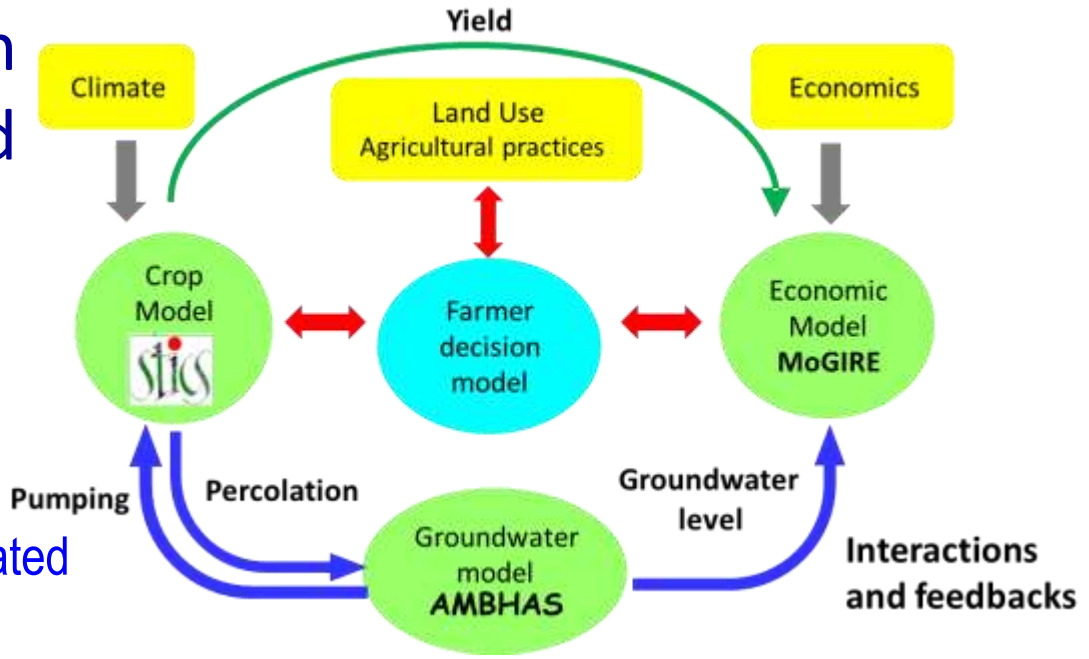


- Approaches to parameterize soil+ crop parameters for the selected model grid in DHMs.

Interdisciplinary models

Project - AICHA

Sustainability & adaptation assessment of current and alternative agricultural systems in the context of global changes.



INTEGRATED MODELLING PLATFORM

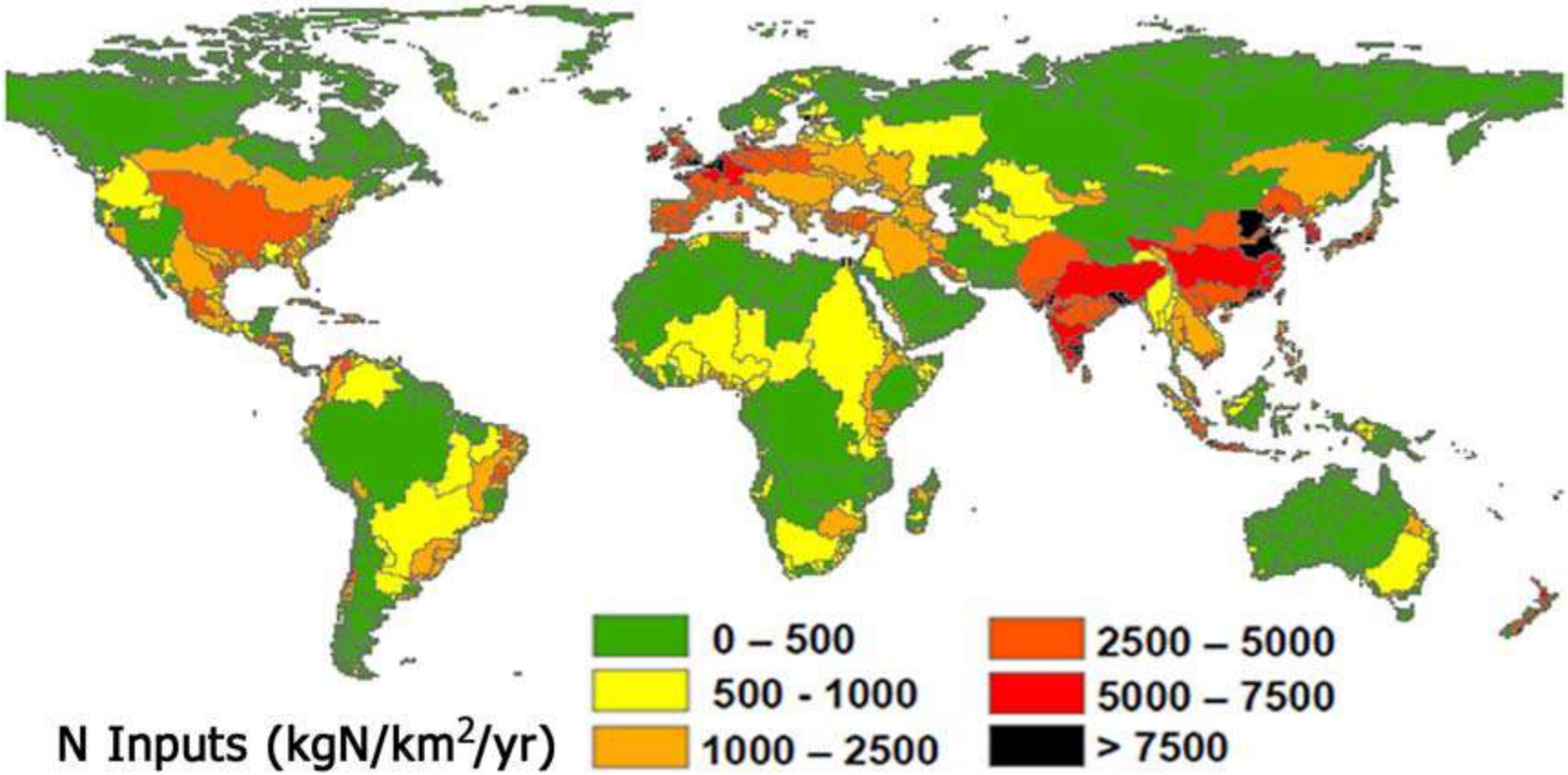
water-food-energy nexus

- Assessment of sustainability of irrigated agriculture must take into account the interactions and feedback between crop growth, water resources availability and economic drivers at the farm scale.

- Models should include farmers decision rules to be able to explore the possible adaptation of farming systems to environmental changes.

Example: Estimated net anthropogenic nitrogen inputs to the world's main river catchments

Source: Sutton et al., 2013

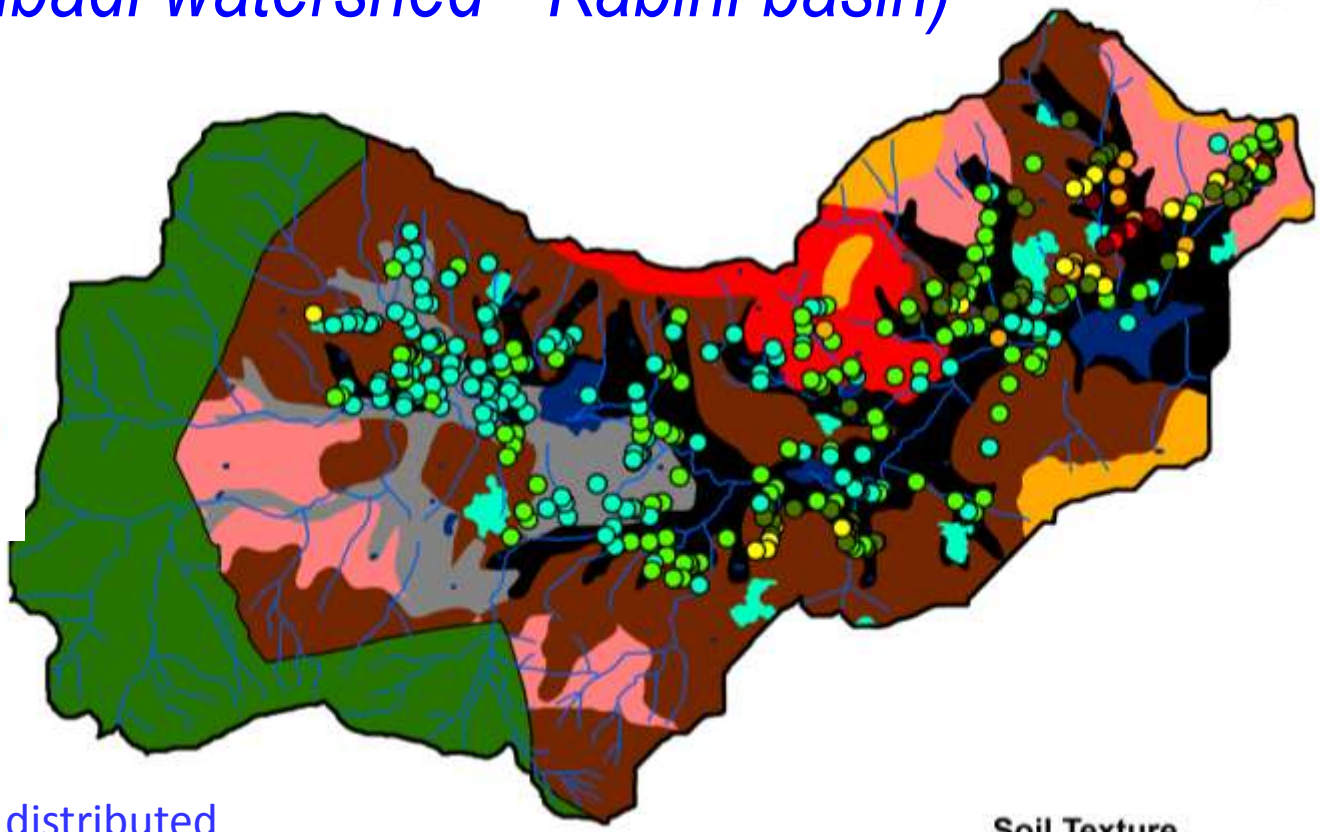


Water Quality – Nitrates

Water Quality – Nitrates in groundwater (Berambadi watershed - Kabini basin)

rz: root zone
vz: vadose zone
hz: hyporheic zone
gw: groundwater
sa: saturated area

of: overland flow
pe: percolation
if: interflow
rf: return flow (exfiltration)
sgf: shallow groundwater flow
dgf: deep groundwater flow



- Sampling Borewells were distributed throughout the watershed, taking into account the heterogeneity with respect to land use,soil type etc.

Legend
- Berambadi boundary
- Drainage
- Forest

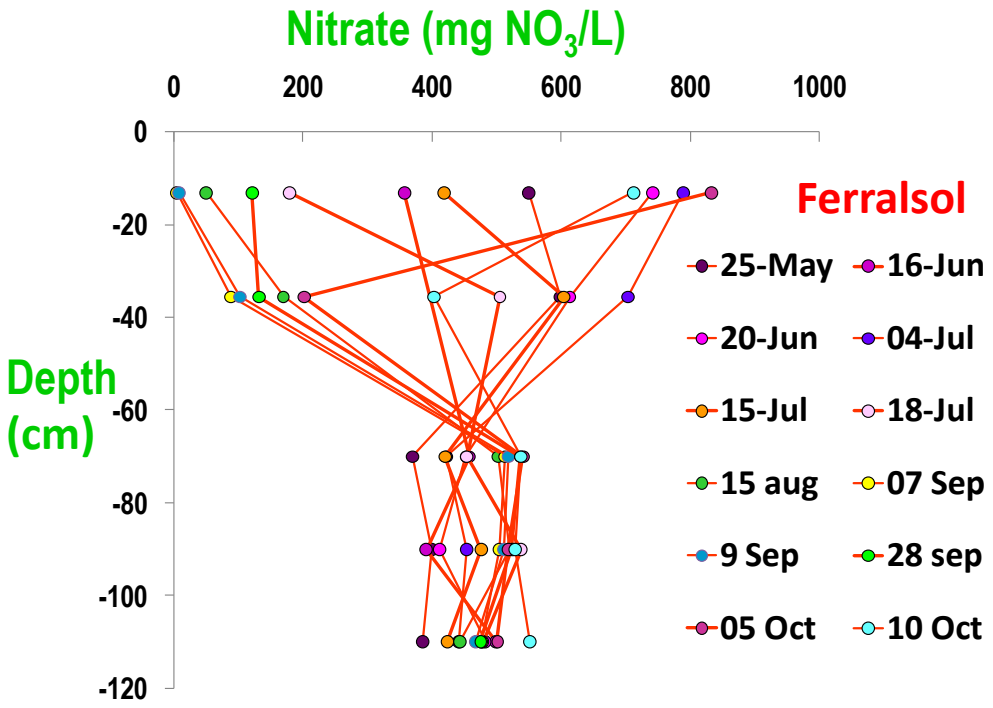
0 1.5 3 KM

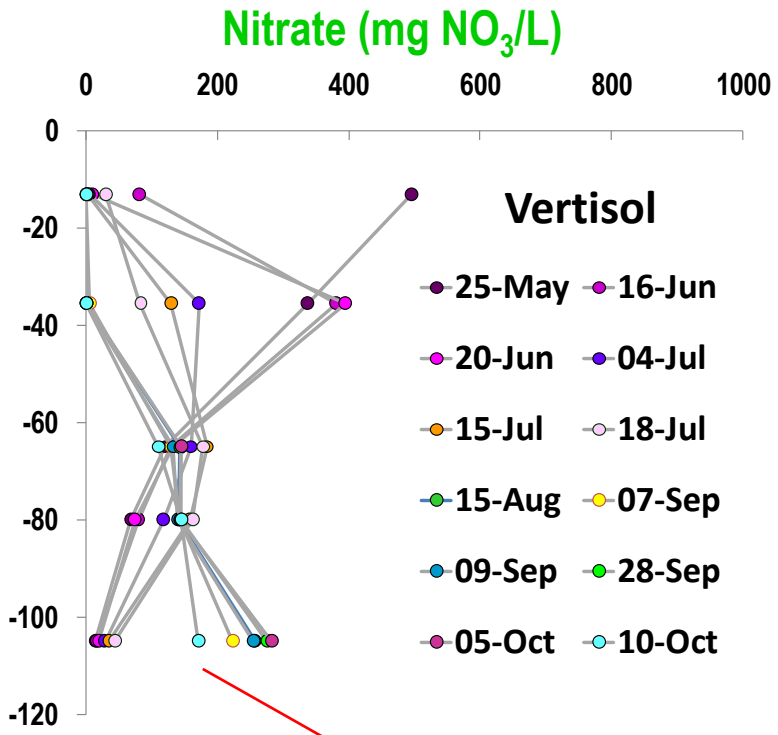
Nitrate (mg/l)
- 0 - 45
- 45 - 100
- 100 - 150
- 150 - 200
- 200 - 250
- 250 - 300
- 300 - 350

Soil Texture
- Clay
- Clay loam
- Gravelly loamy sand
- Settlement
- loamy sand
- Sandy clay loam
- Sandy loam
- Waterbody

26

Soil Plant scale - *pore water nitrate in root zone*

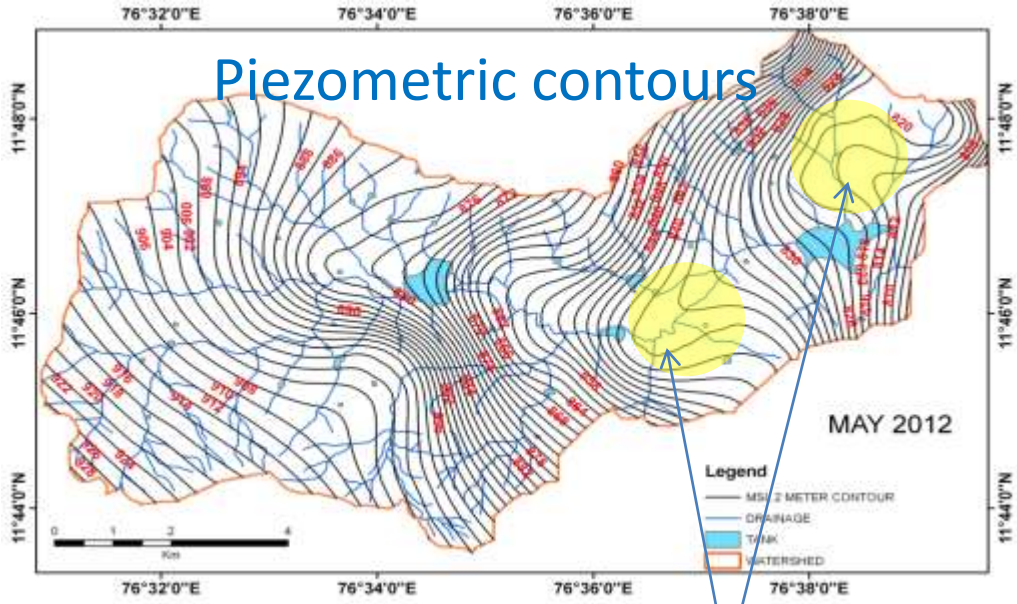




Denitrification

Temporal Variation of Nitrate (=Error bars)

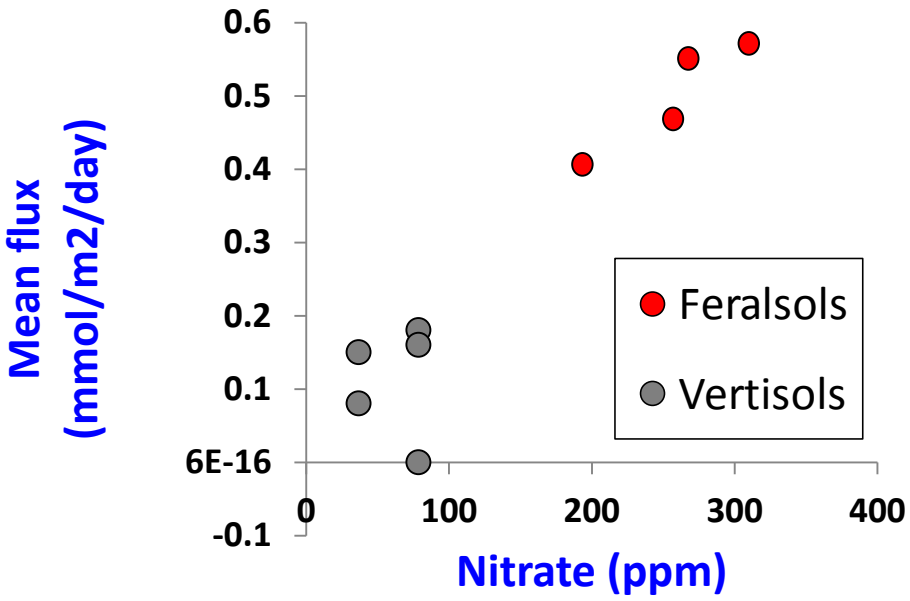
✓Sampling Period: 2012-2015



Zones of slower groundwater movement

How to upscale the nitrate concentrations ?

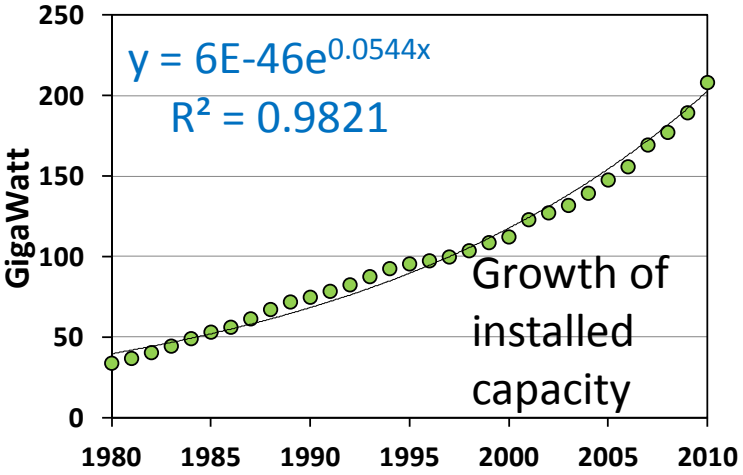
Greenhouse gas emissions



- Greater denitrification in Black soils

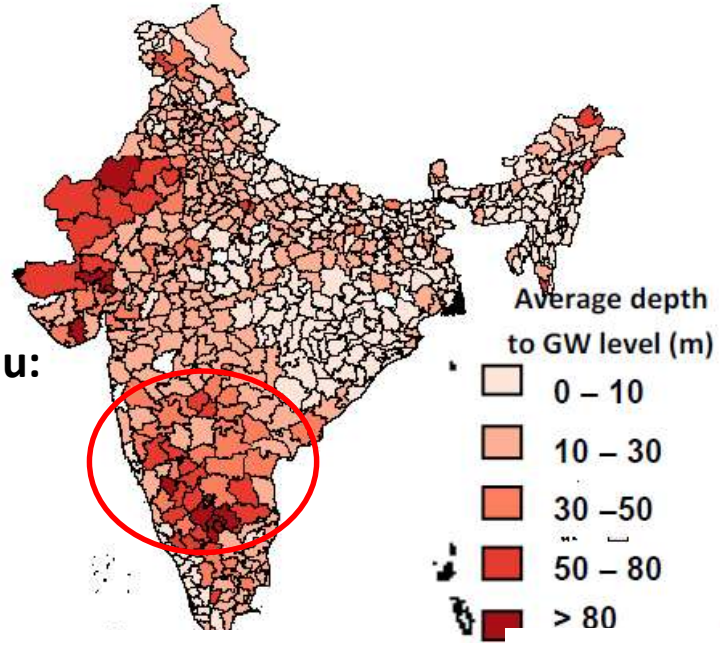
What would be the impacts of future rainfall on denitrification?

Agricultural groundwater use linkage with electricity supply (Water – Food – Energy nexus)

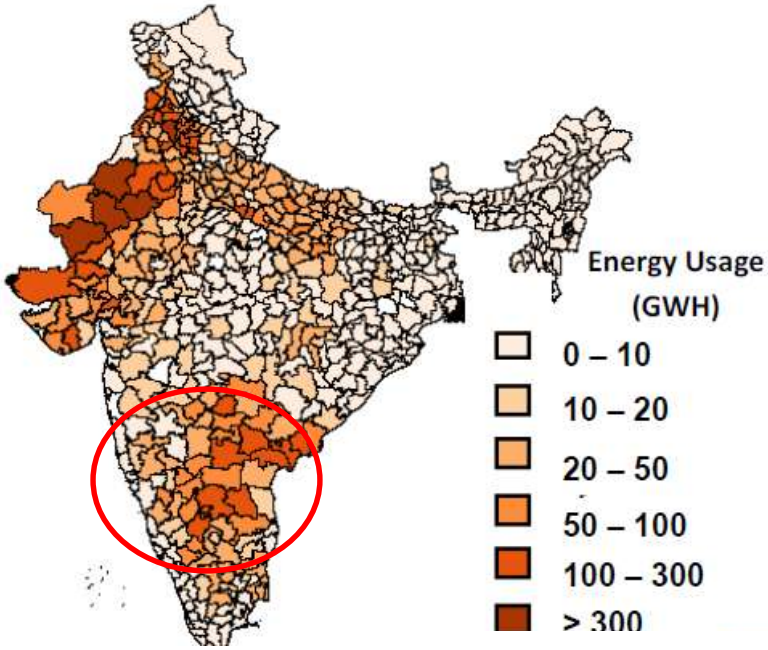


Strong growth of electricity consumption

30% of electricity is for GW pumping – (equivalent of about 50 nuclear reactors !)

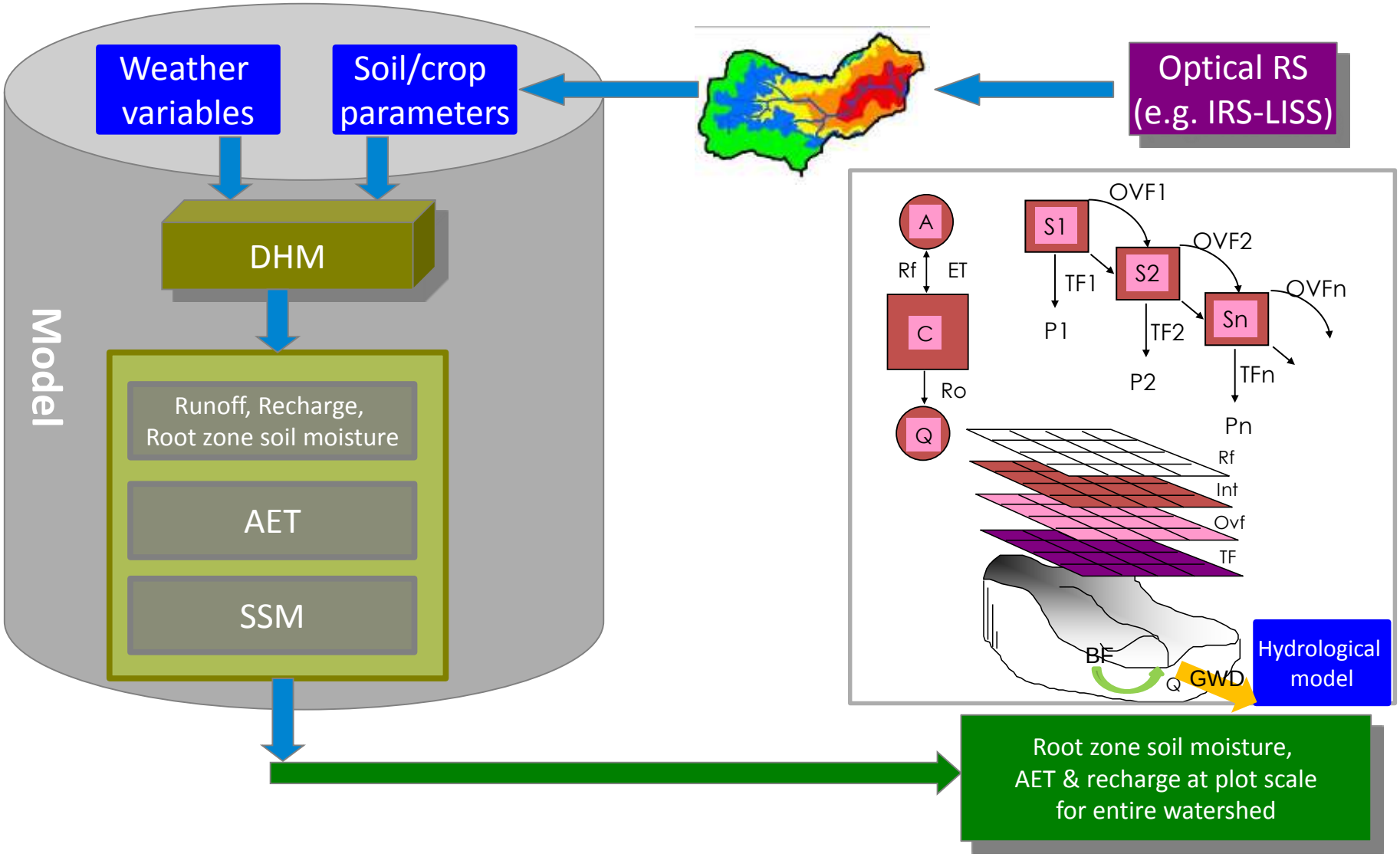


South of Deccan Plateau: Deep GW In spite of good rainfall

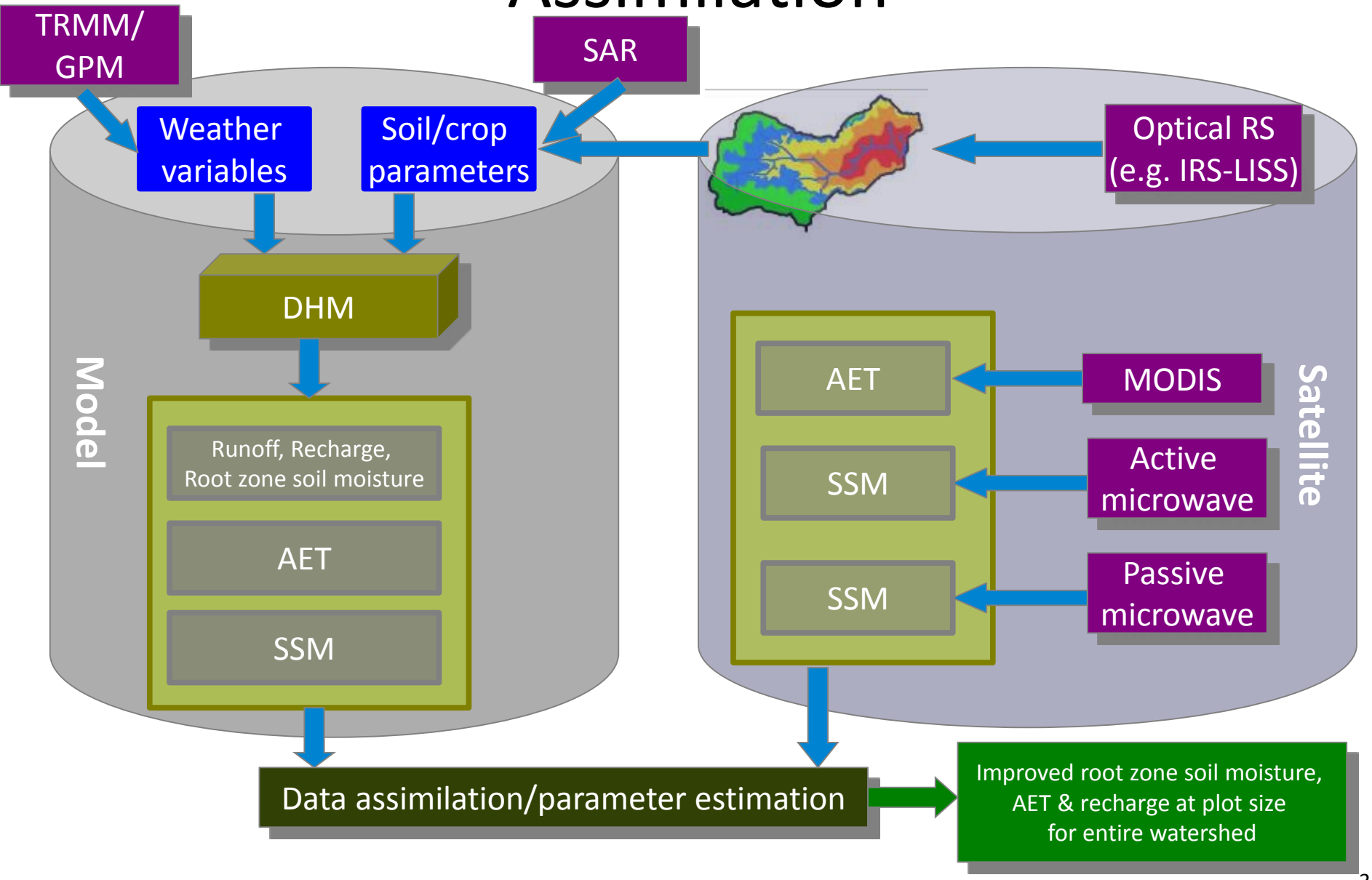


Source: U. Lall (2011)

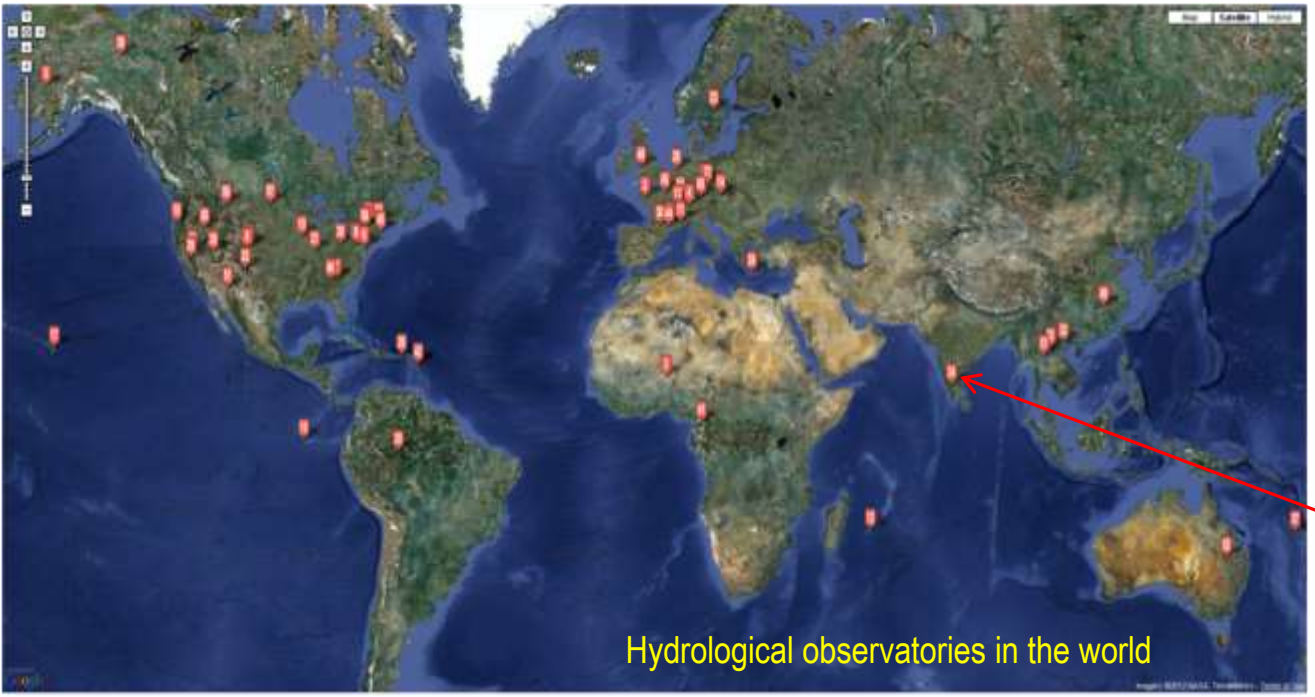
Hydrological Modeling (conventional)



Modeling with Remote Sensing & Assimilation



Observatories



Kabini CZO

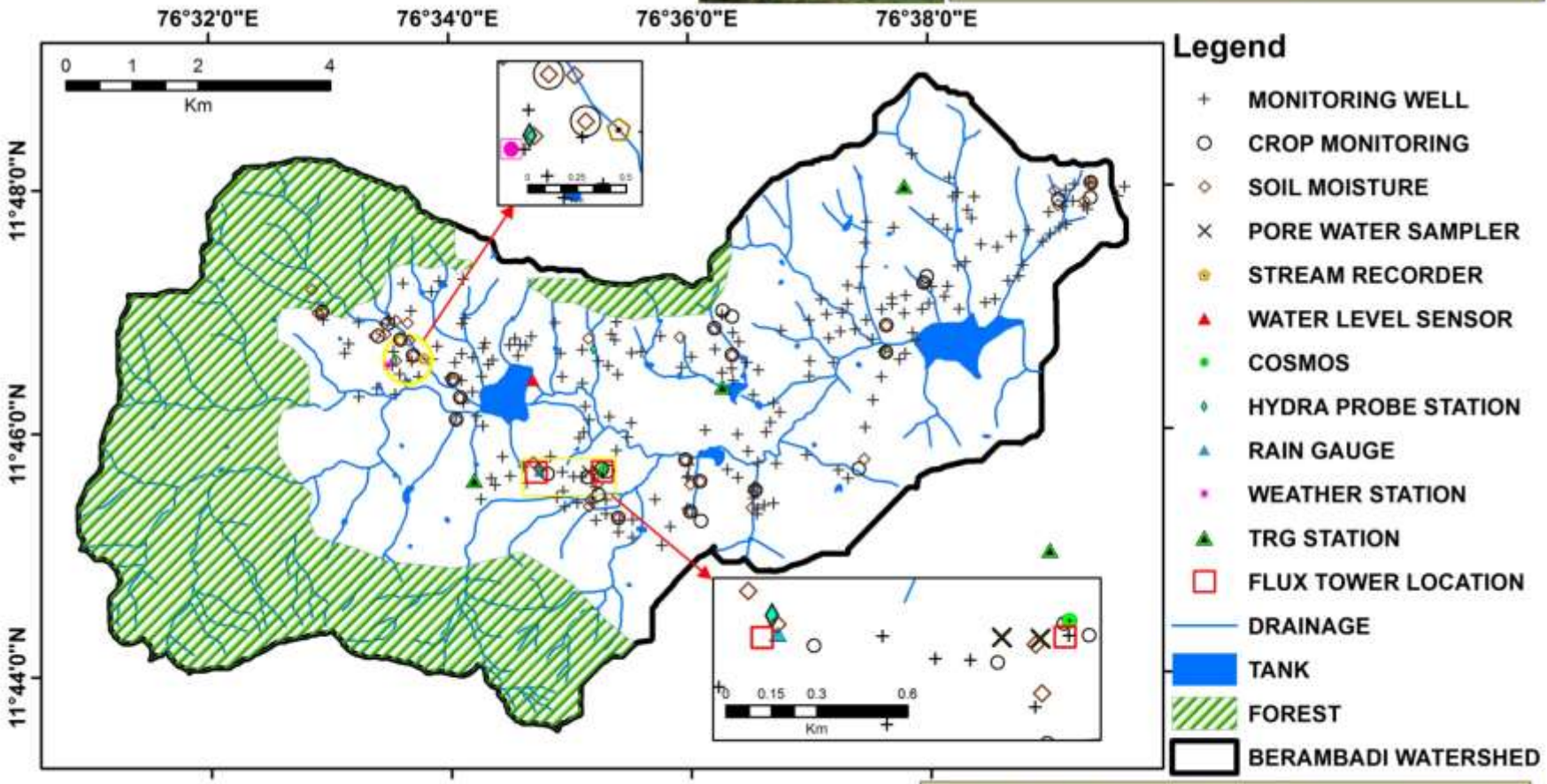
Kabini basin observatory- Response of tropical ecosystems to global changes in Southern India CEFIRSE LMI

- *What controls the resilience, response and recovery of a hydrological system to perturbations of climate and land-use changes?*
- *How can sensing technology and modeling be integrated for simulation and forecasting of essential hydrological variables?*
- *How can theory, data and mathematical models from natural- and social- sciences be integrated to simulate, manage river basin/catchments goods and services ?*

Kabini CZO

INSTRUMENTS INSTALLED ON EDDY TOWER
PLATINUM RESISTANCE THERMOMETER (AIR TEMPERATURE)
CAPACITOR TYPE (RELATIVE HUMIDITY)
3D SONIC ANEMOMETER (3D WIND SPEED AND DIRECTION)
GAS ANALYZER (WATER VAPOUR)
FOUR COMPONENT NET RADIOMETER (NET RADIATION)
FLUX PLATE (SOIL HEAT FLUX)

INSTRUMENTS INSTALLED ON AMS TOWER
PLATINUM RESISTANCE THERMOMETER (AIR TEMPERATURE)
CAPACITOR TYPE (RELATIVE HUMIDITY)
CUP ANEMOMETER (WIND SPEED AND WIND DIRECTION)
TRANSDUCER (ATMOSPHERIC PRESSURE)
TIPPING BUCKET RAINGAUGE (RAINFALL)
FOUR COMPONENT NET RADIOMETER (NET RADIATION)
SHADED PYRANOMETER (DIFFUSE RADIATION)
FLUX PLATE (SOIL HEAT FLUX)
SOIL THERMOMETER (SOIL TEMPERATURE)
DATA LOGGER
YAGI ANTENNA



* COSMOS (COSMIC RAY SOIL MOISTURE OBSERVING SYSTEM)

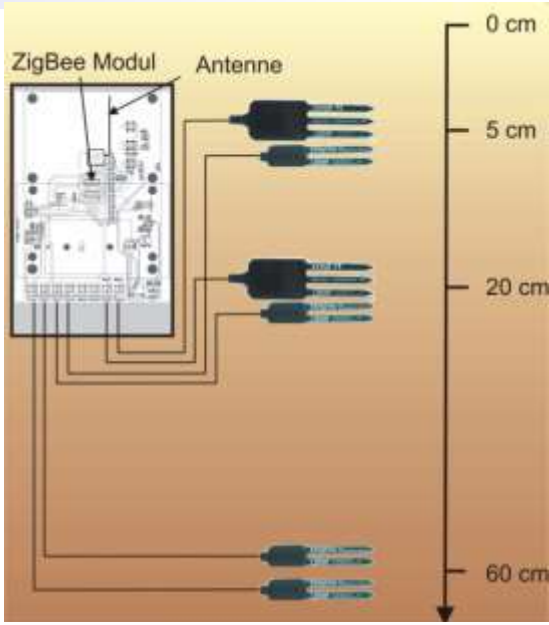

Eddy flux tower
@ Beechanahalli,
Gundlupet TQ.


Cosmos, Steven's Hydra probes & OTT
@ K Madahalli, Chamarajanagar TQ.

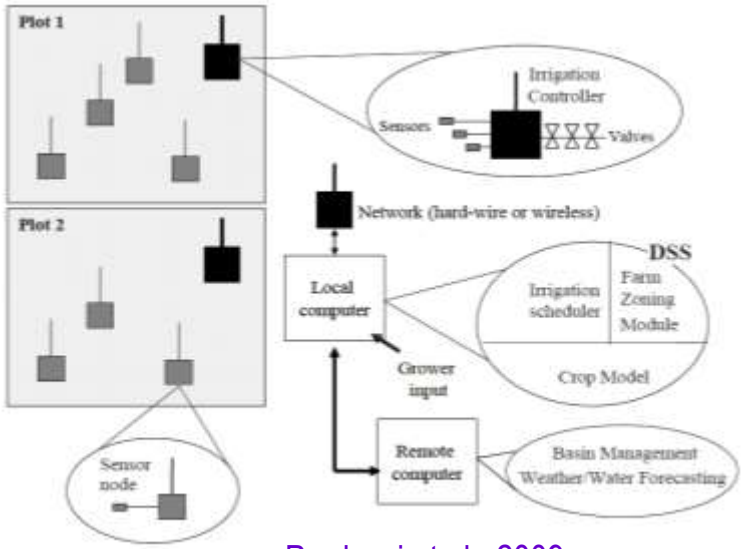

Cosmos & Steven's Hydra probes
@ Singanallur, Kollegal TQ

Integration of Satellite, Sensors & ICT tools

- Integration of satellite, surface observations Bigdata & IoT to support improvements in agricultural water resources management.



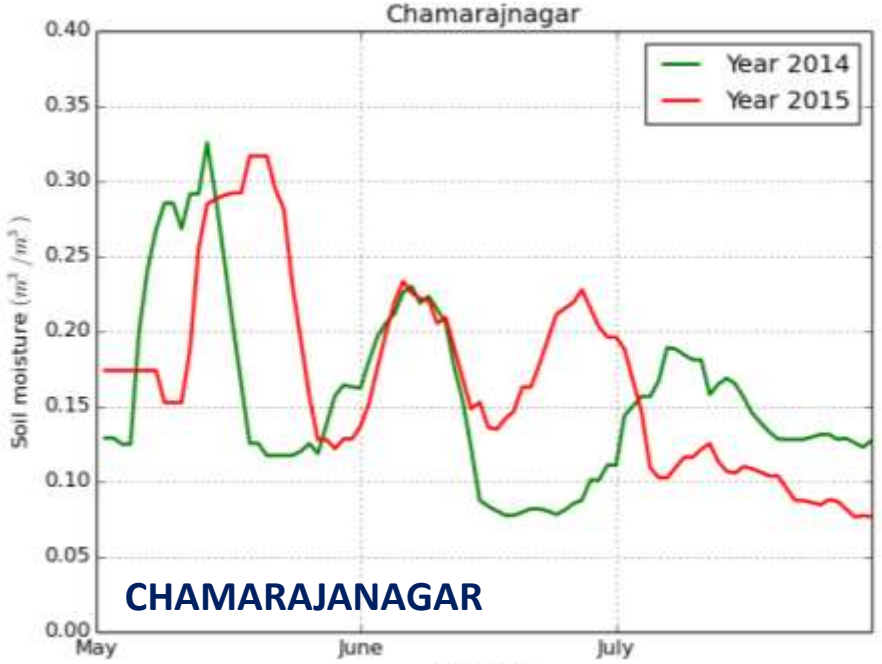
- Soil moisture can be retrieved through remote sensing & combined with calibration from ground 'capacitance' sensors – upscaling of this approach though smart sensors is a way to take the idea from 'bench to field'.
- Crop as a sensor to model & assess the role of critical controlling parameters including water stress.
- To find the optimal & precision irrigation which maximizes the crop yield and to provide the timely electricity to pumps.

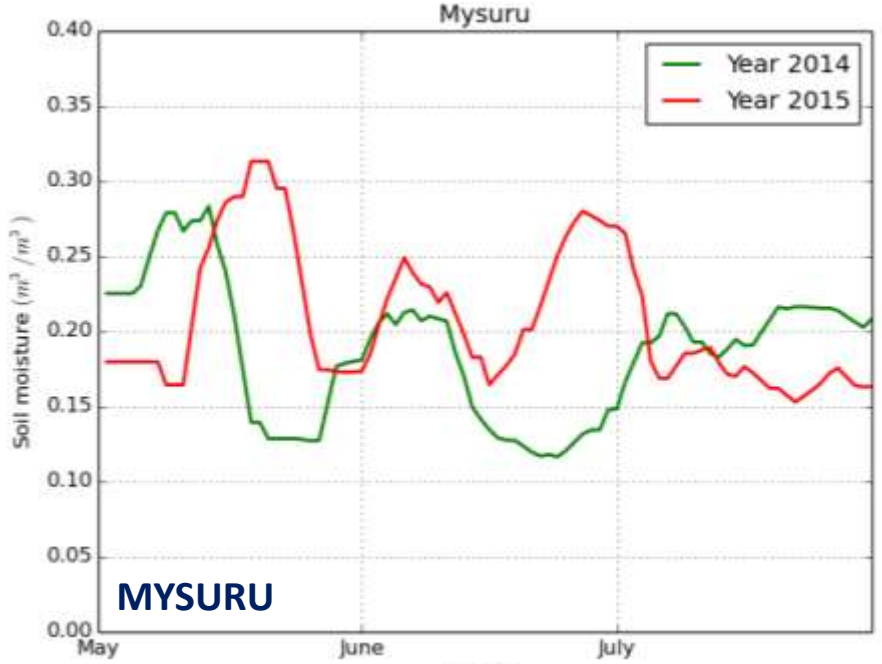


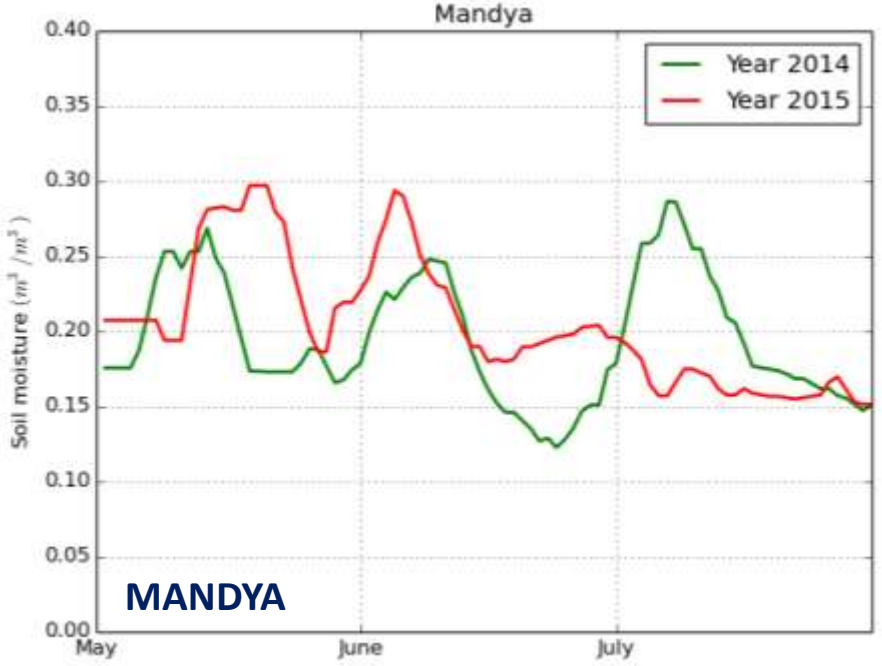
Pardossi et al., 2009

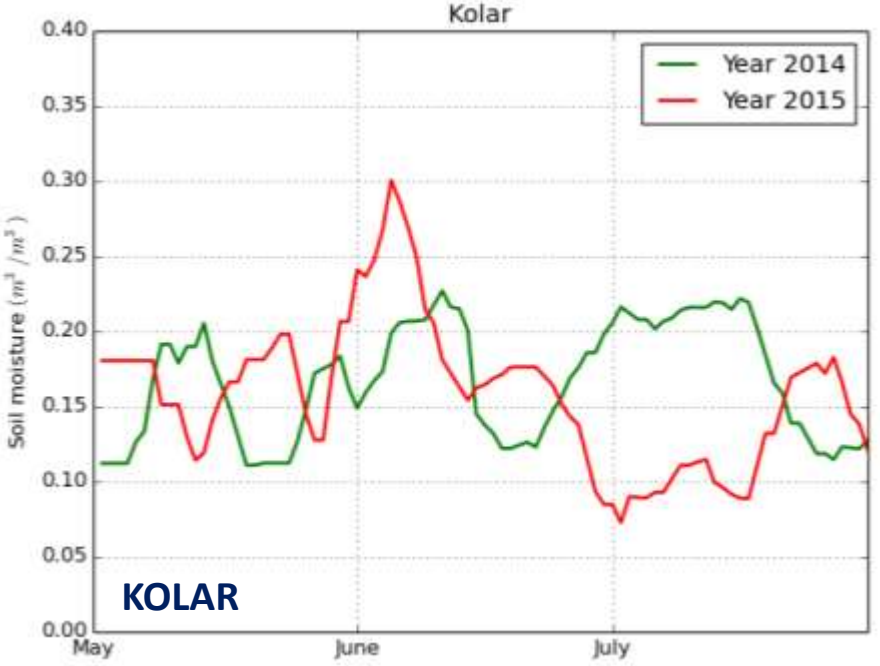

Thank you

SOIL MOISTURE TRENDS IN KARNATAKA - SMOS

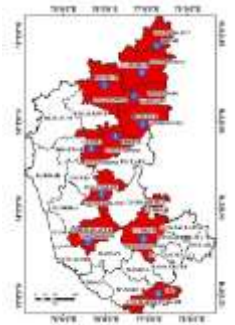


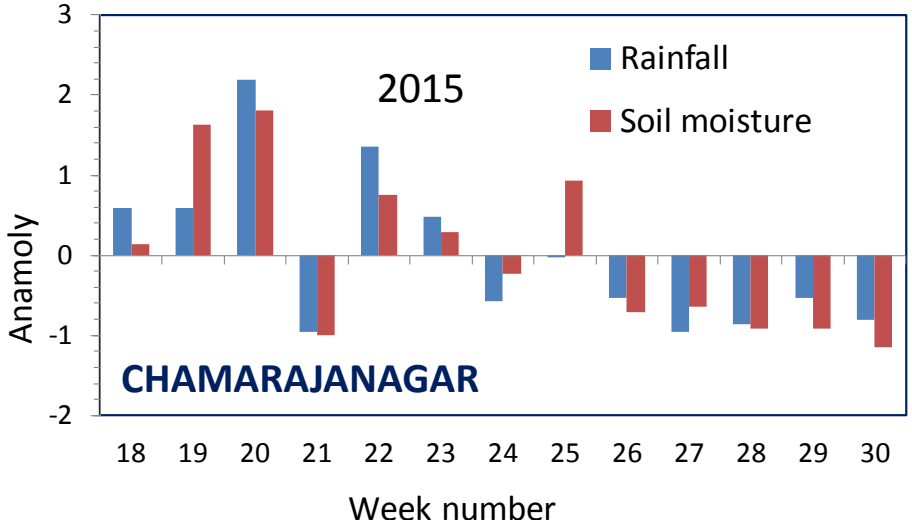


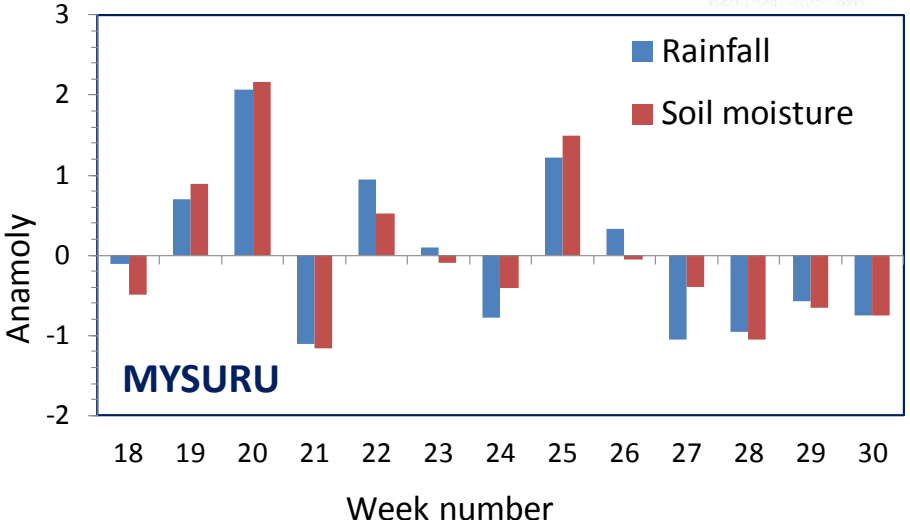


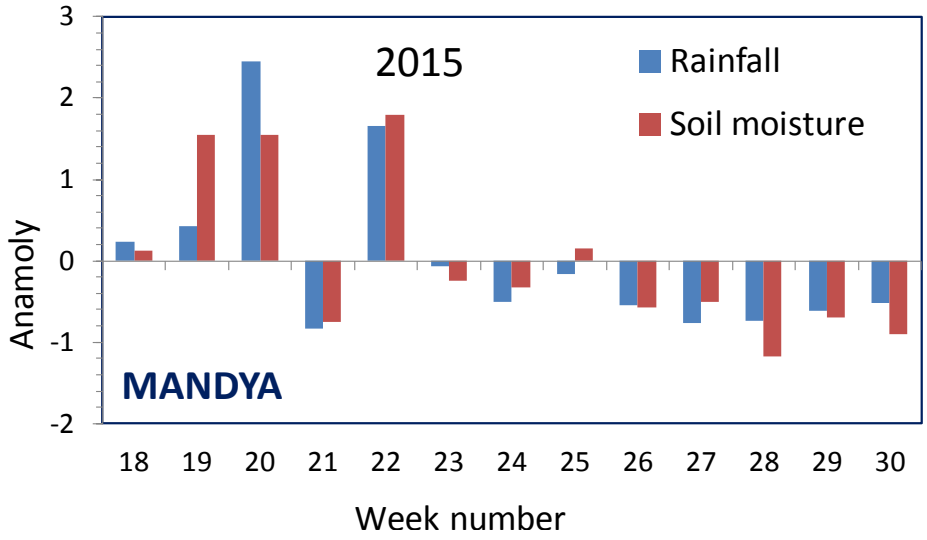


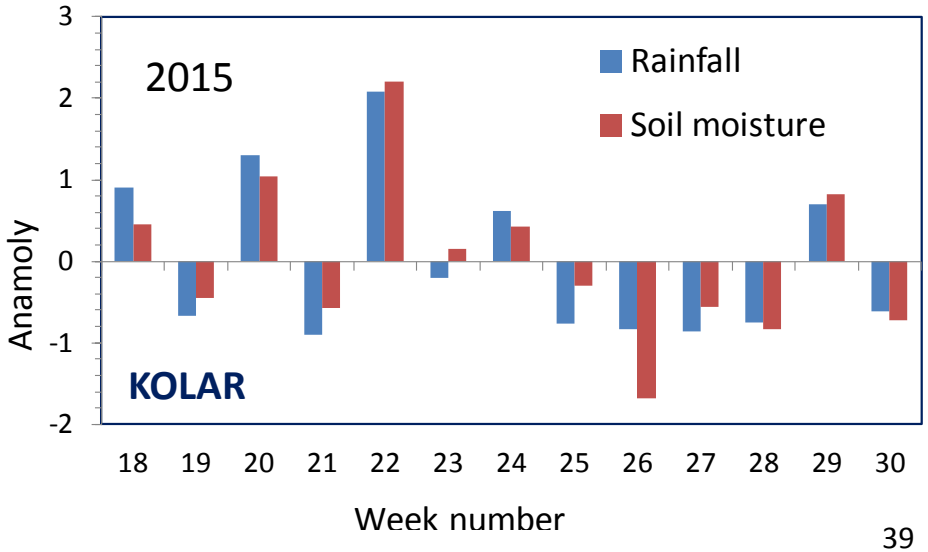
Anomalies of Rainfall & Soil Moisture











MAPSM: Merged Active and Passive Soil Moisture