Land Cover/Land Use Change monitoring with Earth Observation and Land Surface Characterization

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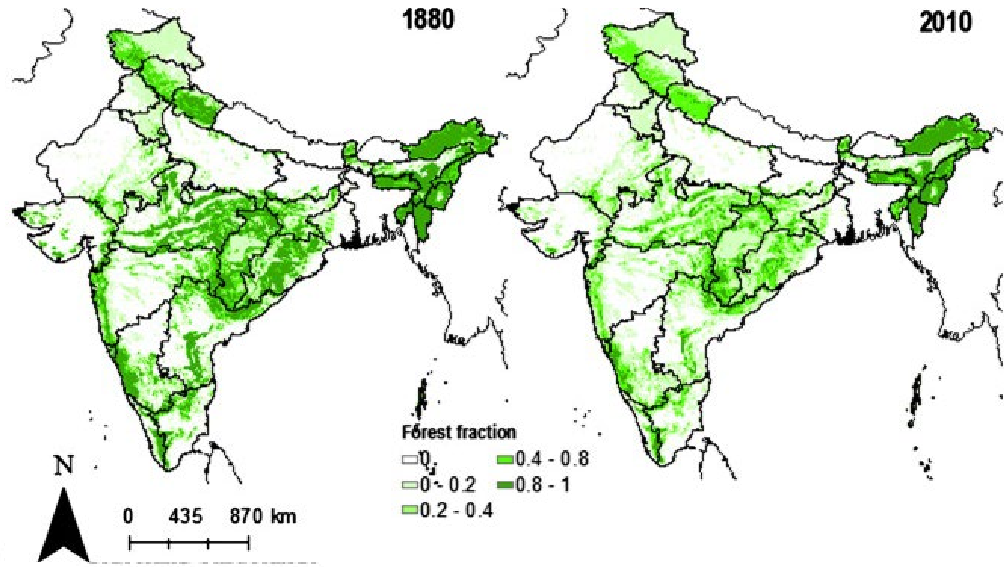
SRMC, IITM, Pune, 05 Dec 2017

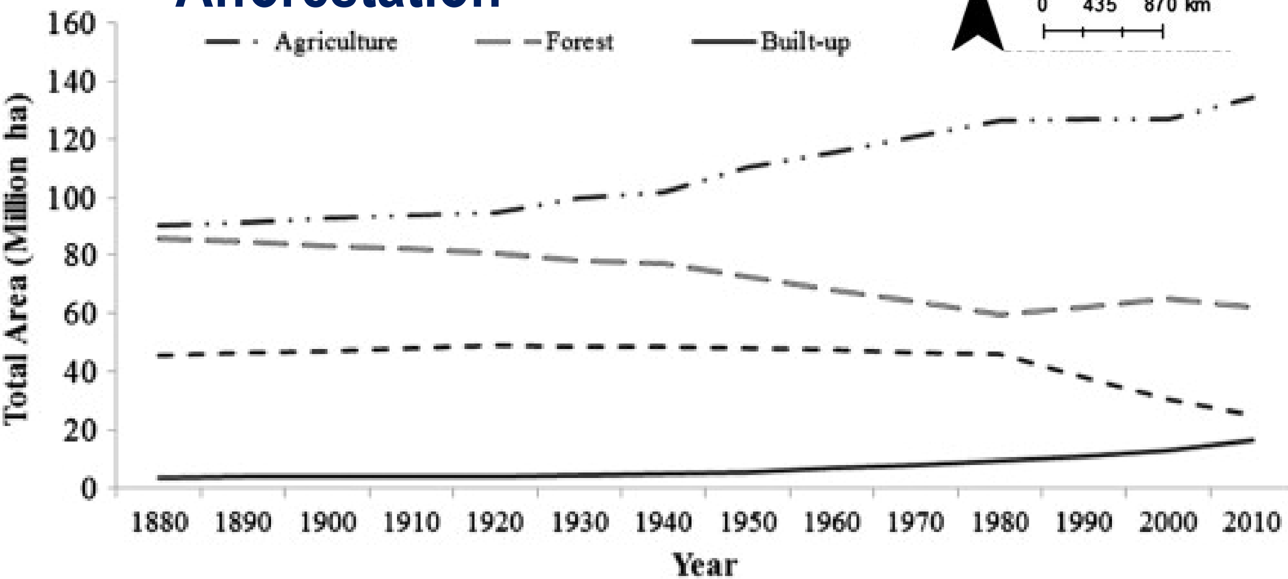
Land : Parameters of Interest

- Land Cover and Land Use
  - Conceptual difference, classification schema, (appropriate for use ?)
- Long-term changes
  - Land transformation : Anthropogenic Impacts
    - Deforestation
    - Expansion of Agricultural Lands
    - Urbanization
    - Wetland loss
- Inter- /Intra-seasonal changes due to natural causes / variability
- Hydrology & Rainfall variability led changes
- Extreme events & long-term effects
- Cryosphere
- Transformation within land use (agriculture, forest, ...)

Land Transformation & C Cycle change

- Large-scale land transformation
- Consequences on vegetation & soil C pools as well as NPP & C emissions
- Spatial Data sets needed
- Additional factors
  - Irrigation
  - Fire
  - Forest Degradation
  - Afforestation

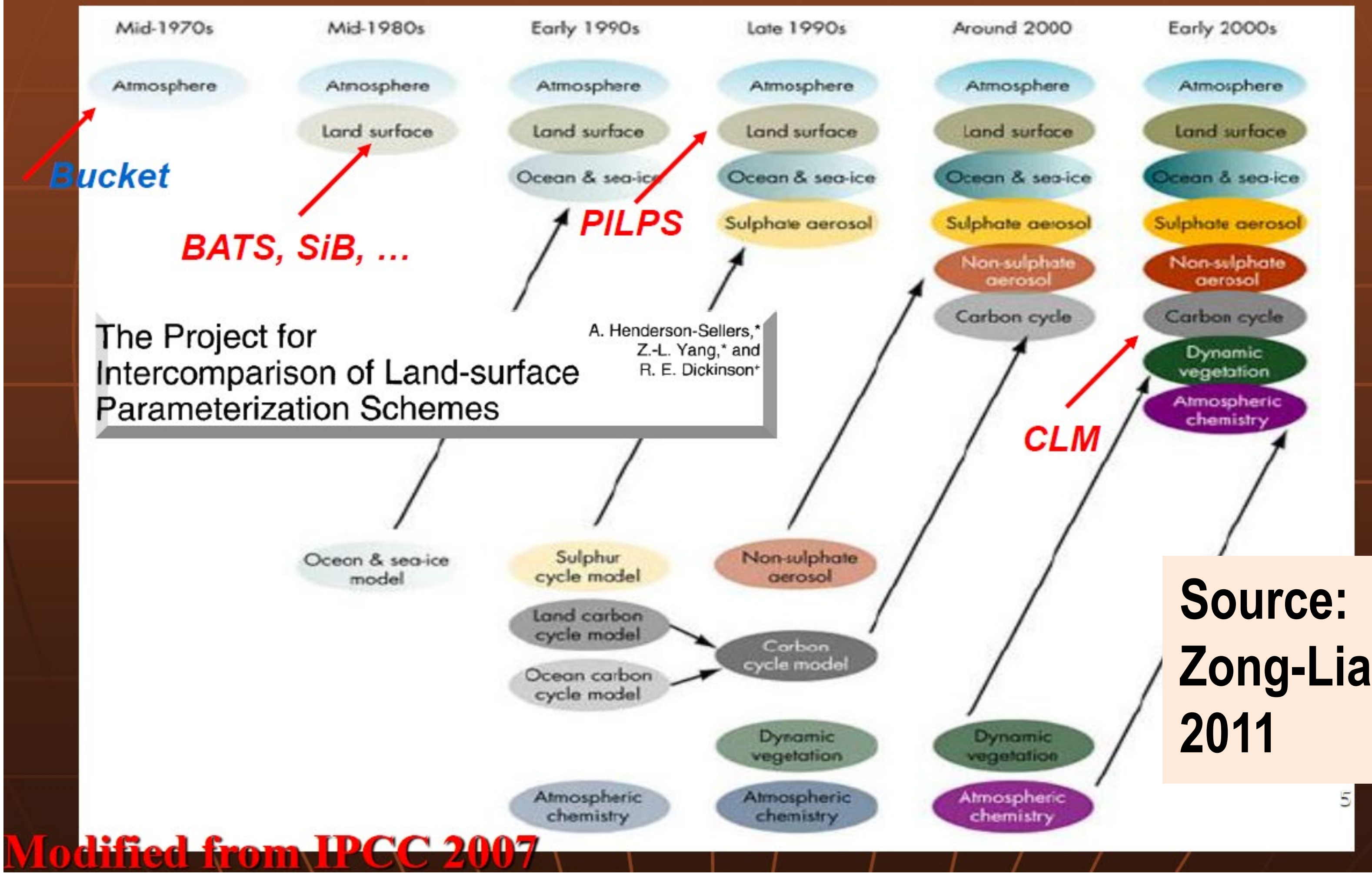




Tian, Banger, Bo, Dadhwal, 2014; Global & Planetary Change

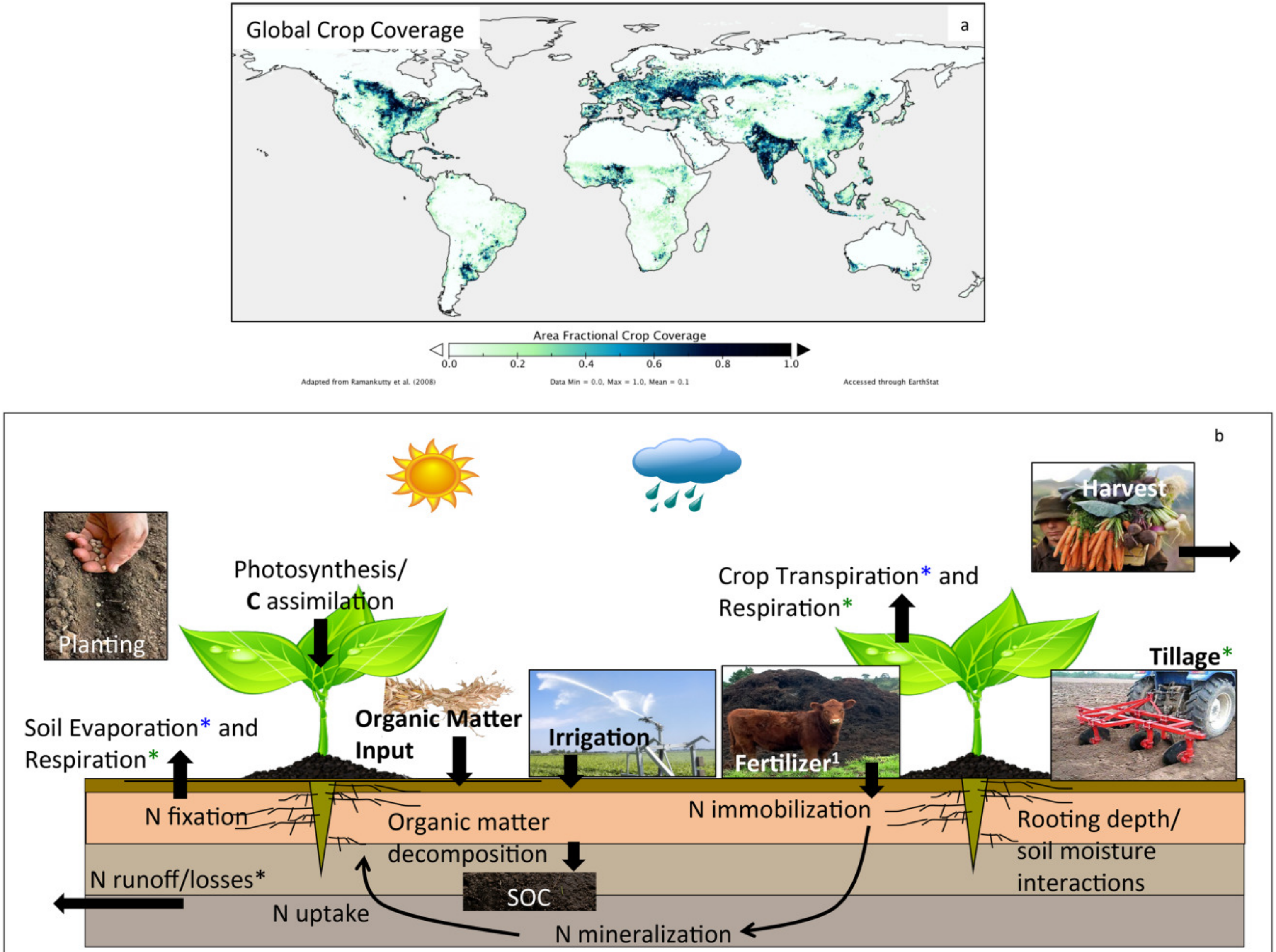
Evolution of Land Surface in Models

History: Land has been an important component in weather and climate models



Source: Zong-Liang Yang, 2011

Representing agriculture in Earth System Models: Approaches and priorities for development



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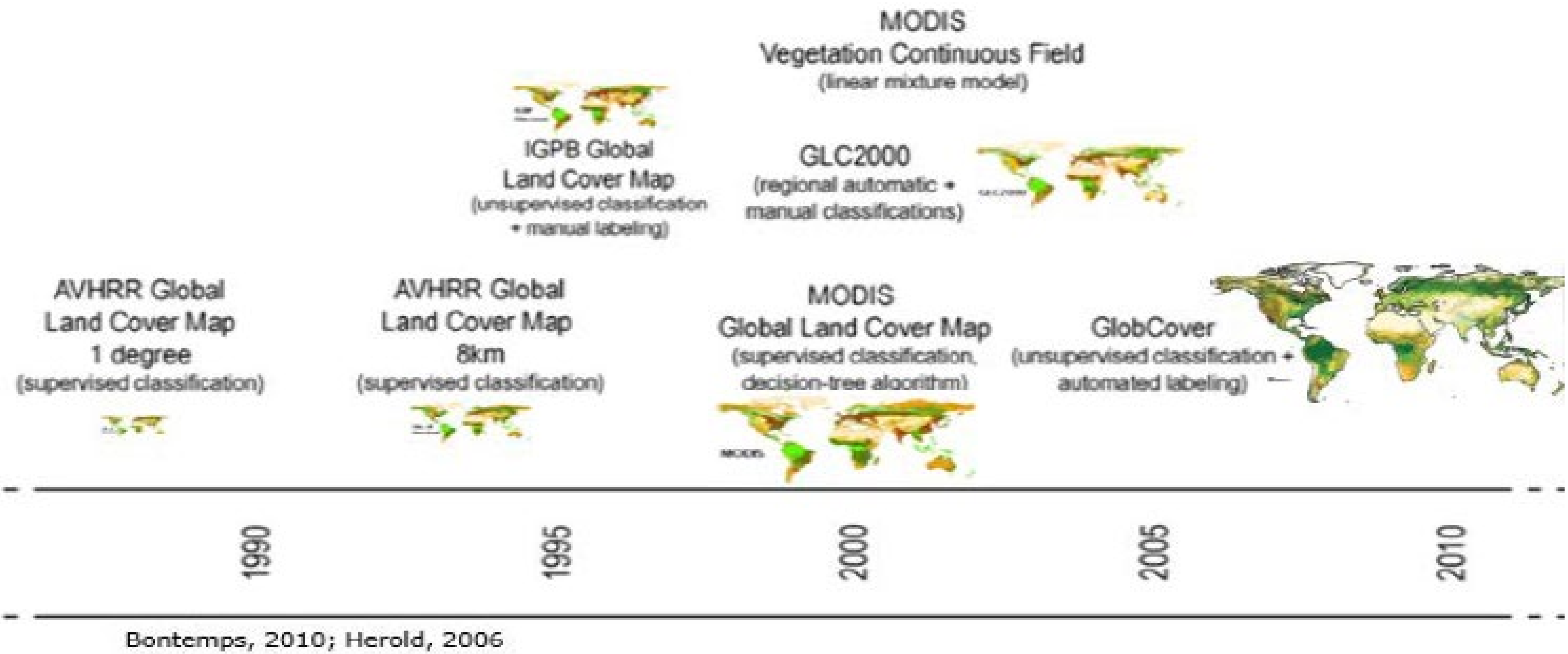
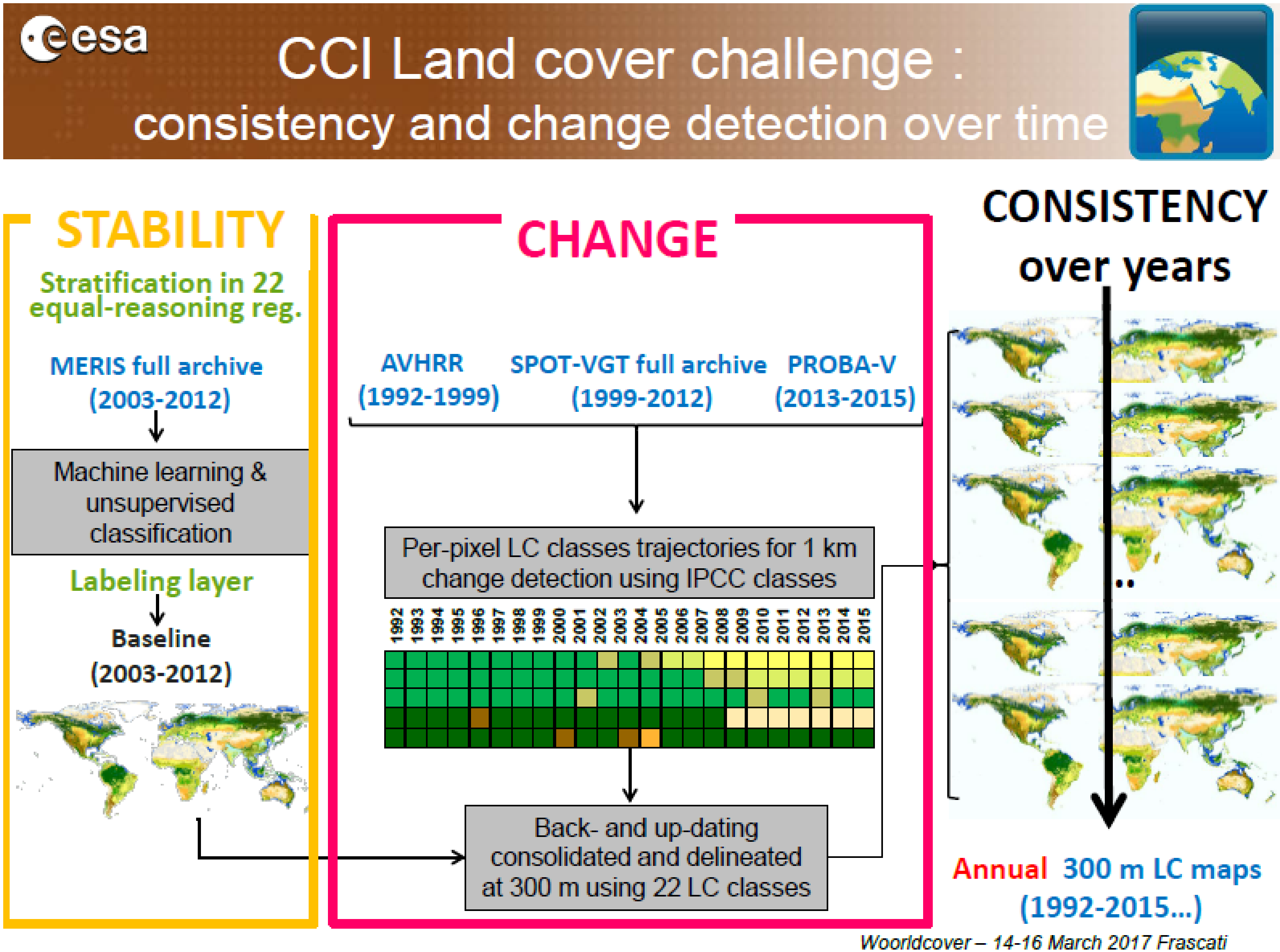
Land Cover, Land Use, Land Resources & Data Sets

GLOBAL LAND COVER MAPPING

- <u>Status of the global land cover</u>
- Single sensor - single year land cover products (except MODIS et MERIS)
- No compatibility between existing products and between typologies
- Continuous but not cumulative improvement from 1°to 300 m in 20 y.

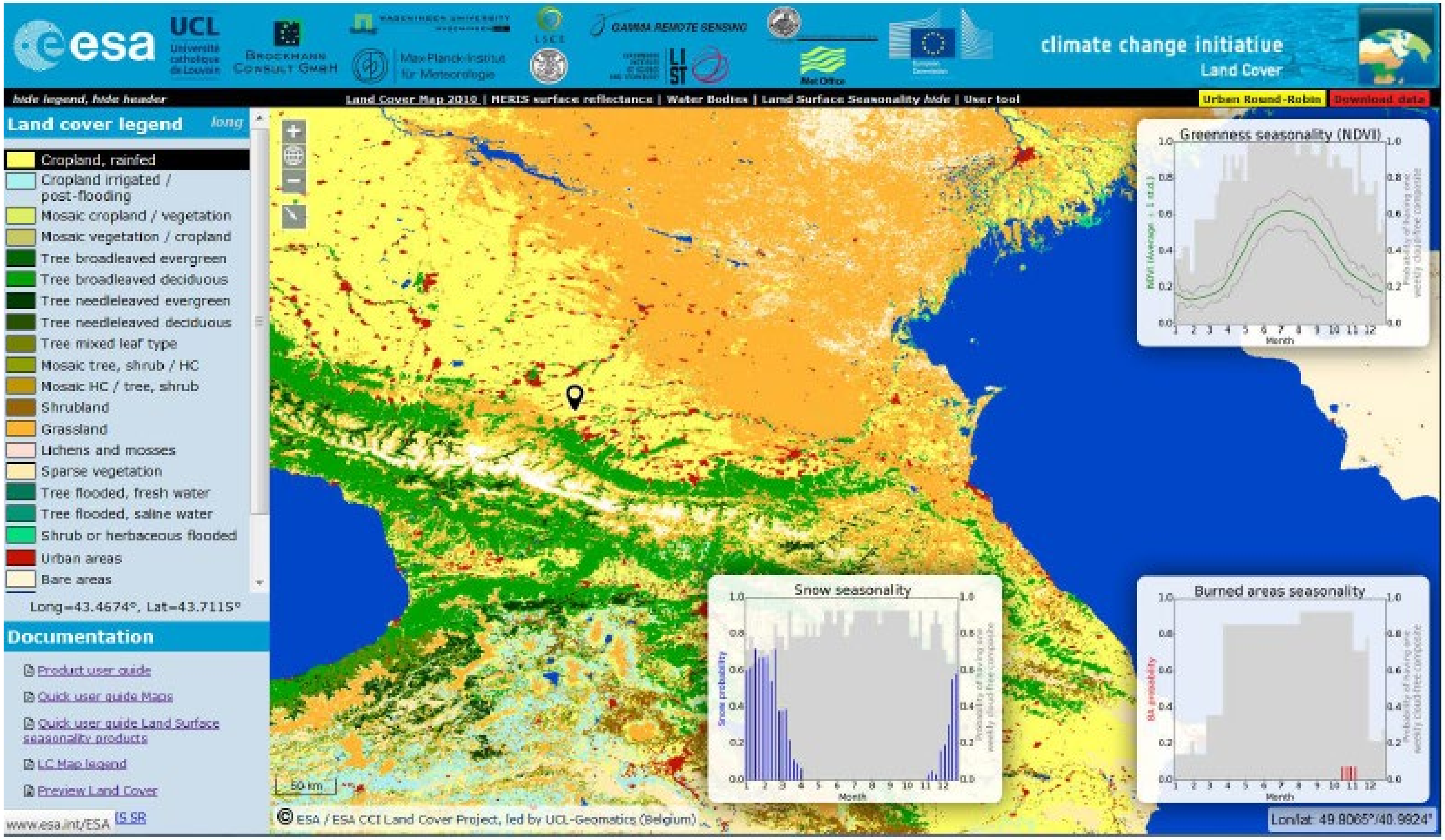


CCI Land Cover : Data Integration Challenge

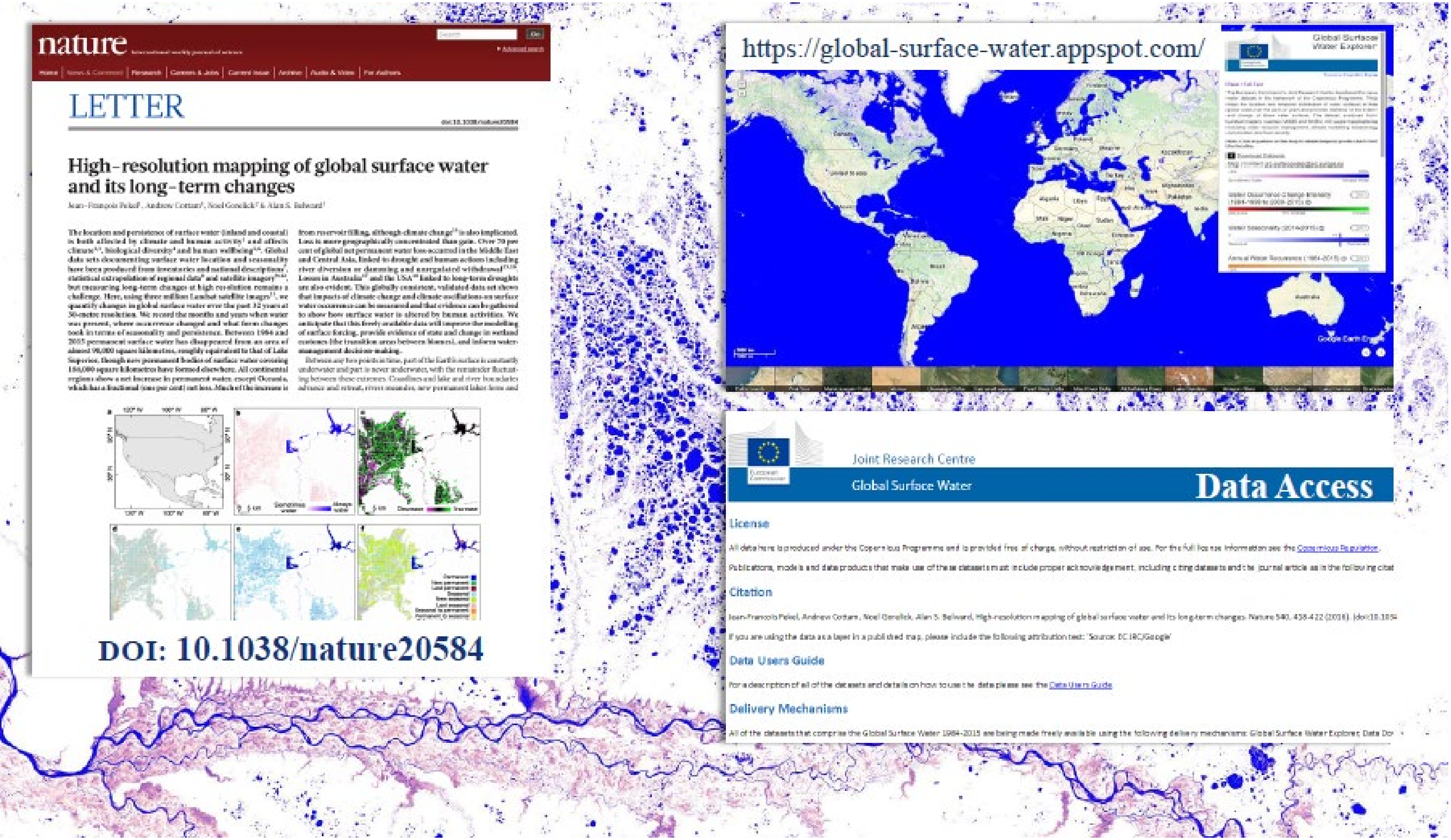


CCI Land Cover : Access & Uses

http://maps.elie.ucl.ac.be/CCI/viewer/index.html



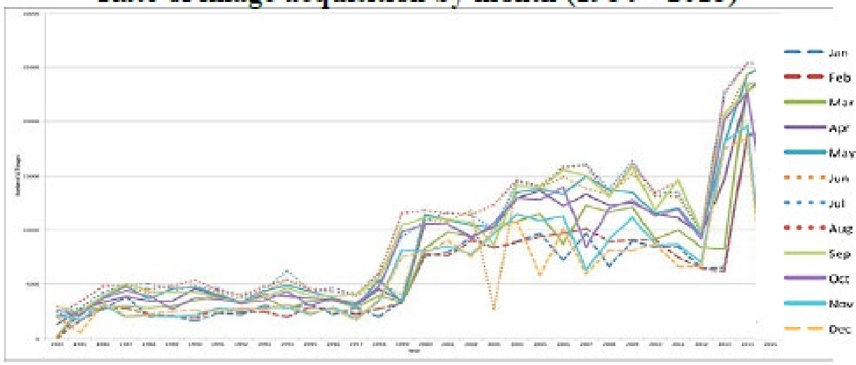
High Resolution Global Surface Water



High Resolution Global Surface Water

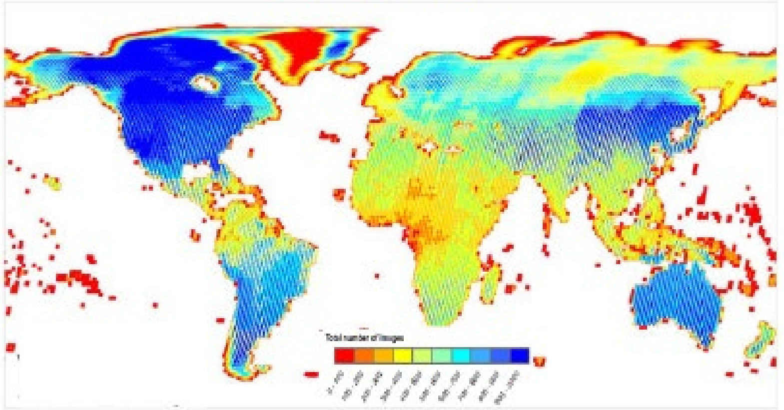
- Expert system classifier, Uses temporal trajectory of pixels in the multispectral feat space and Hue/Saturation/Value colour mo
- Evidential reasoning & visual analytics approach
- Calibrated based on a large spectral library (64,254 samples)
- Each pixel of the 3,066,102 Landsat scenes was classified as water, land or non-valid observation - 1.8 PB of data -
- Processing
  - One CPU would have taken 1,212 years
  - Google Earth Engine took 45 days
- Spatio-Temporal Validation : Based on 40.124 validation samples
- (Omission < 5% ; Commission < 1%)

Rate of image acquisition by month (1984 – 2015)



Geographic and temporal unevenness of the archive

Number of L1T



	Landsat 5			Landsat 7			Landsat 8		
	Overall	Seasonal	Permanent	Overall	Seasonal	Permanent	Overall	Seasonal	Permanent
Commission accuracy	99.45%	98.80%	99.56%	99.35%	98.38%	99.50%	99.54%	98.53%	99.66%
Omission accuracy	97.01%	74.91%	98.79%	95.79%	73.82%	97.72%	96.25%	77.40%	99.10%

High Resolution Global Surface Water

Thematic Products

The validated water history was used to produce thematic products that document different facets of the surface water dynamics

Maps & Temporal Profiles

- Occurrence
- Occurrence Change Intensity
- Seasonality
- Recurrence
- Water Transition
- Max Water Extent

Full monthly water history

(+Metadata layers)

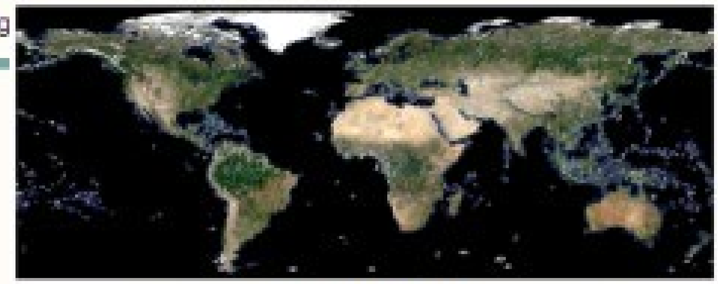
https://global-surface-water.appspot.com/

Habitation/Built-up : Global Impervious Layer

Global Impervious Cover From Landsat

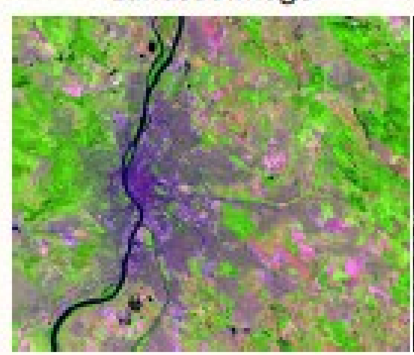
E. Brown de Colstoun[1], C. Huang[2] et al.

1 NASA Goddard Space Flight Center, Greenbelt, MD
2 Department of Geographical Sciences, University of Maryland, Colleg

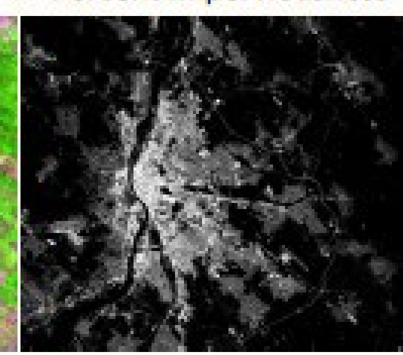


- Current estimates of urbanization are at scales of ~500-1000m but changes in the urban fabric occur at much finer scales (~15-30m).
- Landsat resolution provides a good balance for global coverage, spatial details and repeatability.
- The GLS-IMP project is producing the first Global 30 m impervious surface products using Global Land Survey (GLS) Data.
- Subpixel estimation is essential since most urban pixels are highly mixed.
- We have derived a very large global training data set from the NGAs non-classified commercial satellite image archive (e.g. Quickbird, Worldview). Access to these free data and global Landsat data are critical.
- Approach is object-based, automated:
  - *Surface reflectance provides consistent radiometry.*
  - *Regression tree algorithm is able to model complex nonlinear relationships and handle massive training set.*
  - *Image segmentation tools (Hseg) provide hierarchical image objects for training and for post-processing*

Landsat image



Percent Imperviousness



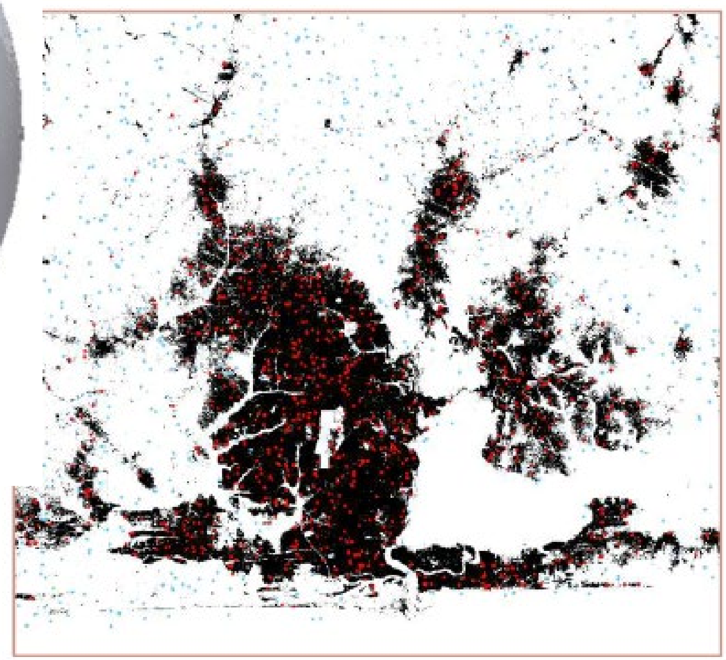
First 30m Global Urban Product

Global Urban Footprint (GUF 15)

- **Automatic extraction of training areas (urban / non-urban)**
- **Classification based on Support Vector Machines (SVM)**
- **Combination & post-classification enhancement ruleset**

Global Urban Footprint (GUF), a mask of built-up areas derived from TerraSAR-X and TanDEM-X data acquired between 2011 and 2013

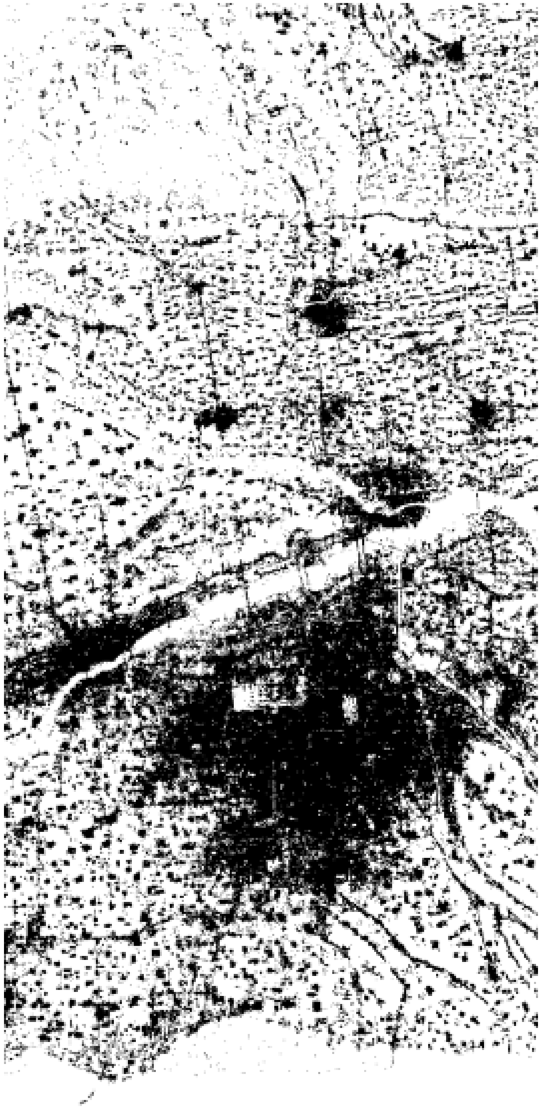
Validation



50 x [(1000 + 1000) x 9] = **900.000** validation samples

- Three possible labels:
  1: Urban
  > 50% covered by buildings
  2: Moderately Urban
  < 50% covered by buildings
  3: Non-Urban
  No buildings

GUF+15 has extra information from GHSL

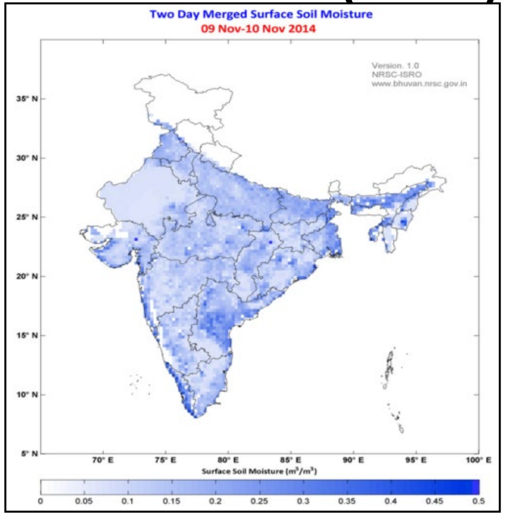


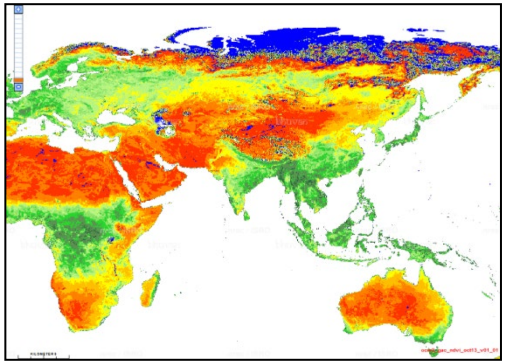
GHSL – 38m

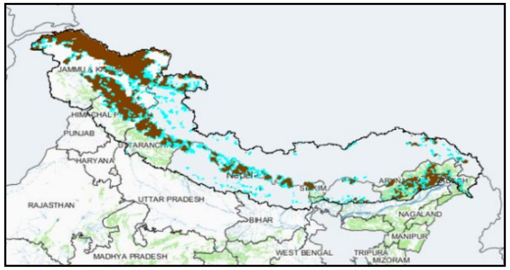
NOEDA: National Information System for Climate and Environment Studies (NICES)

Total Downloads from Bhuvan > 3 Lakhs (Satellite Data + Products)

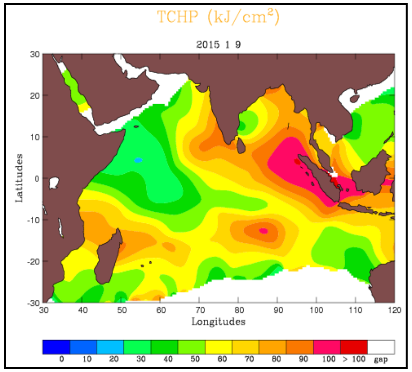
Products	Resolution/ Gridsize	Availability	Frequency
Atmospheric and Climate Sciences			
Derived Tropospheric Ozone	1° x 1°	2010 – 2013	Daily
Ocean Sciences			
Daily Ocean Heat Content	0.25°	2002 - 2015	Daily
Daily Tropical Cyclone Heat Potential	0.25°	1998 – 2015	Daily
Model Derived Depth of 26°C Isotherm	0.5° x 0.5°	2013 - 2015	Daily (15 days lag)
Model Derived TCHP	0.5° x 0.5°	2013 - 2015	Daily (15 days lag)
Ocean Wind Curl	0.5° x 0.5°	2012 – 2014 (Feb)	Daily
Ocean Wind Stress	0.5° x 0.5°	2012 – 2014 (Feb)	Daily
Ocean Wind Velocity	0.5° x 0.5°	2012 – 2014 (Feb)	Daily
Terrestrial Sciences			
AWiFS: Snow Cover Fraction	3' X 3' Grid	2014-2015	15 Days
AWiFS: Water Bodies Fraction	3' X 3' Grid	2004 – 2013, 2014-2015	Monthly, 15 Days
Mesoscale compatible inputs for: MM5	30 sec, 2, 5 mins	2004-05 to 12-13 (9 Cycles)	Yearly
Mesoscale compatible inputs for: WRF	30 sec, 2, 5 mins	2004-05 to 12-13 (9 Cycles)	Yearly
OCM2: Albedo	1 Km	2013 – 2014	15 Days
OCM2: NDVI - Global Coverage	8 Km	2013	Monthly
OCM2: NDVI - Local Coverage	1 Km	2011, 2012-2014	Monthly, 15 Days
OCM2: Vegetation Fraction	1 Km	2011, 2012-2014	Monthly, 15 Days
Snow Melt and Freeze	2.225 Km	2009 – 2013	2 Day
Surface Soil Moisture	0.25° x 0.25°	2012 – 2014	Daily
Surface Soil Moisture - 2 Day	0.25° x 0.25°	2012 – 2014	2 Day

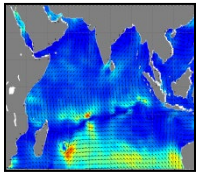


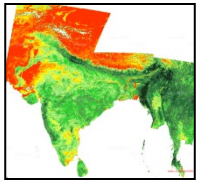


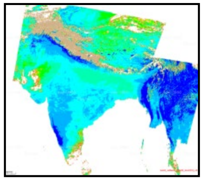


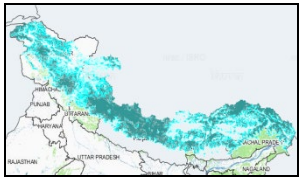
Products	Downloads
OCM2	4799
AWIFS	28172
OHC	348
NICES	1695
hysi	4102
TCHP	883
OCM2: Albedo	551
OCM2: NDVI	2933
OCM2: VF	1183











Spatial Databases for Vegetation

- Vegetation parameters cover – Vegetation Type, Vegetation phenology, LAI, Vegetation Cover/Fraction, Biomass & accompanying parameters of albedo, conductance, roughness, interception
- Vegetation Type is covered in Land Cover/Use
- Vegetation Phenology, LAI, VF currently are covered by surrogate remote sensing variable NDVI (Normalised Difference Vegetation Index)

- Global products are available from AVHRR & MODIS sensors.

- Procedure & processing chain established for product generation from ISRO missions – Ocean Colour Monitor (OCM) of Oceansat-II and AWiFS of Resourcesat-2

OCM Geophysical Products: NDVI, VF, Albedo

- National Products – OCM-LAC
- NDVI & Vegetation Fraction, Albedo [Visible (0.3 to 0.7 um), Broadband (0.3 to 3 um)]
  - @ 1 km resolution, Fortnightly Products, Maximum value Composite of 8 datasets

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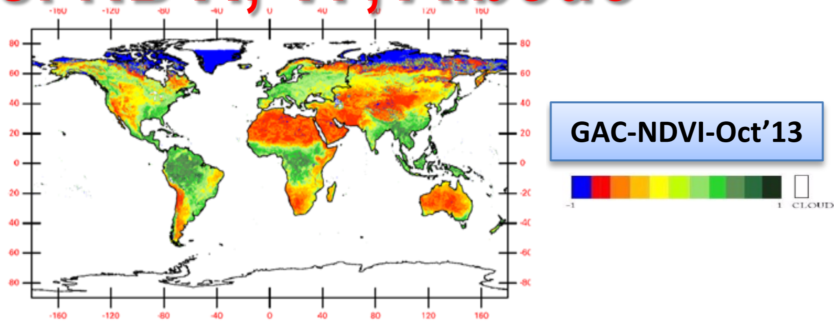
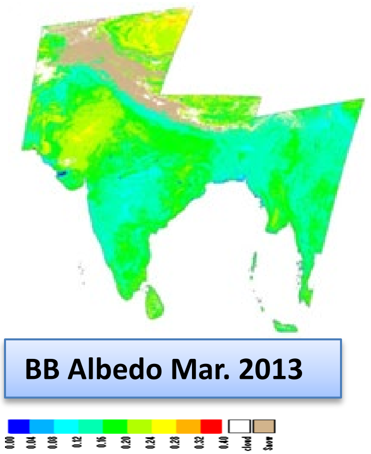
- Global Products – OCM – GAC
- NDVI Products
  - @ 8km resolution, Monthly Products, Maximum Value Composite of 4 datasets

Features

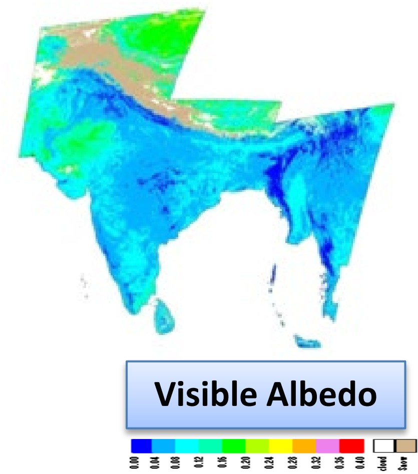
- Ortho Rectified to sub pixel level
- Atmospherically corrected
- Compositing to minimize cloud contamination
- Good correlation with MODIS (> 90%)
- Bhuvan Downloads: 2760



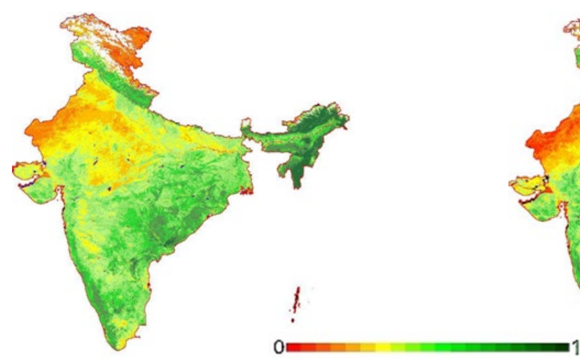
GAC-NDVI-Oct'13



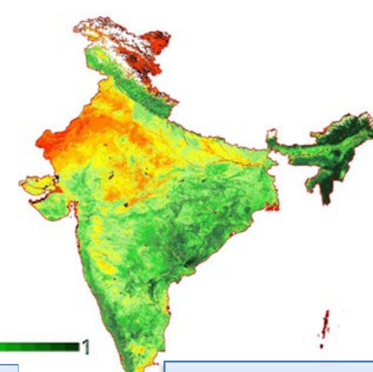
BB Albedo Mar. 2013



Visible Albedo

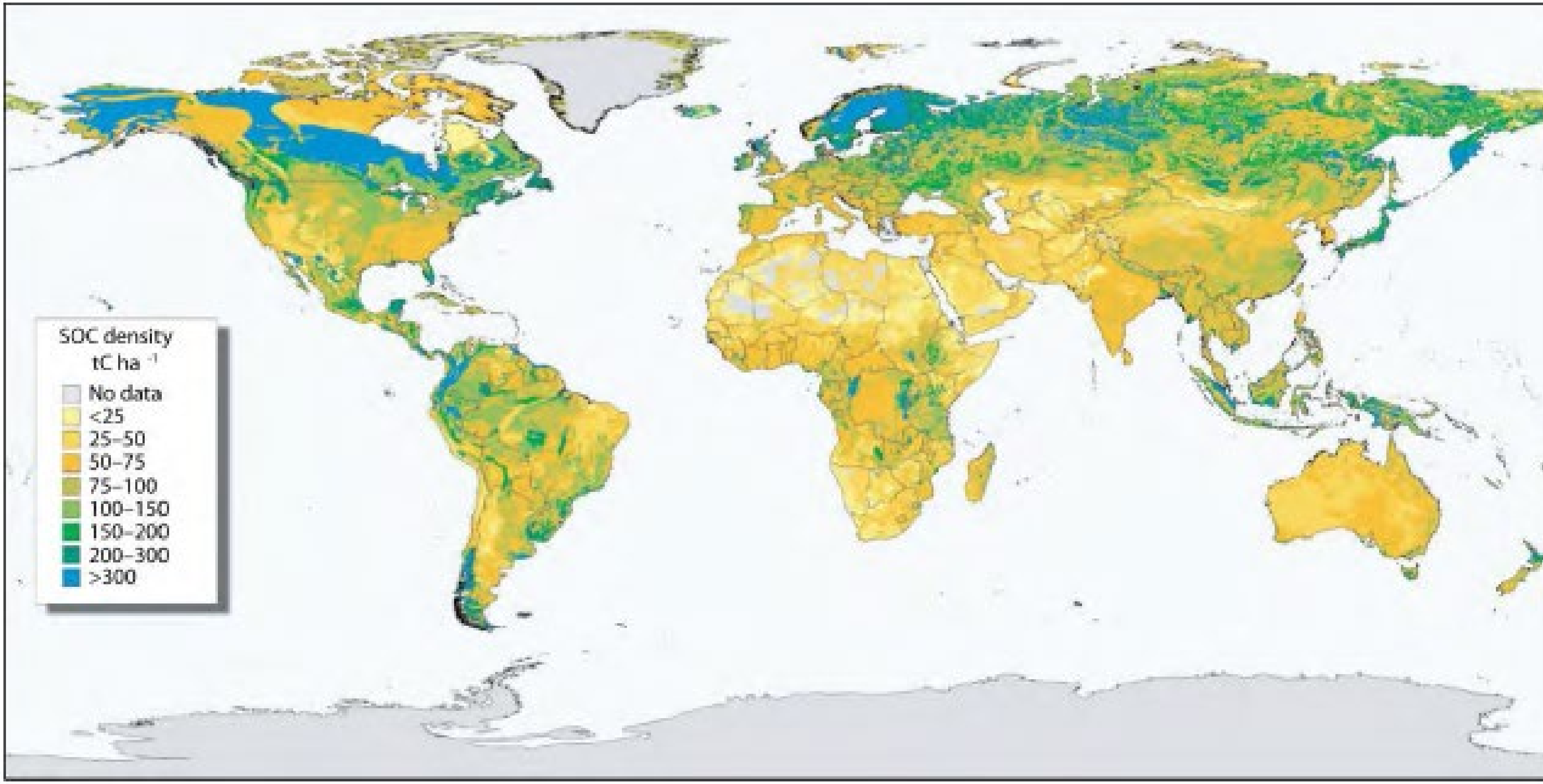


Vegetation Fraction - Nov'13



NDVI: Nov'13

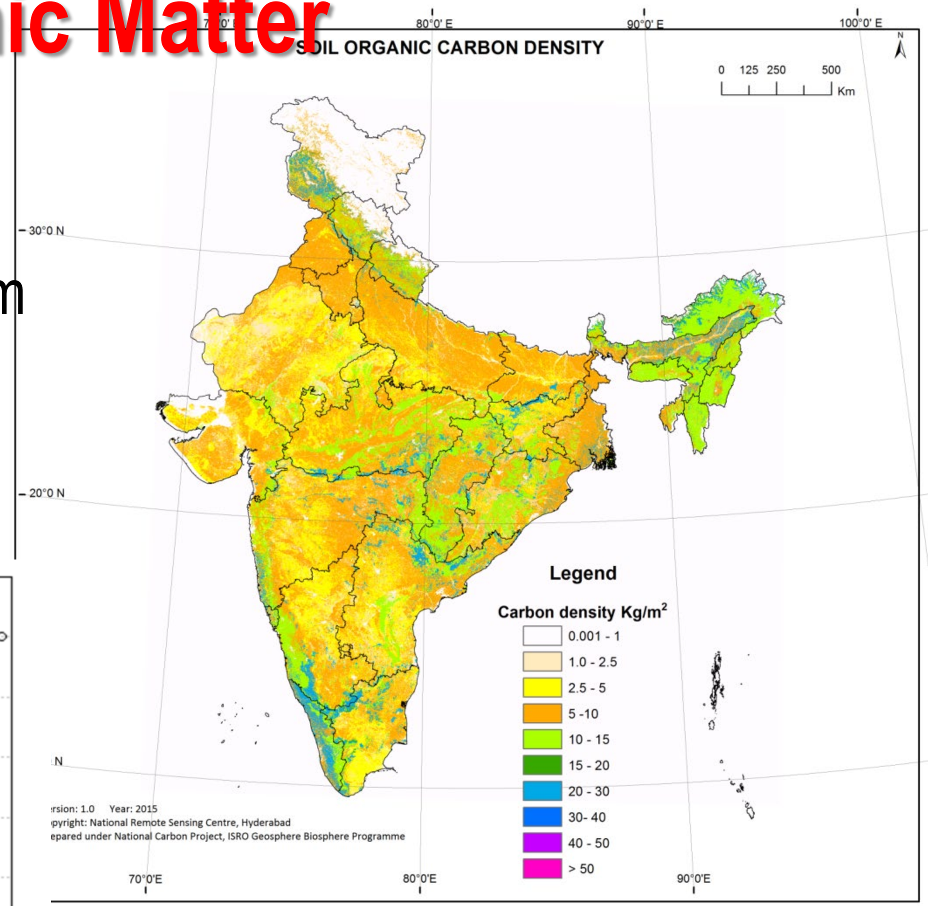
Global Soil Organic Carbon : EO assisted

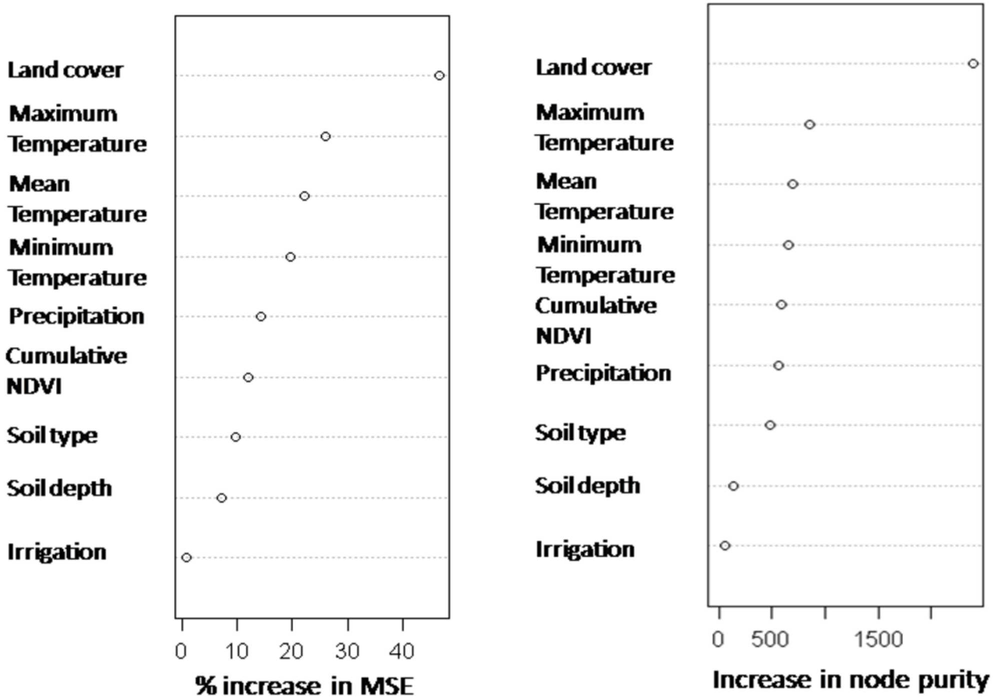


Soil organic carbon (t°C°ha−1) to 1°m depth based on the Harmonized World Soil Database Source: Scharlemann et al. (2014) (GCOS – 195, Fig 68)

Soil Organic Matter

- SOM is largest terrestrial pool
- SOM is larger than Biomass
- Estimates are by soil type or ecosystem class
- Spatial modeling with controlling parameters developed



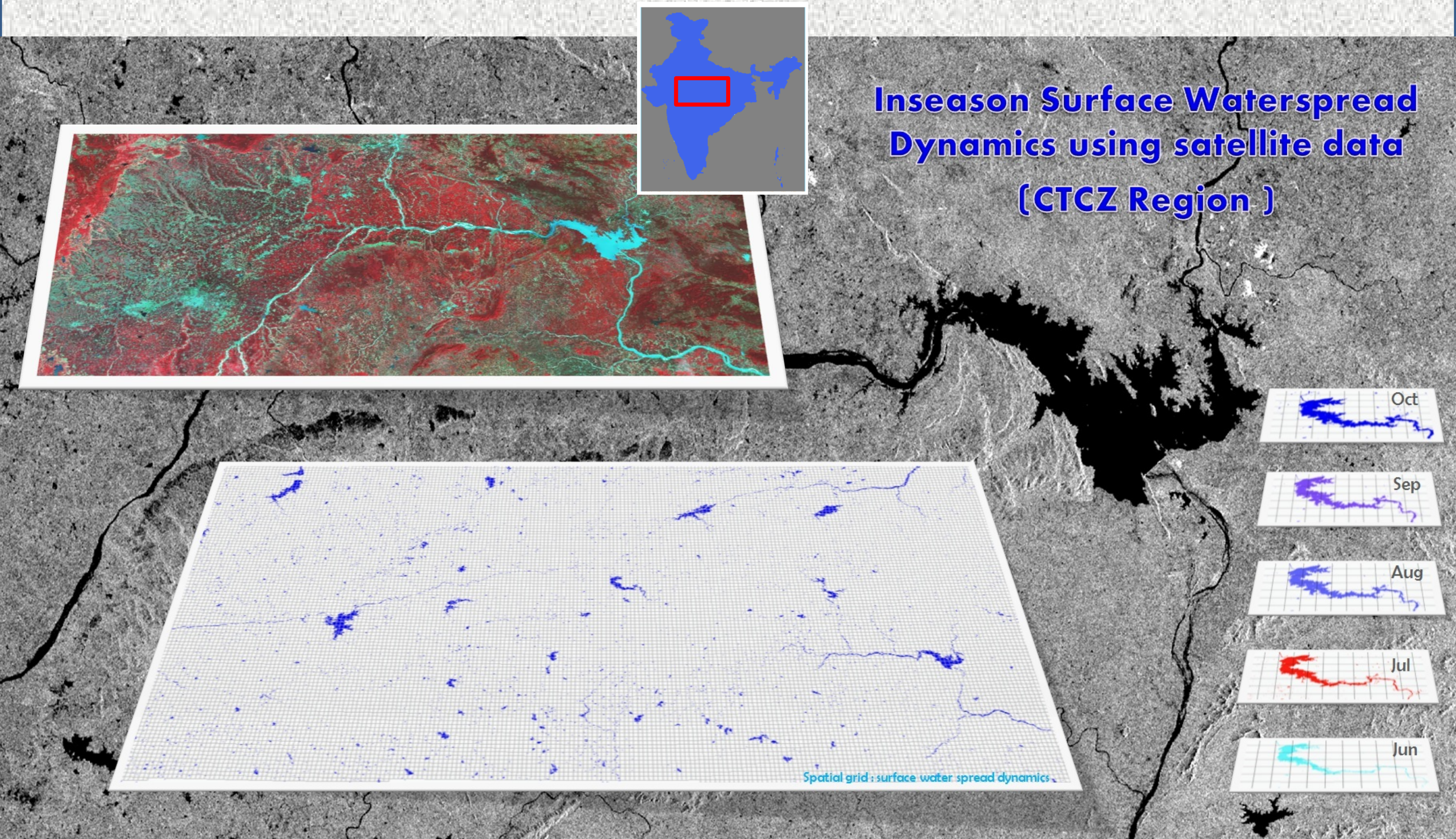


Organic carbon density

Sreenivas et al., 2017, Geoderma

Spatial Databases for Hydrology (EO-based)

- Required /available parameters include precipitation, snow cover, surface … water, soil moisture,
- Indian EO based snow cover & wetlands being produced as monthly datasets by NRSC (AWiFS on Resourcesat-2 used)
- Special study on central CTCZ using SAR highligted large monthly variation in surface water (wetlands & rice crops) during monsoon (2011)
- Automation of surface water using Risat-1 SAR initiated
- Experimental soil moisture by a combination of techniques (VIC, bucket model, EO-derived initiated)

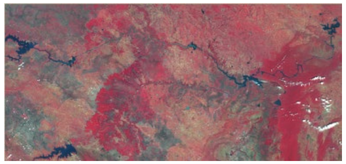

Inseason Surface Waterspread
Dynamics using satellite data
(CTCZ Region)
Oct
Sep
Aug
Jul
Jun
Spatial grid : surface water spread dynamics

Automated Satellite Data Processing

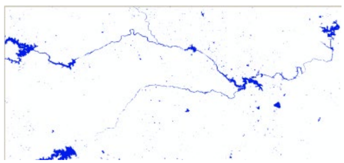
Geophysical Products : Water Bodies Fraction, Snow Cover Area

Resourcesat-2 AWiFS

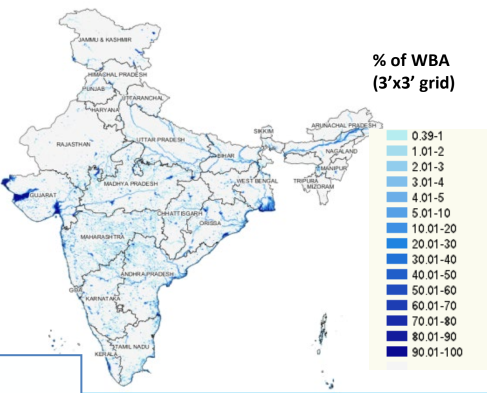
AWiFS Image

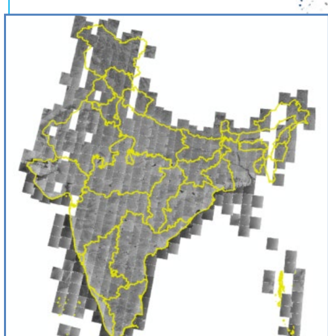


Water layer

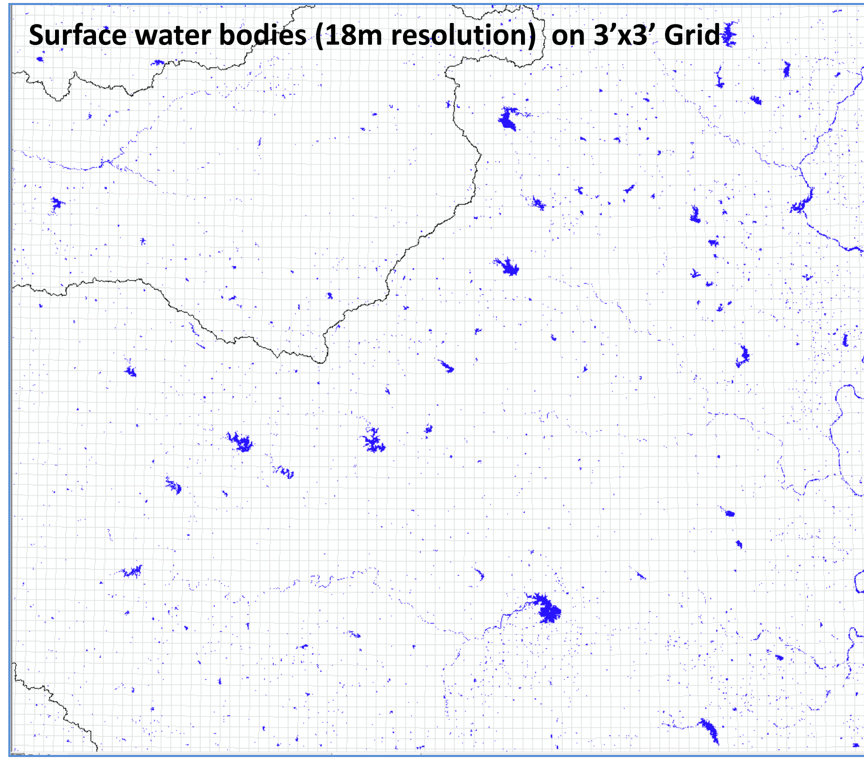


Water Bodies Fraction





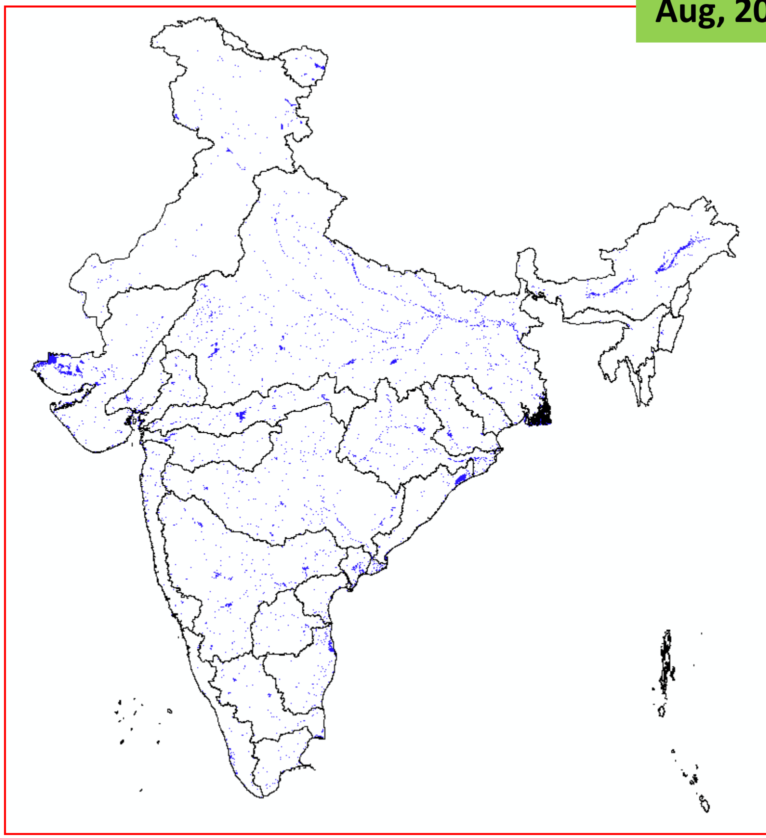
RISAT-1 MRS data is used



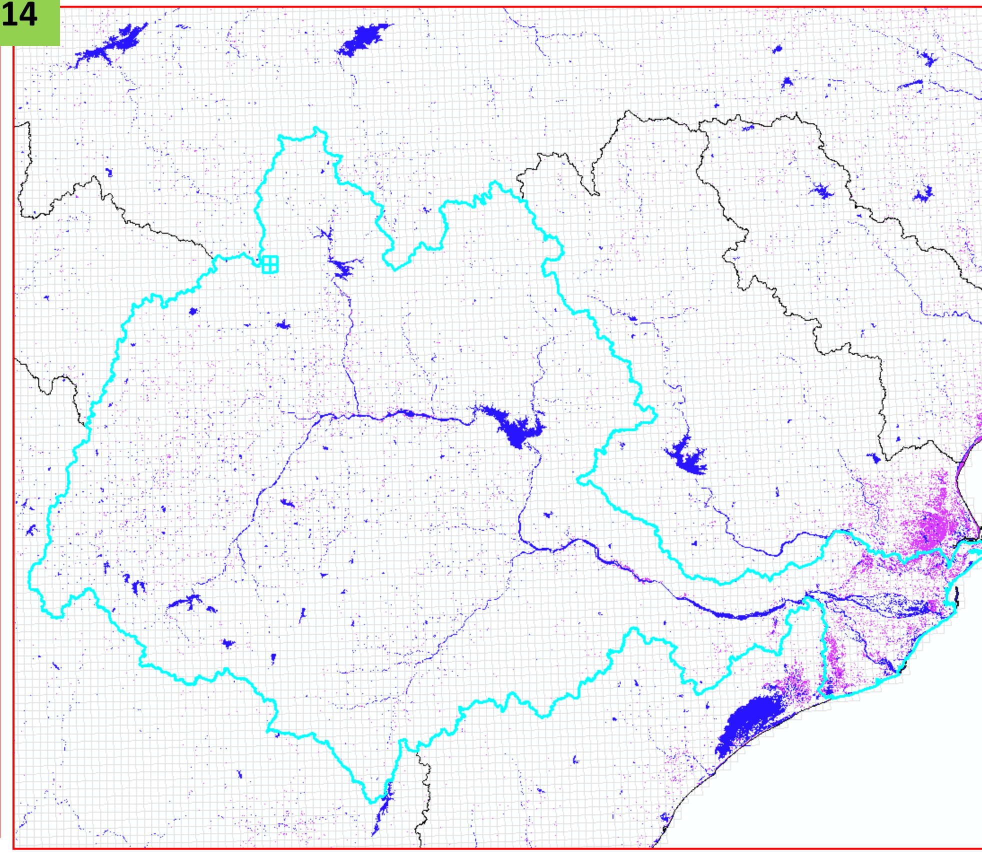
Satellite / Sensor	Frequency	Outputs
Resourcesat-2 AWiFS	15 Days	56m Water bodies Layer 3'x3' Grid Water bodies fraction
RISAT-1 MRS	Month	18m Water bodies Layer 3'x3' Grid Water bodies fraction
Resourcesat-2 AWiFS	15 Days	Snow cover fraction at 3'x3' Grid

Water Bodies Fraction : August 1-25th , 2014 -RISAT-1 MRS Data

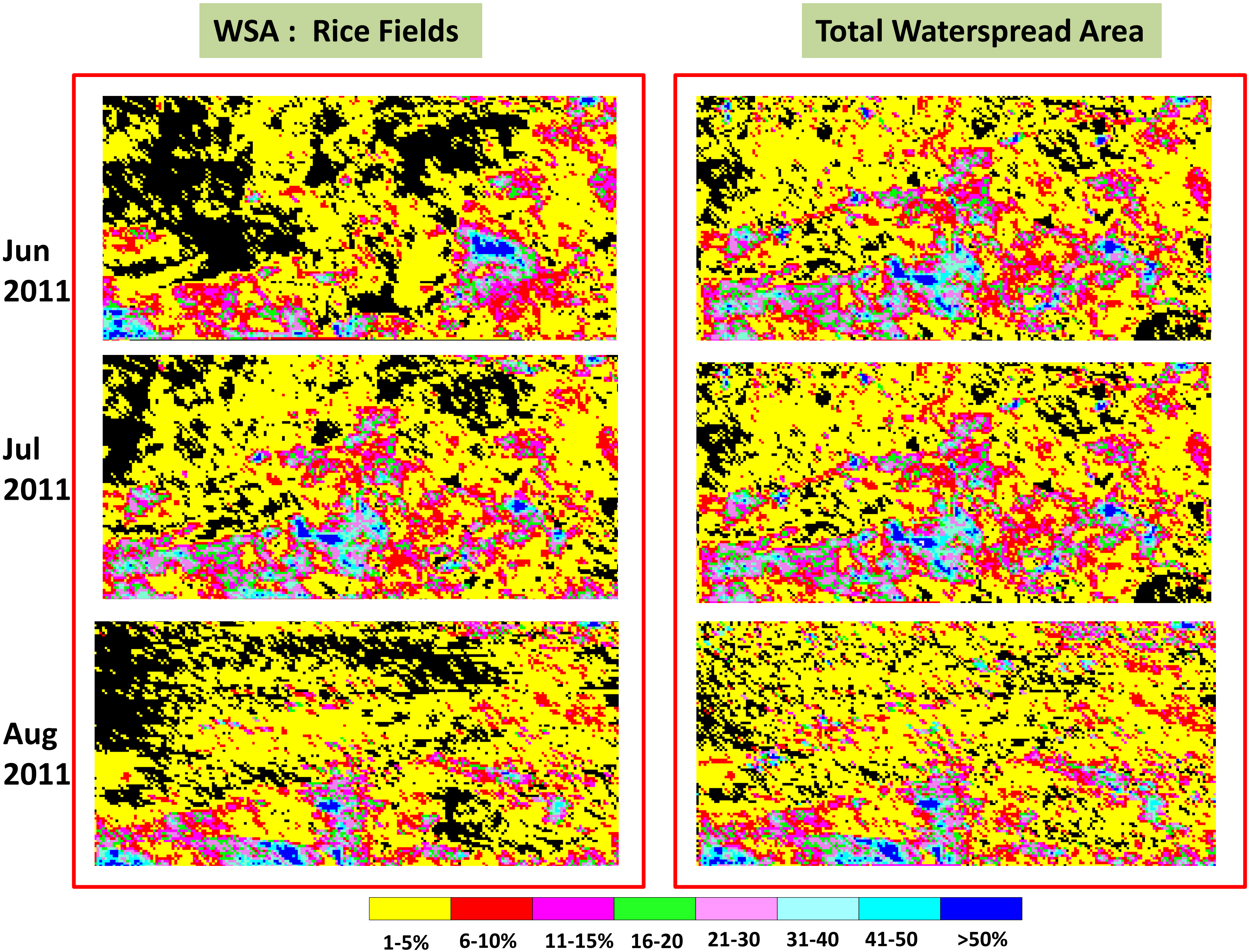
Aug, 2014



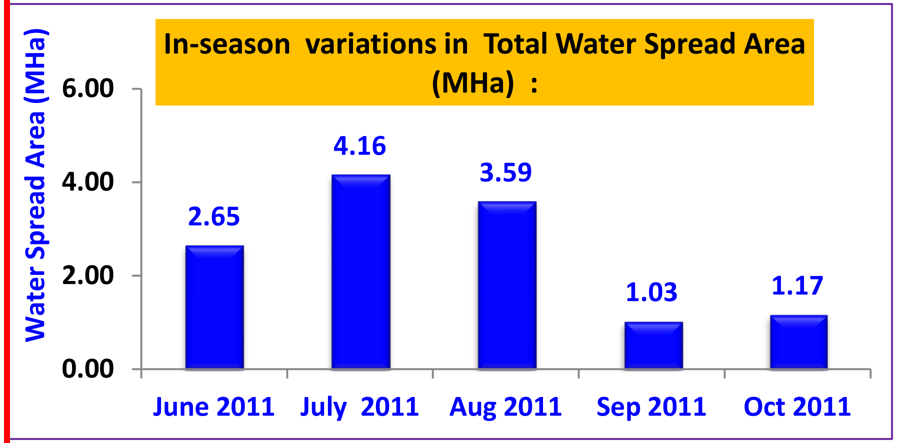
Surface water bodies (18m resolution)
derived from RISAT-1 MRS (1-25th August 2014)

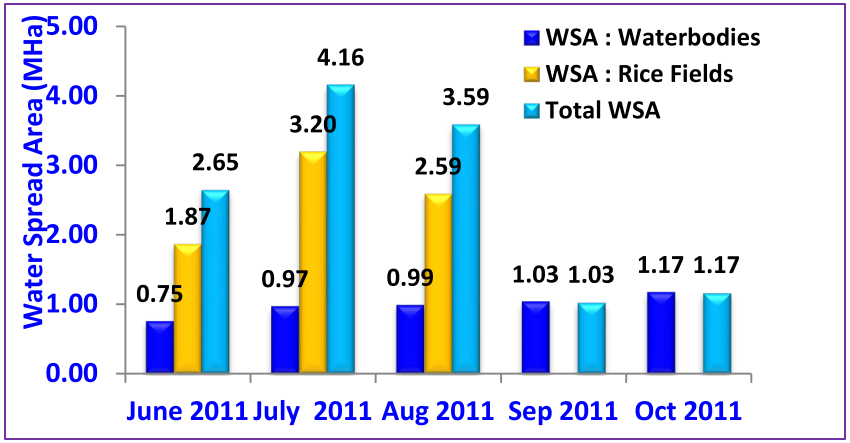


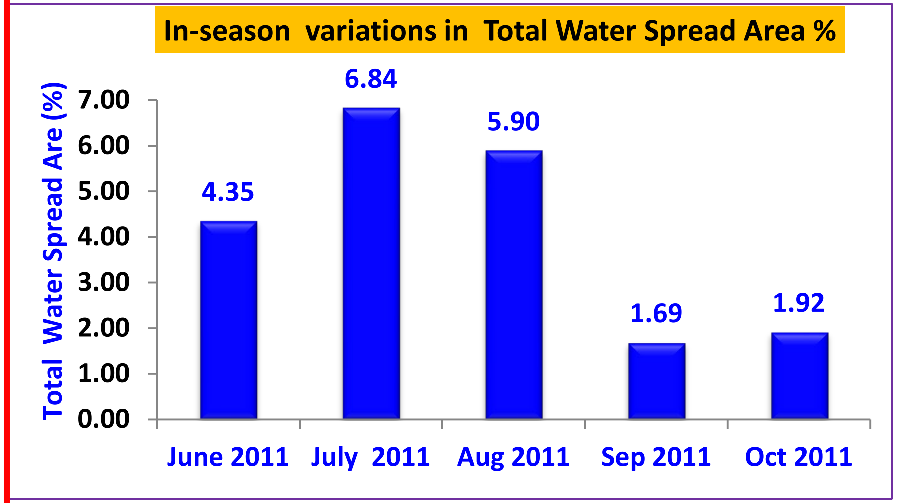
Mahanadi River Basin

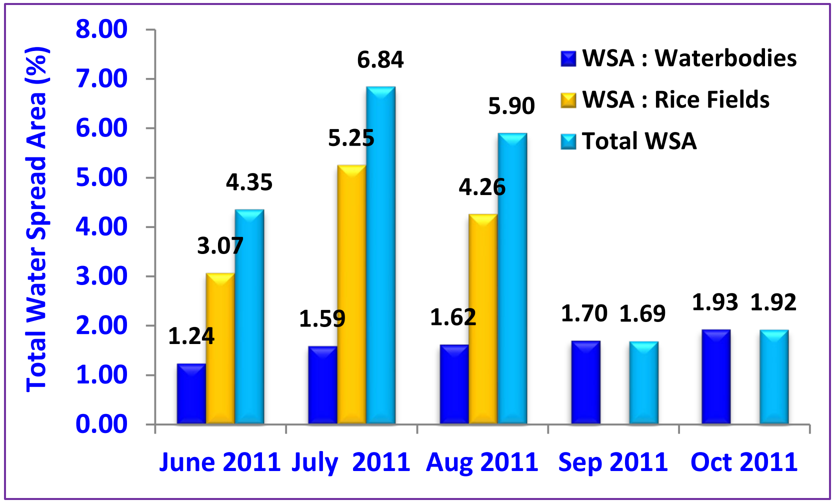

WSA : Rice Fields
Total Waterspread Area
Jun 2011
Jul 2011
Aug 2011
1-5%
6-10%
11-15%
16-20
21-30
31-40
41-50
>50%

Water spread area

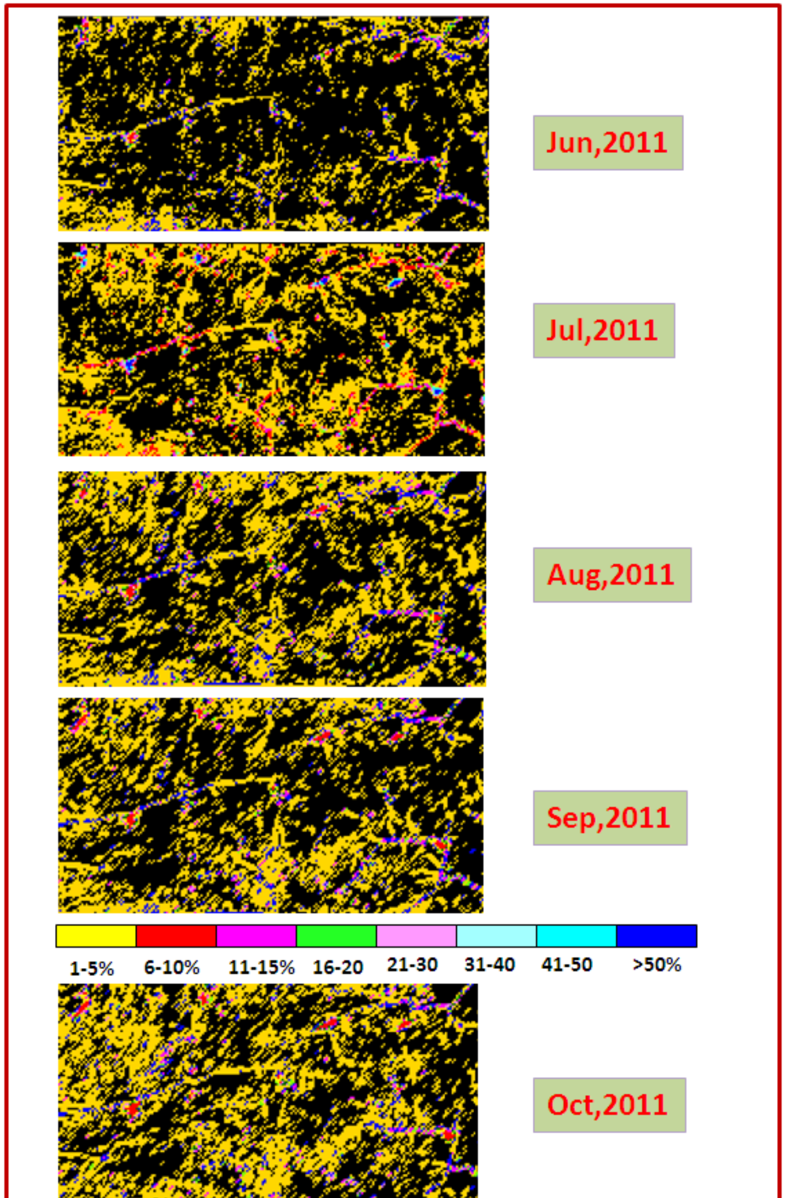




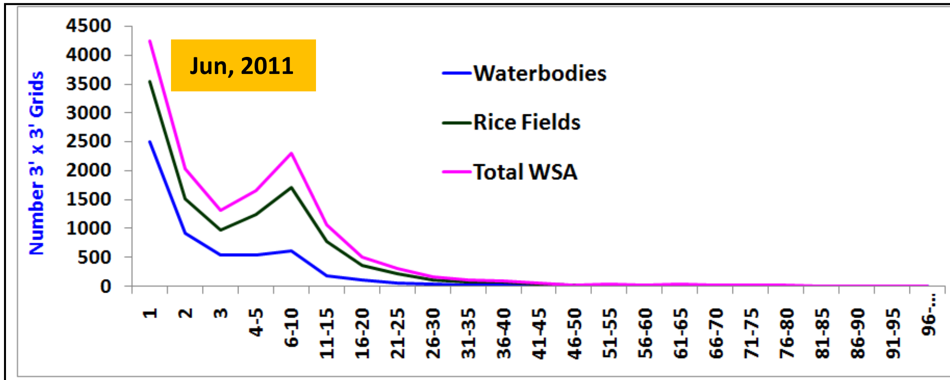


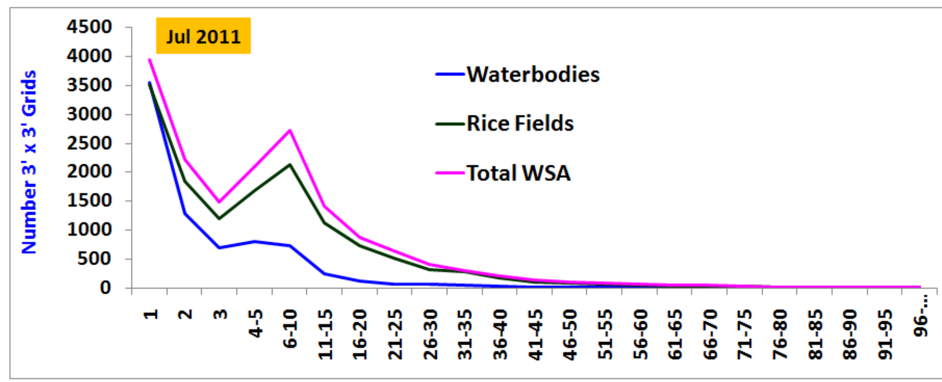


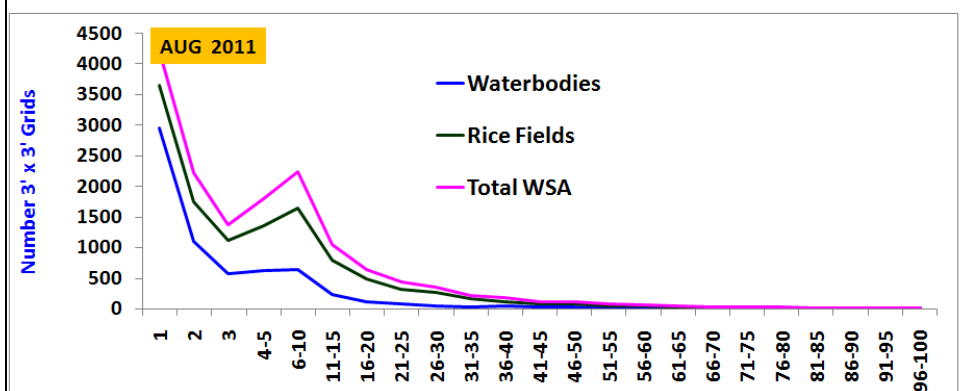
Waterspread Area : Spatial View



Inseason Spatial water bodies (% of 3’ 3’ grid)







Land Geophysical Products from OCM: VEGETATION INDICES, ALBEDO, WATER LAYER

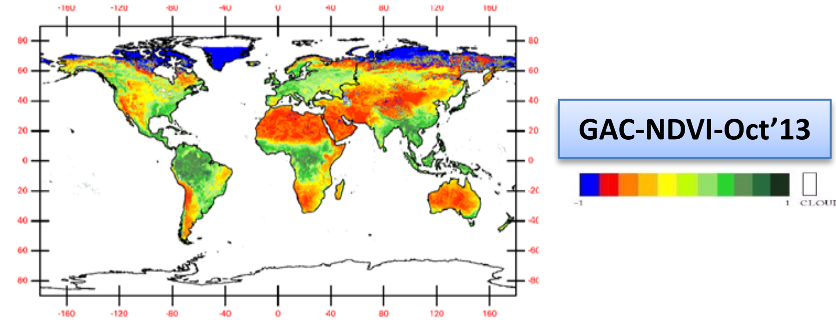
Geophysical and Special Products

- **NDVI & Vegetation Fraction Products from OCM-LAC :**
  - Fortnightly Products
  - Maximum value Composite of 8 datasets
  - @ 1 km resolution
- **Land Surface Albedo Products from OCM-LAC Visible (0.3 to 0.7 um)**

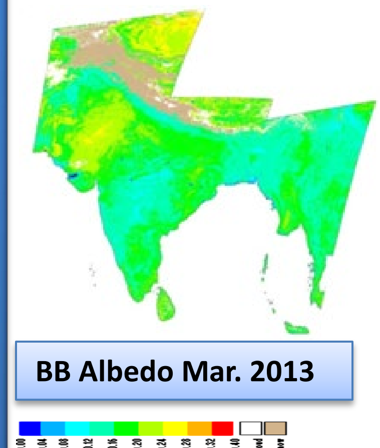
  Broadband (0.3 to 3 um)
  - Fortnightly Products
  - @ 1 km resolution
- **Global NDVI Products from OCM-GAC (2013)**
  - Monthly Products
  - Maximum Value Composite of 4 datasets
  - @ 8km resolution

Features

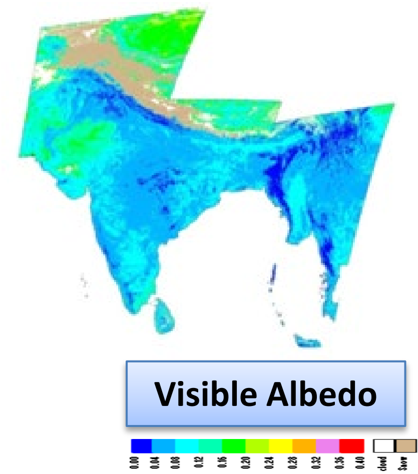
- Ortho Rectified to sub pixel level
- Atmospherically corrected
- Compositing to minimize cloud contamination
- Good correlation with MODIS (> 90%)
- Bhuvan Downloads: 2760



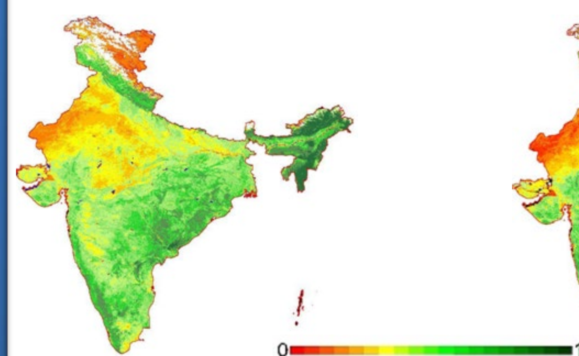
GAC-NDVI-Oct'13



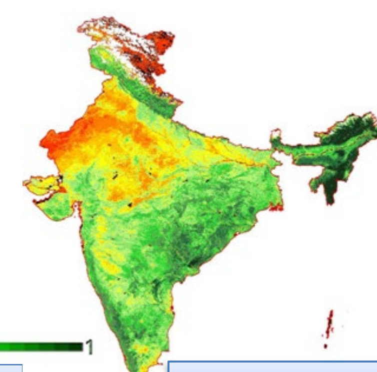
BB Albedo Mar. 2013



Visible Albedo

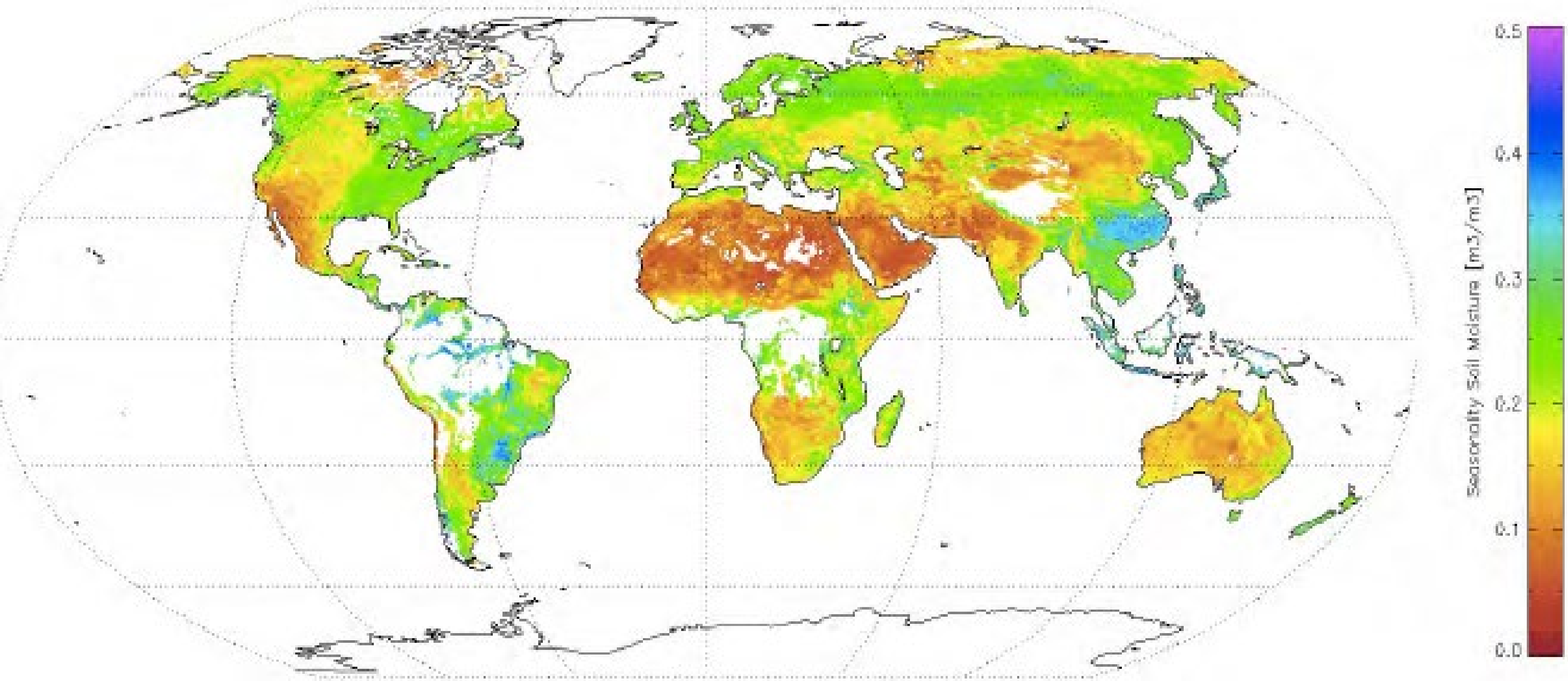


Vegetation Fraction - Nov'13



NDVI: Nov'13

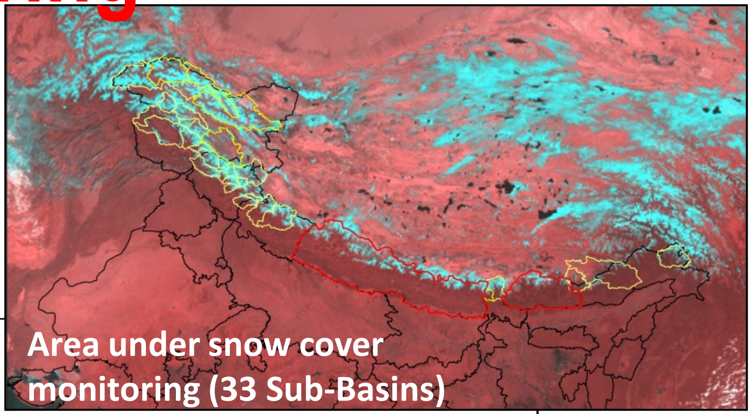
Global Soil Moisture

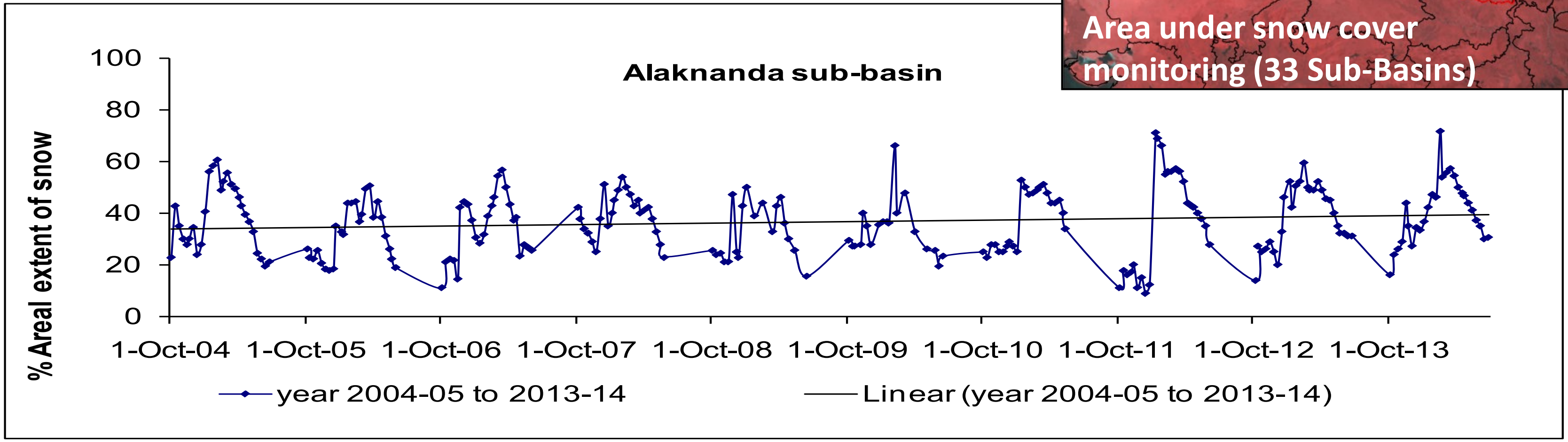


- **Mean volumetric soil moisture for May derived from combined use of passive and active satellite MW data for 1979–2010 (GCOS – 195, Fig 70)**
- **Source: ESA Soil Moisture CCI, http://www.esa-soilmoisture-cci.org/**

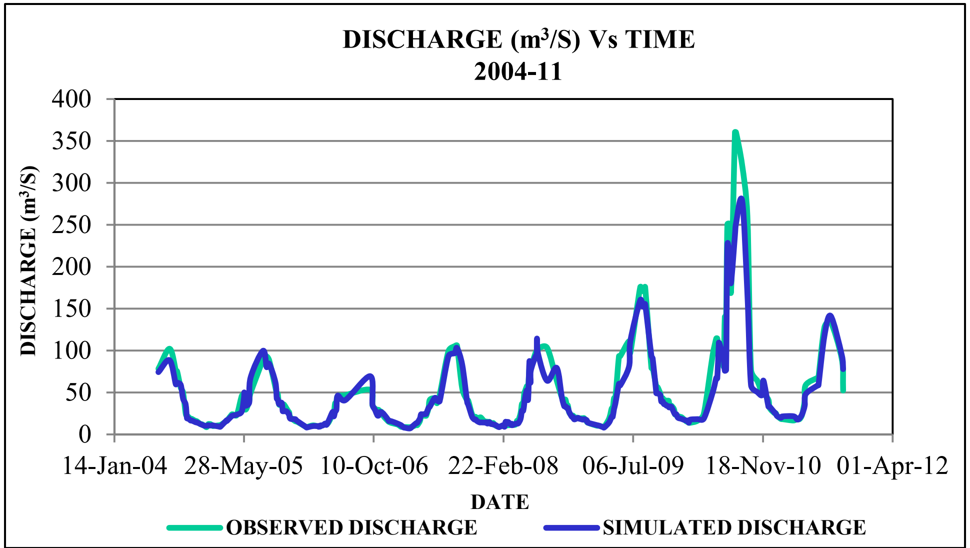
Snow Monitoring

- Snow Monitoring (2004-2014)
  - 85% to 22% of geog. Area (12.5 Mha)





- Snowmelt Runoff
  - Modeling & Prediction

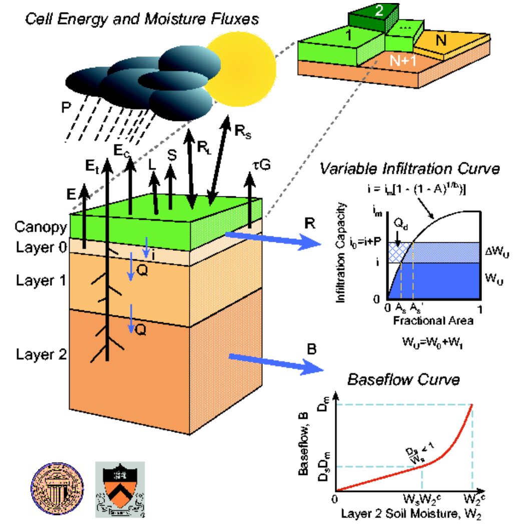


Land Surface Modelling

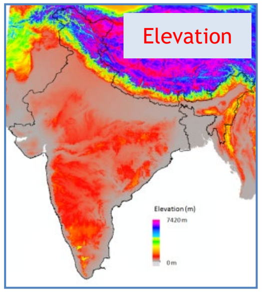
- Basin Scale hydrological modelling for Mahanadi Basin
- Geo-Physical products : NRSC BHUVAN Portal –for CTCZ studies
    - In-season surface water spread dynamics
    - High spatial resolution land use –land cover datasets for pre-monsoon and monsoon season
    - Intra seasonal vegetation dynamics (Fortnightly/Monthly: VF,NDVI)

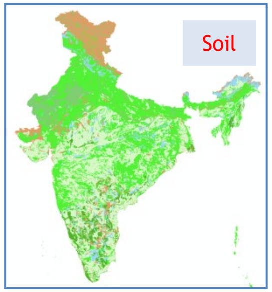
Land Surface Hydrological Modelling - Mahanadi River Basin

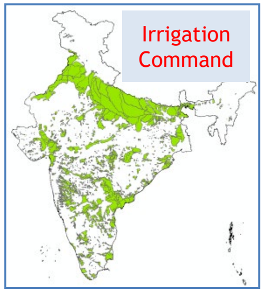
- Variable Infiltration Capacity Hydrological Model
  - *Open source; Grid-wise water and energy balance*
  - *Sub-grid heterogeneity of Land cover*
  - *Soil depth-wise hydrological response*
  - *Vegetation phenological changes*
  - *Daily / sub-daily time step*

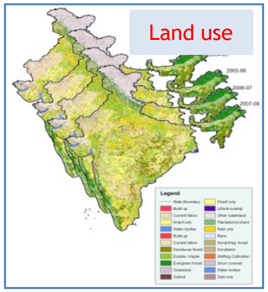


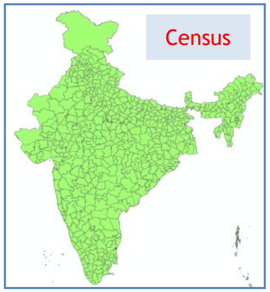
- 9 min (~16.5km), 3 min (~ 5.5km) Grid-wise data base
- Geo-spatial data
  - *Terrain - Topographic, Soil (NBSSLUP), LULC (NRC-250k), LAI, Albedo, Irrigation*
  - *Meteorological - Rainfall, Temperature, … (CDAS/CPC)*
  - *Hydrological - River discharge, Reservoir Storage/Releases, GW levels, …*
- Calibration with river discharge data (India-WRIS)

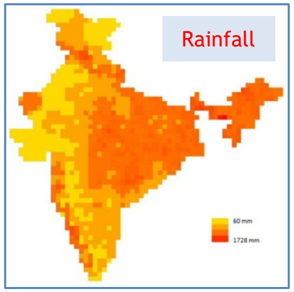


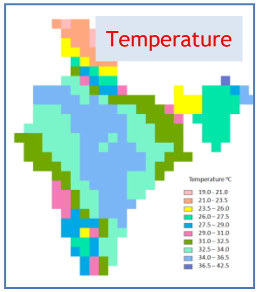




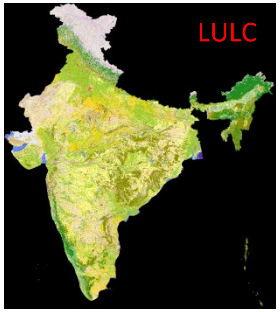








Land Use / Land Cover Parameterization

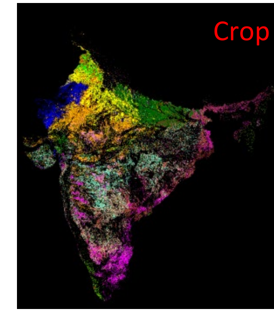


Build up
Kharif only
Rabi only
Zaid only
Double / triple
Current fallow
Plantation/orchard
Evergreen forest
Deciduous forest
Scrub/Deg. forest
Littoral swamp
Grassland
Other wasteland
Gullied
Scrubland
Water bodies
Snow covered
Shifting Cultivation
Rann

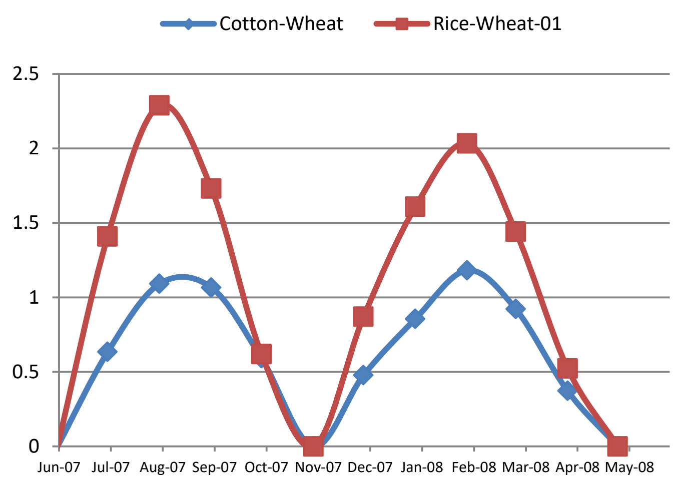
13 Agriculture Classes

Cotton-Wheat
Rice-Wheat-01
Rice-Wheat-02
Rice-Rice
Rice-01
Maize-Bajra
Soybean
Rice-02
Bajra
Jowar
Coconut
Rice-03
Ragi
Plantation/Orchard
EG Forest
Deciduous Forest
Scrub/Deg. forest
Grassland
Scrubland
Gullied
Other Wasteland
Littoral Swamp
Build Up
Water Bodies
Snow covered
Rann

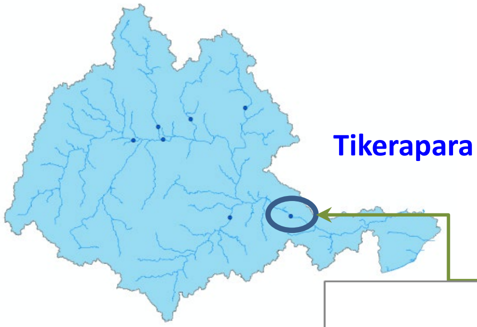
26 Vegetation Classes



LAI Profile

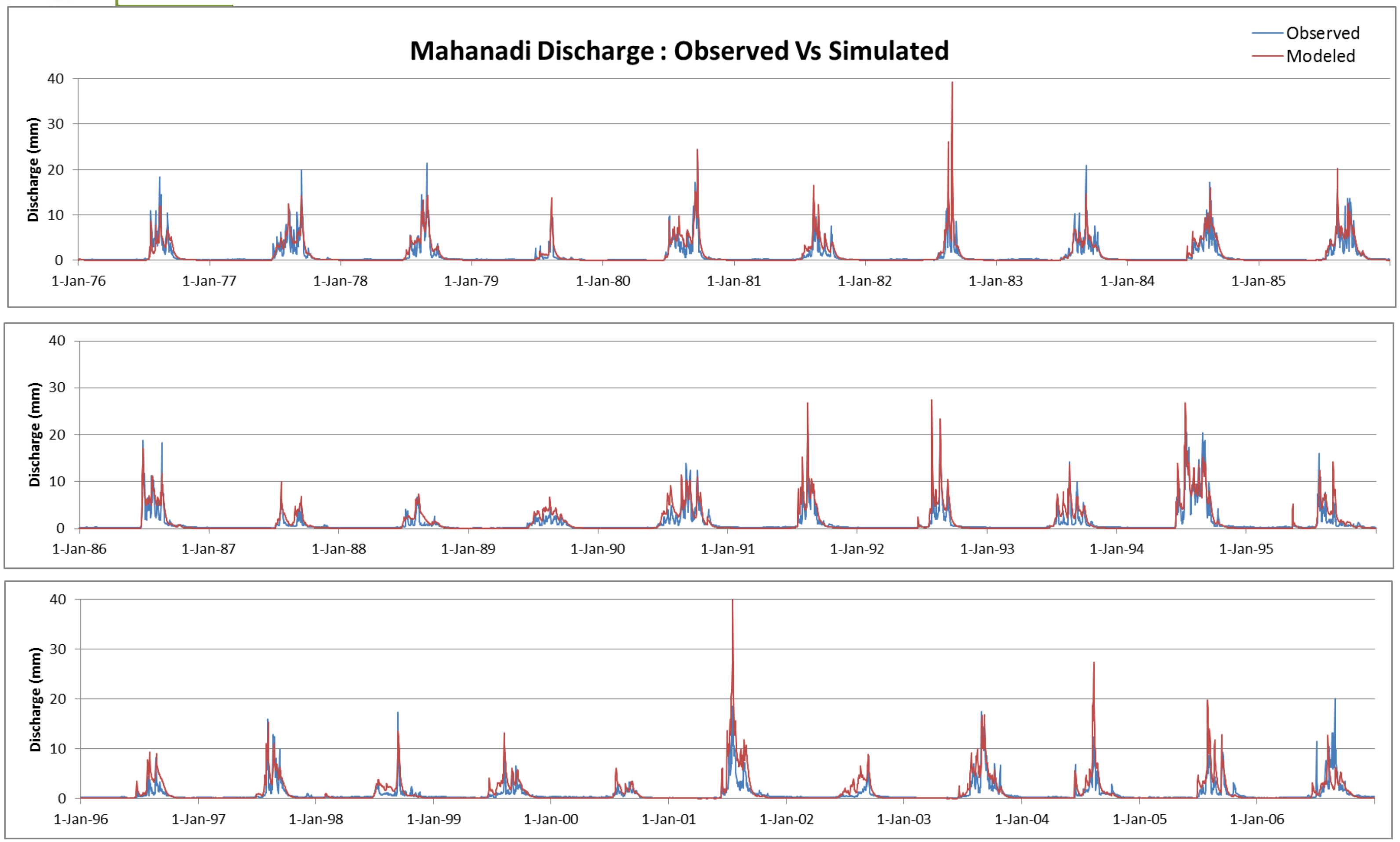


Calibration with River Discharge

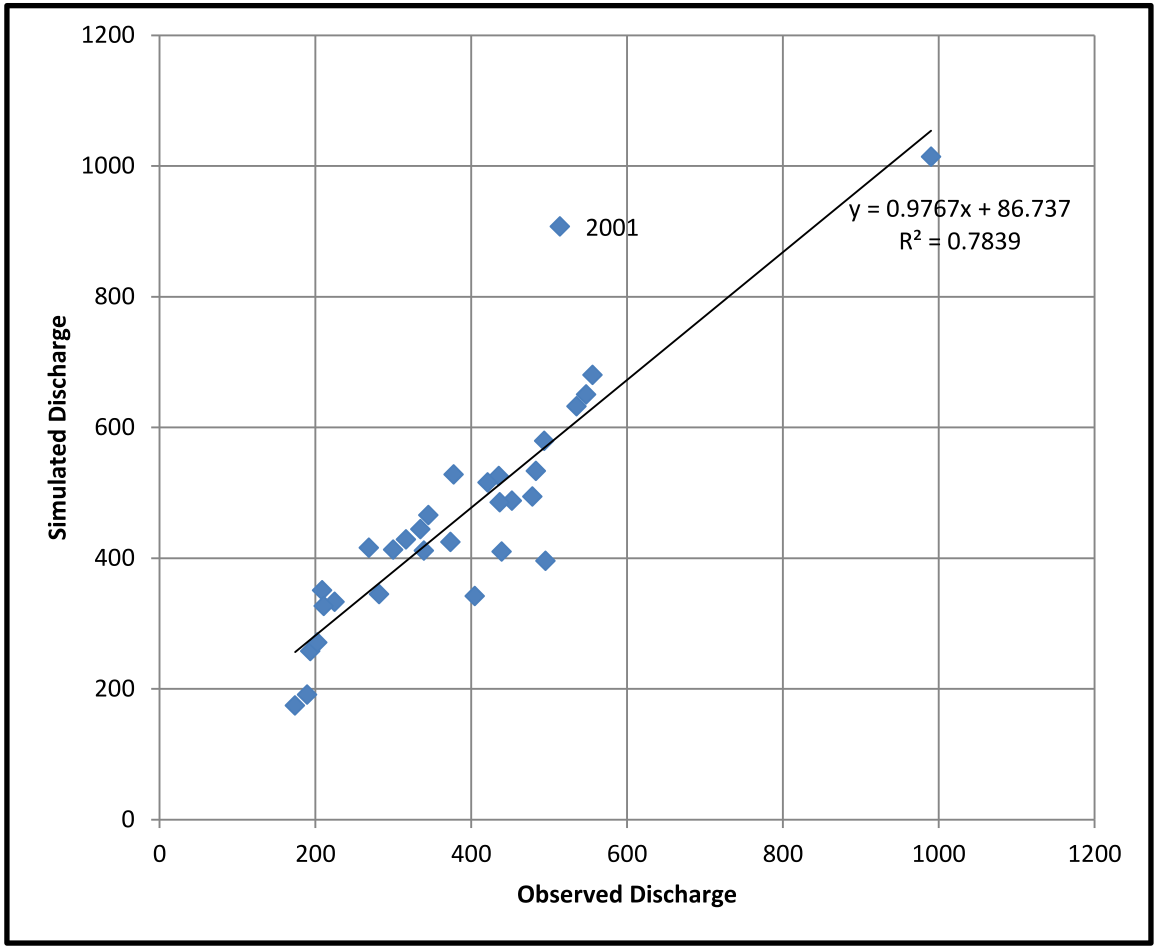


Mahanadi Basin

- Historic run time period – 31yrs (1976-2006)
- Gauge station - Tikerapara
- Nash Sutcliffe Coefficient – 0.65

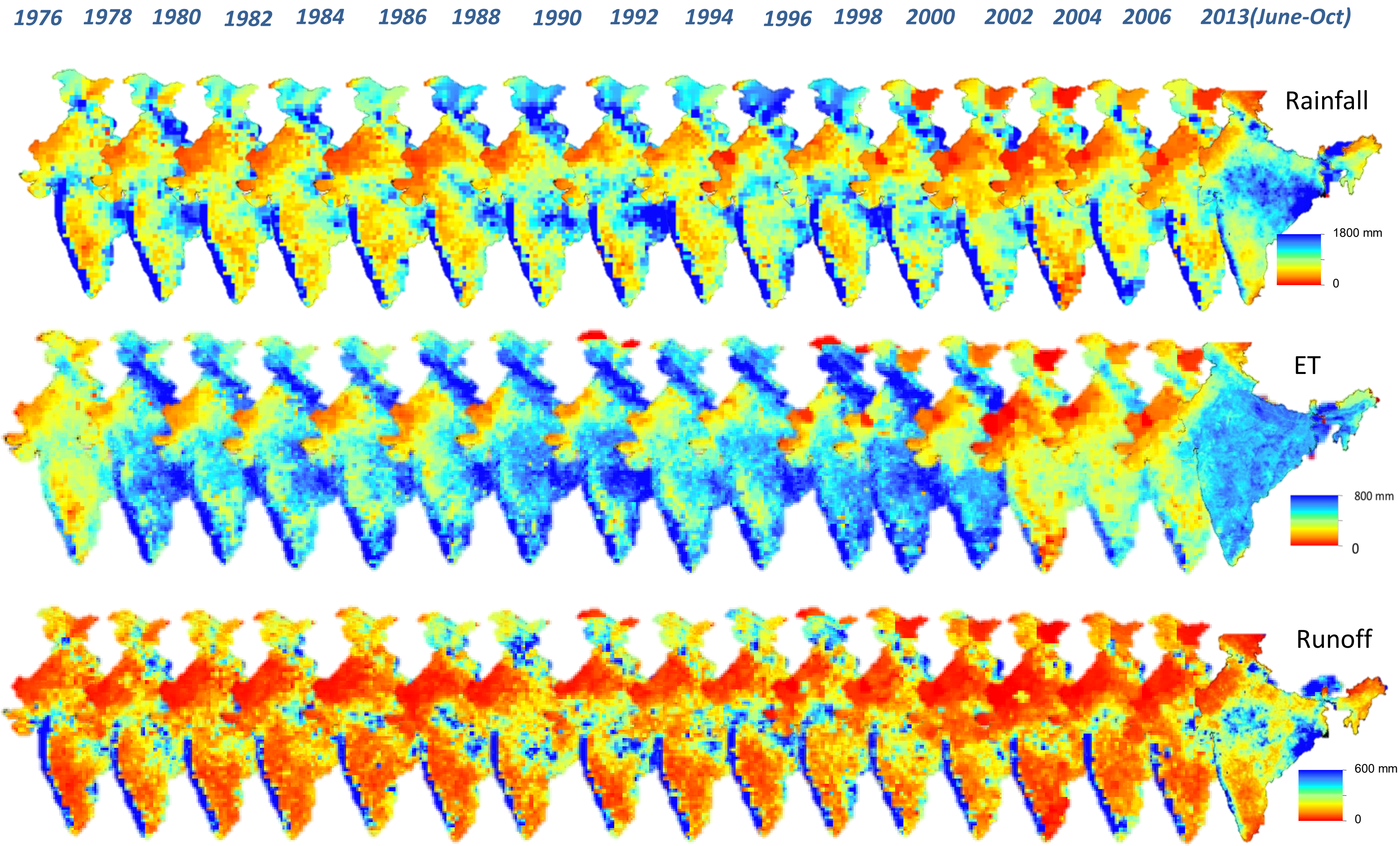


Mahanadi (Tikerapara) Annual Discharge

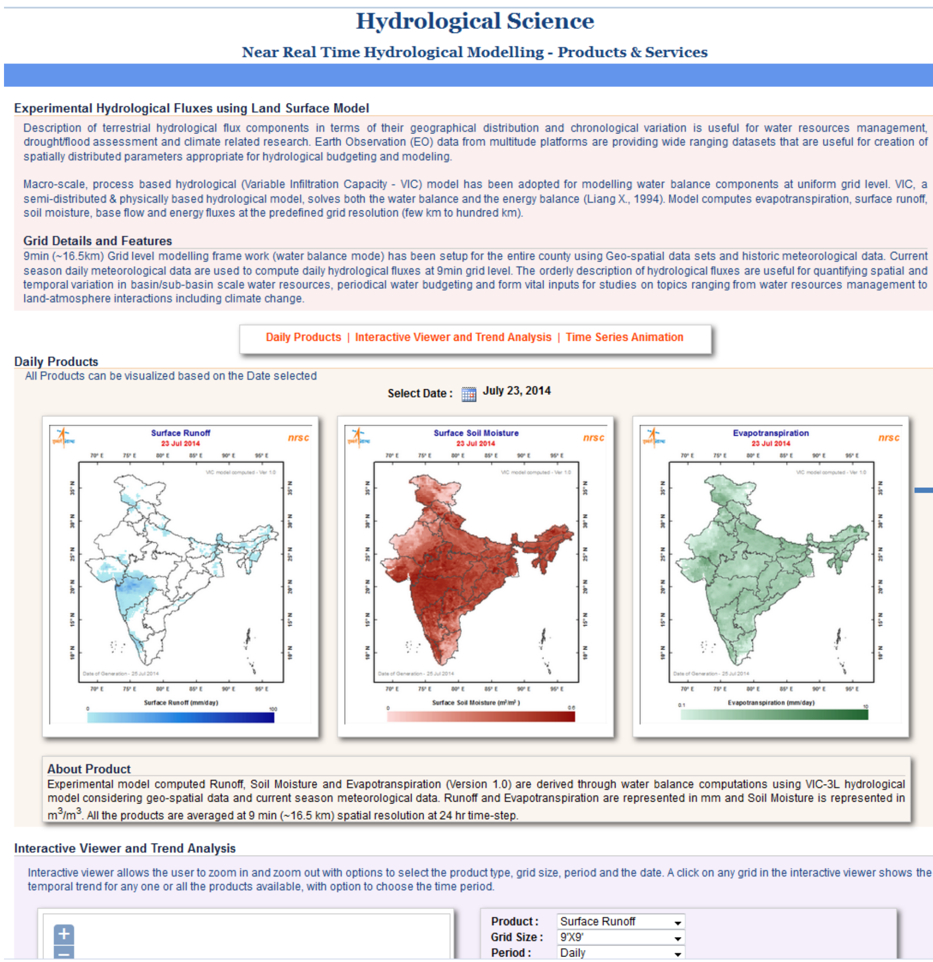


Long Term Fluxes

nrsc



Near Real Time Hydrological Modelling - Products & Services



Hydrological Science

Near Real Time Hydrological Modelling - Products & Services

Experimental Hydrological Fluxes using Land Surface Model

Description of terrestrial hydrological flux components in terms of their geographical distribution and chronological variation is useful for water resources management, drought/flood assessment and climate related research. Earth Observation (EO) data from multitude platforms are providing wide ranging datasets that are useful for creation of spatially distributed parameters appropriate for hydrological budgeting and modeling.

Macro-scale, process based hydrological (Variable Infiltration Capacity - VIC) model has been adopted for modelling water balance components at uniform grid level. VIC, a semi-distributed & physically based hydrological model, solves both the water balance and the energy balance (Liang X., 1994). Model computes evapotranspiration, surface runoff, soil moisture, base flow and energy fluxes at the predefined grid resolution (few km to hundred km).

Grid Details and Features

9min (~16.5km) Grid level modelling frame work (water balance mode) has been setup for the entire county using Geo-spatial data sets and historic meteorological data. Current season daily meteorological data are used to compute daily hydrological fluxes at 9min grid level. The orderly description of hydrological fluxes are useful for quantifying spatial and temporal variation in basin/sub-basin scale water resources, periodical water budgeting and form vital inputs for studies on topics ranging from water resources management to land-atmosphere interactions including climate change.

Daily Products | Interactive Viewer and Trend Analysis | Time Series Animation

Daily Products

All Products can be visualized based on the Date selected

Select Date : July 23, 2014

About Product

Experimental model computed Runoff, Soil Moisture and Evapotranspiration (Version 1.0) are derived through water balance computations using VIC-3L hydrological model considering geo-spatial data and current season meteorological data. Runoff and Evapotranspiration are represented in mm and Soil Moisture is represented in m^3/m^3. All the products are averaged at 9 min (~16.5 km) spatial resolution at 24 hr time-step.

Interactive Viewer and Trend Analysis

Interactive viewer allows the user to zoom in and zoom out with options to select the product type, grid size, period and the date. A click on any grid in the interactive viewer shows the temporal trend for any one or all the products available, with option to choose the time period.

Product : Surface Runoff

Grid Size : 9'X9'

Period : Daily

Source -- http://bhuvan.nrsc.gov.in/nices/

- Experimental model computed Runoff, Soil Moisture and Evapotranspiration (Version 1.0) are derived through water balance computations using VIC-3L hydrological model considering geo-spatial data and current season meteorological data using IMD Temperature point data with satellite based derived rainfall data of CPC & TRMM. All the products are averaged at 9 min (~16.5 km) spatial resolution at 24 hr. time-step.

- Daily Hydrological fluxes are generated and uploaded to NRSC/Bhuvan in near real time with a lag of 2days.

Daily Products

Interactive Viewer & Trend Analysis

Time Series Animation

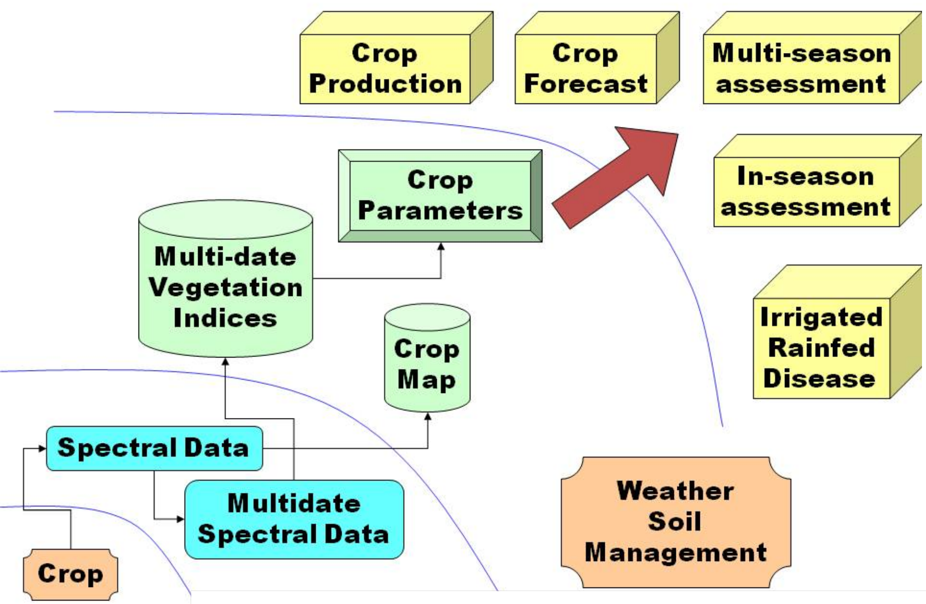
Land Surface Geophysical Products from ISRO Sensors

- Operational (OCM)
  - Vegetation Indices Products
    - National & Global
  - Surface Albedo Products (Snow-Free)
  - Water bodies products
- New Initiatives (AWIFS)
  - Vegetation Indices Products
  - Snow Albedo Products
  - Water fraction products

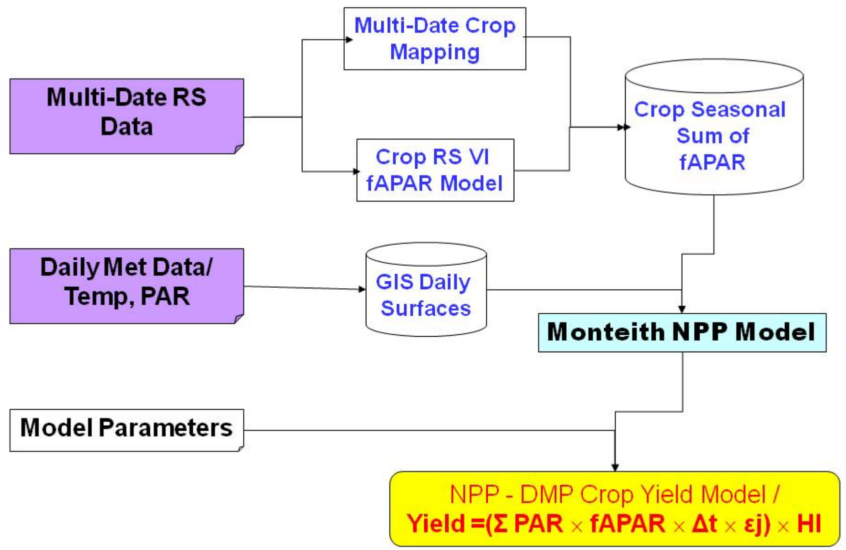
Agriculture : Crop Mapping & Crop Productivity

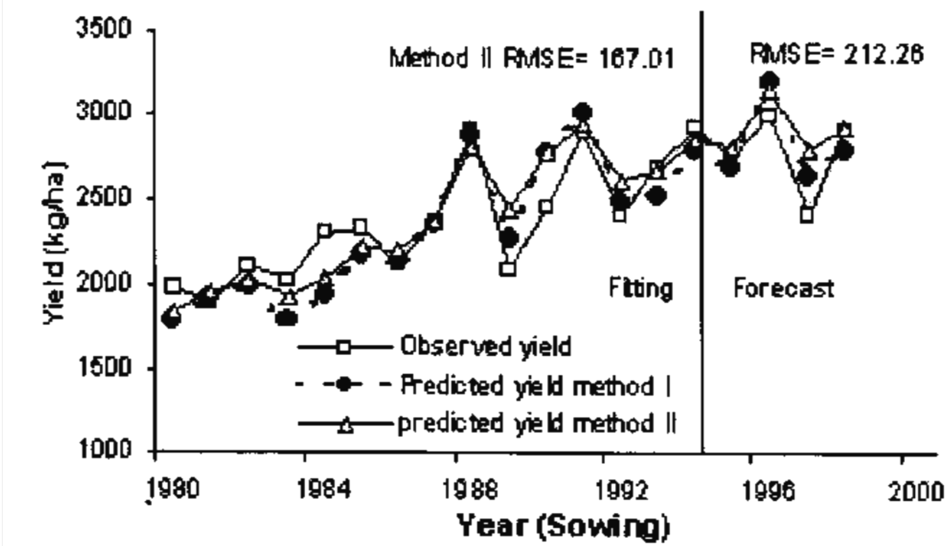
Agriculture – Yield – Simulation Model - NPP

Rationale for RS-based Crop Monitoring



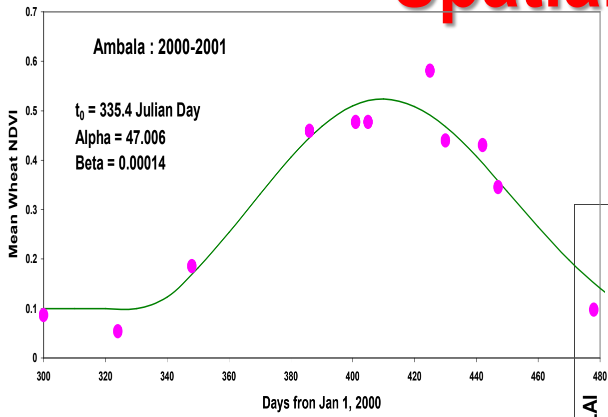
RS-NPP Approach for Crop Biomass /Yield



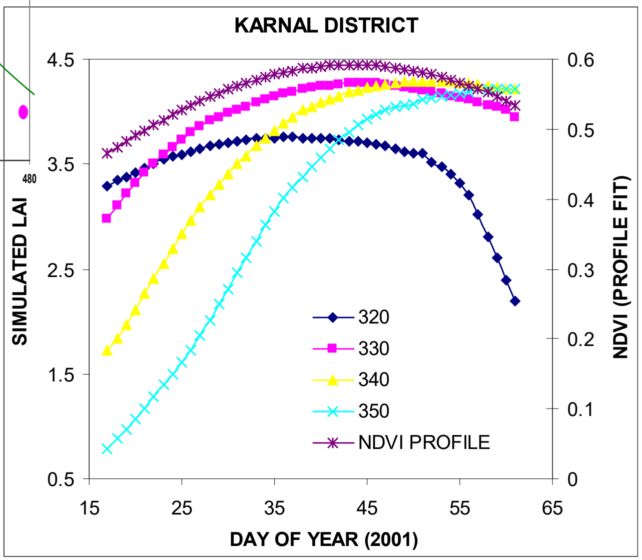


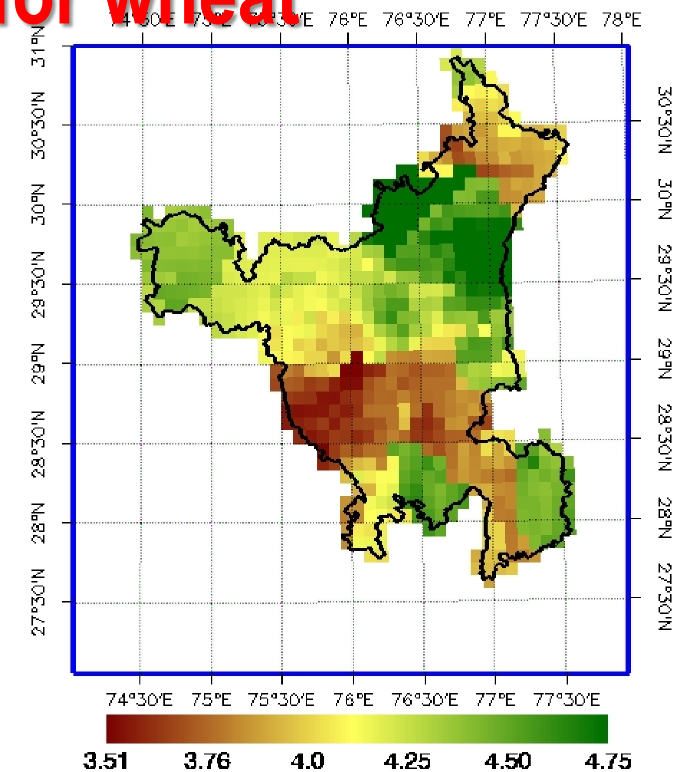
CERES WHEAT : District Wheat Yield
Nain & Dadhwal 2000-2003
J Agrometeorology
J agric sci (camb)

Spatial Crop Simulation for wheat



WiFS Profile

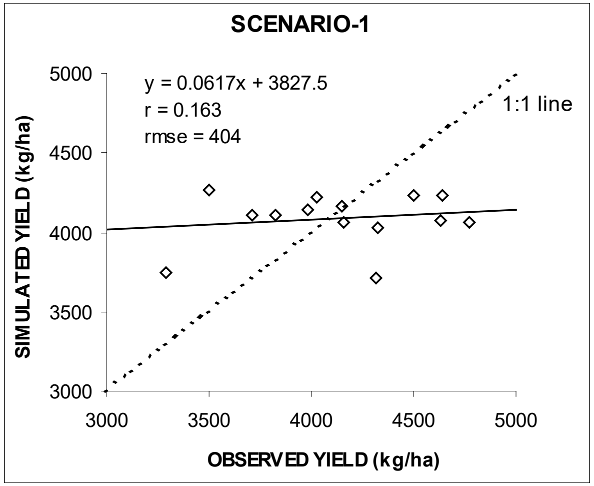




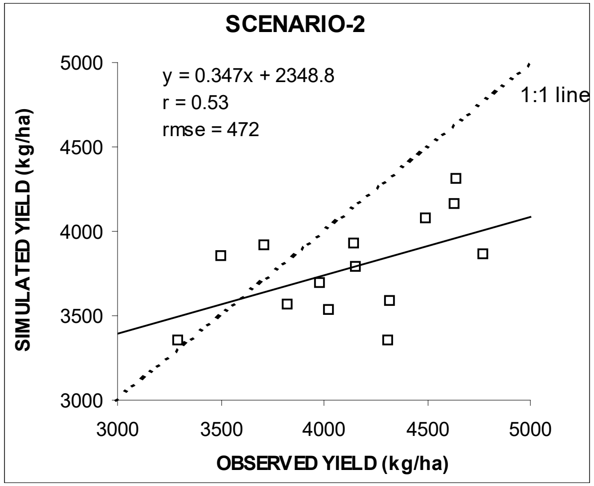
SPATIAL MAP OF WHEAT YEILD (t/ha) OF HARYANA (96-97)

Sehgal VK & Dadhwal VK & others (2002-5)

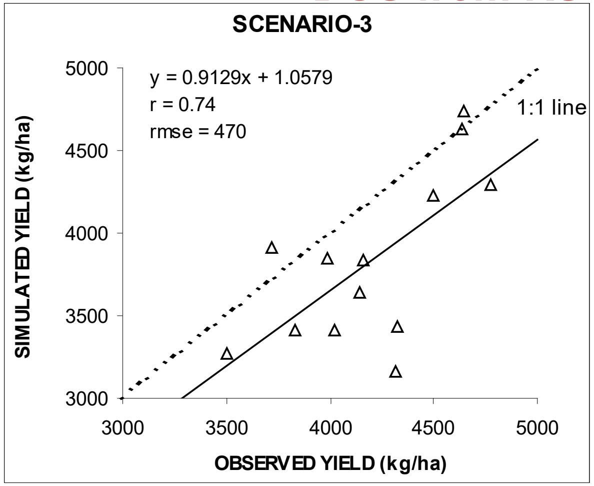
Fixed Inputs (DOS, I, N)



Variable Inputs (I, N)

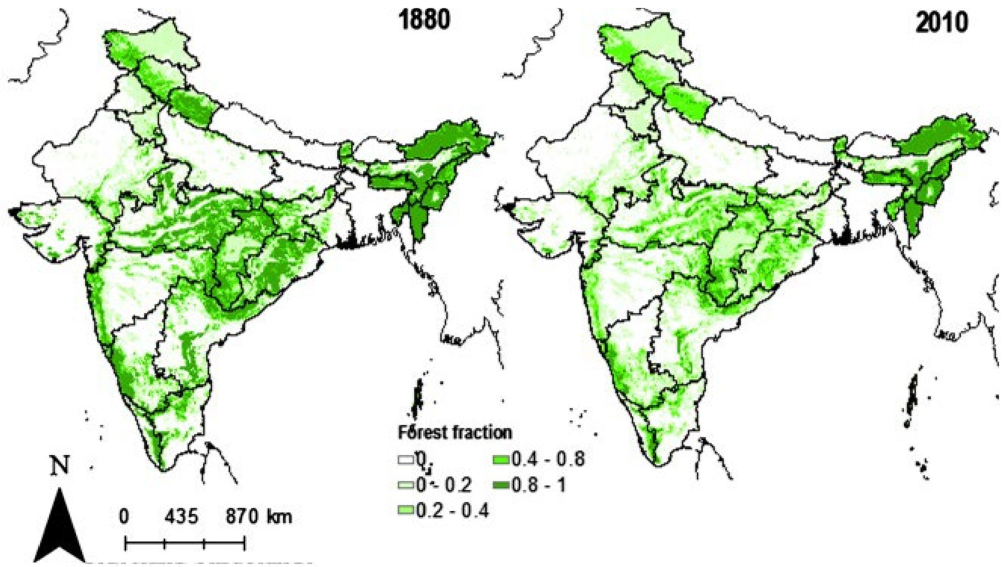


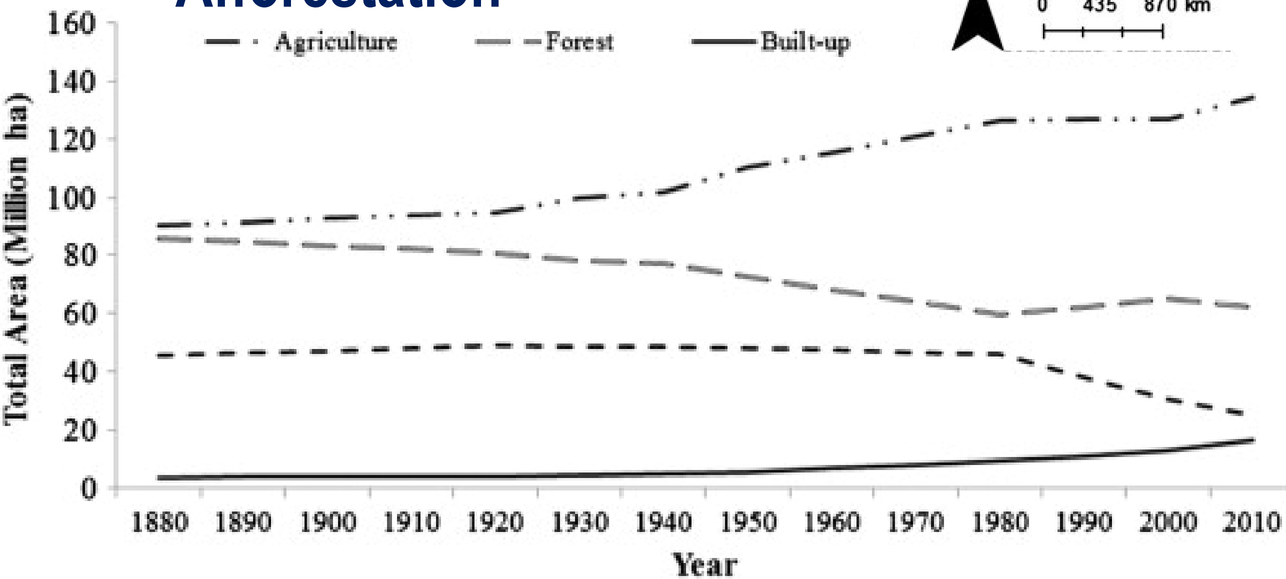
DOS from RS



Land Transformation & C Cycle change

- Large-scale land transformation
- Consequences on vegetation & soil C pools as well as NPP & C emissions
- Spatial Data sets needed
- Additional factors
  - Irrigation
  - Fire
  - Forest Degradation
  - Afforestation

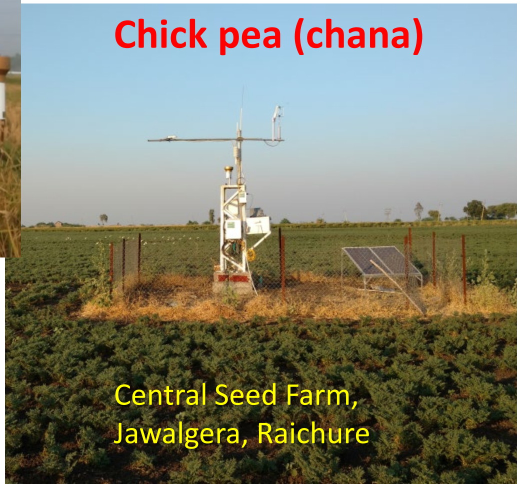




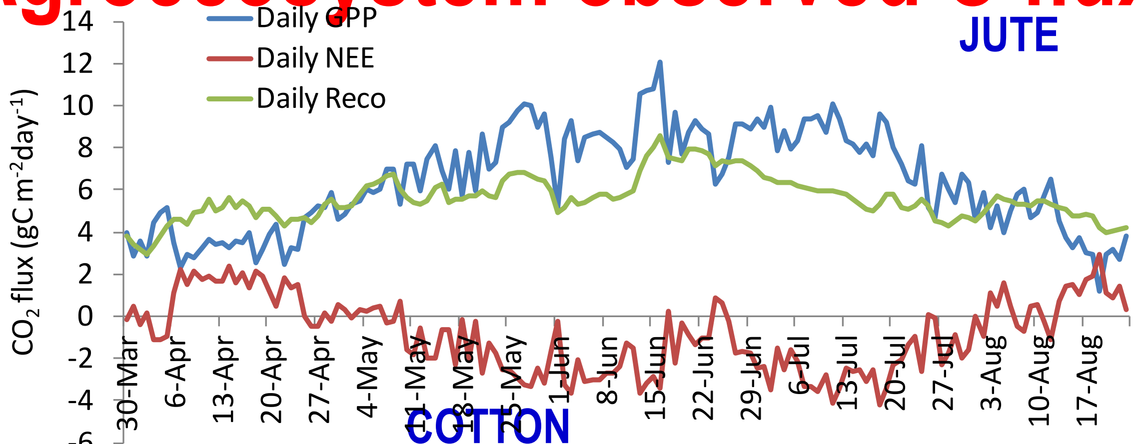
Tian, Banger, Bo, Dadhwal, 2014; Global & Planetary Change

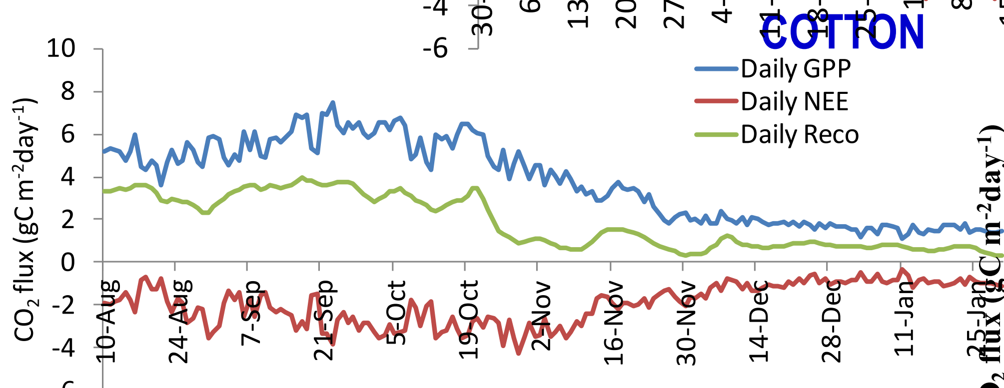
Agroecosystem flux tower sites

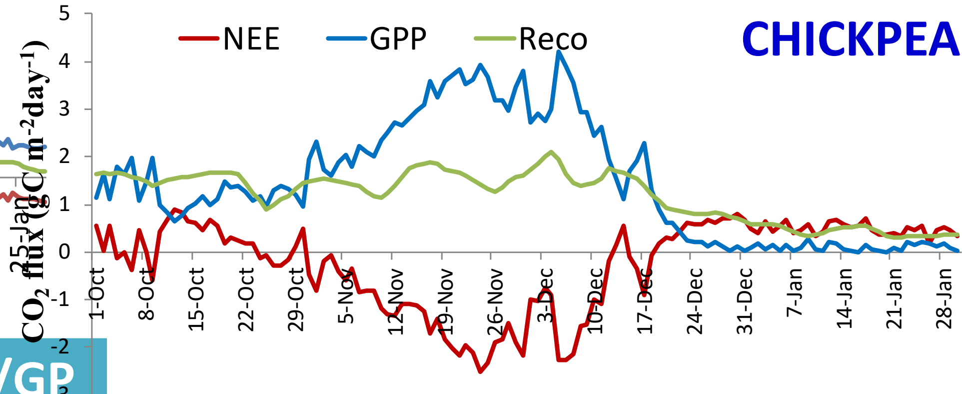
- Agro-ecosystems being addressed:
- Irrigated Wheat : Meerut : SP Univ, UP
- Flooded Rice : Maruteru, W Godavari : ANGRAU, Andhra
- Rainfed Chickpea :Jawalgera : CSF, Raichur, Karnataka
- Rainfed Cotton : Nagpur : ICAR-CICR, Nagpur
- Jute : Barrackpore : ICAR-CRIJAF, W Bengal



Agroecosystem observed C fluxes



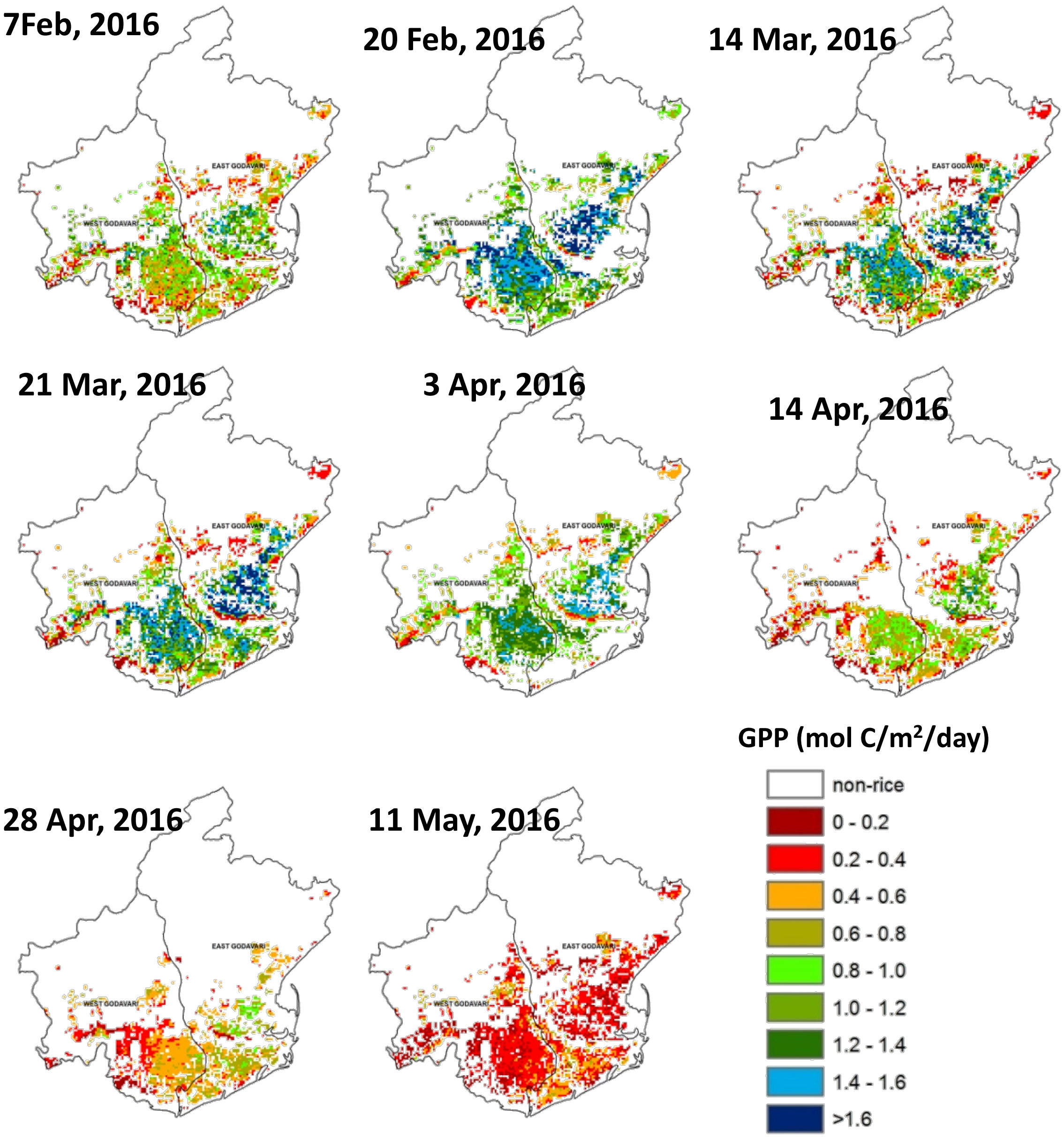


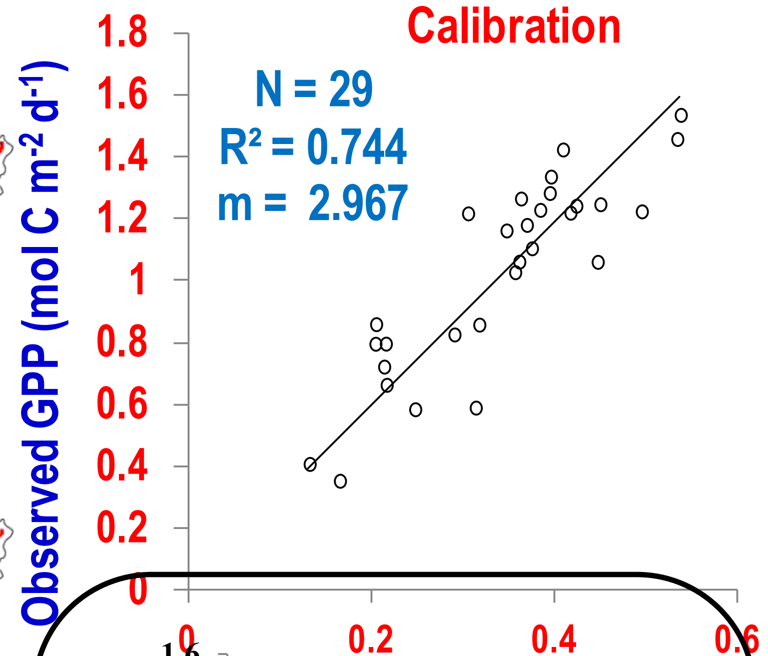


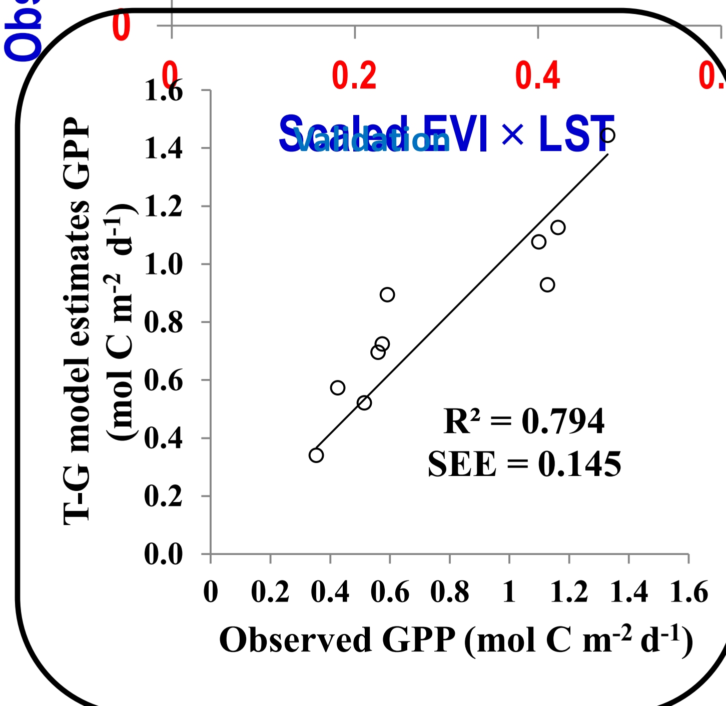
	GPP	NEE	RE	RE/GPP (%)
Cotton, 370 d	659	334	324	50
Jute , 124d	859	140	719	83
Chickpea, 106d	160	32	127	77
Rice, 100d	993	418	575	57

Abhishek Chakraborty, 2019, Unpublished

Flux tower NEE upscaled for Rice (W. Godavari)

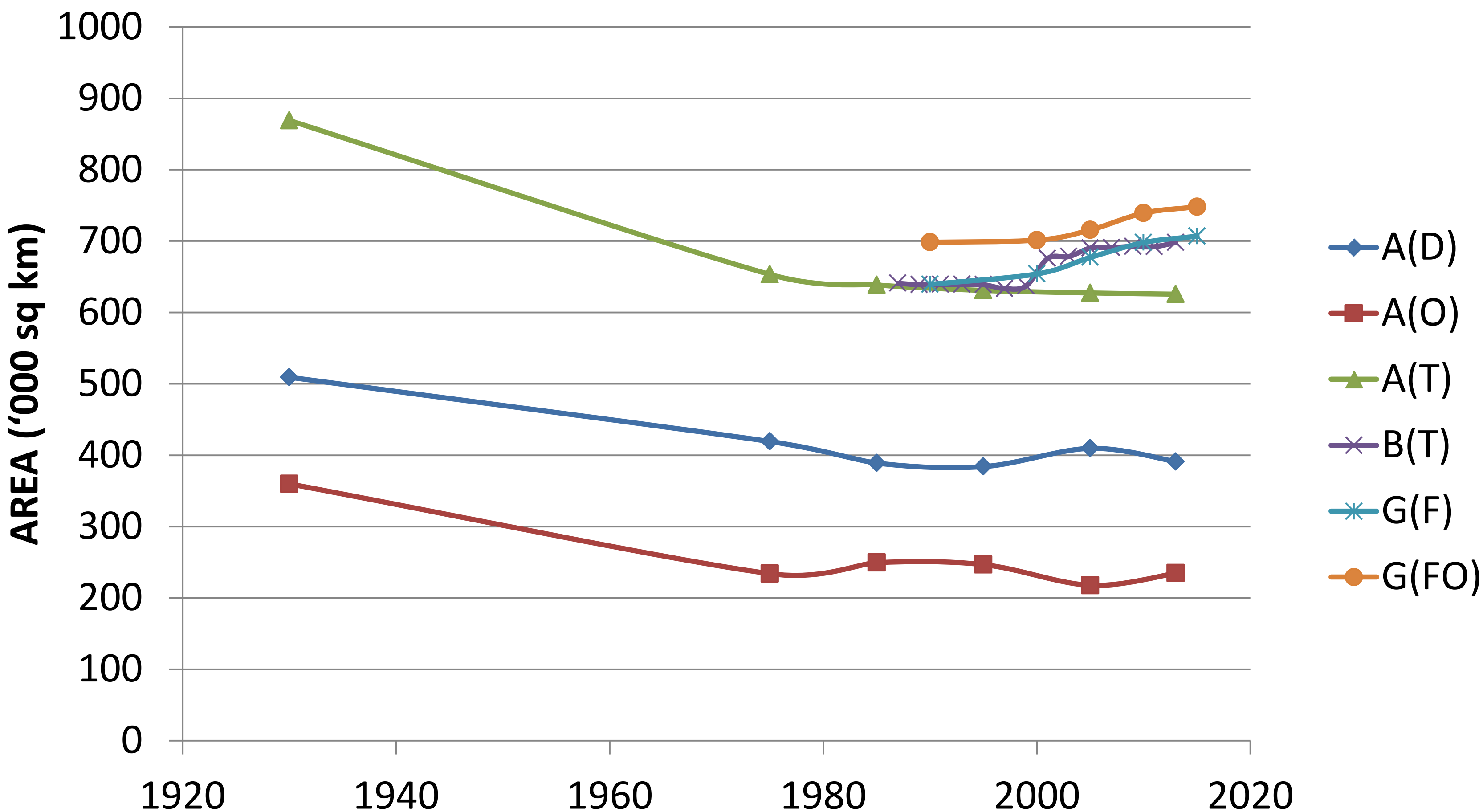






Land Surface Modelling for Forest & Indian carbon Cycle

Forest Area : Sources & Definitions



G: Global UN FAO GFRA2015; F-Forests, O-Other Wooded Land

B: India FSI, Forest Cover, Biennial State of Forest Reports

Deforestation in India 1930-2013

Biodivers Conserv
DOI 10.1007/s10531-015-1033-2

CrossMark

ORIGINAL PAPER

Quantification and monitoring of deforestation in India over eight decades (1930–2013)

C. Sudhakar Reddy[1] · C. S. Jha[1] · V. K. Dadhwal[1] · P. Hari Krishna[1] · S. Vazeed Pasha[1] · K. V. Satish[1] · Kalloli Dutta[1] · K. R. L. Saranya[1] · F. Rakesh[1] · G. Rajashekar[1] · P. G. Diwakar[1]

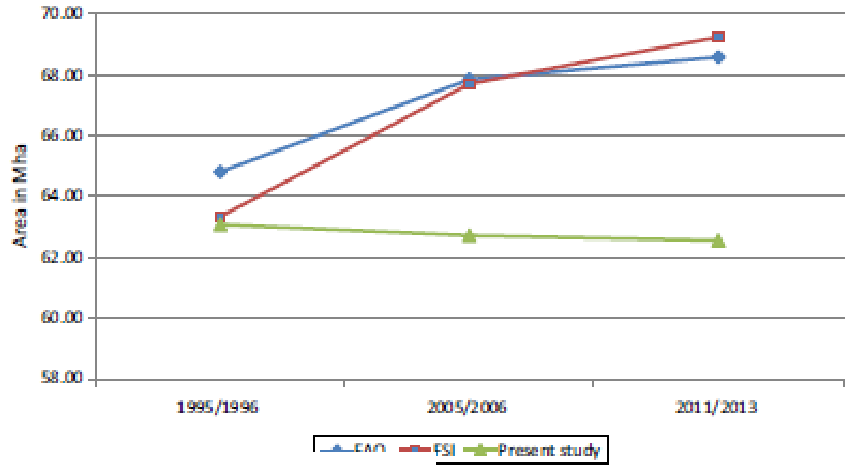
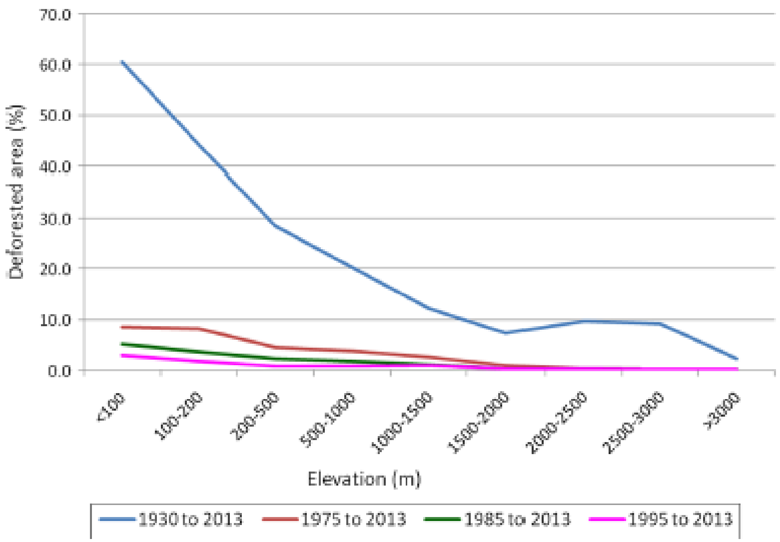


Table 1 Details of spatial data used in the study

Sl. no	Type	Period	Scale/ resolution*	No. of maps/ satellite scenes
1	Topographical maps	1920–1940	1:250,000	251
2	Landsat MSS	1972–1977	80 m	356
4	Landsat MSS	1985	80 m	452
5	IRS 1A/1B LISS-I	1995	72.5 m	470
6	IRS P6 AWiFS	2005	56 m	64
7	Resourcesat-2 AWiFS	2013	56 m	64

* Scale for topographical maps; spatial resolution for satellite datasets

Deforestation in India 1930-2013



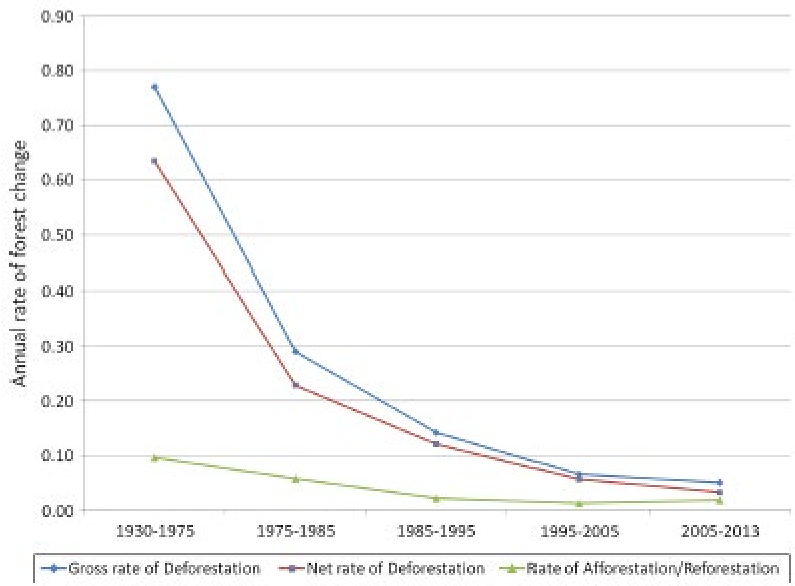


Fig. 3 Annual rate of forest change in India

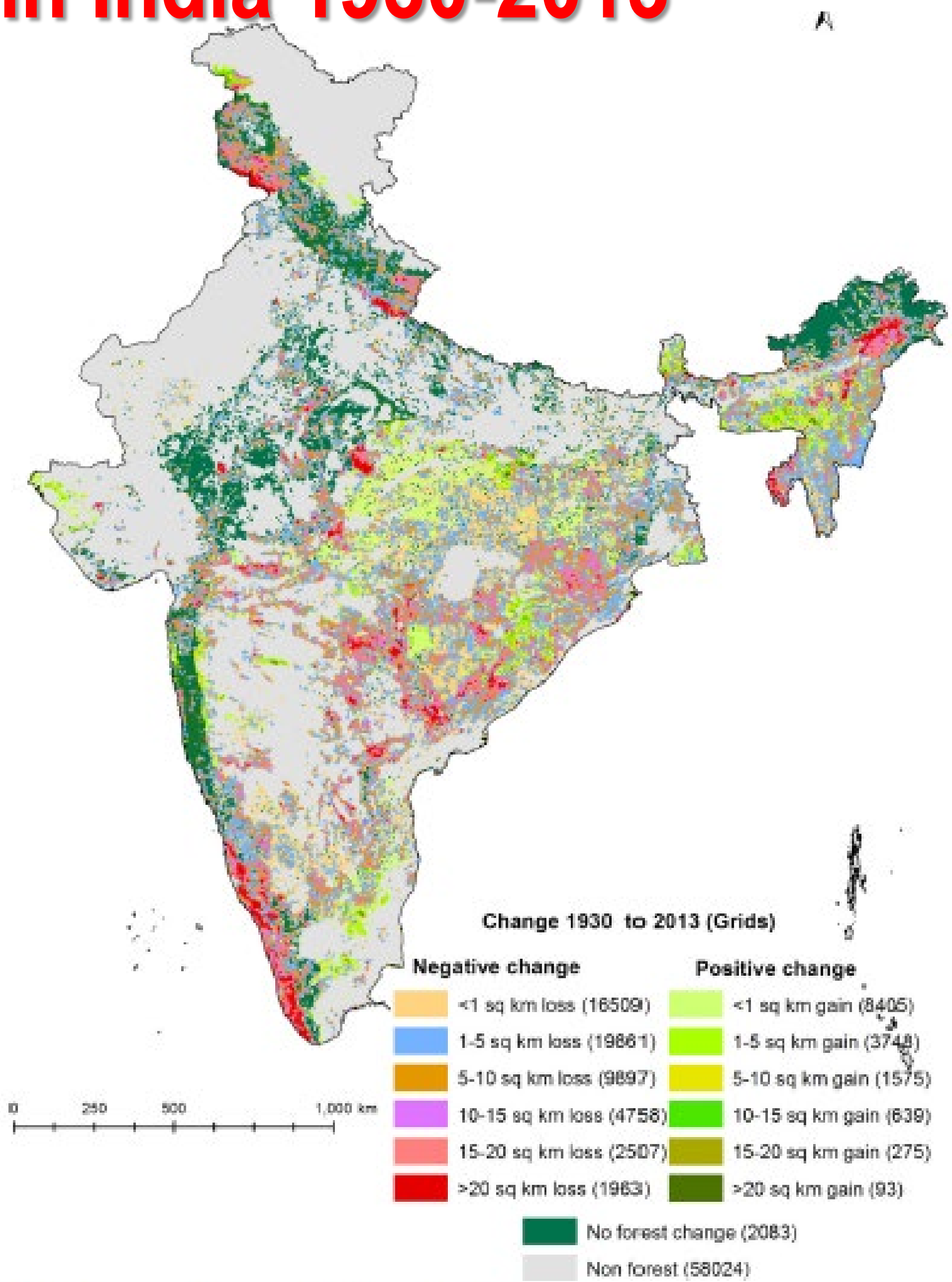


Fig. 2 Forest cover change map of India: 1930–2013

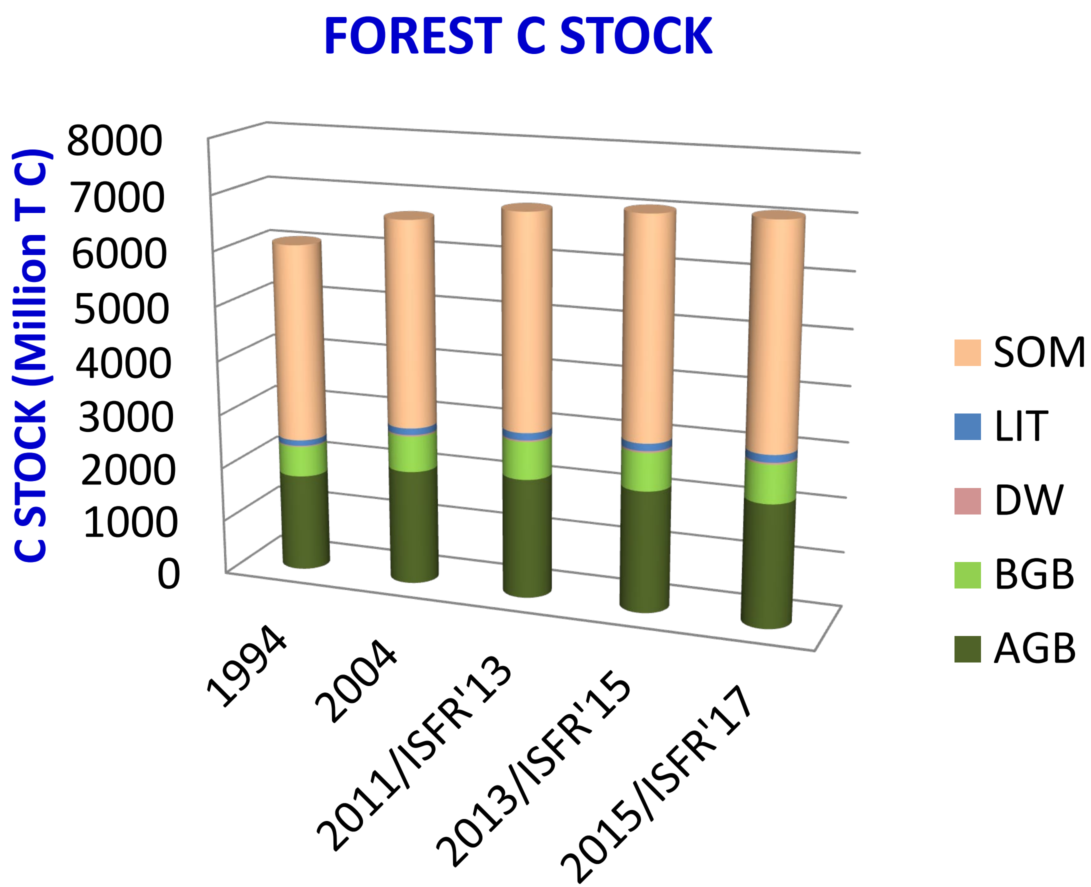
Summary of Carbon estimates for Indian forests

Summary of estimated forest BM in Indian Forest:

S N	Year	Methodology Adopted	BM (T g)	C Pool(PgC)
1.	1985	field inventory of growing stock and using single conversion factor	4432	1.99
2.	1986	RS based forest area, BM densities from literature for five crown cover for some of the forest types and extrapolating the same for entire India	8372	4.18
3.	1982	Strata wise RS based forest area, field inventory based GS, Biomass	7960	3.98
	1991	Expansion Factor (BEF) for two crown density classes	8142	4.07
4.	1993	State wise field inventory based data on growing stock, biomass expansion factor for 3 crown density classes and 4 forest categories	8685	4.34
5.	1993	strata wise field inventory data, mean wood density for various strata and BEF ranging from 1.51 to 1.59 for different forest composition	4313	2.16
6.	1984	Strata wise estimation of GS based on forest inventories, thematic	2398	1.085
	1994	map and vegetation maps for different density class. wood biomass further estimated using specific gravity and calculated GS for states	2395	1.083
7.	1988	district wise RS forest area, field inventory based GS, BEF for two	7742	3.871
	1994	crown density classes	7748	3.874
8.	1995	stratum wise field inventory of growing stock as reported by FSI and standard conversion factor as per IPCC guidelines	4504	2.03
9.	1992	strata wise RS based forest area, field inventory based GS, state	5253/6141	2.6/3.1
	2002	wise mean wood density and two different values for BEF calculated from earlier studies	5321/6359	2.7/3.2
10.	1999	RS based forest area biomass density national level improved	6244	3.122
	2005	estimates on branches and twig	6622	3.311
11.	1980	Ecological studies based mean phytomass density for two forest types 2	580	1.29

1. Dadhwal & Nayak 1993. 2. Ravindranath et al., 1997 3. Dadhwal & Shah., 1997 4. Chhabra et al., 2002a 5. Haripriya., 2000 6. Manhas et al., 2006 7. Chhabra et al., 2002b 8. Lal and Singh 2000 9. Meenakshi Kaul 2011 10. Kishwan et al., 2011 11. Hingane 1991

Indian Forest Carbon Pools (FSI)



- Mean estimates by Forest Types, Physiographic Zones & Density Class
- Input data from 178 districts over multiple cycles 2002-2008 .ca 22,000 points
- *(Spatial Mapping & Uncertainty Analysis to be carried out)*

Carbon Stock change from deforestation

Contents lists available at ScienceDirect

Global and Planetary Change

journal homepage: www.elsevier.com/locate/gloplacha

Geospatial assessment of long-term changes in carbon stocks and fluxes in forests of India (1930–2013)

C. Sudhakar Reddy *, F. Rakesh, C.S. Jha, K. Athira, Sonali Singh, V.V.L. Padma Alekhya, G. Rajashekar, P.G. Diwakar, V.K. Dadhwal

National Remote Sensing Centre, Indian Space Research Organisation, Balanagar, Hyderabad 500 037, India

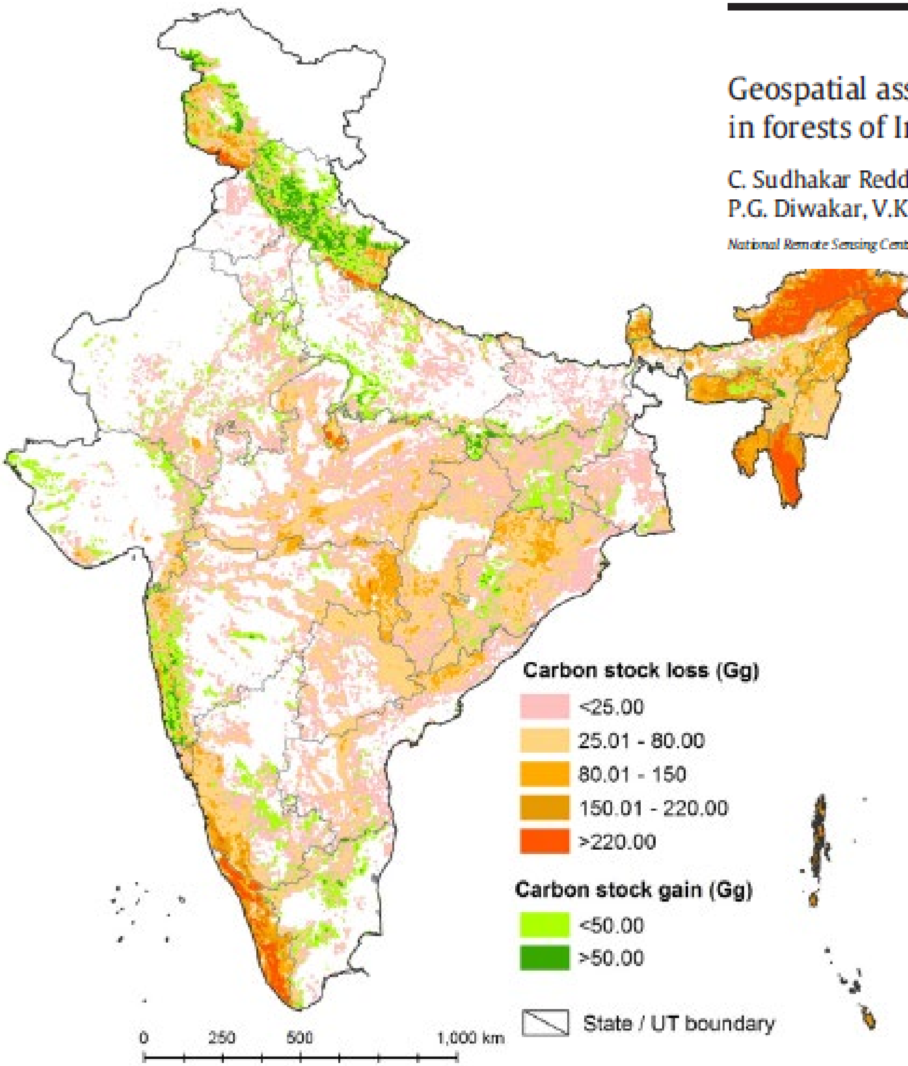


Fig. 9. Change in above ground biomass carbon stock in India from 1930 to 2013.

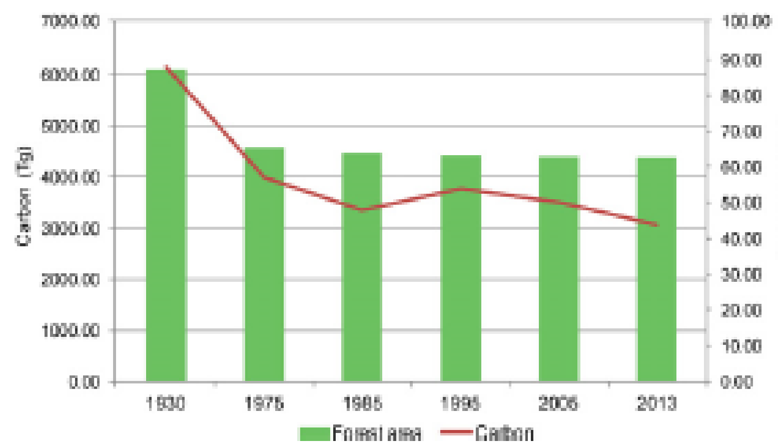
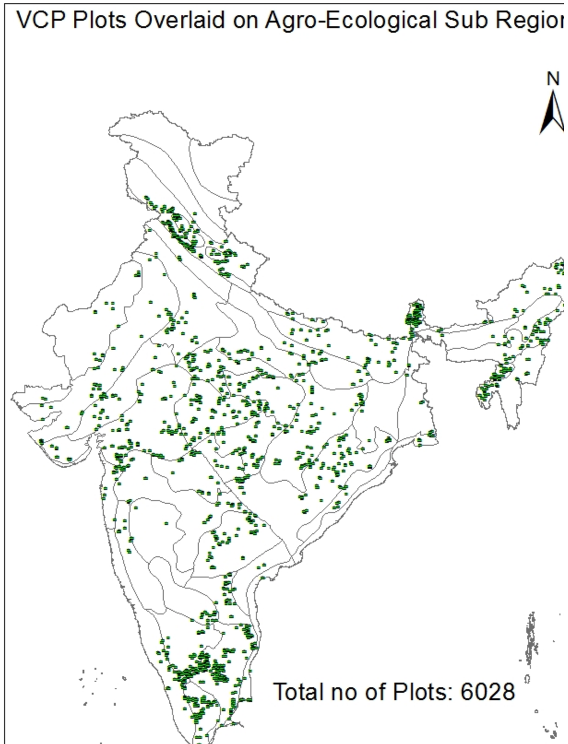
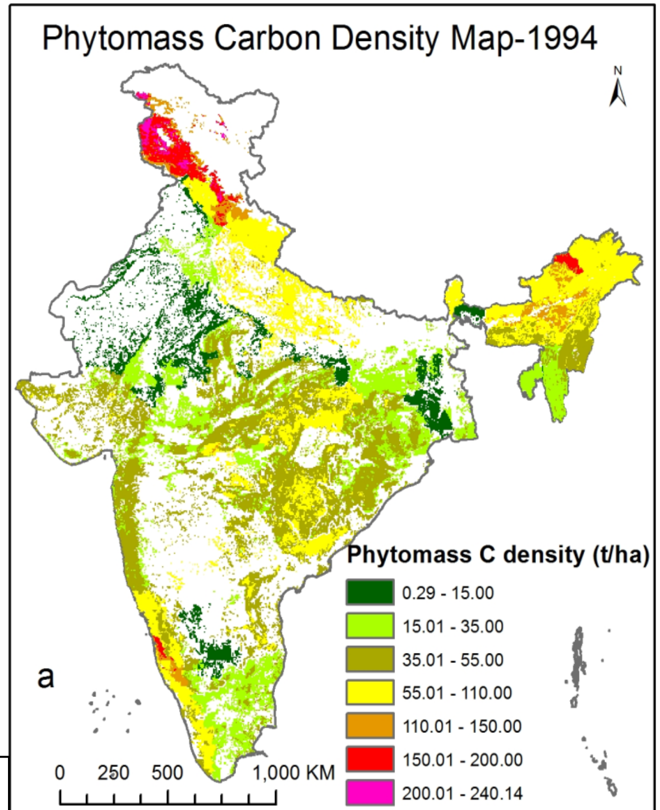


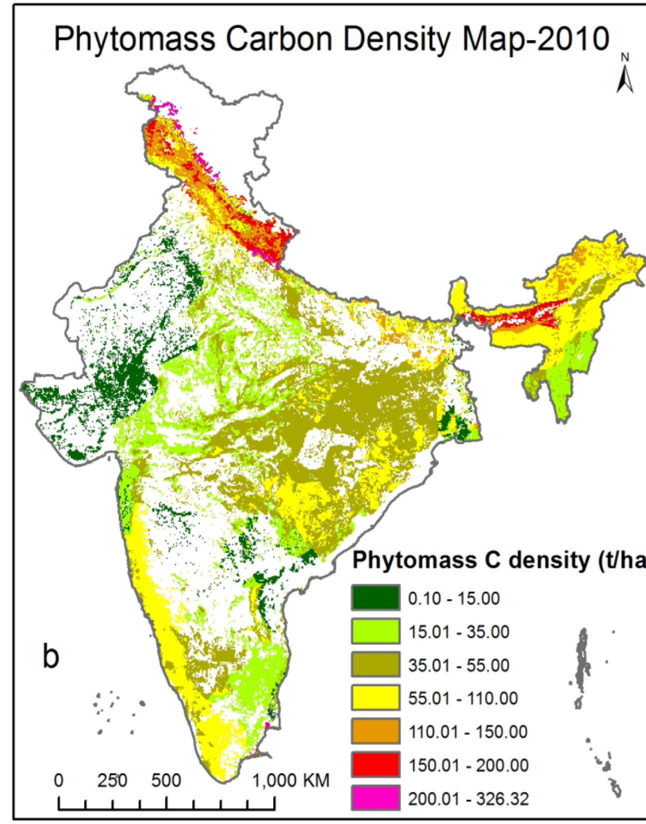
Fig. 2. Forest area and Above Ground Carbon biomass stocks in India: 1930 to 2013.

Forest phytomass C pools & change

Phytomass C density change analysis (1994-2010)/ Variable Spatial Details







173 species volume equation

Remote sensing forest area(FSI 2009)

Physiographic zone and 5x5 km grid.

Avg Phytomass density (dense & open)

PD= GS x DEN x CC x RC x EF

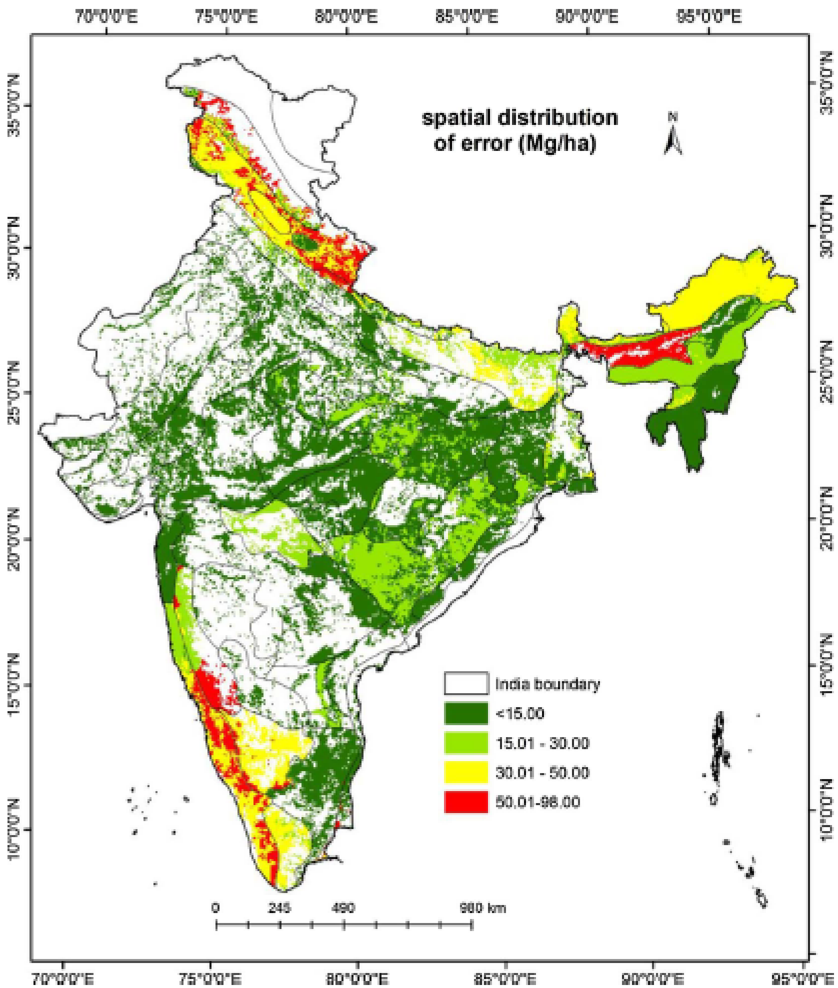
Growing Stock (m^3) Density of Wood (g/cc) ,

CC = 0.5, RC: 1.16 , EF: exp. factor

Comparison	1994	2010
Phytomass C :	**3911 TgC**	**4368TgC**
C in dense forest :	**2895 TgC**	**3176 TgC**
C in open forest :	**1016 TgC**	**1192 TgC**
5km C density range :	**0.29- 240.14 t/ha**	**0.10- 326.32 t/ha**
Open forest C density :	***38.47 t/ha***	***41.69 t/ha***
Dense forest C density :	***77.08 t/ha***	***80.24 t/ha***
Forest Cover:	***61.14 Mha***	***64.08 Mha***

Rajashekar, Rakesh ,Jha, Ganeshaiah, Singh, Dadhwal (2015) Forest Ecology and Management. (Under Review)

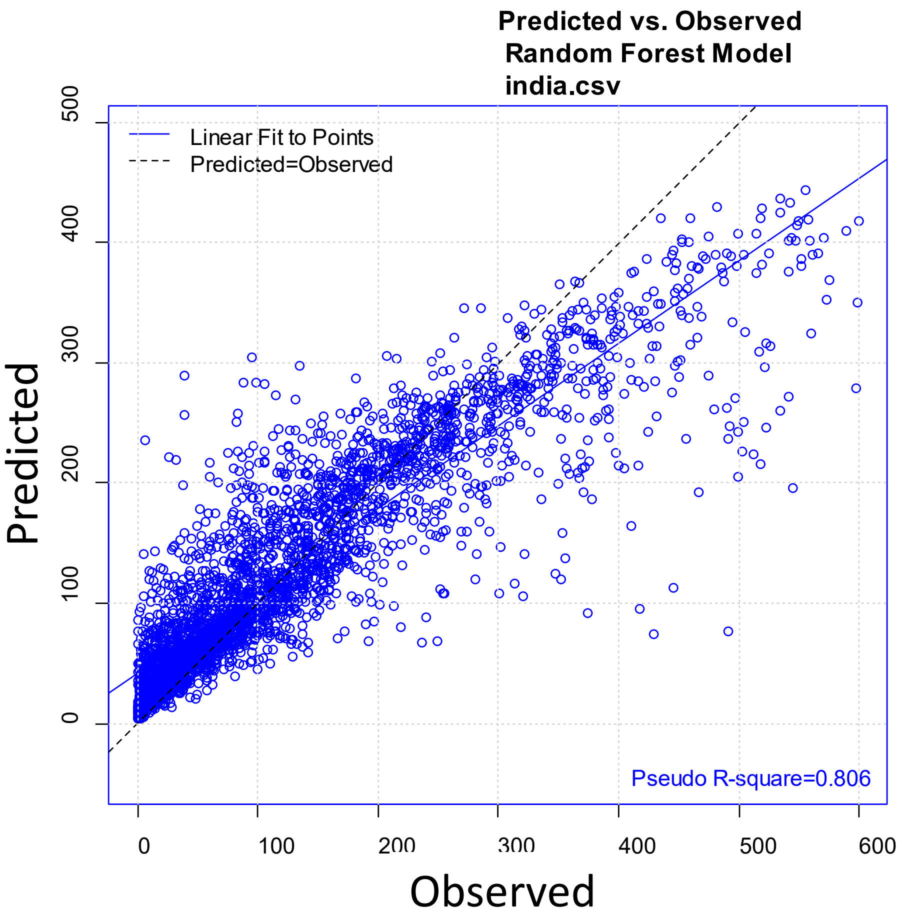
Methodology Upgrade : Estimation of error

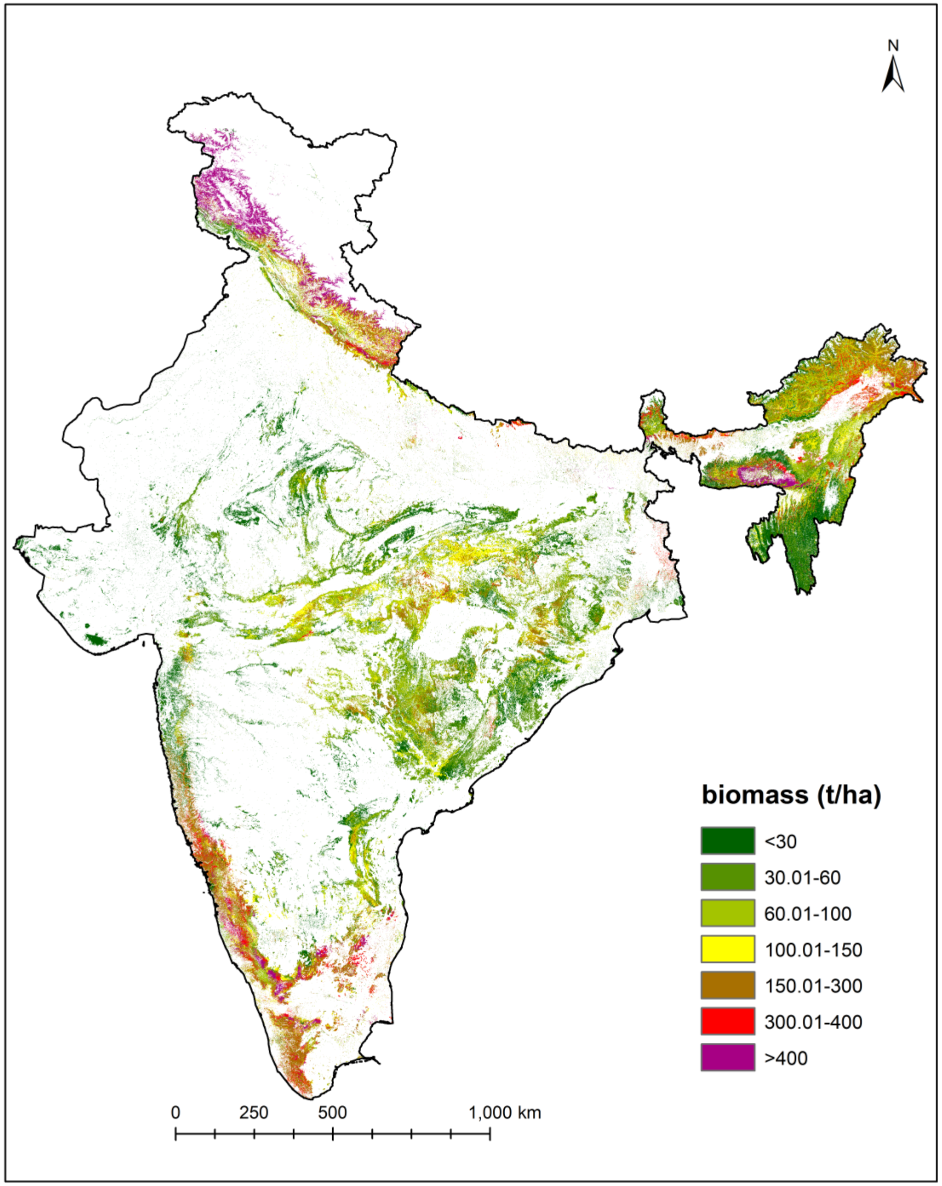


Rajashekar, Fararoda, Reddy, Jha, Ganeshaiah, Singh, Dadhwal, Ecological Indicators, 2018, 85:742

National Biomass Map estimated using ALOS-PALSAR and forest height

Knn estimate with a RF distance measure





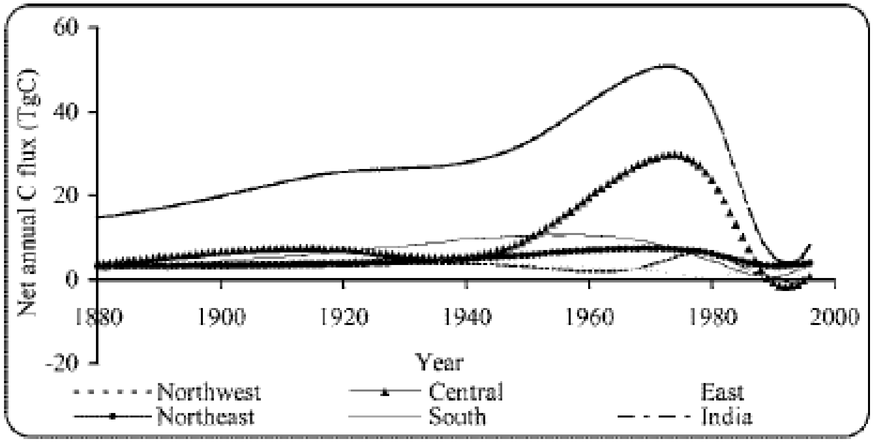
Estimates of C emissions (deforestation, LUC)

(Reddy, Rakesh, Jha, Athira, Singh, Alekhya, Rajsekar, Diwakar, DADHWAL, 2016, Global Planet Change, 146:50)

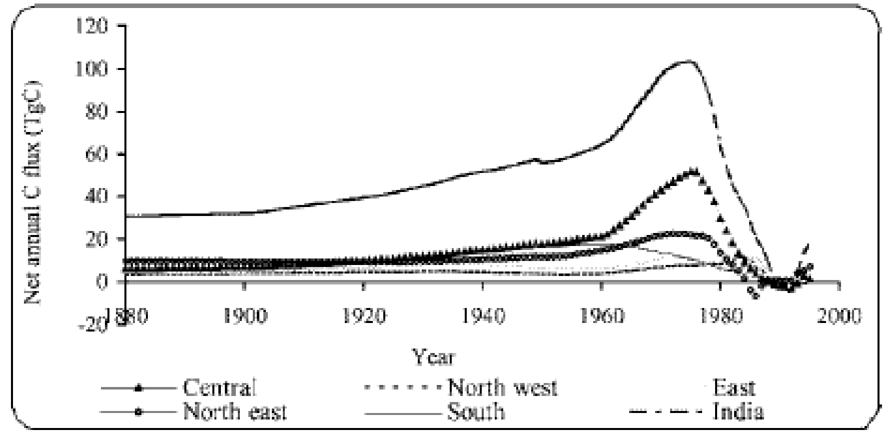
Period	Net C release ($Tg\ C\ yr^{-1}$)	Remarks	Reference
1980	−3.98	Volume based biomass estimates using net C flux model	Hall and Uhlig (1991)
1980	41.3	0.75 of forest phytomass in deforested area	Hingane (1991)
1980	33	Model of land use transformation	Houghton et al. (1987)
1980	20.2	As % of global net C release using deforestation rate	Ahuja (1991)
1985	42.52	Estimates from fire, firewood, shifting cultivation and deforestation	Mitra (1992)
1985	25.7	Comprehensive inventory of greenhouse gas emission	Subak et al. (1993)
1986	−5	Net difference between emissions (63.g Tg) and removals (68.9 Tg C)	Ravindranath et al. (1997)
1987	38.21	Net emission from deforestation and logging	WRI (1990)
1989	32.75	Net C release from deforestation and logging	WRI (1992)
1990	0.4	IPCC revised 1996 guidelines	ALGAS (1998)
1991	5.73	IPCC revised 1996 guidelines	WRI (1994)
1994	12.8	Estimates based on fluxes between forest biomass (live or dead), soils, forest products and atmosphere	Haripriya (2003)
1994	3.86	IPCC revised 1996 guidelines	NATCOM, 2004
1982–1992	5.65	IPCC revised 1996 guidelines	Kaul et al. (2009)
1985–1996	9	Using a simple book keeping MBL model estimates from deforestation, afforestation and phytomass degradation	Chhabra and Dadhwal (2004)
1880–1996	47.00	Using a simple book keeping MBL model estimates from deforestation, afforestation and phytomass degradation	Chhabra and Dadhwal (2004)
1992–2002	−1.09	IPCC revised 1996 guidelines	Kaul et al. (2009)
2003–2005	50.7	IPCC revised 2003 guidelines	Sheikh et al. (2011)
2005–2007	31.1	IPCC revised 2003 guidelines	Sheikh et al. (2011)
1930–1975	48.19	IPCC revised 2006 guidelines	Present study
1975–1985	63.18	IPCC revised 2006 guidelines	Present study
1985–1995	−41.4	IPCC revised 2006 guidelines	Present study
1995–2005	26.23	IPCC revised 2006 guidelines	Present study
2005–2013	53.97	IPCC revised 2006 guidelines	Present study

C-emission from land transformation

(c)



(d)



TgC = 10^{12}gC

Cumulative net carbon flux [PgC] from Indian forests due to landuse changes (1880–1996) under different scenarios

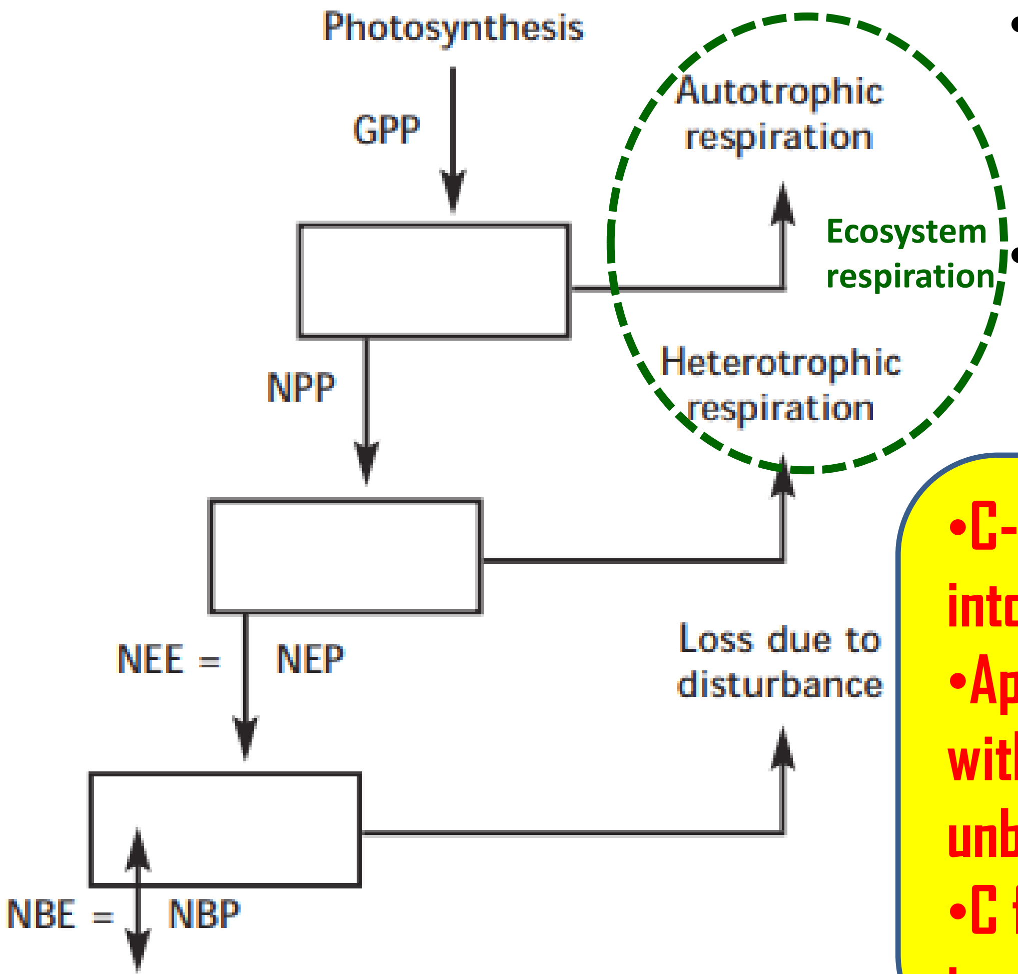
	India	Central	East	NE	NW	South
Scenario 1	2.34	–	–	–	–	–
Scenario 2	3.24	–	–	–	–	–
Scenario 3	3.25	1.14	0.417	0.55	0.37	0.76
Scenario 4	5.45	1.75	0.75	1.24	0.52	1.17

NE: Northeast region; NW: Northwest region.
Scenario 1: deforestation + afforestation, low biomass.
Scenario 2: deforestation + afforestation, high biomass.
Scenario 3: deforestation + afforestation, variable biomass (regional level).
Scenario 4: deforestation + afforestation + phytomass degradation, variable biomass (regional level).

Chhabra & Dadhwal, 2004, Climate Change, 64: 341-360

Primary Productivity and Carbon Flow

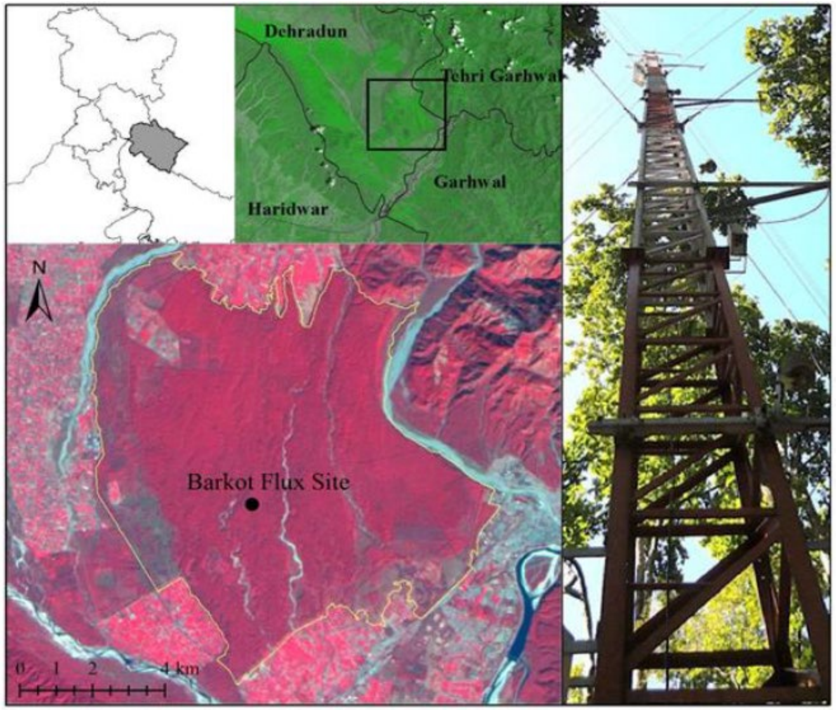
Plant Carbon balance

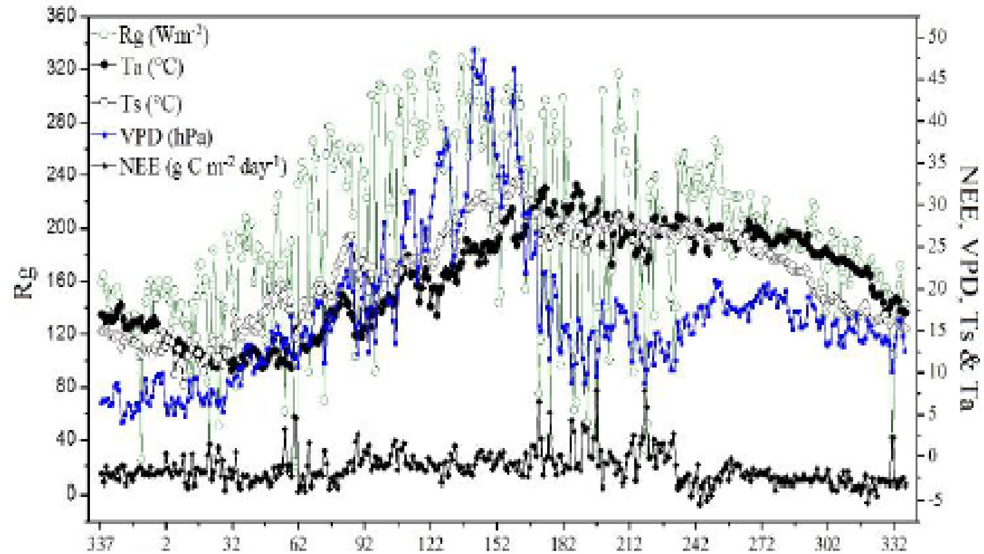


- GROSS **PP**
- NET **PP**
- NET ECOSYSTEM **P**
- NET ECOSYSTEM EXCHANGE (of C)
  - Measured by eddy covariance
- NET BIOME **P**
  - Regional/Global studies

- C-POOLS result from balance of fluxes into & out of each pool
- Approach of direct pool estimate without flux estimation are incomplete, unbalanced & have large uncertainty
- C flux observation & models are important part of NCP

Sal forest Flux tower - Barkot





Cumulative Annual gC/m2

GPP : 2916.2

Re : 2408.

NEE : -507.9

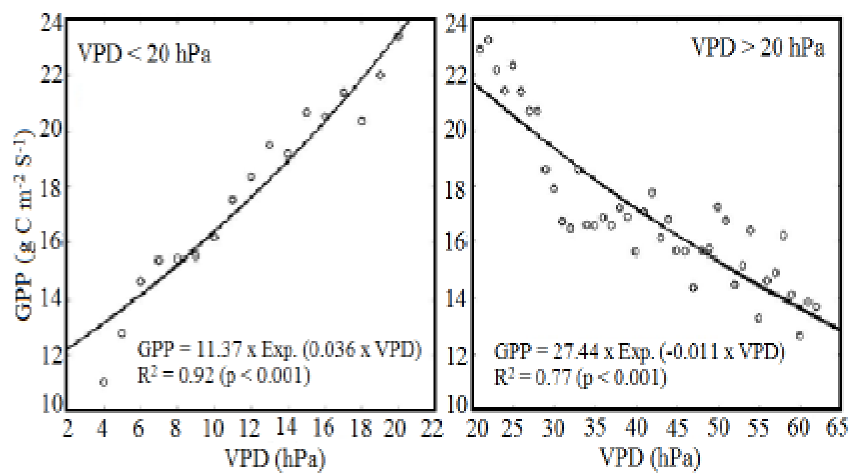
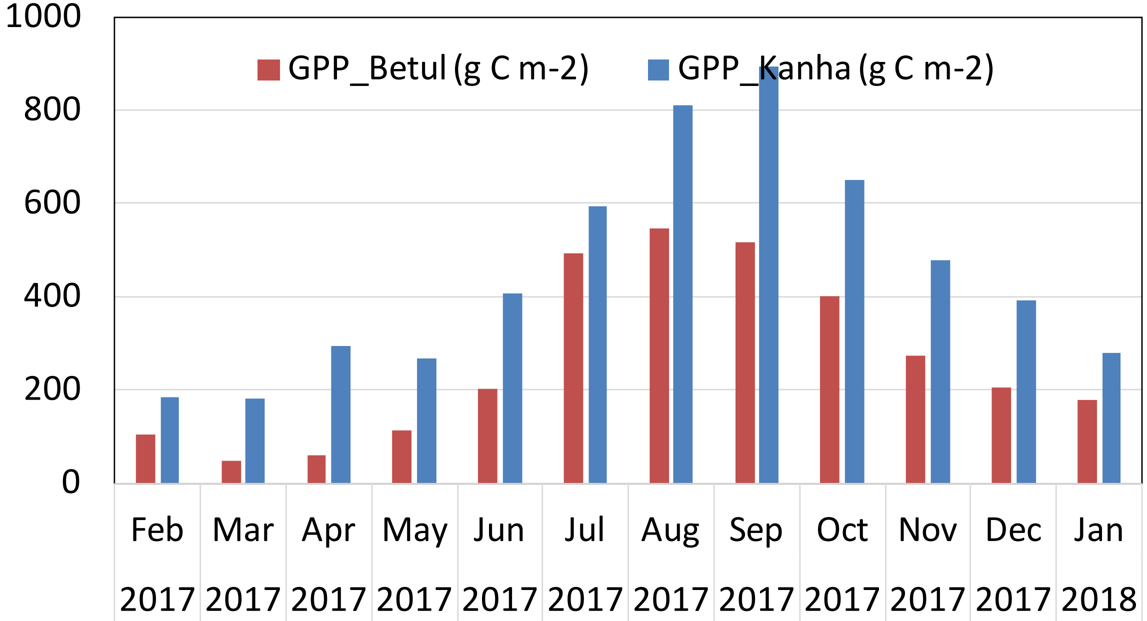


Fig. 8. Relationship between gross primary productivity (GPP) and vapour pressure deficit (VPD).

Watham, Kushwaha, Patel, Dadhwal, Kumar 2017, Trop Ecol, 58:761

Forests : Sal vs Teak



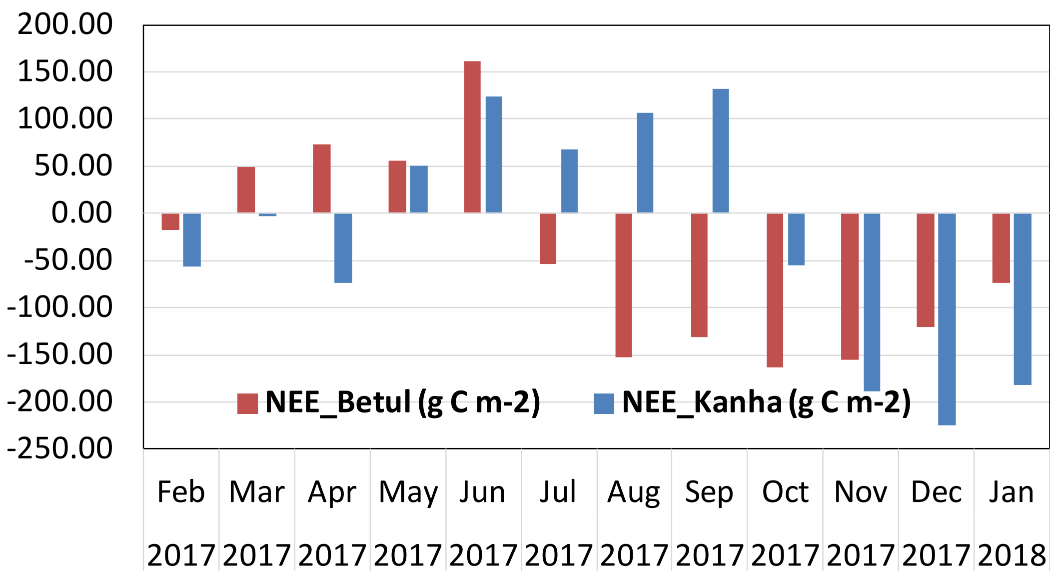
- First Annual Comparison of differences in productivity including NEE for Feb 2017 to Jan 2018

Annual Sum: GPP

1. **Kanha (Sal Forests) – 5428 g C m-2**
2. **Betul (teak Forests) – 3135 g C m-2**

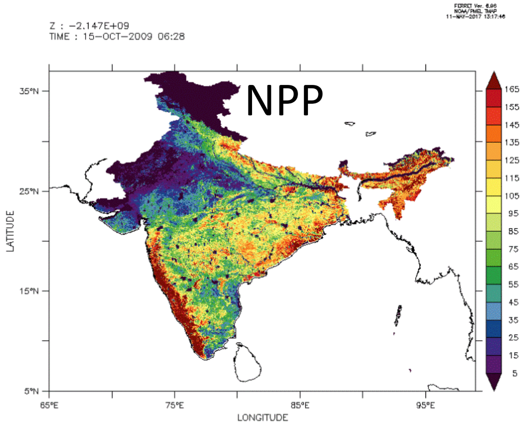
Annual Sum -NEE:

1. **Kanha (Sal Forests) – 303 g C m-2**
2. **Betul (teak Forests) – 526 g C m-2**



Jha, Chand, Rodda, 2019,Unpublished

Simulated monthly NPP & NEP (1981-2006)



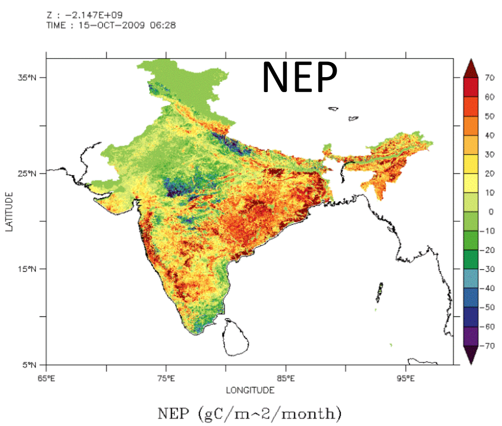
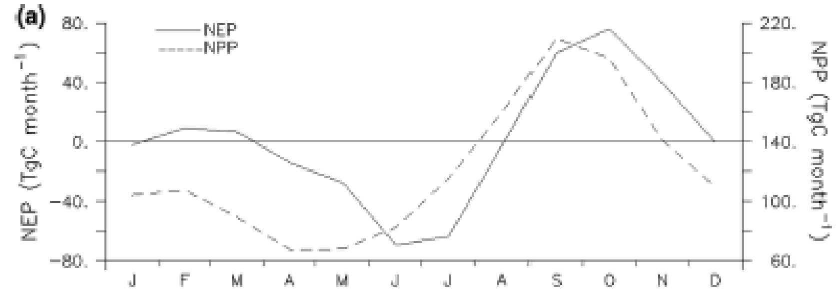


Fig. 2 Temporal evolution of monthly NEP (*continuous line*) and NPP (*dash line*) over India during the climatological years (1981–2006) is shown in the *upper panel*. The *lower panel* shows the evolution of NEP and NPP for the agriculture, the shrub–grass and the forest land-cover types in the country



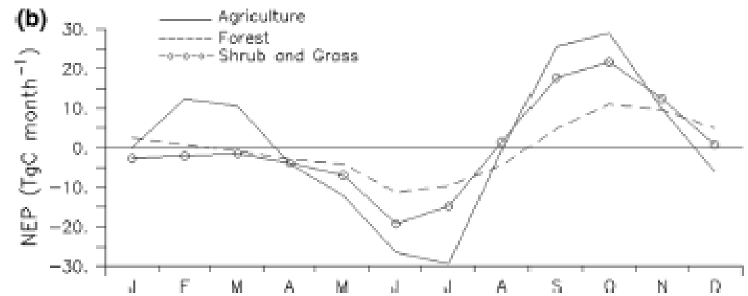


Fig. 3 Bar plot of NEP budgets of India during 1981–2006 agricultural years

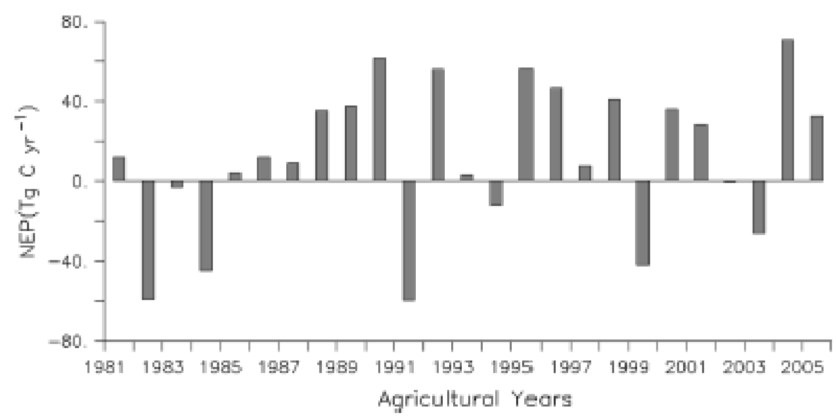
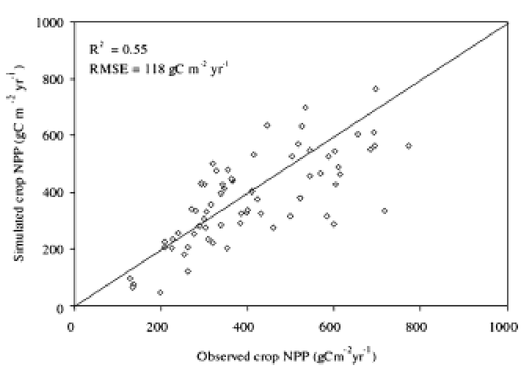


Fig. 8 Comparison of simulated annual NPP using the CASA model vis-à-vis ground-based NPP estimates from crop statistics in the western India (Rajasthan, Gujarat, and Punjab)



Nayak et al. 2009, Envi Mon Asess
Nayak et al. 2015, Environ Earth Sci,

Enhanced Use of EO / RS for Land Surface Characterization to Support LSM

Recent Studies on use of EO/RS

- High Resolution Crop Maps
- Crop Phenology (from RS) & parameterization (e.g. Thermal time)
- Irrigation Mapping
- Crop-wise Irrigated Area Mapping (source-wise)

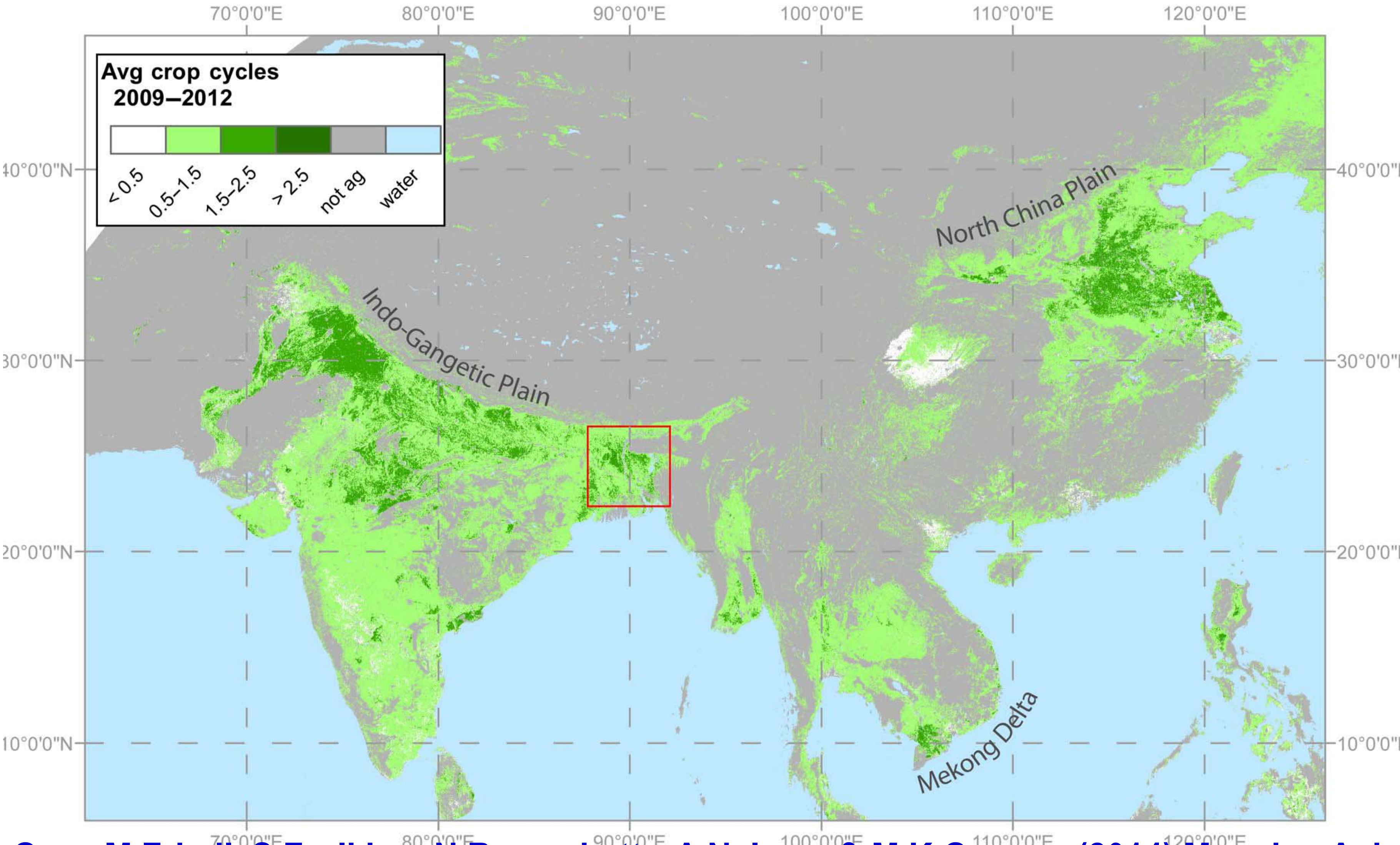
Geosci. Model Dev. Discuss., https://doi.org/10.5194/gmd-2019-85
Manuscript under review for journal Geosci. Model Dev.
Discussion started: 25 April 2019

Geoscientific Model Development Discussions
Open Access

Developing a sequential cropping capability in the JULESvn5.2 land–surface model

Camilla Mathison[1,2], Andrew J Challinor[2], Chetan Deva[2], Pete Falloon[1], Sébastien Garrigues[3,4], Sophie Moulin[3,4], Karina Williams[1], and Andy Wiltshire[1]

Cropping Intensity from EO Data



J Gray, M Friedl, S Frolking, N Ramankutty, A Nelson, & M K Gumma (2014) Mapping Asian Cropping Intensity With MODIS. IEEE J OF SELECTED TOPICS IN APPLIED EARTH OBSERVATIONS &REMOTE SENSING, VOL. 7(8)3373

INTERNATIONAL JOURNAL OF DIGITAL EARTH, 2016
VOL. 9, NO. 10, 981–1003
http://dx.doi.org/10.1080/17538947.2016.1168489

ISDE RADI Taylor & Francis
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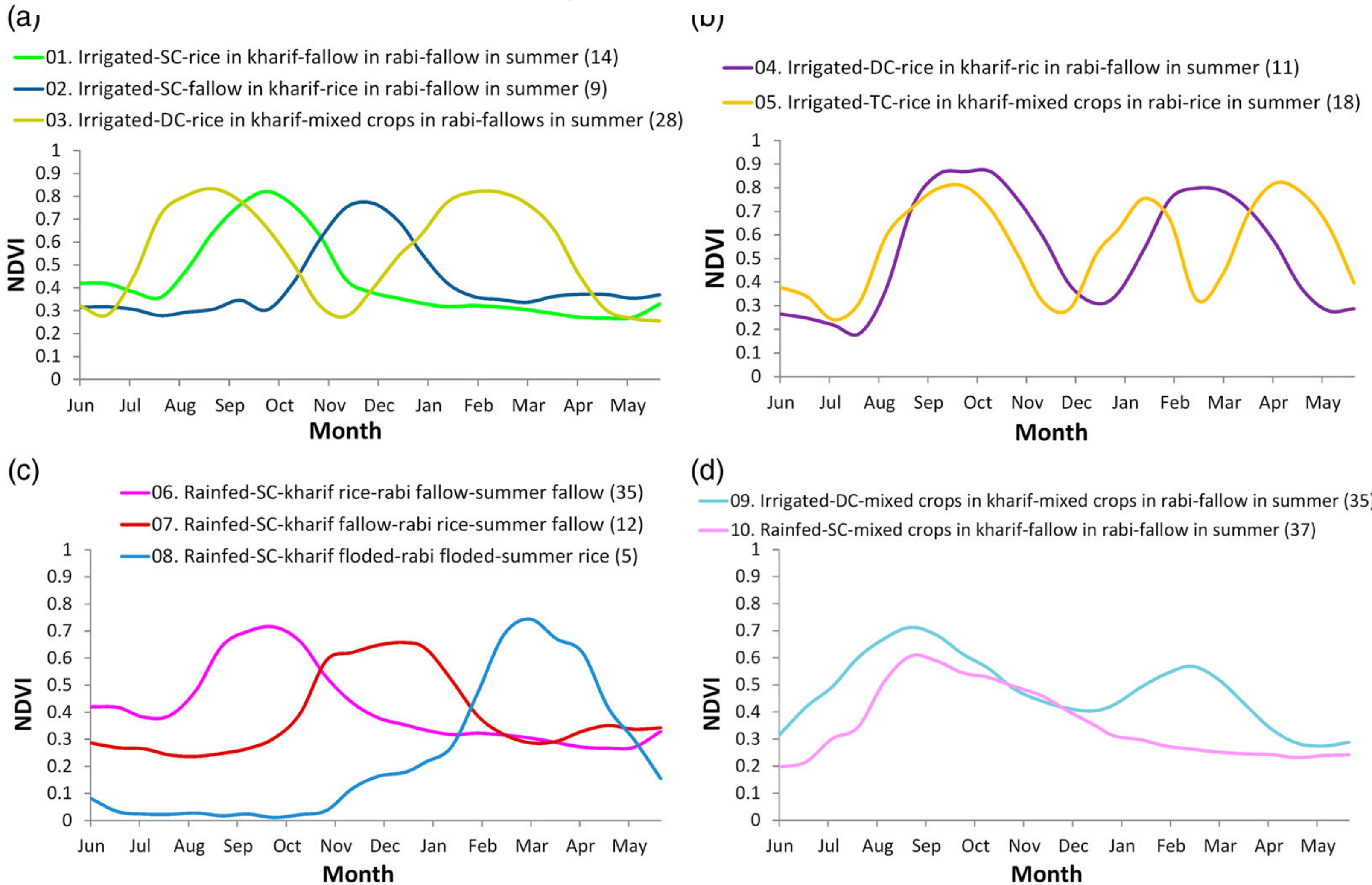
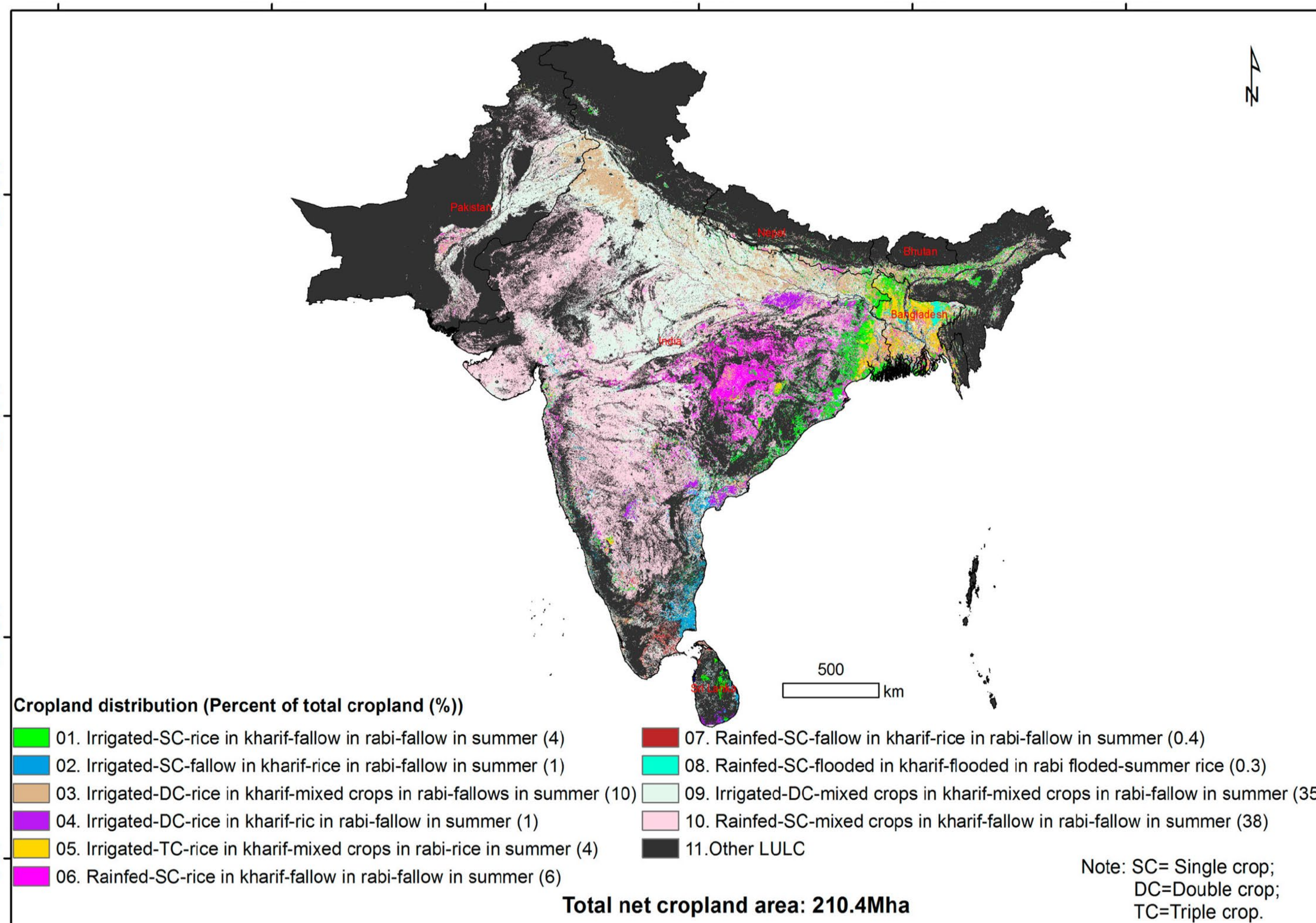
OPEN ACCESS

Mapping rice-fallow cropland areas for short-season grain legumes intensification in South Asia using MODIS 250 m time-series data

Murali Krishna Gumma[a], Prasad S. Thenkabail[b], Pardharsadhi Teluguntla[b], Mahesh N. Rao[c], Irshad A. Mohammed[a] and Anthony M. Whitbread[a]




Pakistan
Nepal
Bhutan
Bangladesh
India
Sri Lanka
N
500
km
30°0'0"N
20°0'0"N
10°0'0"N
0°0'0"
50°0'0"E
60°0'0"E
70°0'0"E
80°0'0"E
90°0'0"E
100°0'0"E
Cropland distribution (Percent of total cropland (%))
01. Irrigated-SC-rice in kharif-fallow in rabi-fallow in summer (4)
02. Irrigated-SC-fallow in kharif-rice in rabi-fallow in summer (1)
03. Irrigated-DC-rice in kharif-mixed crops in rabi-fallows in summer (10)
04. Irrigated-DC-rice in kharif-ric in rabi-fallow in summer (1)
05. Irrigated-TC-rice in kharif-mixed crops in rabi-rice in summer (4)
06. Rainfed-SC-rice in kharif-fallow in rabi-fallow in summer (6)
07. Rainfed-SC-fallow in kharif-rice in rabi-fallow in summer (0.4)
08. Rainfed-SC-flooded in kharif-flooded in rabi floded-summer rice (0.3)
09. Irrigated-DC-mixed crops in kharif-mixed crops in rabi-fallow in summer (35)
10. Rainfed-SC-mixed crops in kharif-fallow in rabi-fallow in summer (38)
11.Other LULC
Note: SC= Single crop;
DC=Double crop;
TC=Triple crop.
Total net cropland area: 210.4Mha

IRRIGATION in LSM

- India (with China & US) dominates in adoption of irrigation
- Irrigation includes surface and ground water which changes over time (strongly affected by rainfall variability)
- Irrigation is heterogeneous amongst regions, crops and timing as well as amount

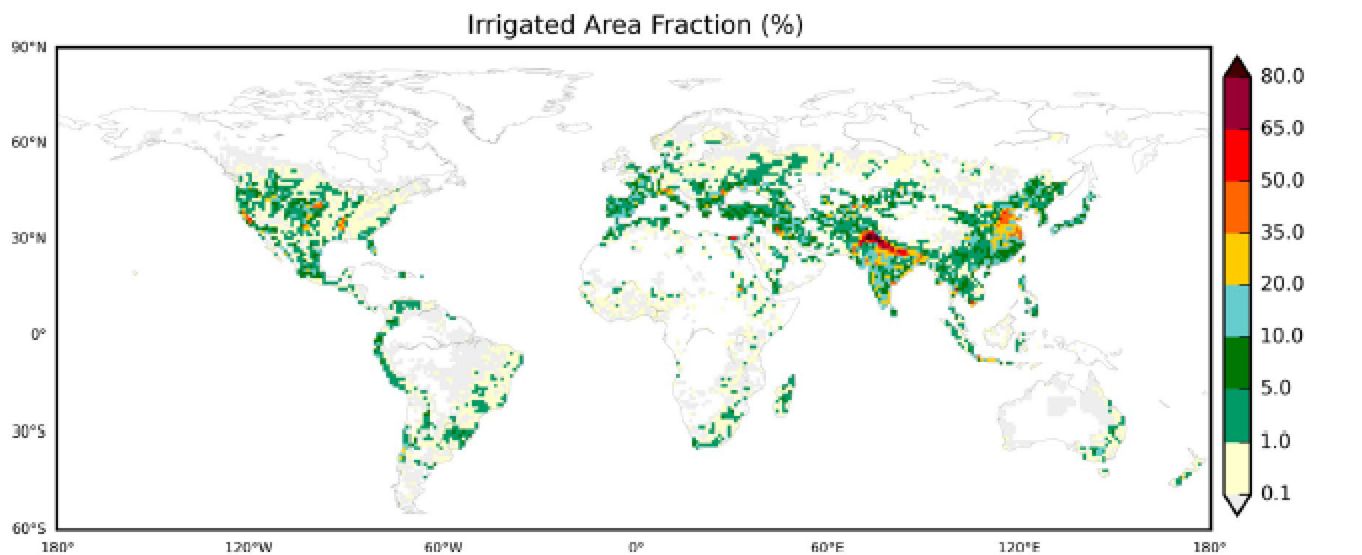


Fig. 5 Irrigated area fraction at 1° grids. *White color* represents either ocean or land not equipped for irrigation. Data source: Siebert et al. (2015). While *color* represents ocean or land without irrigated areas

Model Impact of Irrigation

Pokhrel et al., 2017

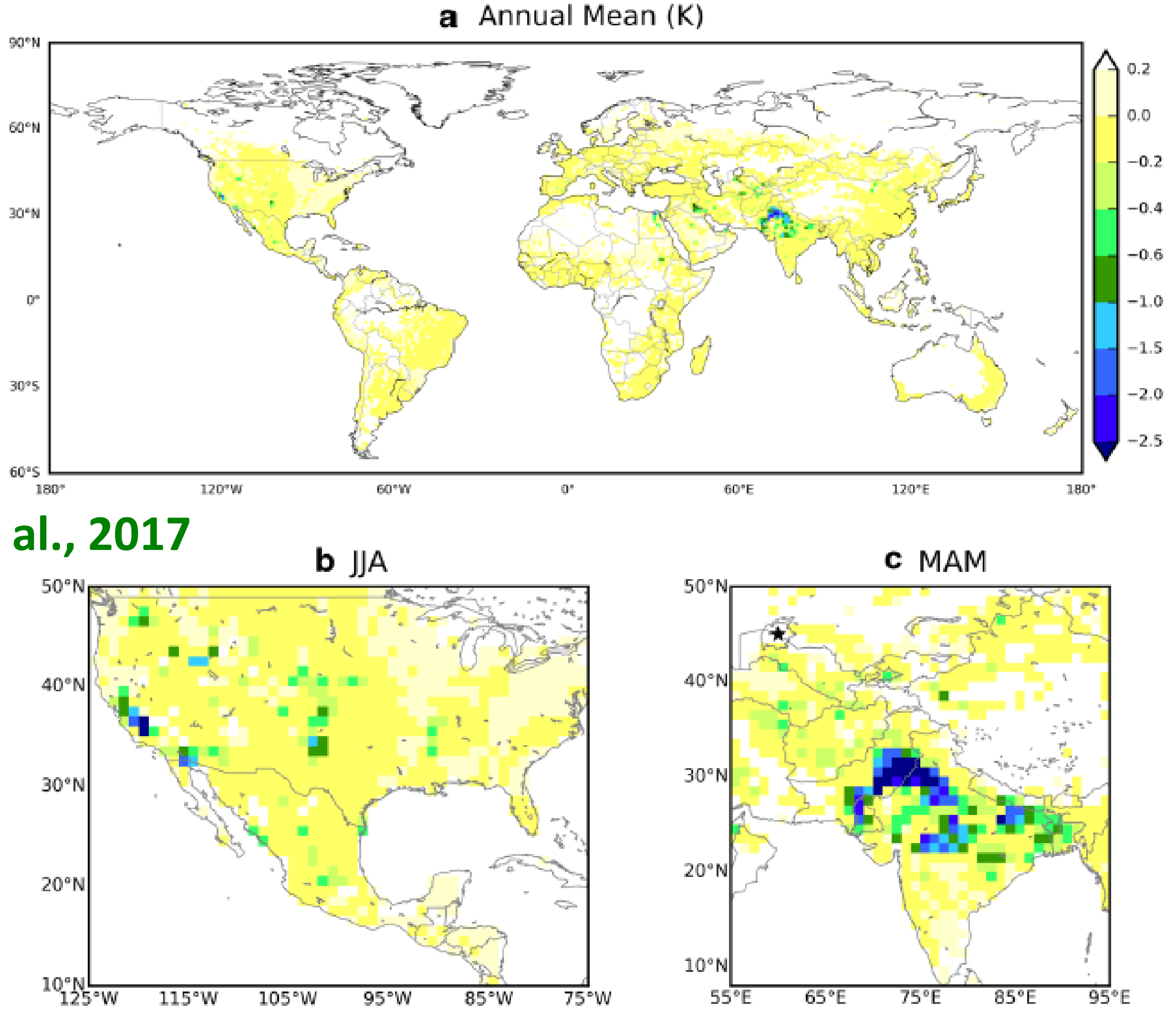


Fig. 4 Changes in grid-averaged annual mean land surface skin temperature due to irrigation (**a**); June–August (JJA) average over the continental US (**b**); and March–May (MAM) mean over the Indian sub-continent and central Asia including the Aral Sea region (**c**). Results shown are the differences between NAT-Offline and HI-Offline simulations. While *color* represents ocean or land without irrigated areas. The *black star* in (**c**) locates the Aral Sea

- A Review of the Available Land Cover and Cropland Maps for South Asia -P Patil & M K Gumma, *Agriculture* 2018, **8**, 111
  - **A number of Global and regional Land Cover, Crop Land and specific crop available from 1km to 30m pixel size. Variation in area amongst data sets could be upto 20 per cent.**

Velpuri_2009_PERS

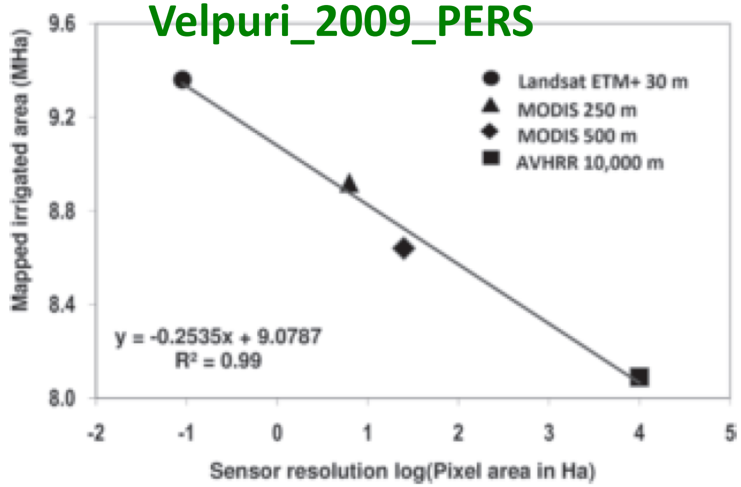


Figure 3. Implication of resolution on areas. The irrigated areas (in million hectares) mapped using (a) NOAA AVHRR 0.1 degree (10,000 m), (b) MODIS Terra visible and NIR bands (500m), (c) MODIS Terra red and NIR bands (250 m), and (d) Landsat ETM+ visible and NIR bands (30 m) plotted against the log (pixel area in Ha) of each sensor.

Change in Irrigation by Source (Tamil Namdu 2000-2009)

Environ Monit Assess (2015) 187:4155
DOI 10.1007/s10661-014-4155-1

Temporal change in land use Nadu and management impli

Murali Krishna Gumma · Kei Kajisa ·
Irshad A. Mohammed · Anthony M. Whitbread
Andrew Nelson · Arnel Rala · K. Palanisami

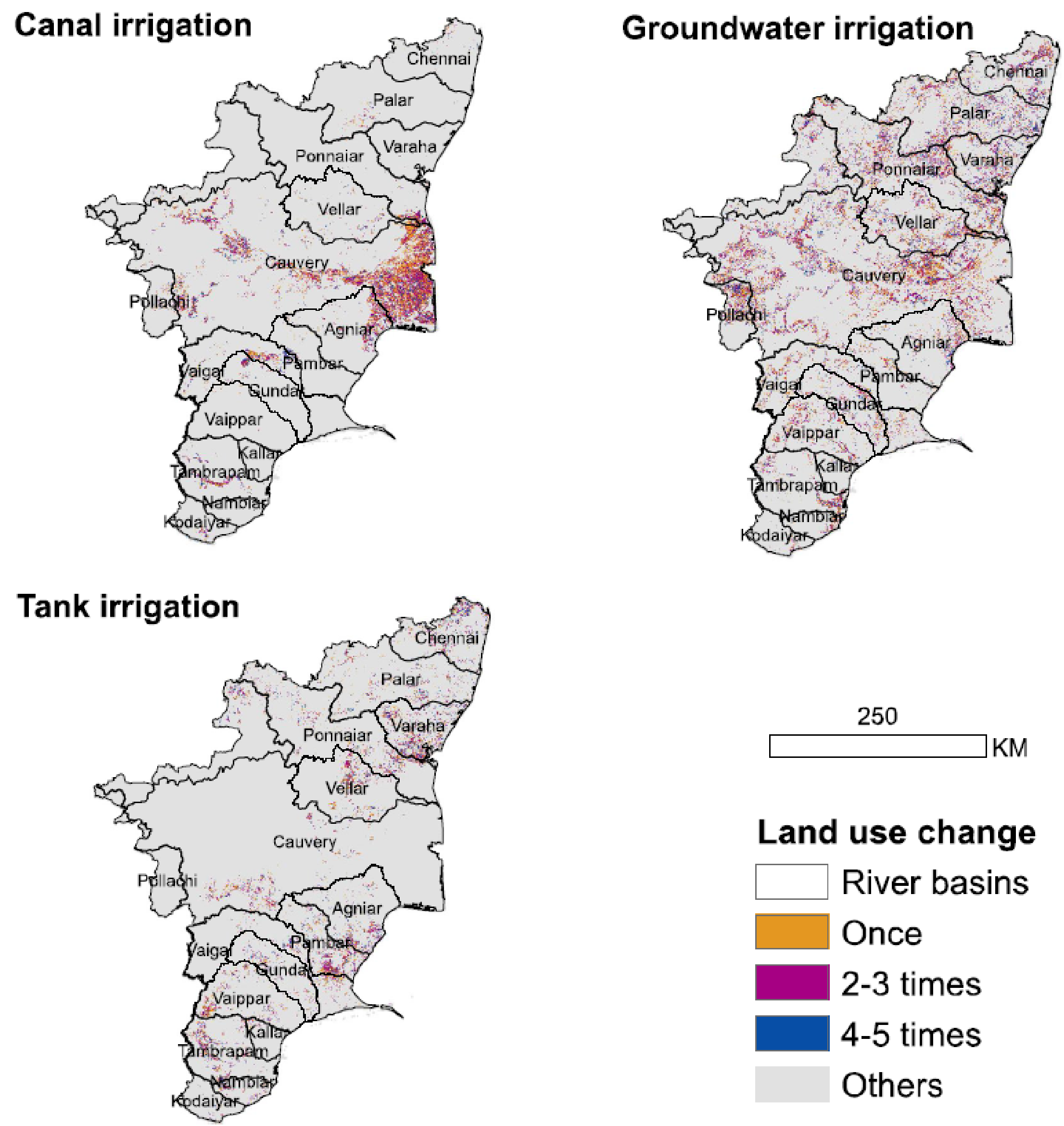


Fig. 6 Irrigated area changes during 2000 to 2009

Land Surface Indian Data Sets

RESEARCH COMMUNICATIONS

Mesoscale model compatible IRS-P6 AWiFS-derived land use/land cover of Indian region

Biswadip Gharai[1,*], P. V. N. Rao[2] and C. B. S. Dutt[3]

Curr Sci, 2019, (MM5 & WRF)

[1]Atmospheric Chemistry and Processes Studies Division,