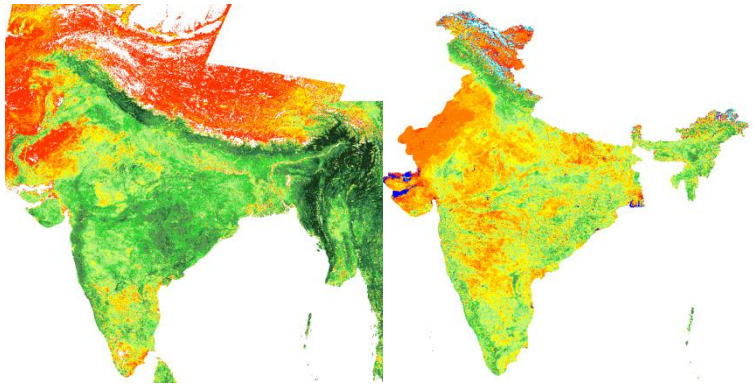
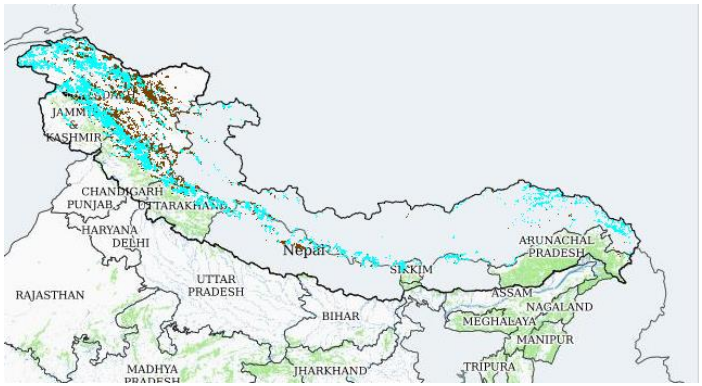
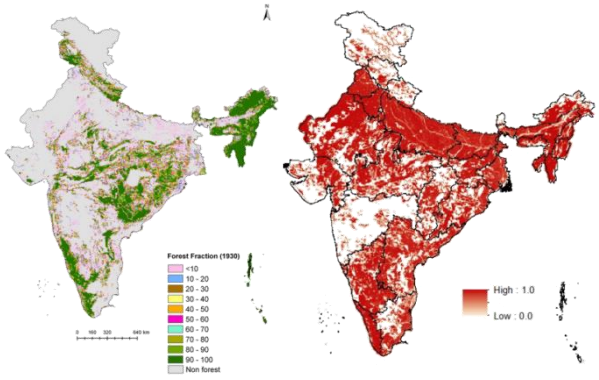
UN/Austria symposium "Space for climate action: experiences and best practices in mitigating and adapting to climate change and supporting sustainability on Earth".

Space Applications for Climate Studies in India



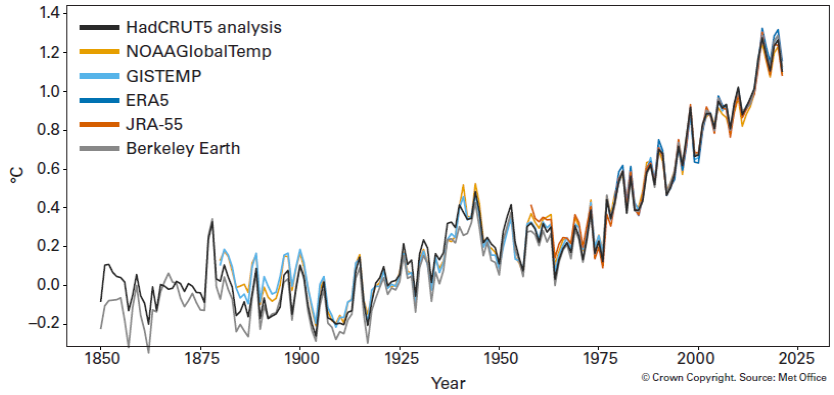




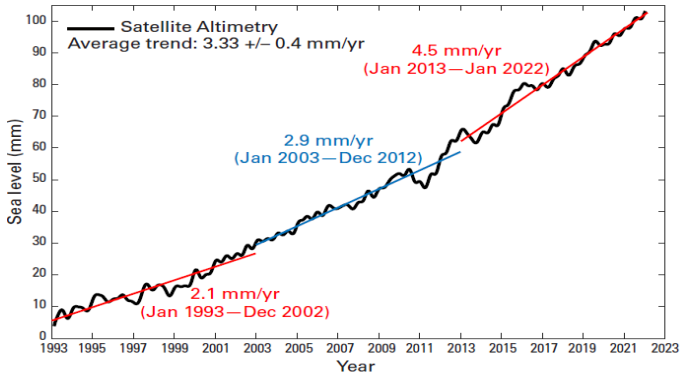
Dr Rajashree V Bothale, Deputy Director
Earth & Climate Sciences Area, National Remote Sensing Centre
Indian Space research Organisation, Hyderabad
India

Climate – Global scenario

Global annual mean temperature difference from pre-industrial conditions (1850–1900)

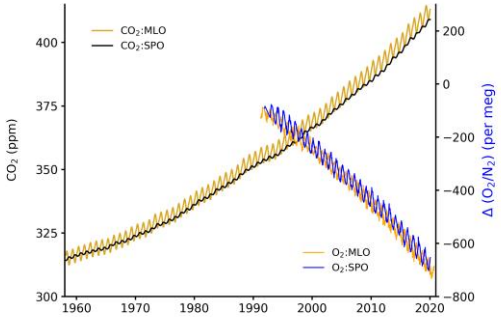


Global Sea level rise



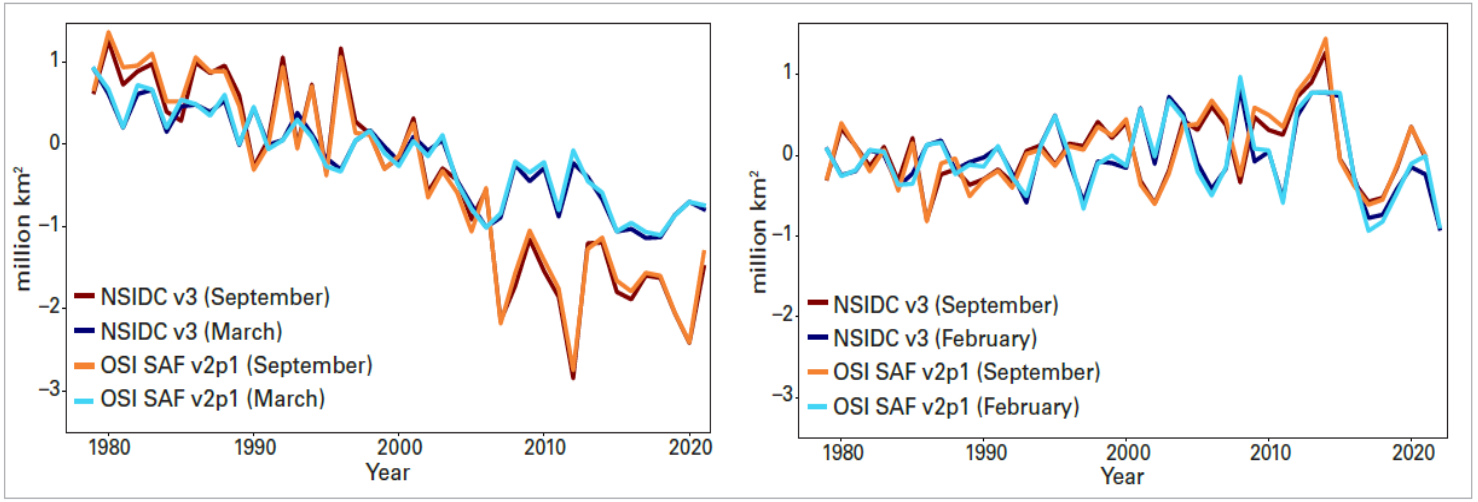
Source: AVISO altimetry

Increase in CO_2



Keeling et al, data source: SIO/UCSD

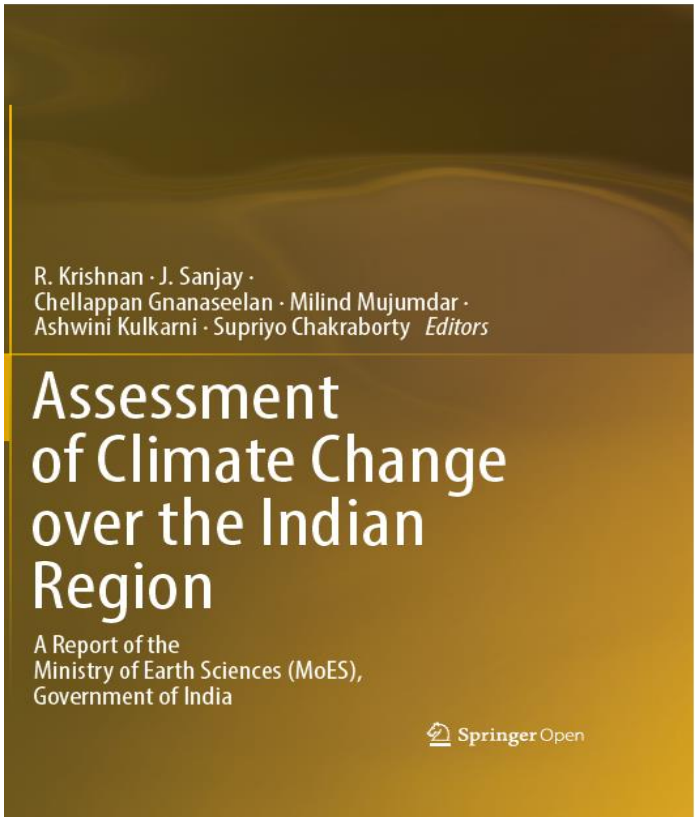
Sea-ice extent difference w.r.t (1981-2010) average



Source: Data from EUMETSAT OSI SAF v2p1 and National Snow and Ice Data Centre (NSIDC) v3 (Fetterer et al., 2017)

Climate – Indian scenario

Assessment of Climate Change over the Indian Region - A Report of the Ministry of Earth Sciences (MoES) Government of India - Editors (R. Krishnan, J. Sanjay, Chellappan Gnanaseelan, Milind Mujumdar, Ashwini Kulkarni, Supriyo Chakraborty

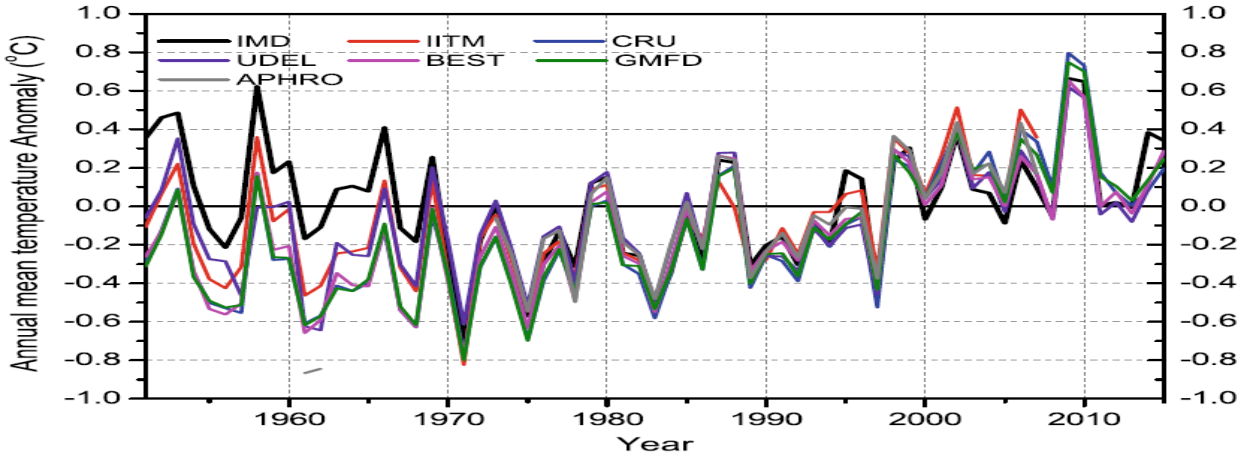


India is unique in geography with land-ocean features – (1) Himalayas, Tibetan Plateau, Western Ghats, eastern Ghats *(2)* Indian Ocean, Arabian Sea and Bay of Bengal

Monsoon oriented climate - Climate is influenced by monsoon seasonal cycles, climate tele-connections and natural and anthropogenic forcing

Main emphasis on - Land temperature, precipitation, GHG and flux measurement, droughts and floods, extreme weather events, Indian ocean warming, se level rise, Atmospheric aerosols and trace gases , Himalayam cryosphere

Annual average land surface air temperature anomalies over India.



Trend during 1986-2015: 0.15°C per decade

Climate change – Indian scenario

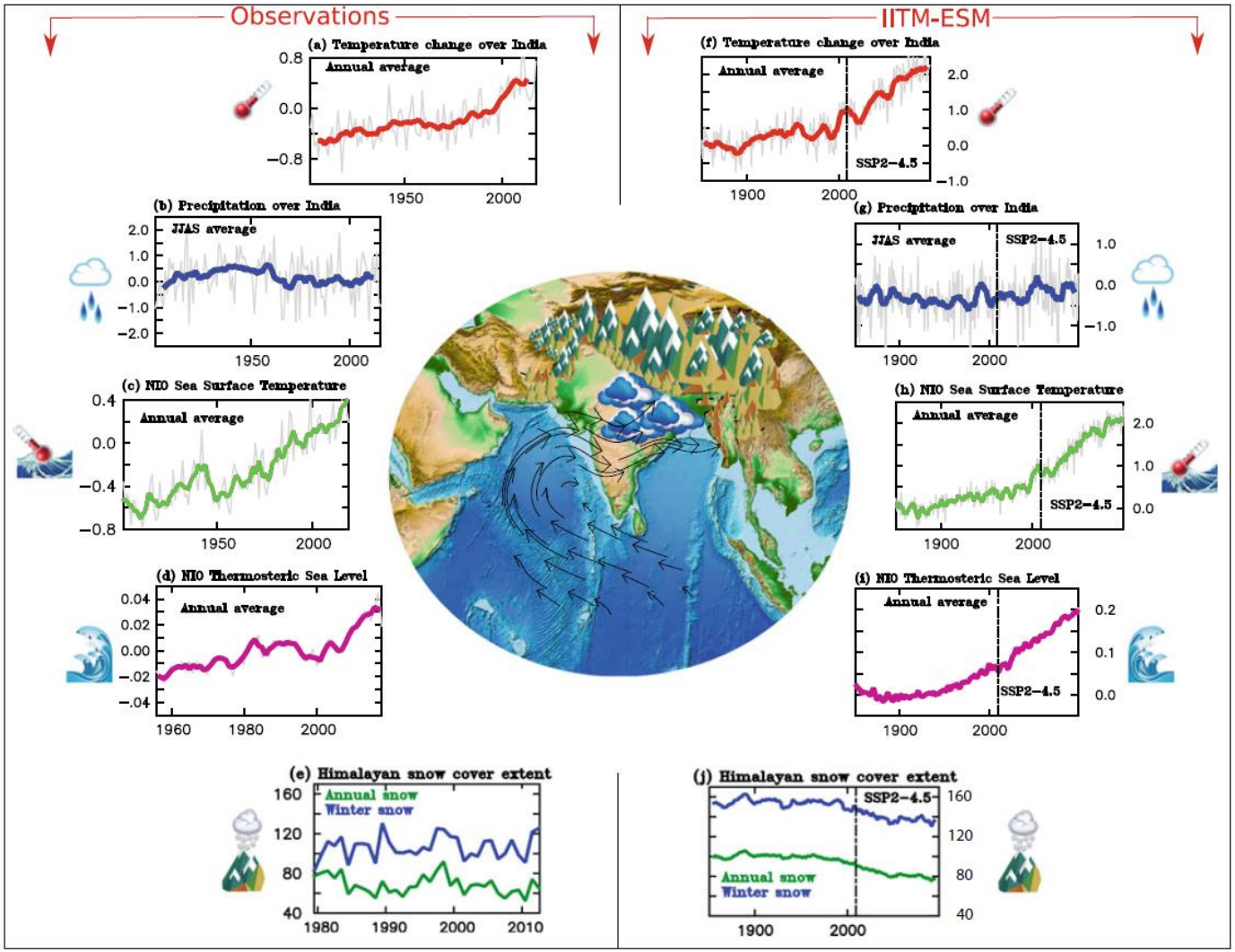
Observational period: 1976-2005

Projection period: 1850-2100

The surface air temperature over India has risen by about 0.7 °C during 1901–2018

The North Indian Ocean (NIO) rose at a rate of 3.3 mm per year during 1993–2017, similar to the global mean.

Thermal expansion (thermosteric) has dominated sea-level rise in the NIO).



Himalayan snow cover extent (x 10000 km²)

The frequency of very severe cyclonic storms over the NIO during the post-monsoon season has significantly increased in the past two decades, despite an overall reduction in the annual TC activity.

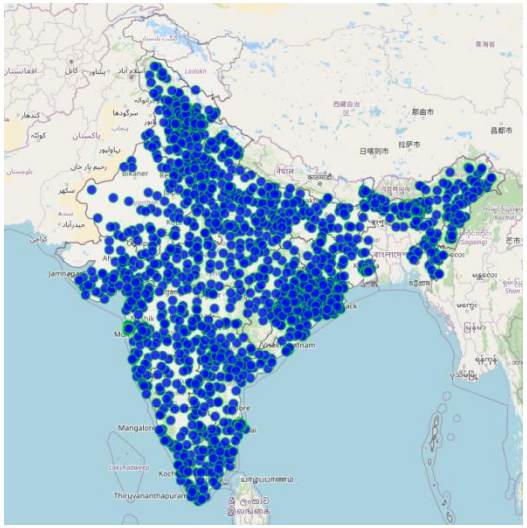
The Hindukush Himalayas (HKH) underwent rapid warming at a rate of about 0.2°C per decade during the last 6–7 decades).

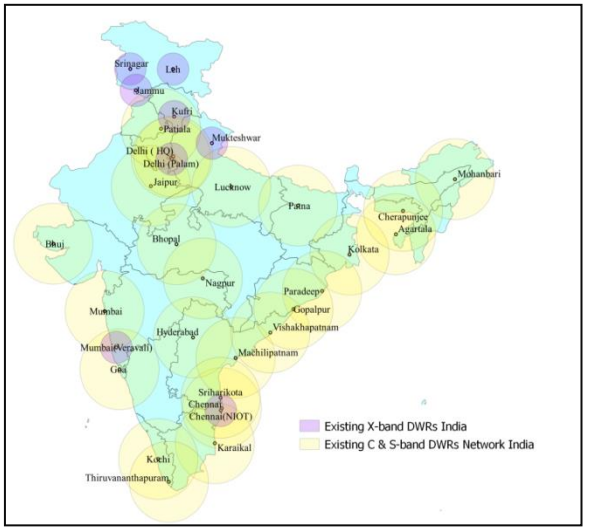
Source: Krishnan et al., Introduction to Climate Change Over the Indian Region, 2020

Climate - Traditional observations

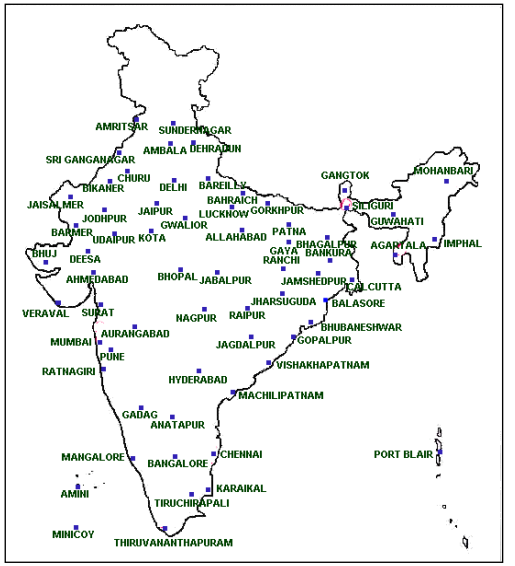
IMD Observation networks

IMD Rainguage network
(total 1377 stations)





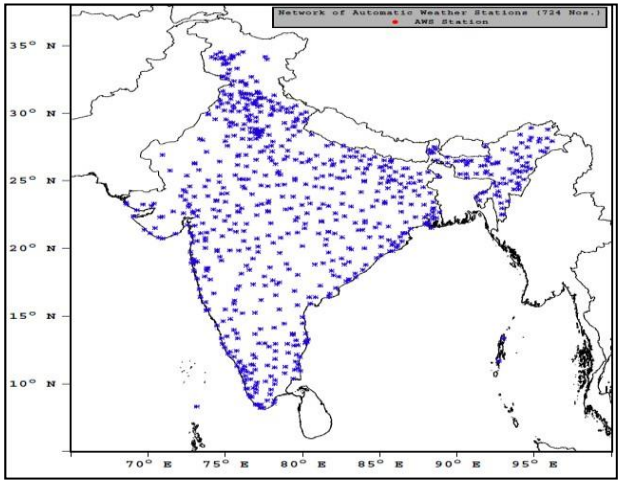
Doppler Weather Radar network



Pilot Balloon Network

Highest Meteorological Centre in India, Leh

Surface Observatories (206 Nos)



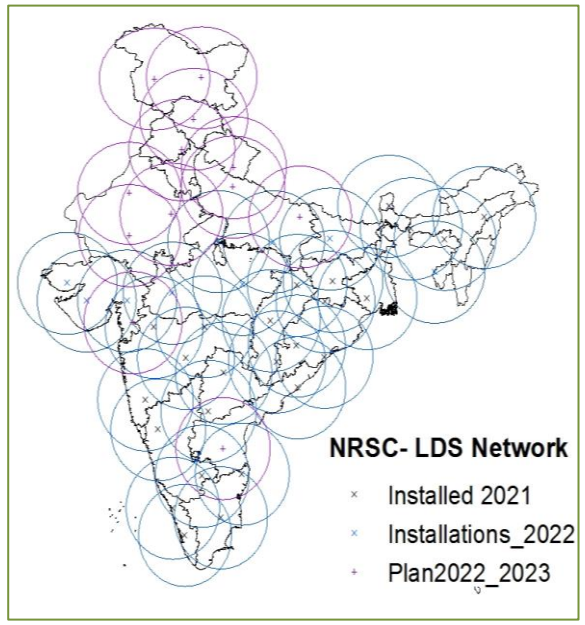
AWS Network (735 Nos)

Climate - Traditional observations

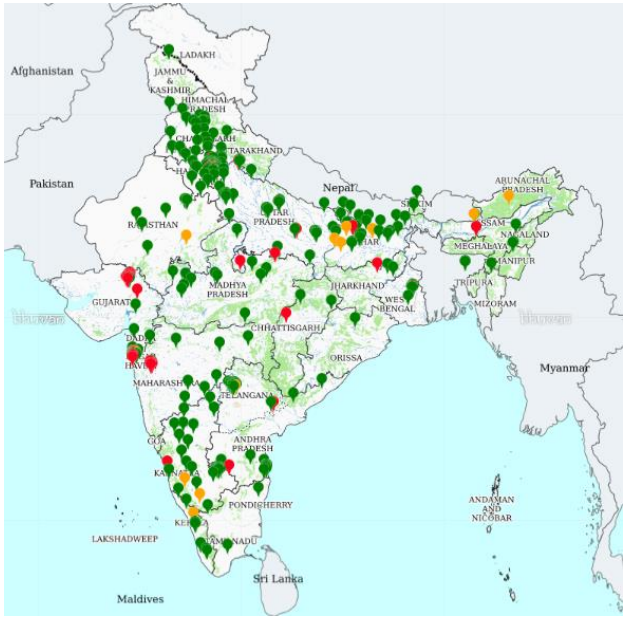
Other Observation networks

Source: A K Patra, NARL

Radar, Lidar, Radio Sonde, Spectrometer @ NARL



Lightening detector network by NRSC

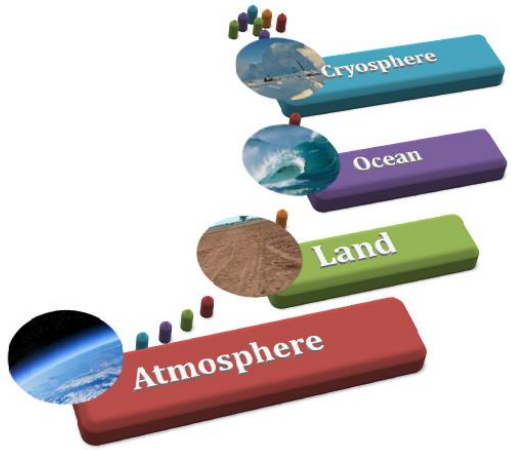


Air quality PM2.5 (Source: NARL)

- Need for better and wide spread observations
- Space observations provide answers to many climate related questions
- Small changes over long term climate change can be mapped from space

Climate - Space based observations

- Local, regional and global observations
- Temporal observations at regular interval
- Multispectral observations
- All weather & day/night observation capability
- Data availability from multiple satellites
- Data availability from polar and geostationary satellites
- Mapping possible for all four pillars of climate



Four pillars of climate

Imaging System	Optical	Thermal	Microwave
Measurements	Reflectance (ρ)	Brightness Temp B(T)	B(T), Backscatter
Rationale	Spectral signature $\rho(\lambda) = \frac{\pi . L_{sensor}}{E_0 . \cos\theta_s}$	Planck's law $B(\lambda,T) = \frac{2\pi . h . c^2}{\lambda^5 . (e^{\frac{hc}{\lambda kT}} - 1)}$	Dielectric property $P_r = \frac{P_t . G_t . G_r . \lambda^2 . \sigma}{(4\pi)^3 . R^4}$
Parameters	**Terrestrial** Vegetation Fraction LAI/fAPAR Soil Moisture Evapo-transpiration ------	**Atmosphere** Temperature Rainfall Trace gases Aerosols ------	**Ocean** Sea Level SST Salinity Ocean Colour -----

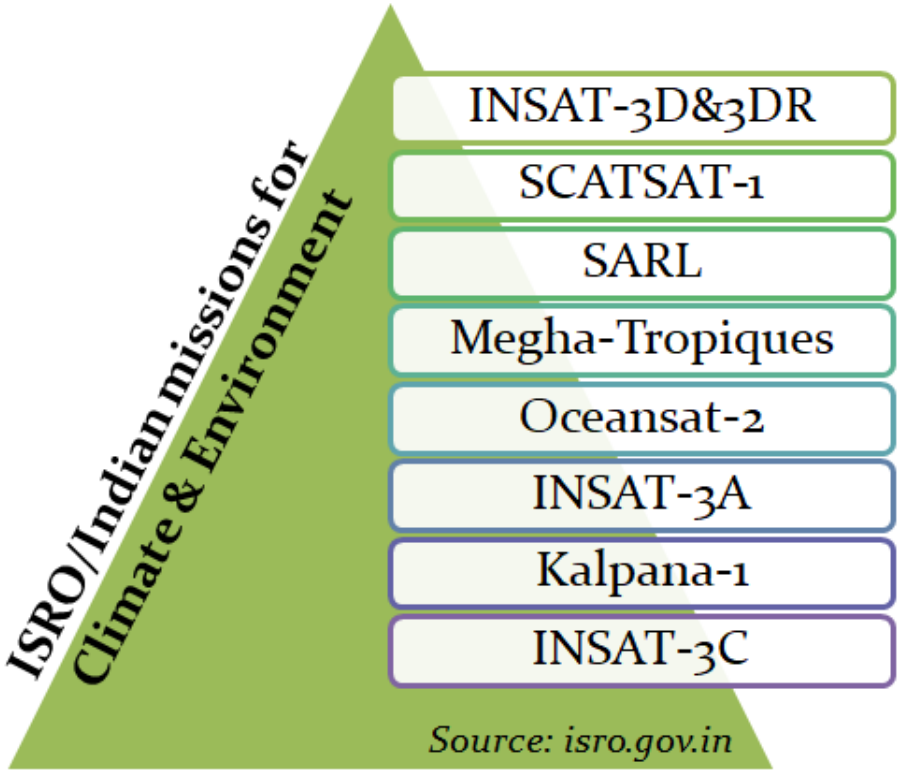
Source: IIRS, Dehradun

Global Climate Observing System
Essential Climate Variables (ECVs) 54 (From Space 35)

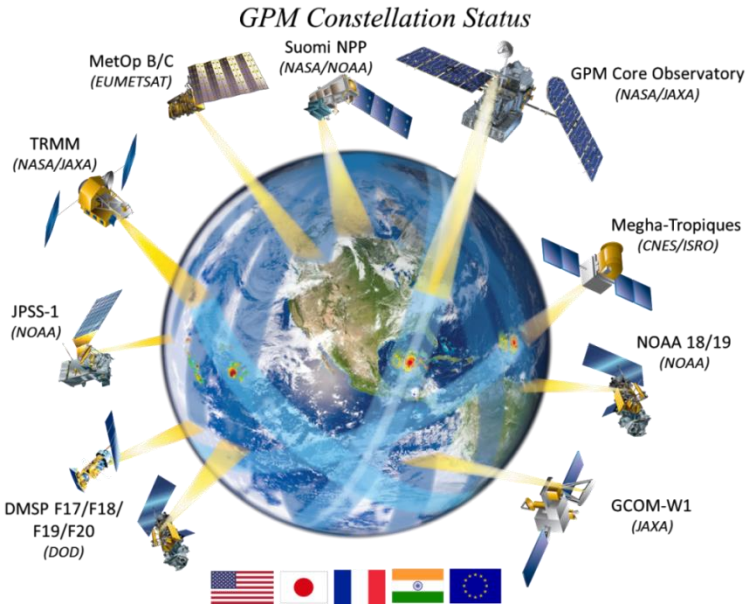
Space based observations – Indian satellites

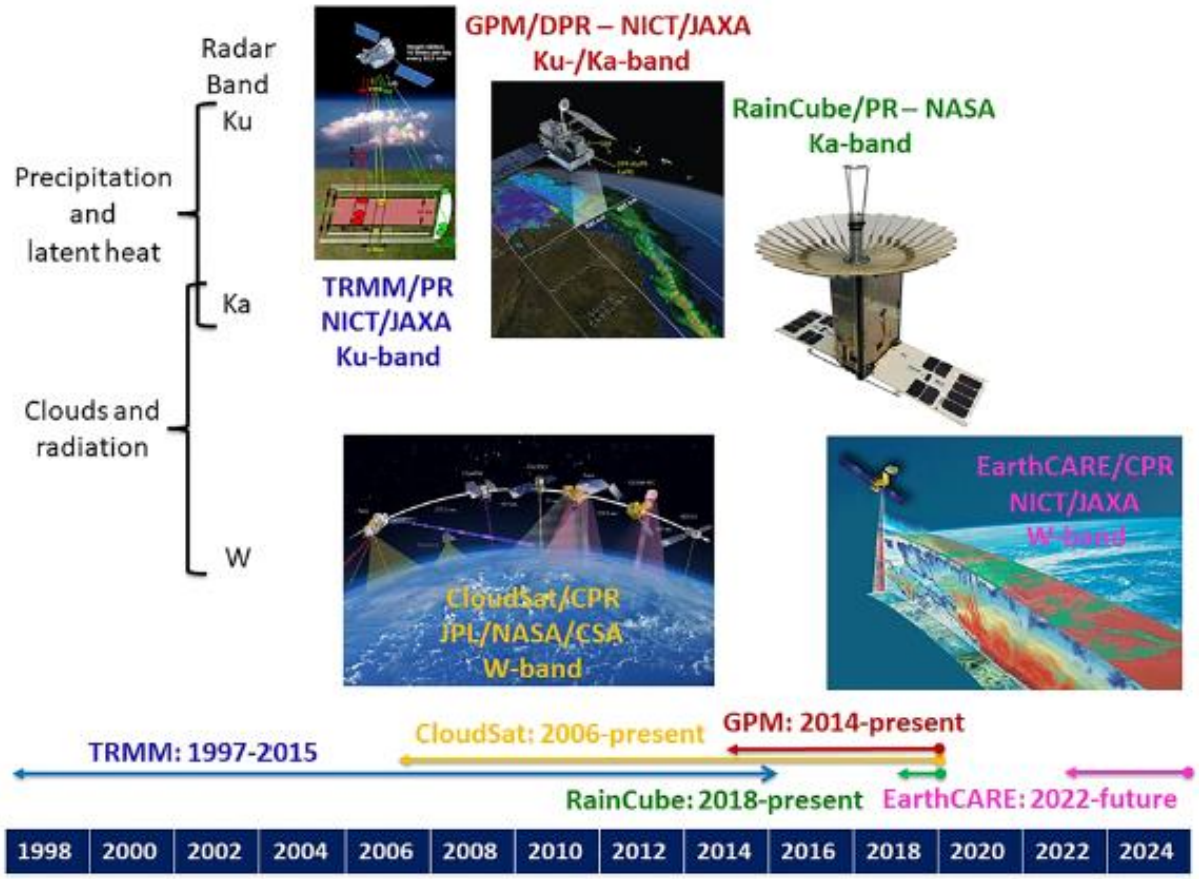
From more than 3 decades, EO satellites have been providing the facts needed to address the challenges of our changing climate.

Terrestrial	Ocean	Atmosphere
IRS Series (IRS-1A/1B/P2/1C/P3/1D) Resourcesat-1/2, IMS-1	IRS-P3	OceanSat-I
Cartosat Series (Cartosat-1/2/2A/3	Oceansat-I	MSMR
INSAT 2E/3A (CCD)	Oceansat-II	INSAT Series
Oceansat-1/2 (MSMR, Scatt. OCM)	SARAL	KALPANA-1
RISAT-1/1A	Megha Tropiques	OceanSat-II
	INSAT-3D/3DR	INSAT-3D
	OCEANSAT-3	Megha Tropiques

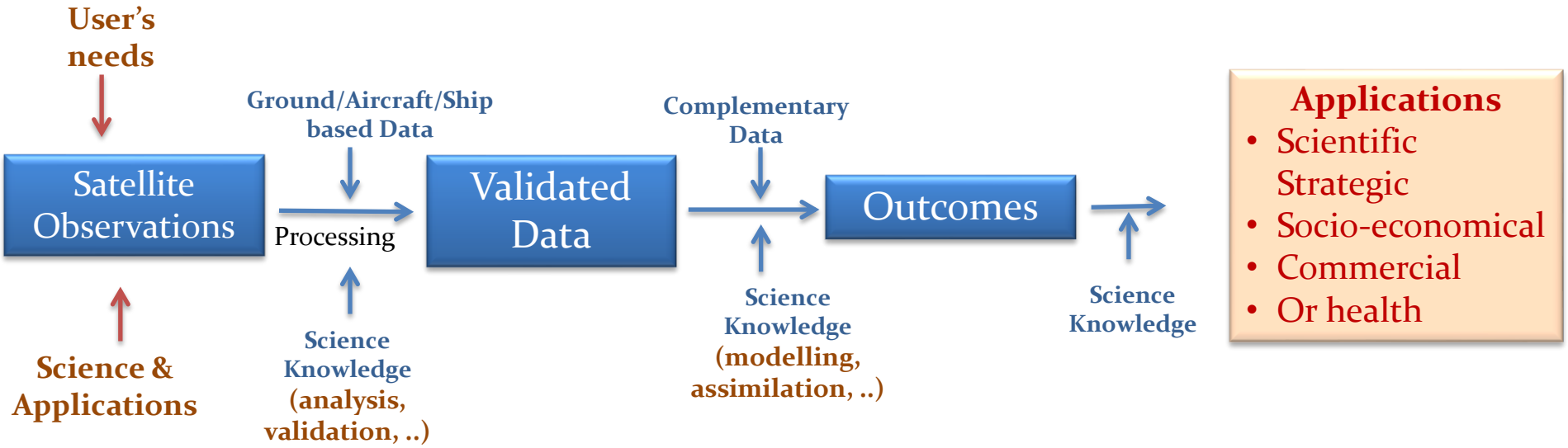


Space based observations – Foreign satellites

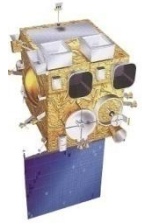




Missions - to - Parameter retrieval



Met Parameters



•INSAT 3D/3DR
•Suomi NPP

Flux Tower
(• Temperature • Wind
•Humidity • Soil Moisture
•Radiation)

Clouds

•INSAT 3D/3DR
•Kalpana •MODIS
•CALIPSO •Cloudsat

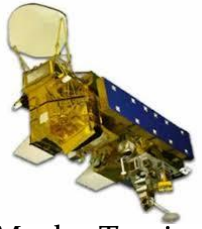
Sky
Imager

Precipitation

•TRMM • GPM
•INSAT 3D

Micro Rain Radar

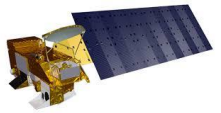
Radiation, Albedo



•Megha-Tropiques
•CERES •MODIS

Netradiometer

Aerosols



•MODIS • CALIPSO

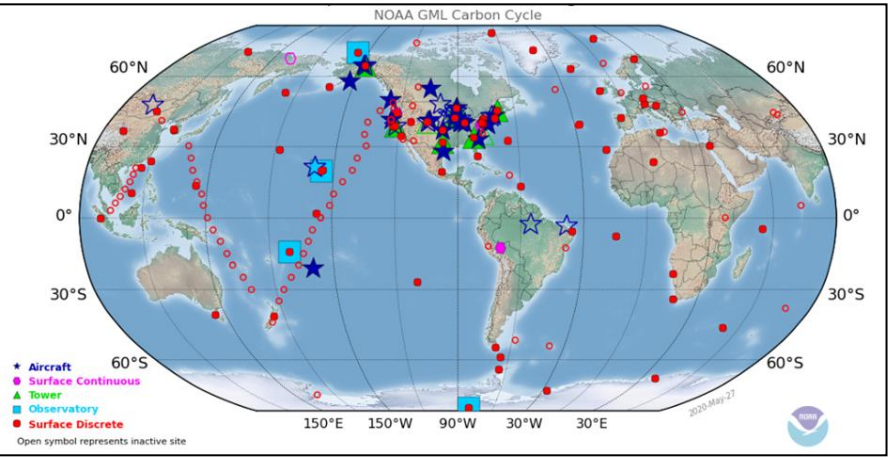
Sky Radiometer

Temperature & Humidity Profiles

•INSAT 3D/3DR
•Suomi NPP

Hyperspectral
Radiometer
+ Trace gas
measurements

Ground & Space observations



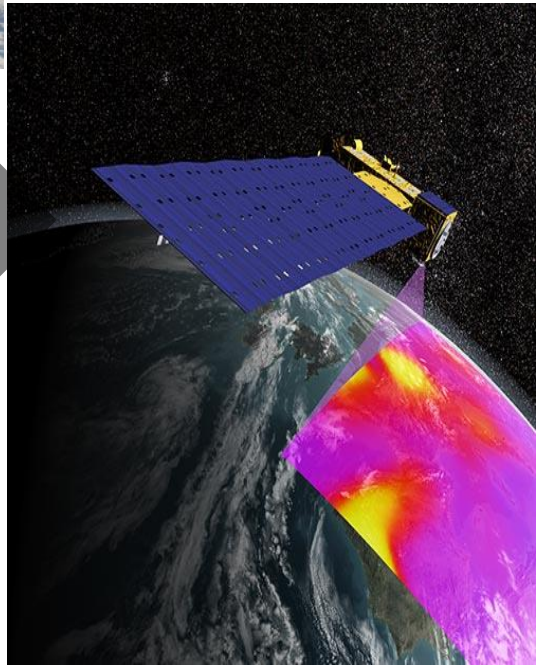
CO_2 observations (https://gml.noaa.gov/ccgg/about.html

Ozone observations
(https://public.wmo.int/en/bulletin/global-atmospheric-ozone-monitoring

1979–2004 by NASA's Total Ozone Mapping Spectrometer (TOMS) instruments

Ground & Space-based

2005–2020 by the Royal Netherlands Meteorological Institute's Ozone Monitoring Instrument (OMI)



Space Applications – Land cover

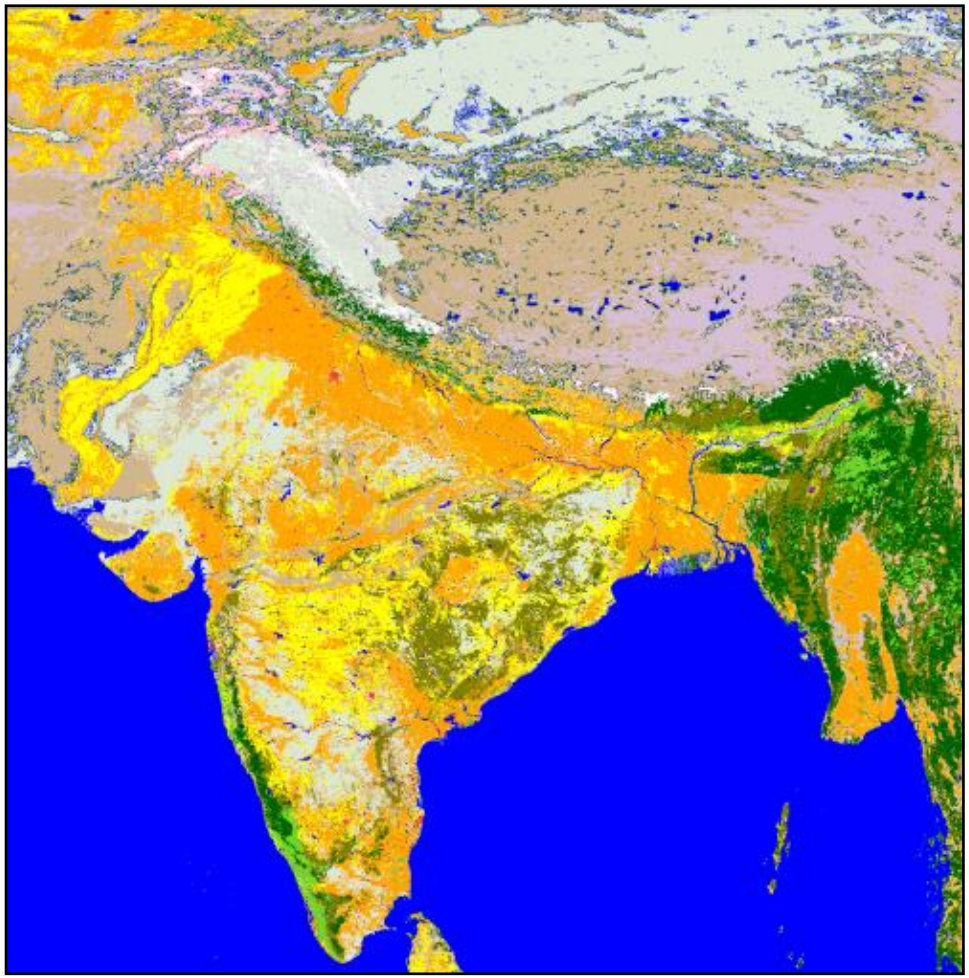
Land cover influences climate by modifying water and energy exchanges with the atmosphere by changing greenhouse gas and aerosol sources/sinks.

Changes in Land-Use-Land-Cover (LULC) occur in response to both human and climate drivers.

The ECV Land Cover (compatible to WRF model) generated at national level using AWiFS data (56m resolution) from the Indian Remote Sensing satellite,

Further, the Indian region of global USGS data has been replaced with the AWiFS derived data such that it is compatible to MM5 & WRF models.

Primary Applications: Climate modelling studies; Impact, Mitigation & Adaptation of climate change studies; Urban sprawl; Coastal land use versus sea level rise; Sustainable development goals; etc.

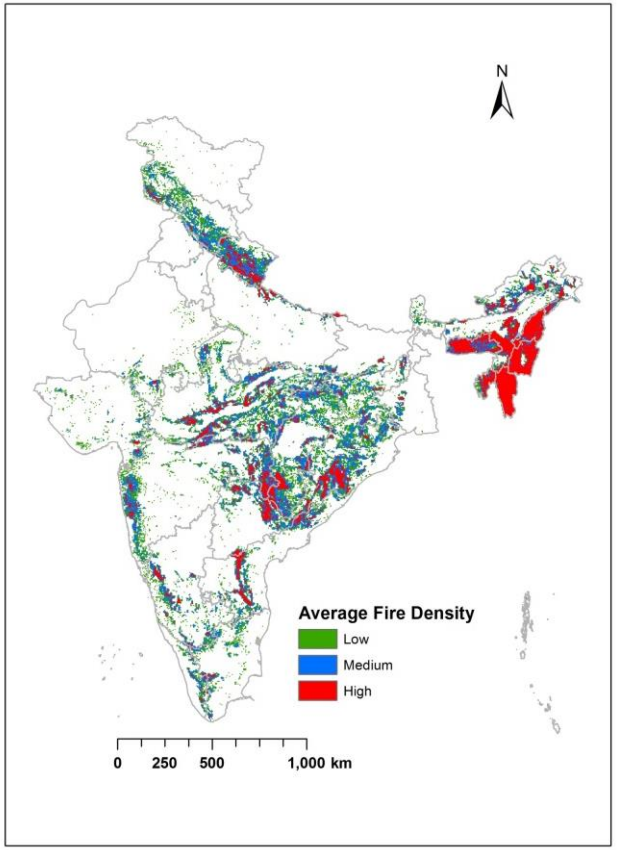


Fires are a major source of aerosols, CO and oxides of nitrogen, apart from emitting CH_4, and thus affect local/regional air quality.

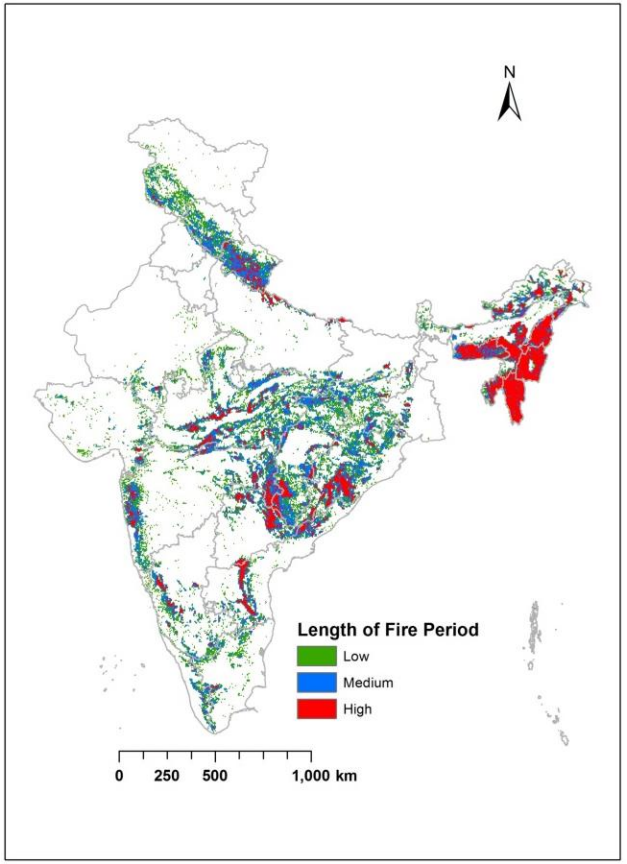
The ECV Fire regime pattern, annual average fire density and length of the fire period, at national level is generated using MODIS fire record and NRSC forest fraction layer at 5km grid.

Primary Applications: Carbon cycle, Climate modeling studies; Fire regime assessment; Air quality studies; Biodiversity; etc.

Average fire density (2003-21)



Length of fire period (2003-21)



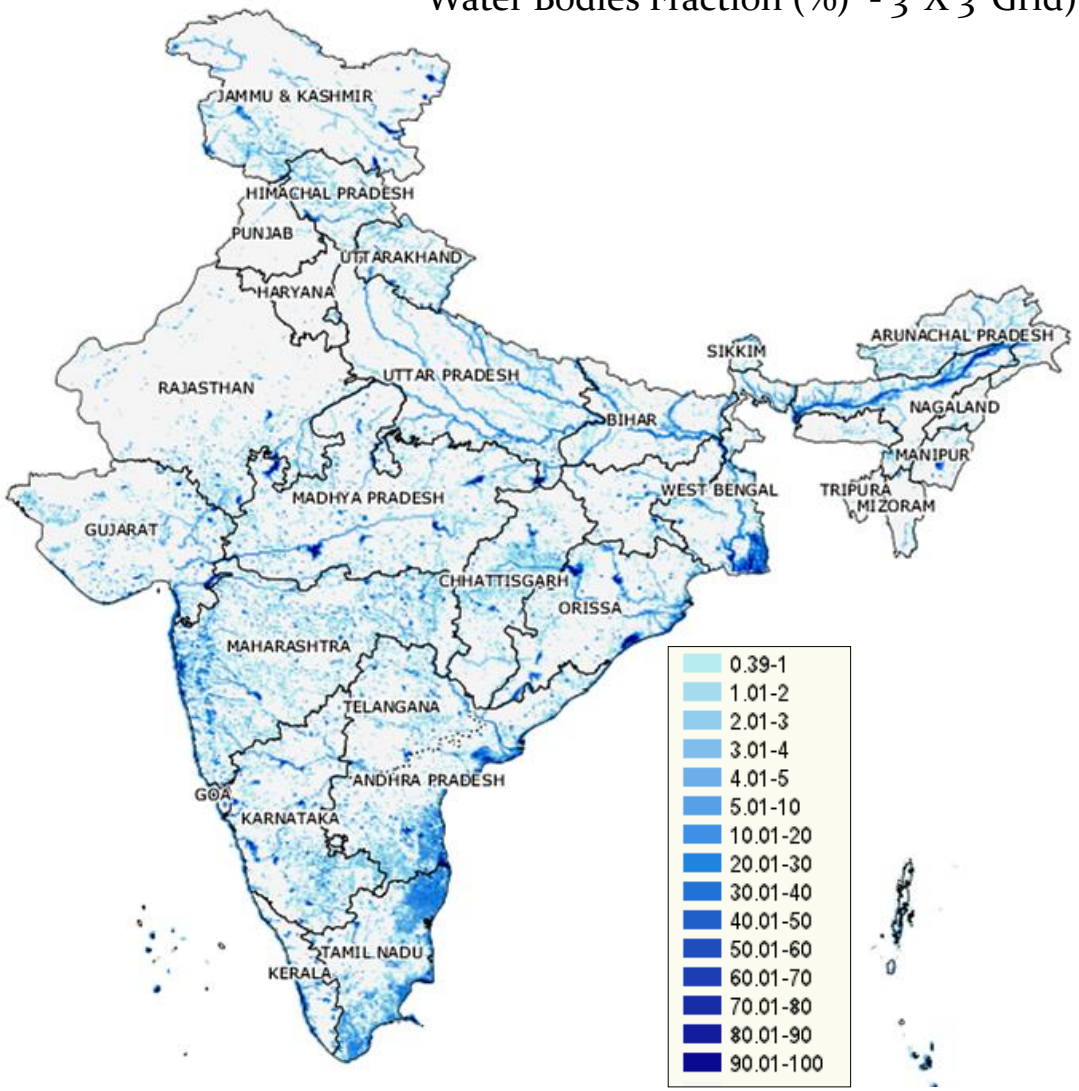
Space Applications – Water bodies

Information on changes in lake level and area is required for climate assessment purposes.

Water bodies consist of all surface water bodies like reservoirs, irrigation tanks, lakes, ponds and rivers/streams. Water pixel from each scene in Resourcesat-2 AWiFS sensor data is extracted and mosaicked for generation of nation-wide water bodies layer.

Primary Applications: Hydrological studies; Climate change and resiliency studies, Freshwater habitat versus invasive species; Aquatic ecosystems health, Sustainable Development Goals.

Water Bodies Fraction (%) - 3' X 3' Grid)



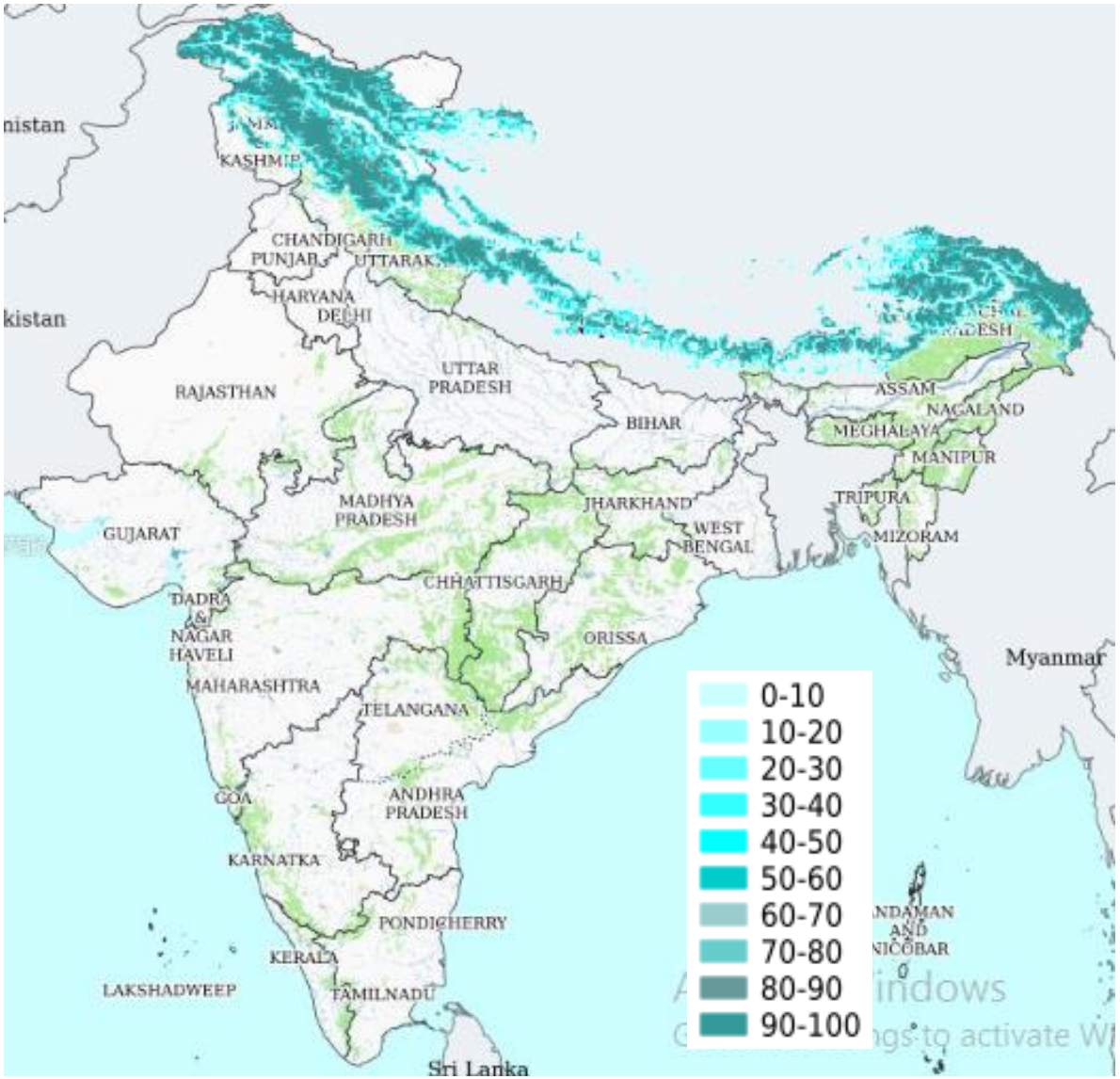
Space Applications – Snow cover

Snow cover is a critical component of the cryosphere and climate system at both local and global scales. Snow cover on the ground plays a significant role in the climate system due to its high albedo and contributes to soil moisture and runoff, hence it is an important variable in monitoring climate change.

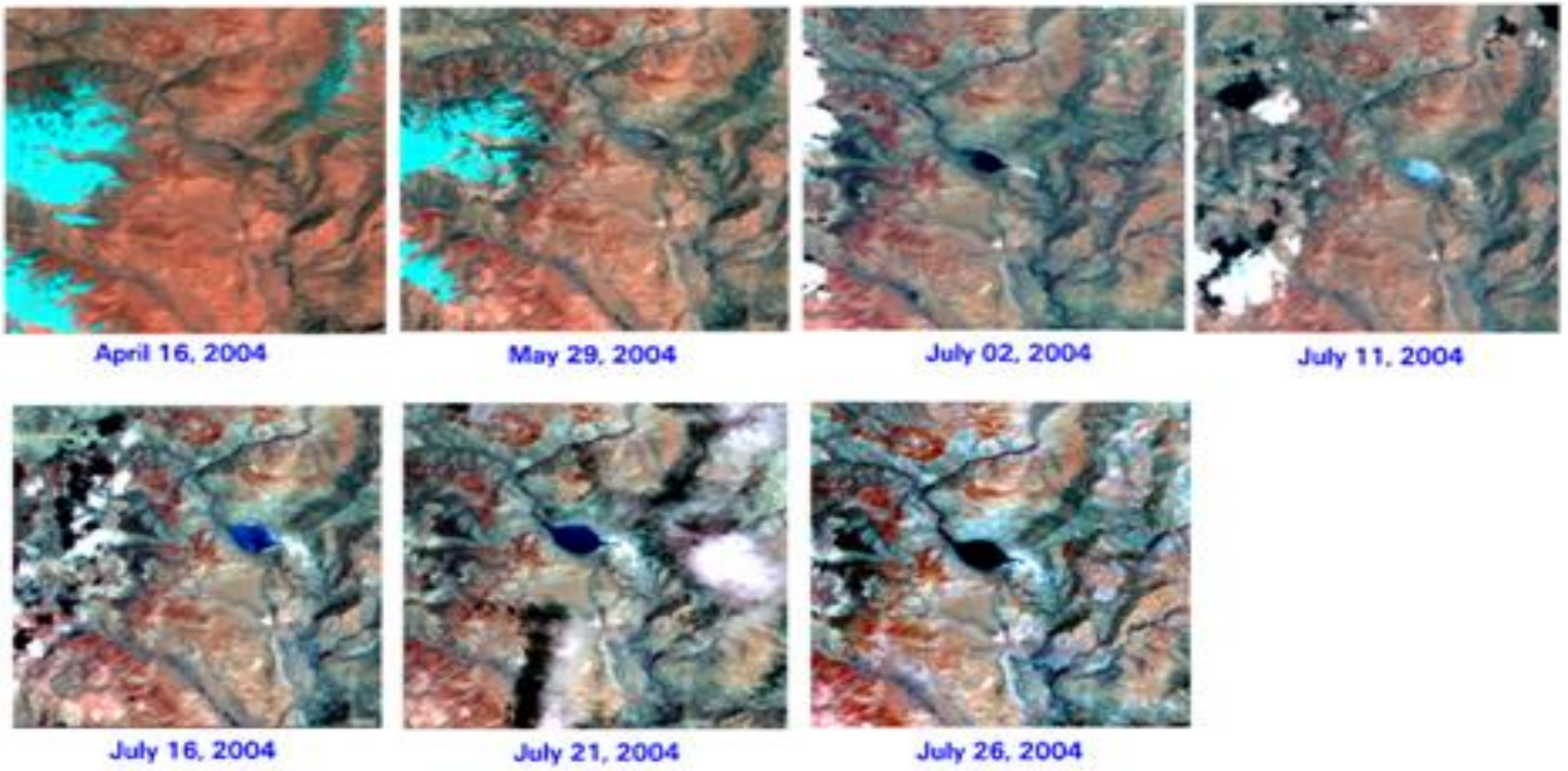
Snow pixel from each scene in Resourcesat-2 AWiFS sensor data is extracted and mosaicked for generation of snow cover information over Himalayan region at fortnight interval.

Primary Applications: Glacier studies; Energy and water balance; cryosphere; climate change.

Snow cover Fraction (%) - 3' X 3' Grid)



Evolution of Parechhu Lake in 2004 in Tibet Himalayan Region



Temporal Variations of the Lake extent using AWiFS

Source: SAC, Ahmedabad

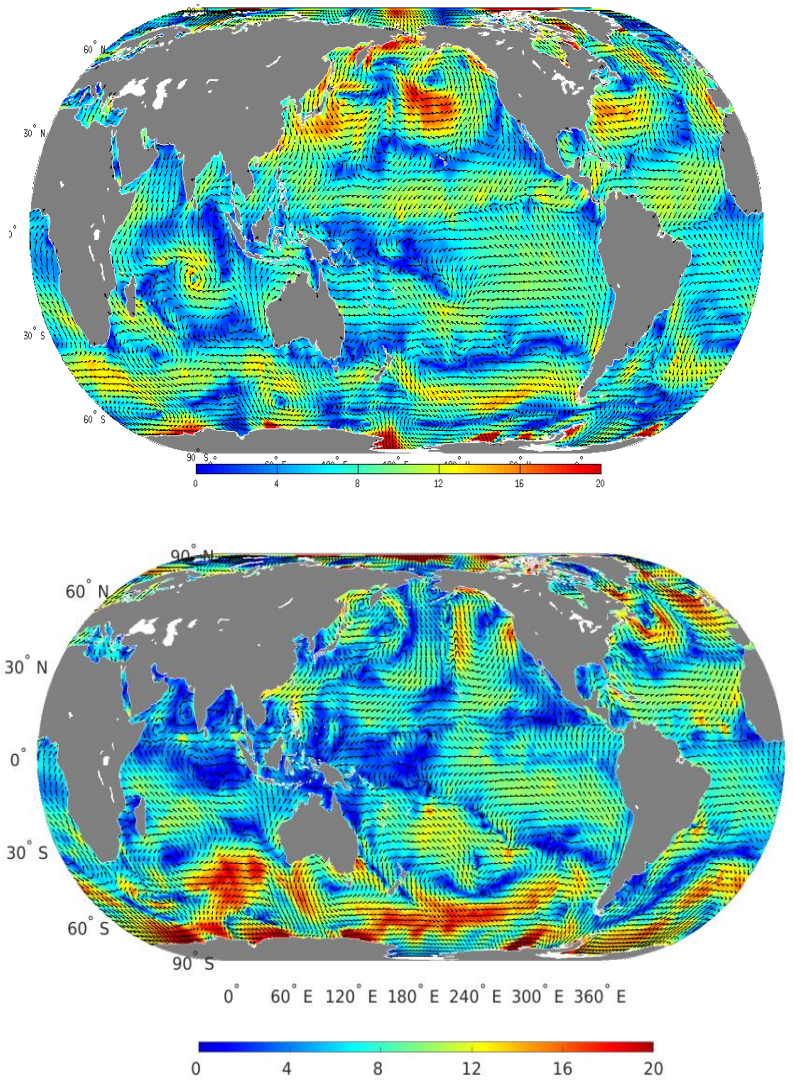
Space Applications – Ocean surface winds

Wind Velocity (m/sec) from OSCAT
2-day composite for Jan 06-07, 2010 & Oct 24-25, 2020

Ocean Surface winds drive the exchange of heat and momentum between the Ocean-Atmosphere, produce ocean waves and provide a key forcing of the ocean circulation responsible for the global transport of carbon. It is one of the main input for the operational oceanography as well as climate studies.

Global gridded wind fields at daily from two-day composite are generated using ascending and descending pass data from Oceansat scatterometer (OSCAT and SCATSAT) and variational analysis.

Primary Applications: Air-sea fluxes; Forecasting cyclones; Ocean currents; nutrient rich upwelling areas; Renewable wind energy; modelling studies; etc.



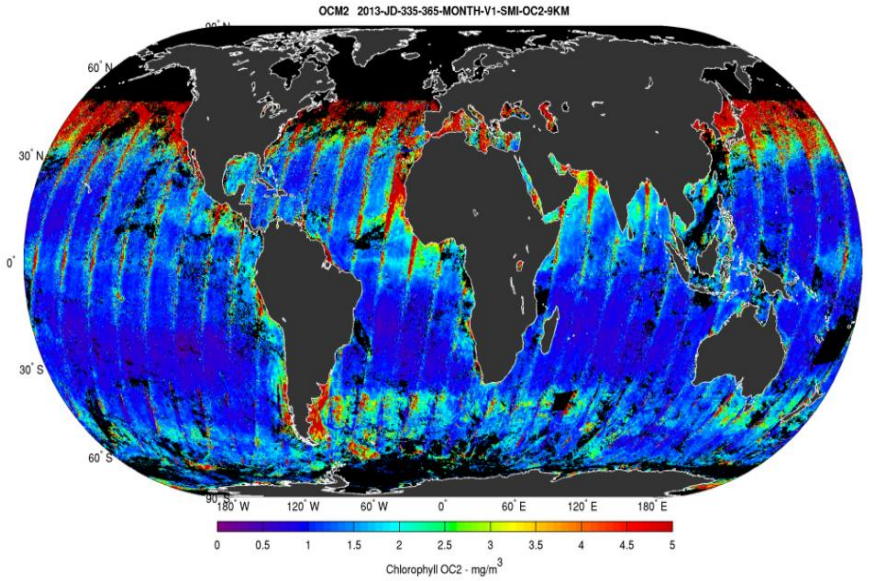
Space Applications – Ocean colour

Monitoring changes in Chl-a is important as they form the foundation of the marine food web, crucial in the carbon cycle and in regulating the biogeochemical processes such as export of carbon to the deep ocean.

Several algorithms and quasi-analytical methods are used to deduce Chl-a from the satellite measured reflectance measurements after taking account of the optically significant constituents in the atmosphere (which can include substantial error). This product Ocean Colour, Chl-a is generated globally using the data from Indian Oceansat (OCM sensor) series satellites and the associated relevant products are being disseminated through NICES web portal.

Primary Applications: Potential fishing zone, Blue economy; Climate variability and change; Carbon cycle; etc.

OCM-2 Chlorophyll (OC2 & OC4) algorithms and products have been generated using SeaDAS (SeaWiFS Data Analysis System) for Global Oceans(GAC

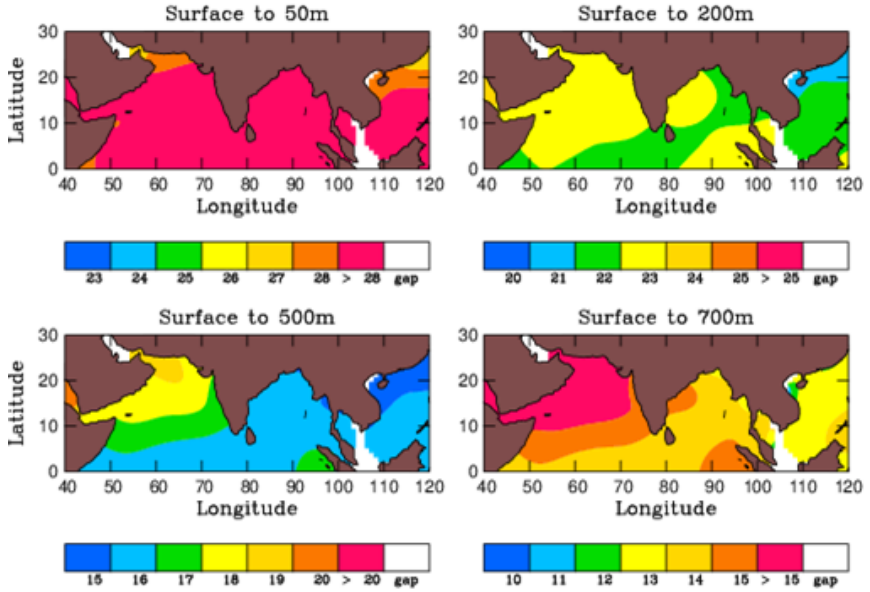


Space Applications – OHC & OMT

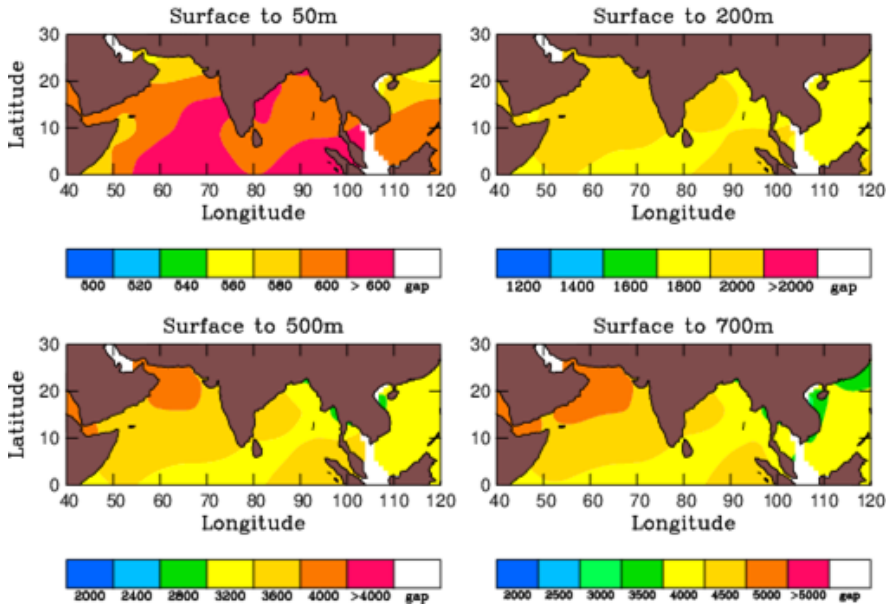
Ocean heat content (OHC) and Ocean Mean Temperature (OMT) are important climatic parameters required to investigate climate dynamics and thermodynamics of the interior ocean.

These parameters are estimated on a daily basis from 1998 to present with a delay of 3 days using artificial neural network techniques and satellite observations of sea surface height anomaly (SSHA), sea surface temperature (SST) from Tropical Rainfall Measuring Mission Microwave Imager. The values of OHC and OMT at various depths (50, 100, 150, 200, 300, 500, 700m) and TCHP as an integral of OHC from surface to 26°C isotherm and it's mean temperature are estimated.

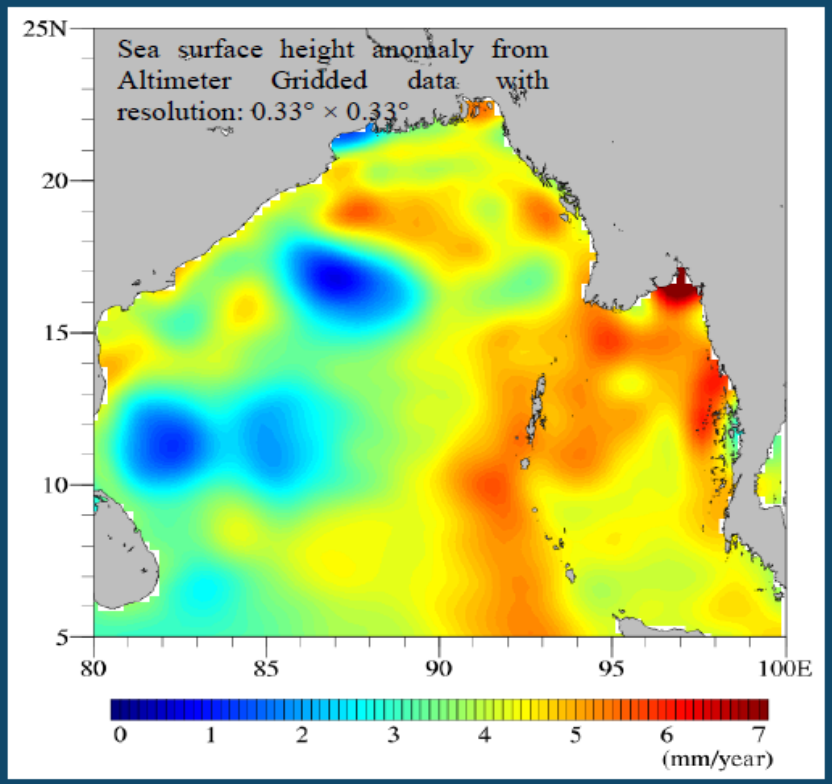
Ocean mean temperature (°C) on 25.5.2022



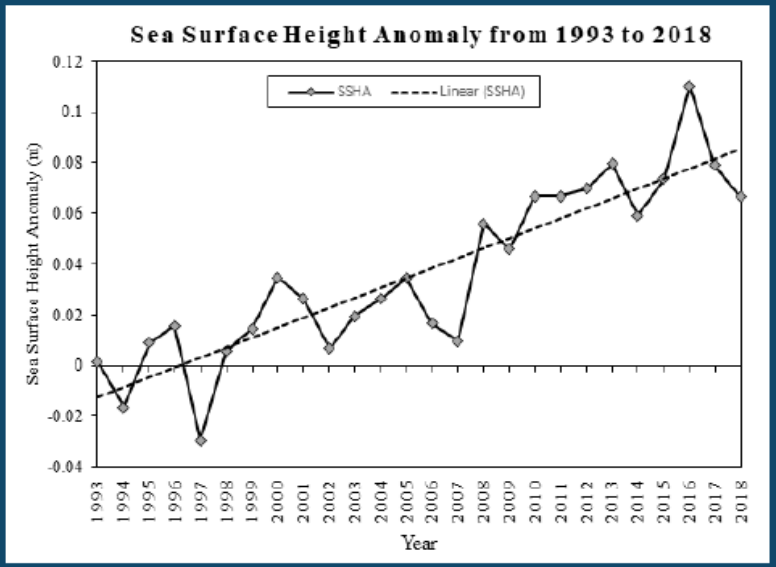
Ocean heat Content (kJ/cm²) on 25.5.2022



Spatial distribution of the Sea Surface Height Anomaly trend during 1993-2018 from the altimeter data over the Bay of Bengal



The entire bay of Bengal (BoB) is exhibiting an increasing trend of Sea Surface Height Anomaly (SSHA) during the period from 1993-2018. The trend in sea level rise over the northern and eastern BoB is found to be predominant with a value of about 6-7 mm/year estimated from the altimeter data.



Time series of SSHA and its linear trend averaged over the BoB (1993-2018)

The sea level increases by almost 12 cm from 1993 to 2018. It can be observed that the sea level falls suddenly in the years 1994, 1997, 2002 and 2007. This can be attributed to the occurrence of positive Indian Ocean Dipole (IOD) as the positive IOD leads to the lower sea surface height in the BoB.

Source: RP Singh, IIRS, Dehradun

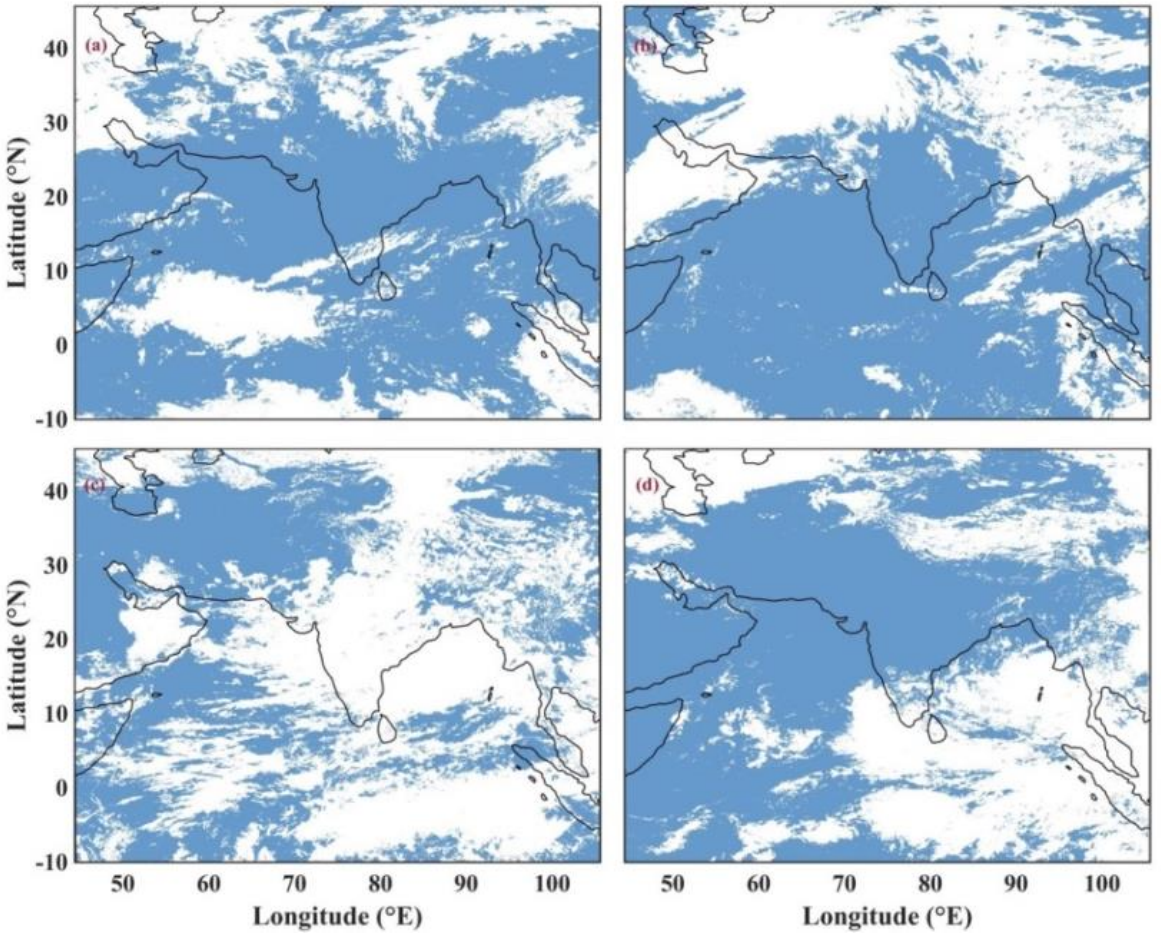
Space Applications – Clouds

Clouds play a vital role in determining and governing weather and climate through their contribution to the Earth's water cycle and impact on the Earth's energy budget. Further, they influence the motion of the atmosphere on many scales and modify the atmospheric composition. Clouds (together with aerosols) contribute the largest uncertainty to the estimates of the Earth´s energy budget, as well as to the potential feedback mechanisms and responses to climate change.

Cloud Properties are being retrieved using Indian geostationary satellites (KALPANA-1, INSAT-3D). Cloud Amount/Fraction is derived from the cloud mask product generated using the channel from Very High Resolution Radiometer (VHRR) on-board Indian Geo-Stationary Satellite KALPANA-1.

Primary Applications: Cloud mask in subsequent algorithms; Radiative Forcing and Climate change studies; solar renewable energy estimation; etc.

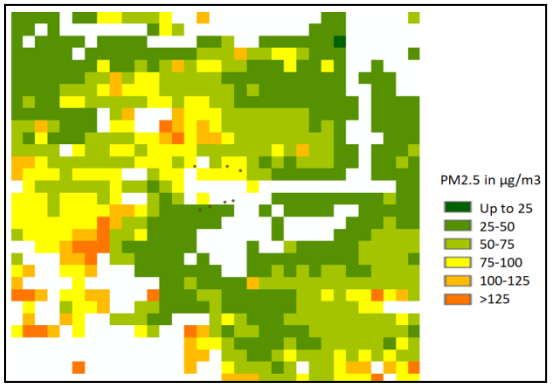
INSAT-3D retrieved cloud mask at 07:30 UTC on (a) Jan 1 (winter season), (b) April 1 (pre-monsoon season), (c) Aug 1 (monsoon season) and (d) Nov 1 (post-monsoon season) of the year 2016.



Space Applications – Air quality

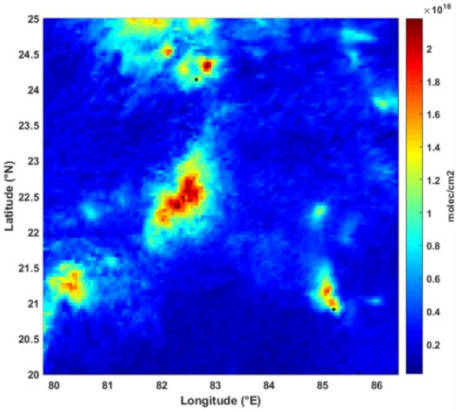
Satellite based PM2.5 monitoring at Singrauli area

True colour of Singrauli Area

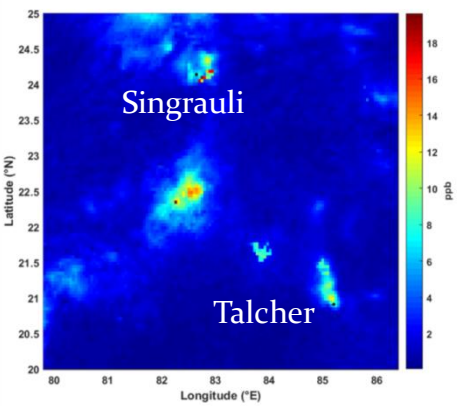


MODIS based Particulate Matter (PM2.5)

Monitoring of Satellite based surface level NO2 Concentration at Singrauli, Korba & Talcher area



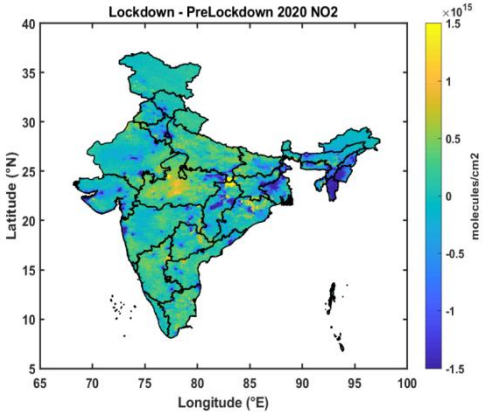
Tropospheric NO_2 (molec/cm2) from TROPOMI

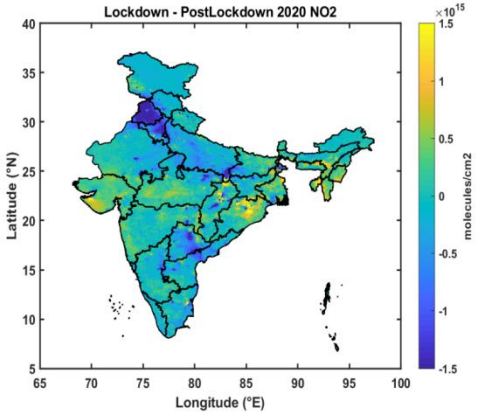


TROPOMI based Surface leve derived NO_2 (ppb)

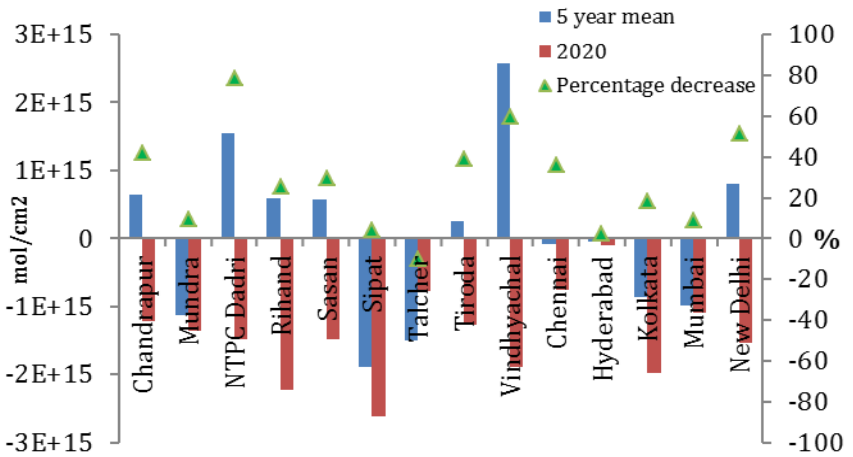
Impact of Lockdown on pollutants using satellites

- Data: TROPOMI/Sentinel-5P & OMI/Aura
- Period: 2015-2019 and 2020
  - Pre-Total Lockdown period: Mar 01 – Mar 20
  - Total Lockdown period (TLD): Mar 25 – May 03
  - Post Total Lockdown period: May 04 – May 31





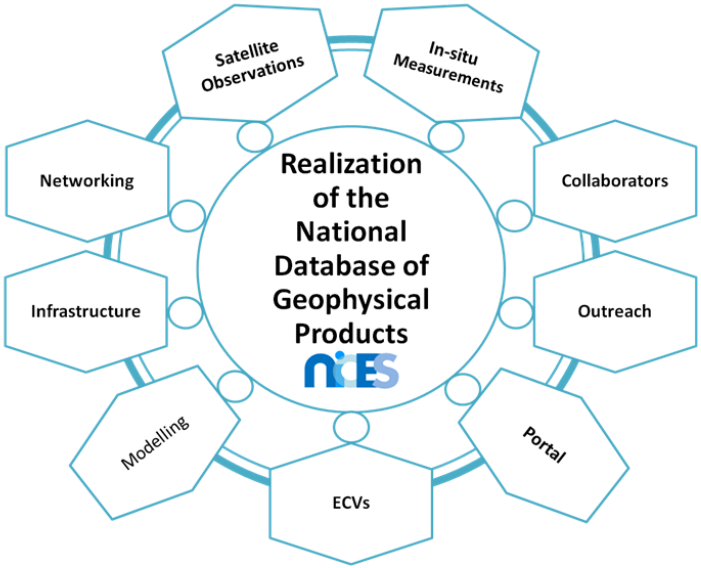
Difference of NO_2 concentration during and pre-lockdown period in 2020 and previous 5 years mean difference during the same period

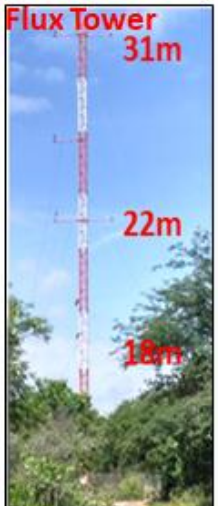


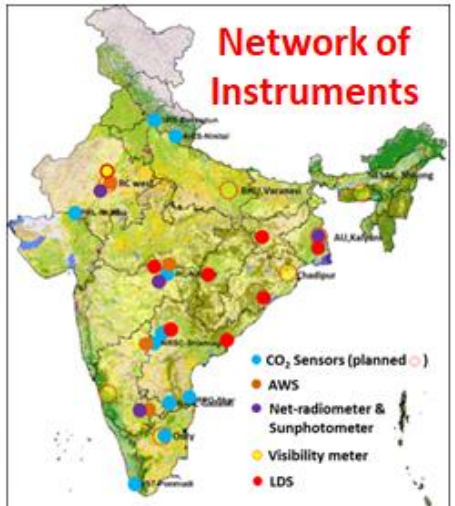
- All metropolitan cities and thermal stations show significant net percentage decrease of NO2 in 2020 wrt previous 5 years.

National Information System for Climate and Environment Studies

- Established in **September 2012**, for Realization of nation level database of long term, consistent climate quality **geo/bio-physical products** pertaining to Terrestrial, Ocean, Atmosphere and Cryosphere for climate change studies
- **Multi-institutional endeavour** (ISRO & other Scientific Organisations/Ministries)
- **Observational network** for **calibration & validation**
- Use of **Essential Climate Variables (ECVs)** for **impact assessment, adaptation, vulnerability, mitigation,** etc.
- **Infrastructure, web-enabled services** and **product dissemination – NICES** under ISRO's geo-portal '**Bhuvan**'







NICES portal

- NICES ECVs and geophysical data products are available through the online portal Bhuvan.
- The portal is operational since October 2013 and hosts more than 70 products.
- https://bhuvan-app3.nrsc.gov.in/data/download/index.php?c=p&s=NI&g=all

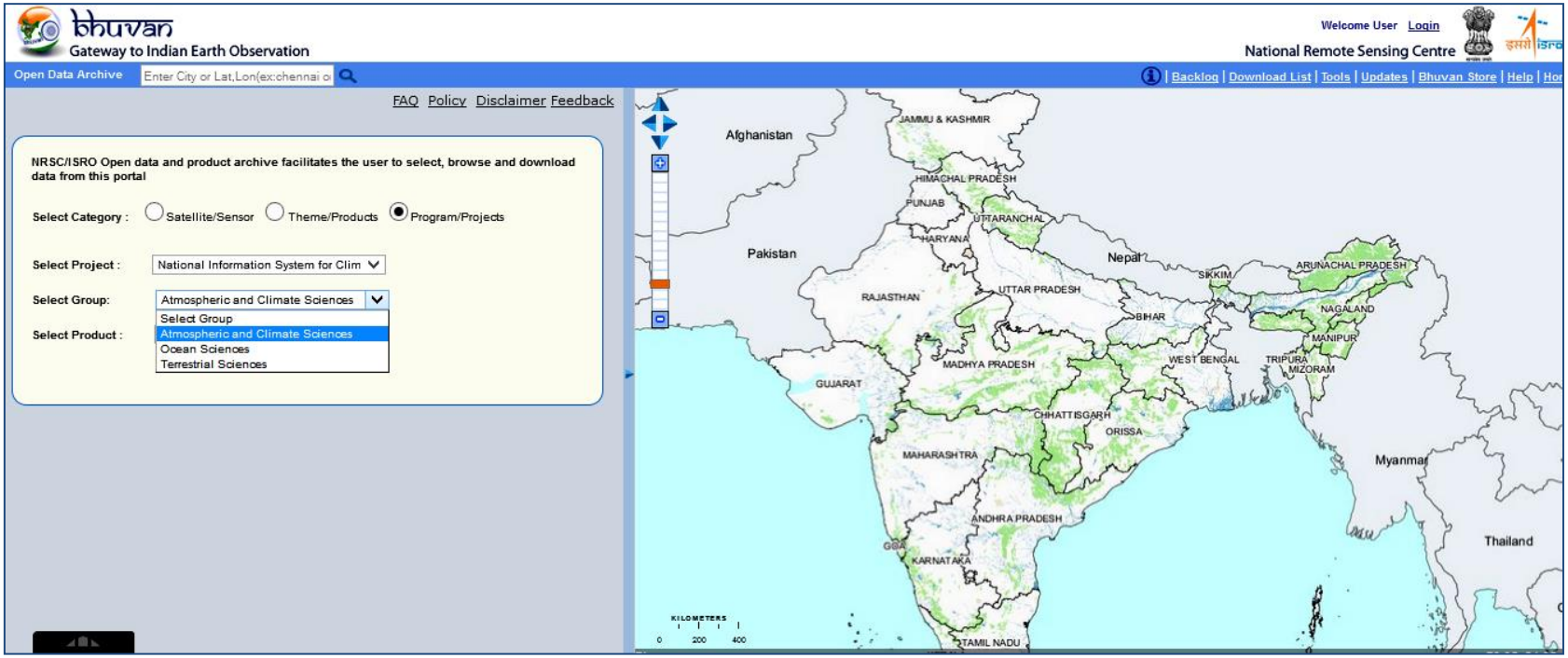
Terrestrial Products

Ocean Products

Atmospheric Products

Model Derived Products

Cryosphere Products



Available through NICES portal

Terrestrial (35)

Geophysical: Albedo, Normalised Difference Vegetation Index (4)

Hydrology: Surface water body, Soil moisture, Evapotranspiration, Runoff (4)

Land cover: Mesoscale Model-5, Weather Research Forecast (WRF) compatible, Veg Fraction (3)

Terrain and Soil: Organic Carbon, Inorganic Carbon, f-soil depth, f-soil texture, f-water erosion, f-wind erosion, f-salt affected, Soil moisture (8)

Vegetation and Ecosystem: Average annual forest fire density, SD of Ave Annual Forest Fire Density (AFFD), length of fire, fraction of forest, forest types, Net Sown Area (Total, Kharif, Rabi), f-Fallow Area, Net Ecosystem Productivity & Primary Productivity (11)

Cryosphere (5): Snow melt and freeze (Indian Himalaya & Antarctica) (2), Snow cover fraction (1), Himalayan glacial lakes and water bodies (1), snow albedo (1)

Ocean (29)

Ocean Heat Content satellite & model derived (2), Tropical Cyclone Heat Potential (2), Ocean Mean Temp (1) = 5

Ocean surface winds (2), Wind stress (2), Wind curl, Ekman currents, geostrophic current, Sea Surface Height Anamoly, ocean surface current, Eddy Kinetic Energy, Monthly mean sea level anomaly (7) = 11

Co-tidal map (2) = 2

Model derived: Sea level pressure (1) = 1

Ocean color: Chlorophyll concn (4), Water transparancy (2), Total Alkalinity, Dissolved Inorganic Carbon, pCO_2 (4) = 10

Atmosphere (6)

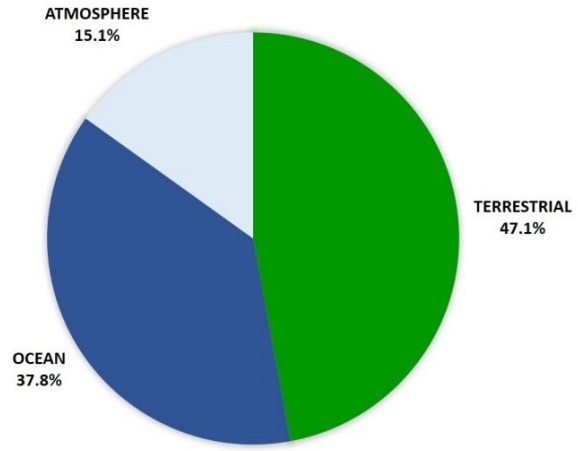
Derived tropospheric Ozone (1), Boundary layer height (1), Cloud fraction (2) & cloud top temperature (2), Lightning (1) = 6

Geophysical products for climate parameters

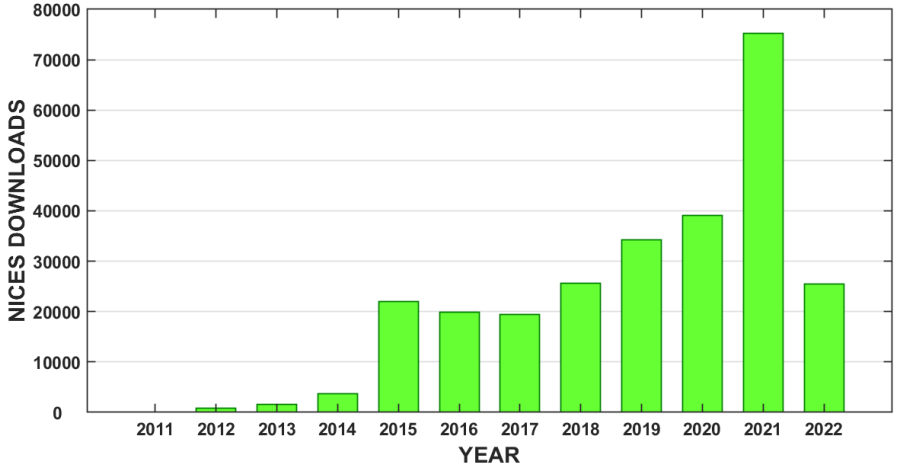
Domain	ECV	Near future	Non-ECV products retrieved	Derived	Satellite + Model based products	Total
Terrestrial	5	1	16	8	5	35
Ocean	3	2	5	11	8	29
Atmosphere	2(+1)	1	0	2	0	6
	10(+1)	4	21	21	13	70

Time span (products)	NICES Geophysical products
20 - 30 years (4)	Ocean Heat Content, Ocean Mean Temperature, Tropical Cyclone Heat Potential, Eddy Kinetic Energy
15 - 20 years (4)	Surface Soil Moisture, Forest Fire, Snow Melt and Freeze, Mean Sea Level Anomaly
10 - 15 years (7)	Chlorophyll, Kd_490, LULC, Land degradation, Tropospheric Ozone, Net sown area (Agriculture), Cloud Cover and Cloud Fraction
5 - 10 years (15)	Albedo, NDVI, Vegetation Fraction, Surface Water Body Fraction, Snow Cover Fraction, Himalaya Glaciers, Snow Albedo, Model-TCHP, Model-D26, Ocean Surface Currents, Total Alkalinity, Dissolved Inorganic Carbon, Planetary Boundary layer Height, Ocean Surface Winds, Wind Stress, Wind Curl, Sea Level Pressure.

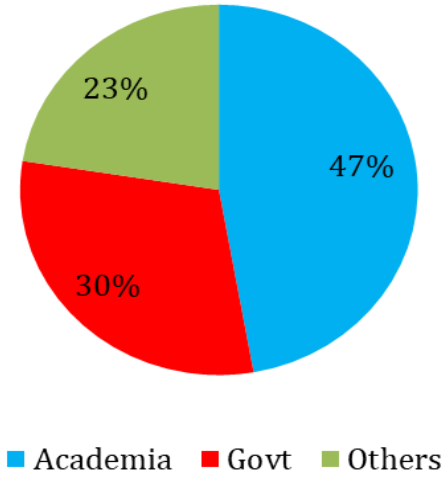
उत्पाद डाउनलोड का प्रकार Type of product downloads



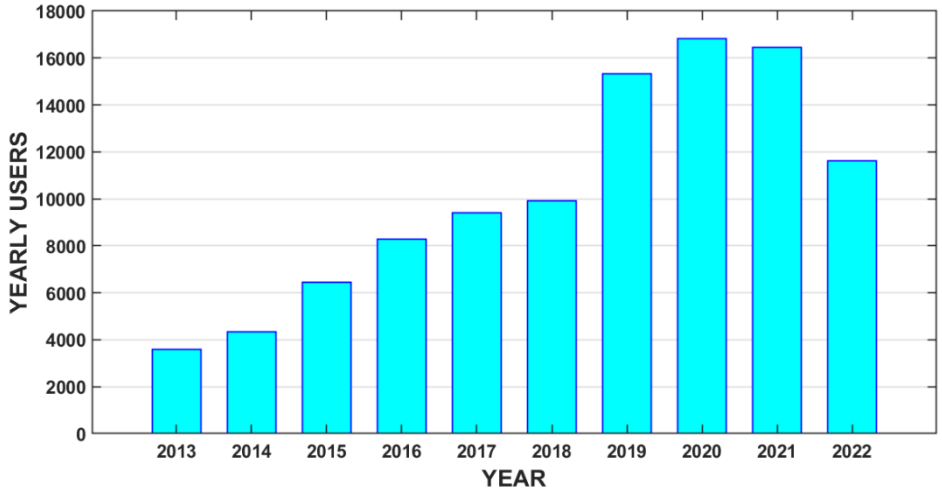
कुल डाउनलोड Total downloads



उपयोगकर्ताओं का प्रकार Type of Users

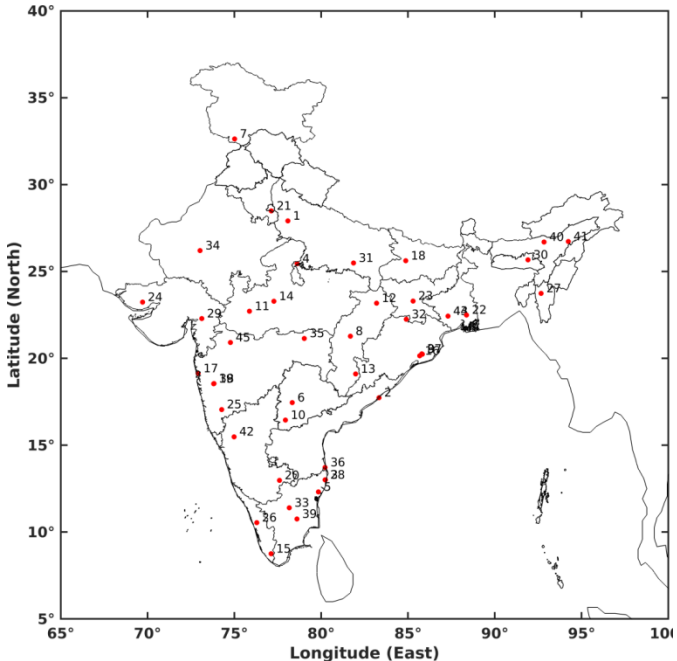


अनूठे उपयोगकर्ता Unique users



Collaboration with others

1	Aligarh Muslim University, Aligarh, UP
2	Andhra University
3	Anna University
4	Bundelkhand University, Jhansi
5	CAS Annamalai University
6	Central University of Hyderabad
7	Central University, Jammu
8	CGCOST, Raipur
9	Chilka Development Authority, Bhubaneshwar
10	College of Horticulture, Morjalla, TG
11	DAVV, Indore
12	Govt Eng. College, Ambikapur
13	Govt. Eng. College, Jagdalpur
14	IISER, Bhopal
15	IIST, Ponmudi
16	IIT, Bhubaneswar
17	IIT, Bombay
18	IIT, Patna
19	IITM, Pune
20	Indian Institute of Science
21	India Meteorological Department, Delhi
22	Jadhavpur University
23	JSAC, Ranchi
24	Kathada Gram Panchayat, Bhu
25	KBPH College, Islampur, Sangli
26	Kerala Agriculture Univeristy, Thrissur
27	Mizoram Central University, Aizawal
28	MGR University, Chennai
29	Navrachana University, Vadodara
30	NESAC, Shillong
31	NIT, Allahabad
32	NIT, Rourkela
33	Paavai Engineering College, Pachal, Tamilnadu
34	RRSC Jodhpur
35	RRSC Nagpur
36	SDSC, Shar
37	SOA University, Bhubaneswar
38	SP, Pune University
39	Tamilnadu Agriculture University, Trichi
40	Tezpur University, Assam
41	TRI, Jorhat, Assam
42	University of Agricultural Sciences, Dharwad
43	Vidyasagar University, Medinapur
44	ZBP College, Dhule

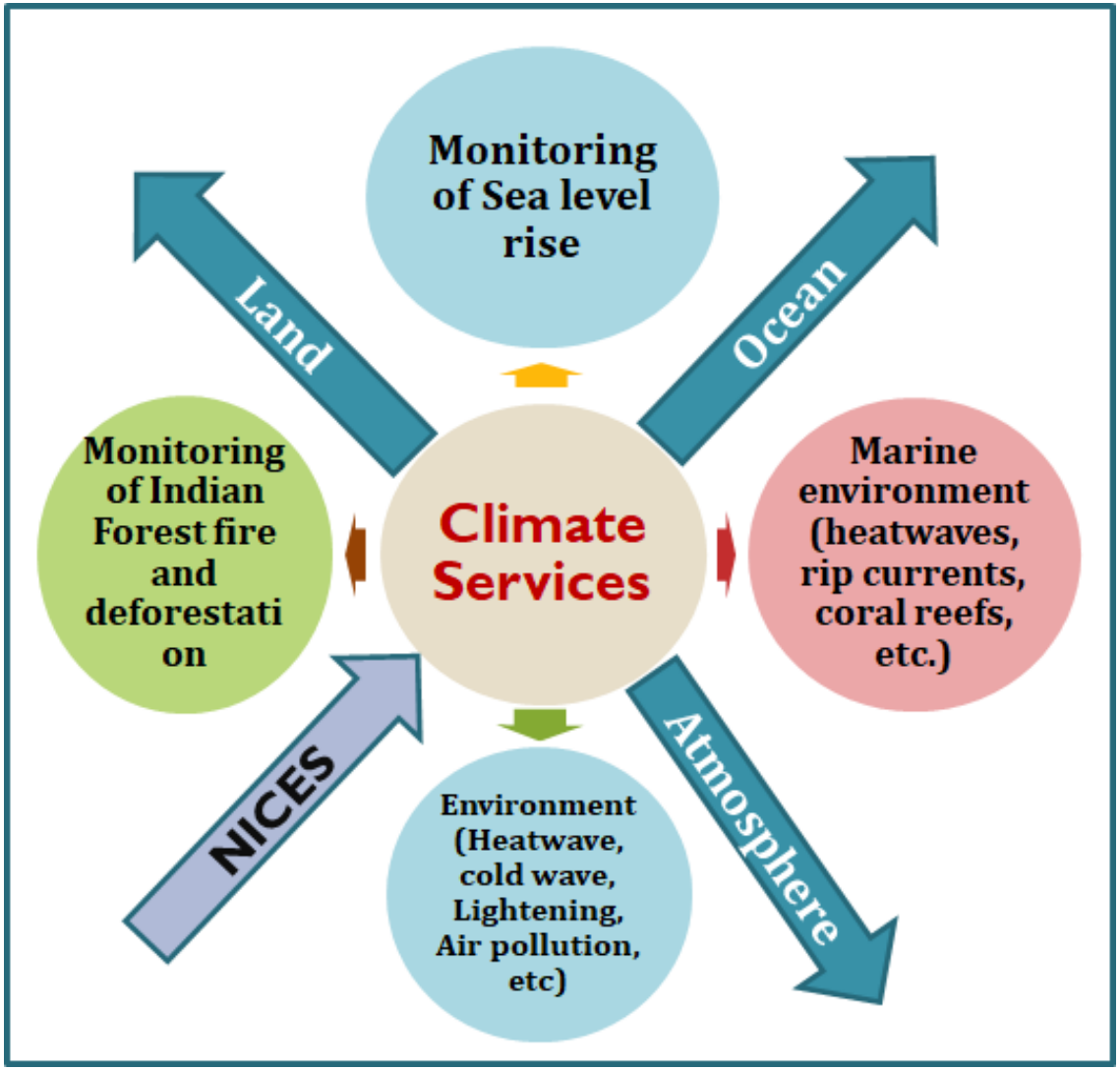


Way forward in climate applications

Climate services are critical for making decisions in climate-sensitive societal areas

- Soil moisture at high resolution
- Air quality
- Solar radiation
- Wind energy
- Hot weather outlook

- Fog & smog
- Water quality
- High resolution Snow cover
- Snow melt & freeze



Mapping indicators, monitoring agents of change and modeling the impact of climate change

Programme Director (NICES)
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For NICES data
https://bhuvan-app3.nrsc.gov.in/data/download/index.php?c=p&s=NI&g=all