CHALLENGES OF CHANGING WEATHER AND CLIMATE VARIABILITY:PERSPECTIVE PLAN OF SERVICES DELIVERY

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भारत मौसम विज्ञान विभाग
INDIA METEOROLOGICAL DEPARTMENT

Meteorology in the Ancient Times

3000 BC – Meteorology in India can be traced back to around 3000 BC, with writings such as the Upanishadas, containing discussions about the processes of cloud formation and rain and the seasonal cycles caused by the movement of earth round the sun

250 BC – Archimedes studies the concepts of buoyancy and the hydrostatic principle. Positive buoyancy is necessary for the formation of convective clouds (cumulus, cumulus congestus and cumulonimbus)

500 AD – In around 500 AD, the Indian astronomer, mathematician, and astrologer: Varāhamihira published his work Brihat-Samhita's, which provides clear evidence that a deep knowledge of atmospheric processes existed in the Indian region

1494 – During his second voyage Christopher Columbus experiences a tropical cyclone in the Atlantic Ocean, which leads to the first written European account of a hurricane

1643 – Evangelista Torricelli invents the mercury barometer.

1648 – Blaise Pascal rediscovers that atmospheric pressure decreases with height, and deduces that there is a vacuum above the atmosphere

1654 – Ferdinando II de Medici sponsors the first weather observing network, that consisted of meteorological stations in Florence, Cutigliano, Vallombrosa, Bologna, Parma, Milan, Innsbruck, Osnabrück, Paris and Warsaw. Collected data was centrally sent to Accademia del Cimento in Florence at regular time intervals.

1662 – Sir Christopher Wren invented the mechanical, self-emptying, tipping bucket rain gauge.

1667 – Robert Hooke builds another type of anemometer, called a pressure-plate anemometer.

1686 – Edmund Halley presents a systematic study of the trade winds and monsoons and identifies solar heating as the cause of atmospheric motions.Edmund Halley establishes the relationship between barometric pressure and height above sea level

Meteorology in the Ancient Times

- 1724 – Gabriel Fahrenheit creates reliable scale for measuring temperature with a mercury-type thermometer.
- 1735 – The first ideal explanation of global circulation was the study of the Trade winds by George Hadley.
- 1738 – Daniel Bernoulli publishes Hydrodynamics, initiating the kinetic theory of gases. He gave a poorly detailed equation of state, but also the basic laws for the theory of gases.
- 1742 – Anders Celsius, a Swedish astronomer, proposed the Celsius temperature scale which led to the current Celsius scale
- 1846 – Cup anemometer invented by Dr. John Thomas Romney Robinson
- 1847 – Hermann von Helmholtz publishes a definitive statement of the conservation of energy, the first law of thermodynamics
- 1849 – Smithsonian Institution begins to establish an observation network across the United States, with 150 observers via telegraph, under the leadership of Joseph Henry. William John Macquorn Rankine calculates the correct relationship between saturated vapour pressure and temperature using his hypothesis of molecular vortices.
- 1850 – Rankine uses his vortex theory to establish accurate relationships between the temperature, pressure, and density of gases, and expressions for the latent heat of evaporation of a liquid; he accurately predicts the surprising fact that the apparent specific heat of saturated steam will be negative. Rudolf Clausius gives the first clear joint statement of the first and second law of thermodynamics, abandoning the caloric theory, but preserving Carnot's principle.
- 1852 – Joule and Thomson demonstrate that a rapidly expanding gas cools, later named the Joule-Thomson effect.
- 1853 – The first International Meteorological Conference was held in Brussels at the initiative of Matthew Fontaine Maury, U.S. Navy, recommending standard observing times, methods of observation and logging format for weather reports from ships at sea.
- 1854 – The French astronomer Leverrier showed that a storm in the Black Sea could be followed across Europe and would have been predictable if the telegraph had been used. A service of storm forecasts was established a year later by the Paris Observatory.– Rankine introduces his thermodynamic function, later identified as entropy.
- 1856 – William Ferrel publishes his essay on the winds and the currents of the oceans.
- 1859 – James Clerk Maxwell discovers the distribution law of molecular velocities.
- 1860 – Robert FitzRoy uses the new telegraph system to gather daily observations from across England and produces the first synoptic charts. He also coined the term "weather forecast" and his were the first ever daily weather forecasts to be published.

Meteorology in Ancient Times

- 1870 – The **US Weather Bureau** is founded.
- 1872 – The "Oficina Meteorológica Argentina" (today "Argentinean National Weather Service") is founded.
- 1872 – **Ludwig Boltzmann** states the **Boltzmann equation** for the temporal development of **distribution functions** in **phase space**, and publishes his **H-theorem**.
- 1873 – **International Meteorological Organization** formed in **Vienna**. United States Army Signal Corp, forerunner of the **National Weather Service**, issues its first hurricane warning
- 1875 – The **India Meteorological Department** is established, after a tropical cyclone struck Calcutta in 1864 and monsoon failures during 1866 and 1871.
- 1881 – Finnish Meteorological Central Office was formed from part of Magnetic Observatory of **Helsinki University**.
- 1890 – US **Weather Bureau** is created as a civilian operation under the **U.S. Department of Agriculture**.
- 1892 – **William Henry Dines** invented another kind of **anemometer**, called the **pressure-tube (Dines) anemometer**. His device measured the difference in pressure arising from wind blowing in a tube versus that blowing across the tube. The first mention of the term "**El Niño**" to refer to climate occurs when Captain Camilo Carrilo told the Geographical society congress in **Lima** that Peruvian sailors named the warm northerly current "El Niño" because it was most noticeable around **Christmas**.
- 1896 – **IMO** publishes the first **International cloud atlas**.[55] **Svante Arrhenius** proposes **carbon dioxide** as a key factor to explain the **ice ages**.
- 1898 – US Weather Bureau established a **hurricane** warning network at Kingston, Jamaica

History of Meteorology in India

- In 1686, Edmond Halley published his treatise on the Indian summer monsoon, which he attributed to a seasonal reversal of winds due to the differential heating of the Asian land mass and the Indian Ocean.
- The first meteorological observatory was established in India by the British East India Company. These included the Calcutta Observatory in 1785, the Madras Observatory in 1796 and the Colaba Observatory in 1826. Several other observatories were established in India during the first half of the 19th century by various provincial governments.
- The Asiatic Society, founded in Calcutta in 1784 and in Bombay in 1804, promoted the study of meteorology in India.
- Henry Piddington published almost 40 papers dealing with tropical storms from Calcutta between 1835 and 1855 in The Journal of the Asiatic Society. He also coined the term cyclone, meaning the coil of a snake.
- After a tropical cyclone hit Calcutta in 1864, and the subsequent famines in 1866 and 1871 due to the failure of the monsoons, it was decided to organise the collection and analysis of meteorological observations under one roof. As a result, the India Meteorology Department was established in 1875. The agency has gained in prominence due to the significance of the monsoon rains on Indian agriculture since the times of Sir Gilbert Walker from 1904. Since then, IMD has been playing a vital role in preparing the annual monsoon forecast, as well as in tracking the progress of the monsoon across India every season.
- Henry Francis Blanford was appointed the first Meteorological Reporter of the IMD. In May 1889, Sir John Eliot was appointed the first Director General of Observatories in the erstwhile capital, Calcutta. The IMD headquarters were later shifted to Shimla in 1905, then to Pune in 1928 and finally to New Delhi in 1944.
- IMD became a member of the World Meteorological Organization after independence on 27 April 1949.

Department of Meteorology & Oceanography- Andhra University

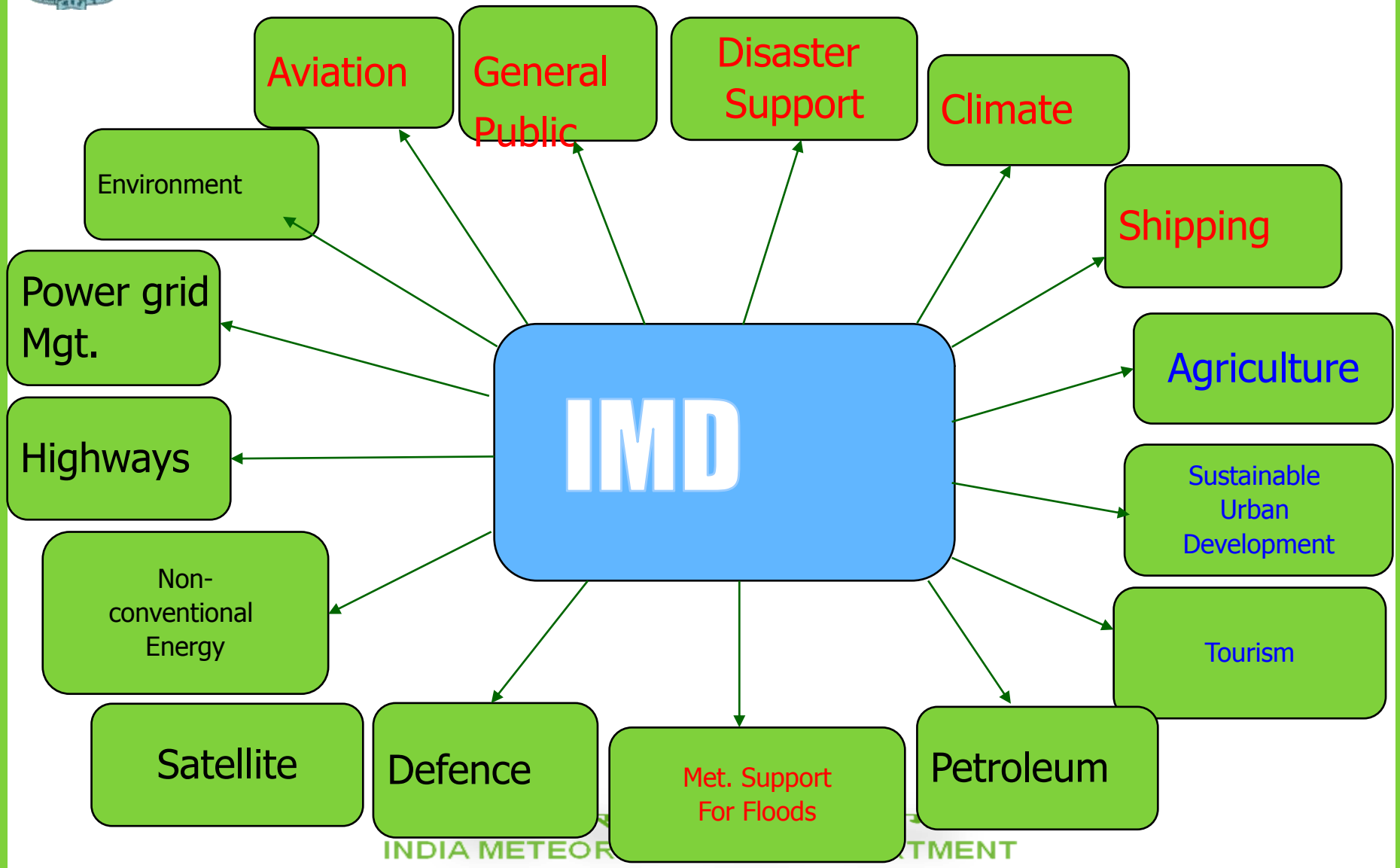
- Established in the year 1948 to educate the students in Oceanic and Atmospheric sciences through a special resolution passed by Madras Residency under British India.
- The systematic scientific studies of tropical systems in the Bay of Bengal and Arabian Sea, was started during the 19th century by Henry Piddington.
- Piddington utilised meteorological logs of vessels that navigated the seas and published a series of memoirs, in the "Journal of the Asiatic Society of Bengal" between 1839 and 1858.
- These memoirs gave accounts and tracks of individual storms in the Bay of Bengal and the Arabian Sea
- During the decade (1940-50), increased frequency of tropical cyclones over the Bay of Bengal was noticed.
- East coast of India was getting effected severely due to cyclones
- As per its tradition of always leading in offering contemporary academic courses, Andhra University started offering Masters Degree in Meteorology & Oceanography
- Courses were taught by Faculty from British initially and gradually Indian Faculty - Prof. R Ramanathan and Prof V P Subramanyam took the Department to the new heights.

Vision

To serve the nation as knowledge based service enterprise in the realm of weather and climate science for public safety and socio-economic benefits to the society.

Services

- Core Services
- Accelerated efforts to improve services
- Support Services



INDIA METEOR TMENT

MoES Agencies dealing with various Natural Hazards

HYDRO-METEOROLOGICAL HAZARDS –IMD

Monsoons, Support for Floods, Tropical Cyclones, Local Severe Storms, Rainfall Monitoring, Support for Snow Avalanches, Winter Systems

GEOLOGICAL HAZARDS

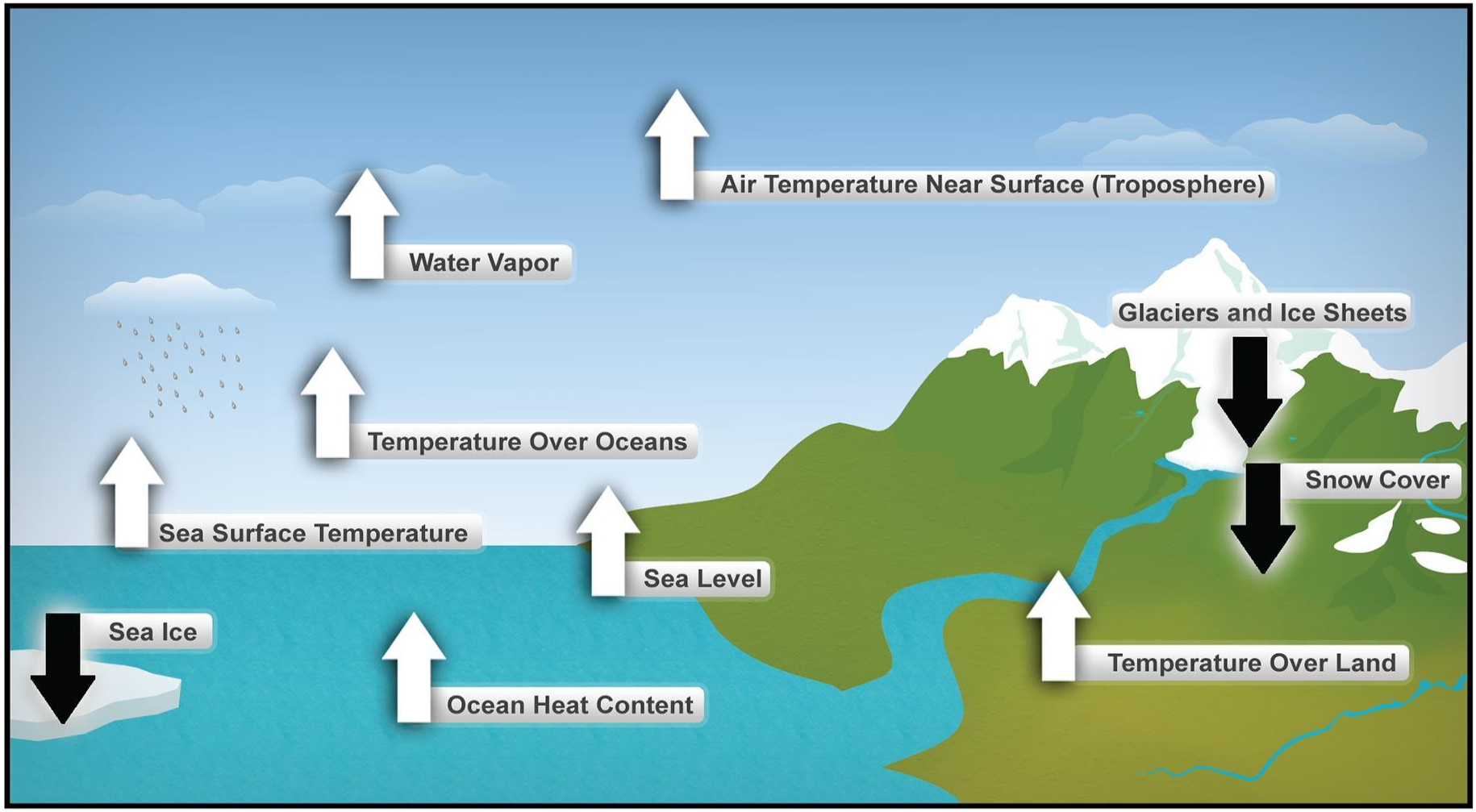
Earthquakes & Tsunamis (NCS and INCOIS)
Support for Rain Induced Landslides/Mudslides (IMD)

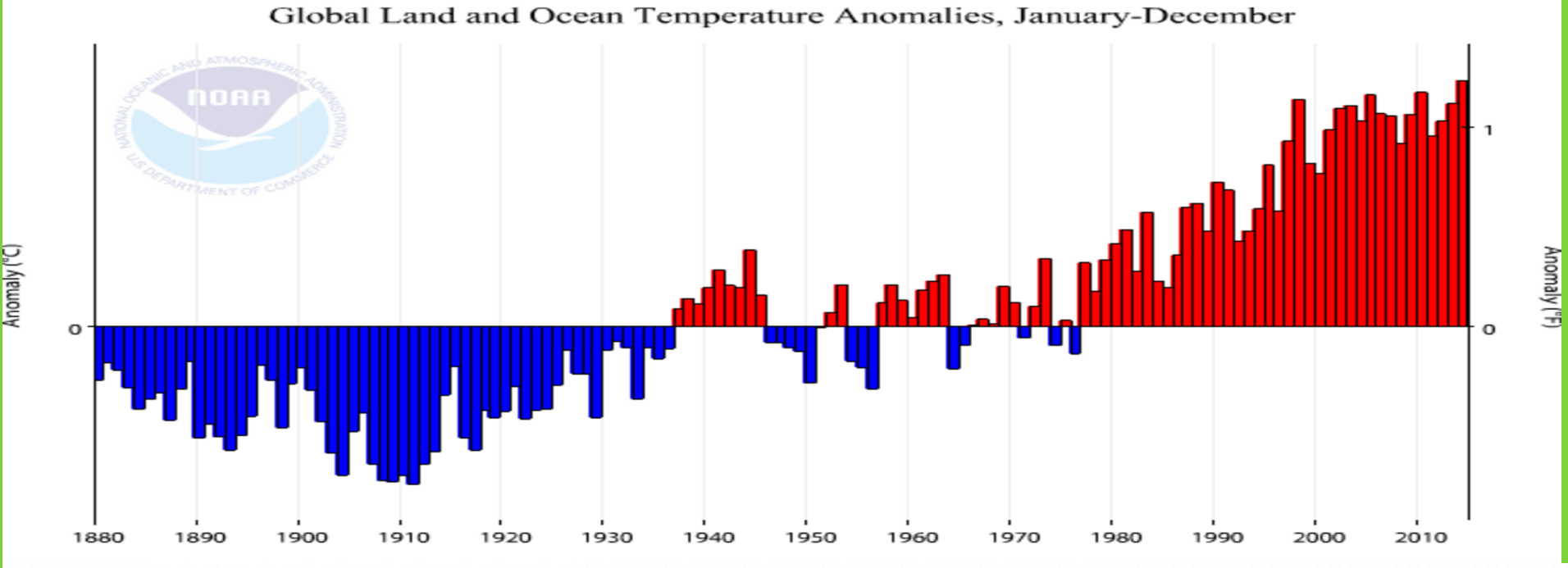
ENVIRONMENTAL IMPACTS

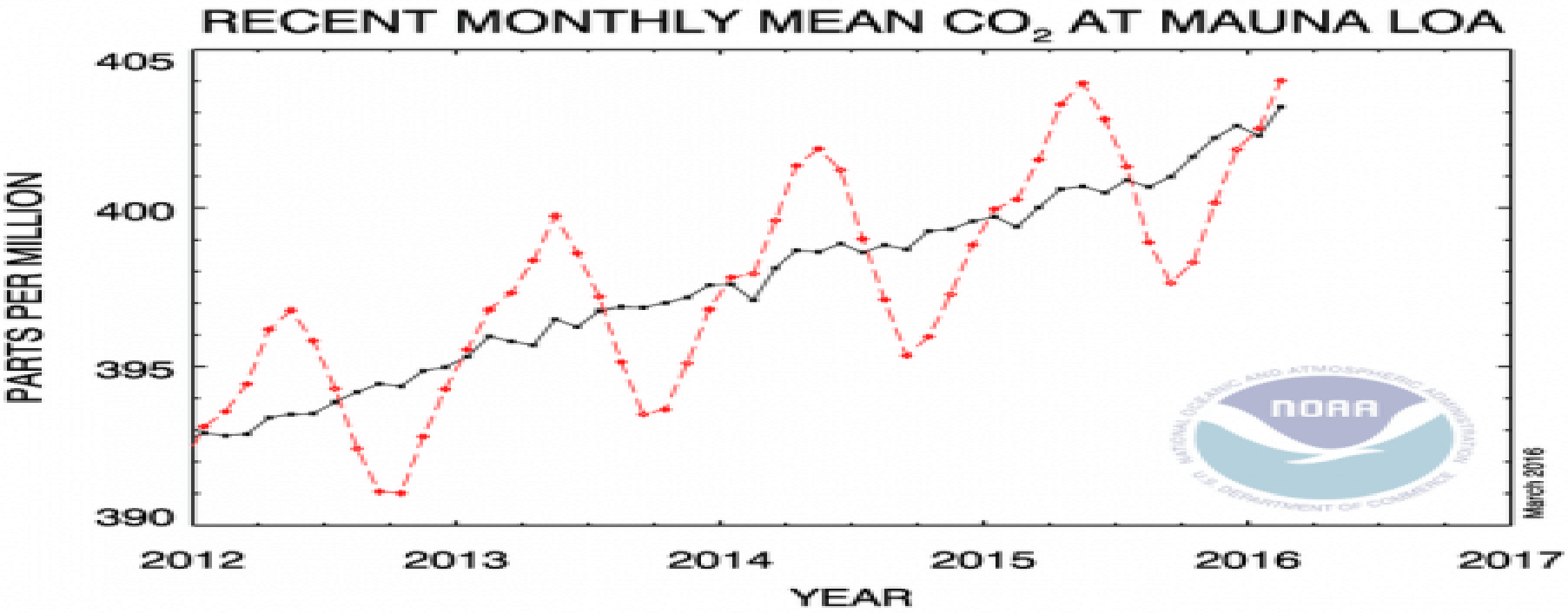
-Air Quality Forecast & Haze, FOG, Smog (IITM;IMD)
-Coastal Zone Management (ICMAM)
-Coastal Erosion & Shoreline Management (ICMAM; NIOT)
-Eco-system monitoring/ modeling (IITM and ICMAM)
-Climate change impacts on severe weather events (IITM)
-Climate Services (IMD)

Indicators measured globally over many decades that show that the Earth's Climate is Warming

Ten Indicators of a Warming World




Global Land and Ocean Temperature Anomalies, January-December
Anomaly (°C)
Anomaly (°F)
0
1
1880
1890
1900
1910
1920
1930
1940
1950
1960
1970
1980
1990
2000
2010


RECENT MONTHLY MEAN CO_2 AT MAUNA LOA
PARTS PER MILLION
405
400
395
390
2012
2013
2014
2015
2016
2017
YEAR
March 2016

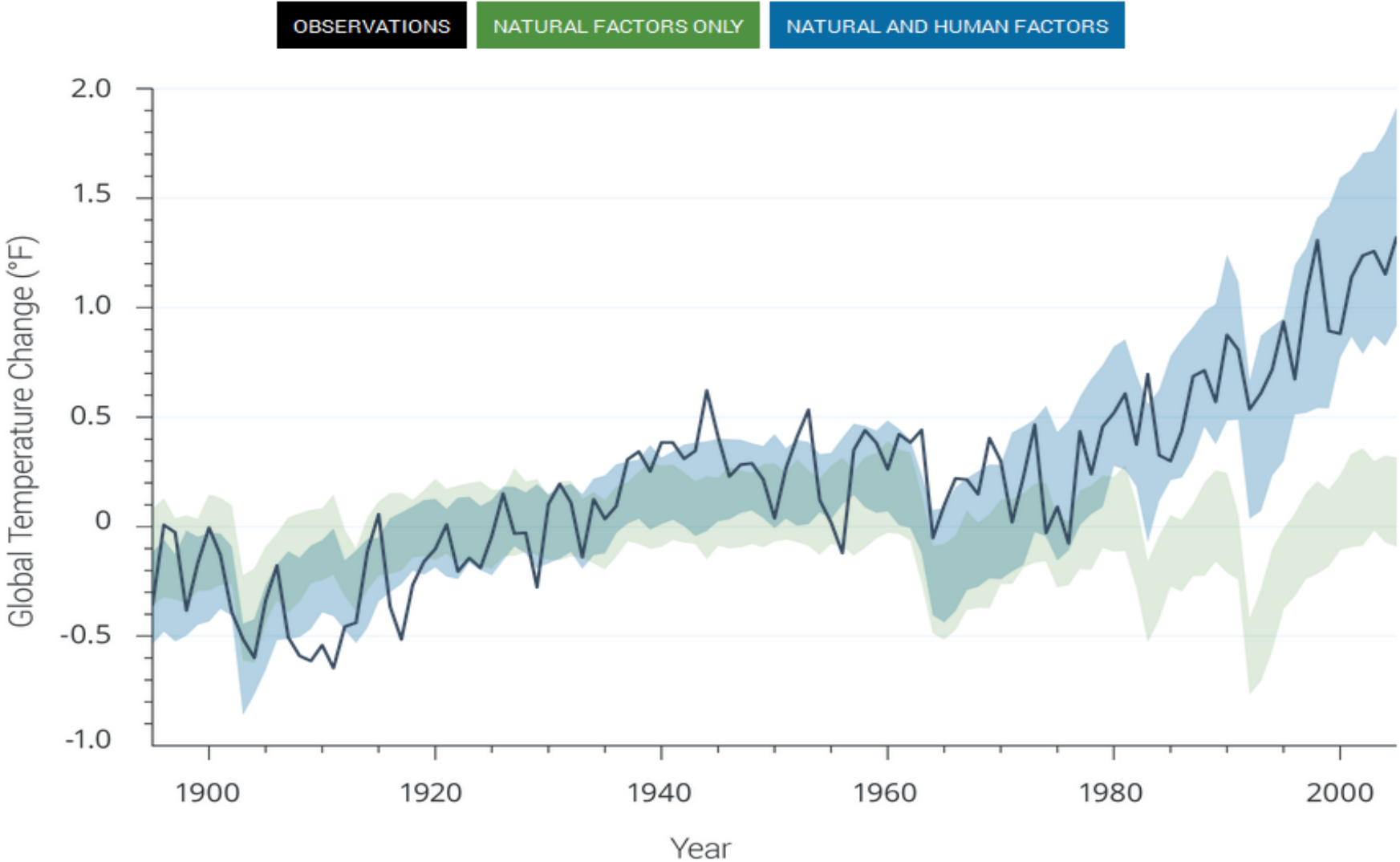
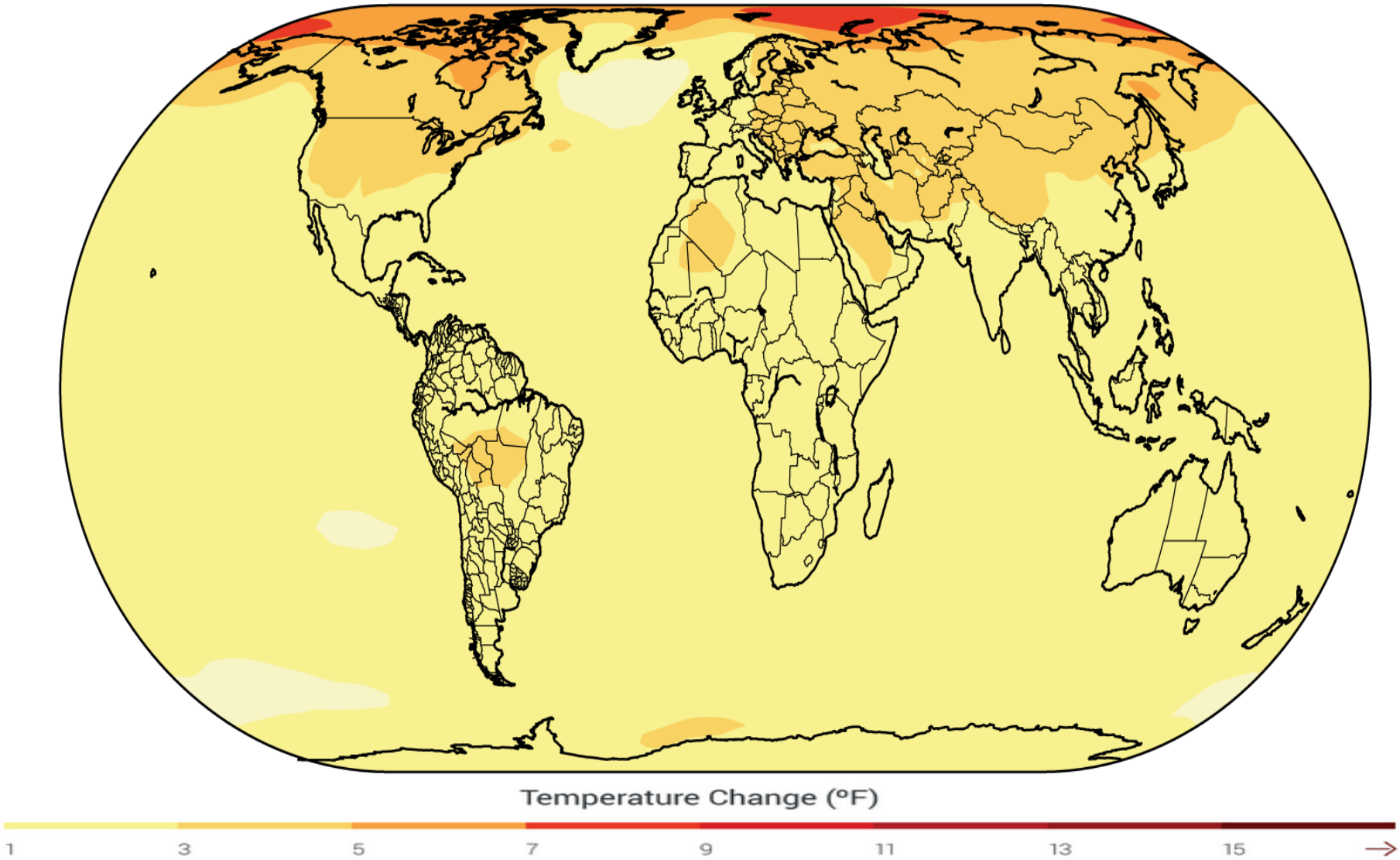
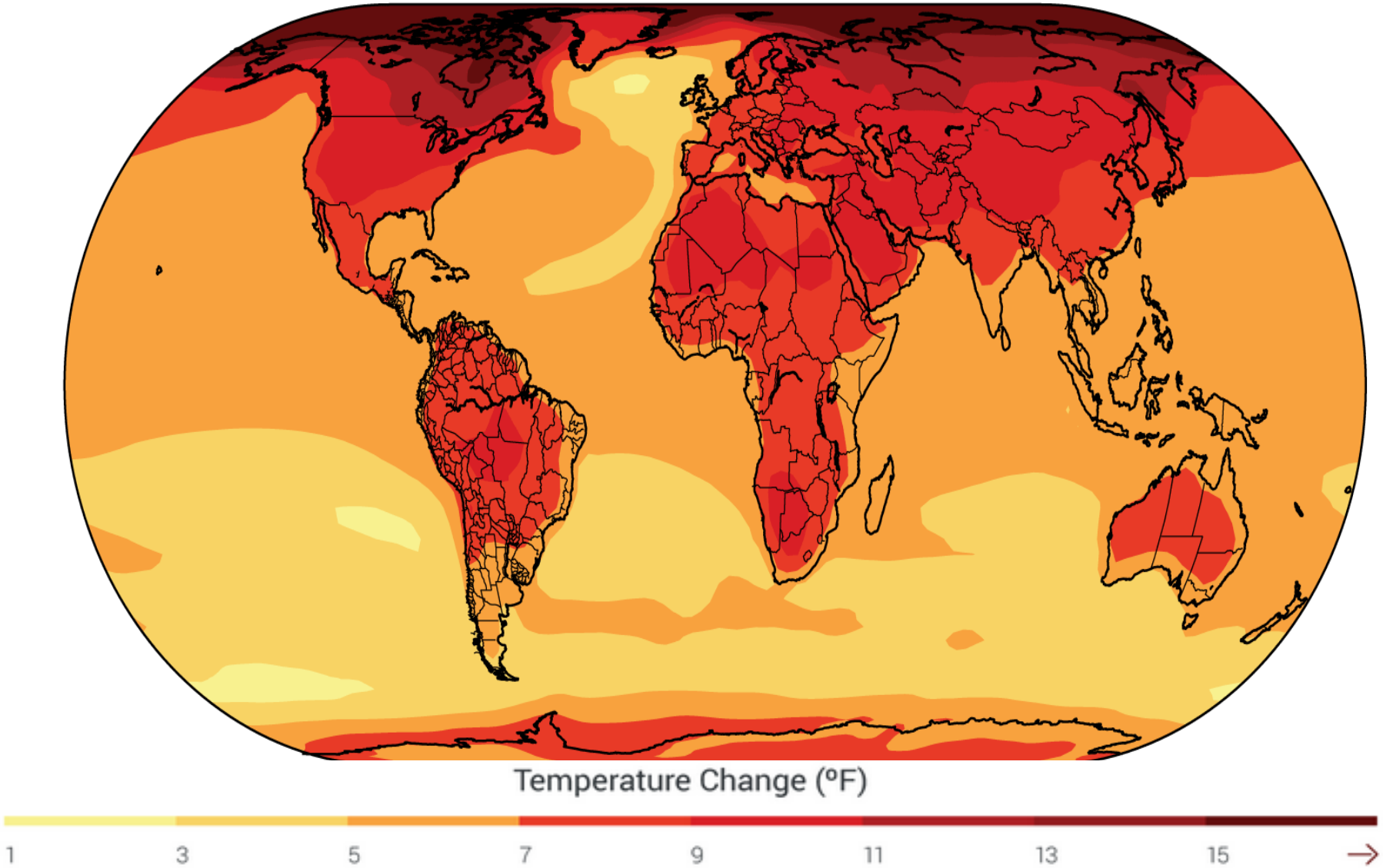


Figure 2.3: Observed global average changes (black line), model simulations using only changes in natural factors (solar and volcanic) in green, and model simulations with the addition of human-induced emissions (blue). Climate changes since 1950 cannot be explained by natural factors or variability, and can only be explained by human factors. (Figure source: adapted from Huber and Knutti[34]).

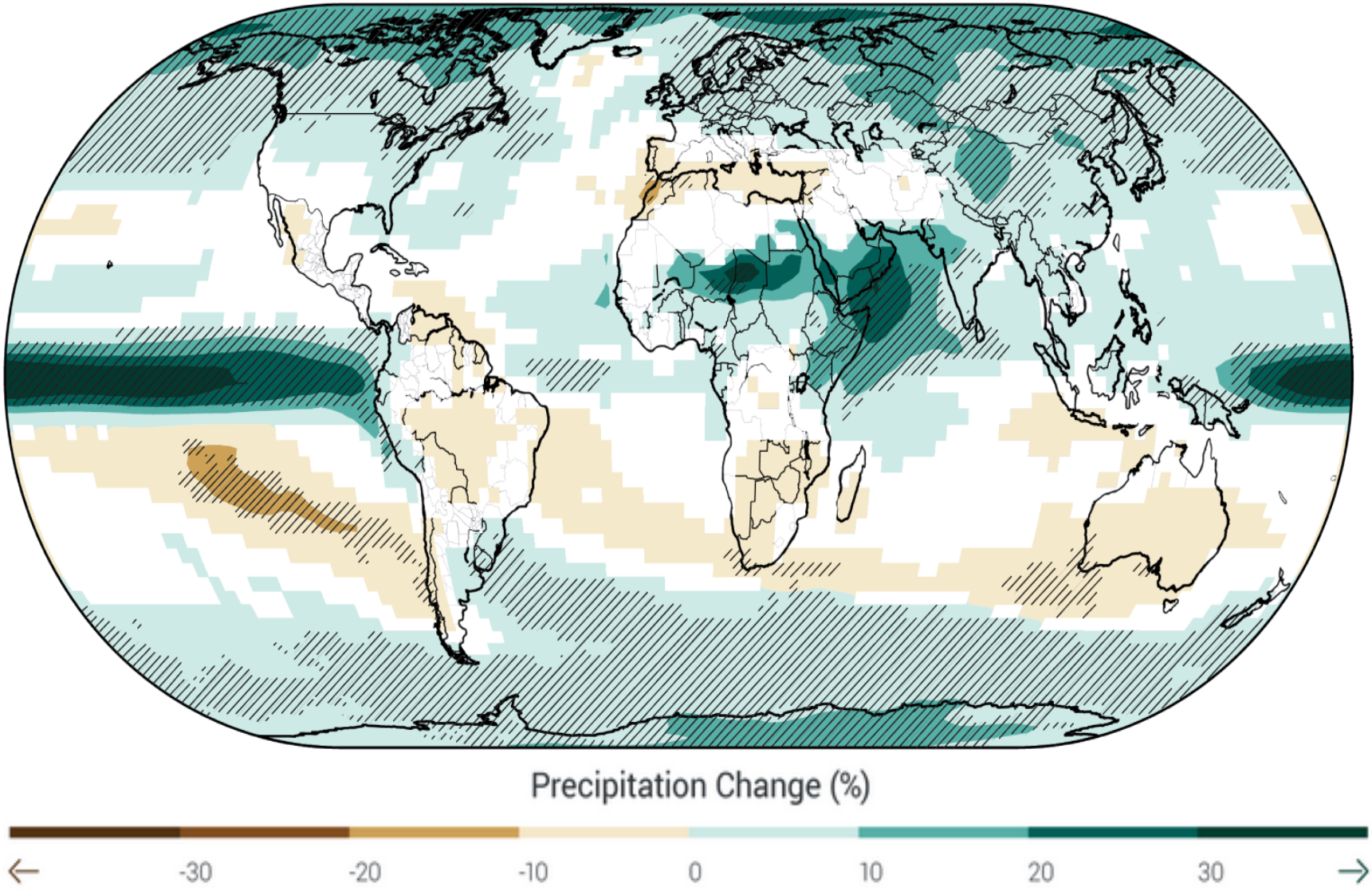
Rapid Emissions Reductions (RCP 2.6)



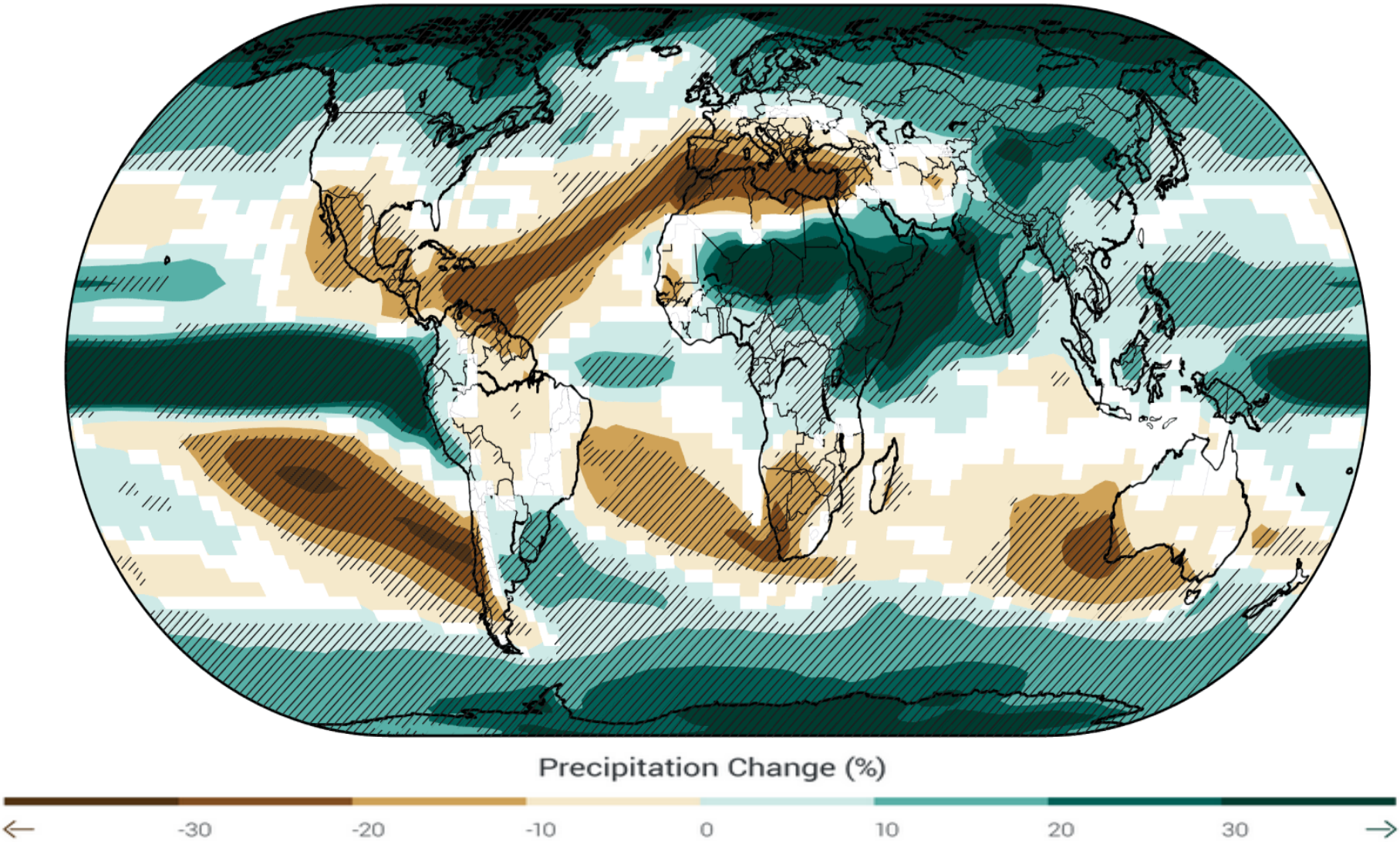
Continued Emissions Increases (RCP 8.5)



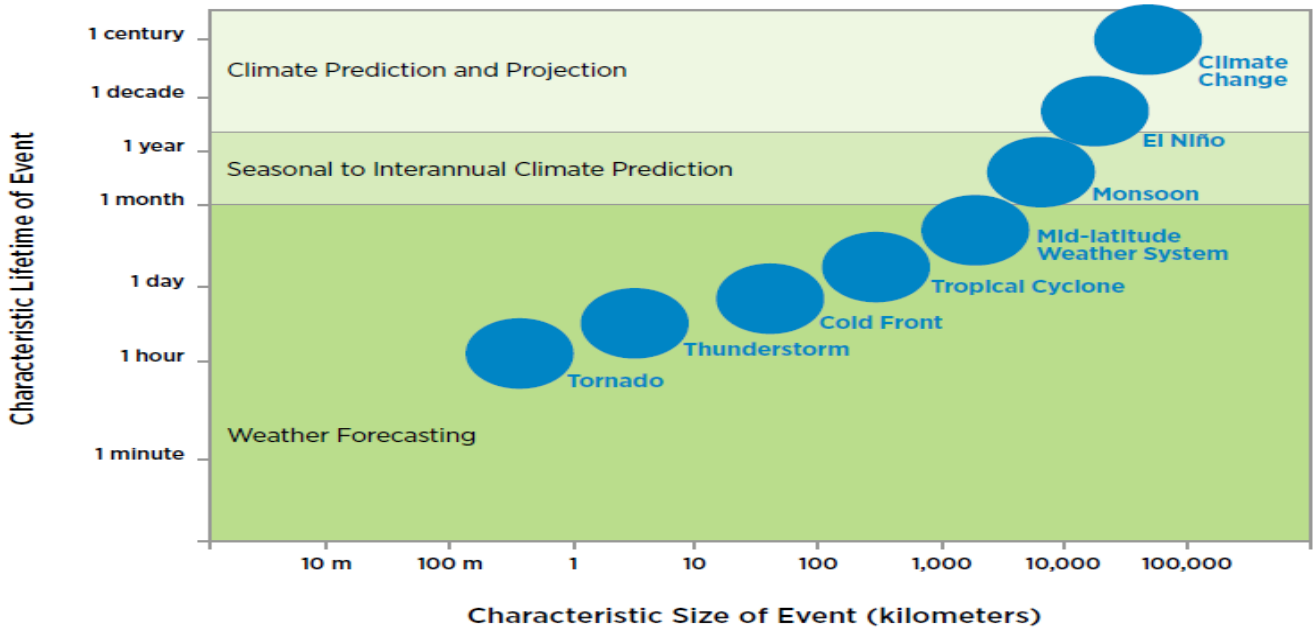
Rapid Emissions Reductions (RCP 2.6)



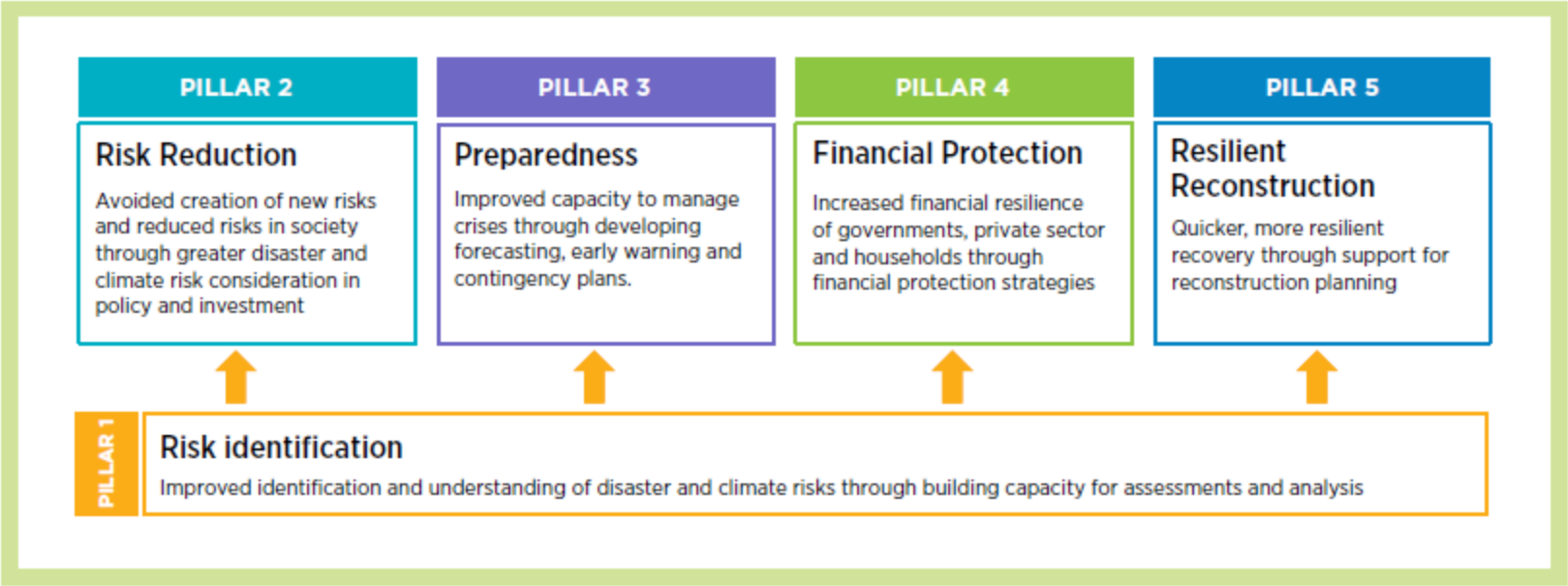
Continued Emissions Increases (RCP 8.5)



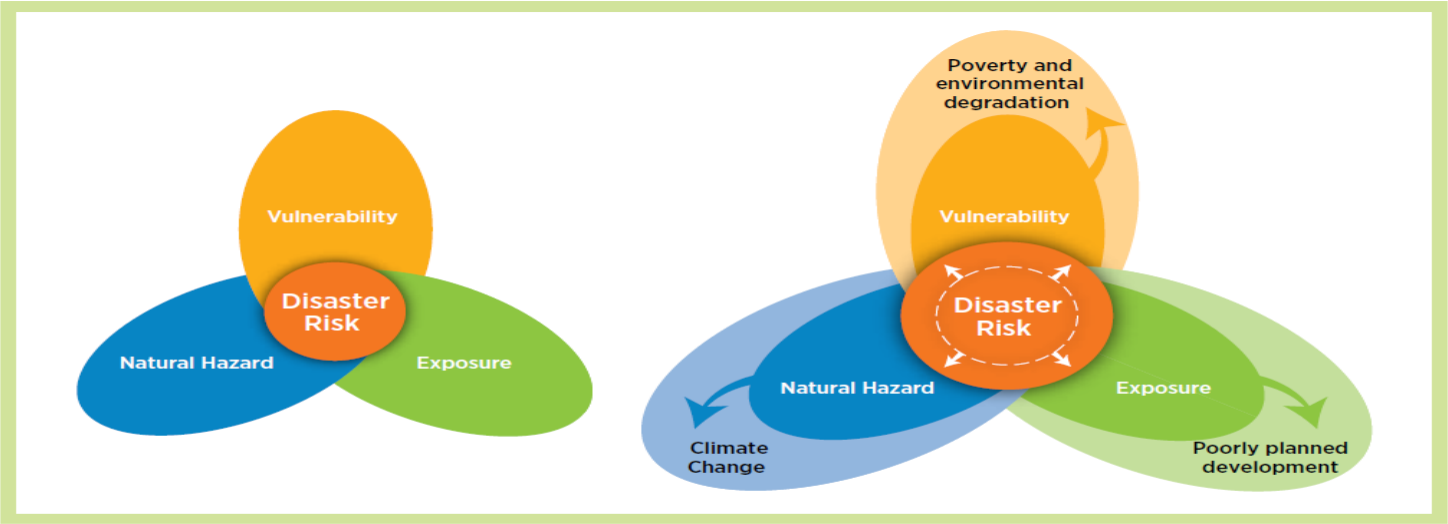
Inputs of climate information services to various stages of the climate resilient framework



An operational framework for managing climate and disaster risk

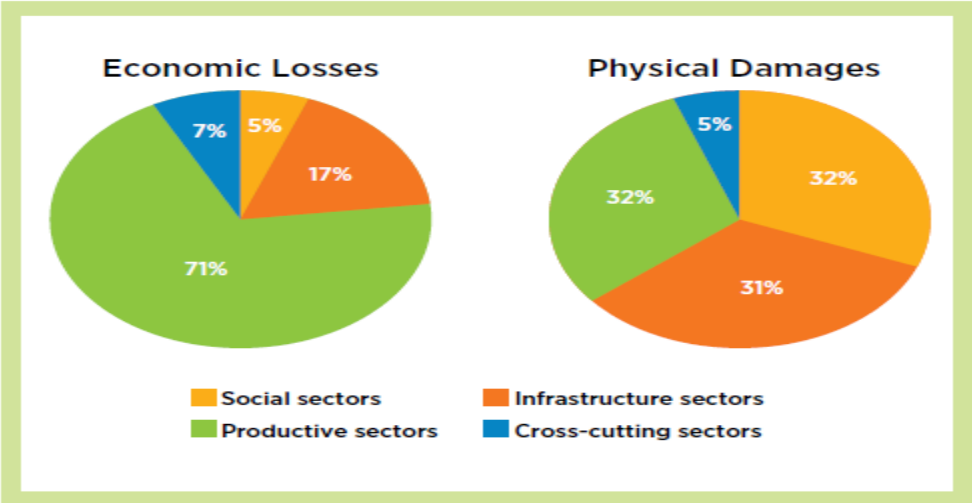


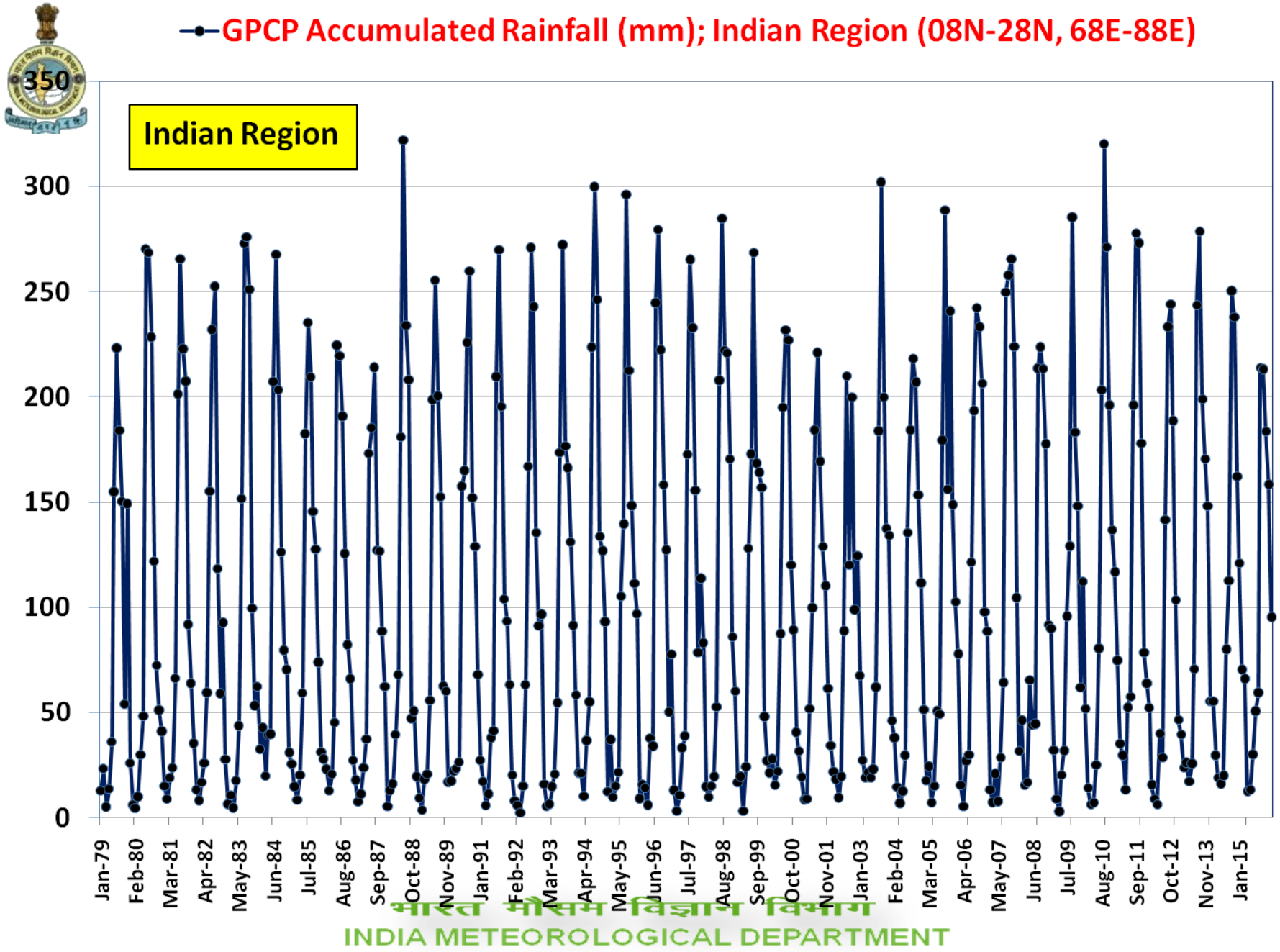
Disaster and Climate Risk



Disaster risk is determined by the occurrence of a natural hazard (e.g., a cyclone), which may impact exposed populations and assets (e.g., houses located in the cyclone path). Vulnerability is the characteristic of the population or asset making it particularly susceptible to damaging effects (e.g., fragility of housing construction). Poorly planned development, poverty, environmental degradation and climate change are all drivers that can increase the magnitude of this interaction, leading to larger disasters.

Total loss and damage from hydro-meteorological disasters, by affected sector (1972–2013)




GPCP Accumulated Rainfall (mm); Indian Region (08N-28N, 68E-88E)
Indian Region
350
300
250
200
150
100
50
0
Jan-79
Feb-80
Mar-81
Apr-82
May-83
Jun-84
Jul-85
Aug-86
Sep-87
Oct-88
Nov-89
Jan-91
Feb-92
Mar-93
Apr-94
May-95
Jun-96
Jul-97
Aug-98
Sep-99
Oct-00
Nov-01
Jan-03
Feb-04
Mar-05
Apr-06
May-07
Jun-08
Jul-09
Aug-10
Sep-11
Oct-12
Nov-13
Jan-15
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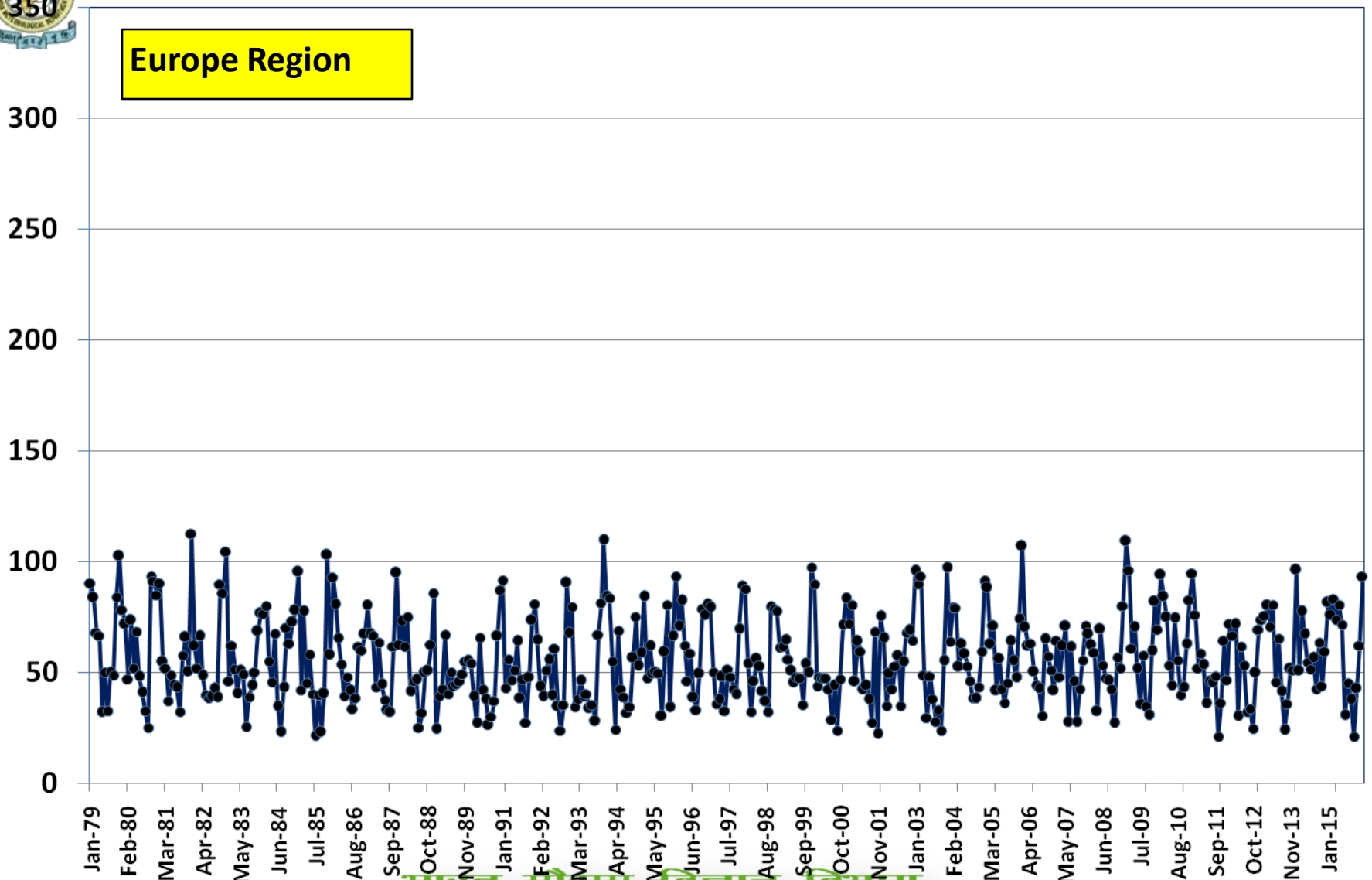
GPCP Accumulated Rainfall (mm); Europe Region (30N-50N, 05E-25E)



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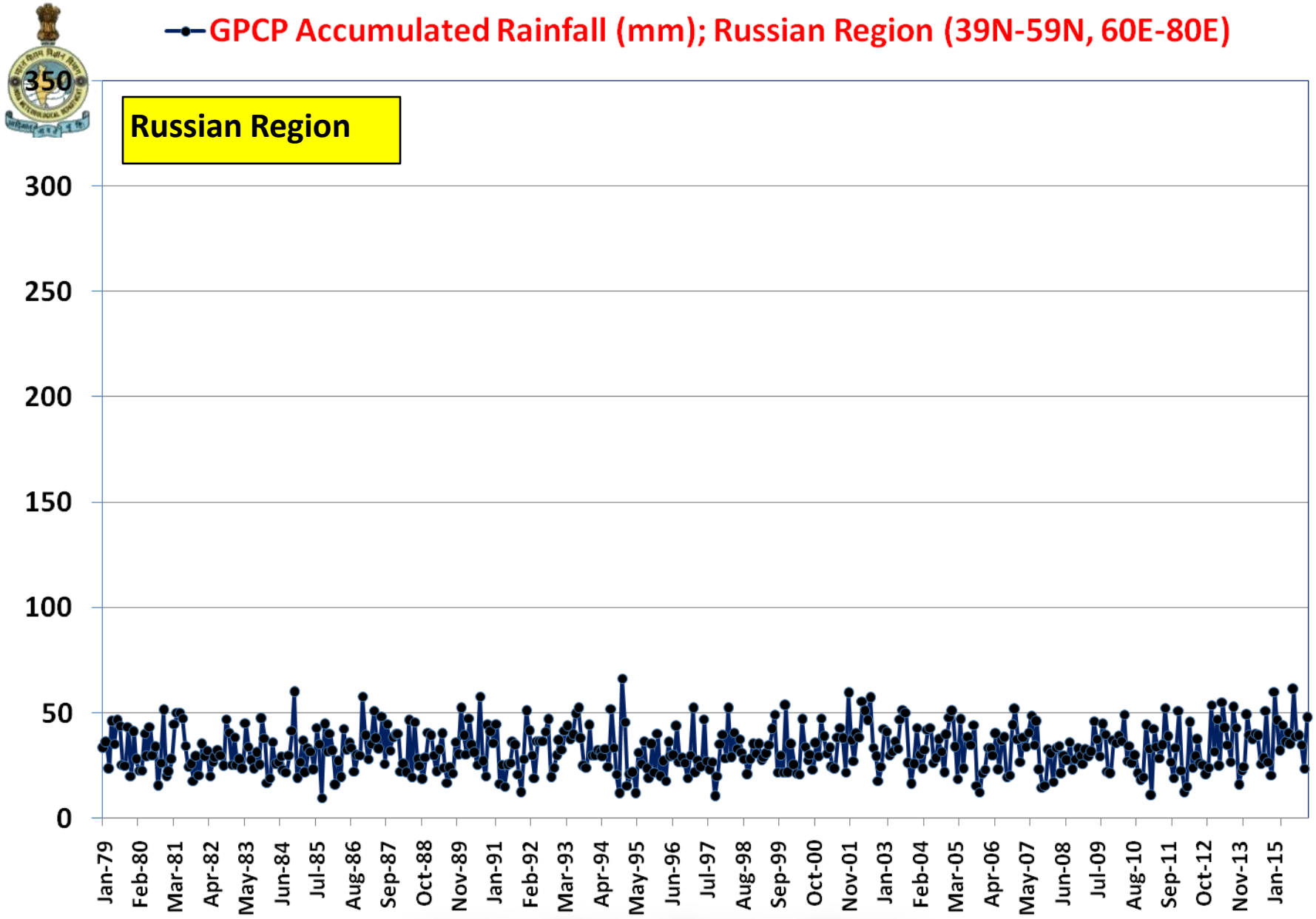

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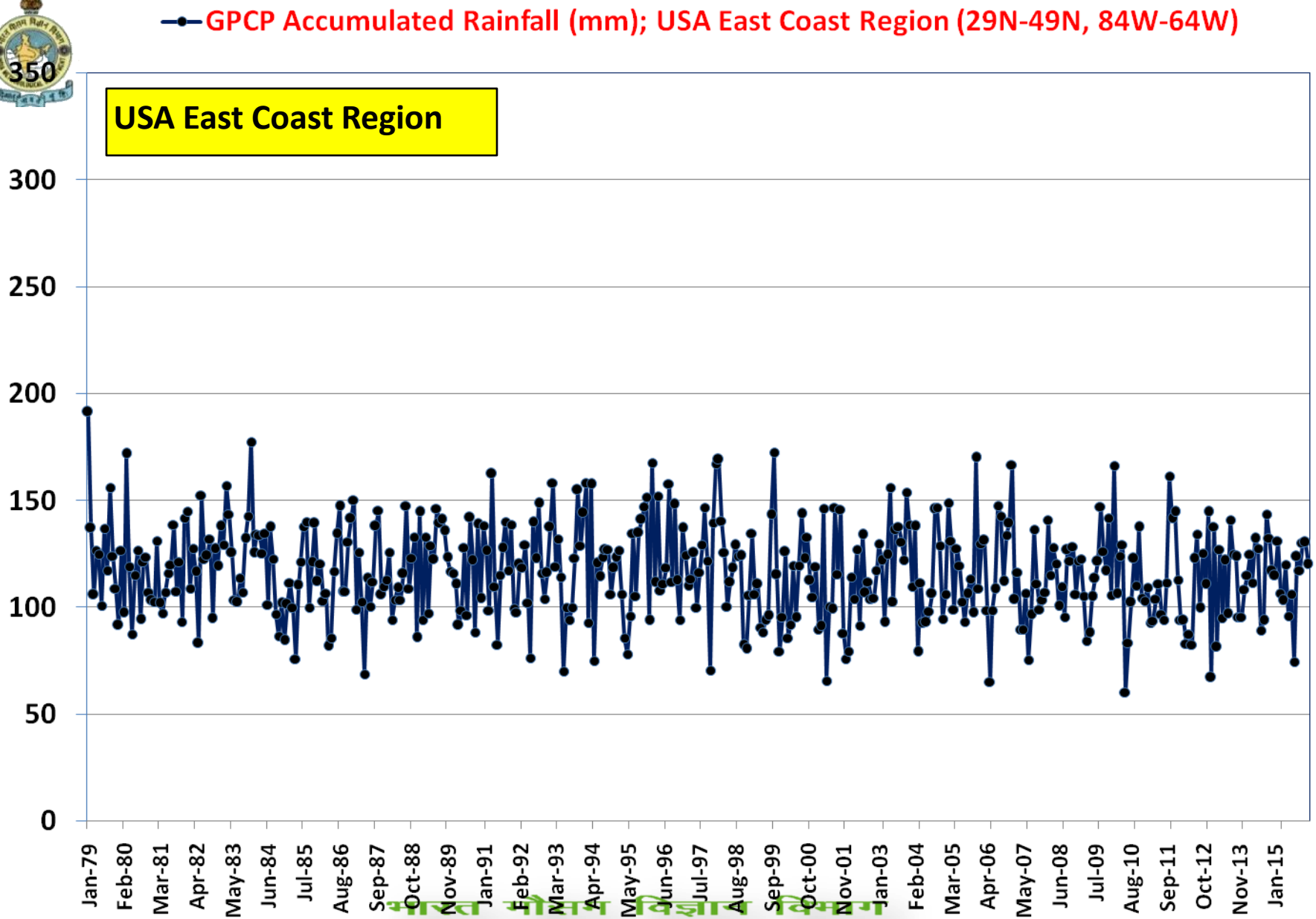

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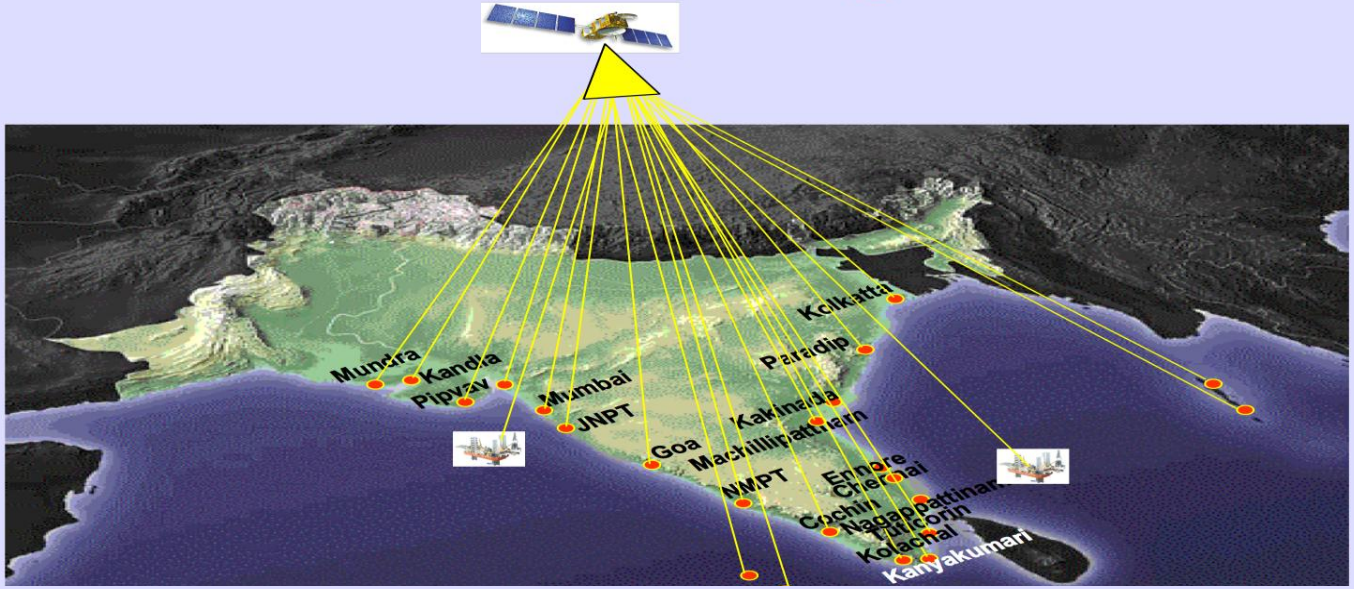
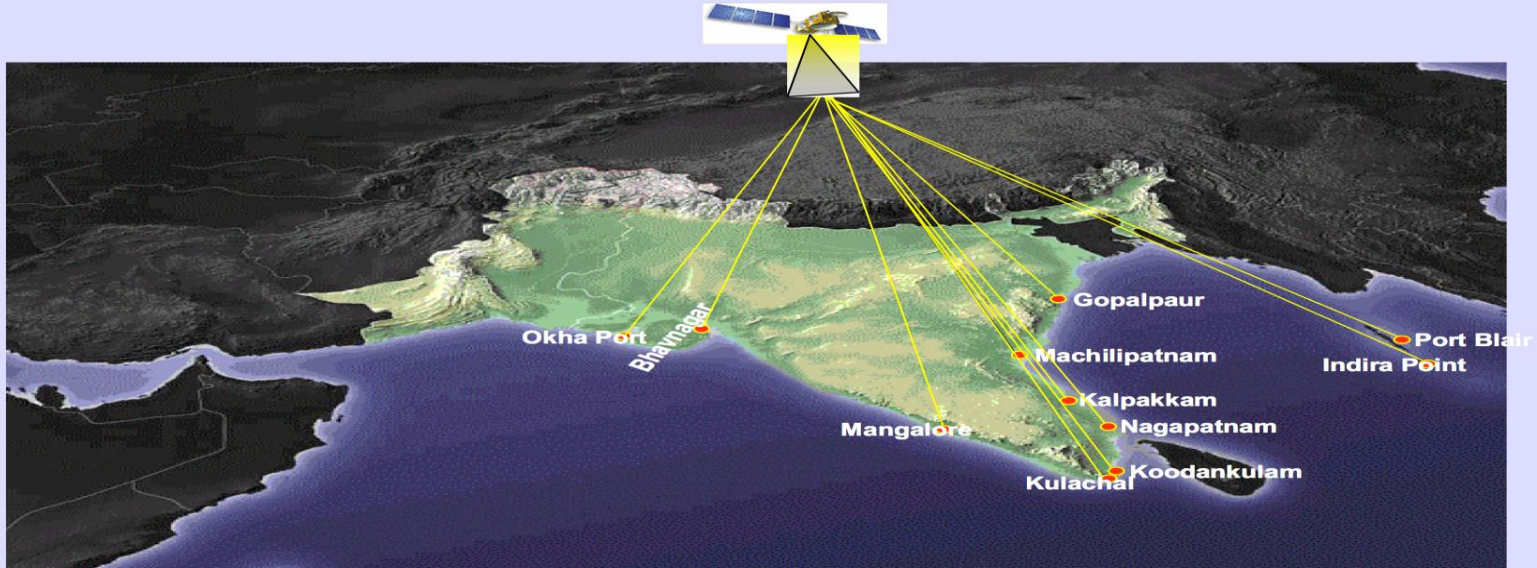
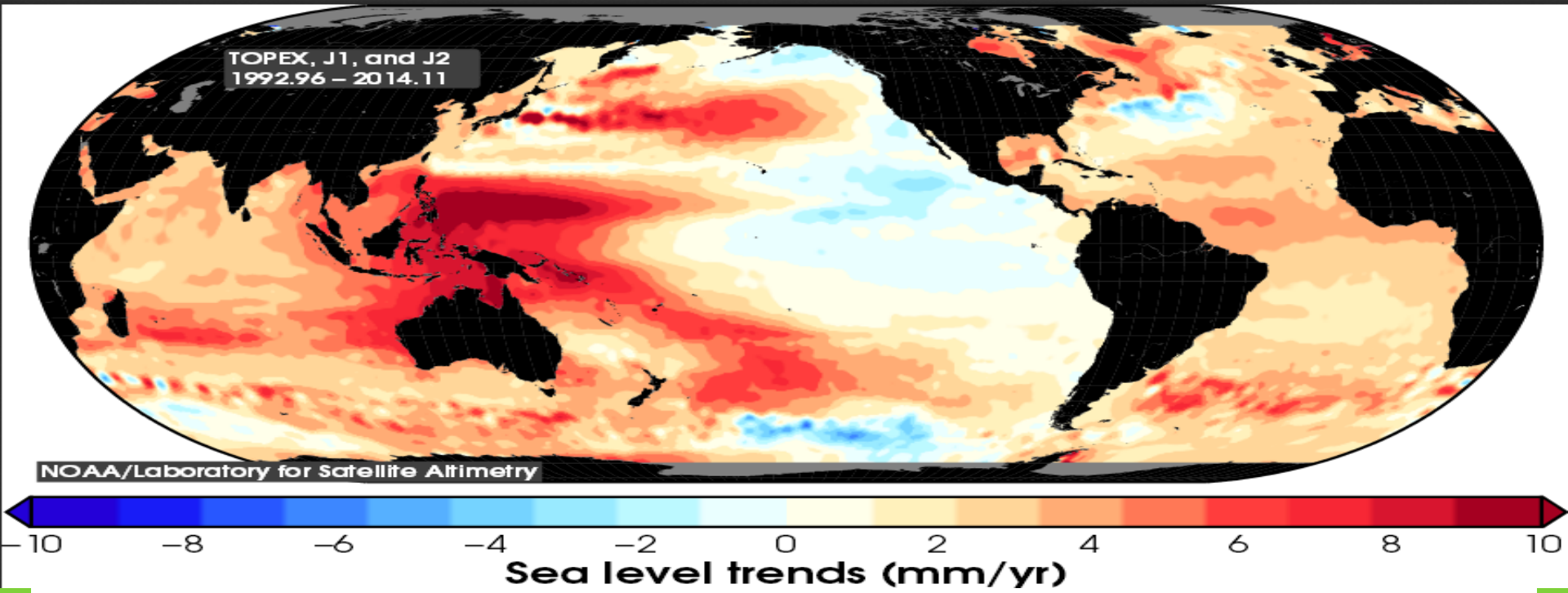
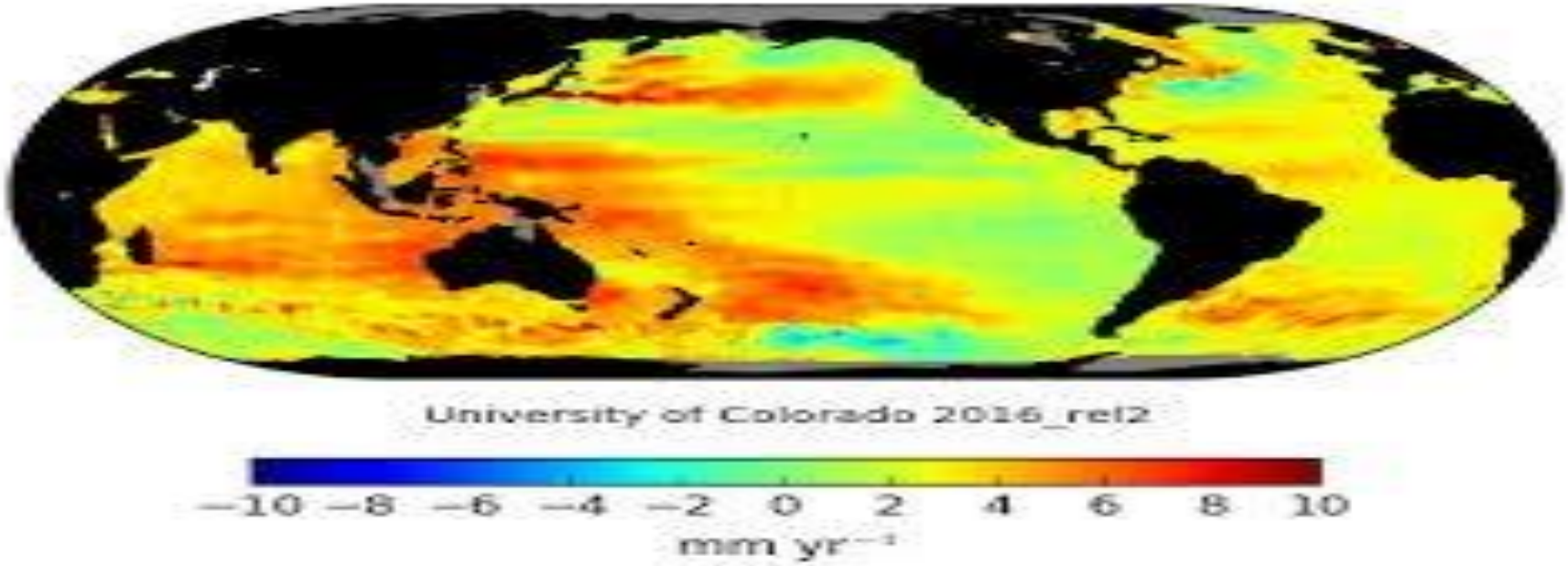
Sea Level Monitoring Stations



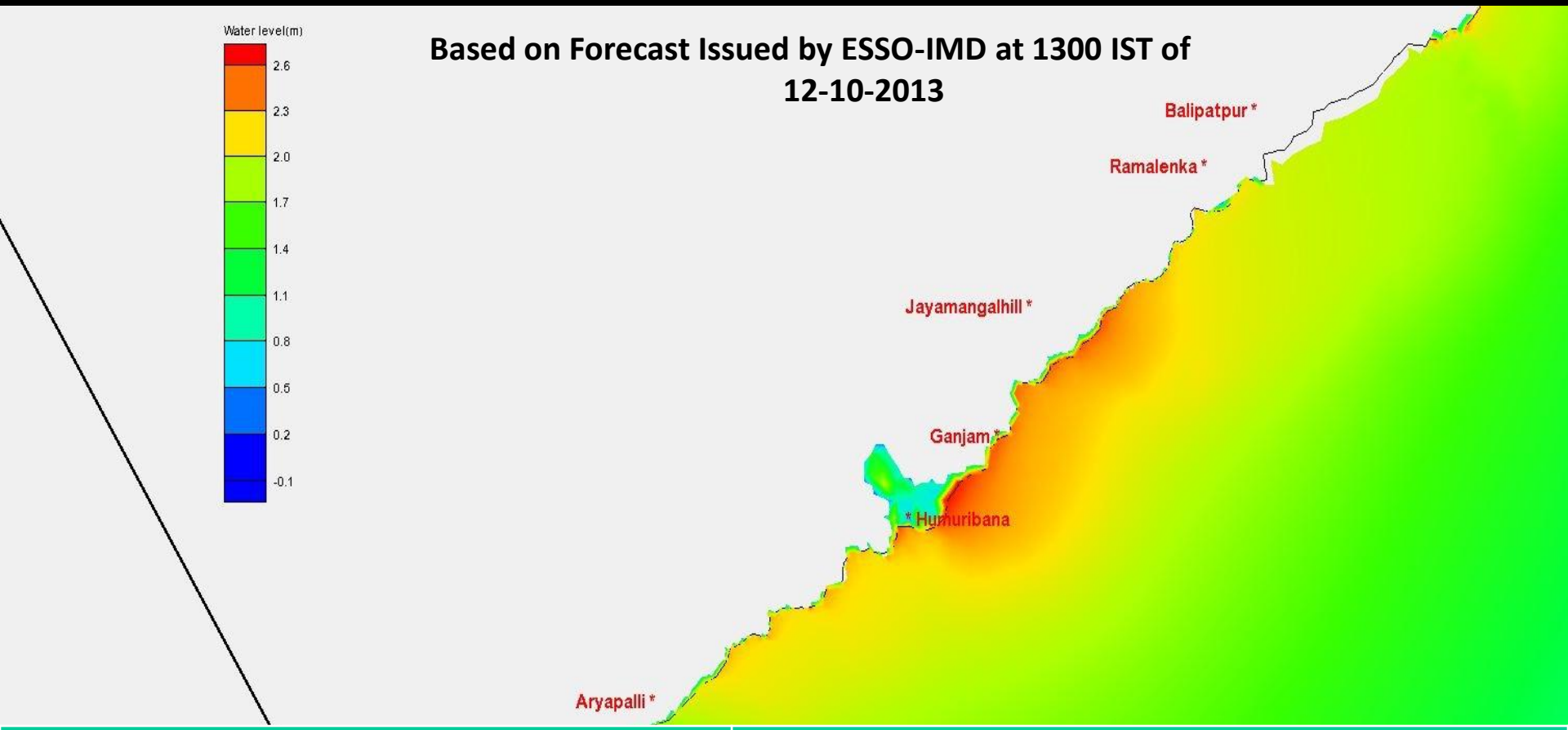
HF Radar-based Monitoring of Surface Current and Wave




TOPEX, J1, and J2
1992.96 – 2014.11
NOAA/Laboratory for Satellite Altimetry
−10 −8 −6 −4 −2 0 2 4 6 8 10
Sea level trends (mm/yr)

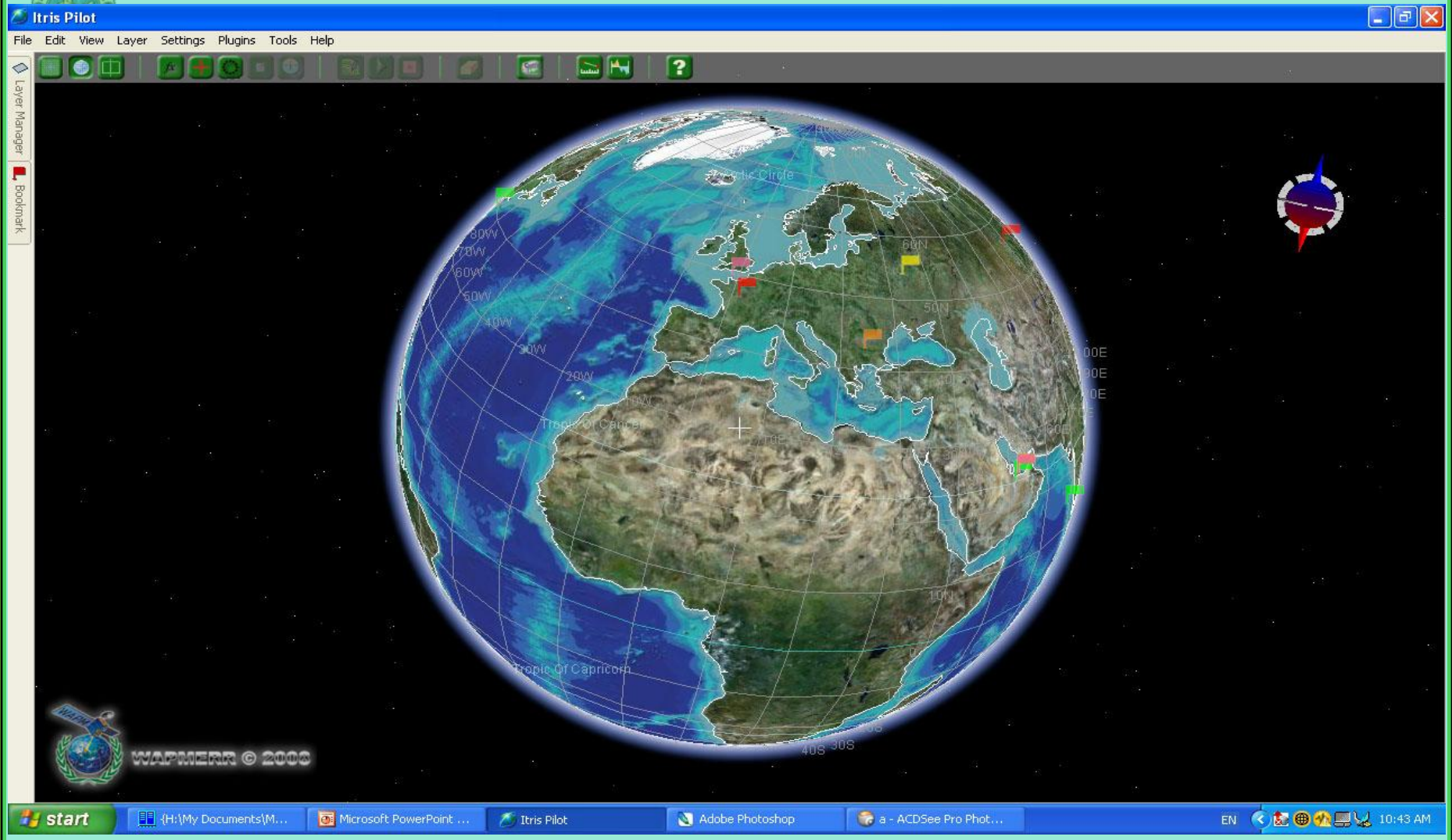

University of Colorado 2016_rel2
−10 −8 −6 −4 −2 0 2 4 6 8 10
mm yr⁻¹

Storm Surge Modeling –Phailin Cyclone



EXPECTED TIDE AT PARADEEP	**-0.3M DURING LANDFALL**
EXPECTED WIND SPEED	210 - 220 KMPH
MAX EXPECTED SURGE	2.6 M AT GANJAM, ORISSA
MAX EXPECTED INUNDATION EXTENT	3 KM THROUGH RIVER NEAR GANJAM, ORISSA

3D GIS



Main window shows 3D model of the Earth surface.
The cities having 3D building models are marked by colored flags.

Allows to select any area of the Earth surface and zoom in on this area up to the highest resolution 60 cm (if a certain satellite imagery of the highest resolution is available)

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INCOIS

Manipulation with realistic 3D models and textures of real buildings.
Inclusion of real object images (peoples, items, signs) in a 3D model.
The building brief (address, telephone, owner) appears in the pop-up information box.

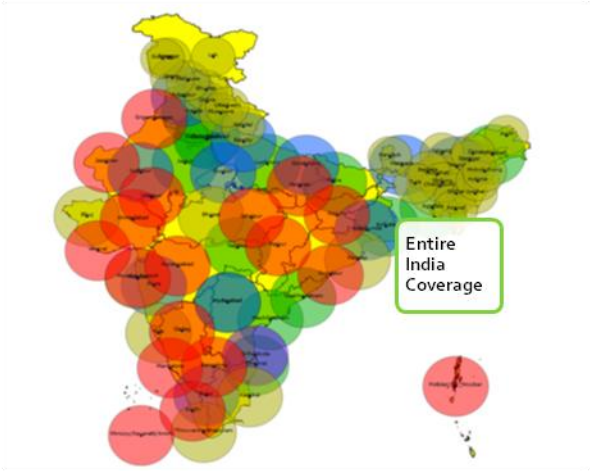
The example of design a photographically exact 3D model. These real buildings are the buildings for public worship in Nagapattinam (India).

DWR Network

2003

2016

By 2019-20



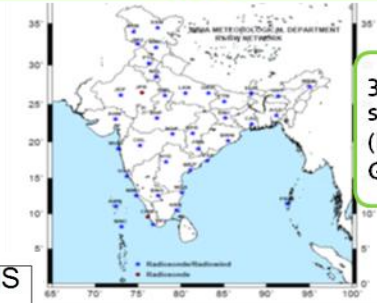
Erstwhile 11 S-band cyclone detection radars (CDRs) along east and west coast of India replaced by Doppler Radars in a phased manner.

Very soon, DWR network will cover entire coast line of India for cyclone monitoring.

Another 22 Radars are planned by IAF and IMD for the plain areas; Exclusive DWR networks are under implementation for Himalayas and under approval for NE States.

Upper Air Network

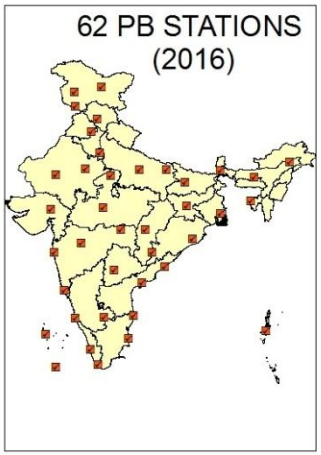
2006

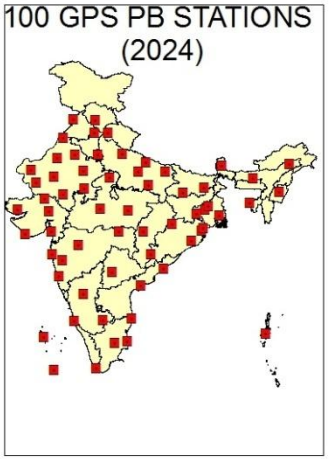


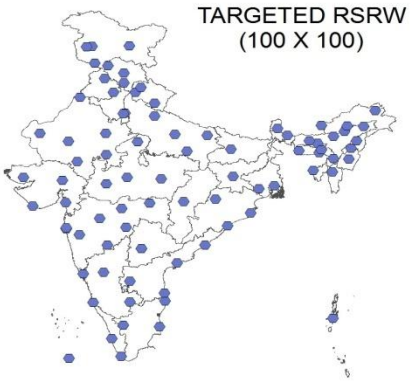
39 stations (Non-GPS)

2016

43 GPS stations







2019-20 (57 GPS)

2020-24 (~120 GPS)

100X100 km

Data from Indian network was rejected, till 2007-08 when non-GPS, by leading Global NWP centers largely due to large errors in temperature and height data.

Now, GPS network is extended to 43 stations, substantially improved data quality with full acceptance by the global & national NWP centers.

PB Network to be replaced with GPS Pilot stations.

Surface Observational Network

Departmental Surface Observatories

203

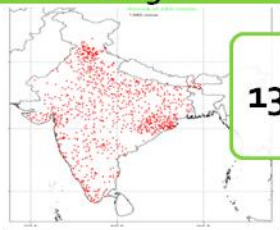
Non-Departmental Surface Observatories

247

Automatic Weather Stations

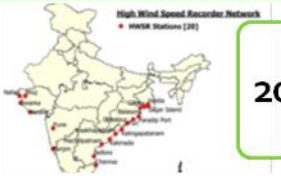
675*

Automatic Rain Gauges



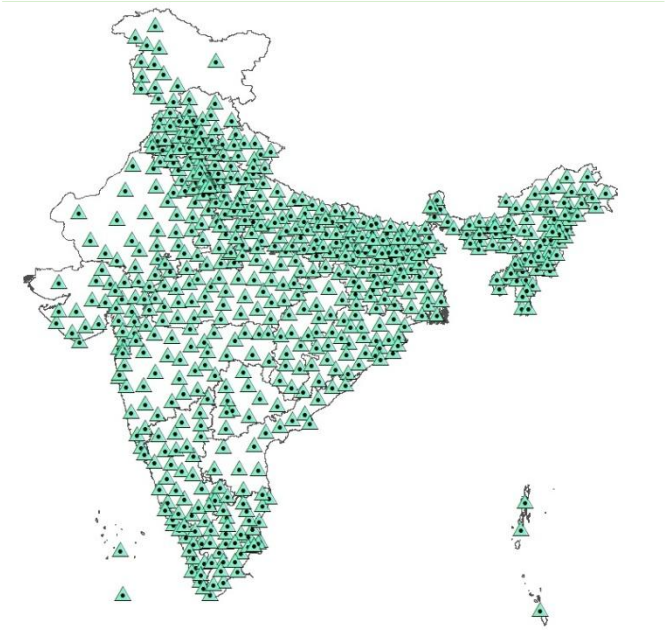
1330*

High Wind Speed Recorder (HWSR)



20*

Surface Observational Network by 2024



10X10 km

*Established after 2006; All 70 Airports will have rainfall sensors; 660 DAMUs will also have quality surface observations; 33,000 rain sensors; 17,000 all sensors

Satellite Meteorology

2006

- Kalpana satellite was providing observations every half hourly and products were generally in image form.

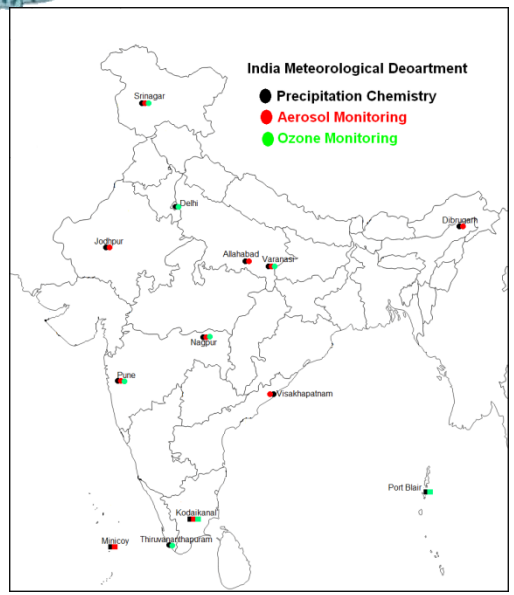
2016

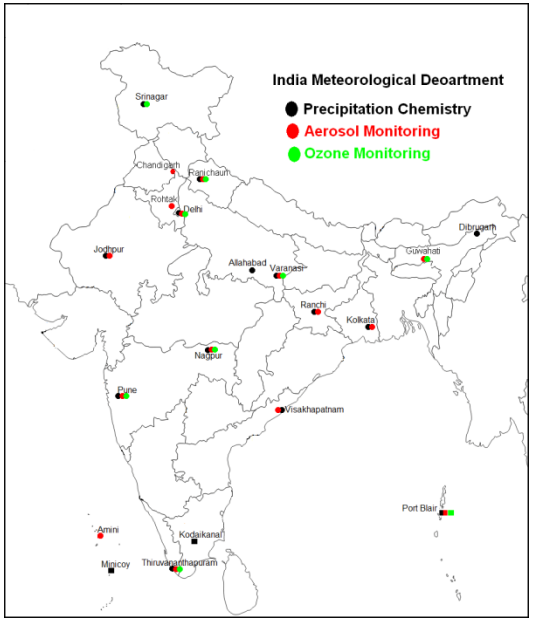
- Imageries and digital data from INSAT 3-D with increased resolution has further complimented the observational capabilities towards monitoring severe weather events and for better initialization of NWP models.
- INSAT 3DR launched, will enable to provide pictures & products every 15 minutes.
- Web analysis tool **" RAPID" hosted on webpage.**
- **GNSS data processing center 30** stations.
- **INSAT-3D derived Winds and radiances** are being assimilated in NCMRWF and IMD NWP models

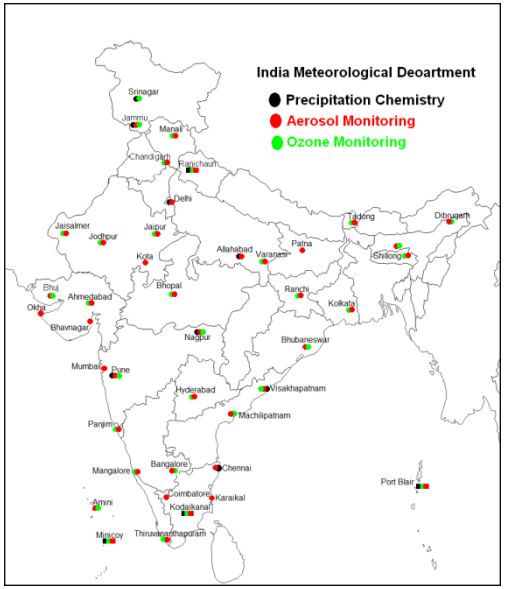
By 2020-24

- Establishments of Processing systems to receive, process, derivation of products from imager and sounder payloads data of INSAT 3DS, SCATSAT, OCEANOSAT-III, GISAT& Advanced GISAT.

Environmental Monitoring







2006	2016	2024
Precipitation Chemistry (10 Station)	**Precipitation Chemistry (11 Station)**	**Precipitation Chemistry (15 Station)**
Aerosol Monitoring (10 Station) (Hand-held Sun Photometer)	**Aerosol Monitoring (13 Station)** (Sun-sky Radiometer: 12, Black Carbon: 16, Nephelometer:12)	**Aerosol Monitoring (45 Station)** (Sun-sky Radiometer: 45, Black Carbon: 45, Nephelometer:12)
		National Aerosol LIDAR Network: 12
		Background Reference Station: 3
Ozone Monitoring Network (Surface Ozone:6, Columnar Ozone: 3, Ozonesonde:3)	**Ozone Monitoring Network** (Surface Ozone:10, Columnar Ozone: 3, Ozonesonde:3)	**Ozone Monitoring Network** (Surface Ozone:40, Columnar Ozone: 6, Ozonesonde:5)

Data Communication systems

2006

- Conventional Automatic Message Switching Systems (AMSSs) at six airports.

2016

- New AMSSs, CIPS, CLISYS, Synergy installed to make available the met data, observations, products and forecasts to IMD Offices and users of the region.
- **Migration from RTH to GISC and WIS:** Global Information System Centre (GISC) installed at Pune under WIS (WMO Information System) programme of WMO. **IMD status risen from Regional to International level Global data dissemination centre.**
- New in-house developed/ re-designed website (user friendly/ easy to navigate): Launched by Hon'ble Minister on 141st IMD foundation day (2016).

By 2024

- Cloud Computing and Storage
- Big Data Analytics for Weather, Climate variability and Change and related hazards
- Web-GIS based Decision Support Systems up to Sub-District scale

Numerical Weather Prediction (NWP) Modeling- 2016: Backbone for Forecasting and Warning Services

Models in 2006 : Deterministic Limited Area Model, GFS T80 Model

Models in 2016 :

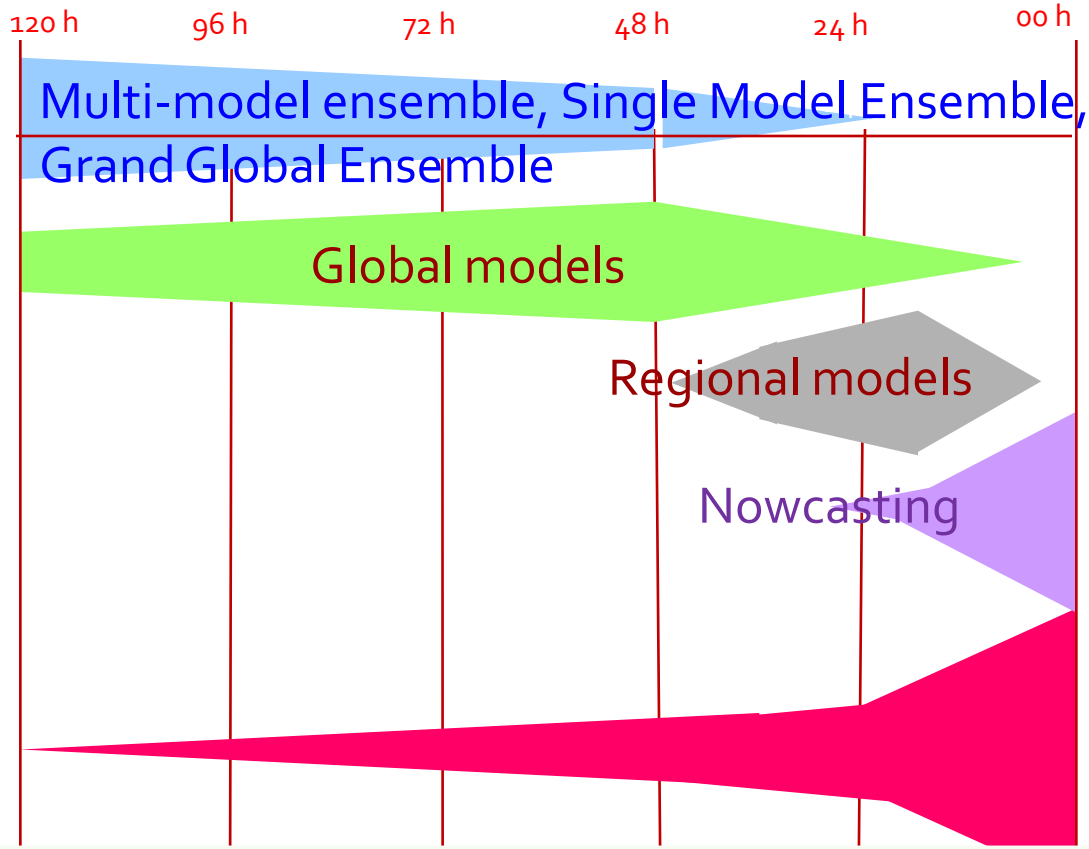
Ensemble Pred. Tools
GEFS, UMEPS

Global Models
GFS(T1534), Unified Model

Regional Models
WRF, HWRF

Nowcasting Tools
(WDSSII, ARPS Model)

Warnings Activities



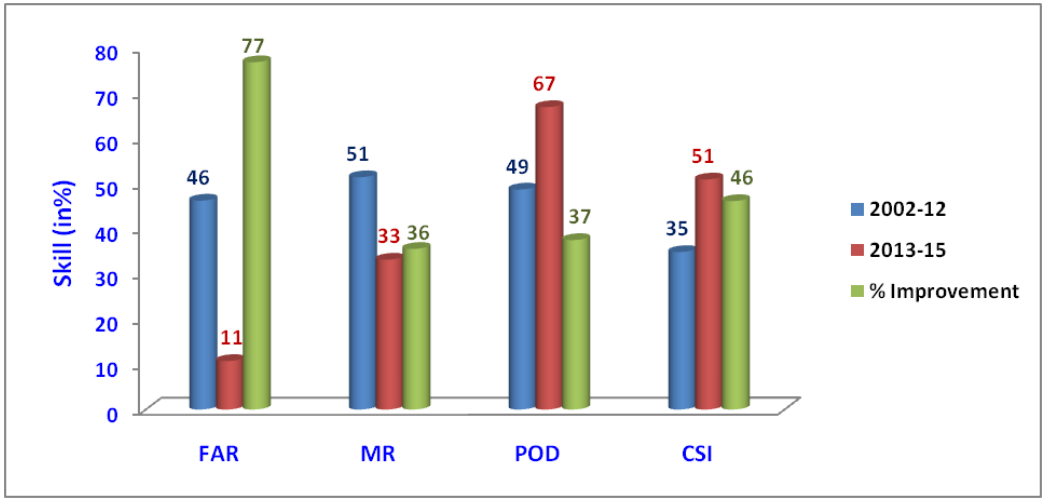
By 2019 : 12 km Global Model Ensemble prediction system, 1-3 km Regional multi-model prediction system, ocean-atmosphere coupled severe weather pred. systems, Parametric models and Expert systems – severe weather Warning up to 5-7 days, Forecast outlook up to 10-15 days

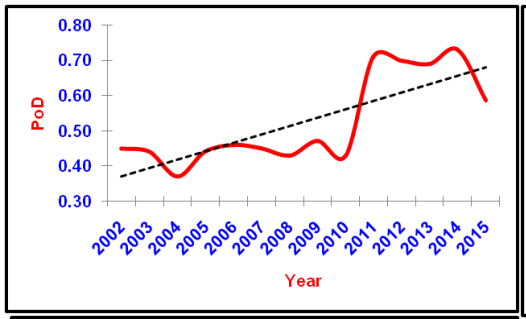
Severe Weather Forecast & Warnings skills

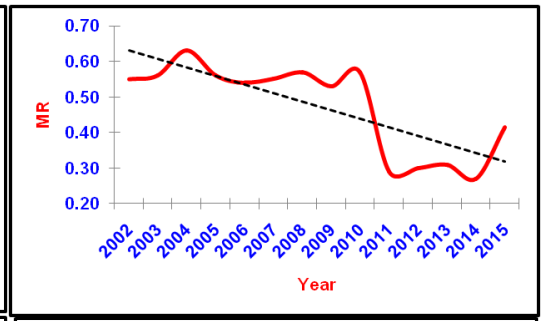
Noticeable improvements achieved in Skills of Heavy Rainfall Forecast (**False Alarm Rate reduced from 46% to 11% & Probability of Detection increased from 49% to 67% from 2002-12 to 2013-15**)

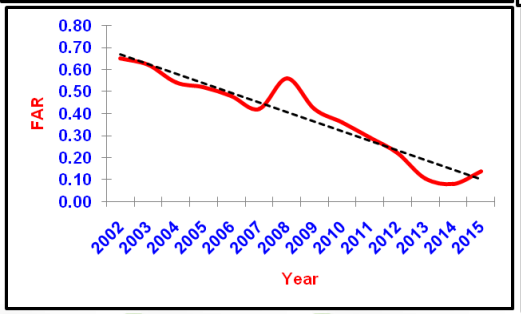
Lead time of warnings increased from 3 to 5 days in respect of Rainfall, heat wave, cold wave etc.

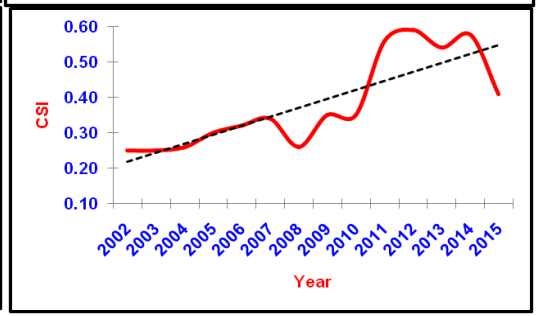
Introduced new **Forecast bulletin Terminology**





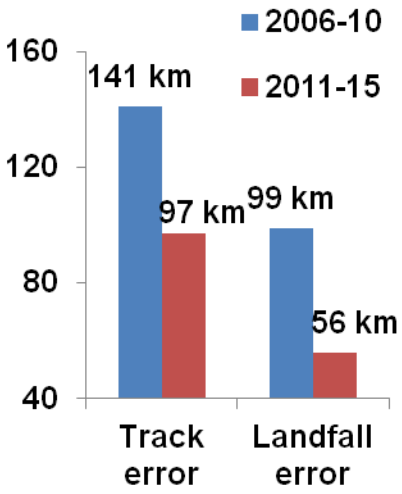




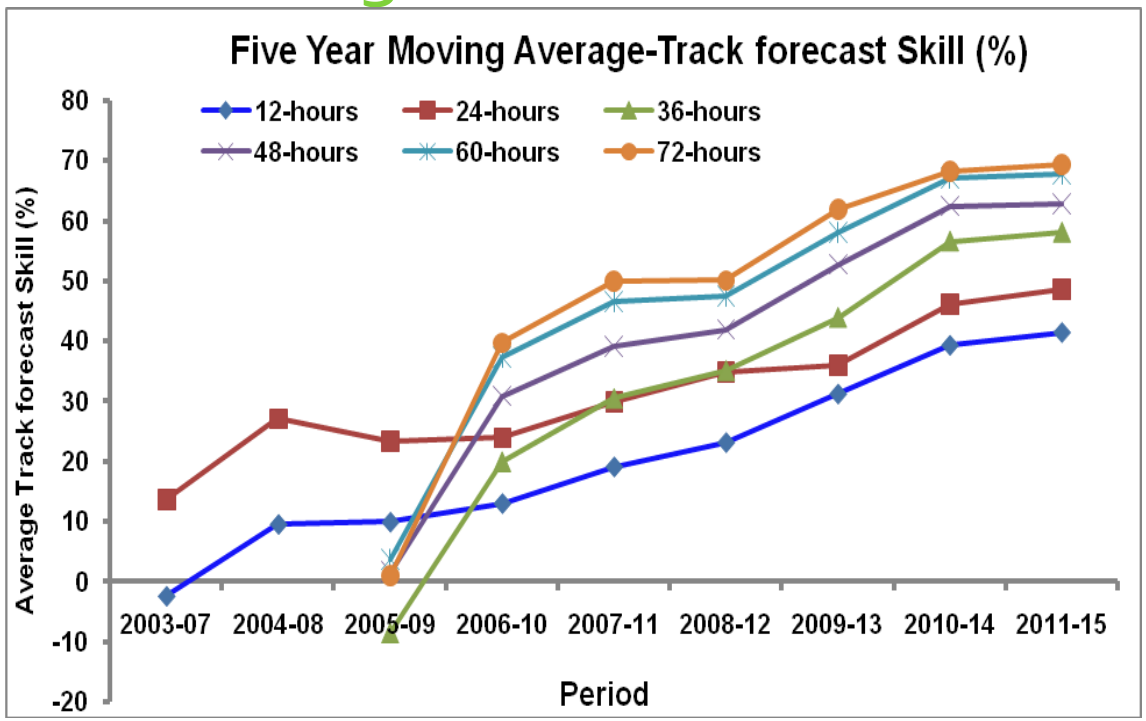


Target for 2019 : Improvement of accuracy and skill by 20% up to 7 days

Cyclone Warning Services



24 hr forecast errors



IMD acts as **WMO recognized Regional Centre** to provide cyclone advisories to all countries in north Indian Ocean region.

Noteworthy improvement in track and intensity forecast of the tropical cyclones (**24 hour forecast error in track prediction reduced from 141 km to 97 km and Landfall error from 99 Km to 56 Km during 2006-10 to 2011-15**).

Probabilistic genesis Forecast up to 3 days and Track and intensity forecast up to 5 days in text and graphics

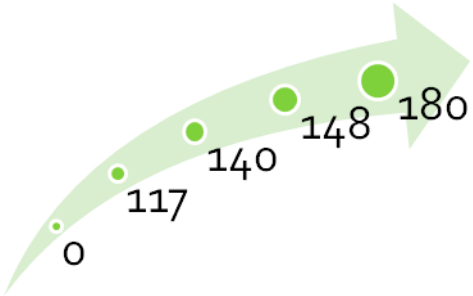
Target for 2024 : Reduction in error and Improvement of skill by 20% up to 7 days

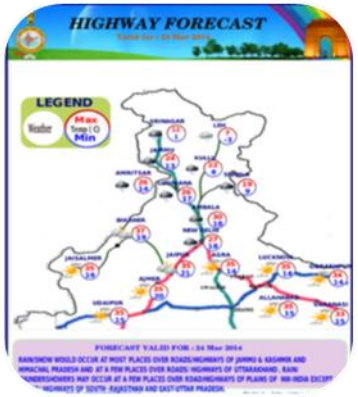
City specific forecasts

Introduced Thunderstorm /Now cast for cities covered under DWRs for 180 cities.

Introduction of Highway Forecast

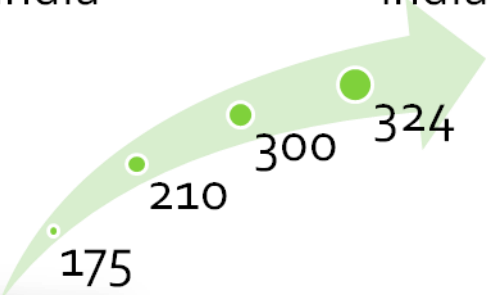
Increase in city forecast from around 30 in 2006 to 324 in 2016.





Northwest India

Southeast India



Target for 2024 : 600 cities and improvement in accuracy and skill by 20%

TOURISM FORECAST

Target (2016-19): 100 Places

Category of Places:

- Hill Stations
- Coastal Stations
- Historical Places
- Religious Places

Climatological information

Current and forecast Parameters Required:

- Meteorological
- Air Quality (AQ)
- Location specific for various spots
- Climatological forecast to Nowcast

Infrastructure requirement:

- Observational site (No. of AWS as per size of place)
- AQ monitoring Station
- High resolution model for location specific forecast
- Decision Support tools
- Man Power

Communication:

- Website
- Mobile Apps
- Display Boards
- IVRS

Augmentation of Aviation Meteorological Services

2006

- Only Conventional systems at airports

2016

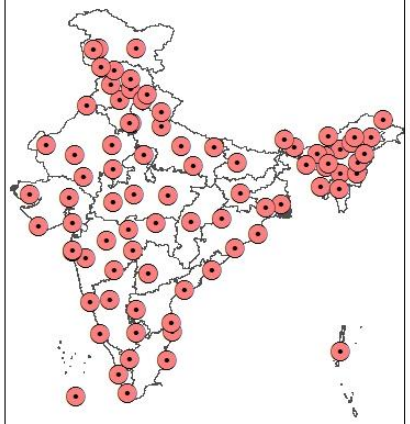
- Drishti system developed for the measurement of Runway Visual Range (RVR) at Airports and installed at 20 locations.
- Aviation meteorological services automated through an On Line Briefing System.
- An indigenous Aviation Weather Observing System developed at NAL Bangalore in collaboration with IMD. Presently under testing
- HAWOS installed at Mumbai (Juhu) & Sanji Chhat, Vaishno Devi for the benefit of helicopter pilots

By 2020

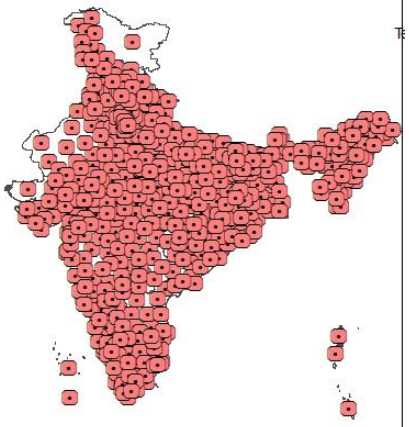
- To develop a State-of-the-Art **Support System for Aviation Safety** with the advanced meteorological instruments and forecasting tools through installation of indigenous AWOS & DRISTI RVRs for all the civil airports and HAWOS for heliports in the Country.

Gramin Krishi Mausam Sewa

EXISTING
(130 STATIONS)



TARGETED
(660 STATIONS)



2016

- District level advisories through 130 Agromet Field Units (AMFUs) to all 636 agricultural districts.
- Presently around **1.91 Crores** farmers are directly benefitted by this service being provided through SMS.
- Regular agrometeorological information twice a day and at increased frequency is being provided through DD Kisan launched specifically by the government for benefit of the farmers.

By 2019-24

- Setting up functional District Agro-meteorological field Units (DAMU) in all 660 districts.
- Improved services with additional climate & soil information for rainfed agriculture and irrigated agriculture zones of the country at block level.

Strategy for rapid expansion of SMS based Agro-Met Service Bulletin

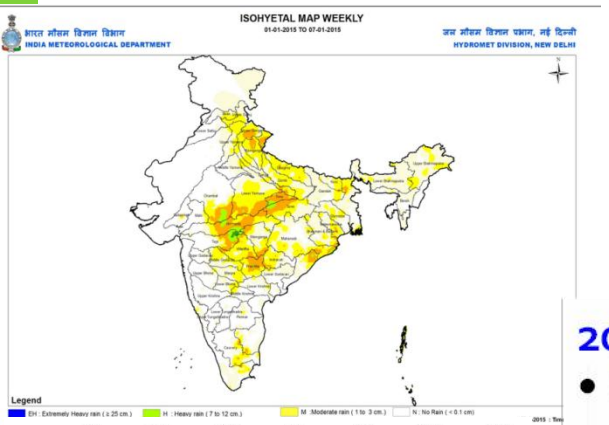
- Expand outreach through Kisan Portal, PPP Partners and service providers across the country in 18 states from 19.1million SMSs to 90million farming households through building partnership with new partners- POST OFFICES; VILLA GE AGRICULTURE ASSISTANTS; AGRICULTURE MARKET YARDS: e-NAM; LOCAL CABLE NETWORKS; FM RADIO CHANNELS; FARMER COOPERATIVES/WATER USER ASSNs; NGOs; CORPORATES
- Gram Panchayats: 2,50,000
- No. of Post Offices: 1,54,239 (1,39,222 rural)
- Postman/Messenger 1,29,237 Dak Sevaks; 1 per 8054 people covering 21.22 sq. Km.
- Village Agri. Assts: Agri. Ext. work carried out for States
- Leverage both the Sources for creating household cell Database in 3-6 months with Web GIS compliance
- Agri DSS will push SMS based on rainfed/irrigated crops cultivated
- Pushing of Advisories through local FM Radio/cable networks/Print Media
- Awareness campaigns at sub-district level by NGOs, Farmer Coops, Water User Assns.

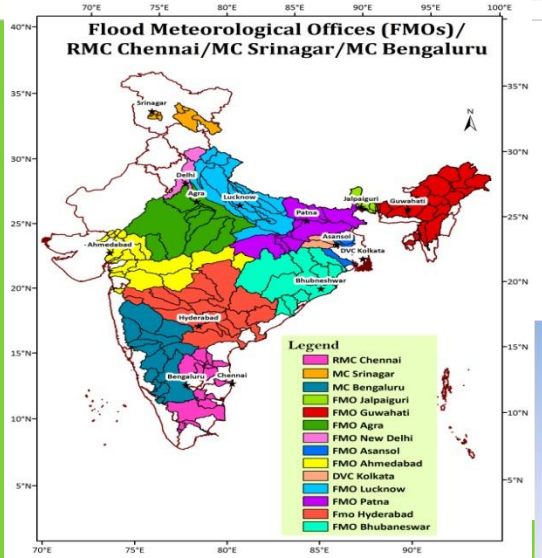
HYDROLOGICAL SERVICES

2016 : Preparation of Rainfall Statistics; daily, weekly& monthly. Commended by the President of India.

- Provides real-time rainfall information by means of GIS based rainfall products.

The district-wise and river basin-wise rainfall statistics is helpful to farmers for their agricultural activities and flood forecast/ water management.





2006

- Conventional Quantitative precipitation forecast (QPF) to CWC for flood forecast purposes for 125 river basins

2016

- Quantitative precipitation forecast (QPF) to CWC for flood forecast purposes increased from 125 to 146 river sub-basins.
- QPF increased from 5 day to 7 days from flood season 2015.
- Sub catchment wise QPF from NWP models- GFS for 7days in addition to WRF, MME for 3 days
- QPF for 4 new catchments Jhelum, Pennar, Torsa, Sankosh which involves 12 sub catchments.

By 2019 : Develop a State-of-the-Art Hydrological Information System and Flood Warning Support for all the Major River Basins of the Country.

- Monitor the three dimensional variability of regional hydrological cycle and assess its expected changes and impacts in the future.

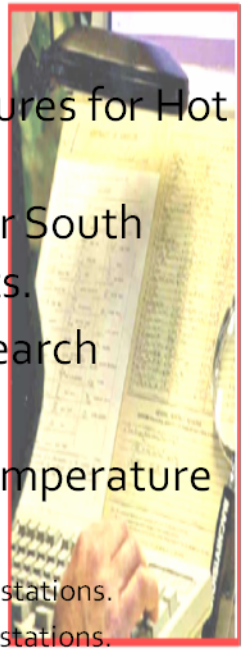
Climate Services

2006

- Preparation of climate normals, Climate Bulletins, Research Reports etc.

2016

- Started Seasonal Outlook for Temperatures for Hot Weather Season (April-June) 2016.
- Introduced Seasonal Climate Outlook for South Asia and monthly ENSO & IOD Forecasts.
- Climate normals, Climate Bulletins, Research Reports.
- High resolution grid point rainfall and temperature data
  - 1°X1° Gridded daily rainfall data (1951-2015) based on 2140 stations.
  - 1°X1° Gridded daily rainfall data (1901-2015) based on 1384 stations.
  - 0.5°X 0.5° Gridded daily rainfall data (1971-2005).



By 2017-20: Climate Services will be rolled out using IITM Coupled Ocean-Atmospheric Model monthly and seasonal forecasts

- Implementation of **Advanced Regional Climate Services** Framework to cater to the needs of Agriculture, Water Resources, Alternate Energy Resources and Health on the basis of location specific and user specific knowledge of the climate variability and predictions of climate variables. Assessment of extremes and impacts.

Restructured Functional Activities (under GFCS umbrella of WMO)

- Climate Monitoring and Analysis
- Climate Research and Prediction
- Climate Data Management and Services
- Climate Applications and User Interface
- Information Technology and Scientific Secretariat
- Regional Climate Services
- Training & Capacity Building on the use of regional climate products for climate services

Coupled Ocean-Atmospheric Dynamical Forecasting System

Monthly and seasonal rainfall and 2m temperature anomaly maps for the south Asia are prepared using the latest high resolution (T382L64) research version of the coupled forecasting system (CFS) model (Updated every month)

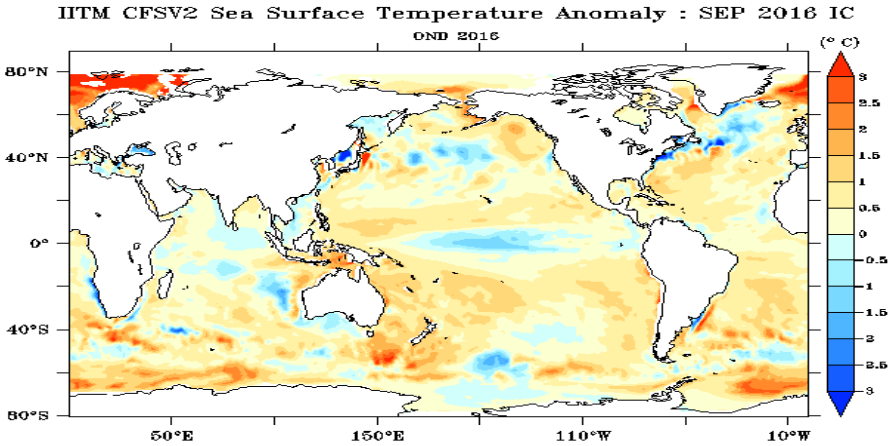
Ensemble size:	12 members for hindcast and 40 members for forecast
Lead-time:	One-month lead forecasts
Period of verification:	Three-month
period of Hindcast:	1981-2009
List of parameters:	Precipitation, T2m and SST
Details of verification:	Precipitation: GPCP, T2m: ERA40, SST: NCEP

Operational Long Range Forecasts for India

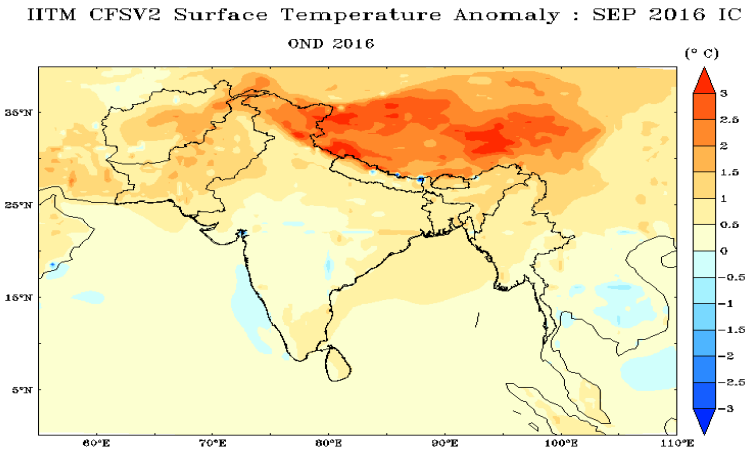
Sr. No.	Forecast for	Region for which forecast issued	Issued in
1	Winter Season (Jan- March) Precipitation	Northwest India	**December**
2	**Hot Weather Season Outlook (Apr-Jun)**	**Country as a whole**	**31st March**
3	SW Monsoon Season (June to September) Rainfall	Country as a whole	**April**
4	SW Monsoon Season (June to September) Rainfall	Country as a whole	**June**
5	South-West Monsoon Onset	Kerala	**May**
6	SW Monsoon Season (June to September) Rainfall	Four broad geographical regions: Northwest India, Northeast India , Central India and South Peninsula	**June**
7	SW Monsoon Monthly Rainfall for July and August	Country as a whole	**June**
8	SW Monsoon Second half of the Season (August- September) Rainfall	Country as a whole	**July**
9	September Rainfall	Country as a whole	**August**
10	NE Monsoon Season (October to December) Rainfall	South Peninsula	**September**
11	**Cold Weather Season Outlook (Dec-Feb)**	**Country as a whole**	**30th November**

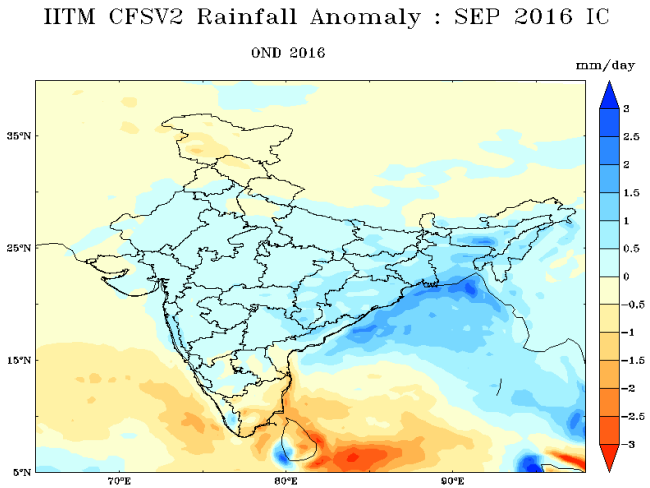
LRF Maps

Global SST Ano. Forecast



South Asia 2m Temp. Ano. Forecast





India Rainfall Ano. Forecast

ENSO & IOD Forecast Bulletin (Every month)

Ministry of Earth Sciences

Ministry of Earth Sciences
Government of India

El Niño/La Niña
Indian Ocean Dipole
Update (15th October 2016)

1. Current Sea Surface Temperature (SST) Conditions over Pacific & Indian Oceans

During September 2016, cool SSTs anomalies persisted along much of the equator in the eastern and central Pacific crossing the date line, while positive SST anomalies were observed over north and south of this band. Cool SST anomalies (since August 2016) were observed over North Pacific Ocean off the west coast of North America, which was warmer as observed in July month. Cool SST anomalies persisted in the subtropical north and south Pacific. SST anomaly difference from August to September (Fig.1b) shows there was SST cooling of up to -1°C over the small patches along the equator in the eastern and central Pacific and a smaller region in east pacific showing warming of SSTs. Slight increase in SST positive anomaly over some pockets of east Pacific Ocean was observed as compared to August month, where cooling was observed over the entire equatorial Pacific Ocean.

During September 2016, cool SST anomalies were observed over most parts of Arabian Sea, equatorial Indian Ocean and south subtropical Indian Ocean (Fig.1a) and warm anomalies is observed over Bay of Bengal and over maritime continents in the east equatorial Indian Ocean. The positive anomalies which were observed over the maritime continents in August continue to exist. During September, cooling of SST was observed over the entire Indian Ocean while warm SSTs persisted over maritime continents in east equatorial India Ocean (Fig.1b).

1.1. El Niño Southern Oscillation (ENSO) conditions over the Pacific Ocean

The monthly time series of Niño3.4 SST anomalies for the last 12 months (Fig.2a) suggest that the El Niño conditions which started since April 2015 after peaking during December 2015 have continued to weaken to neutral conditions in summer 2016. In association with the decay, cool subsurface anomalies were observed in the western Pacific crossing the date line towards east (Fig.2 b).

1.2. Indian Ocean Dipole (IOD) Conditions over Indian Ocean

Warm subsurface (Fig. 2d) anomalies were observed in the eastern Equatorial Indian Ocean. Cool subsurface anomalies which were seen over a region centred at 50°E at thermocline level (approximately about 100m depth) in September. The subsurface dipole strength is stronger in September compared to August. The September Dipole Mode index (DMI) suggests negative IOD conditions currently present in the Indian Ocean (Fig. 2c).

2. ENSO & IOD Forecast

The SST forecast were prepared using the ESSO-IMD-IITM high resolution Coupled Forecast System (AGCM T382L64; 38 km and OGCM 25km in tropics) based on 2016 September initial conditions. The initial conditions for the model runs were obtained from ESSO-INCOIS and ESSO-NCMRWF analysis. Probability density function (PDF) correction, based on hindcasts for the period 1982-2008 was applied over the forecasts of Niño3.4 index (Fig.4a) and DMI (Fig.4b).

The forecasted 3-month season averaged SST anomalies (Fig.3) indicate cooler SST anomalies in the central equatorial Pacific Ocean in OND season, which persisted till DJF with reduced intensity. Warming of SST conditions is observed in either side of this narrow band till JFM season. There is neutral El Niño condition currently prevailing in Pacific Ocean which is likely to remain the same for the forecasted seasons (Fig.4a). In the central Indian Ocean, cool SST anomalies are observed in OND season and are likely to remain near normal in the later forecasted seasons (Fig.3). The IOD conditions over Indian Ocean are likely to remain negative in OND season (Fig.4b) and remain neutral in the later forecasted seasons.

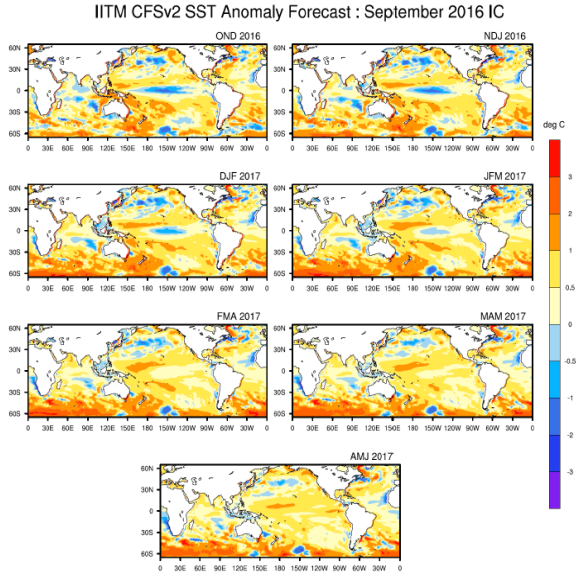


Fig.3: Forecasted Seasonal mean SST anomalies for 3 monthly seasons, (a) October through December (OND), (b) November through January (NDJ), (c) December through February (DJF) (d) January through March (JFM), (e) February through April (FMA), (f) March through May (MAM) and (g) April through June (AMJ).

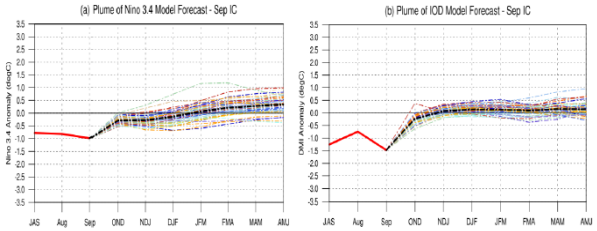


Fig.4: Plume of (a) Niño 3.4 SST anomalies, (b) Indian Ocean Dipole Mode Index forecasted by high resolution CFSv2. The forecasts were PDF corrected for bias and variance. The solid red line is the observed SST anomaly (INCOIS-GODAS) and dashed black line is the ensemble SST anomaly forecast mean of 47 members (CFSv2). The individual ensemble member forecasts are shown in light dotted lines of different colours.

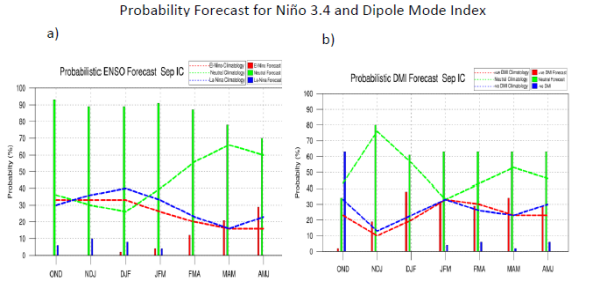


Fig.5: Probability forecast along with climatological probability of **(a)** Niño 3.4 and **(b)** Indian Ocean Dipole Mode Index from high resolution CFSv2. Data source for Climatology probabilities: NOAA Extended Reconstructed SST V3b. Criteria used for Probabilistic ENSO Forecast: ≤ -0.5 La Niña, >0.5 to <-0.5 neutral, ≥ 0.5 El Niño. Criteria used for Probabilistic DMI Forecast: ≤ -0.2 negative DMI, >0.2 to <-0.2 neutral, ≥ 0.2 positive DMI.

The probability forecast suggests that there is highest probability for ENSO neutral conditions for the season OND and later seasons, which gradually reduces to about 70% in the AMJ forecasted seasons. The probability for neutral ENSO condition remain significantly above the climatological probability throughout the forecast range, which indicate high confidence for the forecast of neutral ENSO condition. The probability for a La-Niña condition is very small and not at all significant, while there is a slight probability for the revival of another episode of El-Niño in the coming pre-monsoon season (AMJ), which is further subjected to the limitations of the spring barrier of ENSO predictability.

The DMI probability forecast for OND season indicates high probability (63%) for negative IOD mode conditions but reduces sharply during NDJ and remain not significant based on climatological probability. Neutral DMI forecast probability indicates increase from OND season to NDJ season and thereafter a slight decrease from DJF season and continue to remain constant and significant till AMJ season.

Seasonal Climate Outlook for South Asia

Ministry of Earth Sciences
Earth System Science Organization

India Meteorological Department
WMO Regional Climate Centre
(Demonstration Phase)
Pune, India

SEASONAL CLIMATE OUTLOOK FOR SOUTH ASIA

(September to December 2016)

Issued in September 2016

- During August 2016, neutral El Niño conditions prevailed over equatorial Pacific Ocean with sea surface temperatures along the equatorial Pacific being cool. The latest coupled model forecast suggests moderate warming will start from January 2017.
- The 2016 spatial pattern of the SON precipitation forecast indicates above normal precipitation over most parts of Central India, whole of Bangladesh, Bhutan, eastern Nepal and Myanmar. The OND precipitation is likely to be similar as that of SON season but with less intensity.
- The country averaged monthly precipitation is likely to be below normal for Afghanistan and Pakistan and normal to above normal for rest of the South Asian countries for the month September, October, November and December .
- The 2016 SON mean temperatures are likely to be normal over all the South Asian countries except for extreme northern parts of India. The OND mean temperatures shows similar pattern as that of SON with increase in the intensity of the anomalies.
- The country averaged monthly mean temperature is likely to be above normal for all South Asian countries for all months (September, October, November and December).

DISCLAIMER:
(1) The long range forecasts presented here are currently experimental and are produced using techniques that have not been validated.
(2) The content is only for general information and its use is not intended to address particular requirements.
(3) The geographical boundaries shown in this report do not necessarily correspond to the political boundaries.

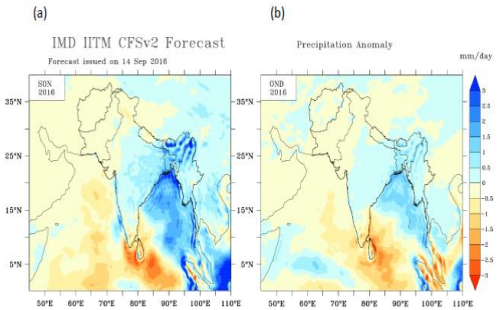


Fig.5: Seasonal forecasts of precipitation anomalies (mm/day) for (a) SON and (b) OND (right) based on Initial conditions of August 2016.

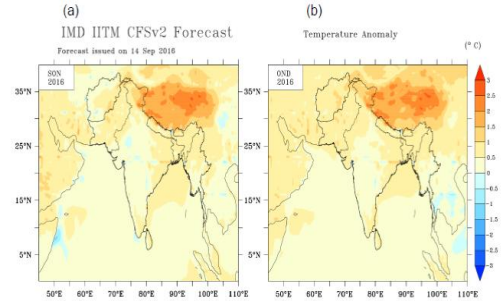


Fig. 6: Seasonal mean temperature anomalies (°C) for (a) SON and (b) OND (right) based on Initial conditions of August 2016.

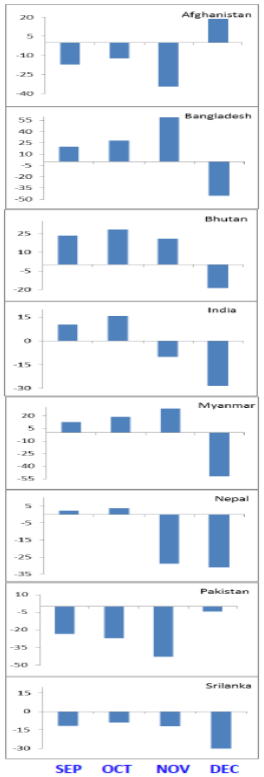


Fig.7: Monthly country averaged rainfall forecast expressed as percentage departures (%) during September to December, 2016 (Normal % departure range 10≥0≥-10).

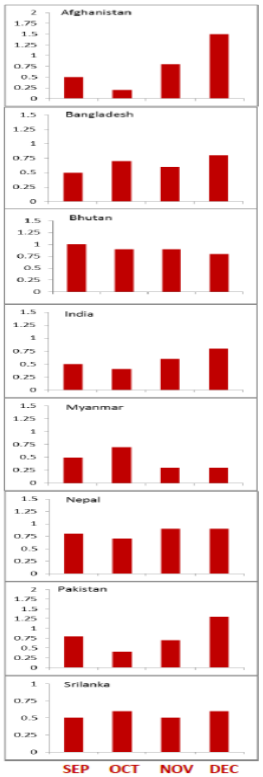


Fig.8: Monthly country averaged temperature anomaly (°C) forecast during September to December, 2016 (Normal anomaly range 0.25≥0≥-0.25)

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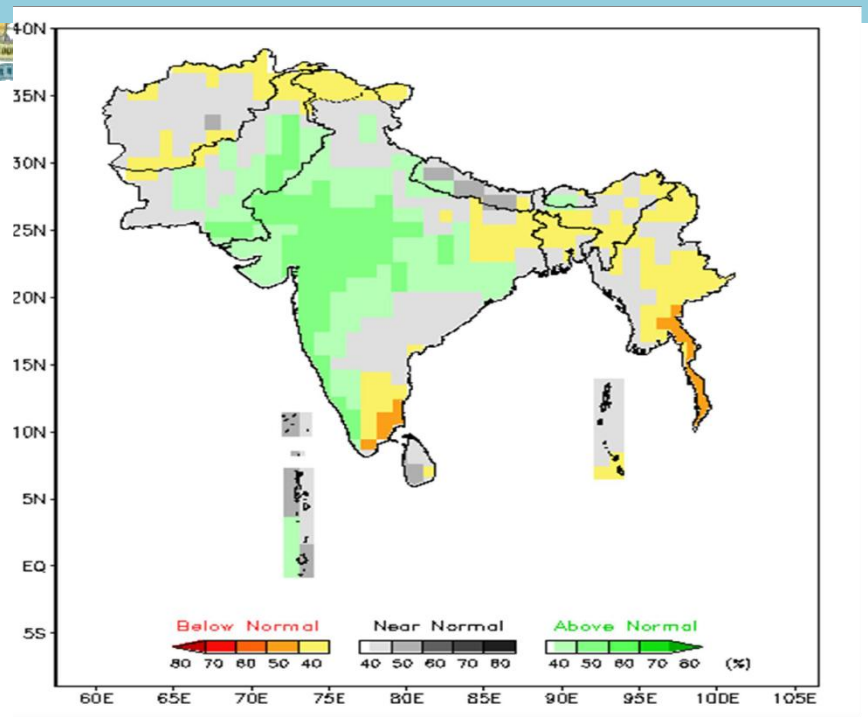
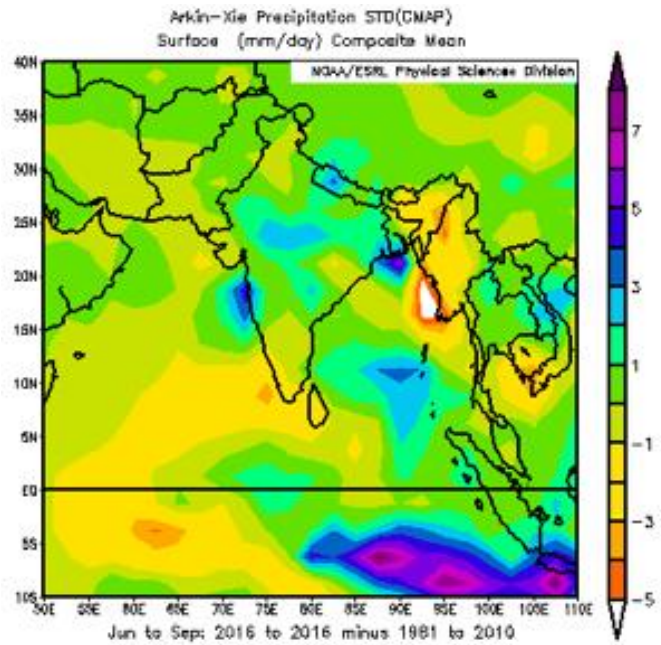
SASCOF meetings

- SASCOF is co-sponsored by WMO and coordinated by India (under the demonstration phase for a WMO RCC for South Asia)
- Participating Countries- Afghanistan, Bangladesh, Bhutan, India, Maldives, Myanmar, Nepal, Pakistan and Sri Lanka.
- SASCOF I-III SW Monsoon April (2010-2012) held in India

SASCOF-IV	SW Monsoon	April 2013 held in Nepal
SASCOF-V	SW Monsoon	April 2014 held in India
SASCOF-VI	SW Monsoon	April 2015 held in Bangladesh
SASCOF-VII	NE Monsoon	OCTOBER 2015 held in India
SASCOF-VIII	SW Monsoon	April 2016 held in Srilanka
SASCOF-IX	NE Monsoon	OCTOBER 2016 held in Myanmar

Consensus forecast of 2016 SW Monsoon Rainfall over South Asia (issued in April every year)





Above-normal rainfall is most likely during the 2016 southwest monsoon season (June – September) over much of South Asia. More specifically:

· Above-normal rainfall is most likely over broad areas of central and western South Asia.

· Below-normal rainfall is most likely over eastern parts of the region and the southeastern part of the peninsula.

· Normal rainfall is most likely over the remaining areas.

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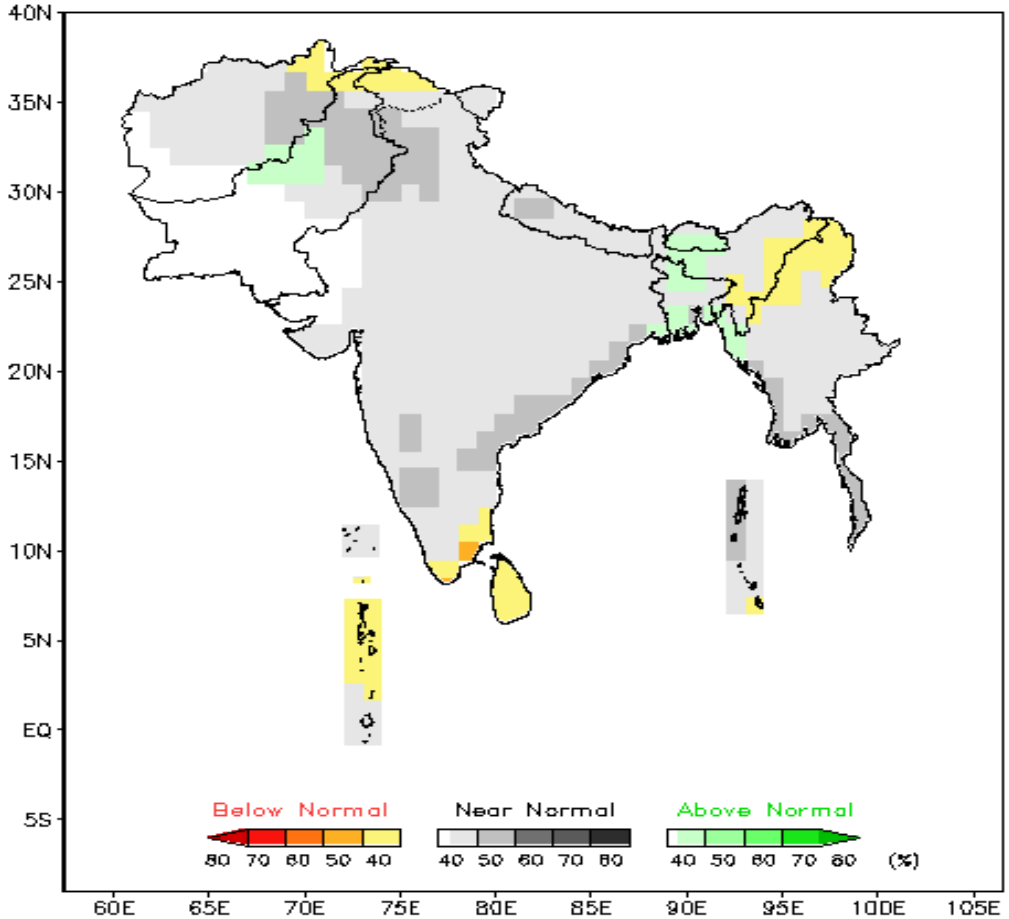
Consensus Forecast Map: 2016 Northeast Monsoon Season (OND)

OND Precipitation



Normal rainfall is most likely over most parts of south Asia during the 2016 Northeast monsoon season (October – December). However, below normal rainfall is likely over some areas of southeast peninsular India, Sri Lanka and Maldives. Below normal rainfall is also likely over some areas of north and eastern parts of the region. Above normal rainfall is likely over western and northwestern parts of Pakistan and some northeastern parts of the region.

During the season, normal to slightly above normal temperatures are likely, over most parts of the region.

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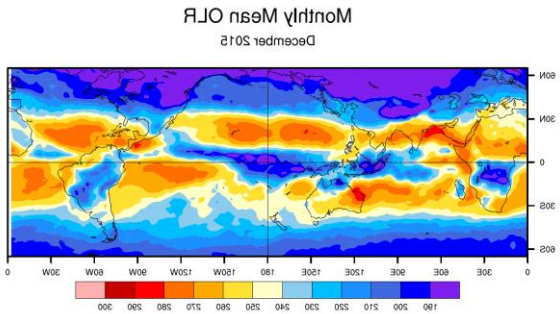
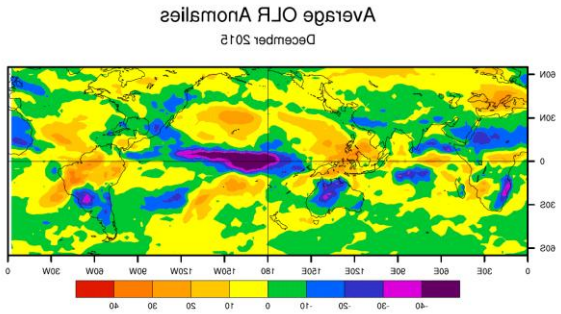
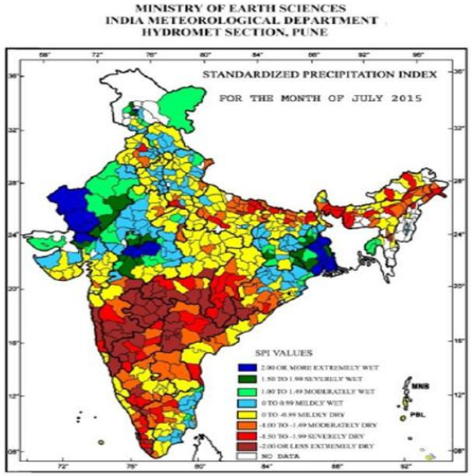
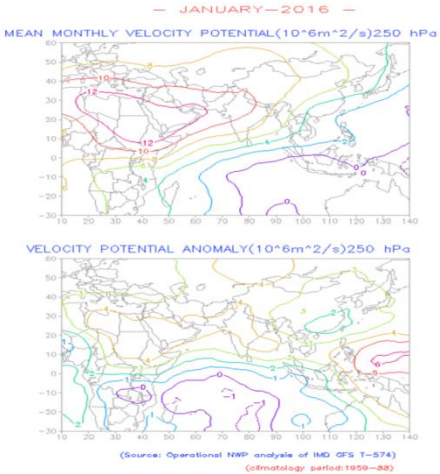
Spatial Maps of Climate Variables

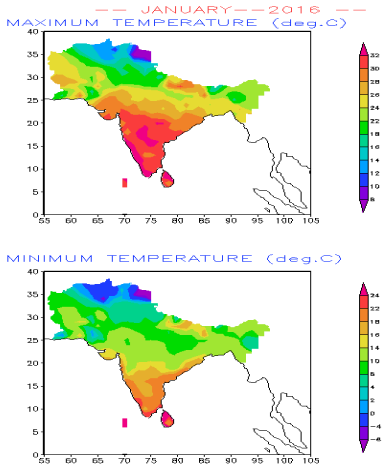
- Mean Sea Level Pressure
- Maximum & Temperature Temperatures
- Rainfall Mean
- Wind Anomaly
- Velocity Potential
- Stream Function
- OLR Anomaly
- ENSO Indices
- Indian Ocean Dipole











Data Services

Digitized data set of Daily Maximum and Minimum Temperatures recorded during the period 1889 to 1930 (based on 8 AM observations) from India and 109 stations data from south and West Asia.

The following high resolution gridded climate data sets over Indian region are available. The data are being updated regularly.

- **1^oX1^o Gridded daily rainfall data (1951-2014)**
- **1^oX1^o Gridded daily rainfall data (1901-2014)**
- **0.5^o X 0.5^o Gridded daily rainfall data (1971-2005)**
- **0.25^o X 0.25^o Gridded daily rainfall data (1901-2014)**
- **1^oX1^o Gridded daily Temperature (mean, maximum and minimum) data (1951-2013).**
- **In addition, 0.5^o X 0.5^o Gridded daily rainfall (Guage + TRMM) data (1998-2013) over south Asia.**

Information Dissemination system

2006

- Cyclone warnings for disaster managers and general public were issued through AIR, TV, Telephone/FAX, website, Print & electronic media in 2006.

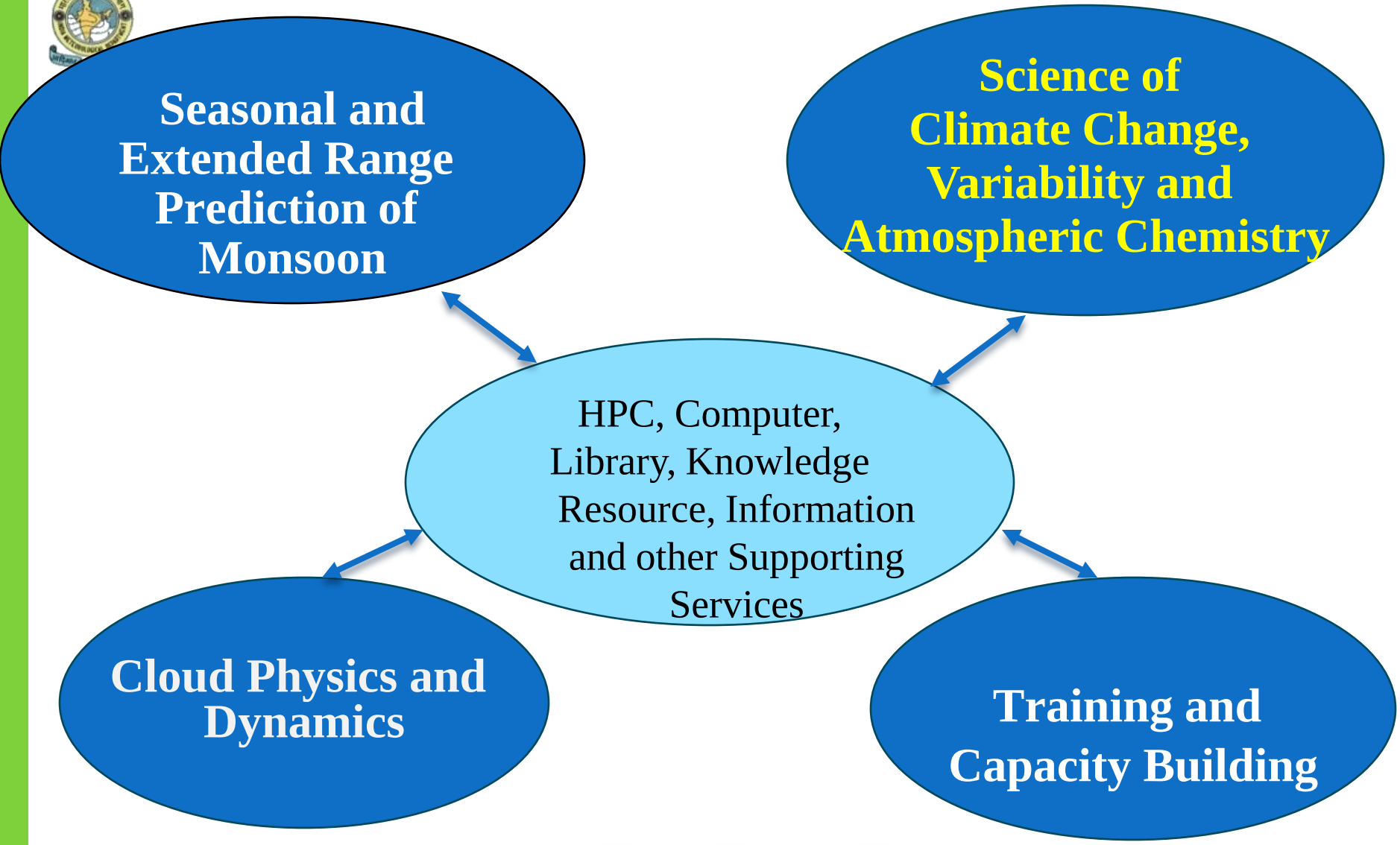
2016

- Increase its reach out among general public, media, disaster managers, specific users and decision making authorities through new initiatives.
- Cyclone warnings for disaster managers and general public were issued through AIR, TV, Telephone/FAX, website, Print & electronic media in 2006. By 2016, the additional modes of dissemination such as FM radio, community radio, e-mails, SMS, Kisan Portal, Google Alerts etc.
- Information dissemination of **alerts & warnings on android based smart phones/tabs**.
- Use of FM and community radio and SMS alerts during last two years has further increased the reach out of

By 2024

- Generation of apps and more use of IT to increase its reach out among general public, media, disaster managers, specific users and decision making authorities.
- Display System at all mega cities and tourist places
- Mobile APP for all cities and tourist places, Common Alert Protocol for all hazards

Focused Science Plan: MoES Missions



Activities Critical for Coastal Areas

– multi-scale networks over Land (**Doppler Weather Radars; Automatic Weather Stations/Rain Gauges; High Wind Speed Recorders etc.**), Sea (

in-situ airborne & ship borne platforms and Satellite Based systems (**INSAT, Kalpana, OCEANSAT, Megha Tropique, NOAA, EUMETSAT** etc.) for real time data transmission and reception

-

Cyclones; Tsunami and Storm Surges; other severe weather systems; River basin scale meteorological support for CWCs river warning system

risk reduction, sustainable shoreline management natural resource management

Future Plans for Coastal Areas

capture vital signatures of the earth system response to climate variability and change

Changing Water Cycle; thermal expansion of Bay of Bengal and Arabian Sea; Sea Level Changes & coastal zone impacts;

coupling of various sub-systems (ocean-atmosphere; land-atmosphere; cryosphere-atmosphere; biogeo-chemical cycles over ocean and land; aerosols-GHGs-clouds-precipitation etc

agriculture, water, health and climate and disaster risk management