Weather and Climate Modelling Efforts at MoES

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Major Weather and Climate Prediction Activities

- IMD is supported by NCMRWF and IITM Pune for modelling activities.
  - Short to medium range prediction
  - Extended Range Prediction
  - Seasonal Forecasts
  - Modelling of Water Cycle
  - Fog Prediction efforts
  - Air Pollution Emergencies

- Two modelling frameworks are being used:
  - NCEP GFS and CFS models
  - UK Met Office Unified Models
  - Seamless prediction
Models being used for operational work at MoES

• Short to Medium Range
  • GFS Model T1534 (12 Km) – Deterministic
  • GFS Model T 574  - Ensemble (20 Members)
  • UKMO UM N768 (17 Km) Deterministic
  • UKMO UM N400 (33 Km) Ensemble – 44 Members
  • UKMO UM Regional Model- 4 km

• Extended Range
  • CFS/GFS Model T126 – Original and bias corrected
  • CFS/GFS Model T382 - Original and bias corrected

• Seasonal Forecasts
  • CFS Model T382- 40 Ensembles

• Climate Change Projections- Earth System Model
  • CFS Model -T62
<table>
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<th>Observation Type</th>
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<tr>
<td>AMSU/MHS radiances</td>
<td>NOAA, MetOp Satellites</td>
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<td>HIRS clear radiances</td>
<td>NOAA, MetOp Satellites</td>
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<td>IASI and AIRS radiances</td>
<td>MetOp satellites (IASI), Aqua (AIRS)</td>
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<td>ATMS &amp; CrIS radiances</td>
<td>Suomi NPP</td>
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<td>MT-SAPHIR radiances</td>
<td>Megha-Tropiques</td>
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<td>Geo Imager – cloud clear IR radiances</td>
<td>Meteosat, GOES Satellites</td>
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<td>Geo Sounder – cloud clear IR Radiances</td>
<td>INSAT-3D</td>
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<td>GPS RO bending angles</td>
<td>COSMIC, MetOp/GRAS, GRACE</td>
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<tr>
<td>GPS ZTDs</td>
<td>Global observations (various locations)</td>
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<tr>
<td>Satellite Atmospheric Motion Vectors</td>
<td>INSAT-3D, Meteosat-7&amp; 10, GOES-E&amp; W, Himavari-8, AQUA, NOAA &amp; MetOp Satellites</td>
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<tr>
<td>Scatterometers : Sea-surface winds</td>
<td>MetOp Satellites (ASCAT)</td>
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<td>Surface soil moisture/wetness</td>
<td>MetOp Satellites (ASCAT)</td>
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<tr>
<td>Aerosol Optical Depth (for dust)</td>
<td>AQUA, INSAT-3D (experimental)</td>
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</table>
Comparison of NCMRWF 4D-VAR with Hybrid 4D-VAR DA System
(Hybrid 4D-Var system uses 44 member Ensemble forecast of NCMRWF)

Hybrid 4D-VAR replaced the 4D-VAR Data Assimilation system at NCMRWF in Sept-2016

Recent improvements in Data Assimilation (DA) System at NCMRWF

NCMRWF is providing required initial atmospheric conditions for both GFS/CFS and UKMO UM.
Radar Data Assimilation in 4 km NCUM Regional Model
Verification of Rainfall forecast

Rainfall Observation
(IMD-NCMRWF)

24 hr forecast:
DA with GTS+Satelite Obs

DWR Radial Wind Assimilation in Regional NCUM DA system

Rainfall valid at
00 UTC 27-July-2016
(24 hr forecast based on
00 UTC 26-July-2016 initial condition)

24 hr forecast: DA with
GTS+Satellite+Radar

DWR wind observations used in DA

Number of DWR radial wind observations used in DA from each radar is given in the brackets

1. Srinagar (3)
2. Patiala (122)
3. Delhi (99)
4. Patna (342)
5. Agartala (249)
6. Jaipur (426)
7. Bhopal (204)
8. Hyderabad (227)
9. Visag (111)
10. Machilipatnam (177)
11. Chennai (145)
12. Karaikal (177)
Coupled OCN/ATM model

Data Assimilation

forecast

analysis

OCN obs

Strongly Coupled DA

OCN obs

Data Assimilation

forecast

analysis

ATM obs

Weakly Coupled DA

Coupled OCN/ATM model

Data Assimilation

forecast

analysis

OCN obs

ATM obs
Forecast valid for 0300UTC of 13-Dec

Total rainfall (cm) over 12-14N, 79-80.5E contributed from various categories (cm/day)

X axis: rainfall bins
Y axis: rainfall (cm)
Based on 10 Dec IC

2016 Tropical Cyclone Tracks
Storm: NI0116 (VARDAH)

Forecasts: Beginning 2016121000
Observed: Beginning 2016121000, every 12 hours
Recent very heavy rainfall over west coast predicted by GEFS T574 (30 km) with the probability


11-20 cm/day prob

20cm/day & more

As per the IMD records, the 24 hr accumulated station rain on 23 Sep 2016 over

Colaba:45mm; SantaCruz: 40 mm;
Harnai, Goa: 136.7 mm
Probabilistic Prediction of Heavy rain over Chennai associated with Cyclone VERDAH 12 Dec 2016

Forecast valid for 00Z13Dec2016

IC: 00Z12Dec2016
Figure 10. POD for Day-1 to Day-5 forecasts of the MoES models for four different rainfall categories namely (a) Very Light Rain, (b) Light Rain, (c) Moderate Rain and (d) Heavy Rain.
Figure 11. FAR for Day-1 to Day-5 forecasts of the MoES models for four different rainfall categories namely (a) Very Light Rain, (b) Light Rain, (c) Moderate Rain and (d) Heavy Rain.
Extended Range Forecasts
Gain through CGEPS MME system:

1. Improved spread and Reduction in RMSE
2. Improvement in Probabilistic forecast Skill

Considerable improvement in MME is contributed from the increased spread, which overcomes the under-dispersive nature of the individual models in EPS.

Abhilash et al. 2015, JAMC; BAMS
Prediction of MOK during 2015 monsoon

MOK date has been calculated for all 44 members of CGEPS and the mean of all of them is given as the final predicted MOK date.
Prediction of Heavy Rainfall Events

Uttarakhand event in June 2013 (IC: 0605)

MME, Forecast Valid Time = 00Z06JUN2013
Extreme Precipitation (Probability)

OBS, Time = 00Z06JUN2013
Rainfall (shaded, mm/day) & 850hPa winds (vector, 20°)

MME, Forecast Valid Time = 00Z06JUN2013
Rainfall (shaded, mm/day) & 850hPa winds (vector, 30°)
Prediction of Cyclogenesis

Cyclone Roanu in May 2016

IC: 11 May
MJO Reconstruction March-April 2009 period

MJO Filtered spatial anomalies
OLR(shaded) and OBS Chi at 200hPa(contourx10^6)

OBS 20090327

MJO verification of 0327 2009 forecast
MME OBS

West Rem. & Africa

Indian Ocean

RMM1

RMM2

CONTOUR FROM -10 TO 10 BY 1
Prediction of Heat Waves

Heat Wave in May 2016

Predicted Heat Index
IC: 0516

Forecast Valid Time = 17 MAY 2016
Probability of Occurrence for:

Observed Heat Index

HOT

HW

SHW
Seasonal Forecasts
STATE OF THE ART COUPLED MODELS PREDICTION SKILL (Correlation between observed and Predicted) OF TROPICAL PRECIPITATION (Prior to Monsoon Mission)

Earlier version models
1979-1999

Latest models (ENSEMBLES)
1979-1999

Poor skill
Preeti et al., (2009)

High skill
Rajeevan et al., (2011)
IITM CFS Model: Seasonal Prediction

Atmospheric Model
GFS
T382 L64 levels

Land Model
NOAH

Ice Model

Ocean Model
MOMv4
global
1/2° x 1/2° (1/4° in tropics)
40 levels

COUPLER

ATMOSPHERE INITIAL CONDITIONS FROM GSI (NCMRWF)

OCEAN INITIAL CONDITIONS FROM GODAS (INCOIS/IITM)

Initial conditions for Hindcast runs are obtained from CFSR

(Original model is adopted from NCEP)
Anomaly Correlation Between Observed and Predicted (Rain: 1982-2008)
Monsoon Mission Model Performance (Prediction Skill as well as interannual variance) is better than other models for Indian Monsoon.
Forecast Verification for 2015 Summer Monsoon
IITM CFS T382

Observed, 84%
Feb. IC, 91%
Apr. IC, 84%
For the first time, IMD issued a seasonal forecast for hot weather season, which has become a very successful.
GCRMs have arrived.

BUT, GCRMs can now be run for a few simulated months, at most.

Cloud Resolving Models
Superparameterized CFSv2-T62 (SPCFS) Analyses of 6.5 year free run

Convective tendencies are explicitly simulated with a Cloud Resolving Model running in each GCM grid column which replaces the traditional cumulus parameterization of the GCM.

• Model integrated for 6.5 years and five years are analyzed

SP-CFS has improved the bias in synoptic and ISO variance.
ILS is incorporated in CFSv2, which involves incorporation of five prognostic variables into ESMF, initial conditions, restart file

- A preliminary result from the simulation of one year it is evident that amount of snow is much reduced in new version of CFSv2
- There is further scope to improve snow depth simulation using new schemes (continuing)
Most of the models produce ~80-90% convective rain and 10-20% stratiform rain as against 55% convective and 45% Stratiform rain in reality.
Revised Cloud-Convective-Radiation in CFSv2 T126

Clouds are the result of complex interactions between a large number of processes.

SAM: System of Atmospheric Model

Courtesy: Partha
Revised convection, modified microphysics and radiation is able to improve the mean state and Intra-seasonal variability of CFSv2T126

Annual Rainfall Cycle
<73°-85°E,15°-25°N>

Annual TT Difference
<40°-100°E,5°-35°N> - <40°-100°E,15°S-5°N>

<40°-120°E,15°S-30°N>

Abhik et al. (under revision)
Vertical distribution of clouds (JJAS) averaged over 80-90E and 90 to 100E

CFS

CFS-CR

Low Cloud captured by CFS-CR as seen in CloudSat observations. CFSv2 does not capture.

T. Narayan Rao, Aneeshkumar et al.

Courtesy: Dr Partha, IITM
IMD Pune now has been recognized by WMO as the Regional Climate Centre to provide regional climate services.

www.imdpune.gov.in
Climate Change Modelling
The coupled ocean-atmosphere-land model with interactive ocean bio-geochemistry developed at CCCR, IITM to study the long-term changes in Climate with special emphasis on Asian Monsoon. The components of IITM ESM are Atmosphere (NCEP GFS, Ocean (MOM4p1, GFDL) and Land (NOAH) model.
CMIP6 Concept: A Distributed Organization under the oversight of the CMIP Panel

Initial proposal for the CMIP6 experimental design has been released

IITM ESM will participate in the climate modeling CMIP6 experiments for the IPCC 6th Assessment Report
Time-varying aerosol distributions in IITM ESM from CMIP

(Courtesy: Ayantika Dey Choudhury; Data source: Stefan Kinne, Bjorn Stevens, Max Planck)
Chlorophyll Concentration (Mg m$^{-3}$)

Obs (SeaWiFS)

IITM ESMv2

Courtesy: Sandeep, CCCR
Improvements in IITM ESMv2 Mean Monsoon Characteristics

Significant reduction in precipitation bias

Reduced bias in JJAS Tropospheric Temperature ($^\circ$C, 200-500 hPa)

JJAS ISO northward propagation speed similar to observed of 1 ms$^{-1}$

Lead/lag correlation between ISMR and monthly Nino 3.4 Index

Courtesy: Swapna, CCCR
Large scale ocean overturning circulation - AMOC

Streamfunction (AMOC)

Salinity

(a) CSFv2 (AMOC)

(b) ESMv1

(c) ESMv2

(a) SAL (WOA)

(b) ESMv1

(c) ESMv2
The CORDEX vision is to advance and coordinate the science and application of regional climate downscaling through global partnerships.

**CORDEX South Asia Co-ordination @ CCCR, IITM, Pune**

- Development of multi-model ensemble projections of high resolution (50km) regional climate change scenarios for South Asia
  - Generation of regional climate projections at CCCR-IITM
    - LMDZ variable grid global climate model
    - RegCM4 regional climate model
    - Co-ordination with partner institutions for multi-model ensemble projections – SMHI, IAES, CSC, CSIRO, ICTP...

- Development of an Earth System Grid (ESG) node at CCCR-IITM for CORDEX South Asia
  - Archival, Management, Dissemination of CORDEX South Asia data

- Evaluation of regional climate projections over South Asia
  - For reliable regional climate change information for effective harnessing of science-based climate information by Vulnerability, Impact Adaptation (VIA) community

- Development of regional capacity for assessment of regional climate change
CORDEX South Asia (WAS-44) Datasets Published on Earth System Grid Federation (ESGF)

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Published:
- Control (1951-2005): 8
- RCP2.6 (2006-2100): 3
- RCP4.5 (2006-2100): 8
- RCP8.5 (2006-2100): 8

Finished:
- Control (1951-2005): 19
- RCP2.6 (2006-2100): 3
- RCP4.5 (2006-2100): 18
- RCP8.5 (2006-2100): 16
Modelling of Water Cycle
Simulated Discharge using various types of Input datasets

Sarita Tiwari et al (2016) HSJ, under review
Prediction of Fog
WIFEX 2016-2017 (IGI Airport, New Delhi)

(32 scientific equipment to monitor:
Ground and surface properties, Surface layer meteorology, Radiation fluxes, aerosol and fog microphysics, optical properties,

Atmospheric profiles (102 meter high resolution T&Rh)

Nano size particle measurements
(Secondary aerosols, CCN, water partitioning in system, visibility parameterization)

➢ Fog microphysics
➢ Chemical analysis of aerosols (PILS)
➢ 102 meter high resolution Rh & T profile
➢ New flux measurements at Hisra
➢ Experimental forecast: IITM GFS (12km) and WRF (2 km)
18h Forecast Generated using IITM GFS (12 km) and IITM-WRF (2 km) for recent fog event

30 November

1st December
The trend of visibility is predicted reasonably well by the model, however, model predicted visibility values are much higher.
Future Strategy for next 3-7 years

• Global Ensemble High Resolution Weather Forecasting System (10-12 Km resolution).
  • Probabilistic forecasts of severe weather events
  • Nowcasting systems (Radar/Satellite and Model based)
  • Urban Meteorology
  • Services to Energy Sectors (wind and solar)

• Multi Model Ensemble Extended Range Forecasting system
  • All the seasons, heat and cold waves,
  • More applications (Hydrology, Agriculture, Health).

• Multi-Model Seasonal Forecasting System
  • All the seasons, more applications, Regional climate services

• Hydrometeorological Forecasting system-
  • QPF for Flood Warnings, Urban and Flash Floods

• Prediction of Fog, Air Pollution Emergencies
Observations and Services

• Augmentation of regional meteorological observational network
  • Ideally 25 X 25 km surface and 100 X 100 km upper air, supplemented by satellite, RADARs, lightning sensors, LIDARs, Radiometers etc

• Improved Agro-meteorological Services
  • Block Level Forecasts through 660 District Centres

• Research Testbeds
  • Fog Prediction- at IIG Airport, Delhi
  • Monsoon Convection- At Sagar University, Madhya Pradesh, Bhubaneshwar

• Climate Reference Stations
  • Climate Change Monitoring
  • To start with 50 Pristine locations

• Special Observational network over NW Himalayas and North-eastern States.
Thank you