**Improving the Monsoon Prediction through Advancement in Data Assimilation, Model Physics and Resolution** of NWP System: **NCMRWF Experience** 

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### National Centre for Medium Range Weather Forecasting (NCMRWF)

### **Core Operational Capabilities:**

- High Resolution Regional Models for Short Range NWP
- Global NWP system for Medium Range forecast
- Coupled Forecast System for S2S forecast (Coupled Medium-Range forecast system will be operational soon)
- Data Assimilation Atmosphere, Ocean, Sea-Ice & Land Surface
- Global & Regional Reanalysis (NGFS & IMDAA Reanalysis)

**NCMRWF** Mission

continuously develop advanced NWP systems, with increased reliability and accuracy over India and neighboring regions through research, development, and demonstration of new and novel applications, while maintaining the highest level of knowledge, skill, and technical expertise



NCMRWF: Operational NWP since 1994

(Analysis/Forecast Charts Valid on 30 Oct 1996 from operational T80L18 global model )





## Improvement in NWP : Efforts of NCMRWF

- Improvement in model resolution (Global & Regional)
- Use of Coupled Systems
- Better representation of Physical process Use of advance Physical Parametrization
- Data Assimilation improvements Advanced Methods & Use of more observations
- Focus on Diagnostics & Verification
- Development of products based on user needs

All are achieved though collaborations & in-house R&D

## **Observation Reception & Processing**

- NCMRWF Data Assimilation (DA) systems uses millions of observations from global sources daily to produce Atmospheric, Ocean, Sea-Ice and Land Surface analyses, which serve as the initial conditions for model forecasts.
- NCMRWF DA systems provide model initial condition to GFS/GEFS systems of IMD and UM based NCUM/NEPS NWP systems of NCMRWF.

#### Meteorological Observation Reception System DBNet INSAT3D Imager EOS-6 (Oceansate-3) ISRO INSAR 3DR Sounder & Ima IMD EOS-7 (Microsate-2B) GNSS-IPW ARGO-AWS A. 31. H. 9. State owned AWS Satellite Winds CUSAT ST RADAR Satellite Radiance Navy Wind Profilers OTHERS NOAA Other Satellite Ot Suominet (GPS-IPW) CMA (FY4A) KMA (COMS2)

Satellite Winds

DBNet

Satellite Radiances

Other Observations

EUMET

Cast



GTS

Surface Obs.

· Upper Air Obs.

· Satellite winds

GNSS

Satellite Radiances

#### **Reception of Global Observations (Atmosphere, Ocean, Sea Ice & Land Surface)**





## Major Upgrades of NCMRWF Global Data Assimilation Systems



## **Indian Satellite Data** Added to the NCMRWF **NWP System: Timeline**



**INSAT-1D (1996)** Prasad et al., (2003)



Kar et al., (2003) Das et al., (2004)

### Impact of observations in the NCMRWF Data Assimilation System 2014-2024



### **Impact of Observation on 24-hour Forecast Calculated using FSOI**



(Left) Relative impact of observation on 24 hr global NCUM forecast, obtained using adjoint-based Forecast Sensitivity to Observation Impact (FSOI) method during the Indian Summer Monsoon period (JJAS) of 2020, 2021, 2022 and 2023

## **Global Atmospheric Models : Resolution Improvements**



#### **Current Operational Global NWP System**

#### Model

#### **Data Assimilation**

Name:NCUM-G Resolution: 12km UM vn: 11.2 Domain: Global Levels:70 Grids: 2048x1536 Timesteps: 5min Science : GA7 Dynamics: ENDGame Forecast lead time: 10 days Atmospheric DA: Hybrid 4D-Var Cycling periods: 00,06,12,18 Observation cut off: 3hours Land DA: sEKF (only soil moisture)

#### **Experimental Systems:**

- (1) Coupled Global NWP system of 10 km horizontal resolution atmosphere, 25 km Ocean with weakly coupled DA – will operation in mid-2025.
- (2) 6 km resolution Global Atmospheric Model

#### KERALA (WAYANAD) HEAVY RAIN (cm/day) PREDICTION BY NCUM-Global VALID FOR 03Z 30 JULY 2024



#### MEAN RAINFALL NCUM-G 15 JUN – 14 JUL 2024 DAY-5 FCST

BIAS



- Compared to observations GAL7 shows more precipitation along the west coast
- Precipitation maxima was slightly towards the south along the west coast.
- More precipitation over CoMorph-A over the open ocean.
- Overall slightly improved performance for GAL8 compared to GAL7.

#### NCUM-Global Lightning scheme – Improvements Monsoon case study (IC 14 July 2023)



#### **Modified Lopez**



#### Modified PR92



#### **Blended scheme**





## **Developments in Coupled Modelling**

### Short & Medium-Range Weather Prediction (Experimental)

- The new coupled NCUM model has s atmosphere, ocean, sea ice, and land components with 10 km atmospheric and 25 km ocean resolution. It successfully produced experimental forecasts during the 2024 summer monsoon.
- NCMRWF is also developing a high-resolution regional model for India with 4 km atmospheric and 2.2 km ocean resolution to improve forecasts for tropical storms and extreme weather.

#### S2S Prediction System (Operational)

- NCMRWF developed a Subseasonal-to-Seasonal (S2S) prediction system in the late 1990s using the T80L18 global model with observed Sea Surface Temperature (SST).
- A decade ago, NCMRWF adopted the UK Met Office's GLOSea coupled model system (GC2) for S2S forecasts.



## **Coupled Model for Medium-Range NWP**

## Mean Bias

Coupled Model Forecast has shown reduction in Bias over the eq. Indian Ocean and core monsoon zone

#### July 2024



**July 2023** 



## **Coupled Global Model : Comparison of Forecast Skill**

#### July 2023

July 2024



## Coupled Global Model : Extreme Event Case study

Himachal Pradesh experienced an unprecedented 436% more rainfall than normal from July 7th to 10th, 2023, resulting in devastating landslides, flash floods, and significant socio-economic losses.

#### Performance of Coupled Model seems better in long lead times



#### Forecast Valid for 00 UTC 10<sup>th</sup> July, 2023

## High Resolution Global Model Development : NCUM 6 km Model

## Atmospheric Kinetic Energy Spectra

Accurate representation of the global Kinetic Energy wavenumber Spectrum is considered essential in weather and climate models, partly because it establishes the saturation bounds for forecast errors at each scale



Figure indicates the spectral slope in the 6 km global model is closer to the -5/3 slope and hence a better representation of mesoscales in NCUMG-6 km than the NCUMG-12 km.

Niranjan Kumar et al., (2023), QJRMS, <u>https://doi.org/10.1002/qj.4531</u>

#### Gridded Satellite (GridSat) Imagery 10 JUL 2023 09UTC

NCUM-6G Forecast

## Explicit Simulations (NCUM-6G)

Improvements is seen in the mesoscale energy spectral slope, particularly with the explicit convection (EXPL) scheme in a high-resolution model from NCMRWF, showing better agreement with the -5/3 slope.







#### NCMRWF-6km Global Model

 Tropics has shown significant improvement in explicit convection experiment, particularly in terms of energy spectra and a spectral slope approaching -5/3 in the mesoscale region.

### **Operational Runs of Global Coupled Model (60 km) for S2S Forecast** (NCUM+JULES+NEMO+CICE)



### Multi-week/Extended Range:

Weekly (every Thursday)

- Number of Forecast members: 16
  - Lag Ensemble Day= Sunday to Wednesday, 4 member per start date
- Number of hindcast members: 23 years\*6 per year (1993-2015)
- Hindcasts are used to define the weekly anomalies

### Seasonal (23<sup>rd</sup> Day of month)

- Number of Forecast members: 55
- Start dates: 12<sup>th</sup> to 22<sup>nd</sup> of each month & 5 member per start date
- Number of hindcast members: 23 years\*6 per year (1993-2015)
- Hindcasts are used to define the normal for percentage departures
- Hindcasts are used to define threshold for tercile categories for probabilistic forecasts

#### Since 2020

#### **Since 2018**

**15-Days forecast** 

**Coupled Course** 

resolution NWP

**Frequency:** Daily

25 Km Global Ocean

NEMO/CICI

60Km UM/JULES

Atmosphere/Land-

Surface

Since 2018



Verification of 2024 ERP

L.H.ST. HI, P.BI



## NCMRWF : Milestones of Global Ensemble Prediction System

- **1995**: Installed 8-member global ensemble prediction system using T80L18 model, focusing on significant weather events.
- **2012**: Upgraded GFS-based ensemble to T170L28 with 20 members for real-time probabilistic forecasting.
- 2015: Implemented advanced global ensemble system based on Unified Model (UM) with 45 members at 33 km resolution; 10-day forecasts operational.
- 2018: Global ensemble system upgraded to 12 km resolution with 22 members – Highest resolution global ensemble prediction at that time
- **2019**: Regional ensemble system (NCUM-R) for 3-day highresolution probabilistic forecasts at 4 km with 12 members (Experimental)



## **NCMRWF: Advancement of High-Resolution Regional Models**



## NCMRWF: Experimental Regional Coupled Model

#### For the extreme events and coupled process studies

Regional coupled environmental model with "Ocean", "Atmosphere" and "Wave" components.

#### **ATMOSPHERE & LAND SURFACE**

Resolution: 4.05 km x 4.05 km, Easternmost Longitude: 64.9835 E, Southernmost Latitude: 3.464 N, Westernmost Longitude: 101.393 E, Northernmost Latitude: 40.0355 N Domain Size: 900x904x80 grids <u>OCEAN & WAVE</u> Resolution: 2.2 km x 2.2 km, Wave Model: WaveWatch III Easternmost Longitude: 64.9835 E, Southernmost Latitude: 3.464 N, Westernmost Longitude: 101.393 E, Northernmost Latitude: 26.558 N, Domain Size:

#### 1100x1760x75 grids

UM13 NEMO 4.0.4 WAVEWATCH III (vn7.12) Successfully Installed & tested (with MetOffice IC/LBC)





NCMRWF plays a crucial role in the global weather forecasting community by contributing verification scores for both deterministic and ensemble models to key World Meteorological Organization (WMO) platforms. These platforms include the Lead Centre for Deterministic NWP Verification and the Lead Centre for Ensemble Prediction System Verification. Through these contributions, NCMRWF ensures transparency and alignment with global forecasting standards, helping improve the consistency and reliability of forecasts worldwide while fostering collaboration among international meteorological agencies.

BOM CMA CMC

CPTEC

DWD ECMWP

jma Kma

NCEP NCMRWI RUMS

UKMO



## **NCMRWF Reanalysis for Weather & Climate Applications**

## IMDAA Regional Reanalysis (1979-2020)

Domain: 30°E–120°E, 15°S–45°N Boundary Data: ERA-Interim Assimilation: 4D-Var for Atmosphere, EKF for Soil Moisture Atmosphere Model: Unified Model Resolution: ~12 km, 63 vertical levels (up to 40 km) Observation Sources: NCMRWF, IMD, ECMWF, UK Met Office Surface Insights: Soil moisture across 4 layers (3 meters deep) Sea Surface Temperatures: HadSST2 & OSTIA





## NGFS Global Reanalysis (1999-2019)

Assimilation: 3D-Var for Atmosphere Atmosphere Model: GFS Resolution: ~12 km, 64 vertical levels (up to 40 km) Observation Sources: NCMRWF, IMD, NOAA, NCEP Sea Surface Temperatures: NOAA OI SST

#### IMDAA Regional Reanalysis (42 years since 1979)



#### J. Climate (160+ citations): https://doi.org/10.1175/JCLI-D-20-0412.1

Total Registered Users: 4650+ Total data Download: ~ 2 TB Hourly 2D fields 3 Hourly 3D fields

#### **IMDAA Data Access:**

- 1. Register in the <a href="https://rds.ncmrwf.gov.in/">https://rds.ncmrwf.gov.in/</a>
- 2. Verify your mail
- 3. Submit your request
- 4. Also, please subscribe to <u>rds-ncmrwf-request@freelists.org</u>

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The National Centre for Medium Ran, the Centre is to continuously develo development and demonstration of ne high resolution (12km, 1-hourly) reg reanalysis, from 199b to 2018. For th operational NCMRWF Unified Mode hourly intervals. Multi-level IMDAA:	ge Wenther Forecasting (NCMRWF) is a Centre op advanced numerical weather prediction syste we and novel applications, maintaining the high gional reanalysis over India, from 1979 to 2018 te continuity of the IMDAA regional reanalysis ( IOCUM) globah NWP system of 12 km resolut -Like products are available only at 18 pressure l	of Excellence in Wenther and Climate Modelli ms, with increased reliability and accuracy set level of knowledge, skills and technical b (Extended upto December 2020) and (2) N Iataset beyond 31 December 2020, NCMRW ion. Unlike IMDAA reanalysis products, a fe evels. For more details kindly refer table in th	ing under the Ministry of Earth Sciences. The missis over India and neighboring regions through rese ases. This data web portal contains (1) <b>IMDAA D</b> <b>GFS Data</b> - high resolution (25km, 6-hourly) G F is releasing <b>IMDAA-Like</b> products derived from w of the <b>IMDAA-Like</b> products are only available e "ABOUT IMDAA" tab.
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IMDAA Reanalysis Updates - 1	18 October 2023		
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## Use of AI/ML at NCMRWF : New initiatives



✓ Outcome: Delivered heatwave classifications, indices, and insights into heatwave dynamics

## **Key Focus Areas:**

- **1. NWP Science & Technology**: Developing high-resolution coupled models with improved representation of physical process to provide more accurate forecasts.
- 2. Improved DA Methodology, Use of more observations
- **3. Products for Diverse Applications**: Providing tailored NWP products for sectoral applications in agriculture, energy, water resources, disaster management etc.
- **4. Al/ML in Weather Prediction**: Incorporating Artificial Intelligence and Machine Learning to optimize and improve forecast models, developing full AI models.
- **5. Capacity Building & Collaboration**: Strengthening technical expertise to build a skilled workforce capable of advancing NWP.

# Thank You

