Ministry of Earth Sciences

An overview of IMDAA Regional Reanalysis

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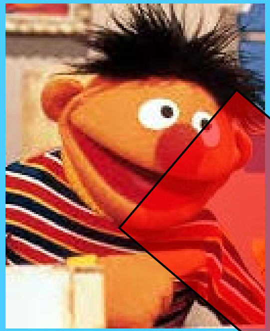
Acknowledgments: **IMDAA is a collaborative project among NCMRWF, IMD, and the UK Met Office under the National Monsoon Mission (NMM) project of the Ministry of Earth Sciences, GOI.**

What is Data Assimilation?

- Models give a complete description of the atmosphere, but **errors grow rapidly** in time
- Observations provide an **incomplete description** of the atmospheric state, but bring up to date information
- Data assimilation **combines** these two sources of information to produce an optimal (best) estimate of the atmospheric state
- This state (**the *analysis***) is used as **initial conditions** for extended forecasts.
- Operational NWP data assimilation system changes when assimilation methods and assimilating models improve – this creates discontinuities in the “analyses”, from one system to another.

What is Reanalysis?

Want a very long time – series of atmospheric data, Climate monitoring



Observations

•Not available everywhere

•Limited variables

•Physical consistency?

NWP

•System changes regularly

•Variable quality

An **analysis** is an estimation of the most likely current state of the atmosphere given observations and previous forecast.

- A **reanalysis** is similar to analysis, but for a historical period. Usually a long series of reanalyses are produced using a frozen system.
- Reanalyses provide comprehensive snapshots of atmospheric conditions at regular grids and intervals over long time periods; whereas observation alone can provide only a limited understanding of the past weather and climate.

Aims and uses of Reanalysis

- Frozen modern assimilation scheme
- Best use of all appropriate, available observations
  - No `cut-off’
  - Consider using more observations than operational analysis
- Produce a long time-series of reanalyses (usually decades)

Uses

- **produce a scientific resource**
- **validate models**
- **study use of observations/assimilation system**
- **study historical weather events**
- **study large and small variations in weather**
- **study predictability**
- **produce weather statistics**
- **study extreme events**
- **to lead into operational climate monitoring**
- **link observation record to climate models**
- **AI/ML, Data Science**

User communities

Scientific and modelling community: reanalysis data as a proxy for “truth”, for initialization, or as boundary condition

Observation community: reanalysis for data quality monitoring

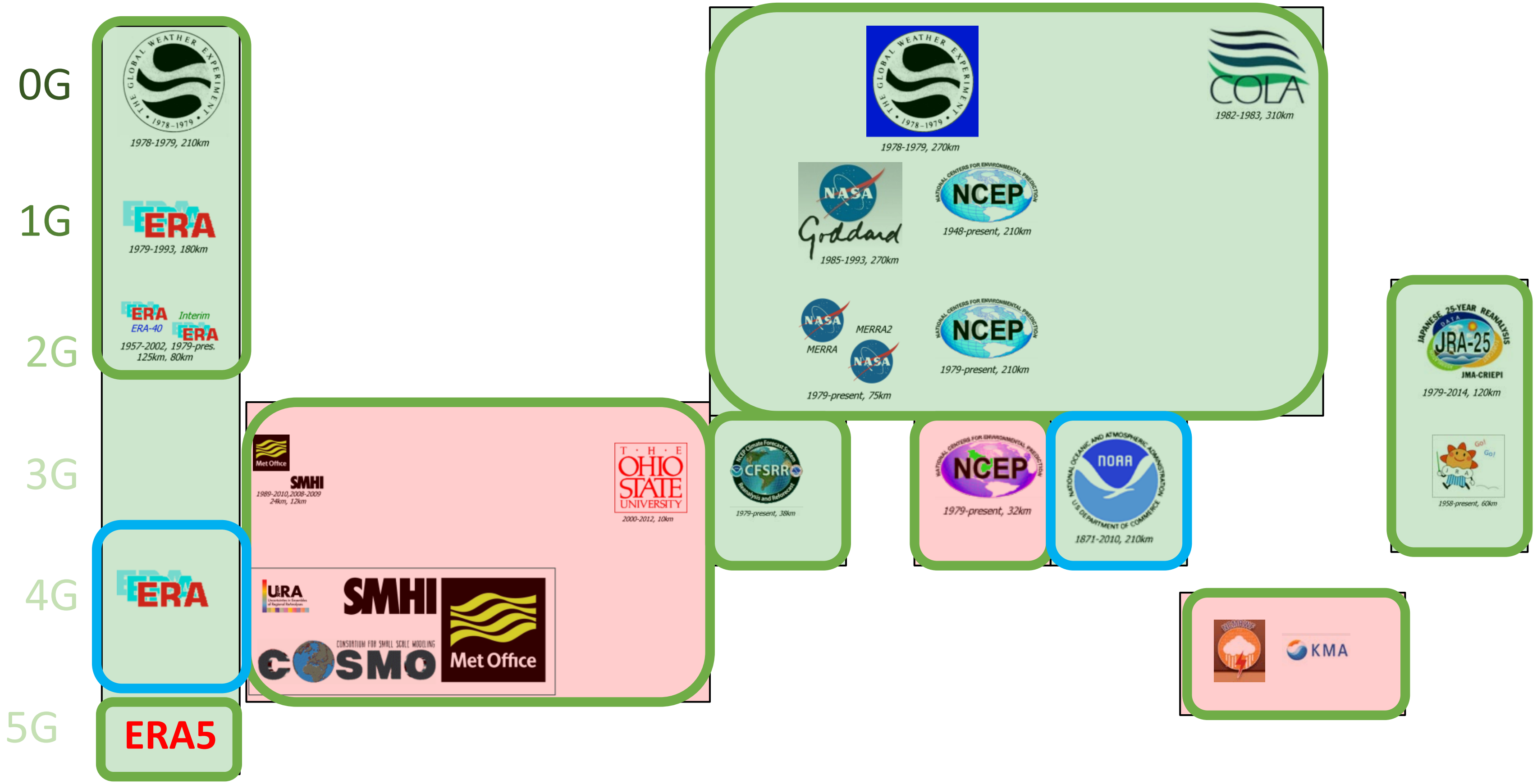
Scientific analysers: process studies, time series analysis

AI/ML: Longterm data

Need data where none are observed

Reanalysis Types

- **Global**



- **Regional**

- **Climate Monitoring**
  - **Use all available observations**
- **Climate Change**
  - **Use only observations available throughout**

Why do we need Regional Reanalysis

- Low resolution (global) reanalyses are not suited for studying local and regional scales due to inadequate descriptions of mesoscale features.

- Production of high-resolution global reanalysis is expensive (Cost of computing)

- High resolution regional reanalysis is a plausible choice, which can represent mesoscale weather more realistically.

- **User Products:** 'Complete' multivariate, gridded climate datasets for users (DA combines model and wide variety of observations in consistent manner).

- **Regional focus:** Benefits of high-resolution (resolved orography, high-impact weather), local focus.

- **Model evaluation:** Testbed for extended period (> 35 years) evaluation of regional Weather/Climate Model.

- **Boundary conditions for the regional reanalysis come from a global reanalysis.**

IMDAA Regional Reanalysis

- **Indian Monsoon Data Assimilation and Analysis (IMDAA) project is a collaborative effort among National Centre for medium Range Weather Forecasting (NCMRWF), UK Met Office and India Meteorological Department (IMD) under the National Monsoon Mission (NMM) project of Ministry of Earth Sciences (MoES), Government of India.**

- **State of the art assimilation method (4D-Var) and NWP model (Unified Model, UM (10.2) are used for producing this highest resolution satellite-era regional reanalysis over the Indian Monsoon region from 1979-2018, extended up to 2020. As a continuity to the IMDAA reanalysis, NCMRWF started disseminating Near-real time "IMDAA Like" products derived from the operational NCUM model**

- **There was considerable growth and improvement in the atmospheric observing system during the reanalysis period that helped IMDAA reanalysis.**

- **Hourly/3-hourly temporal resolution, 12km spatial resolution IMDAA dataset is available to the researchers (https://rds.ncmrwf.gov.in/datasets)**

•**For more details:** https://doi.org/10.1175/JCLI-D-20-0412.1

IMDAA Regional Reanalysis

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IMDAA: High-Resolution Satellite-Era Reanalysis for the Indian Monsoon Region

S. Indira Rani[1], T. Arulalan[1], John P. George[1], E. N. Rajagopal[1], Richard Renshaw[2], Adam Maycock[2], Dale M. Barker[2], and M. Rajeevan[3]

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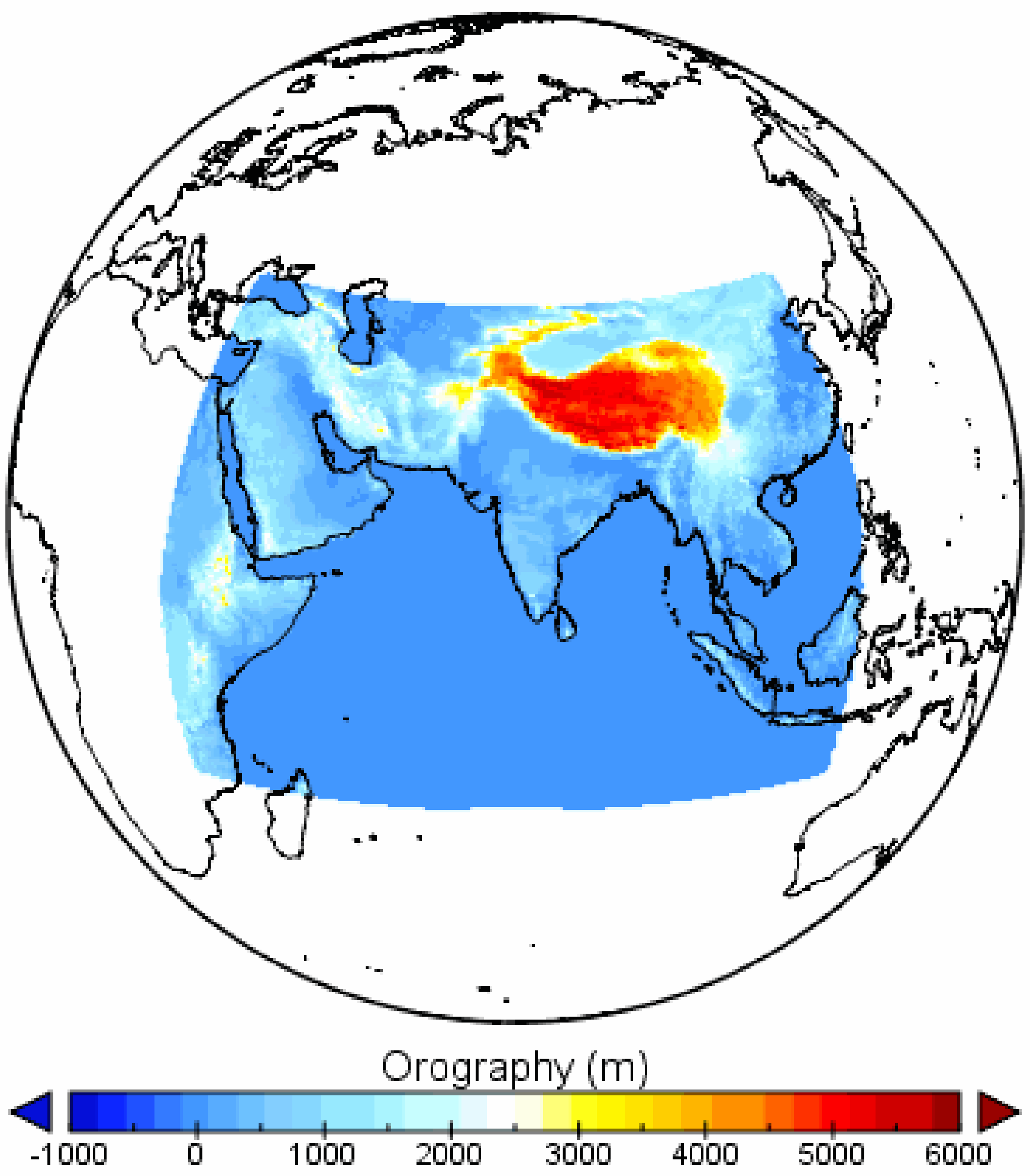
Abstract

A high-resolution regional reanalysis of the Indian Monsoon Data Assimilation and Analysis (IMDAA) project is made available to researchers for deeper understanding of the Indian monsoon and its variability. This 12-km resolution reanalysis covering the satellite era from 1979 to 2018 using a 4D-Var data assimilation method and the U.K. Met Office Unified Model is presently the highest resolution atmospheric reanalysis carried out for

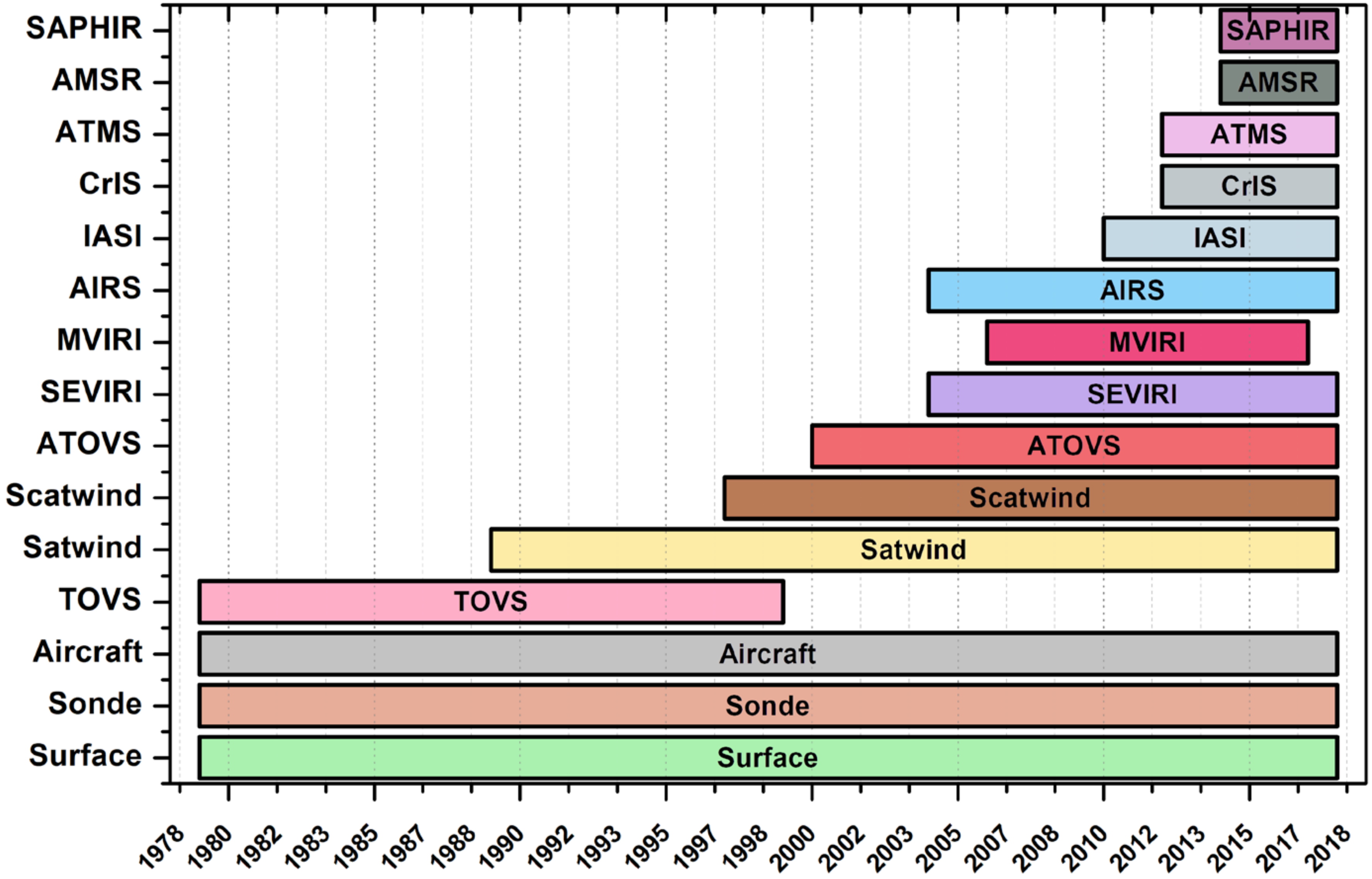
IMDAA Domain



Salient Features

Period	**1979 - 2018** **Extended to 2020 (42 Years)**
Domain	30 - 120˚ E, 15˚ S to 45˚ N
Lateral Boundary Condition (LBC)	ERA-Interim
Data Assimilation Method	**4D-Var (Atmosphere)** Extended Kalman Filter (EKF) method for Soil Moisture
Atmospheric Model	Unified Model
Horizontal Resolution	12 km (~0.11˚)
Vertical Resolution	63 model levels (upto ~ 40 km altitude)
Observation Source	ECMWF, NCMRWF, UK Met Office, IMD
Surface	Soil Moisture Analysis 4 soil levels of soil covering first 3 meters Sea Surface Temperature: HadSST2, OSTIA analysis

Timeline of observations used in IMDAA



Important aspects of IMDAA:

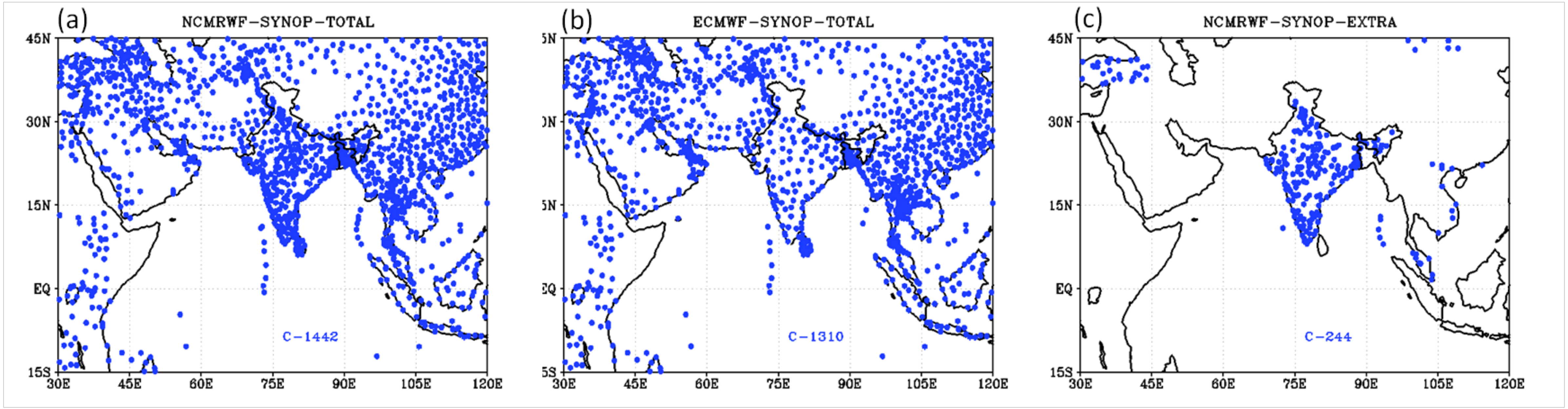
1. Use of historical data from IMD/NCMRWF archival
2. Use of many satellite observations
3. Variational bias correction for satellite radiances
4. Use of state of the art “4D-Var” data assimilation method
5. Soil moisture assimilation using EKF method

Highlights of IMDAA: Use of Historical data from various sources

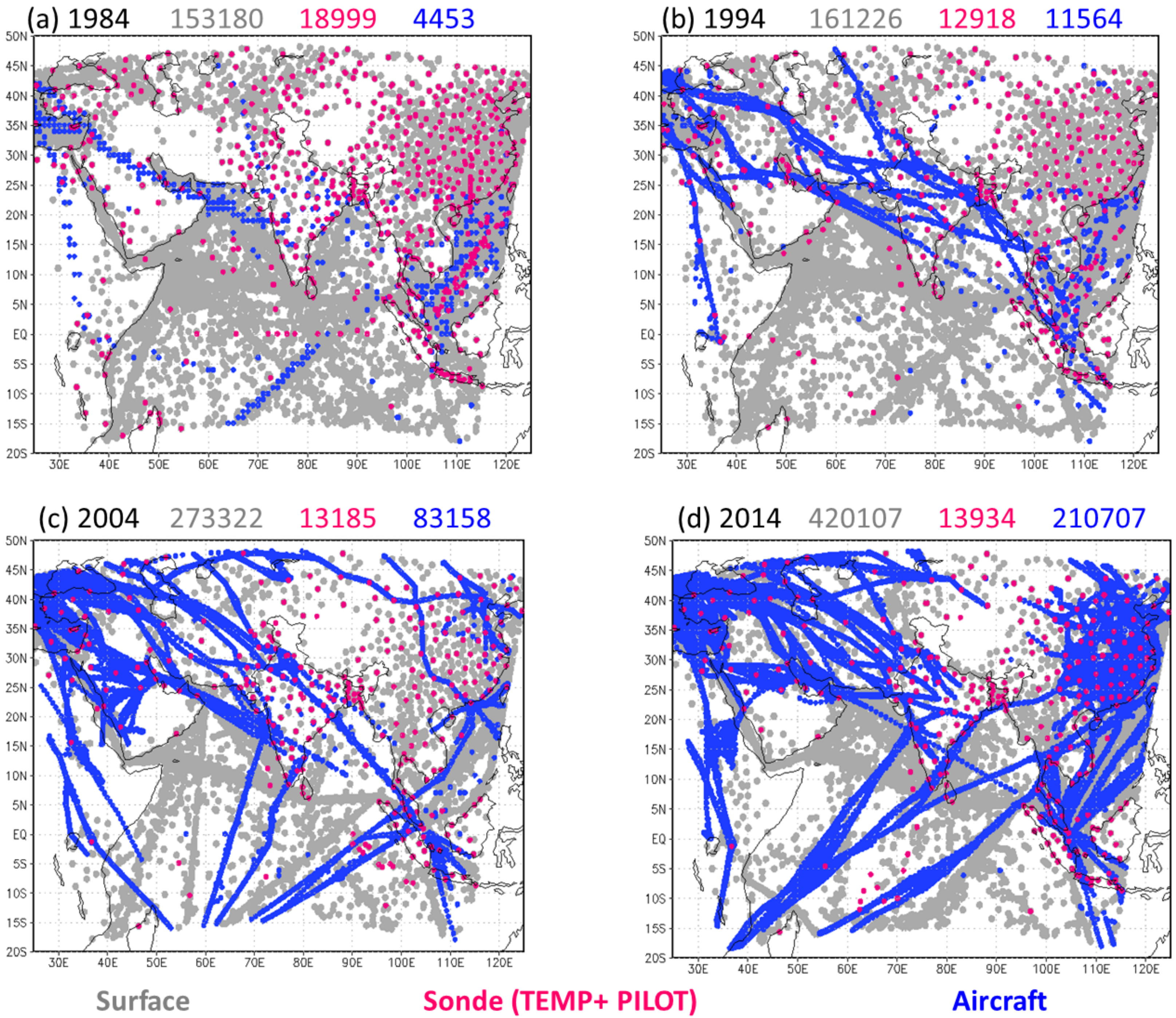
- **Main source of observations for IMDAA reanalysis is ECMWF archival, obtained through UK Met Office.**

- **IMD archival of Surface & upper air observations (and NCMRWF and UK Met Office archival of satellite observations) are also used.**

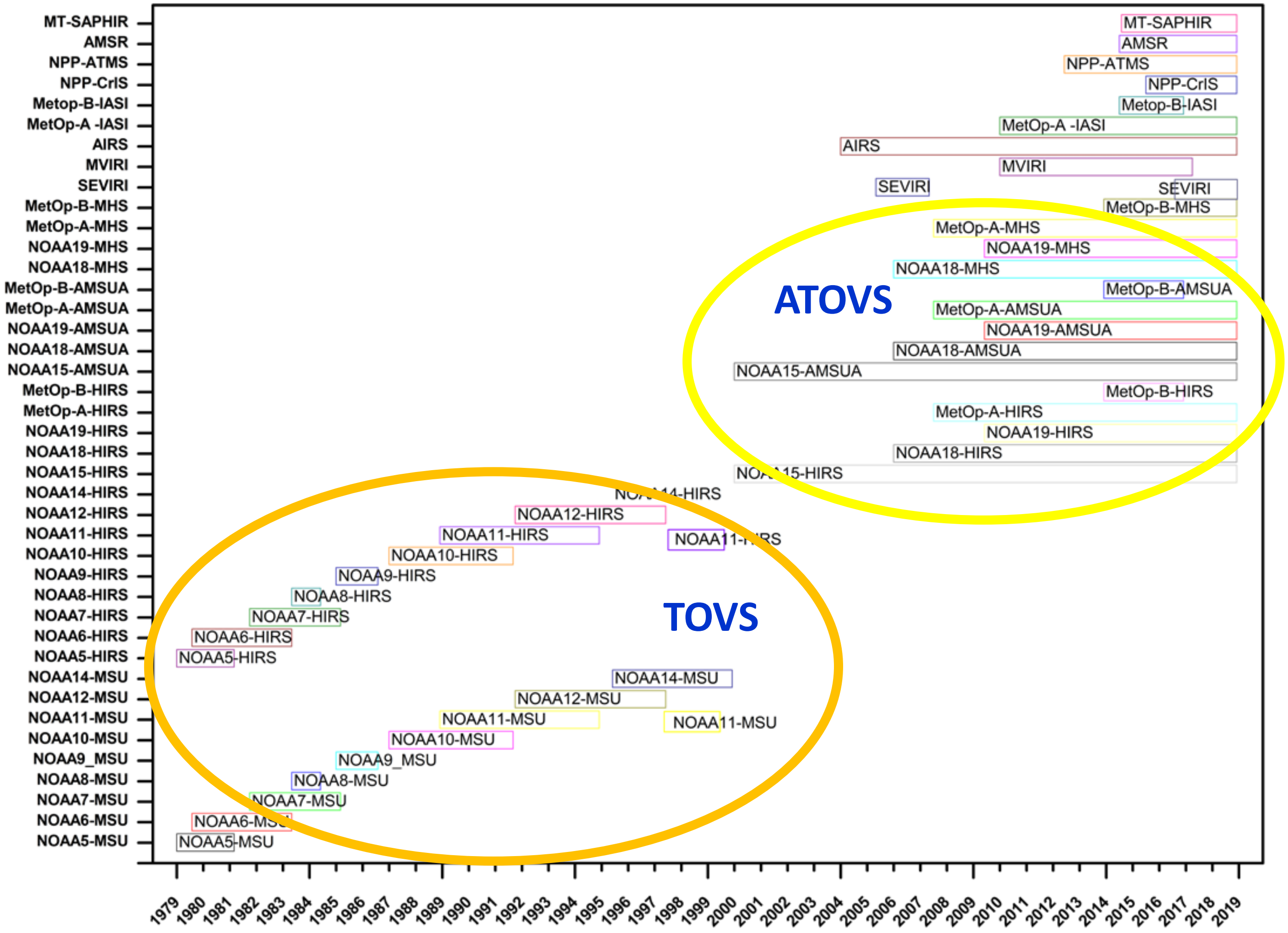
Surface observations over IMDAA domain (April 2014 00Z)



Conventional Observations assimilated (JJAS)



Highlights of IMDAA: Use of large number Satellite observations



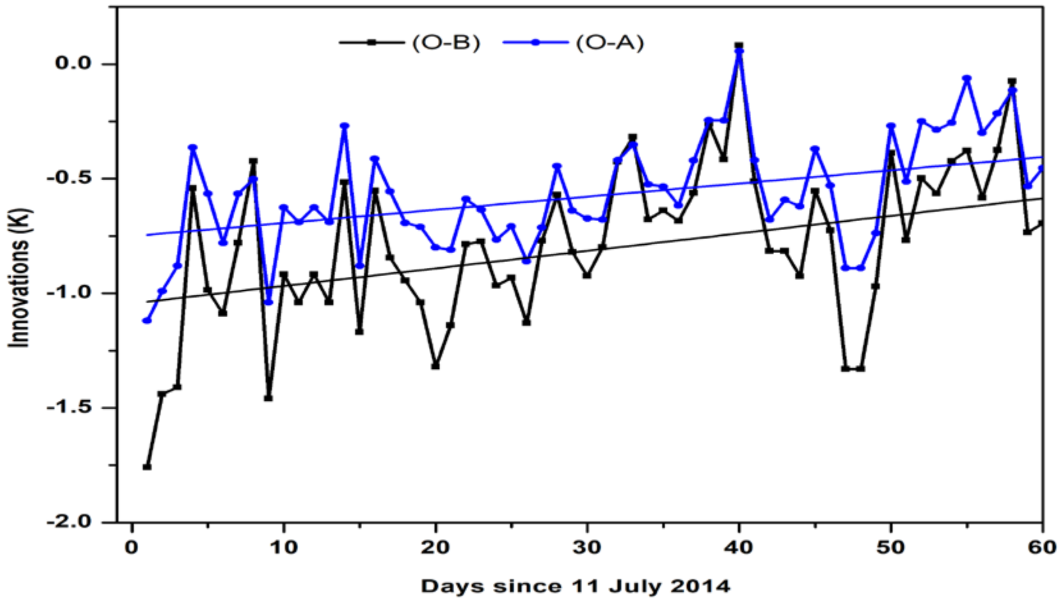
Sources & period of radiance observation used in IMDAA

- **Time-frame of the IMDAA reanalysis is highly challenging - because of the rapid developments in the observing system, particularly satellites.**
- **IMDAA used radiances from more than 40 satellite instruments of which 24 are in the post 2000 period**
- **Satellite instruments, like any other measurement system, are not perfect and are prone to error**
- **An erroneous observation can systematically damage the data assimilation scheme.**
- **Requirement of an advanced observation bias correction scheme**

Highlights of IMDAA: Variational bias correction for satellite radiances

Biases in Satellite radiance vary with time, geography, air mass, scan position etc.

In IMDAA an advanced Variational Bias Correction method (VarBC) is used.

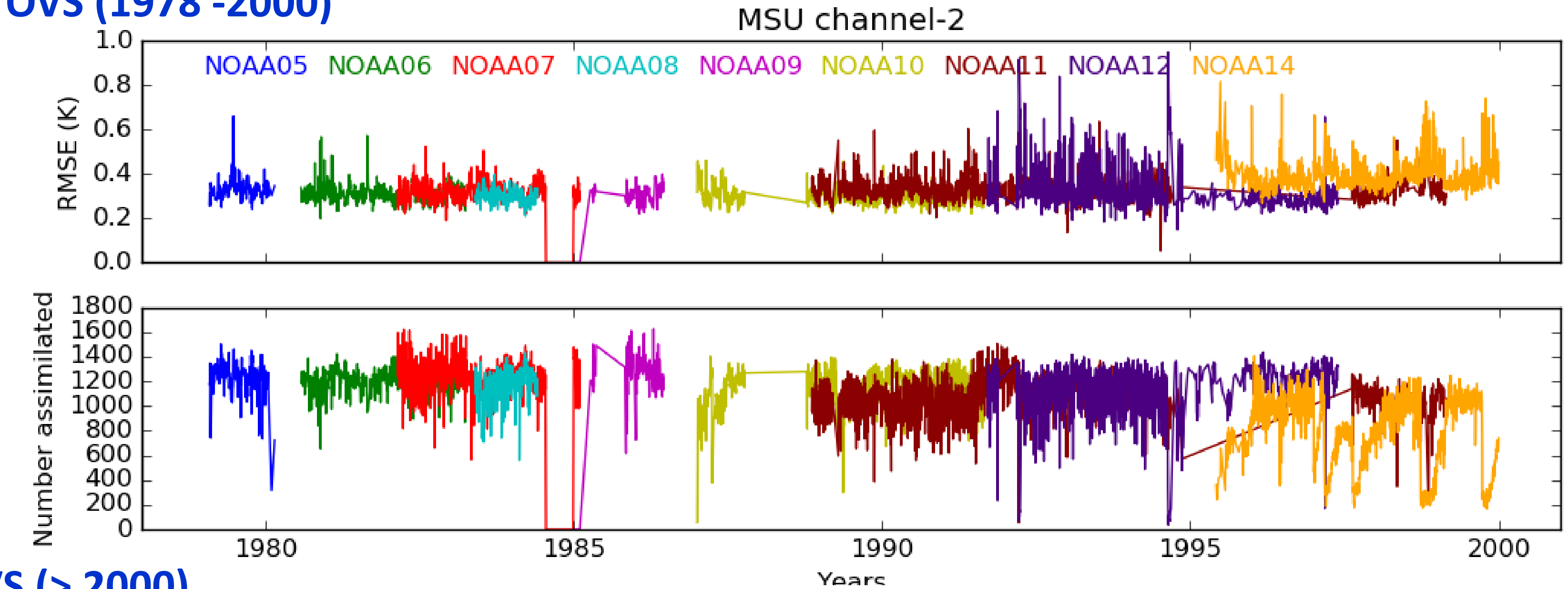


Mean of observed minus background (O-B) and observed minus analysis (O-A) of SAPHIR channel-1 radiances (Megha-Tropiques satellite) which is introduced in the IMDAA system during mid-2014. Initial bias is not perfect and VarBC improves the correction with a bias halving time of approximately 3-4 days.

Use of TOVS and ATOVS in IMDAA

(Stats w.r.t. background fields)

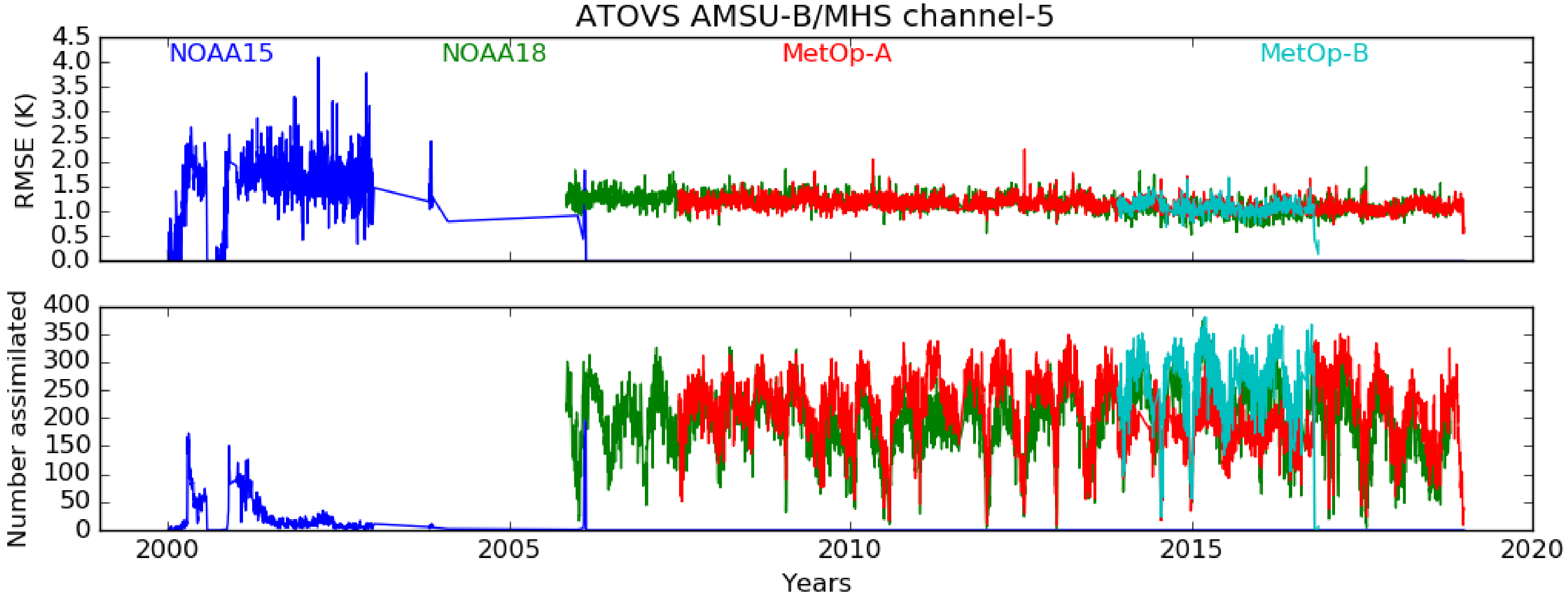
TOVS (1978 -2000)



R matrix value of MSU channel 2 = 2 K

RMSE: < 1 K

ATOVS (> 2000)



R matrix value of AMSU-B/MHS channel-5 = 4K

RMSE: between 1 and 2 K

Highlights of IMDAA: DA Method

State of the art 4D-Var assimilation system (atmosphere)

IMDAA used an incremental formulation of 4D-Var data assimilation method (Rawlins et al. 2007), with 6 hr data assimilation window

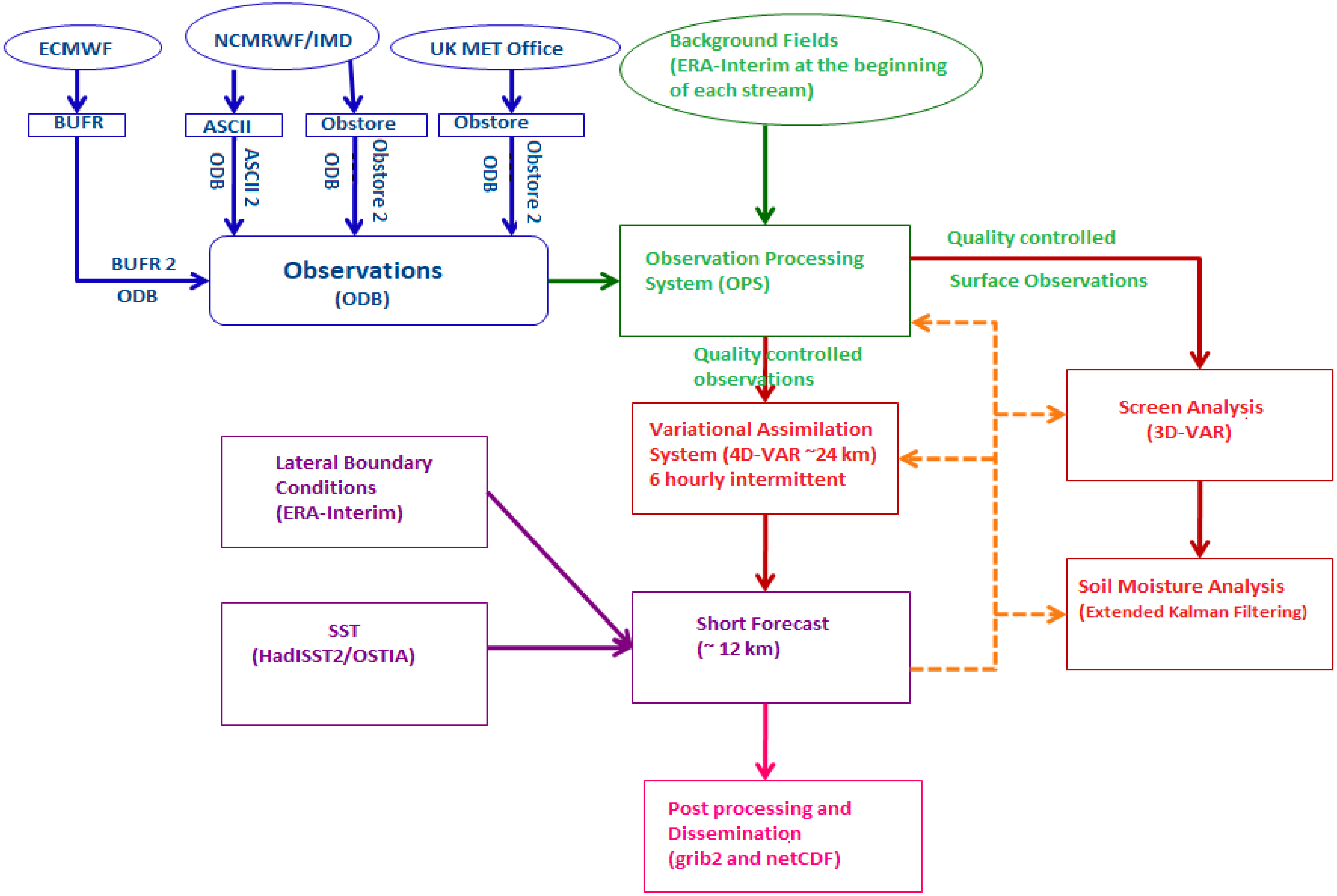
One of the major advantage of 4D-Var is it allows the flow dependent influence of the observations

Land data assimilation : Soil Moisture

IMDAA Soil moisture analysis is produced using a Extended Kalman Filter (EKF) based land data assimilation system (using JULES land surface model).

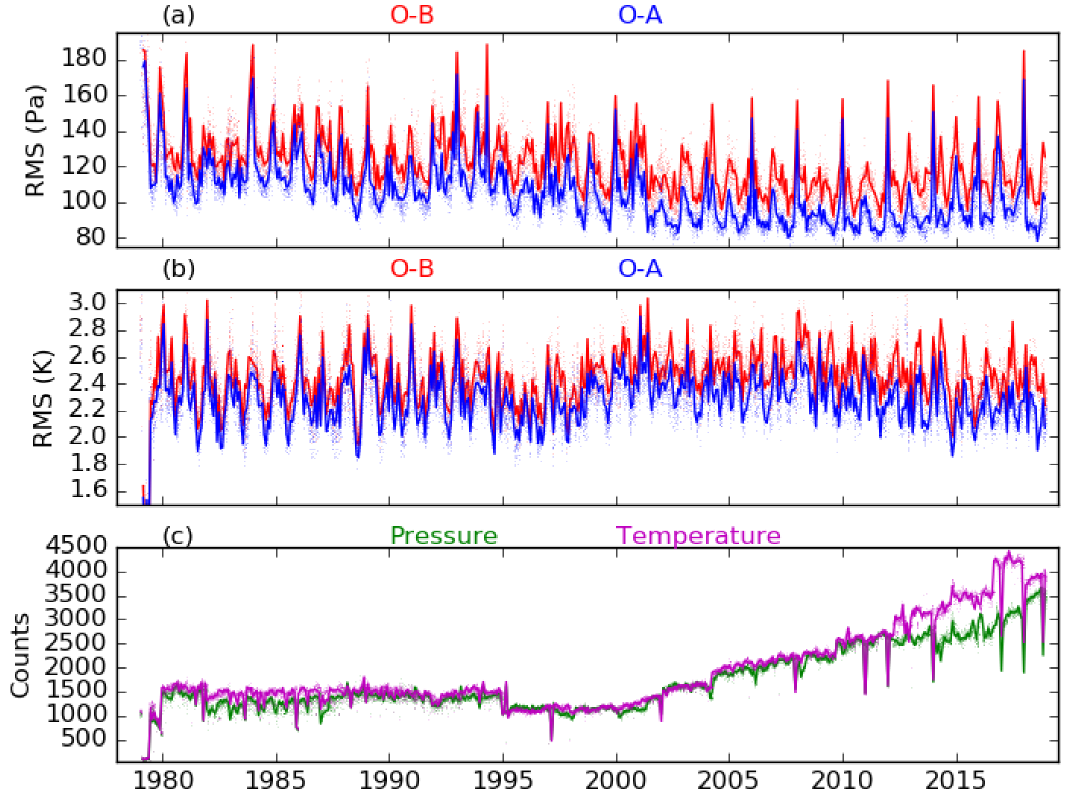
Soil moisture analysis for four soil layers of 10 cm, 25 cm, 65 cm and 2 m thickness is prepared at every assimilation cycle (6 hour) at 12 km resolution and is used to initialize the model (short) forecast in every data assimilation cycle.

IMDAA Reanalysis System Flowchart



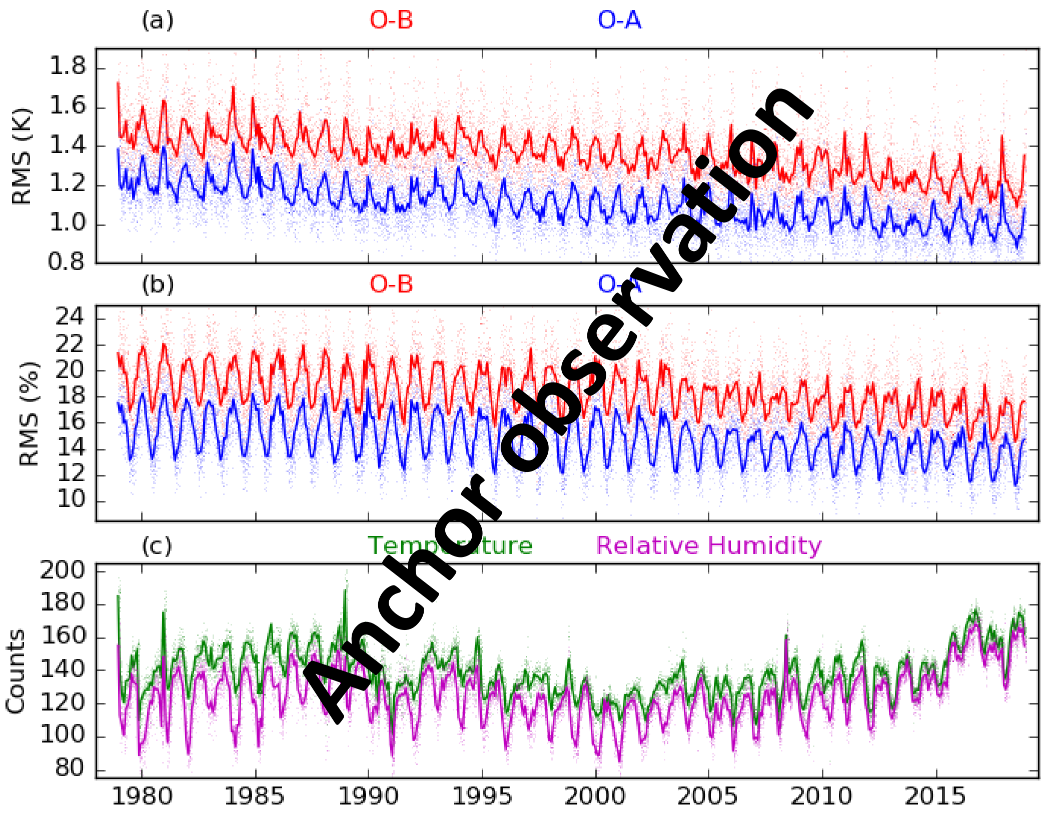
Verification of IMDAA

Background and analysis fit to surface observations



- **Monthly mean RMS departure in surface pressure, O-B and O-A lies between 1 to 1.5 hPa during the initial period of reanalysis, but later both are reduced with O-A below 1 hPa**
- **The RMS departure in surface temperature against observation lies between 2 and 3K, whereas those of analysis are between 2 to 2.6 K**

Background and analysis fit to sonde (500 hPa) observations



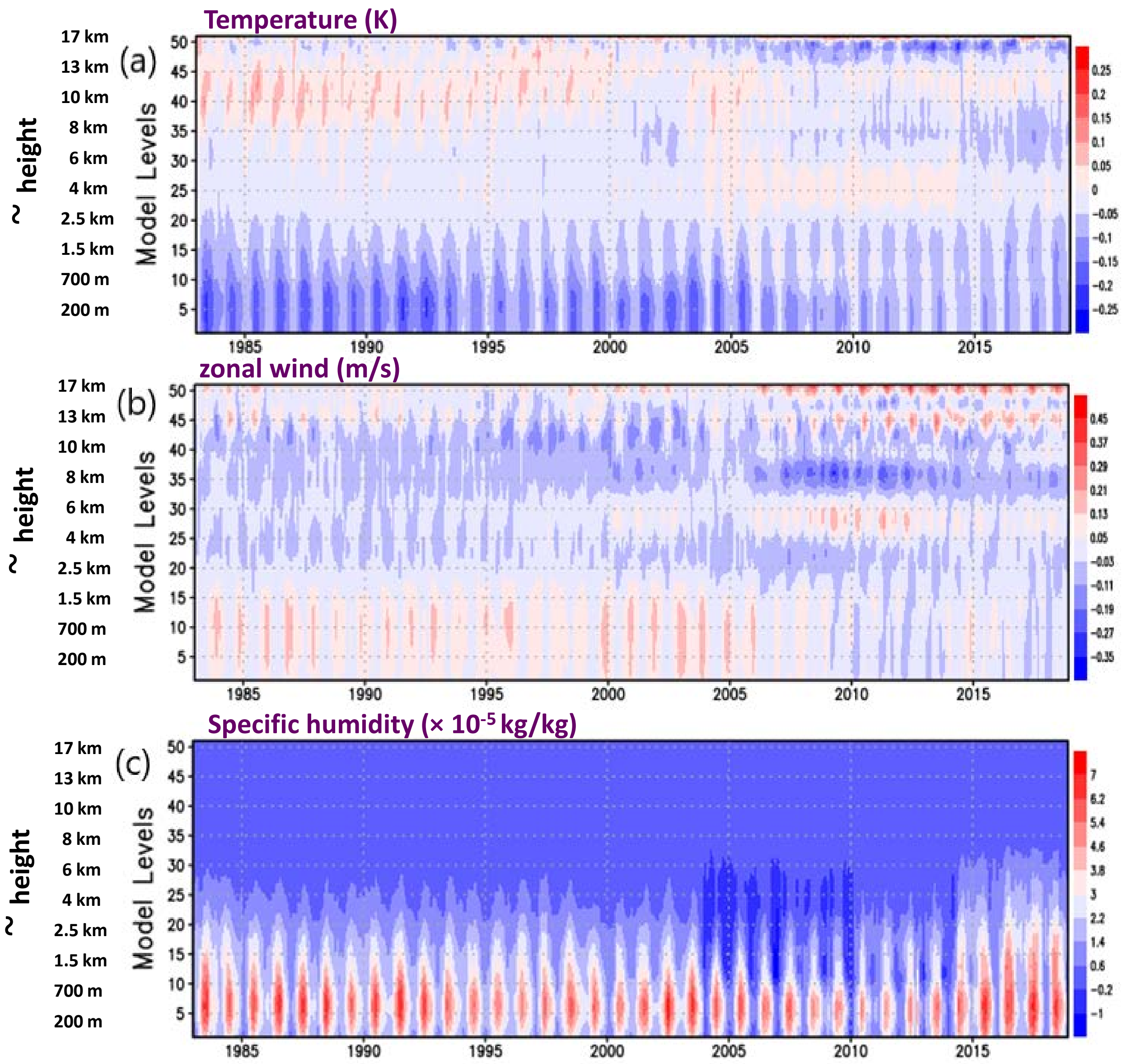
RMS departures in O-B and O-A of 500 hPa temperature lie between 1.2 - 1.8 K, and 0.8 - 1.4 K

RMS departures in O-B and O-A of 500 hPa RH lie between 1.6 - 2.4 %, and 1.2 - 1.8 %

Similar trend in the background and analysis fits of the observations are seen over the Tropics in other leading global reanalyses

Time series of Analysis increments

(a) Temperature, (b) Zonal wind and (c) specific humidity



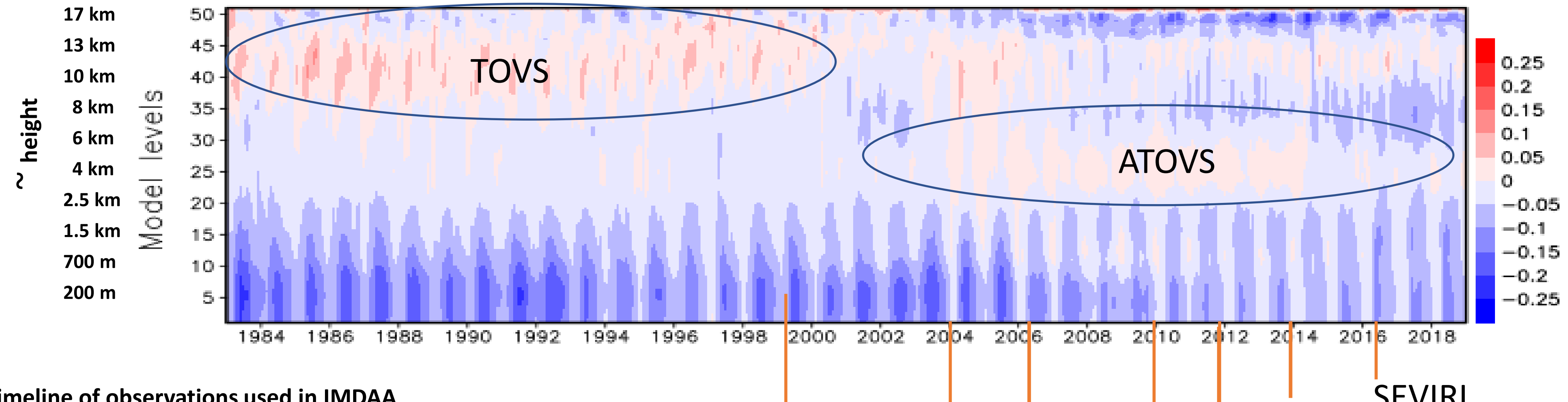
Analysis increments represent the net response of data assimilation to all observations used.

Nature of analysis increment provide important information about the performance of the DA system, including the changes in the observing system - and this is a good proxy for model bias.

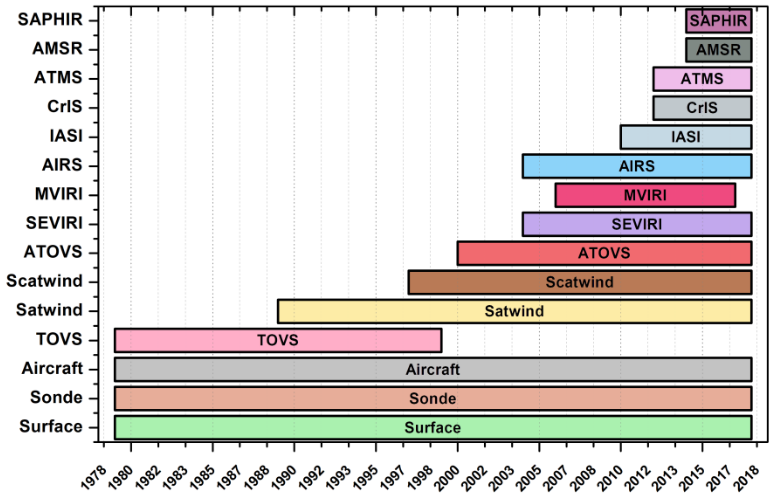
Increased moistening effect during summer monsoon period, and relatively less during other months.

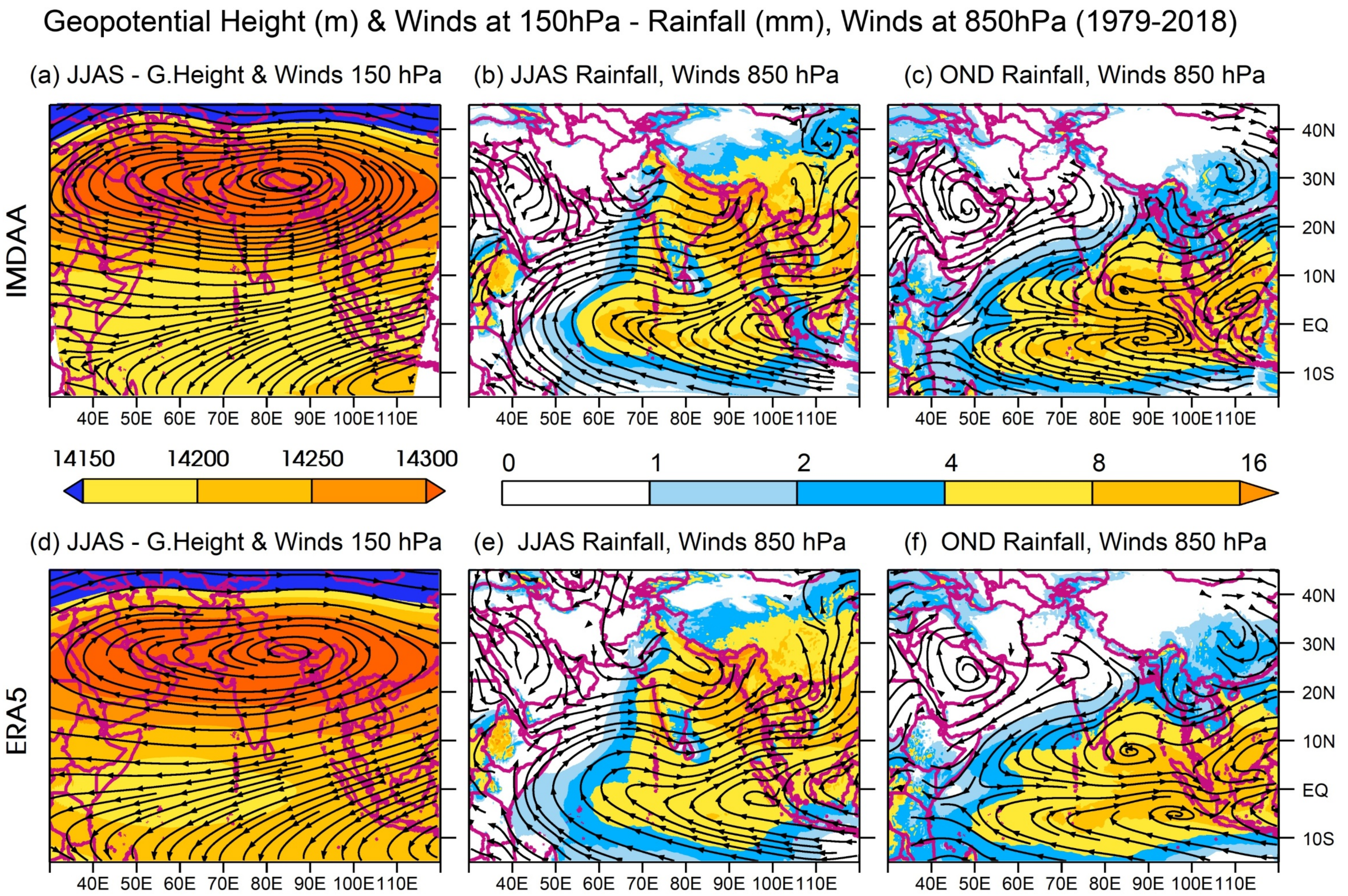
The changes in the analysis increments are in resonance with the observations assimilated

Analysis increment in Temperature: Response to the radiance assimilated

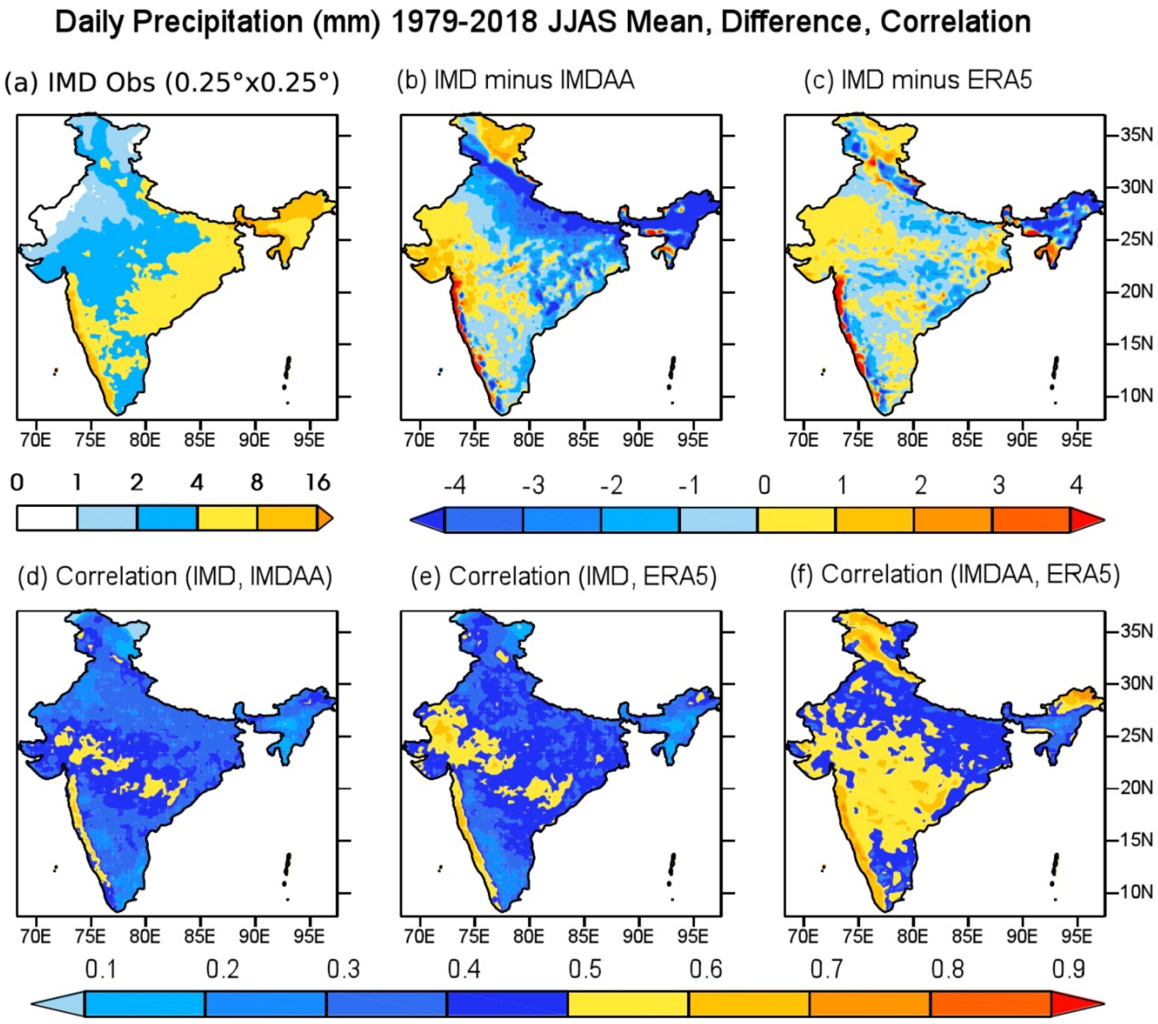


Timeline of observations used in IMDAA

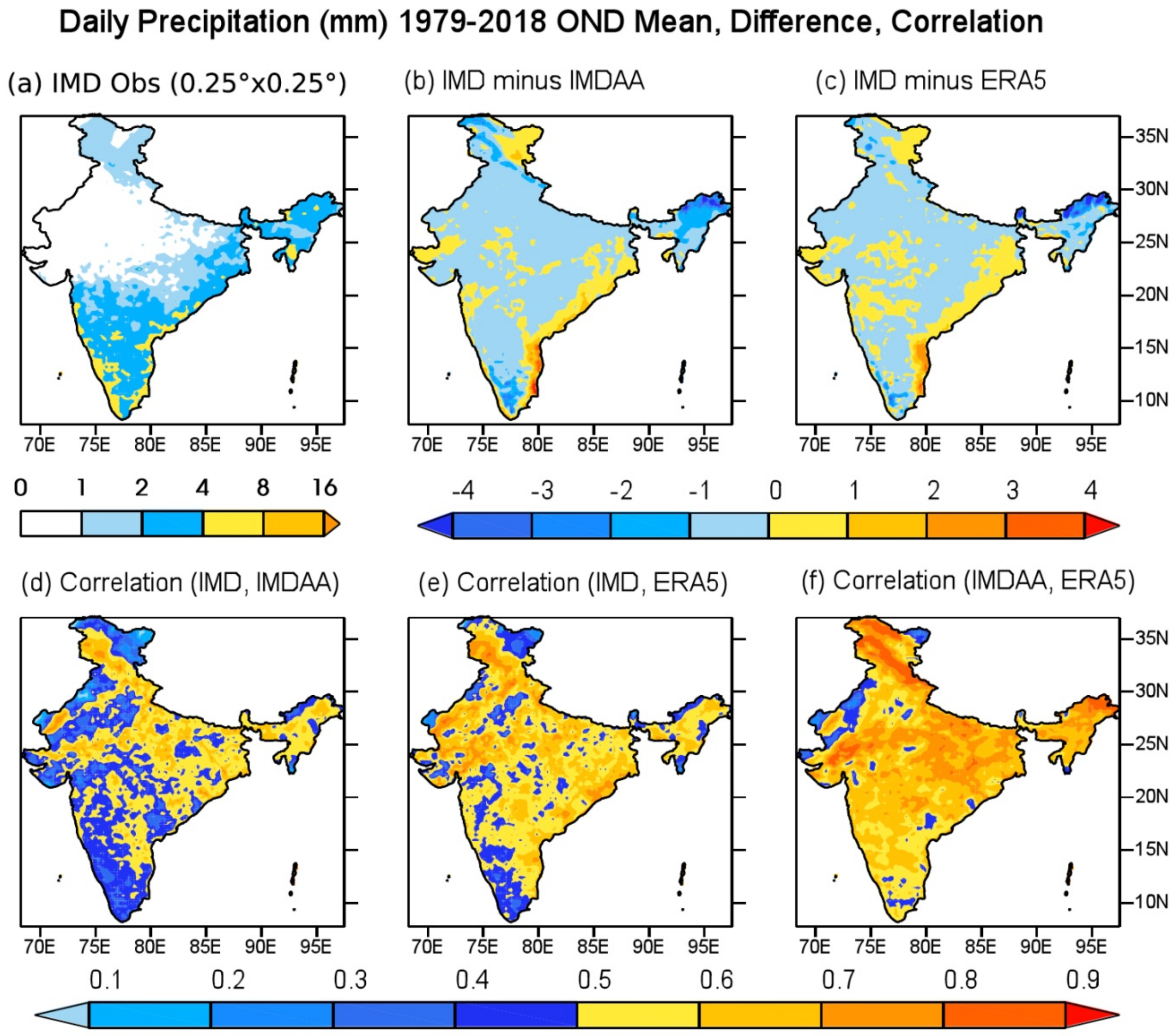




Geopotential Height (m) & Winds at 150hPa - Rainfall (mm), Winds at 850hPa (1979-2018)
(a) JJAS - G.Height & Winds 150 hPa
(b) JJAS Rainfall, Winds 850 hPa
(c) OND Rainfall, Winds 850 hPa
IMDAA
40N
30N
20N
10N
EQ
10S
40E 50E 60E 70E 80E 90E 100E 110E
14150 14200 14250 14300
0 1 2 4 8 16
(d) JJAS - G.Height & Winds 150 hPa
(e) JJAS Rainfall, Winds 850 hPa
(f) OND Rainfall, Winds 850 hPa
ERA5



Daily Precipitation (mm) 1979-2018 JJAS Mean, Difference, Correlation
(a) IMD Obs (0.25°x0.25°)
(b) IMD minus IMDAA
(c) IMD minus ERA5
(d) Correlation (IMD, IMDAA)
(e) Correlation (IMD, ERA5)
(f) Correlation (IMDAA, ERA5)
70E 75E 80E 85E 90E 95E
35N 30N 25N 20N 15N 10N
0 1 2 4 8 16
-4 -3 -2 -1 0 1 2 3 4
0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9



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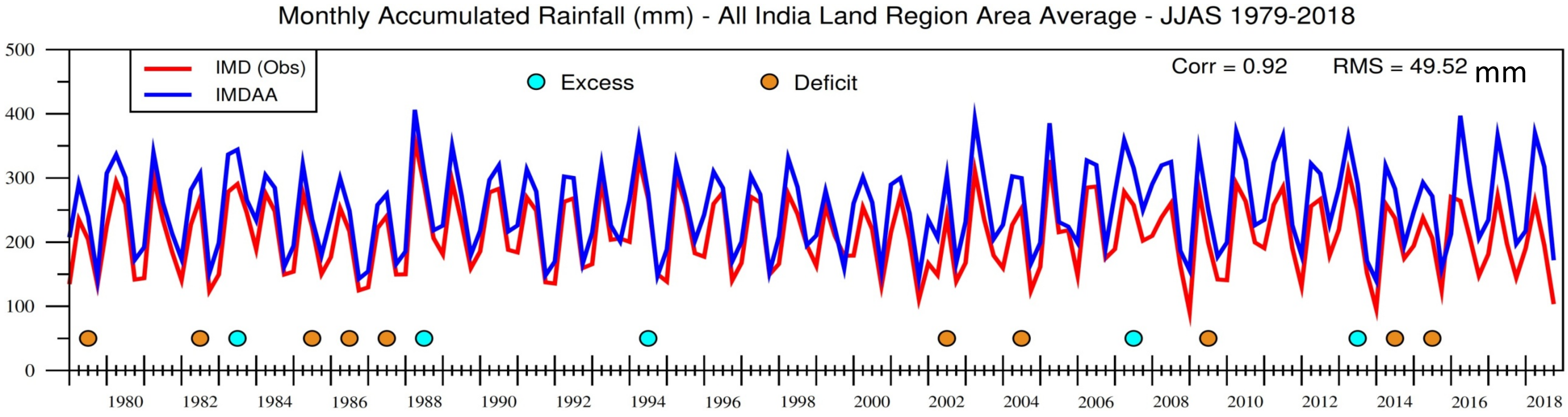
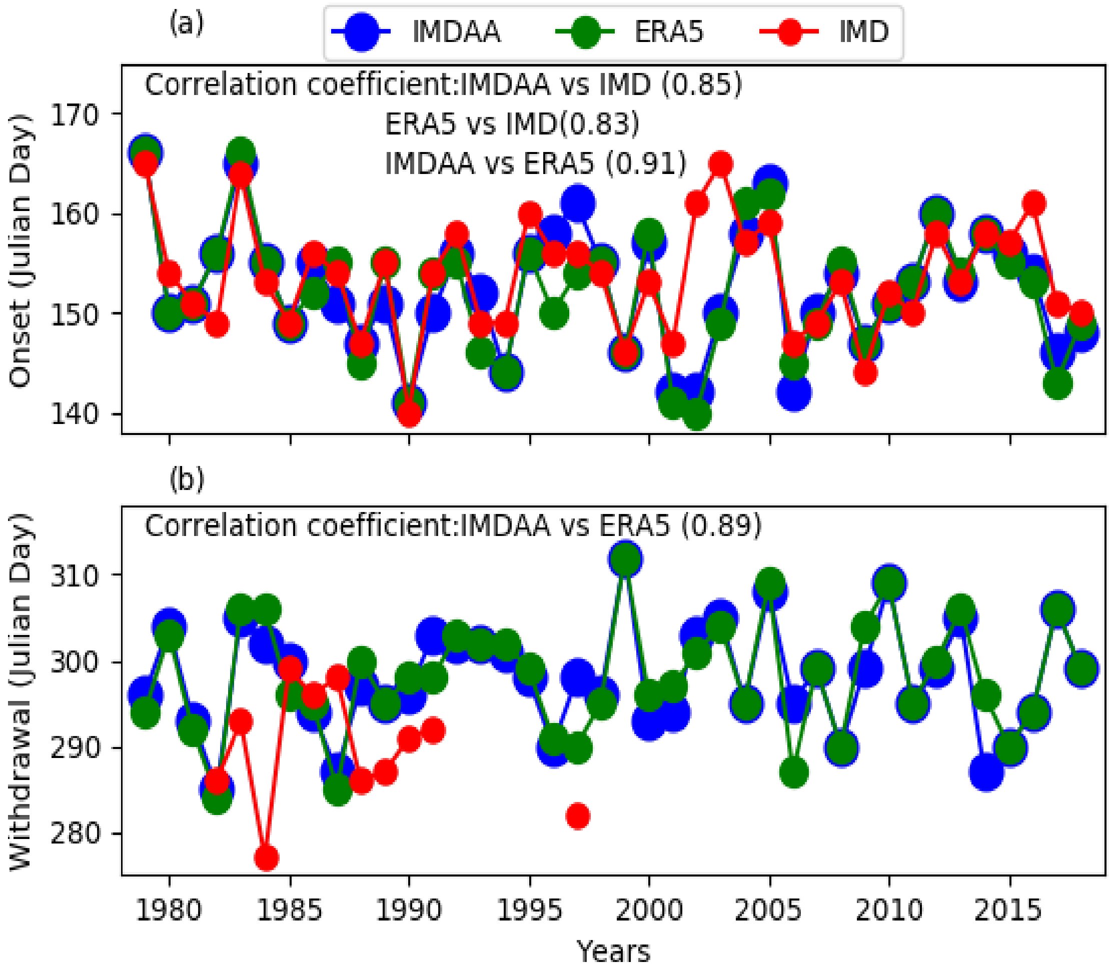
70E 75E 80E 85E 90E 95E
35N 30N 25N 20N 15N 10N
0 1 2 4 8 16
-4 -3 -2 -1 0 1 2 3 4
0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9

All India Summer Monsoon Rainfall of IMDAA (12 km) : Verification against IMD gridded observations (25 km)



Monsoon onset and withdrawal

IMDAA comparison with ERA5 and IMD onset/withdrawal dates



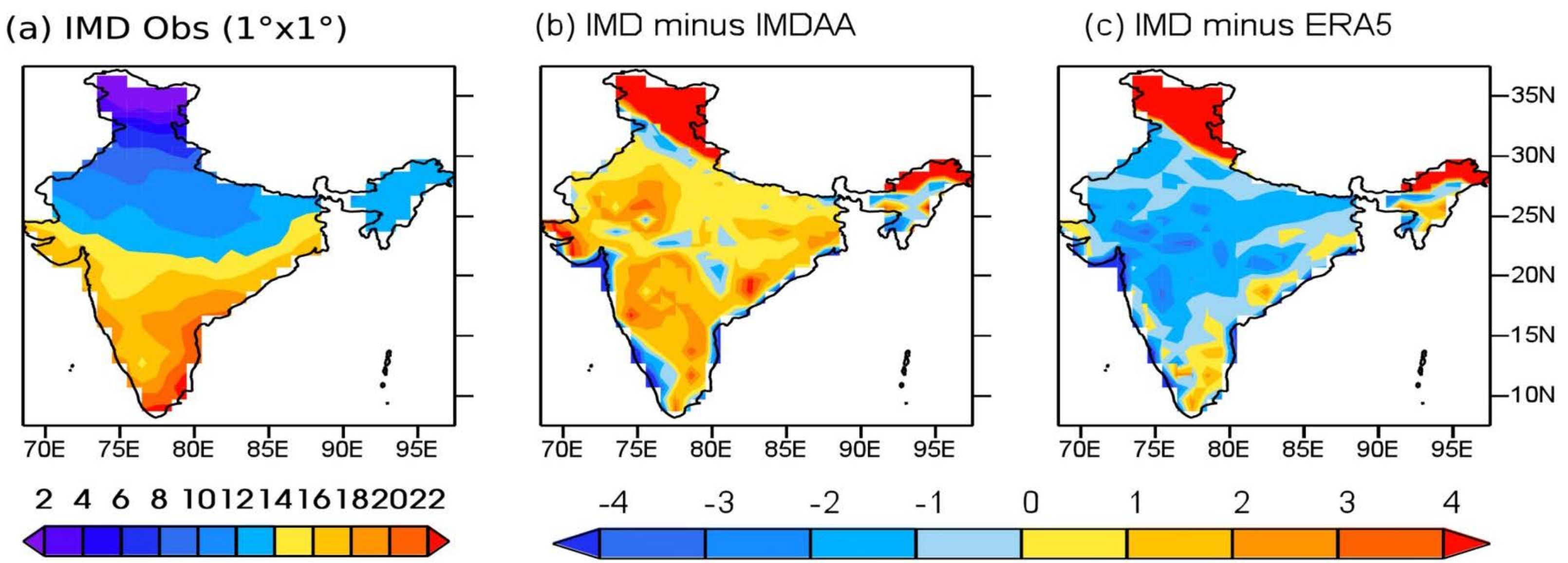
Both IMDAA and ERA5 show an average delay of one day in the monsoon onset dates compared to IMD onset dates.

Correlations between reanalyses and observation are found to be very close with a slight better value for IMDAA (0.85) than ERA5 (0.83).

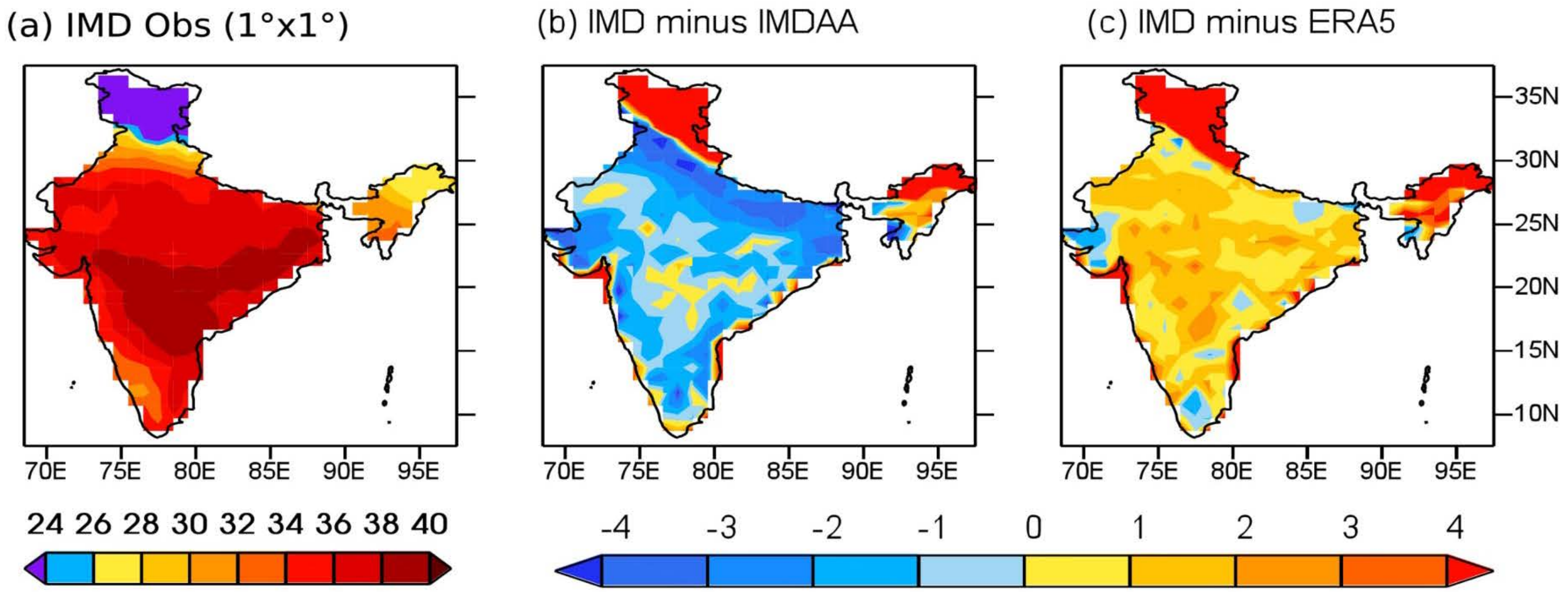
Monsoon withdrawal dates from IMDAA and ERA5 are also highly correlated (0.89)

Vertical Wind Shear Index (VVSI) of Prasad & Hayashi, 2005 is used calculate the onset & withdrawal dates from IMDAA & ERA5

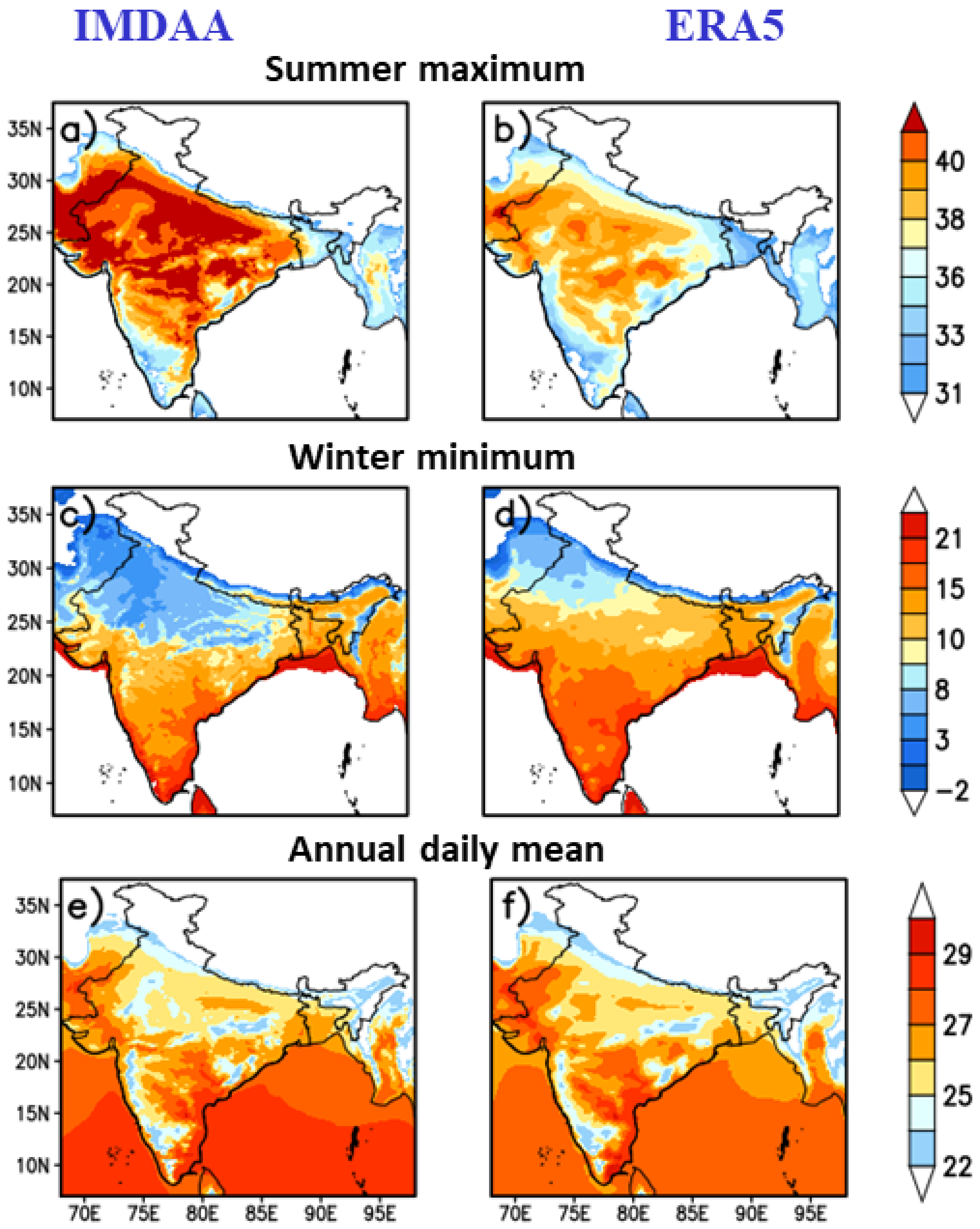
Daily minimum temperature (1979-2018) DJF mean



Daily maximum temperature (1979-2018) MAM mean



Location Specific verification of IMDAA 2m surface temperature for the period 2000 -2018

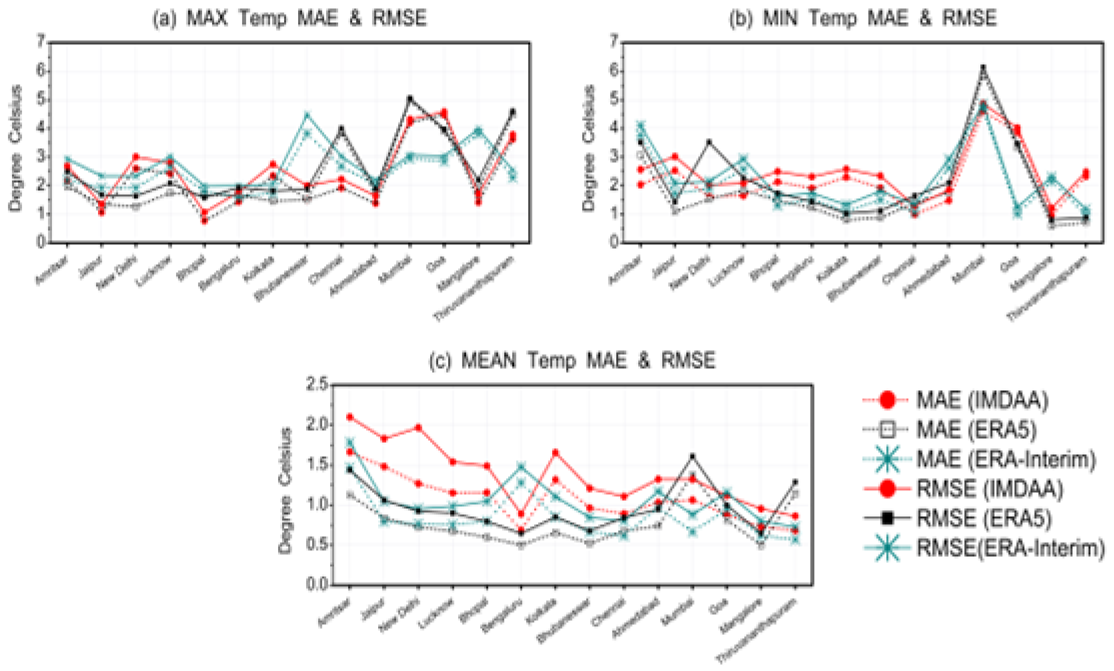


IMDAA data shows hotter summer than ERA5, particularly over north of 20°N

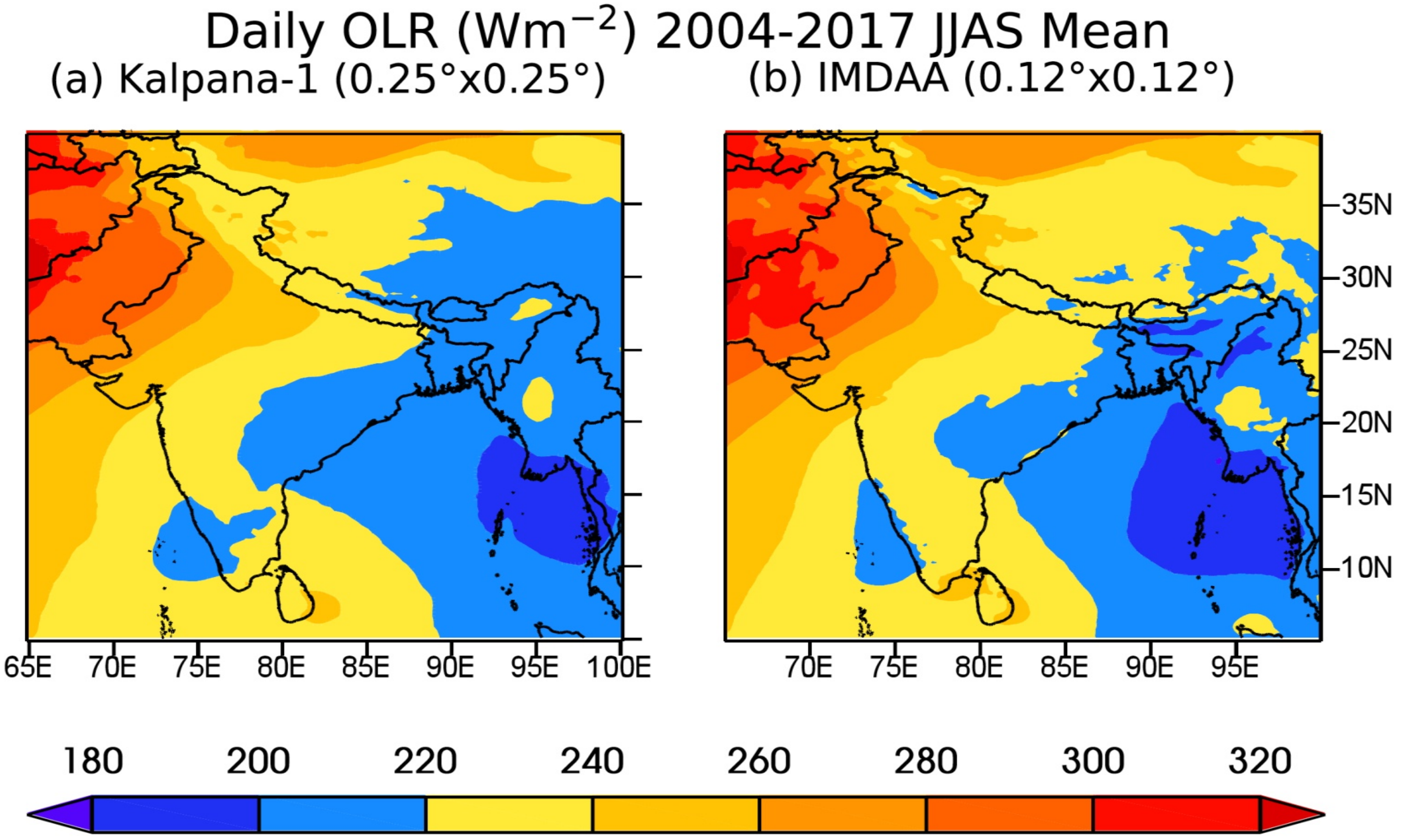
IMDAA data shows cooler winter than ERA5, particularly over north of 20°N

IMDAA is better over south of 20°N in terms of temperature variables

Locations selected

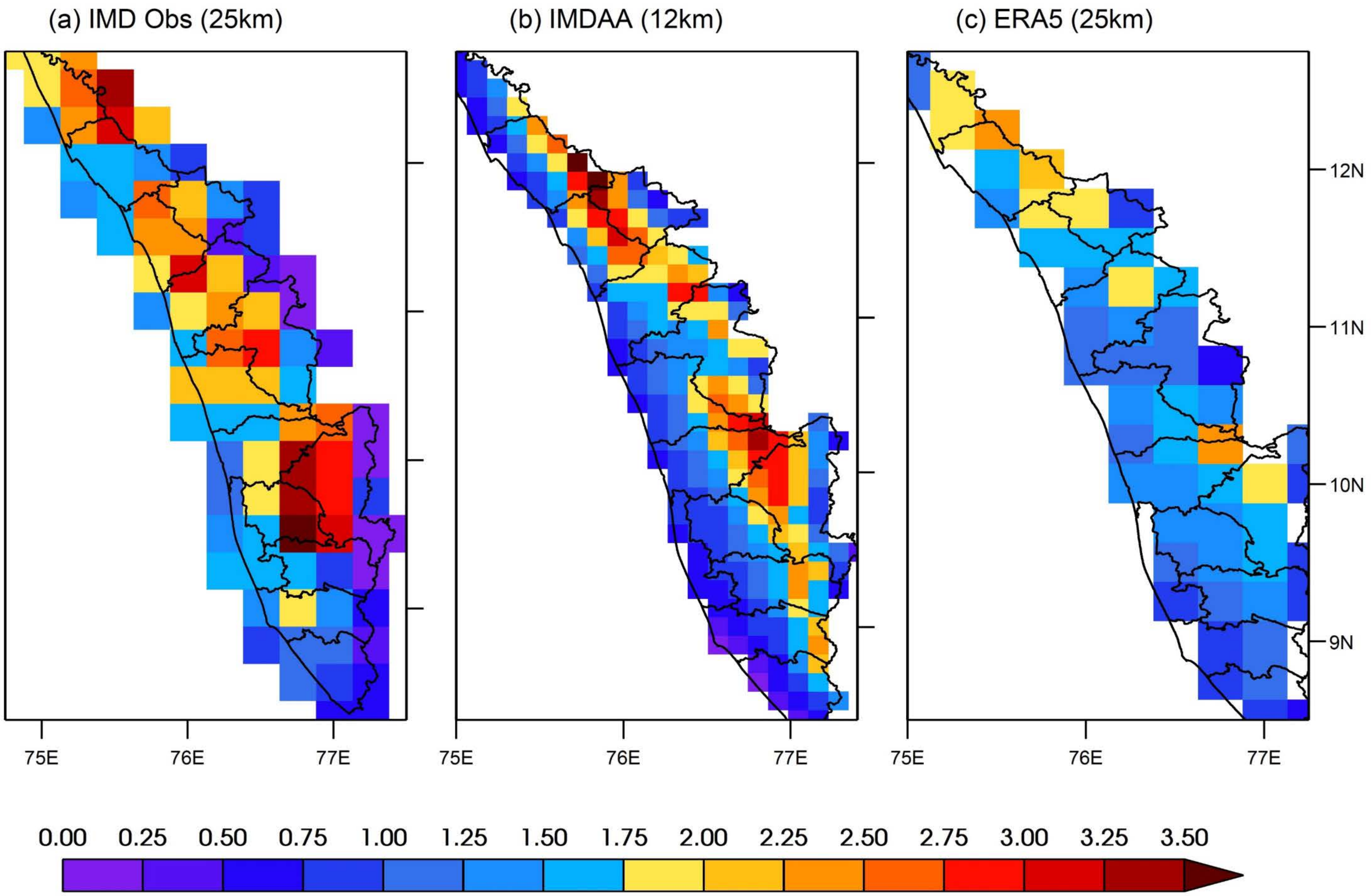


Comparison of OLR : IMDAA with Kalpana Satellite



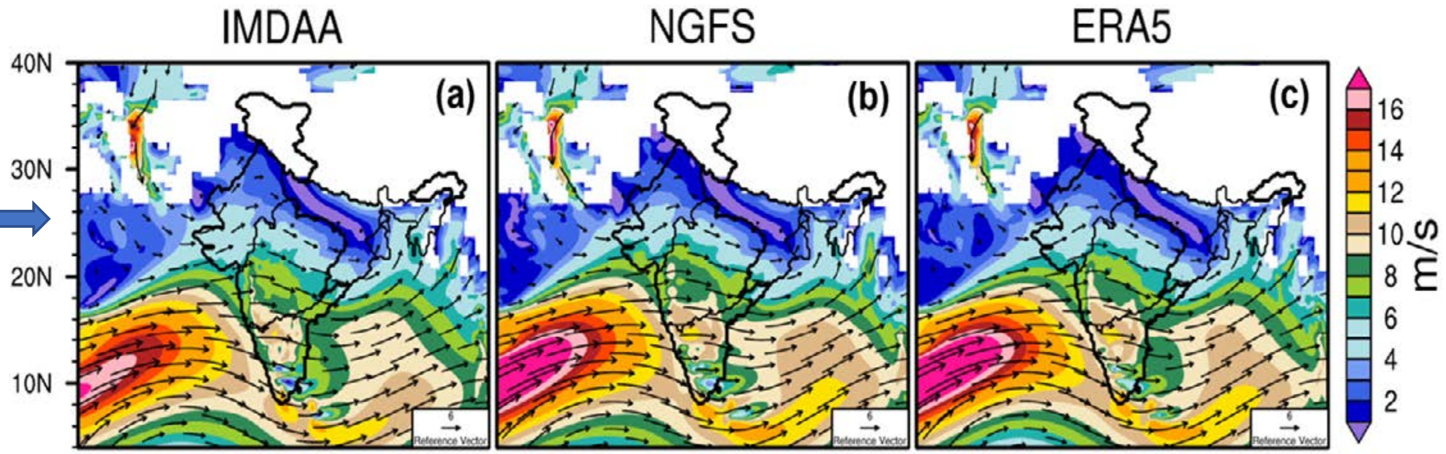
Impact of high resolution and resolved orography on extreme weather: 2018 Kerala Rainfall

Hourly averaged (6–18 Aug 2018) rainfall (mm)

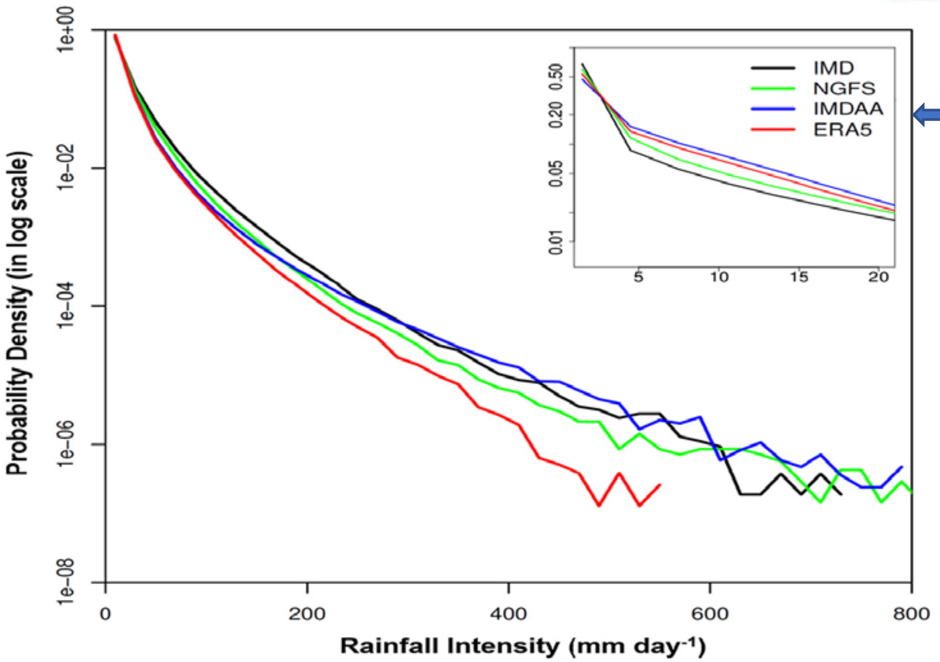


Comparison of IMDAA with NGFS and ERA5 reanalyses

850 hPa wind vectors during monsoon for 1999–2018



Probability Distribution for the rainfall intensity
Inset: Light rain category.



•All the three reanalyses captured the spatial patterns of observed rainfall reasonably well in all the seasons, except over the hilly regions.

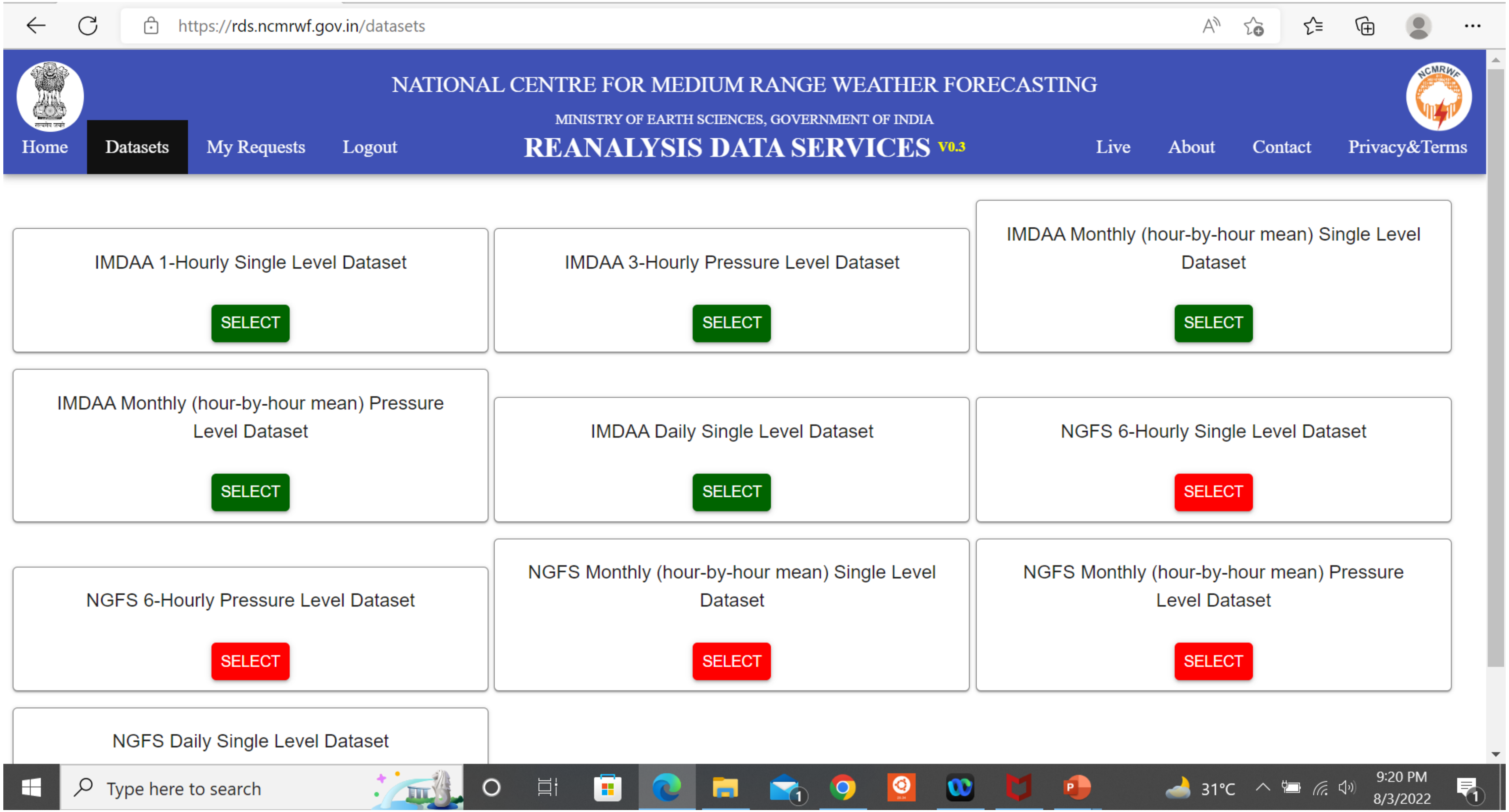
•Both IMDAA and NGFS captured the probability distribution of observed daily rainfall intensity especially the extremes

•Both IMDAA and ERA5 are equally good in capturing the light rainfall

https://doi.org/10.1016/j.atmosres.2021.105679

IMDAA Products & Product distribution

(https://rds.ncmrwf.gov.in)



Journal Publications

S. Indira Rani, Arulalan T., John P. George, E. N. Rajagopal, Richard Renshaw, Adam Maycock, Dale Barker and M. Rajeevan, 2021: **IMDAA: High Resolution Satellite-era Reanalysis for the Indian Monsoon Region**, *Journal of Climate*, https://doi.org/10.1175/JCLI-D-20-0412.1

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S. Indira Rani, John P. George, T. Arulalan, Sumit Kumar, M. Das Gupta, E.N. Rajagopal and Richard Renshaw (2020), **"Evaluation of High Resolution IMDAA Regional Reanalysis Precipitation over India during Summer Monsoon Season"**, CLIVAR Exchanges - Special Issue: India's Monsoon Mission, No.79, Pages 31-33, November 2020 DOI: https://doi.org/10.36071/clivar.79.2020.

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Tarkeshwar Singh, Upal Saha , V. S. Prasad and Munmun Das Gupta, 2021: Assessment of newly-developed high resolution reanalyses (IMDAA, NGFS and ERA5) against rainfall observations for Indian region. Atmospheric Research, DOI: https://doi.org/10.1016/j.atmosres.2021.105679 https://journals.ametsoc.org/view/journals/clim/34/12/JCLI-D-20-0412.1.xml

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Assessment of newly-developed high resolution reanalyses (IMDA and ERA5) against rainfall observations for Indian region

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[b] *Nansen Environmental and Remote Sensing Center, Bergen, Norway*

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ERA5
Reanalysis
IMD
Rainfall

ABSTRACT

In this study, a comprehensive assessment has been provided for the pe resolution reanalysis (IMDAA, NGFS, ERA5) datasets w.r.t. IMD rai monsoon regions of India during 1999–2018. It is necessary to underst are performing spatio-temporally, specifically during monsoon in ord developmental purposes. Focus has been given to assess their relative performance during monsoonal rainfall extremes against IMD observations. Results reveal that all these three reanalysis datasets captured the spatial

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Quantile mapping bias correction methods to IMDAA reanalysis for calibrating NCMRWF unified model operational forecasts

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ABSTRACT

This study focuses on assessing different quantile mapping (QM) bias correction approaches based on empirical and parametric methods to bias-correct the Indian Monsoon Data Assimilation and Analysis (IMDAA) precipitation data and subsequently calibrate the National Centre for Medium Range Weather Forecasting (NCMRWF) Unified Model operational forecasts. The two coastal cities Chennai and Mumbai, India, are chosen here to support the Integrated Flood Warning System (IFLOWS), initiated by the Ministry of Earth Sciences, Government of India, which provides early warning and decision support during flooding. The empirical QM methods are relatively better in correcting the quantiles with calibrated precipitation close to the observed cumulative distribution at these coastal cities. However, in extreme rainfall cases, the skill of calibrated precipitation through parametric methods seems promising and suitable for flood forecasting applications. Hence, this study demonstrates QM methods' performance and their potential in downscaling precipitation that has significant implications for urban flood models.

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Land surface and Hydrological application products

https://rds.ncmrwf.gov.in

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Water Runoff	kg m-2	Sub Surface	Average (hourly)#
Water Runoff Rate	kg m-2s-1	Sub Surface	Average (hourly)#
Upward Water Rate	kg m-2 s-1	Surface	Average (hourly)#
Surface Temperature (skin)	K	Surface	Instantaneous (hourly)*
Surface Pressure	Pa	Surface	Instantaneous (hourly)
Mean Sea Level Pressure	Pa	Mean Sea Level	Instantaneous (hourly)
Surface Roughness	m	Surface	Instantaneous (hourly)*
0-0.1 m below ground Column-Integrated Soil Moisture	kg m-2	Soil	Instantaneous (hourly)
0.1-0.35 m below ground Column-Integrated Soil Moisture	kg m-2	Soil	Instantaneous (hourly)
0.35-1 m below ground Column-Integrated Soil Moisture	kg m-2	Soil	Instantaneous (hourly)
1-3 m below ground Column-Integrated Soil Moisture	kg m-2	Soil	Instantaneous (hourly)
Soil Temperature (0-0.1 m below ground)	K	Soil	Instantaneous (hourly)
Soil Temperature (0.1-0.35 m below ground)	K	Soil	Instantaneous (hourly)
Soil Temperature (0.35-1 m below ground)	K	Soil	Instantaneous (hourly)
Soil Temperature (1-3 m below ground)	K	Soil	Instantaneous (hourly)

Land surface and Hydrological application products

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Analysis of soil moisture estimates from global and regional datasets over the Indian region

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The main objective of this study is to analyse the near-
from two gridded soil moisture datasets and to comp
datasets with the soil moisture data obtained from the
moisture datasets considered in this study are (i) globa
and (ii) Indian monsoon data assimilation and analysis
from modelled output that assimilates soil moisture, wl
dataset are derived from both satellite and modelled ob
the differences of ASCAT soil moisture with GLEAM
differences of ASCAT soil moisture with IMDAA soil
2008–2012. Also, quantitative measures such as improv
spatial and temporal correlation are obtained using th
quantify the relative closeness of the datasets with
measures clearly indicate that over the Indian region,
closer to the ASCAT soil moisture data when compare
over all seasons for the period 2008–2012. Also, GLEAM
error value as compared to IMDAA soil moisture datas
Also, the results of the IP and FP indicate that the lar

Soil Temperature (0-0.1 m below ground)
Soil Temperature (0.1-0.35 m below ground)
Soil Temperature (0.35-1 m below ground)
Soil Temperature (1-3 m below ground)

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ENCES, GO
DATA
g m-2
g m-2s-1
g m-2 s-1

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https://doi.org/10.1007/s12040-022-01873-6

Validation and bias correction of incoming solar radiation from two reanalysis products over India

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g-term meteorological information. Among the many
he important variables in driving various atmospheric
and correct for biases in the R_{sd} data from the Modern-
plications, version 2 (MERRA-2) and the Indian Mon-
analysis products at 8-day and monthly time periods. It
and IMDAA exhibited similar characteristics. A sta-
ecting R_{sd} and the bias was characterized as a function
on. The bias in 8-day R_{sd} improved from 22.03 to 12.95
$^{-2}$ for IMDAA. Similarly, at the monthly time scale, the
MERRA-2 and from 31.60 to 8.67 Wm^{-2} for IMDAA.
ited improved correlation and seasonal variation closer
tiveness of the bias correction procedure.

DAA; MERRA-2.

NCMRWF
Terms

Instantaneous (hourly)
Instantaneous (hourly)
Instantaneous (hourly)
Instantaneous (hourly)
Instantaneous (hourly)
Instantaneous (hourly)

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Invited Articles (Silver Jublee Publication)

Revisiting statistical spectral-agrometeorological wheat yield models for Punjab using MODIS EVI and NCMRWF re-analysis temperature data

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ABSTRACT

Use of space-based spectral information with weather inputs for wheat yield modeling by empirical and crop simulation models is reviewed and extended with enhanced spectral modeling approach for districts in central Punjab. The study uses multi-date and multi-year MODIS data at 250m resolution to both identify wheat crop and develop temporal spectral Enhanced Vegetation Index (EVI) profile for 2001-2019 period. Recently developed high resolution (12km) gridded temperature data from NCMRWF, namely India Monsoon Data Assimilation and Analysis (IMDAA) has been used for computing district-level average of daily (AV) and night-time (NT) temperatures. Multiple linear regression analysis with statistical tests on significance of coefficients for various inputs is used to investigate significance of various input parameters in yield models on multi-district data set. Results identify both area under spectral profile (AS-EVI) and mean peak value (PK-EVI) have significant control on yield. Individual district-level trend based yield (YT) is a significant coefficient in the multi-district models. Model performance is significantly improved by the inclusion of phase-specific temperatures and at specific post-flowering phases the night temperature figured in best models. Significance of the results in development of spatially resolved yields for applications like yield forecast, crop insurance and climate change studies is discussed.

Keywords: Spectral-agromet models; Wheat yield; MODIS EVI; Nighttime temperature.

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Thank you