NCMRWF Forecast Products for Wind/Solar Energy Applications

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Outline

- NCMRWF Unified Modelling System
- Forecast Products for Renewable Energy Applications
- Post Processing & Bias Correction
  - *A few interesting results!!*
- NWP: Ensemble Prediction System
- *Future Plans!!*

Who we are??

- **The National Centre for Medium Range Weather Forecasting (NCMRWF)**
  - ***Centre of Excellence in Weather and Climate Modelling under the Ministry of Earth Sciences, Govt. of India.***
- **The mission**
  - ***to continuously develop advanced numerical weather prediction (NWP) systems***
  - ***with increased reliability and accuracy over India and neighbouring regions***
  - ***through research, development and demonstration of new and novel applications.***

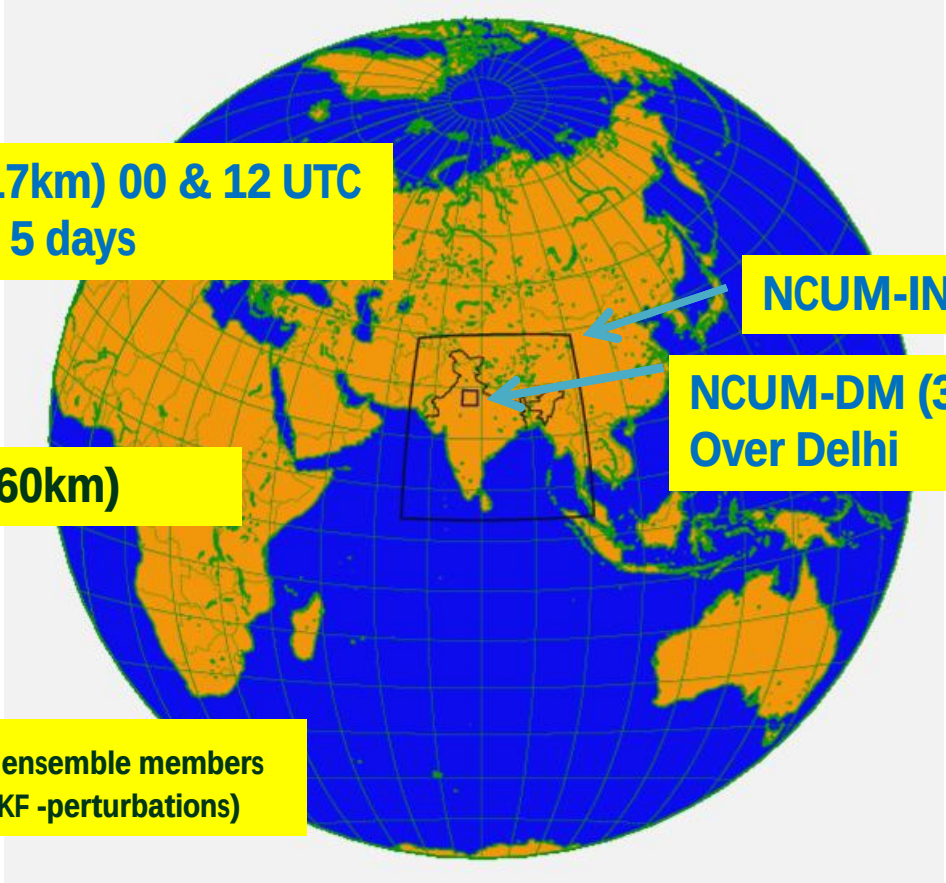
NCUM: Current operational models at NCMRWF

Global Models

NCUM-Global (~17km) 00 & 12 UTC run for 10 days & 5 days

NCUM-coupled (~60km)

NEPS (~33km) 44 ensemble members (33 km resolution) (ETKF -perturbations)

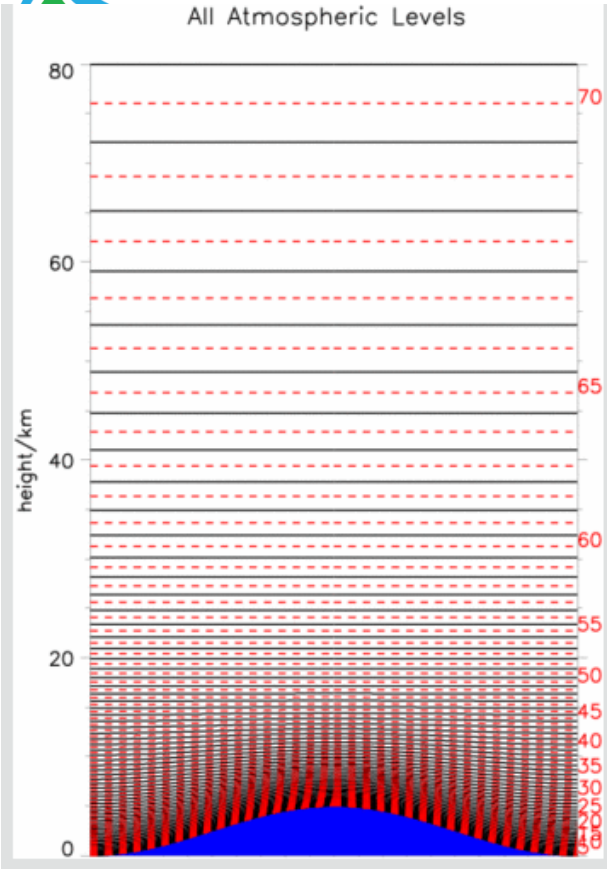


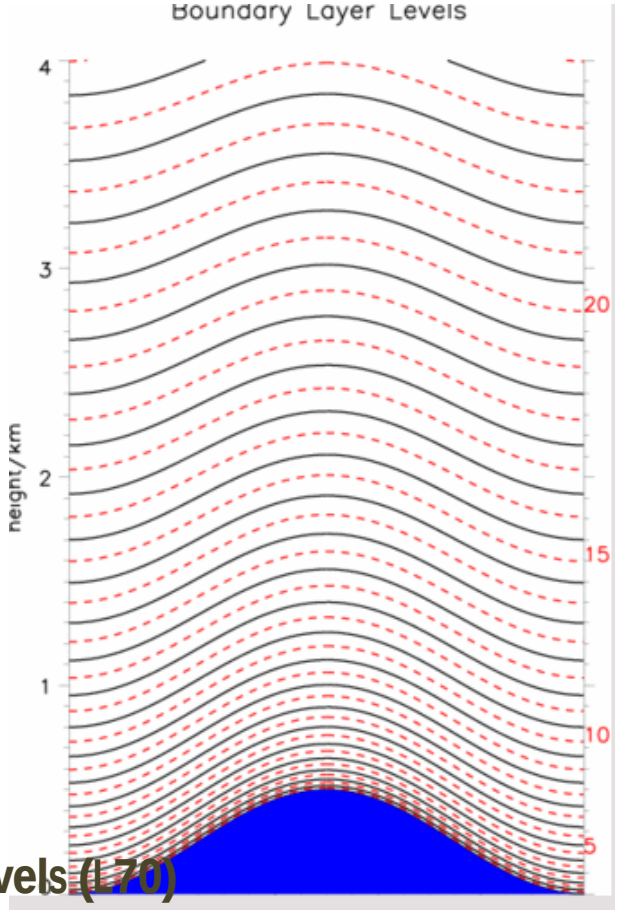
Regional Models

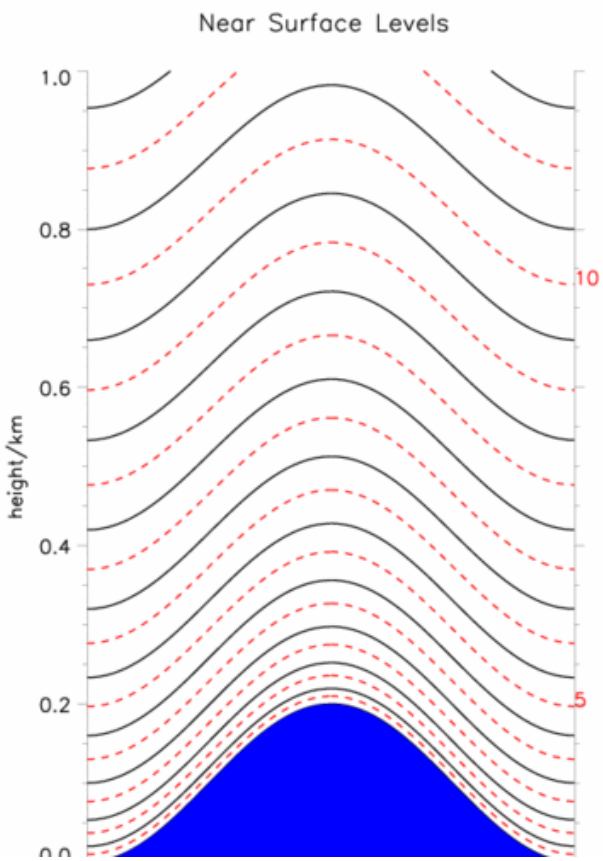
NCUM-IND Regional (4km grid)

NCUM-DM (330m grid) Over Delhi

Vertical Resolution : Near ground







- NWP configurations has 70-levels (L70)
- Hybrid vertical levels
- An almost identical 50 levels below 18 km
- A model lid at 80 km

  23-levels in boundary layer

  11-levels in 1km near ground

NCMRWF Forecast Products for Wind/Solar Energy Applications

- ***Surface winds and solar fluxes are just two of many weather variables a Meteorologist deals with!!***
- ***Challenges??***

- **Data resolution**

  Temporal : *1 hour (Global)* & *15 minutes (Regional)*

  Spatial : 0.25 x 0.25 deg for Global

  0.04 x 0.04 deg for Regional

- **Vertical level** : 10m, 50m & 8 Pr. Level between 1000 hPa-925hPa for Global

- **Forecasting** : Two cycles per day at 00 and 12 UTC up to 10 days and 5 days respectively for Global

  One cycle at 00UTC up to 3 days for Regional

Solar Fluxes: GHI and DNI

Users

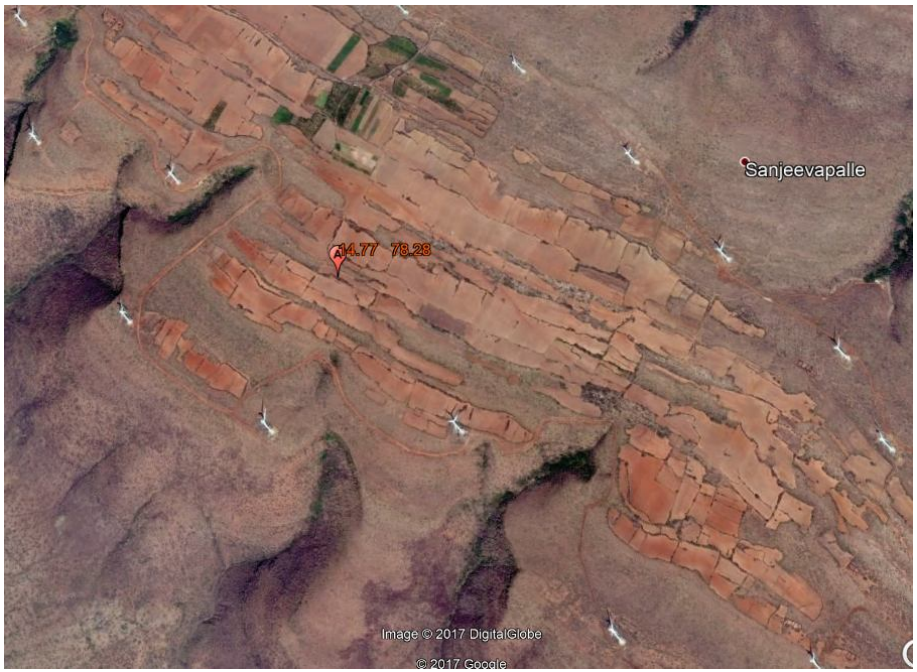
- NIWE WRA & SRA departments
- Private agencies:
  - Manikaran Analytics Limited: Gridded wind/solar data from NCUM Global and Regional model over India being provided for more than 3 years. Feedback is shared on regular basis.
  - Energon Power Resources Pvt. Ltd.: Location specific forecasts for more than 20 locations to cover 7 wind farms from Global and Regional models. Monthly feedback is shared.
  - Energy&Meteo Systems
  - Algo Engines
  - Discussion with Meteodyn, DNV-GL, Hero Futures

CHALLENGES IN NWP??

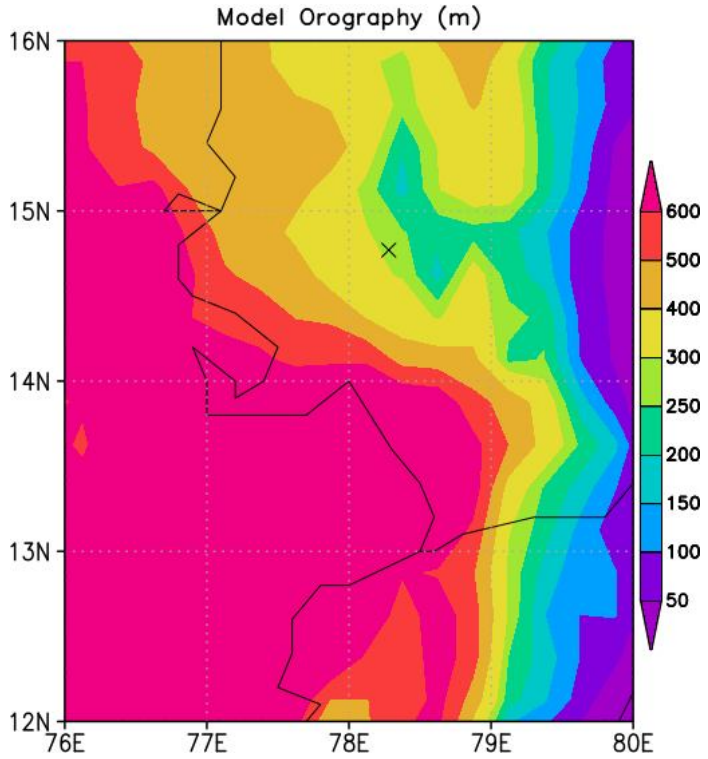
- **While the forecast quality of the NWP models has constantly improved, due to HPC, which allows a finer horizontal grid resolution.**
- **Mountainous terrain, however, still poses a challenge for NWP models mainly due to**
  - ***not sufficient resolution of the underlying topography,***
  - ***physical parameterizations based on assumptions for horizontally homogeneous and flat terrain.***

Topography

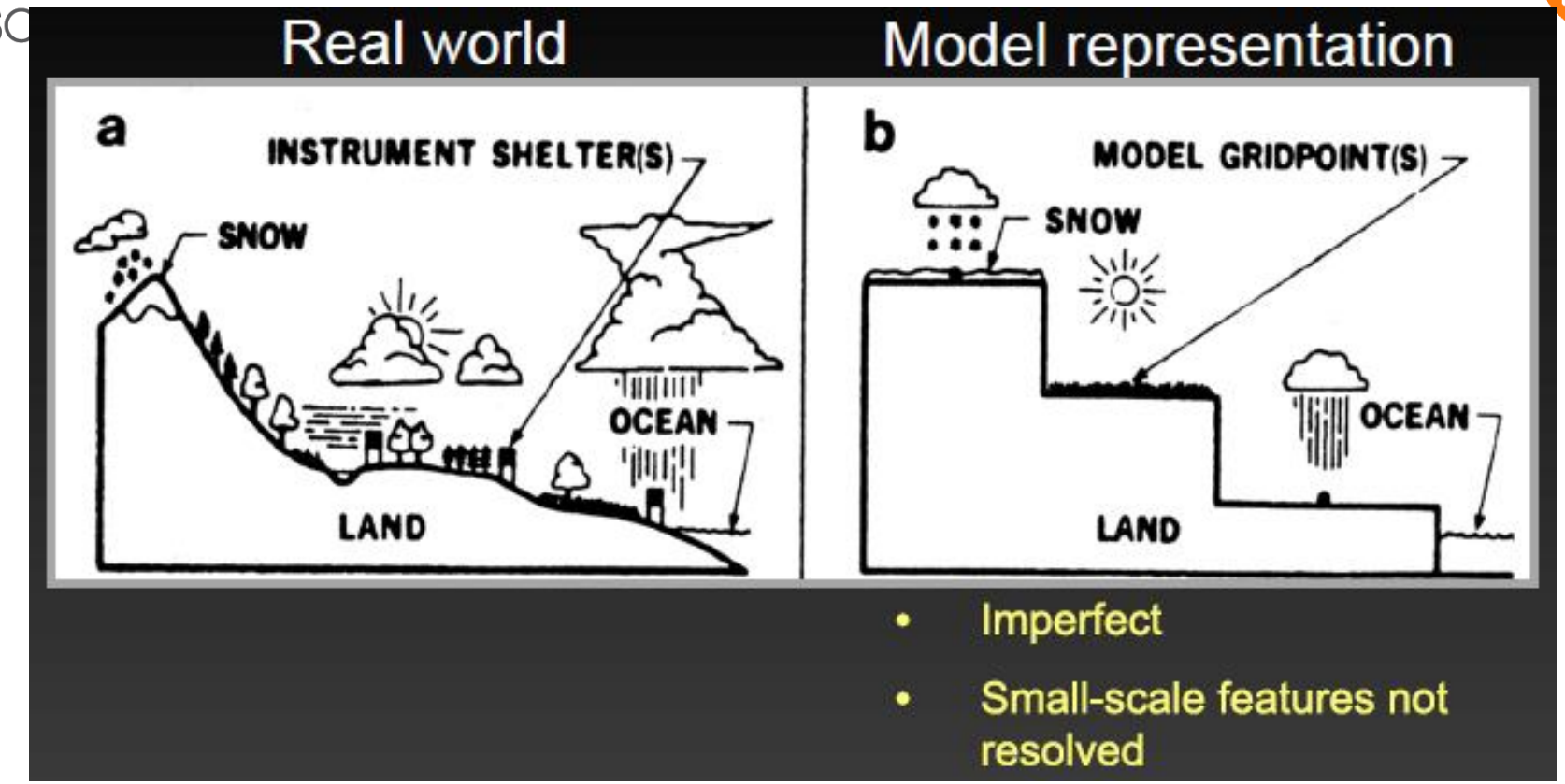
Google Earth



Model



Elevation at this location from Model is 250-300m whereas in G Earth it's between 500-510m.



- **Approximate terrain height, land use etc.**
- **Imperfect model physics, initial conditions, and boundary conditions**
- **systematic errors cause biases in first and second moments (Toth et al 2003)**

Post Processing

- Post processing of forecasts is a necessary and important step for the daily operational runs at NWP centres.
- Reliability, accuracy, and efficiency are the most important issues for daily operations.

Moving Average Bias Correction

1). Bias Estimation: The bias (***b***) for each lead-time (***t***) (6-hour interval up to 384 hours), each grid point (***i, j***) is defined as the different of best analysis (***a***) and forecast (***f***) at the same valid time (t_0) which is up on latest available analysis.

$$b_{i,j}(t) = f_{i,j}(t) - a_{i,j}(t_0)$$

- ***b1, b2*** **and** ***b3*** **be biases for recent past three days (*t-1, t-2* and *t-3* respectively)**
- **The mean bias-**

$$B = b1*(0.5) + b2*(0.2) + b3*(0.1)$$

2). Bias corrected forecast: The new (or bias corrected) forecast (***F***) will be generated by applying decaying average bias (***B***) to current raw forecast (***f***) for each lead time, at each grid point, and each parameter.

$$F_{i,j}(t) = f_{i,j}(t) - B_{i,j}(t)$$

Cui et al. 2012 and 2014

NCMRWF Forecast of Wind Speed over South India

Analysis, Raw and Bias Corrected Forecasts

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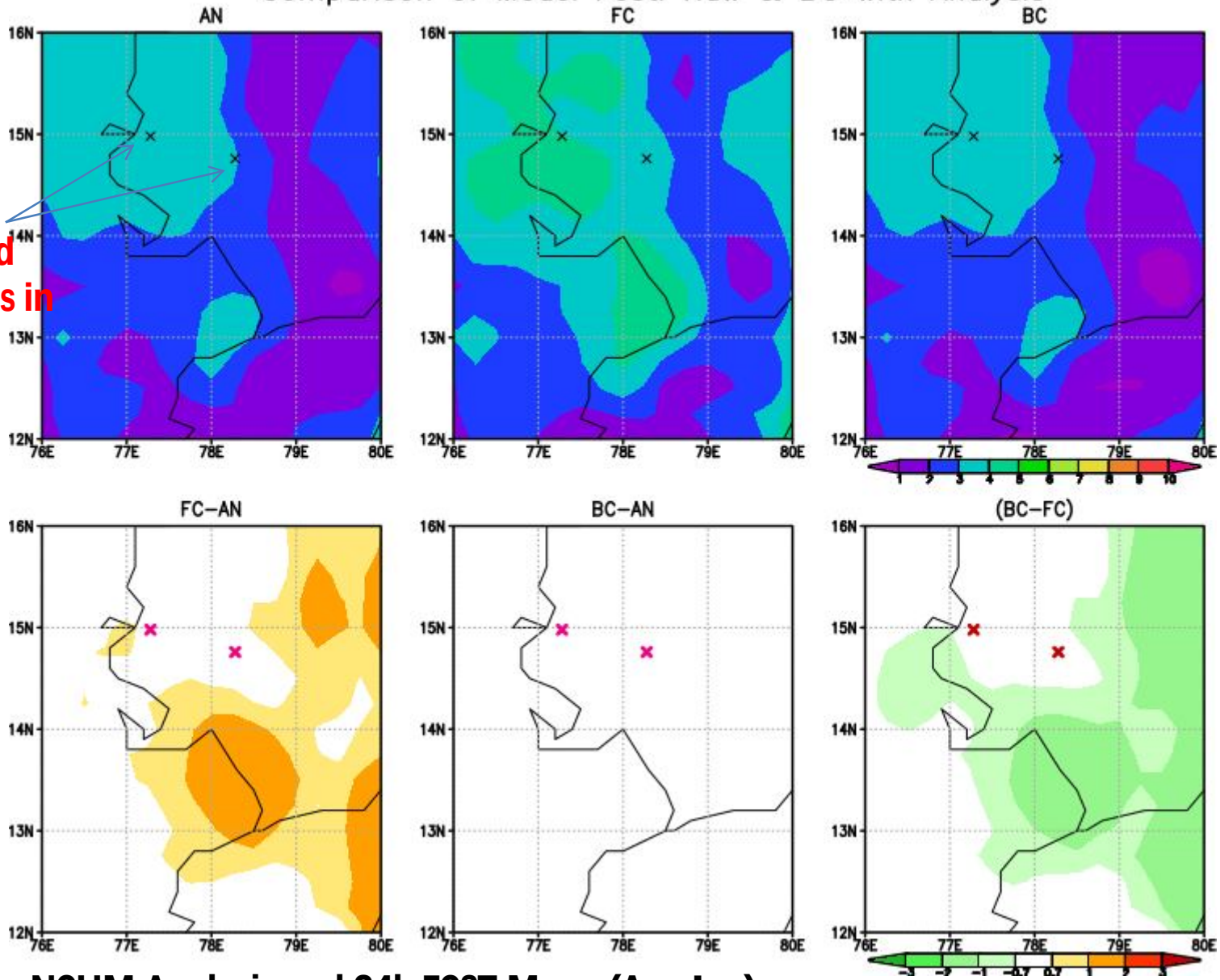
Wind Speed 10m

Two Wind Farm sites in AP



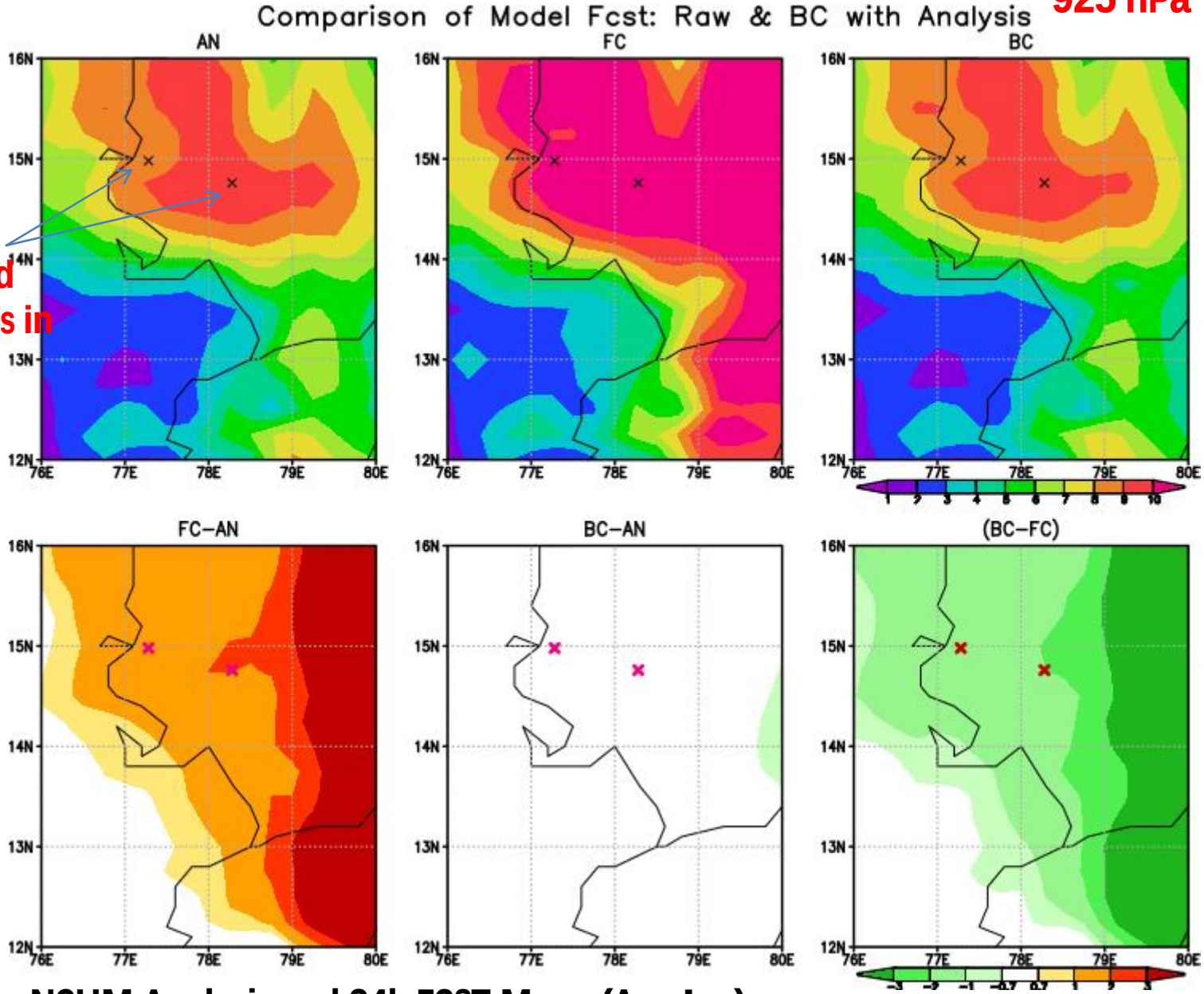
NCUM Analysis and 24h FCST Mean (Apr-Jun)

ESSO

NCMRWF

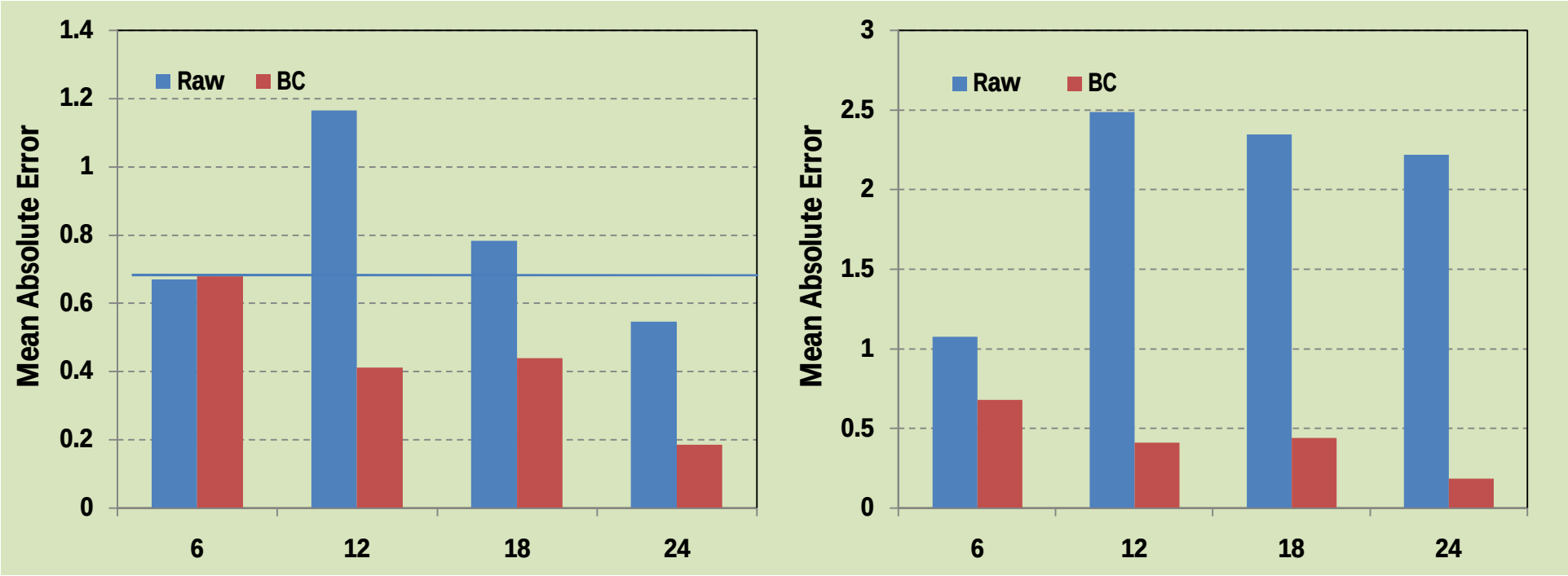
Wind Speed 925 hPa

Two Wind Farm sites in AP



NCUM Analysis and 24h FCST Mean (Apr-Jun)

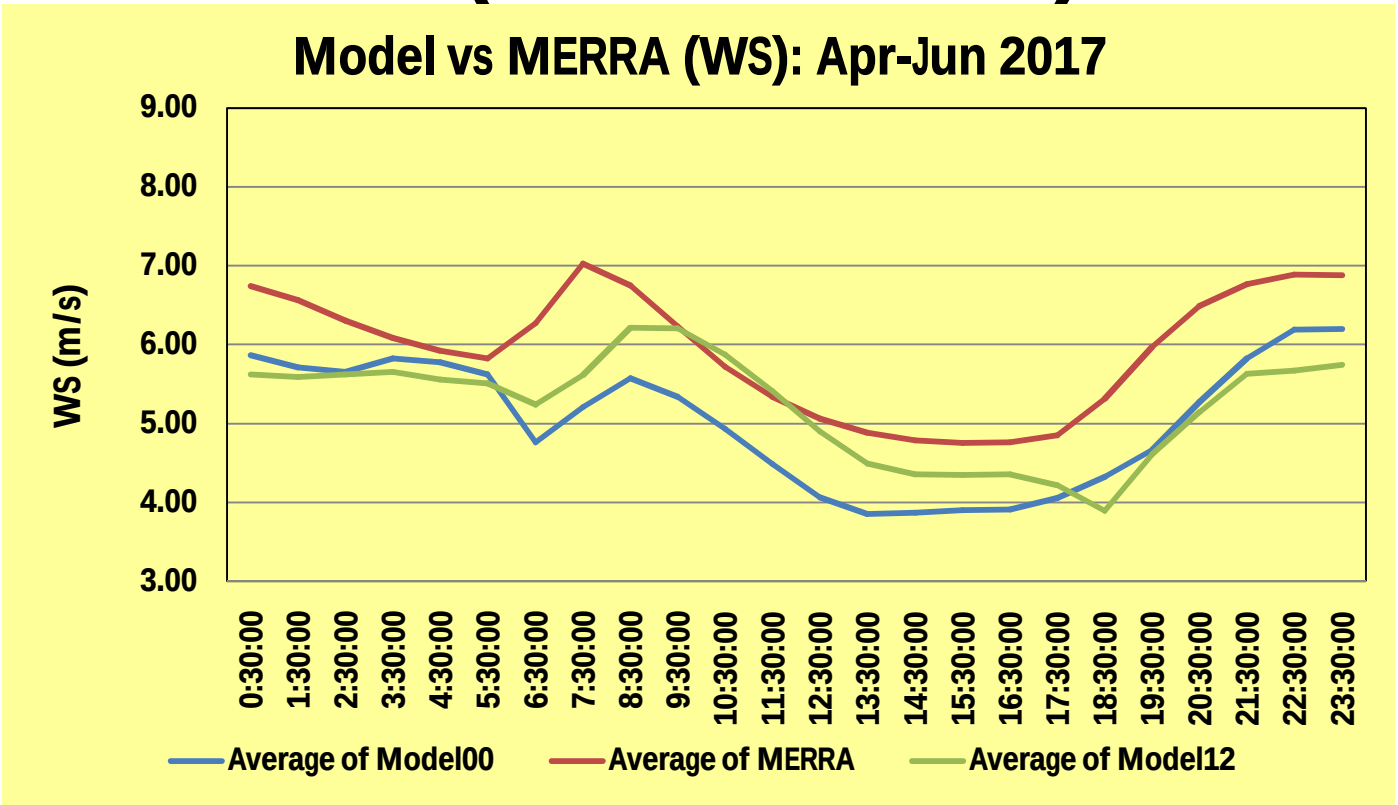
Impact of BC : Reduced MAE in the 10m (L) & 925 hPa (R) Wind Speed



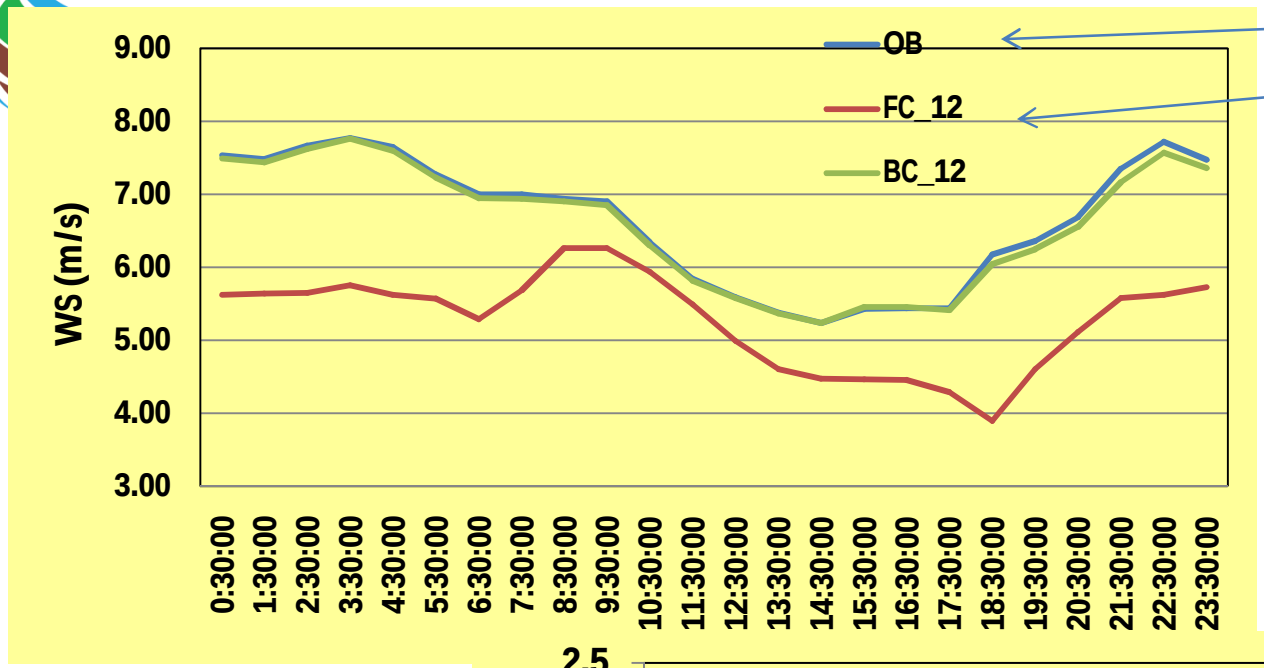
- MEA Reduction by-
- 65%, 44% and 66% in 12h, 18h and 24h forecasts

- MEA Reduction by-
- 75%, 79% and 79% in 12h, 18h and 24h forecasts

Location Specific Forecast (South India : AP)



- Model Forecasts (50m ht) (00 and & 12UTC) are consistent with MERRA Reanalysis (50m ht)

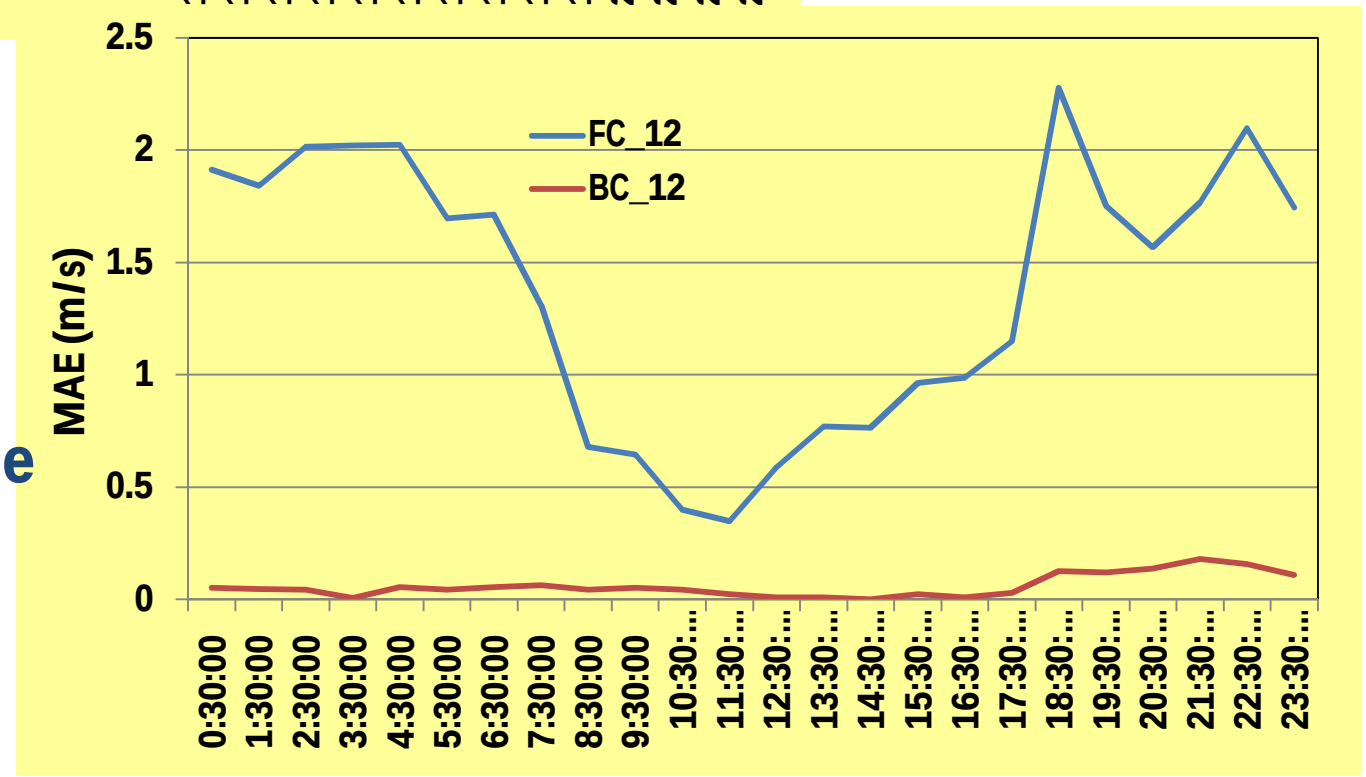


Observed wind at 80m

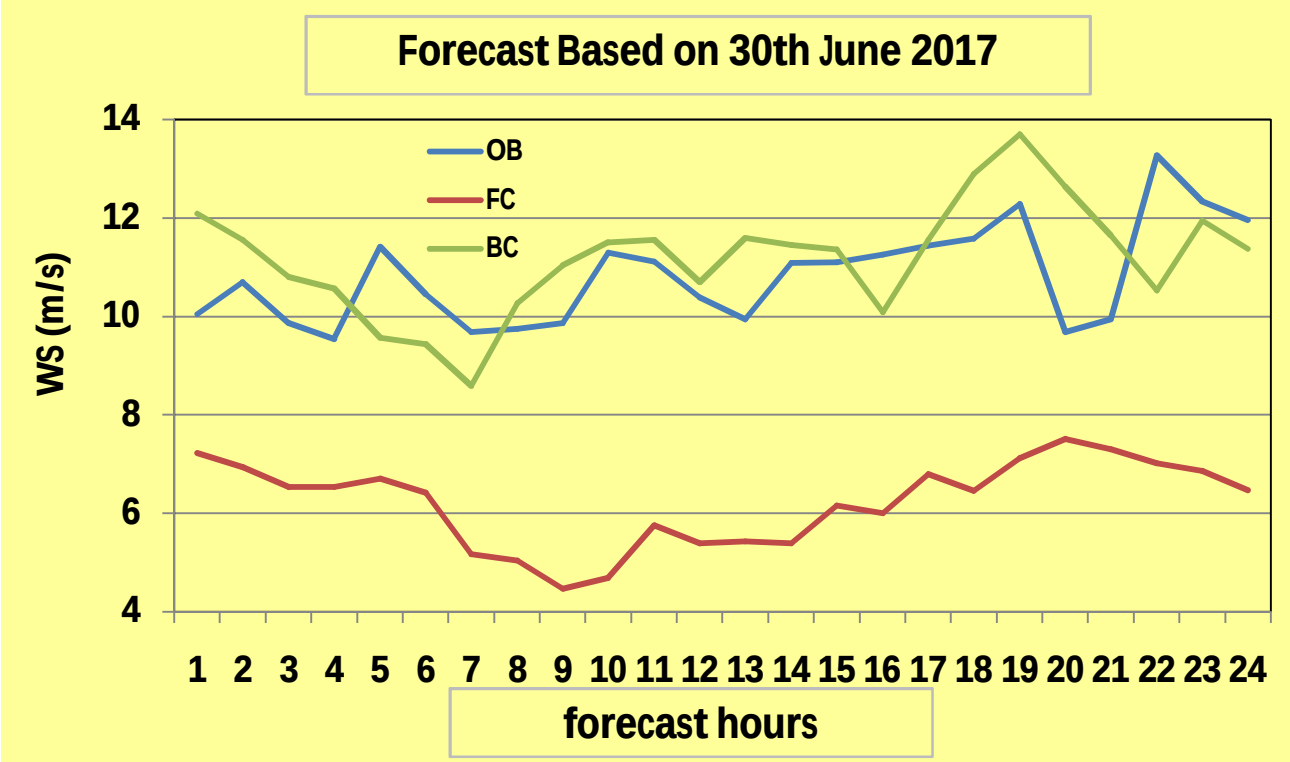
Forecast wind at 80m

Observed and Forecast Wind: Mean (Apr-Jun 2017) Diurnal Cycle

Observed and Forecast Wind: MAE (Apr-Jun 2017) Diurnal Cycle



Forecast on a Typical day (South India : AP)

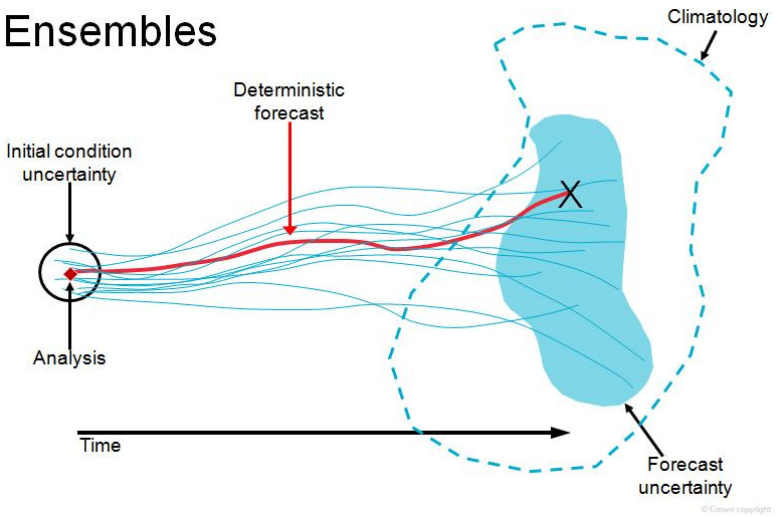


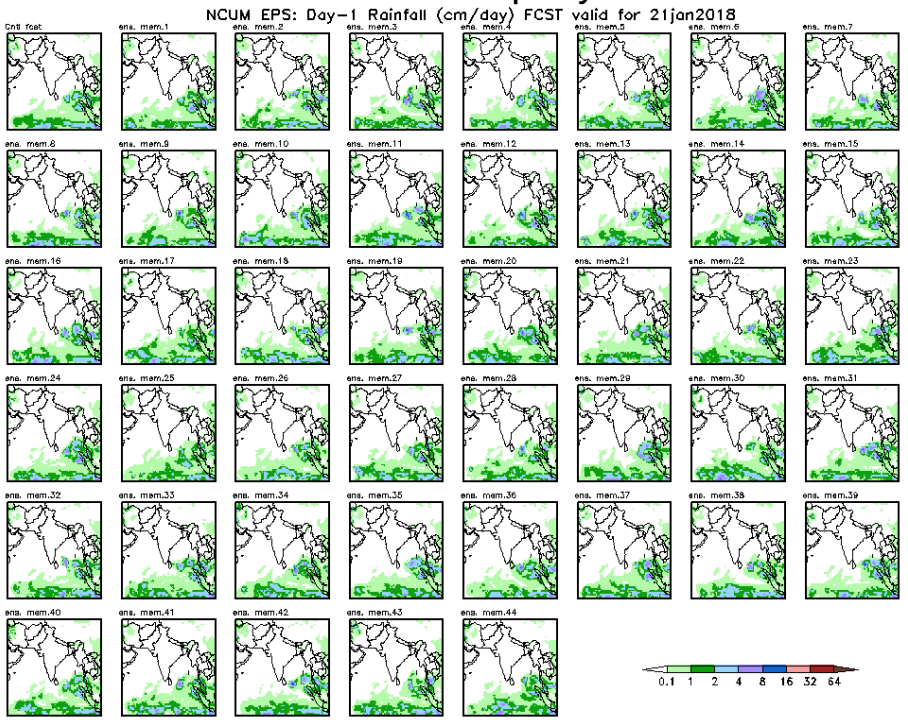
Ensemble Forecasting System

Lack of Observation data – improper initial state of NWP - "Butterfly effect" – small cause could have large effects!!

The atmospheric non-linear behavior, consequently chaotic, must be treated in a probabilistic way (Lorenz, 1963)!!

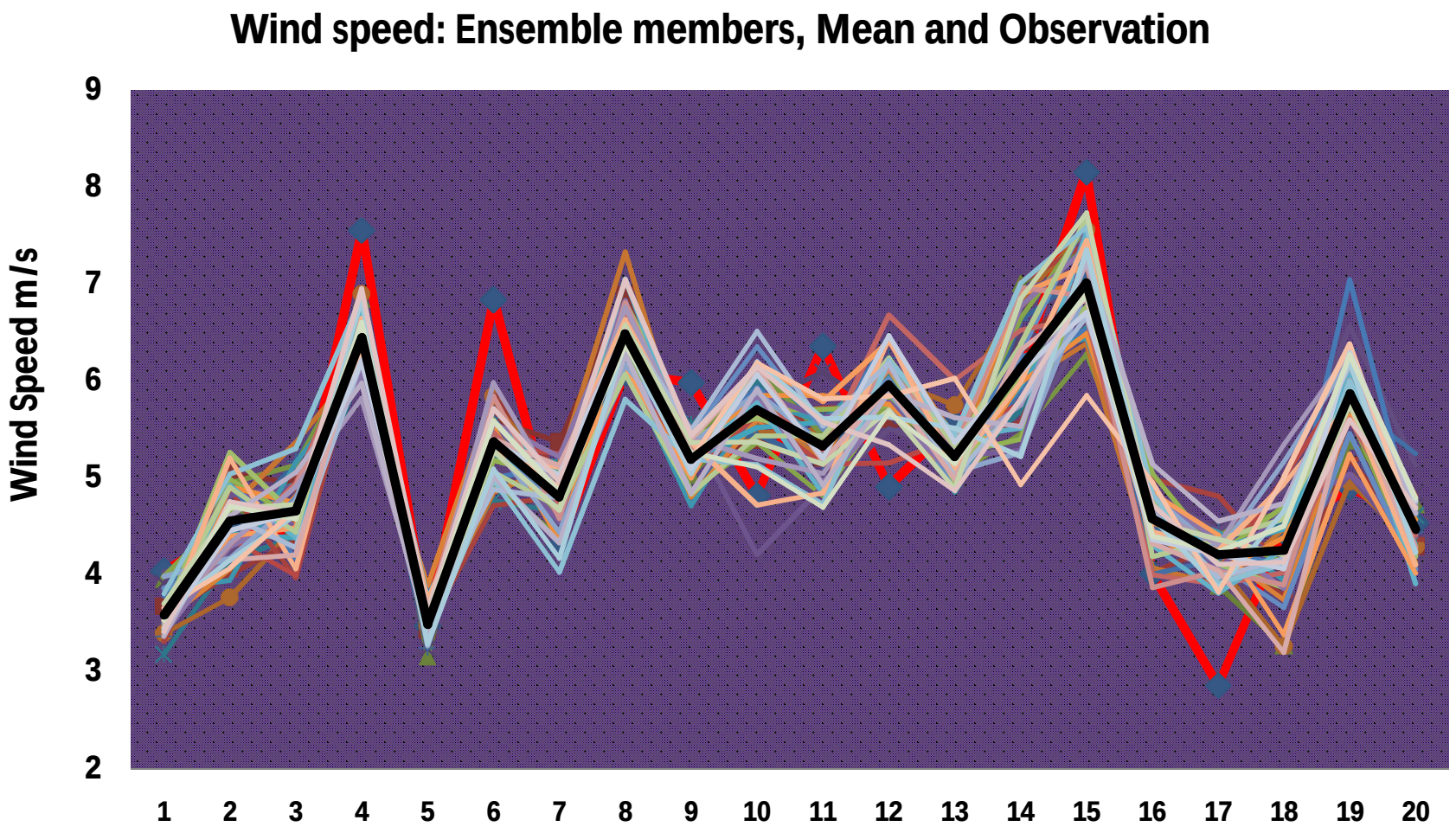
- What is an ensemble forecast?
  - Instead of running just a single forecast, the computer model is run a number of times from slightly different starting conditions. The complete set of forecasts is referred as the ensemble, and individual forecasts within it as ensemble members.
  - Ensemble forecast systems are designed so that each member should be equally likely.





NCMRWF Ensemble Prediction System (NEPS)

44 Members forecast at 6 hour interval



Future Plans

- **New HPC Installation**
  - 6.8 PF supercomputer by MoES
  - Globally ranked 4th dedicated for weather and climate services
- **Modeling system up-gradation**

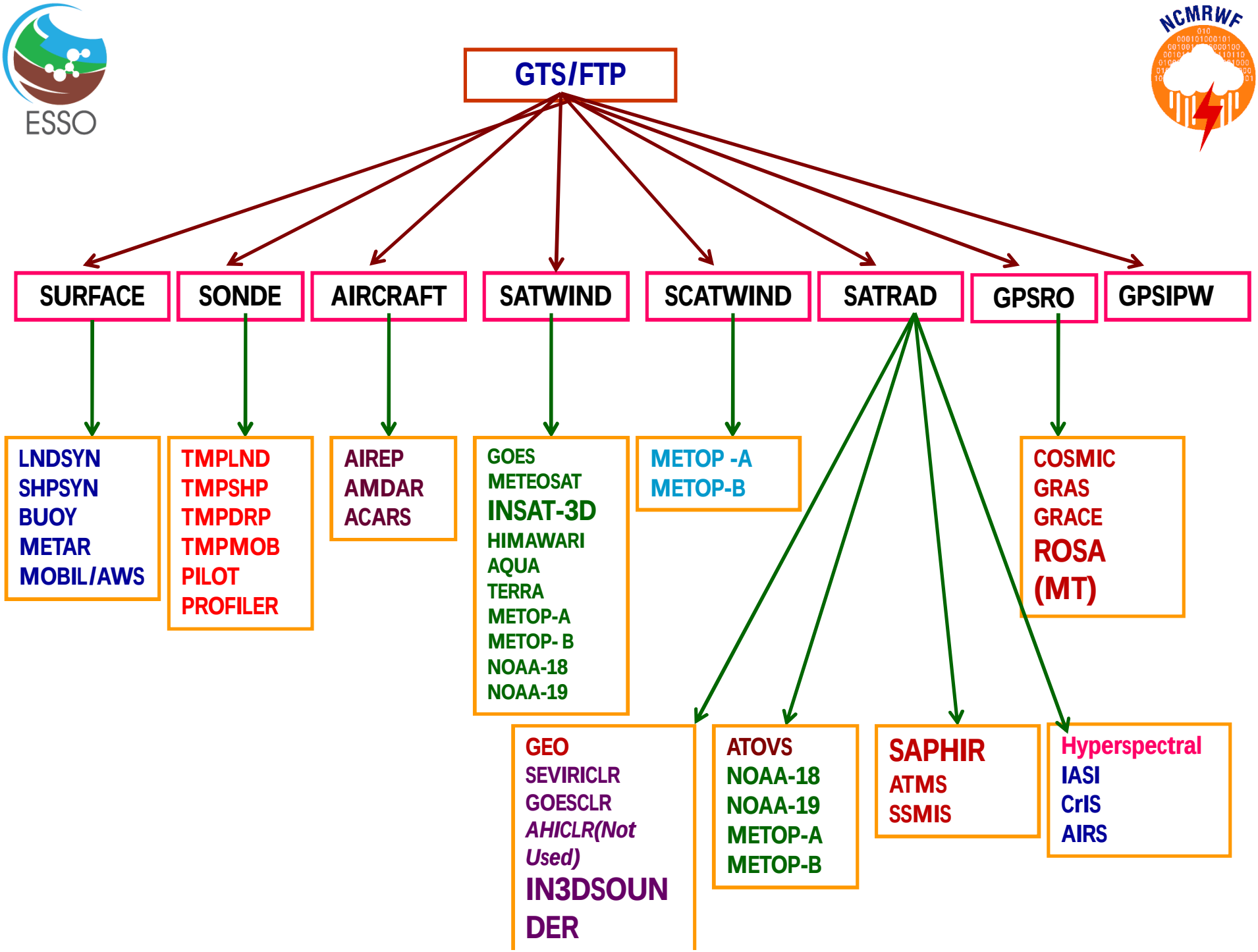
Model	Current Set-up	Future
NCUM-G	Resolution 17 km & 1 hr	Resolution 10 km & 1 hr
NCUM-R	Resolution 4 km & 15 min	Resolution 1.5 km & 15 min
NEPS	Resolution 33 km & 6 hr	Resolution 12 km & 1 hr

- **Renewable Energy Meteorology Project by MoES**

Conclusions

- NCMRWF is making continuous efforts to increase the model resolution and computational resources
- In-house Modeling system is capable of providing specialized forecasting for Wind/Solar industry
- Different Post processing techniques (AI, Statistical, NN etc.) to be integrated with NWP forecasts
- Collaborative projects between NWP centres and Power Forecasters

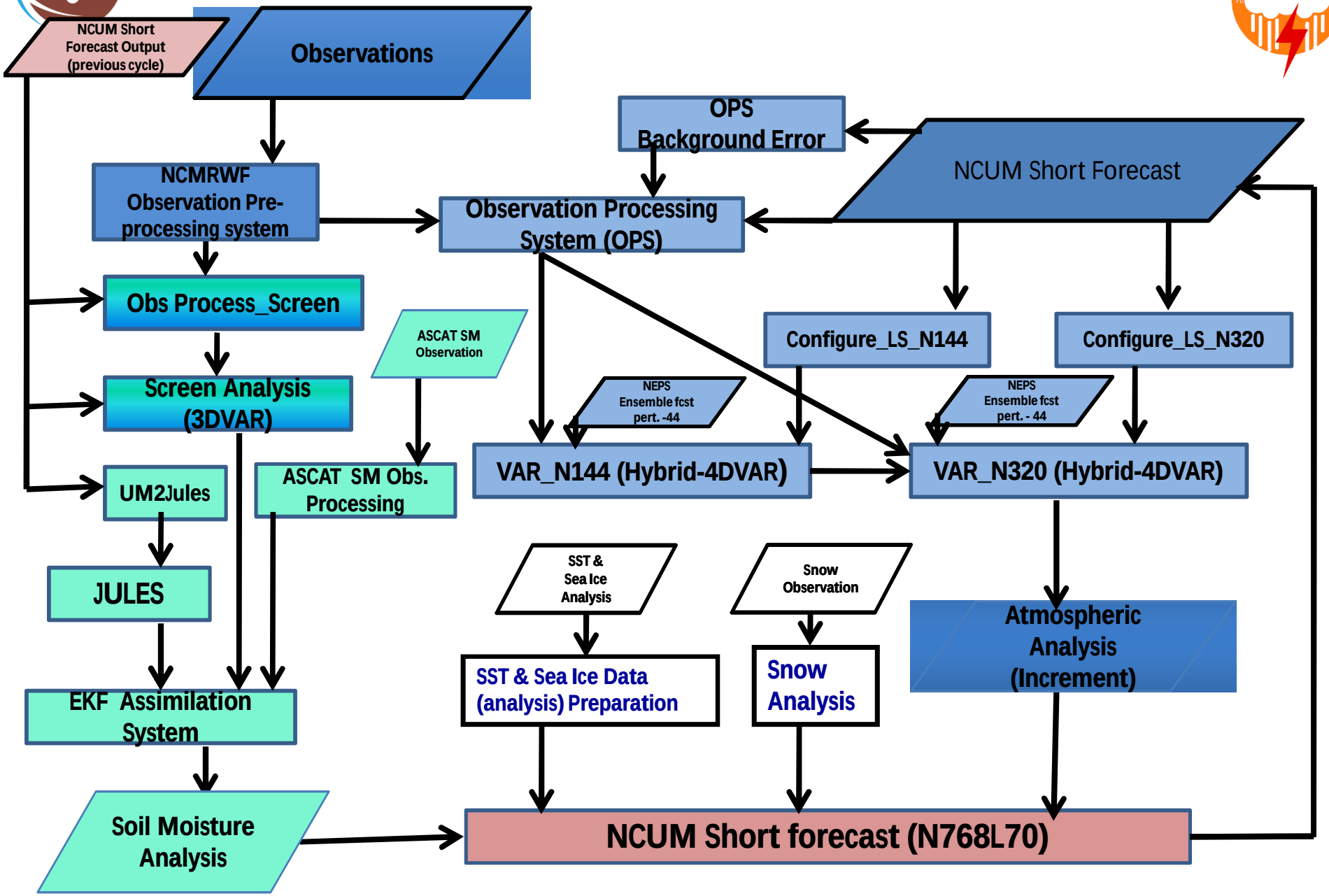
Thanks


ESSO
NCMRWF
GTS/FTP
SURFACE
SONDE
AIRCRAFT
SATWIND
SCATWIND
SATRAD
GPSRO
GPSIPW
LNDSYN
SHPSYN
BUOY
METAR
MOBIL/AWS
TMPLND
TMPSHP
TMPDRP
TMPMOB
PILOT
PROFILER
AIREP
AMDAR
ACARS
GOES
METEOSAT
INSAT-3D
HIMAWARI
AQUA
TERRA
METOP-A
METOP- B
NOAA-18
NOAA-19
METOP -A
METOP-B
COSMIC
GRAS
GRACE
ROSA
(MT)
GEO
SEVIRICLR
GOESCLR
AHICLR(Not Used)
IN3DSOUN DER
ATOVS
NOAA-18
NOAA-19
METOP-A
METOP-B
SAPHIR
ATMS
SSMIS
Hyperspectral
IASI
CrIS
AIRS

Data Used in NCUM Global DA Systems

Obstore	Observation Description	Assimilated Variables
Aircraft	Upper-air wind and temperature from aircraft	u, v, T
AIRS	Atmospheric Infrared Sounder of MODIS	T_b
Scatwind	Advanced Scatterometer in MetOp A & B	u, v
ATMS	Advanced Technology Microwave Sounder in NPP satellite	T_b
ATOVS	AMSU-A, AMSU-B/MHS from NOAA-18 &19, MetOp-A&B	T_b
CrIS	Cross-track Infrared Sensor in NPP satellite	T_b
GOESClear	Cloud clear Imager radiances from GOES E & W	T_b
GPSRO	Global Positioning System Radio Occultation (including MT-ROSA)	Bending Angle
GroundGPS	Ground based GPS observations	ZTD
IASI	Infrared Atmos. Sounding Interferometer from MetOp A&B	T_b
MTSAPHIR	SAPHIR microwave radiances from Megha-Tropiques	T_b
Satwind	Atmospheric Motion Vectors from various geostationary and polar orbiting satellites	u, v
SEVIRIClear	Cloud clear observations from SEVIRI in METEOSAT 10	T_b
Surface	Surface observation from land and Ocean	u, v, T, q, P_s
Sonde	Radiosonde observations, upper-air wind profile from pilot balloons, wind profiles, VAD wind observation from Indian DWR	u, v, T, q
IN3DSndr	INSAT-3D Sounder Radiances	T_b
SSMIS	SSMIS Radiances (F-17 &18)	T_b
AHIClear	Radiances from HIMAWARI-8	T_b

NCUM Data Assimilation System



Present Status: NCMRWF Unified Model (NCUM)

- **NCMRWF Unified Model (NCUM)**
  - NCUM Global (17 km) - Hybrid 4D-Var DA
  - NCUM 4 km (Indian region) (using global analysis) – 3D-Var DA (Parallel runs started from 01-June-2017)

  - High Resolution NCUM (1.5 km & 330 meter) (Delhi Region) - Selected periods/seasons

- **NCMRWF Global Ensemble Forecast System (NEPS) –** 44 ensemble members (33 km resolution) (ETKF -perturbations)

- **Coupled ocean atmosphere system (Experimental) (Global Ocean DA using NEMO-Var – 0.25 Deg**

NCMRWF Forecast 10m and 925 hPa WS over W India

Analysis, Raw and Bias Corrected Forecasts

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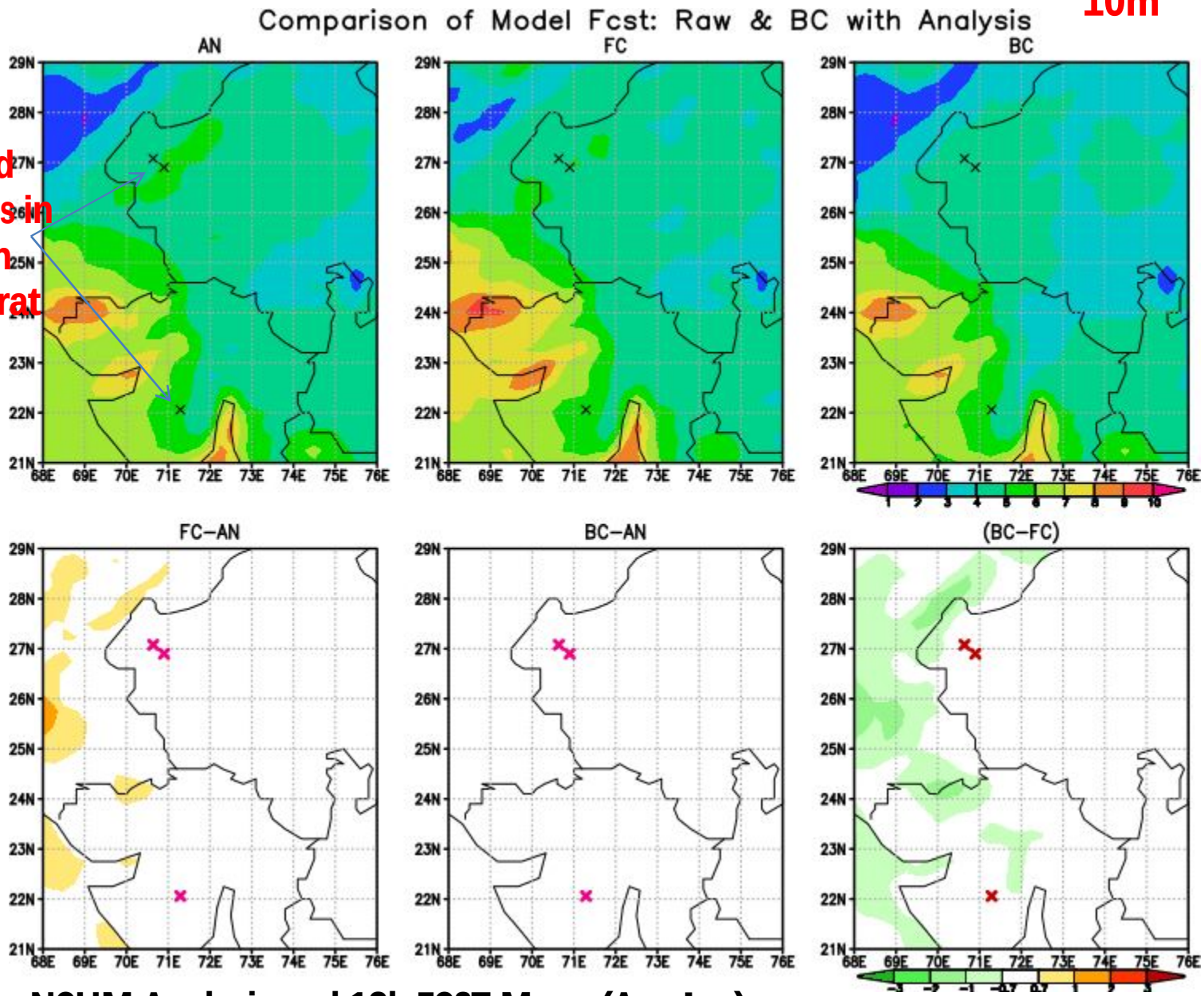
NCMRWF

Wind Speed 10m

Two Wind Farm sites in Rajasthan and Gujarat



NCUM Analysis and 12h FCST Mean (Apr-Jun)

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NCMRWF

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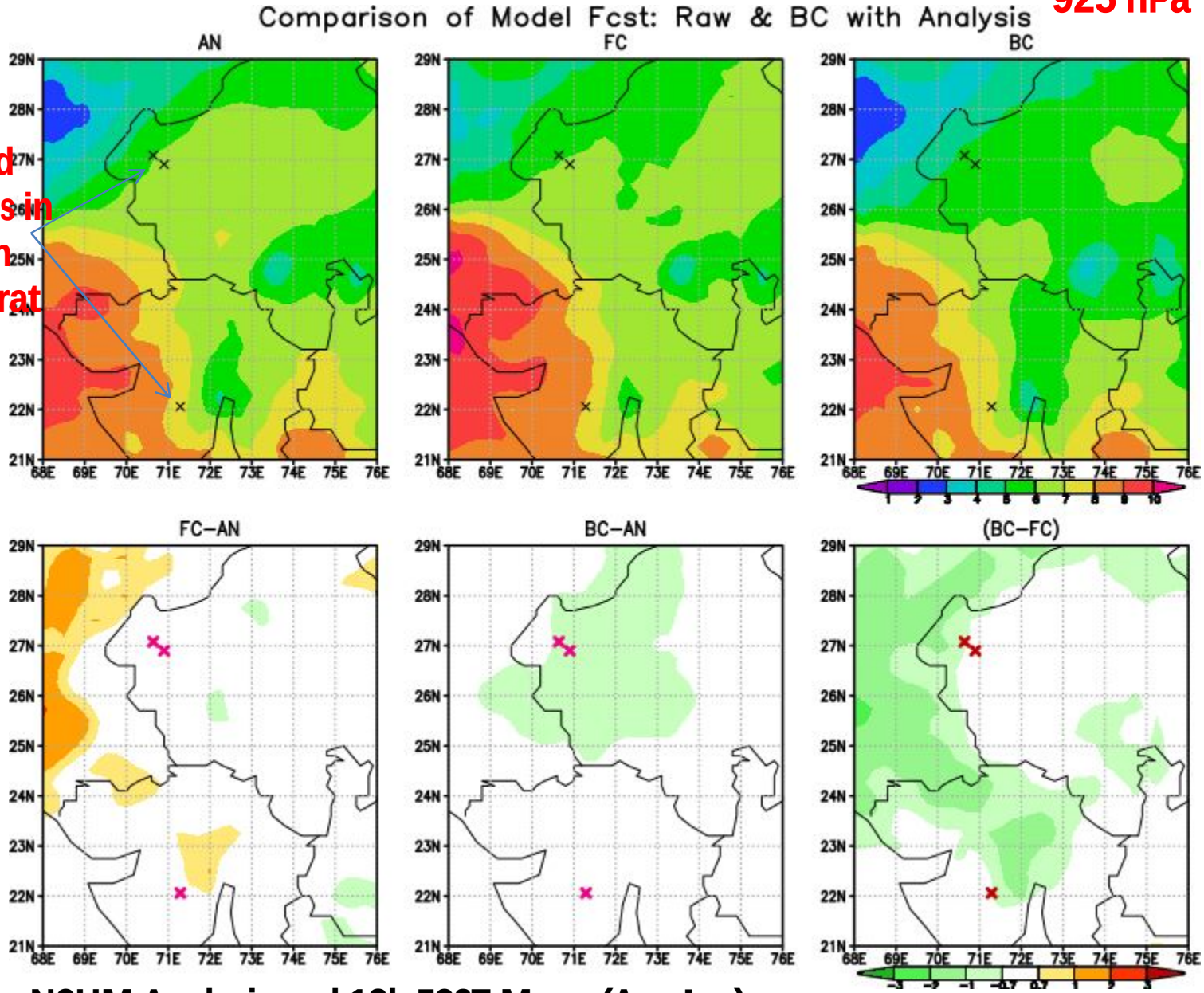

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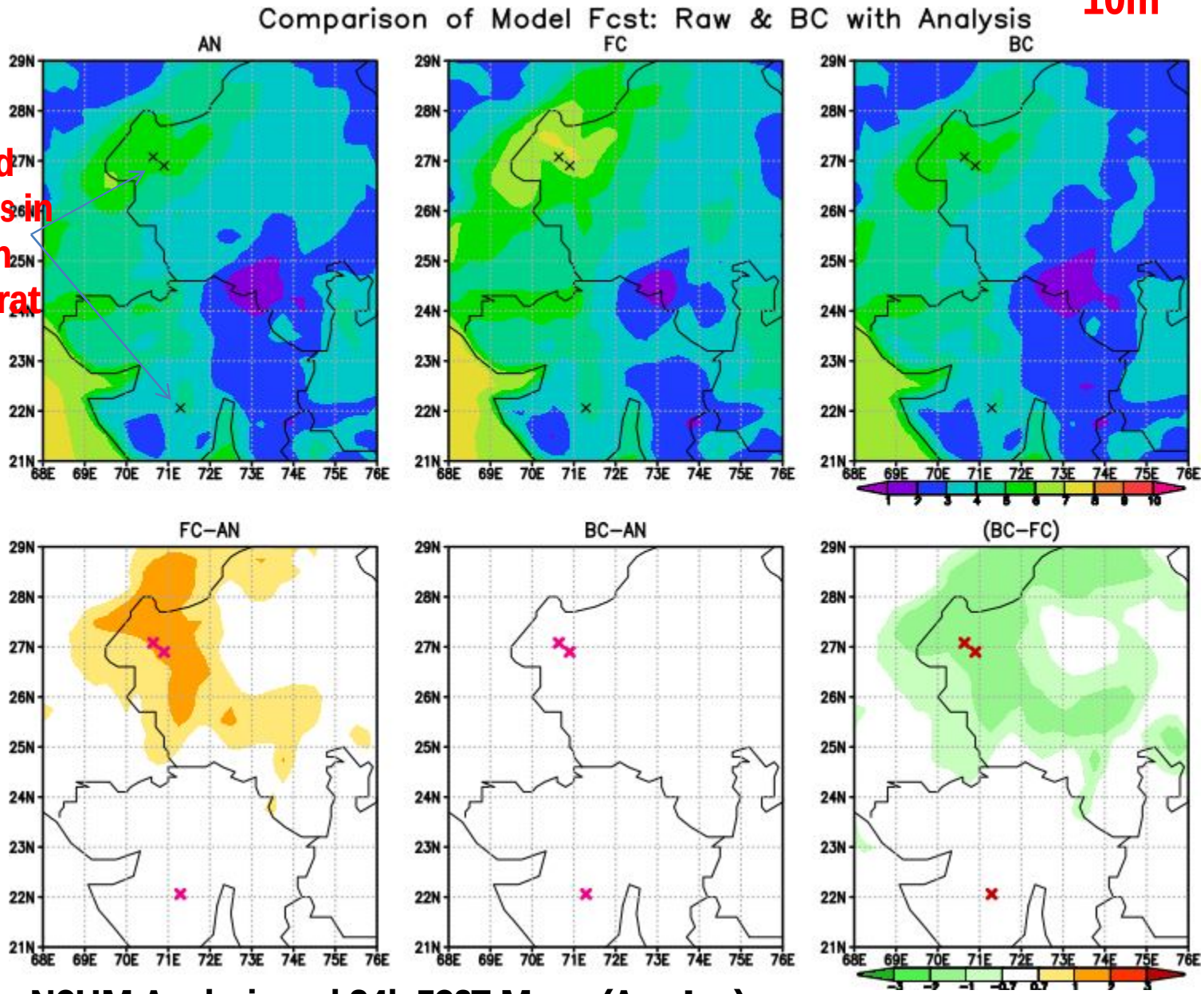

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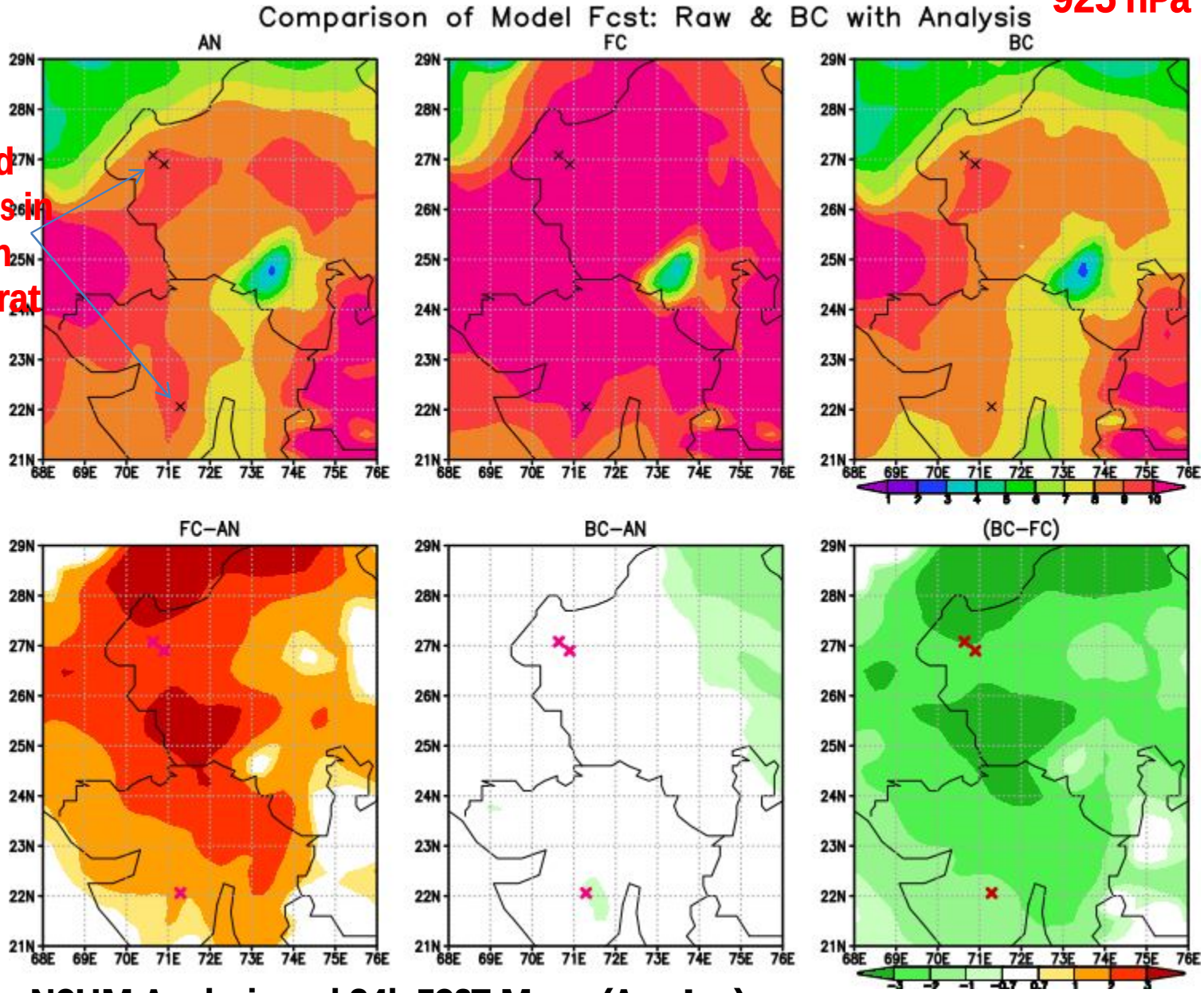

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