Recent Initiative of Solar and Wind Forecasting Using a High Resolution Cloud Resolving Model

Presented by

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Numerical Model : Introduction

Numerical weather prediction (NWP) is a method of weather forecasting that employs a set of equations that describe the flow of fluid. These equations are translated into computer code and use numerical methods, parameterizations of other physical processes and combined with initial and boundary conditions before being run over a domain (geographic area)

Governing Equations

$$\frac{d\mathbf{v}}{dt} = -\alpha\nabla p - \nabla\phi + \mathbf{F} - 2\Omega\times\mathbf{v} \quad (1\text{-}3)$$ Momentum

$$\frac{\partial\rho}{\partial t} = -\nabla.(\rho\mathbf{v}) \quad (4)$$ Mass

$$p = \rho RT \quad (5)$$ Ideal gas

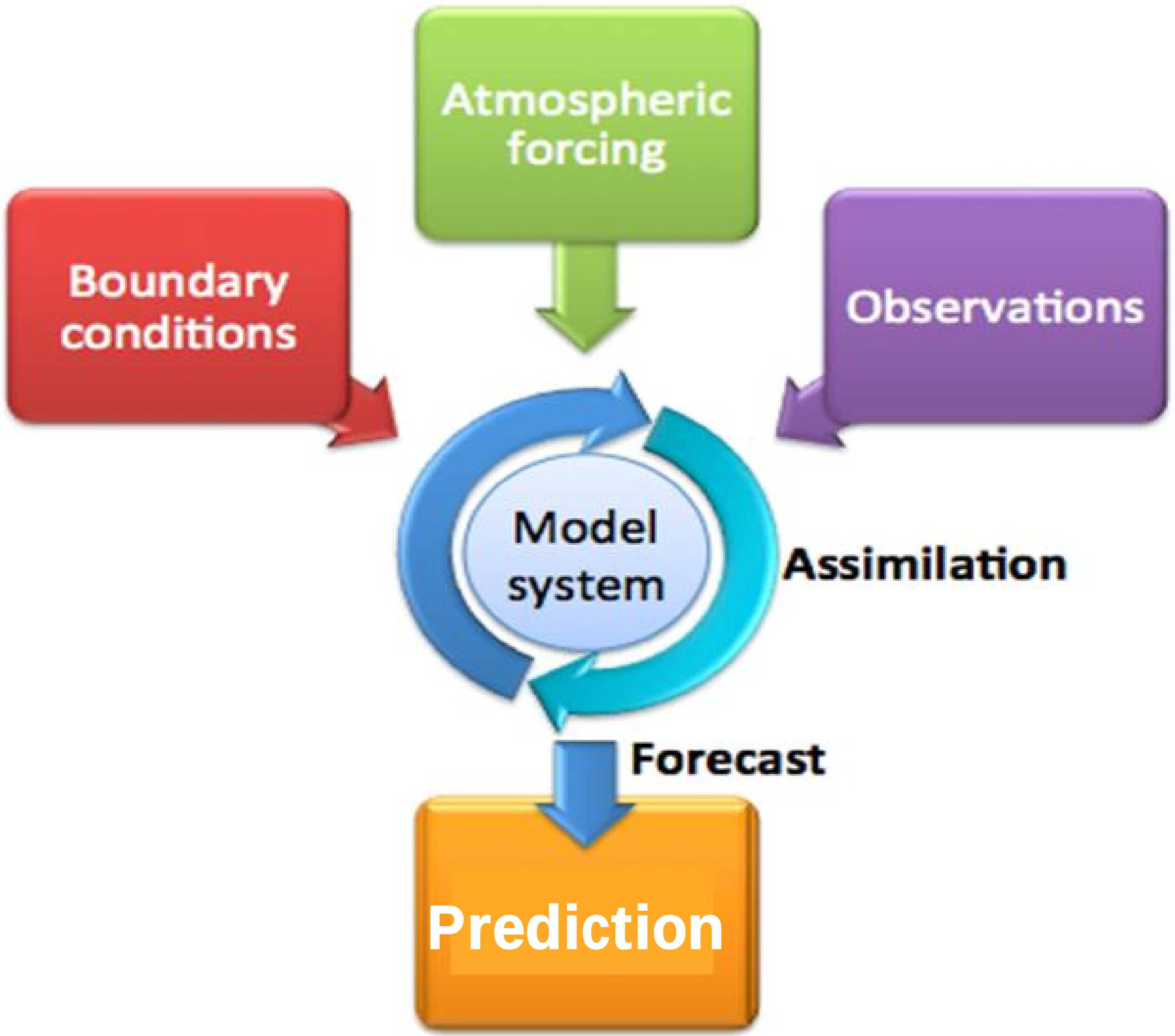
$$\frac{ds}{dt} = C_p\frac{1}{\theta}\frac{d\theta}{dt} = \frac{Q}{T} \quad (6)$$ Energy

$$\frac{dq}{dt} = E - C \quad (7)$$ Moisture

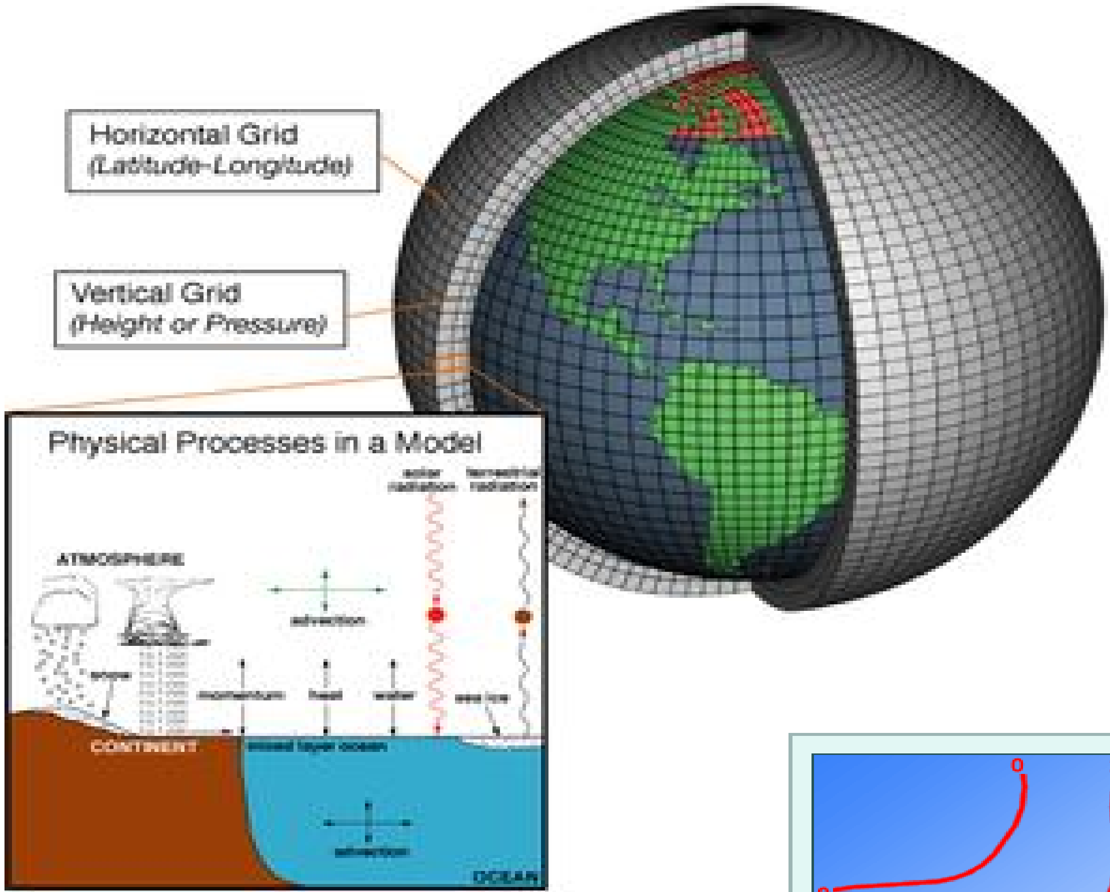
7 equations, 7 unknown (u,v,w,T, p, den and q)

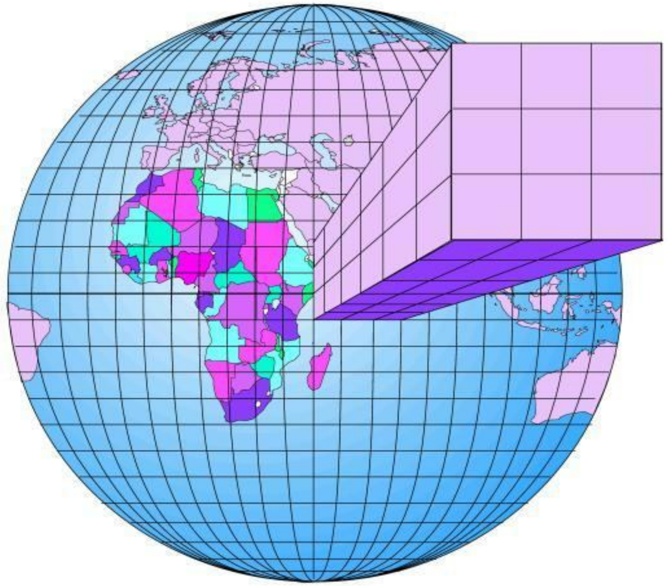
solvable

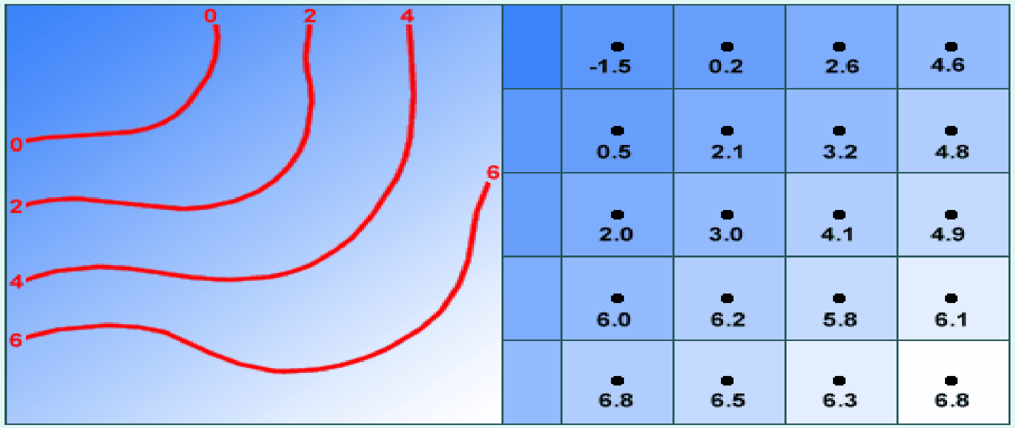
Model System



Model Grid System





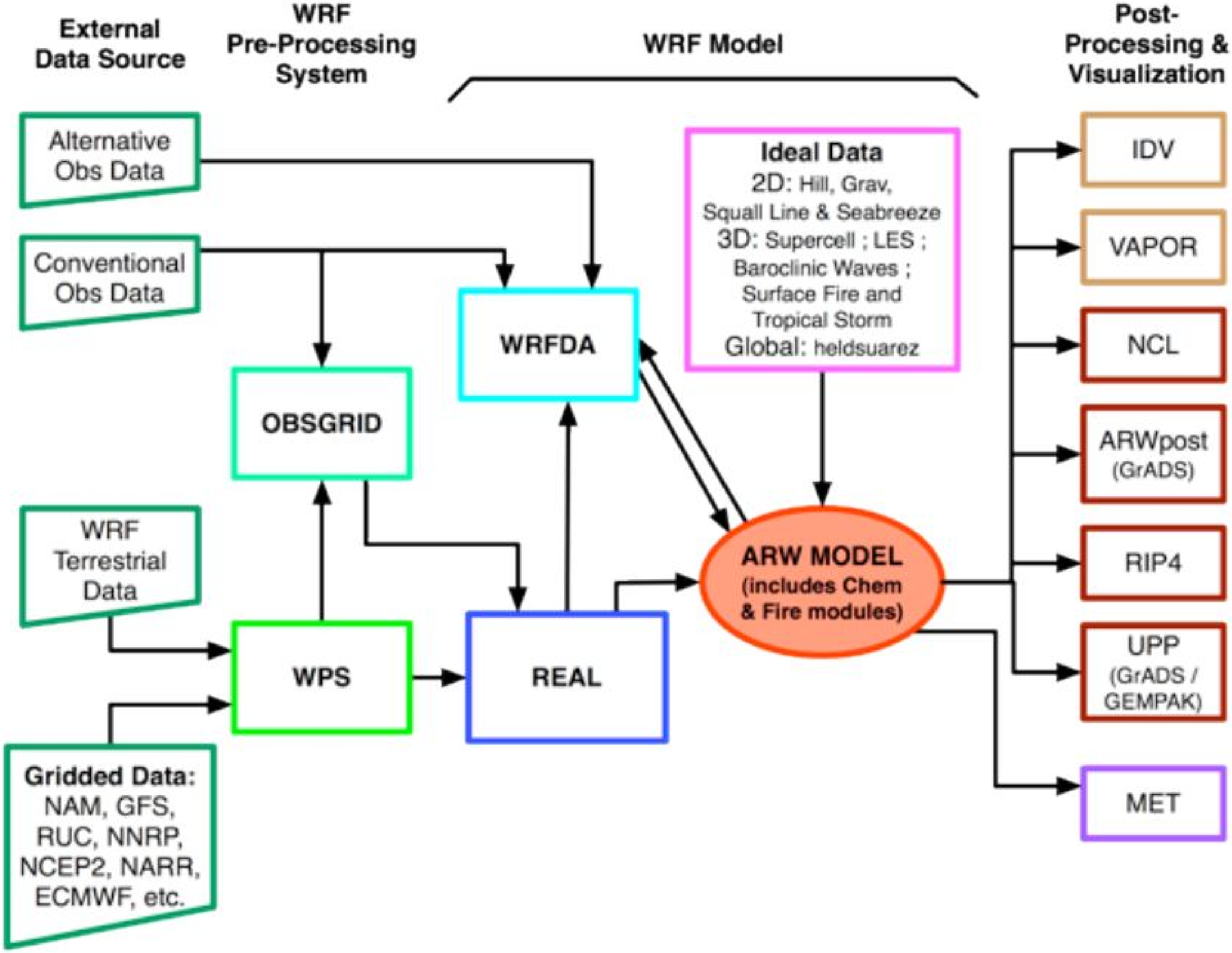


Actual smooth and continuous temperature field in degrees C (similar to spectral model representation)

Grid point model representation of the same temperature field in degrees C

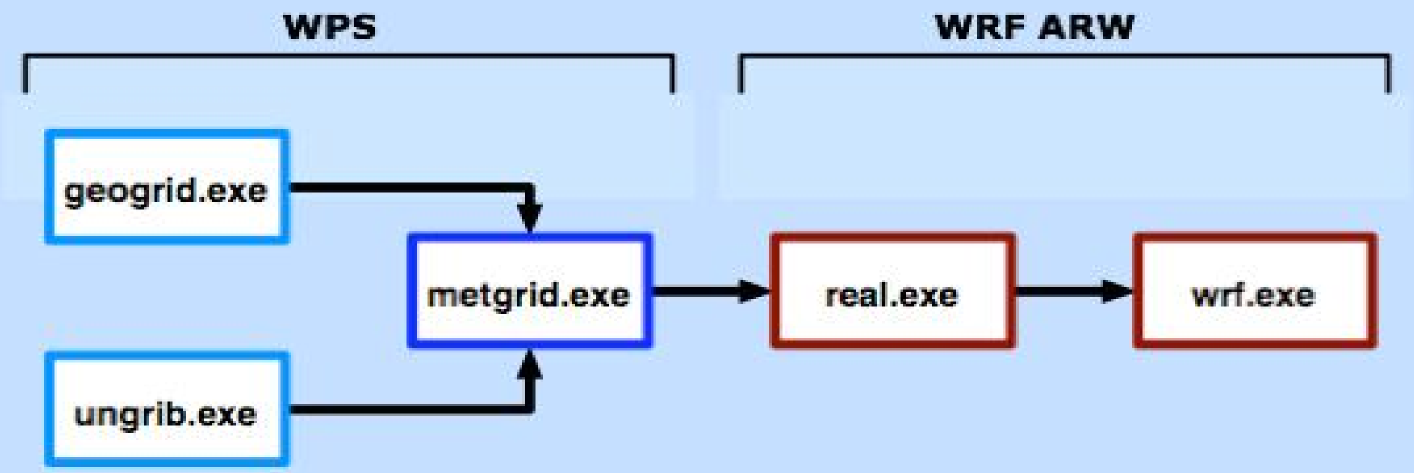
The COMET Program

WRF Modeling System Flow Chart



Source: *WRF ARW Technical note. http://www.mmm.ucar.edu/wrf/users/pub-doc.html*

WRF Modeling System Components



WPS

geogrid.exe creates terrestrial data (*static*).
ungrib.exe unpacks GRIB meteorological data and packs it into an intermediate file format.
metgrid.exe interpolates the meteorological data horizontally onto your model domain.
Output from **metgrid.exe** is used as input to WRF.

WRF ARW

real.exe vertically interpolates the data onto the model coordinates.
wrf.exe generates the model forecast.

Post-Processing:

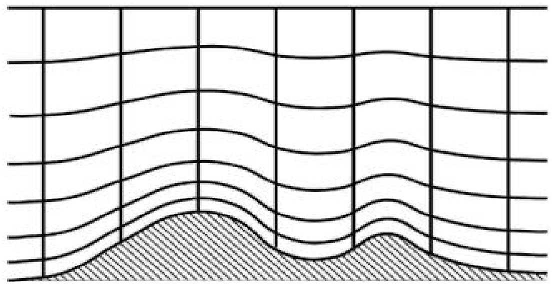
Graphics and verification tools e.g. VAPOR, NCL, ARWPost etc.

- Mass based terrain following coordinate

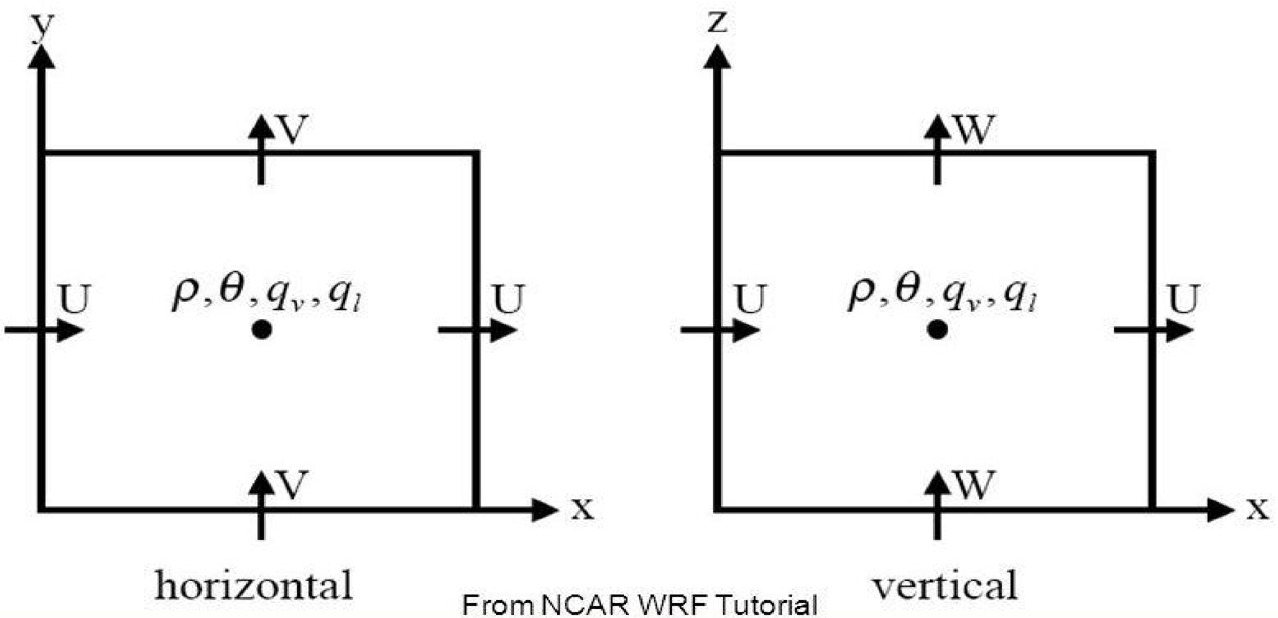
Hydrostatic pressure π

Column mass (per unit area) $\mu = \pi_s - \pi_t$

Vertical coordinate $$\eta = \frac{(\pi - \pi_t)}{\mu}$$

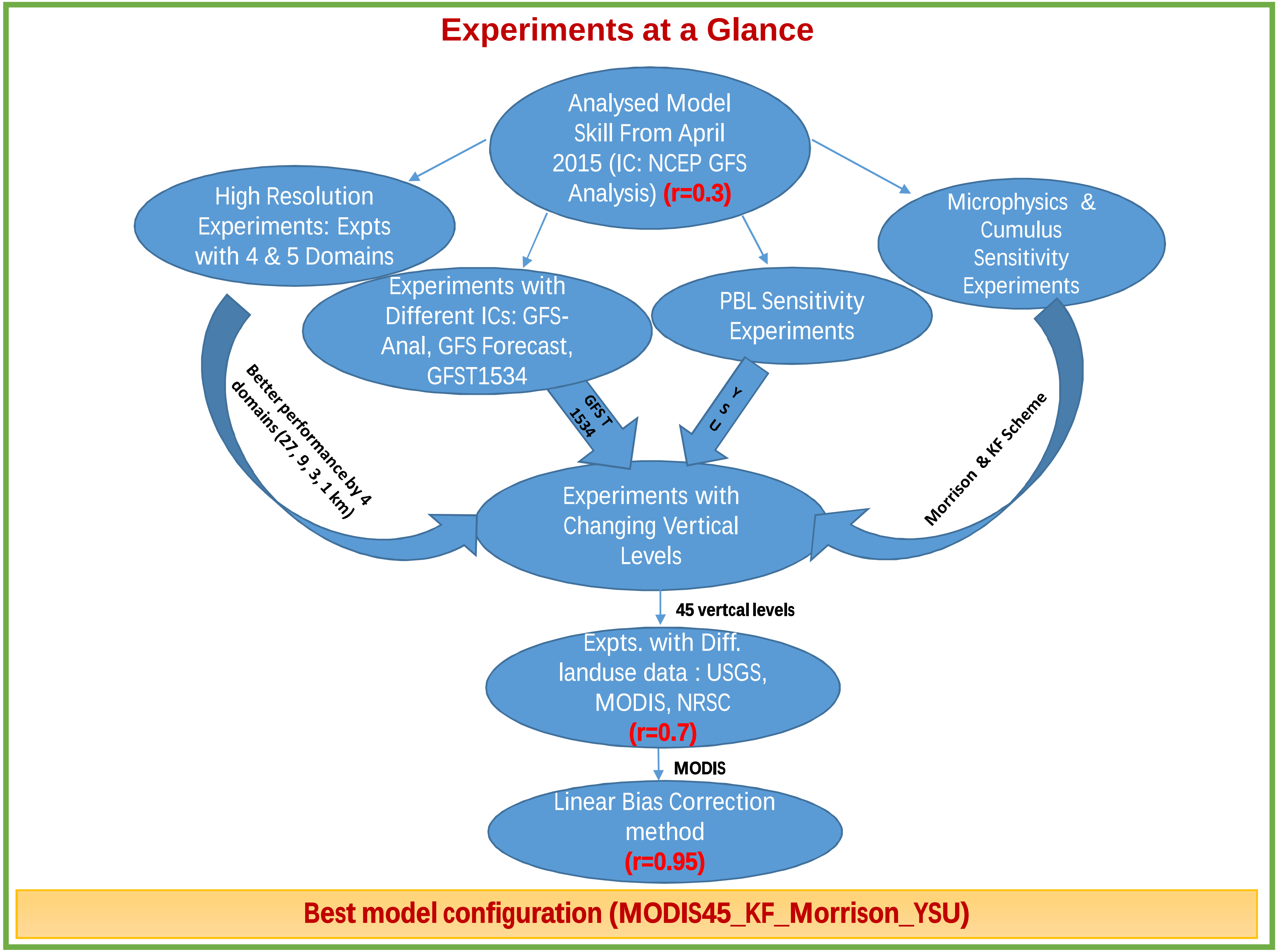


- Arakawa C-grid staggering



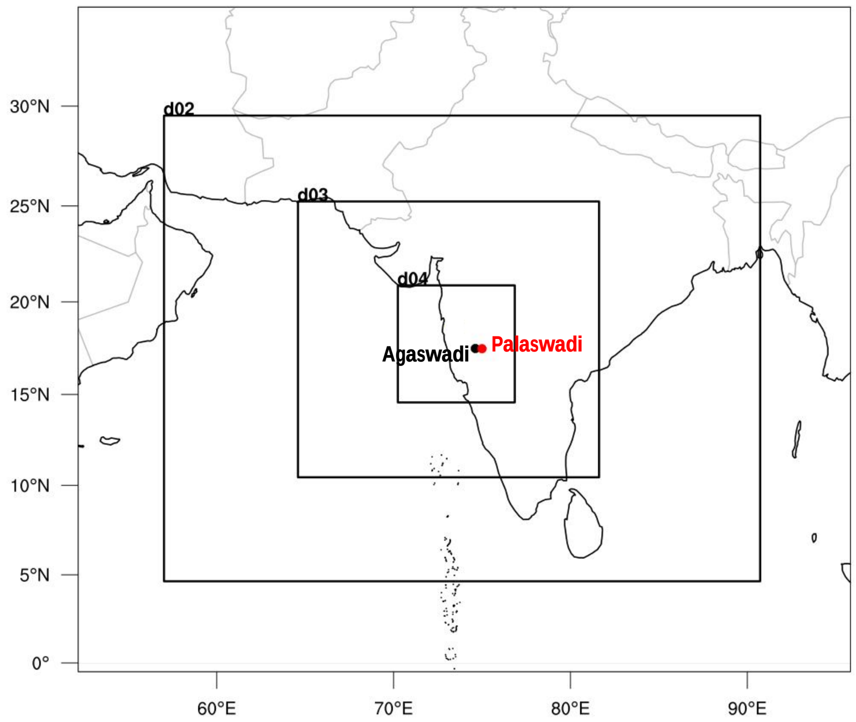
From NCAR WRF Tutorial

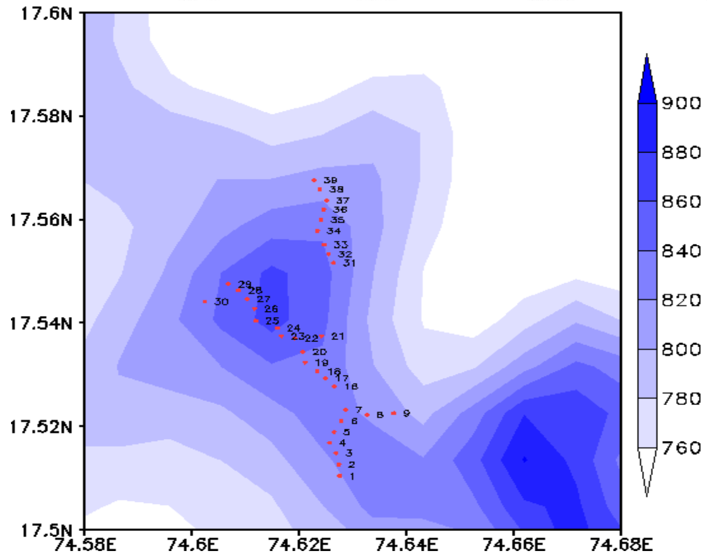
Model Setup for Wind Simulation



Experiments at a Glance
Analysed Model Skill From April 2015 (IC: NCEP GFS Analysis) (r=0.3)
High Resolution Experiments: Expts with 4 & 5 Domains
Experiments with Different ICs: GFS-Anal, GFS Forecast, GFST1534
PBL Sensitivity Experiments
Microphysics & Cumulus Sensitivity Experiments
Better performance by 4 domains (27, 9, 3, 1 km)
GFST 1534
YSU
Morrison & KF Scheme
Experiments with Changing Vertical Levels
45 vertcal levels
Expts. with Diff. landuse data : USGS, MODIS, NRSC (r=0.7)
MODIS
Linear Bias Correction method (r=0.95)
Best model configuration (MODIS45_KF_Morrison_YSU)

WRF Strategy for Wind Prediction



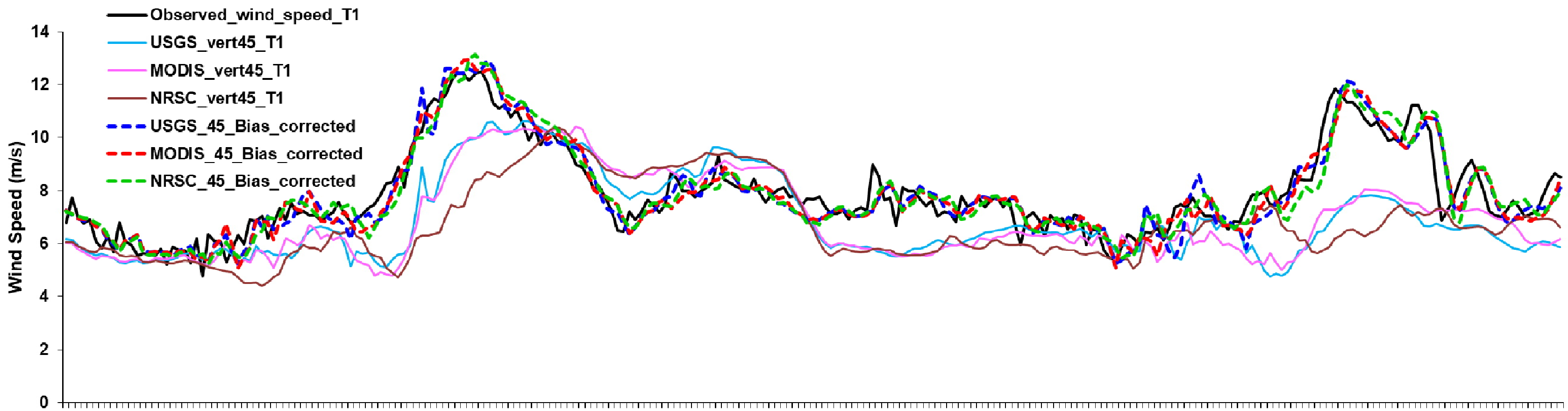


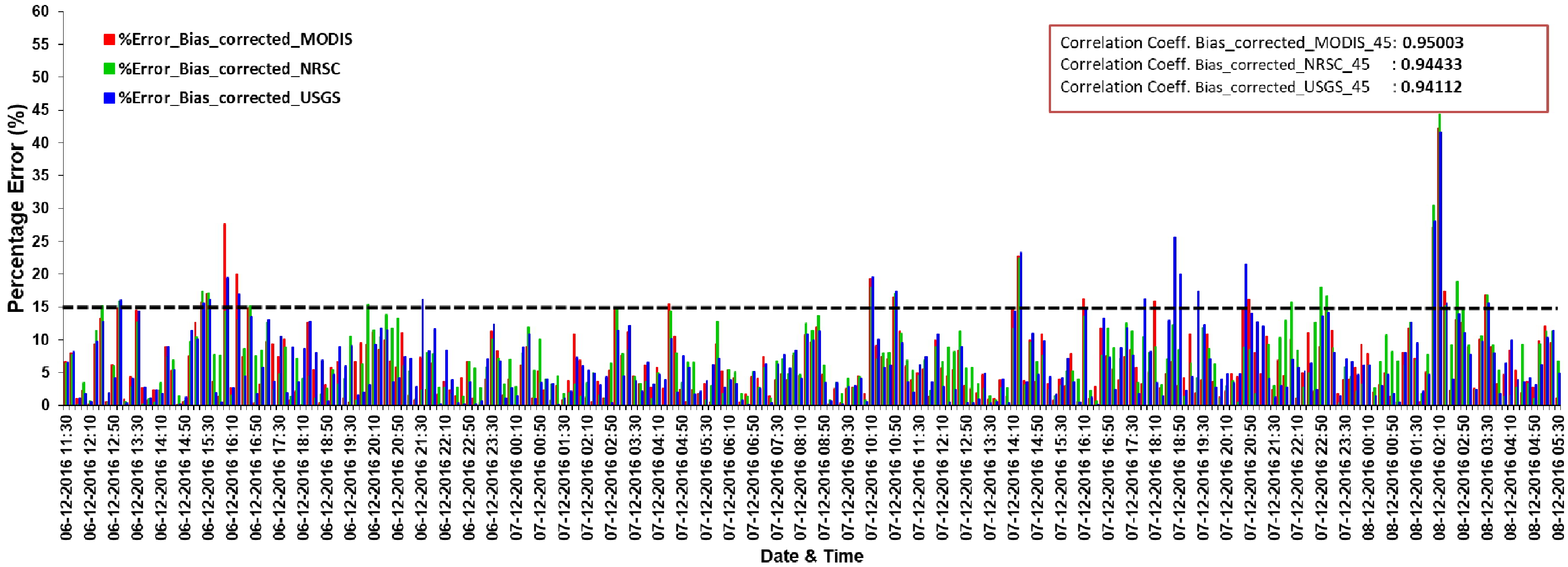
Domains & Resolution	**4 domains** with 27km, 9km, 3km and 1km resolution (Based on domain sensitivity Expt)
Initial Conditions	**GFS T1534 00 UTC** (Based on IC sensitivity)
Model Integration Time	48 h
Model Output	At **2 min** interval for inner domain of 1km
Cumulus Parameterization	**KF Scheme** (Based on Cu sensitivity)
Microphysics	**Morrison Scheme** (Based on Microphysics sensitivity)
Planetary Boundary Layer	**Yonsei University (YSU) Scheme** (Based on PBL sensitivity)
Radiation Scheme	RRTM for Long Wave and Dhudhia for Short Wave

Distribution of wind turbines near Agaswadi (lat:17.5103°N & lon:74.6274°E)

Sensitivity to Different Landuse and Land Cover Data & Impact of Bias Correction

High wind Condition: 06-08 Dec 2016

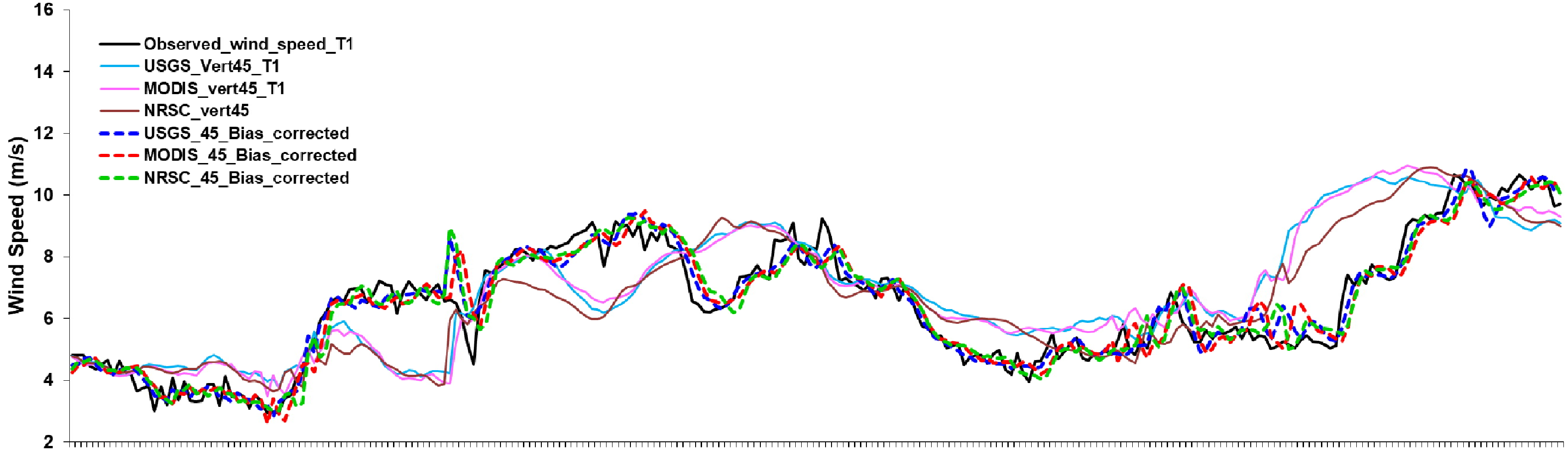


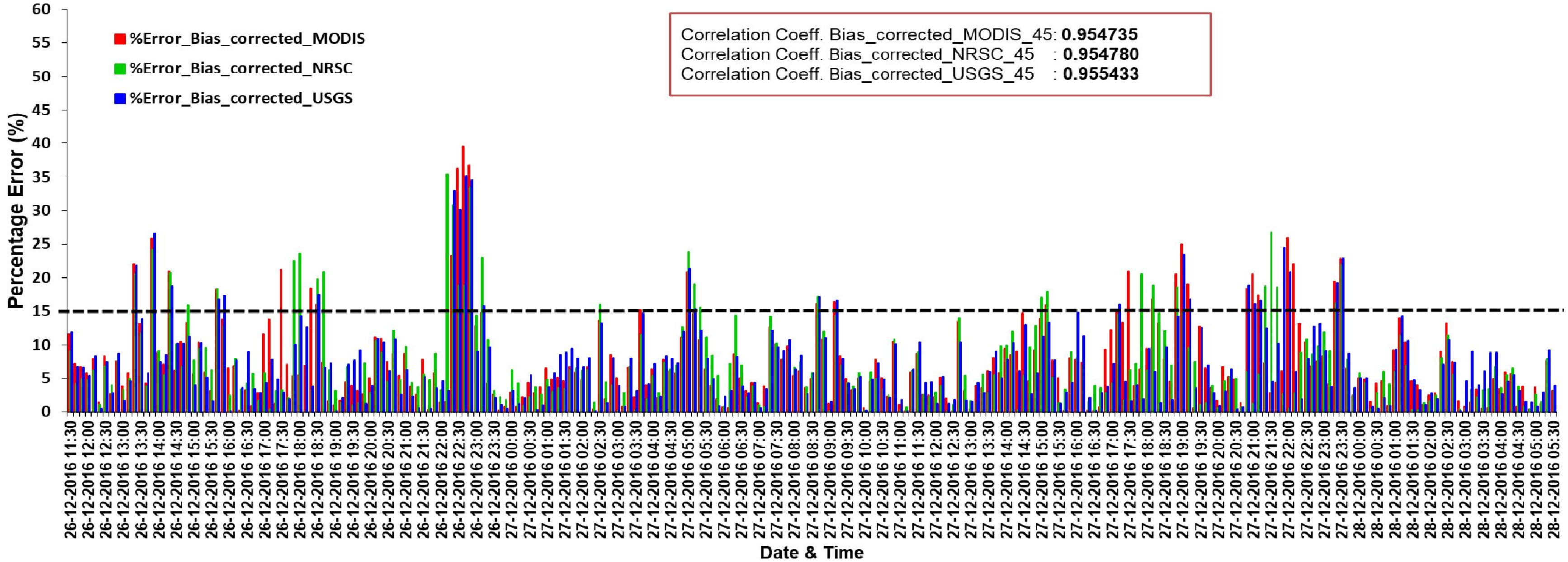


Percentage error at almost all the time remains below 15% after Bias Correction

Sensitivity to Different Landuse and Land Cover Data & Impact of Bias Correction

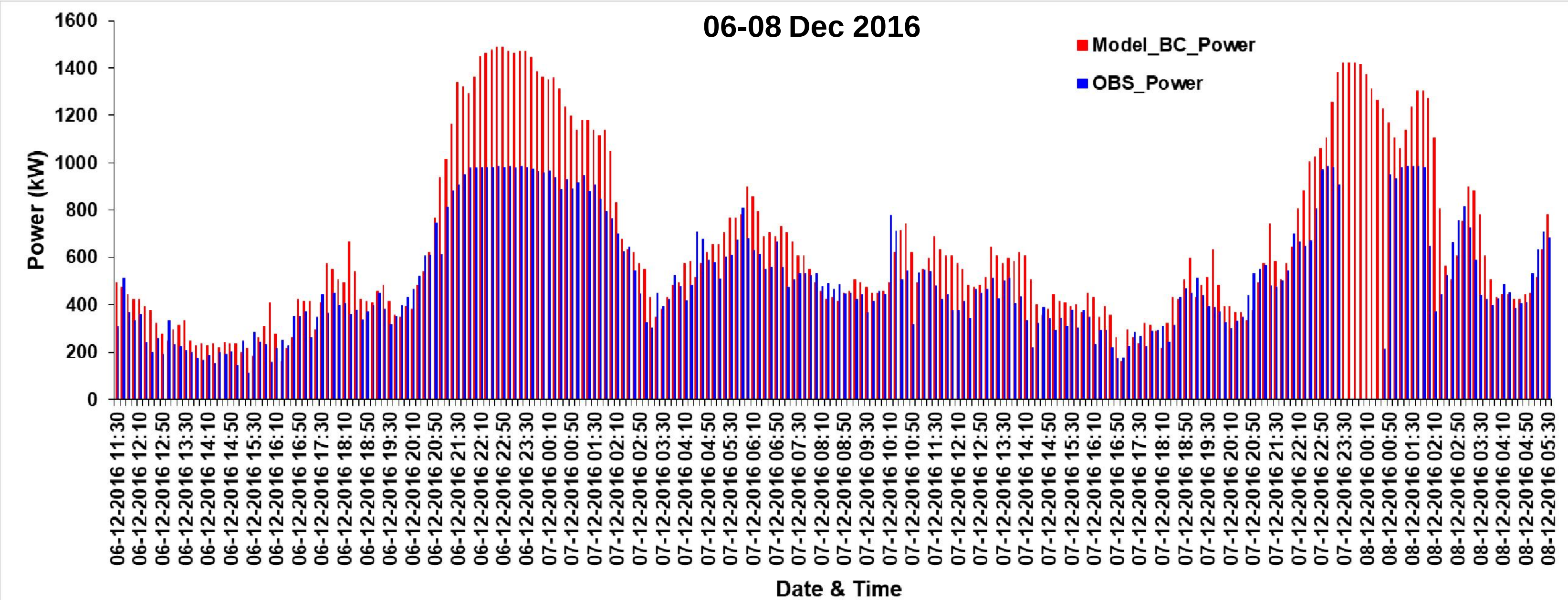
Low wind Condition: 26-28 Dec 2016

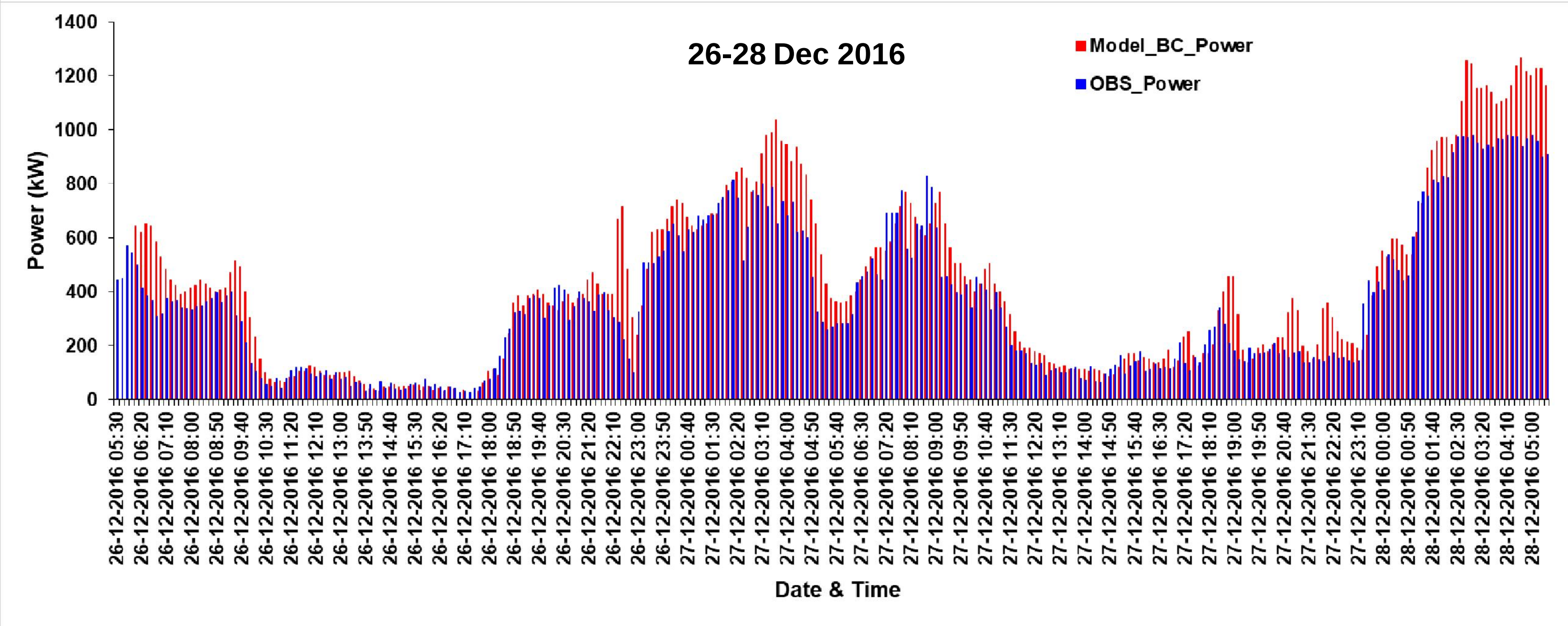




Percentage error at almost all the time remains below 15% after Bias Correction

Power Estimates for High Wind and Low Wind Cases



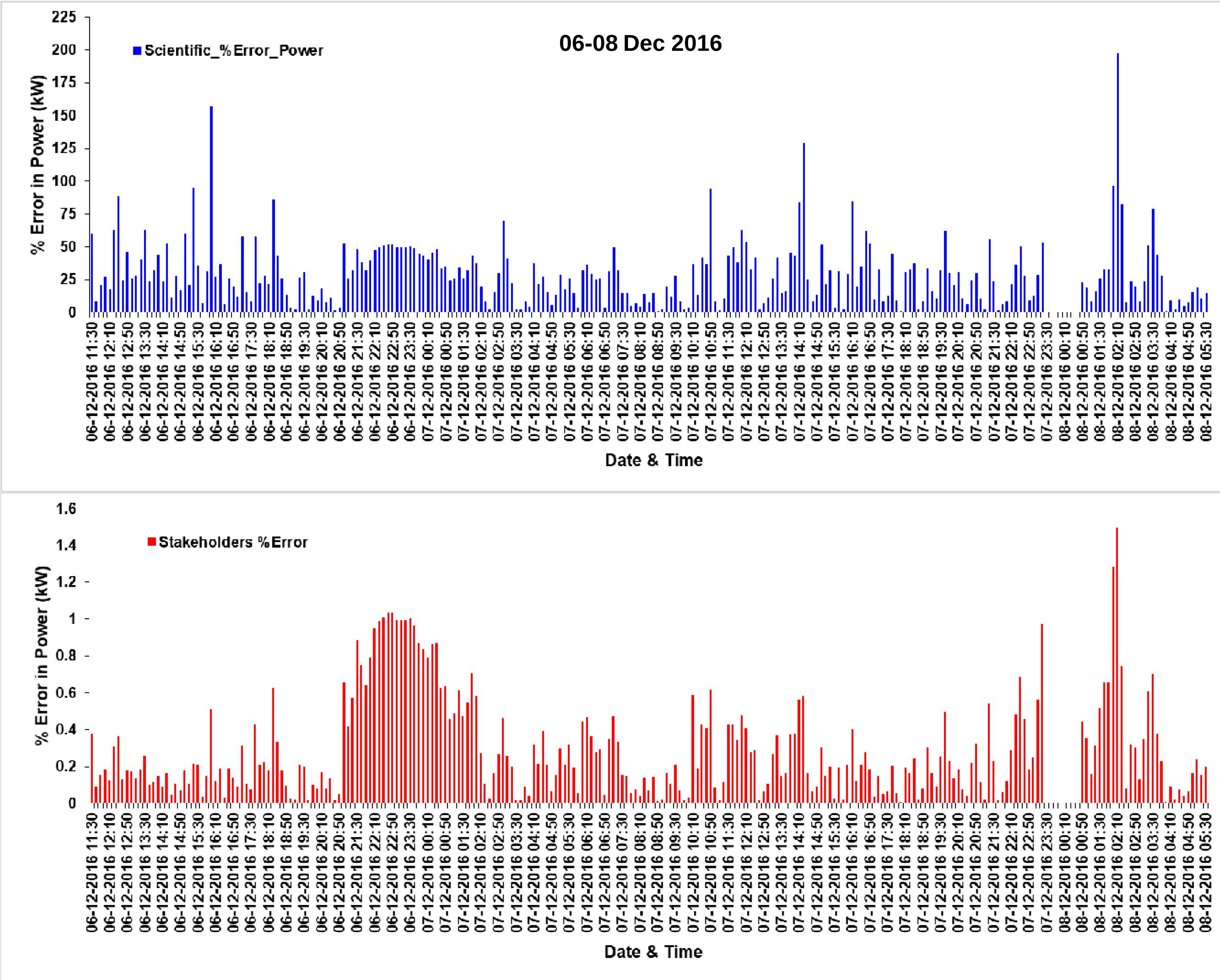


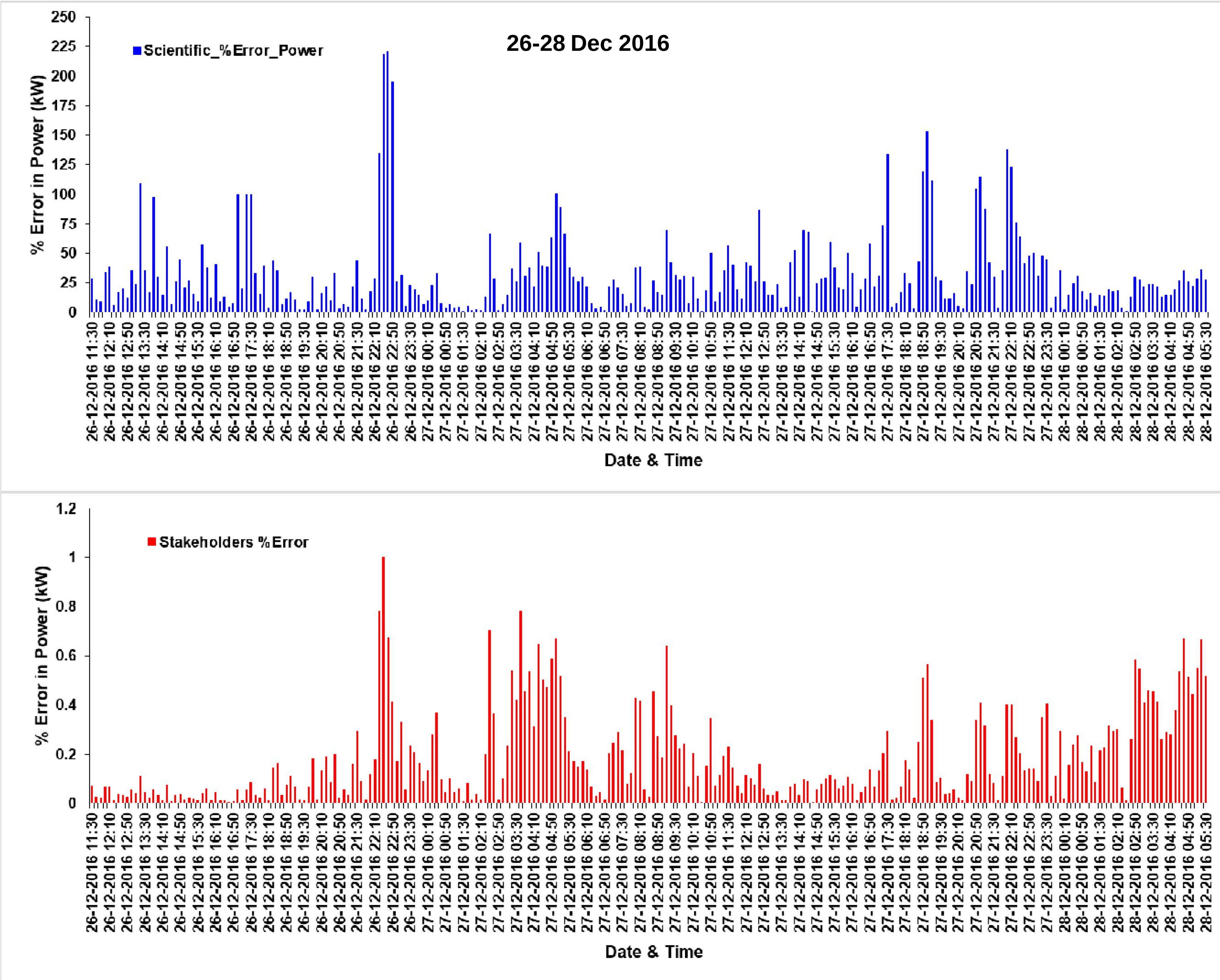
Scientific Percentage Error

$$\text{Percentage Error} = \frac{(\boldsymbol{Model - Observation}) * \mathbf{100}}{(\boldsymbol{Observation})}$$

Percentage Error as per MNRE Stakeholders Formulation

$$\text{Percentage Error} = \frac{(\boldsymbol{Actual\ Generation - Scheduled\ Generation}) * \mathbf{100}}{(\boldsymbol{Available\ Capacity})}$$


06-08 Dec 2016
Scientific_%Error_Power
% Error in Power (kW)
Date & Time
Stakeholders %Error
% Error in Power (kW)
Date & Time


26-28 Dec 2016
Scientific_%Error_Power
% Error in Power (kW)
0
25
50
75
100
125
150
175
200
225
250
26-12-2016 11:30
26-12-2016 12:10
26-12-2016 12:50
26-12-2016 13:30
26-12-2016 14:10
26-12-2016 14:50
26-12-2016 15:30
26-12-2016 16:10
26-12-2016 16:50
26-12-2016 17:30
26-12-2016 18:10
26-12-2016 18:50
26-12-2016 19:30
26-12-2016 20:10
26-12-2016 20:50
26-12-2016 21:30
26-12-2016 22:10
26-12-2016 22:50
26-12-2016 23:30
27-12-2016 00:10
27-12-2016 00:50
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27-12-2016 02:10
27-12-2016 02:50
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27-12-2016 04:10
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27-12-2016 22:50
27-12-2016 23:30
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28-12-2016 00:50
28-12-2016 01:30
28-12-2016 02:10
28-12-2016 02:50
28-12-2016 03:30
28-12-2016 04:10
28-12-2016 04:50
28-12-2016 05:30
Date & Time
Stakeholders %Error
% Error in Power (kW)
0
0.2
0.4
0.6
0.8
1
1.2
26-12-2016 11:30
26-12-2016 12:10
26-12-2016 12:50
26-12-2016 13:30
26-12-2016 14:10
26-12-2016 14:50
26-12-2016 15:30
26-12-2016 16:10
26-12-2016 16:50
26-12-2016 17:30
26-12-2016 18:10
26-12-2016 18:50
26-12-2016 19:30
26-12-2016 20:10
26-12-2016 20:50
26-12-2016 21:30
26-12-2016 22:10
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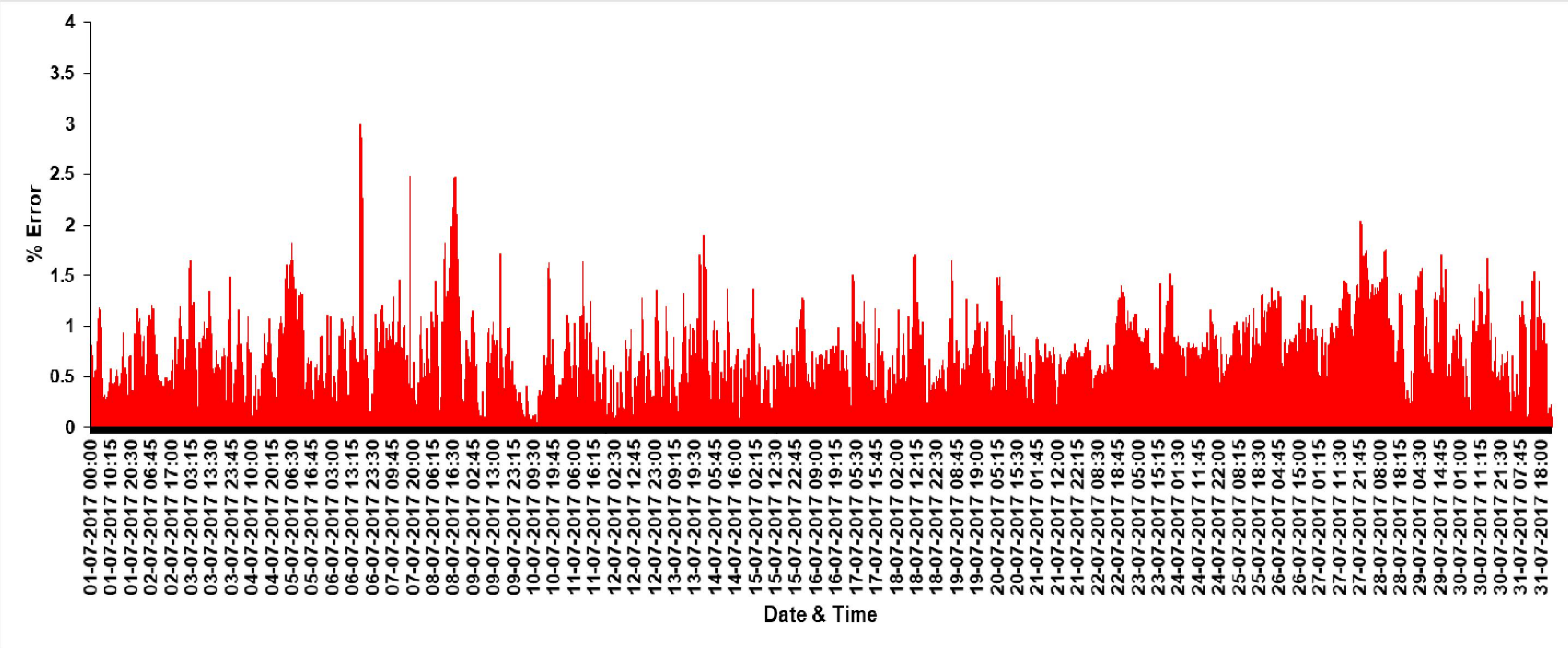
28-12-2016 02:50
28-12-2016 03:30
28-12-2016 04:10
28-12-2016 04:50
28-12-2016 05:30
Date & Time

Percentage Error (Stakeholders): July 2017



Model Setup for Solar Simulation

Comparison of WRF and WRF-Solar

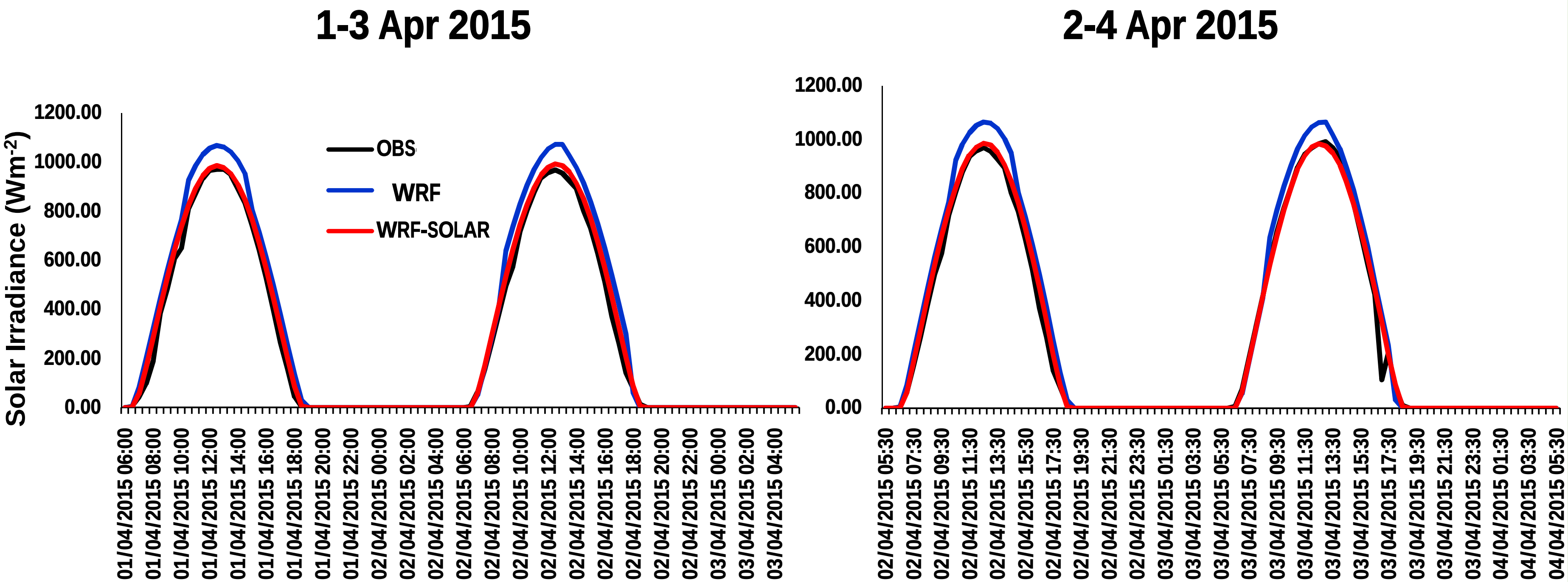
	WRF-Solar	WRF
Solar energy applications	Output DNI and DIF	—
	High-frequency output of surface irradiance	—
	Solar position algorithm includes EOT	EOT is not included
Aerosol–radiation feedbacks	Observed/model climatologies or time-varying aerosols	Model climatology
Cloud–aerosol feedbacks	Aerosol indirect effect represented	—
Cloud–radiation feedbacks	Cloud particles consistent in radiation and microphysics	—
	Shallow cumulus feedback to radiation	—
	Fully coupled aerosol–cloud–radiation system	Uncoupled

Pedro. J.A et al., WRF-SOLAR Description and Clear-Sky Assessment of an Augmented NWP Model for Solar Power Prediction. 2016. Bull. Amer. Meteor. Soc. doi:10.1175/BAMS-D-14-00279.1

Model Strategy: WRF-SOLAR

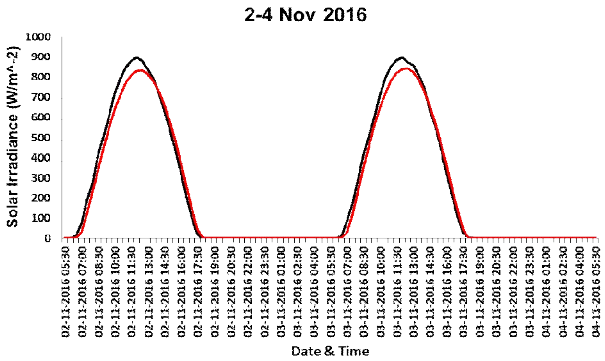
Domains & Resolution	4 domains with 27km, 9km, 3km and 1km resolution
Initial Conditions	GFS analysis data of 0.5º X 0.5º for Apr 2015; GFS T1534 0.125º X 0.125º for other experiments
Model Output	At 30 min interval for inner domain of 1km
Cumulus Parameterization	Grell-Freitas Ensemble Scheme
Microphysics	Aerosol Aware Thompson Scheme
Planetary Boundary Layer	Yonsei University (YSU) Scheme
Radiation Scheme	RRTMG for Long Wave and Short Wave
Experiments Conducted	Clear Conditions: 1-3 Apr 2015, 2-4 Apr 2015, 7-9 Apr 2015 Partially Cloudy Conditions: 5-7 Dec 2016 Heavy Rain Conditions: 16-18 Sep 2016

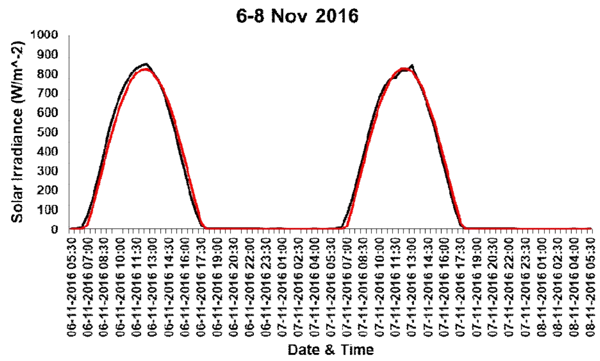
Solar Insolation During Clear Sky Conditions (Location: Palaswadi)

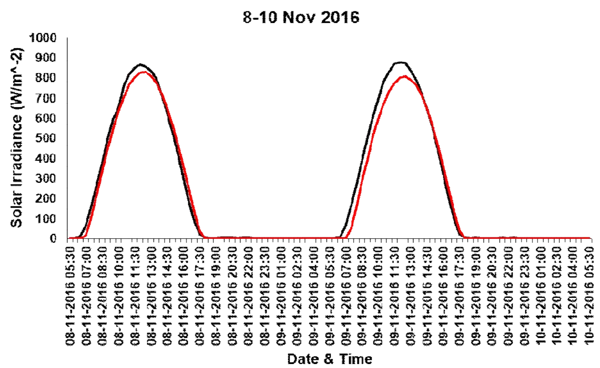


WRF Solar is better than standard WRF

Solar Insolation During Clear Sky Conditions (Location: Pune)

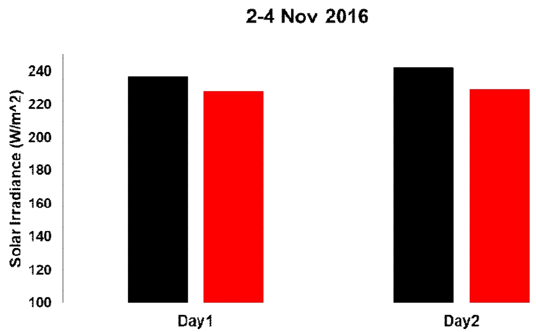


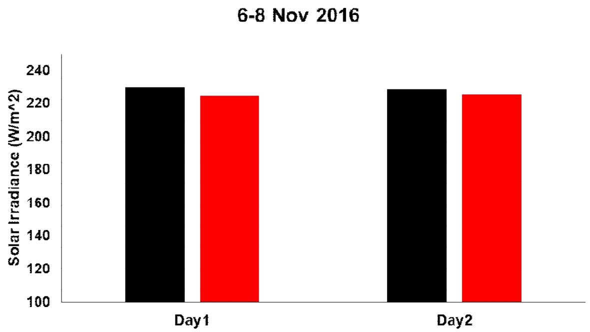


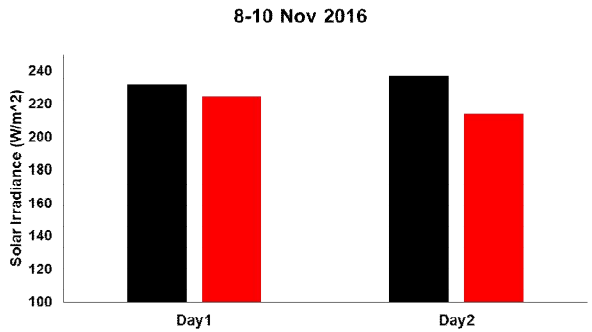


IMD SOLAR

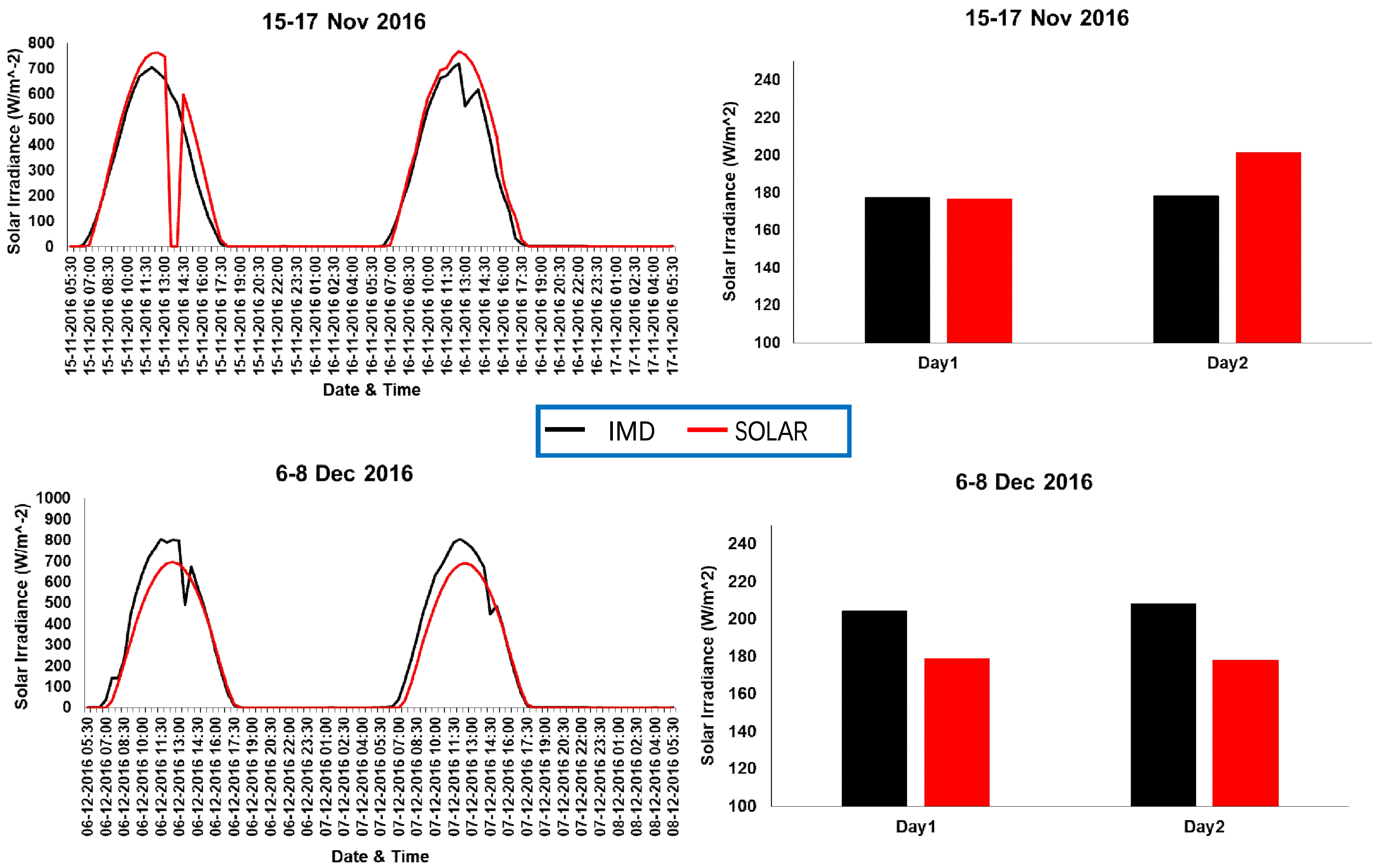
Daily Averaged Solar Insolation



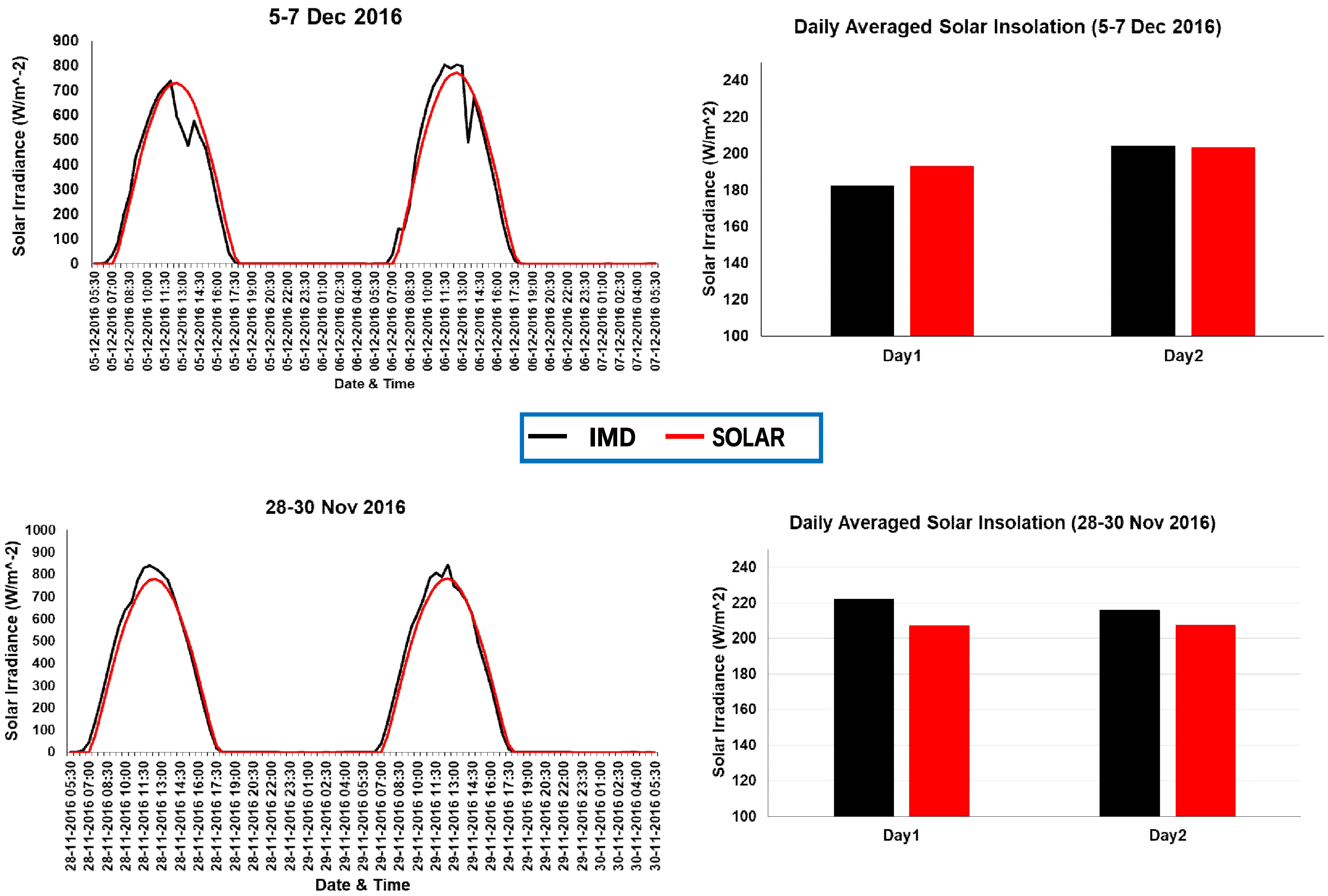




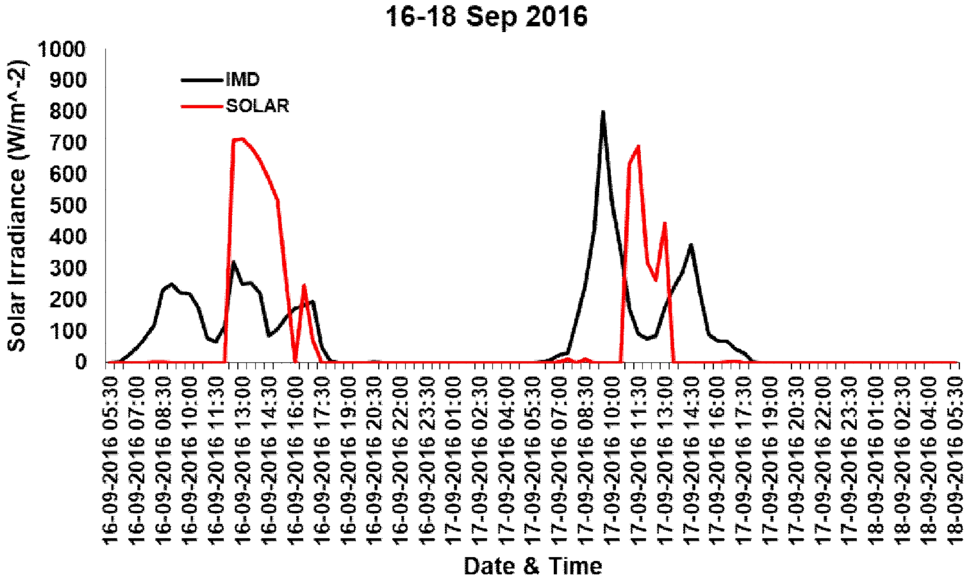
Solar Insolation During Partially Cloudy Conditions (Location: Pune)

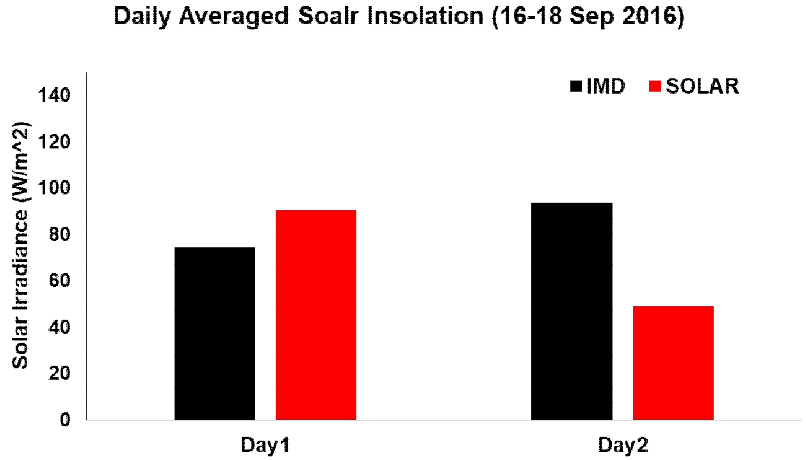


Solar Insolation During Cloudy Conditions (Location: Pune)

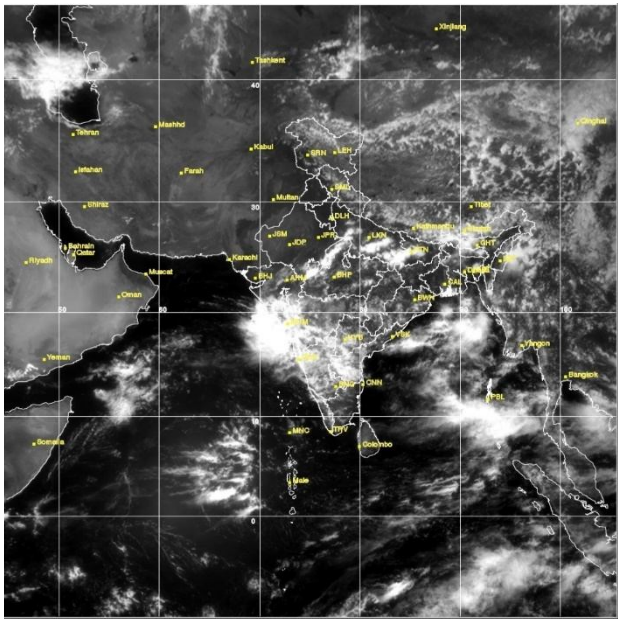


Solar Insolation During Heavy Rainfall Condition (IC: GFST1534, Location: Pune)

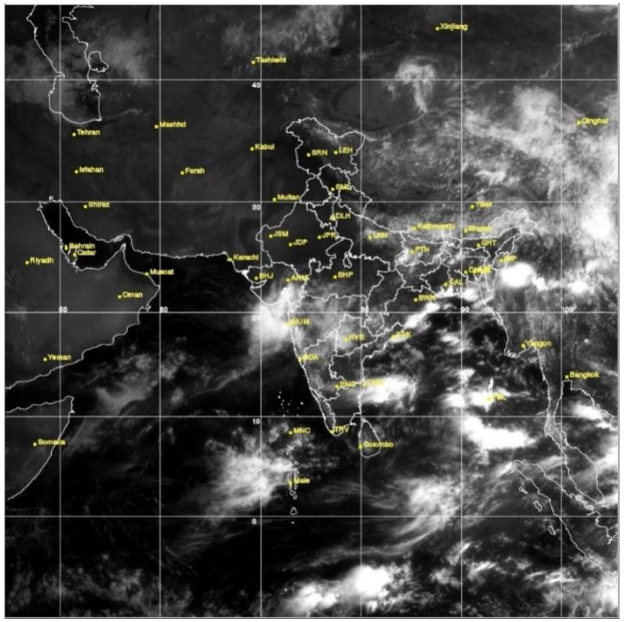




16 Sep 2016 13:45 IST



17 Sep 2016 09:45 IST



Summary

- The high resolution GFS T1534 with 12km resolution shows high potential of providing adequate IC and BCs for cloud resolving forecast of wind and solar.
- The present ARW model configuration with 1 km horizontal resolution, 45 vertical levels, MODIS landuse, Morrison Scheme as microphysics, YSU Scheme as PBL shows better simulation of wind.
- The linear bias correction method has improved the wind forecast with percentage error (Stakeholder) <<< 15%
- The simulation of solar irradiance, WRF-SOLAR gives better simulation than the normal WRF model. It is due to the incorporation of cloud-aerosol-radiation feedback mechanism in the WRF-SOLAR.

Thank You

Linear Bias Correction Method

Date & Time	Obs_ Wind	Model_Wind	Obs_Power	Model_Power	Wind_Error (Model-Obs)	Avg_Error	BC_Model_ Wind	BC_Model_ Power
110717_0530	8.2763	6.76	721.7056	182.48599	-1.52			
110717_0540	8.8956	7.29	852.7614	217.58299	-1.61			
110717_0550	8.9744	7.22	940.4647	213.683	-1.75	1.62		
110717_0600	8.7982	6.95	886.2106	198.08501	-1.85	1.74	8.848806667	348.22
110717_0610	9.2737	6.84	953.7506	186.386	-2.43	2.01	8.683273333	332.62201
110717_0620	9.8982	6.95	982.2347	198.08501	-2.95	2.41	8.853186667	352.12
110717_0630	9.5689	7.22	983.9039	213.683	-2.35	2.58	9.360353333	398.91501
110717_0640	10.1046	7.91	985.0107	268.27802	-2.20	2.50	9.79281	441.811
110717_0650	9.2483	8.70	952.3438	336.521	-0.55	1.70	10.40733	515.90399
110717_0700	9.0396	9.10	952.4189	375.51801	0.06	0.89	10.40035333	515.90399
110717_0710	9.363	9.25	952.7762	387.21701	-0.11	0.20	9.99436	463.259
110717_0720	8.7446	9.26	898.1693	387.21701	0.51	-0.15	9.451626667	408.66501
110717_0730	7.7362	9.30	629.3781	395.01599	1.57	-0.66	9.1035	375.51801
110717_0740	8.223	9.08	710.8985	369.668	0.86	-0.98	8.645413333	326.772
110717_0750	9.4087	9.17	908.7769	379.41699	-0.24	-0.73	8.103733333	283.87701
110717_0800	9.0476	9.18	887.7852	379.41699	-0.14	-0.25	8.43878	309.224

Addition or subtraction of averaged errors from model wind i.e. (Model Wind) + / – (Avg error)

Average (first three rows of error) i.e. running mean of every 3 consecutive errors.

Interpolated value of power for bias corrected wind

STATE OF THE ART HIGH RESOLUTION GLOBAL MODELLING SYSTEM 12KM RESOLUTION

SCHEMATIC OF GFS (SL) T1534 L64 RUNNING AT IITM

GDAS

EnKF – GSI Hybrid Data Assimilation System

Analysis

FORECAST: GFS Semi-Lagrangian T1534 (approx 12 km at equator)

L64 vertical resolution

Runs for 240 hrs (10 days)

POST PROCESSING

240 hr (10 days) forecast

Resolution: Regular grid and Gaussian grid at different resolutions

$0.125^0 \mathrm{x} 0.125^0$ / $0.25^0 \mathrm{x} 0.25^0$ / $0.5^0 \mathrm{x} 0.5^0$ / $1^0 \mathrm{x} 1^0$