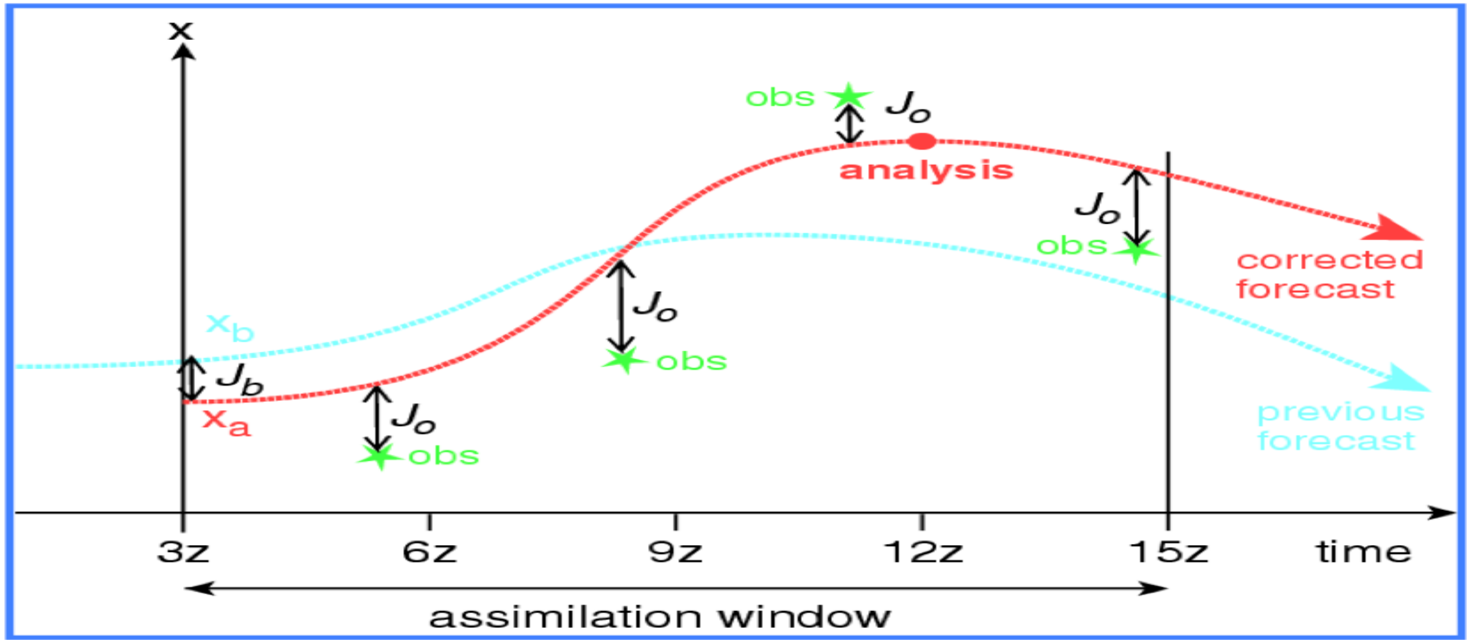
"Importance of Numerical Weather Prediction in Variable Renewable Energy Forecast"

Dr. Abhijit Basu (Integrated Research & Action for Development)
Arideep Halder (Thinkthrough Consulting Pvt. Ltd.)

September 7, 2017



Variable Renewable Energy Forecasts: Essential for Energy Management

- VRE forecast is a crucial and cost-effective tool for integrating VRE resources such as wind and solar into power systems
- VRE forecasting affects a range of system operations including scheduling, dispatch, real-time balancing, and reserve requirements
- By integrating VRE forecasts into system operations, power system operators can anticipate up- and down-ramps in VRE generation in order to cost-effectively balance load and generation in intra-day and day ahead scheduling
- This leads to reduced fuel costs, improved system reliability, and minimized curtailment of renewable resources

VRE Forecast: Facts and Factors

- The availability of solar and wind energy is largely determined by the prevailing weather conditions and their variability, thus making a well constituted weather prediction an essential component of VRE forecast management system
- Accurate forecasts of renewable power production therefore is an essential factor for a successful integration of large amounts of renewable power into the electric supply system
- Precise information on timing and magnitude of power generation from variable sources are needed
- Generally, wind and solar power forecasts for the near term tend to be more accurate than forecasts for longer terms
- Any wind and solar power forecast which is produced in time scales of more than several hours is based on the results of Numerical Weather Prediction (NWP)

NCMRWF Forecast Data for Renewable Energy Prediction:

Forecast Products for Wind Energy:

- Wind velocity forecasts - a week ahead (location specific & spatial, 2 revisions)
- Temporal Resolution: 1 hour (15 mins)
- Horizontal Resolution: Global Model 25 km, Regional Model 4 km
- Vertical levels: 10m, 50m agl & 990, 960 and 925 hPa (fine resolution near the surface to resolve boundary layer features better)
- Data is provided at other pressure levels depending on user's requirement

Forecast Products for Solar Energy:

- Global Horizontal Irradiance (GHI)
- Diffuse Horizontal Irradiance (DHI)
- Direct Normal Irradiance (DNI)
- Surface Temperature
- Cloud cover and optical depth (important for predicting ramp rates and bands of variability for solar power plants)

A week ahead forecast (location specific & spatial, 2 revisions)

Temporal Resolution: 1 hour (15 mins)

Horizontal Resolution: Global Model 25 km, Regional Model 4 km

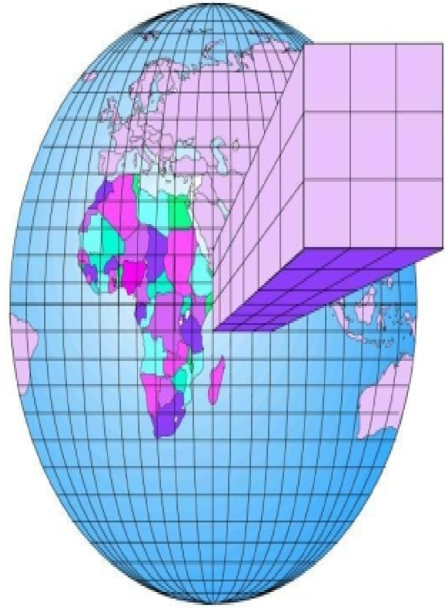
Preference of Numerical Model over Observation data for VRE Forecast:

- Spatially sparse Observed data a major hindrance for Farm based local energy forecast
- Unavailability of substantial past record does not help to build a climatology needed for future projection
- Continuous data measurement is an expensive process, incompatible with forecast costs

Numerical Weather Prediction: Basic Principle

- A numerical model designed to simulate a real time dynamic system; in this case weather.
- NWP Models are based on the laws of physics (Law of Momentum Conservation, Continuity Equation (mass conservation), Equation of state,
- Equations based on those laws are integrated forward in time to simulate changes in the atmosphere

- The atmosphere is modelled as a 3-D grid
  - The smaller the cells of the grid, the more accurate the model and the more detailed its predictions, but the more computational resources are required
  - Variable grid sizes allow for better accuracy in specific areas
- The evolution of the system over time is governed by the laws of fluid dynamics
  - Nonlinear differential equations (Navier-Stokes)
  - Advance the system in time steps, record predicted states



- A partial solution is to *parameterize* the model: replace processes that cannot be simulated in the model directly with simplified representations
- For example, in a global model with a 100km grid size, individual clouds typically not representable
  - Particularly at the fine level of detail needed to convection within clouds via fluid dynamics
- Therefore, parameterize the model with a simplified process that approximates cloud behaviour
  - In sophisticated models, parameters are often complex models in their own right

NWP Process

Gather Observations

To understand the existing atmospheric conditions

Data Assimilation

Initial state of the atmosphere is constructed

Numerical Weather Predictions

To solve the atmospheric variables at a later time

Forecast Postprocessing

Both Spatial and temporal downscaling, bias reduction

Issue forecasts, Evaluate

Ranges of weather forecasting

1.	Nowcasting	0 -2 hours
2.	Very short-range weather forecasting	Up to 12 hours
3.	Short-range weather forecasting	Beyond 12 hours and up to 72 hours
4.	Medium-range weather forecasting	Beyond 72 hours and up to 240 hours
5.	Extended-range weather forecasting	Beyond 10 days and up to 30 days
6.	Long-range forecasting	From 30 days up to two years

Limitation of Numerical models:

- Choice of Assimilation system (4d-Var, 3d-Var etc.)
- Limitation of Physics (radiation, turbulence, moist processes) to replicate reality
- Often not sufficiently resolved to capture local phenomenon e.g. the temporal output intervals would not permit the examination of time dependent cloud cover variability.
- Initial conditions (Atmospheric Reanalysis Products) - define the atmosphere's current state…the starting point
- Lateral boundary conditions - define the atmosphere's state at domains' edges
- Lower boundary conditions – conditions at Earth's surface
- NWP models (especially GFS and NAM) are biased towards forecasting clear conditions resulting in large, positive biases

Evaluation of NWP:

- **Standard methods are the root mean square error (RMSE) and mean bias error (MBE).**
- **Model output statistics (MOS) to reduce persistent errors (MOS could not distinguish between errors in the clear sky models and errors related to cloud prediction, thus unnecessary correcting accurate forecasts)**

Steps required to improve forecast

- Required to develop new capabilities and strategies to quantify and reduce the uncertainty of both the solar and wind data generated from NWP models.
- NWP alone is insufficient for improving VRE forecast accuracy. New methods should be used in conjunction with conventional NWP to minimize error in forecast system
- Instead of a standard forecast framework, a flexible set up is needed, inclusive of suitable techniques and tools as per availability and compatibility to specific sites

RE forecast improvement: Andrade et al. 2017

- Andrade et al. proposes forecasting framework to extract the maximum information from the NWP grid using domain knowledge and eventually combines the gradient boosting trees (GBT) algorithm
- It shows significant forecast improvement compared to one NWP point for a specific location.
- Constructs new variables from the raw NWP data that are used as inputs in the GBT algorithm which can be adopted both for both wind and solar energy.

RE forecast improvement: improved bias correction methodology

- A bias correction methodology which extends beyond ‘fair weather’ conditions, and is also used in predicting an extreme weather event that require shutdown of the wind farm
- Extensive use of CP (Corrected Prediction) and DCP (Double Corrected Prediction) methodology which are known to greatly enhance the timing and accuracy of forecasts from the NWP (Kay et al. 2014)
- Real time data from wind farm needs to be coupled with NWP models to minimize the system error which are consistent in its nature.

RE forecast improvement : New parameterization with a better understanding

- Wind farm parameterization which has been developed for the mesoscale NWP model (Fitch et al. 2017) and shown significant improvement can be used for Prediction at Indian wind farms.
- A greater understanding of the interaction between the atmospheric boundary layer (BL) and wind turbines is necessary to ensure energy production and the lifetime of turbines are maximized.

RE forecast improvement : Persistent approach to improve accuracy

- Zhang et al 2015 suggests a persistent approach which corresponds to using the persistence of the recent observations.
- This method is particularly useful for shorter forecasting periods and when atmospheric variability is smaller (e.g., dry climates, few clouds).

E forecast improvement: Adequate interpolation technique

- Choice of suitable interpolation technique and scales both for spatial and temporal downscaling is very important to improve accuracy.
- Solar power forecasting with one-hour time resolution is to be aimed for adequate accuracy
- Similarly, ECMWF irradiance forecasts show best results when averaging over 4×4 grid points, corresponding to a region of 100km×100km.

RE forecast improvement: Usage of Remote Sensing

- Processing of various remote sensing data (satellite or ground imagery) enables detection of clouds and even characterization, which can be adverted to predict GHI accurately up to 6 h in advance
- Sky camera and geostationary satellite image analyses are employed for accurate short term forecasting
- Hammer et al. 1999 showed 17% rRMSE in satellite imagery for 30 min cloud index forecasts and 30% rRMSE at 2 h forecast horizons which are much better than the NWP model forecasts.
- Even for intra-day forecasts, a reduction in rRMSE by 7–10% compared to persistence forecasts was found

RE forecast improvement: ANN as a post processing tool

- Particularly useful to improve mesoscale WRF solar radiation outputs
- Data of key atmospheric parameters obtained from ground stations are often used and trained to construct the ANN model in order to reduce the bias
- Using training data, typically years of measured ground data , ANNs have been developed to reduce relative RMSE (rRMSE) of daily average GHI by as much as 15% when compared to 12–18 h ahead NWP forecasts
- Voyant et al. 2012 describes a method, an optimized multi-layer perceptron (MLP) with endogenous input and exogenous inputs (meteorological data) are used to forecast the global solar radiation time series with much reduced errors.

RE forecast improvement : Ensemble and Nested approac

- The output of the ensemble members is used to derive the ensemble mean for different atmospheric variables including wind, temperature and pressure.
- This regional scale ensemble forecast is then used for preliminary wind resource assessment after validation with the available measurements.
- The differences in wind, temperature, and pressure data between the ensemble members give the sense of the assessment uncertainty. This is an advantage over the classical approach by depending on single model data.
- By this method, the less predictable features are smoothed out while the predictable features in the forecast remain intact.
- Ensemble approach is also used to reduce the systematic biases in regional climate modeling. WRF model was forced by reanalysis of NCEP-R2, ERA-40 and IRA-25 datasets. The ensemble system showed considerable bias reduction compared to each individual model.
- Similarly, Nesting approach also ensures that the local scale model resolution is fed by the information from coarser scales.

Conclusion

- NWP models although indispensable for VRE forecasts, has its share of limitations which affect VRE forecast accuracy
- There is no standard method of removing the forecast bias, however new strategies and capabilities are to be used along with conventional methods.
- Scientifically updated parametrization method with suitable post processing techniques are equally important for NWP for site specific forecasts.
- Adequate usage of Remote Sensing data, ensemble/nested model approaches are important to enhance forecast accuracy