Wind Power Forecasting
The science & practice

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Presentation plan

- The need
- Science behind
- The path this far
- CERC & SERC regulations
- What needs attention
- Way forward

Background to wind power forecasting

- Effective and efficient grid management requires a fairly good idea about possible power flows into the grid and their consumption on very short time frames of minutes to weeks and months for planning.
- Forecasting thermal or hydro power is simpler in short horizons.
- When grid penetration was low it did not matter much as systems were large enough and the grid frequency variations were forgiven.
- As the RE penetration in terms of installed capacities started increasing and at the same time grid frequency bands started getting narrower, very quickly the regulations were brought in with ever increasing demands on predictability.

The need

- Currently India has considerable share of non major hydro RE power on grid that is weather dependent. It is going to grow further.
- The Indian Grid has to be able to deal with higher variability, storage technologies, reprograming hydro power & development of decision making algorithms.
- Weather conditions have substantial variability.
- Weather modeling is a complex science and is not able to provide closed form solutions presently as is being demanded.
- It is important to understand the nuances of the state of art and work towards best possible way of dealing with uncertainties.
- It is not enough to be able to get estimates with small uncertainties for future time steps.
- It is important to have ability to absorb as much RE power as is feasible economically instead of putting entire onus on RE generator.

The Science behind forecasting

- There are three critical steps
  - Global Weather modeling
  - Regional forecasting
  - Down scaling & power modelling

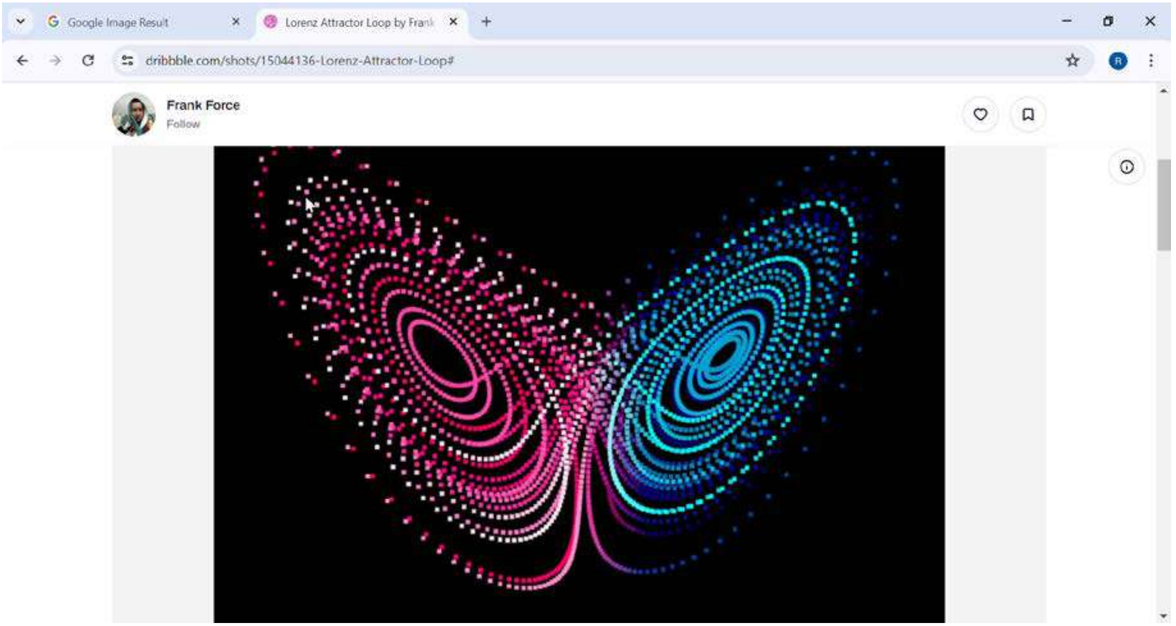
- Global Weather modeling – As the name suggests – is carried out for entire earth at grid points that could be with several kilometer spacing once in six hours.
  - Input data to the model are taken from met services around the world.
  - Notwithstanding guidelines the input data can be very sparse both temporally and spatially
  - Quite a few assumptions, assigned values are used in such cases.
  - The forecasts in such areas would have large uncertainties.
  - Global models are known to work better in upper latitudes.
- Because of these factors results from the global models can not be taken as sacrosanct in our context.

Forecasting State of Atmosphere in future steps

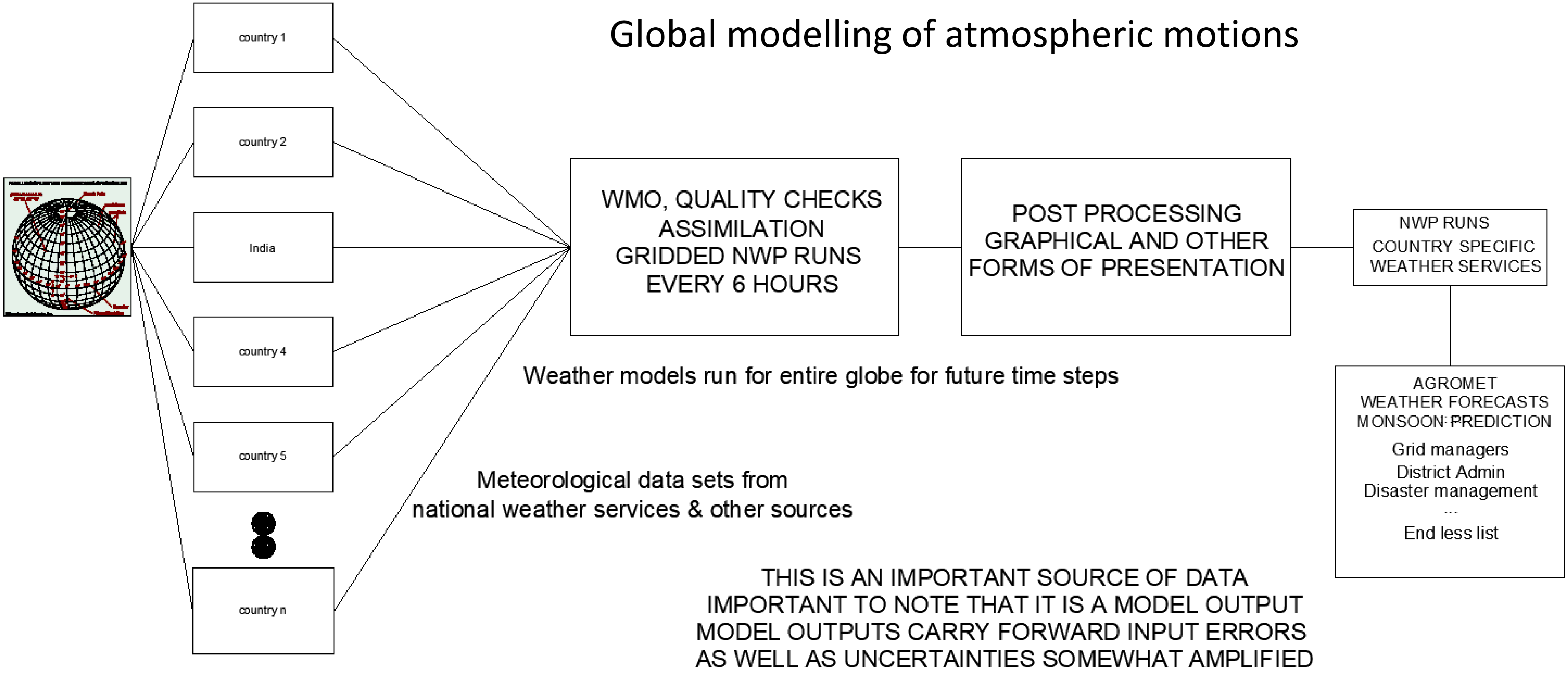
- Meteorological observations are carried out with a view to be able to predict development of atmospheric conditions over short time scales (minutes to weeks).
- These observations are made at pre-fixed times by meteorologists around the world.
- The data thus collected would be used to calculate what will be the state of atmosphere in near future using mathematical models.
- Essentially atmospheric modeling is rooted in equations of mass and momentum conservation (Navier Stokes equations).
- Before we get into this, some background understanding will be helpful.

CHAOS – reality of atmospheric motions

- Chaotic systems are hyper sensitive to inputs given to them.
- Any measurement is always associated with an uncertainty. This point should be kept in mind
- Chaos being what it is, it has to be understood that Accuracy of Input data is of great importance.
- Discovery of Chaos in atmosphere is attributed to Lorenz who stated:
- “The Chaotic nature of atmospheric flow has been popularly described as when a butterfly flaps its wings in Brazil, it could lead to a tornado in Texas”. In other words the outcome of model outputs can be widely divergent for imperceptible changes in the input variables.
- While it may not be as dramatic, it essentially implies is that there is a lot of unpredictability & uncertainty in the way atmospheric flow develops in time and space.



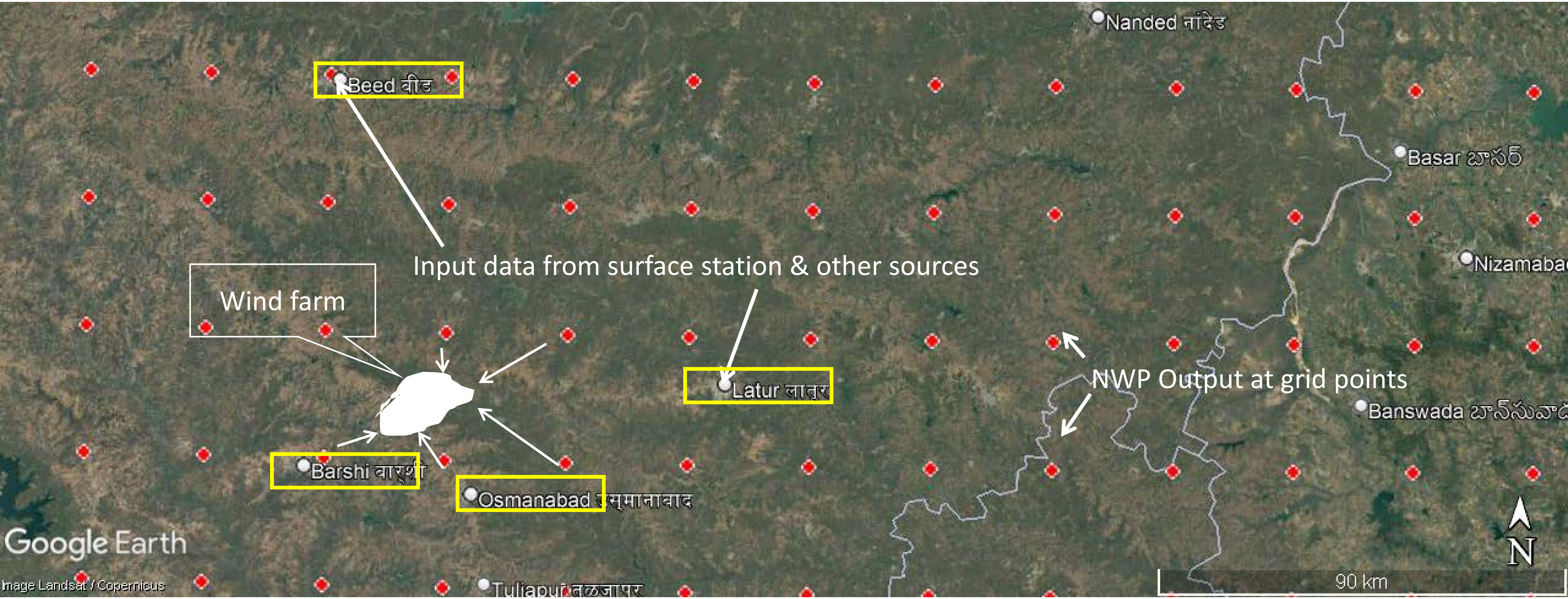
Global modelling of atmospheric motions



Regional forecasting

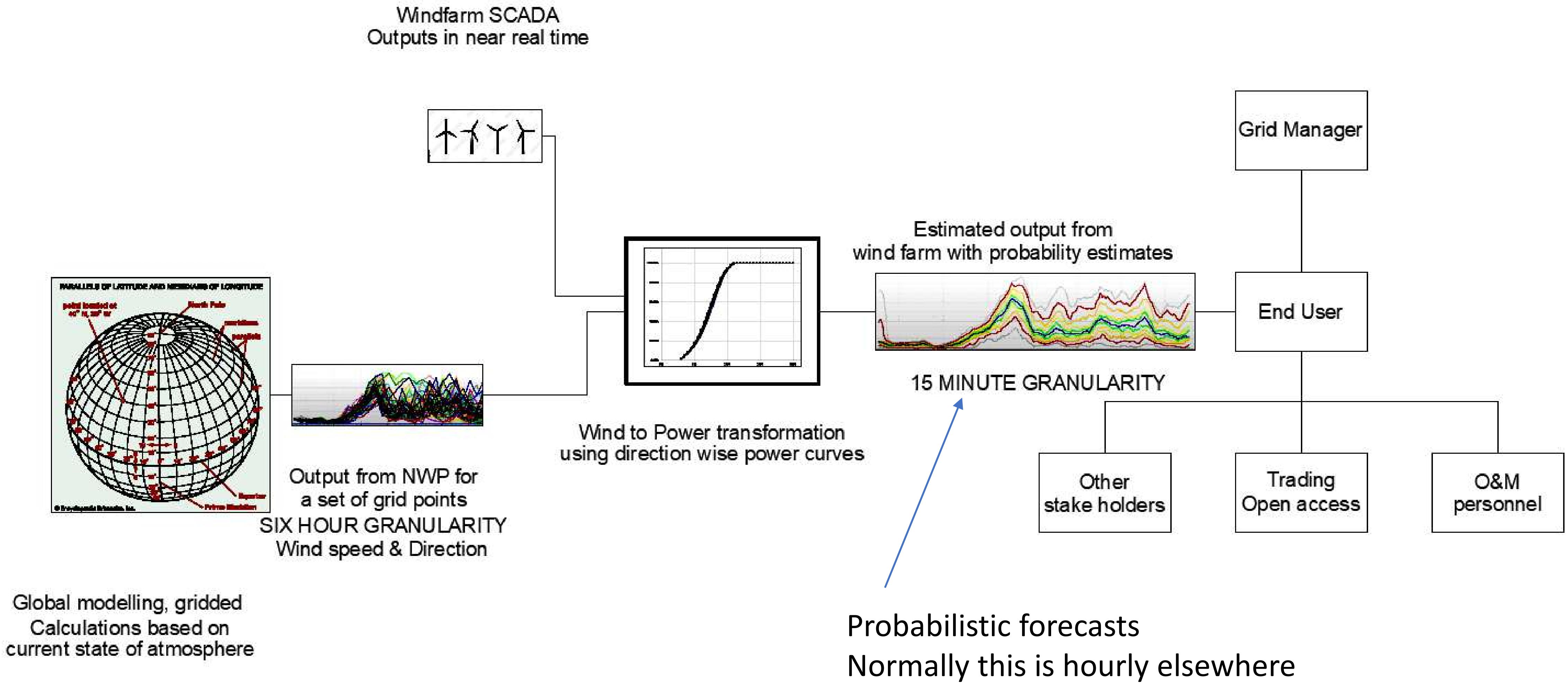
- This kind of forecasting is a sub set of global modelling and can be down scaled to few hundred meter spaced grids. This may provide a little bit better information but could continue to carry the issues forward in results.
- However, based on radar based observations Satellite based inputs and other inputs some improvements – in terms extreme events such as thunderstorms can be captured in advance. However for precise location specific quantitative forecasting is still some distance away.
- There is a possibility of running High Resolution Rapid Refresh (HRRR) models that can be run every hour and making available outputs at one hour or less interval. This is yet to happen for use with RE in India

DOWN SCALING TO WIND FARM SITE



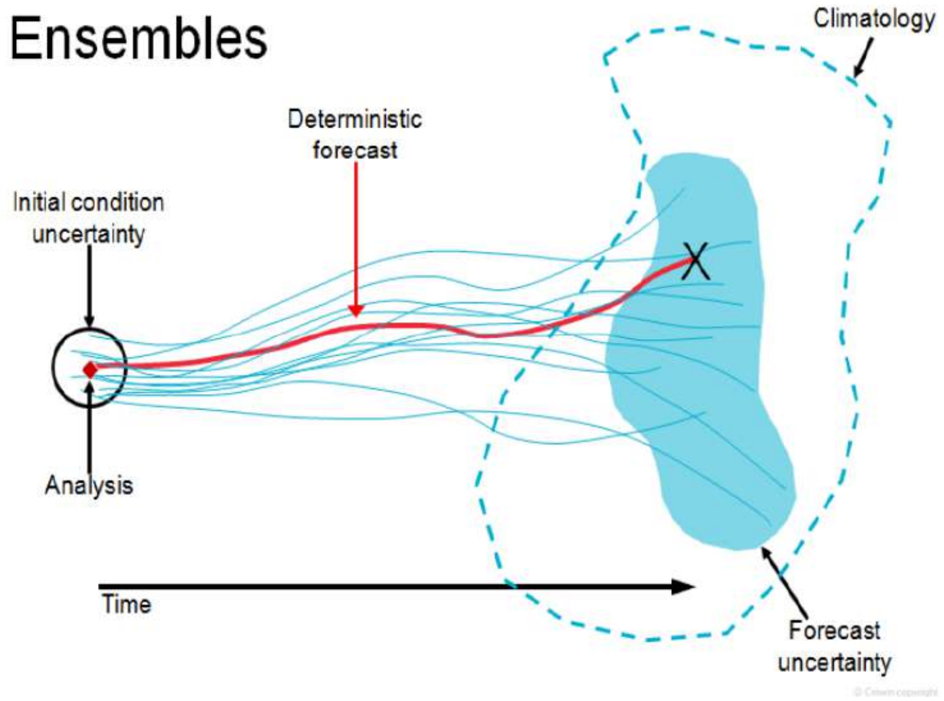
- Inputs to NWP from Observatories (white dots)
- NWP outputs at Grid points as Synthesised data sets (red dots)
- **Nested (Sub-nets) calculations over project area based on local terrain, model training etc. (White patch)**
- **This data used in conjunction with on site SCADA to Produce future power sequences.**

Wind Power Forecasting system



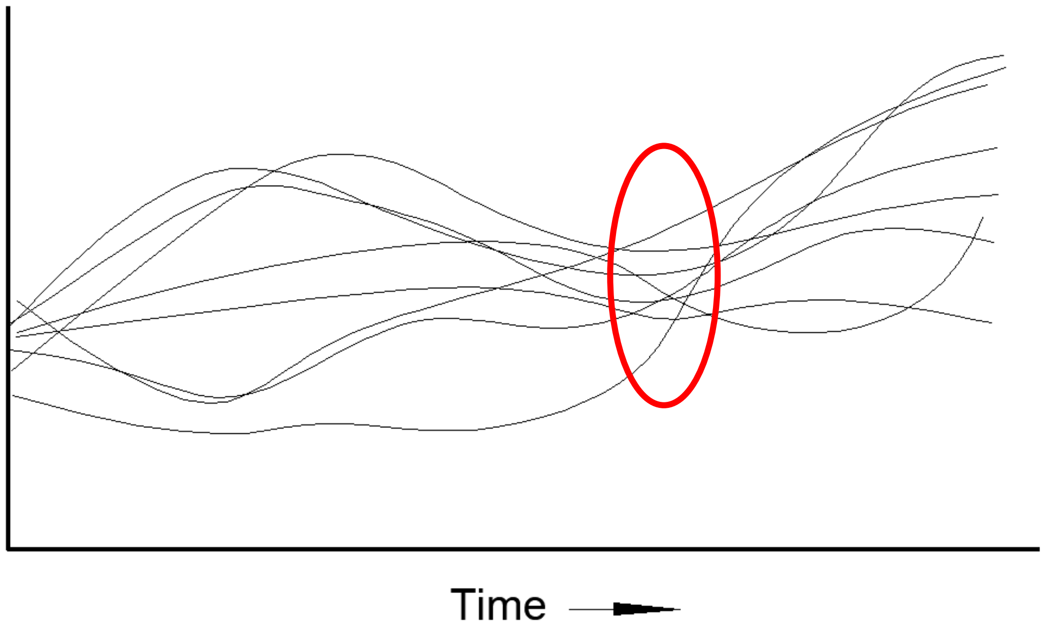
Deterministic & Probabilistic forecasting

- When the inputs to the forecast model are well defined and complete with no uncertainty, the model is expected to output with very low uncertainty. Such forecasts are known as deterministic forecasts.
- In real world this does not happen. In order to deal with this ensemble calculations are carried out. The input variables are varied ever so slightly and a large number of forecasts are obtained.
- There can be some convergence of the output which can be used along with probability quantiles defined



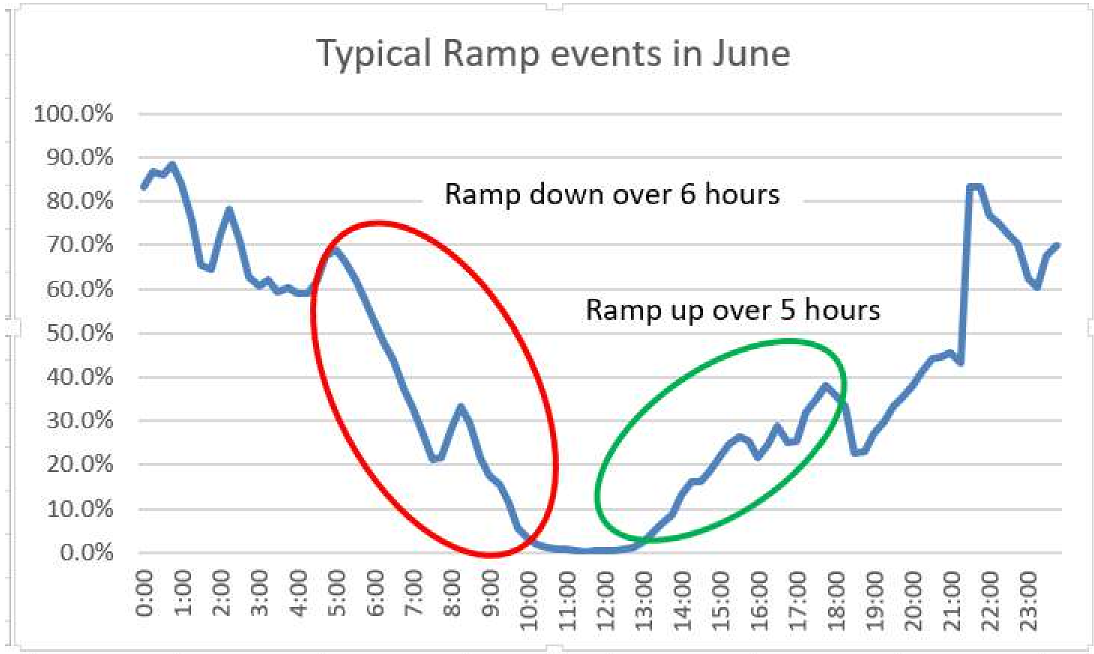
Ensemble Prediction

- The forecast model is run hundreds of times and results so obtained are to be dealt with using probability
- There will be a likelihood that there will be a convergence of the results at future time steps. This would define possible state of atmospheric flow at future time steps.

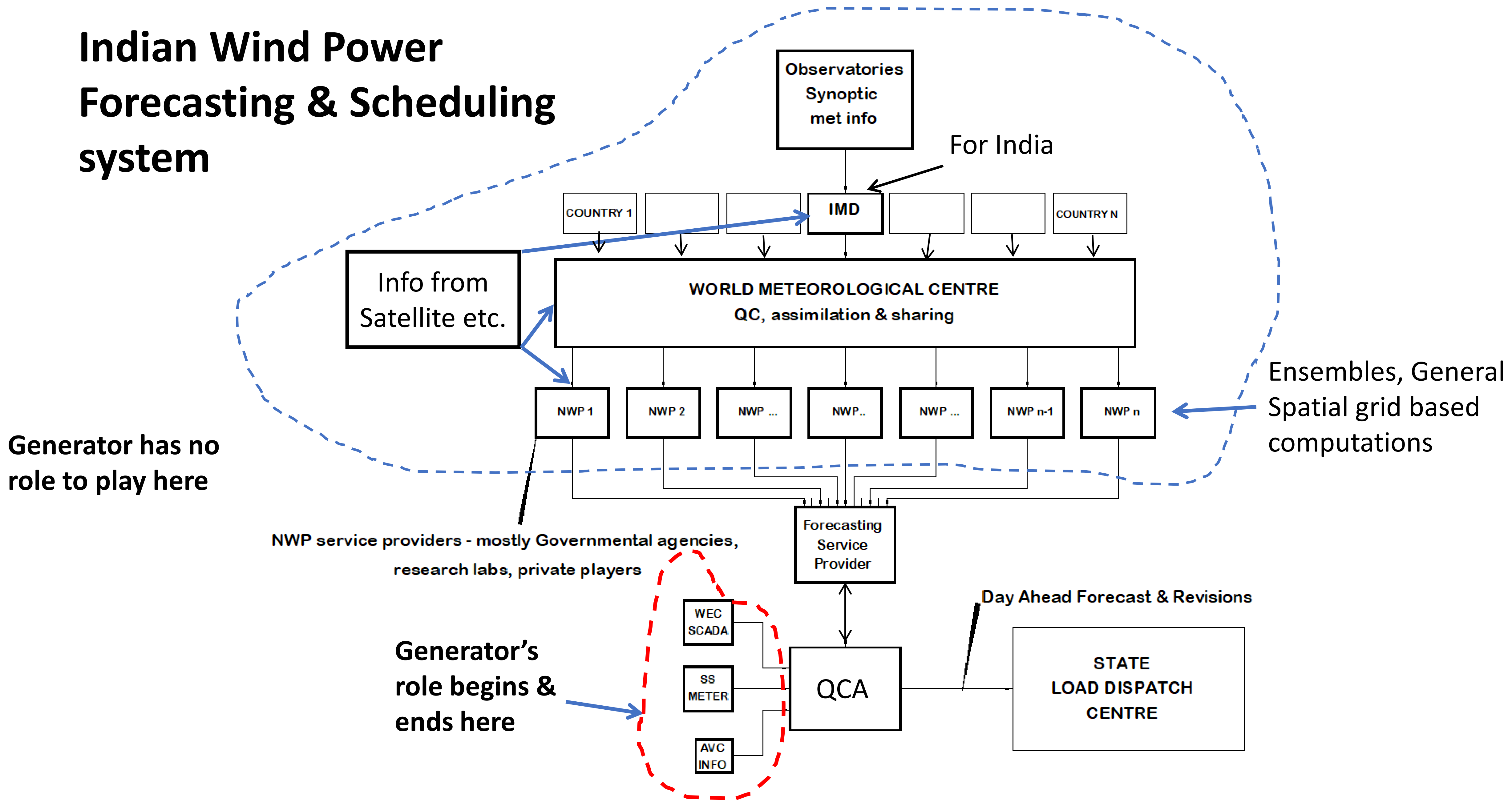


Critical Ramp Events

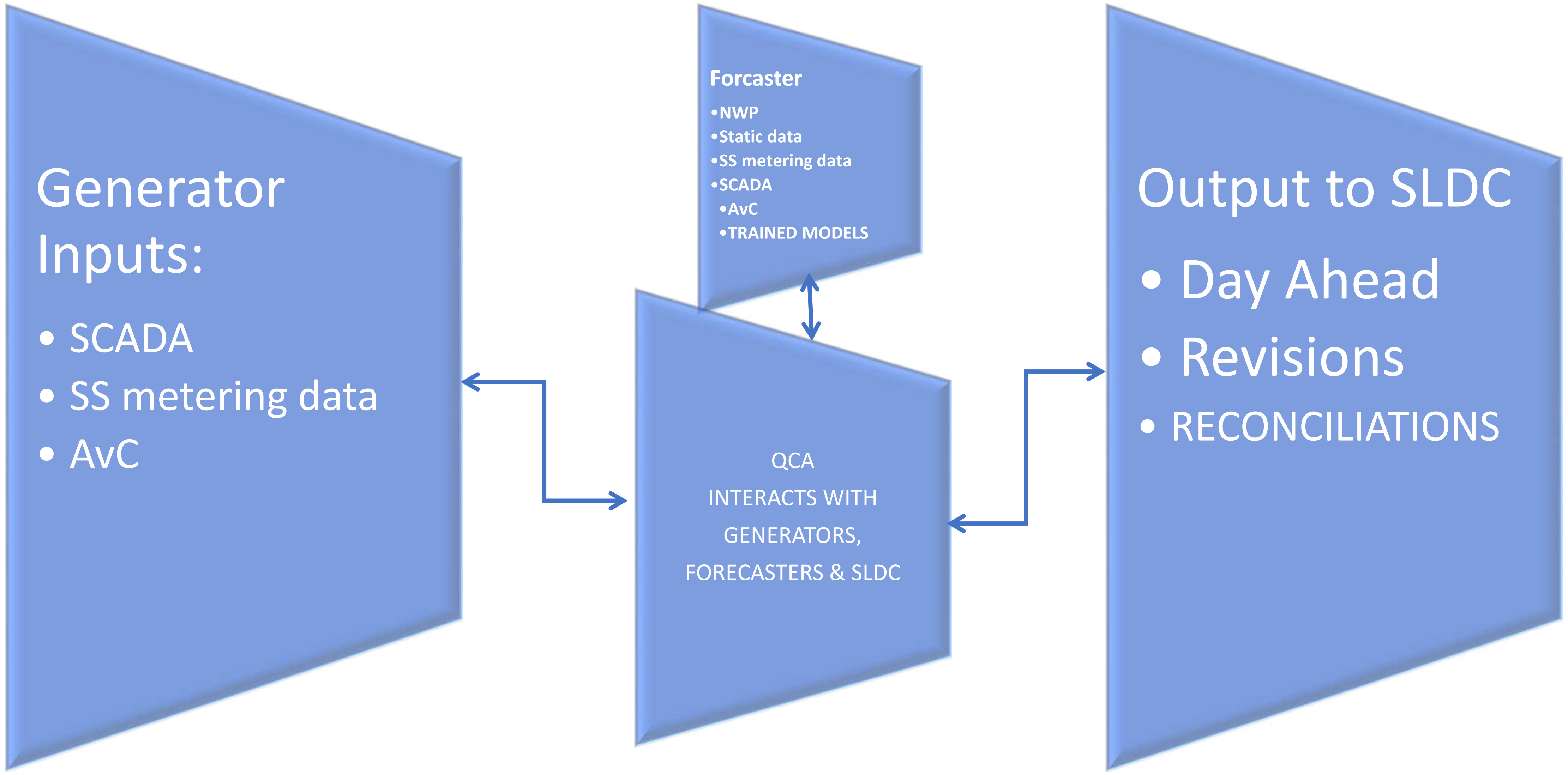
- Ramp events are most often quoted difficulties in absorbing RE power.
- It actually depends on the entire system's ability to take them in their stride at the point of common connection.
- Typically ramping happens over 2 to 4 hours at a ramp rate of 10/15% over 2 to 6 hours.
- If we look at the impact of these swings from the total power flow on the grid at that point, it may not be seen as a major grid event. But it is never reported in that manner.
- Forecaster must be able to take these into account as special cases
- Aggregation will largely even out such situations.
- These events need to be treated using extreme event analysis and require probabilistic methods with time and space dependency.



Indian Wind Power Forecasting & Scheduling system



Process of creating forecasts & schedules in India

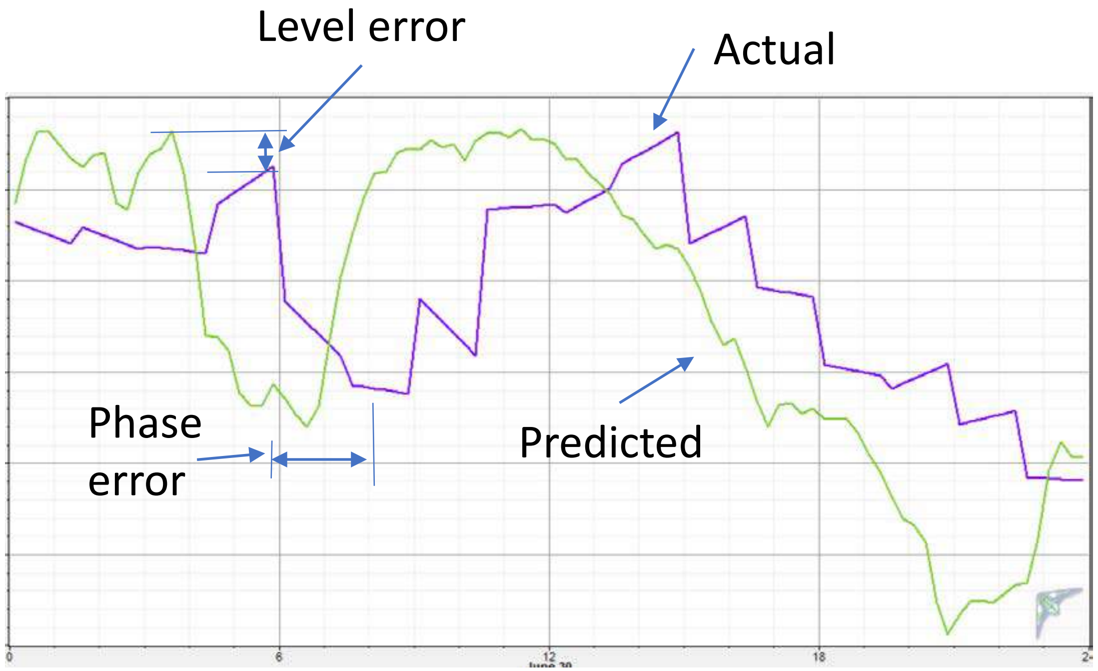


Practical issues while forecasting

- NWP outputs typically come every six hours at predefined grid points.
- The forecast revisions can happen every sixth time block and there is little that the forecaster can do to capture serious ramps to update.
- The other issue is how to deal with grid security based backing down of the wind farm.
- In Day ahead forecast which needs to be provided by 10/11 AM of the previous day, for data starting at 00:00 hours to 23:45 hours, the forecast is already 14 hours old. A certain amount of divergence in results would have already occurred as time advances from zero point

Typical issues of forecast v/s actual trajectory

- The forecasts, due to a variety of reasons come with two significant errors:
  - Phase error – where the time stamp of given forecast can be either advanced or retarded. In both cases the calculated errors would be significant notwithstanding the fact that predictions are close.
  - Level error – could be a case of over prediction or under prediction.
  - Both can happen together.



CERC/SERC regulations

- The regulators started looking at forecasting needs as early as 2009. By 2014 regulations were announced.
- Since then, a number of revisions have been made based on an assumption that since it has been going on for so long, things must have improved considerably.
- In reality there has been no perceptible improvement in the forecasts produced nor is there adequate consistency as the basic issues have not been addressed at all.

DSM charges

- Based on CERC regulations from 2014 to draft regulations of 2024 there has been an increase in DSM charges.
- The regulations need to take into the state of art of forecasting science.
- The basis of creating forecasts and schedules is the weather prediction science which works with limited measured data.

Penal charges as a percentage of net income					
Substation	Capacity	2014	2022	2023	DRAFT CERC 2024
Akal/Jajiya	230 MW	0.48%	4.35%	1.60%	2.67%
Akal Bhu	453 MW	0.41%	4.53%	1.52%	2.34%
Andhra lake MH	106 MW	0.49%	4.32%	1.56%	2.67%
Sadodar	462 MW	0.19%	3.28%	0.69%	1.22%

It can be seen that the DSM charges in different situations has been increasing with each revision of regulations. Basically it shows a disconnect with the advances in forecasting sciences.

Error quantification & forecast value

- There are quite a few firms dealing with forecasting.
- Most of them promise to provide forecasts based on very advanced, AI and ML enabled solutions.
- Unfortunately benchmarking these services is very complex.
- With attempts to minimize DSM charges good forecasting takes a back seat.
- Attention needs to be paid towards bringing in some standardization into the field.
- There are IEA recommendations which could serve as a starting point
- Some of the key indicators of the how well the models are performing needs to be looked at.

How do we deal with Forecast errors

- With the current methods of error evaluation using the IEA recommendations becomes difficult.
- As of the moment even if chosen service provider is consistently giving bad forecasts, the rules are so complex that the generators hesitate to change them.
- It will be necessary to deal with these aspects more holistically and firmly.
- The following slides provide some of the basic definitions that would help in evaluation.

International practices have defined some ways of doing this. At this time we have kept the process simple as per CERC guidelines and not really thinking beyond them.

Forecast error is defined by

$$e_{t+k|t} = \hat{P}_{t+k|t} - P_{t+k}$$

Where,

$e_{t+k|t}$ = is the error corresponding to time t+k for prediction made at time t, where k is the forecast horizon

P_{t+k} is the power measured at time t+k

$\hat{P}_{t+k|t}$ is the predicted power for time t+k

CERC regulation has defined the percentage error as

$\frac{e_{t+k|t}}{AVP}.100\ \%$, AVP= Available installed power

Source:- Prediction Error-Based Power Forecasting of Wind Energy System Using Hybrid WT–ROPSO–NARMAX Model Aamer A. Shah et al

Normalized error is defined by:

$$Ne_{t+k|t} = \frac{e_{t+k|t}}{P_{inst}} = \frac{P_{t+k} - \hat{P}_{t+k|t}}{P_{inst}}$$

CERC has taken cognizance of the fact that the operational installed capacity can be different from the Installed capacity due to a variety of reasons.

Where P_{inst} is the installed power

Mean Average error for a forecast horizon k is given by:

$$MAE_K = \frac{1}{N}\sum_{t=1}^{N}\left|e_{t+k|t}\right|$$

where $|e_{t+k|t}\}$ is the absolute forecast error (both positive and negative errors) defined above.

To make it feasible to compare different wind farms and forecast methods, it is a practice to divide the MAE by installed capacity.

$$NMAE_k = \frac{MAE_k}{P_{inst}}$$

Root Mean Square Error is defined by:

$$RSME_K = \sqrt{\frac{1}{N}\sum_{1}^{N} e_{t+k|t}^{2}}$$

Normalized Root Mean Square Error is given by:

$$NRSME_K = \frac{RSME_K}{P_{inst}}$$

Internationally these definitions are used to define forecast errors and are used to compare outputs from different service providers

A re-look at NWP inputs and possible improvements

- One of the primary inputs that the models require is as much high quality data as is feasible.
- The inputs to global circulation modelling comes from about 500 surface stations, balloon flights from less than 50 stations, satellite based observations few other sources.
- There is a claim about private met stations for specific & special purposes and that does not enter the common pool of data.
- While this may be adequate for some qualitative understanding of state of the atmospheric flows, there is room for much improvement

Way forward

- With the background of forecast accuracies having tabled off it has become essential to look at improvements at the root of the issues we are facing.
- Two important sources of data have been proposed.
  - Wind farm based SCADA can provide Wind Speed and Directions
  - Installation of Automatic weather Stations may be considered.
- Chairperson, CEA set up a working group to make recommendations for next course of action.
- The group headed by IMD supported by NCMRWF and other Governmental establishments (MOP,MNRE etc.) and Associations have made some progress.

Progress This far

- Since the task force was set up in February 2023 the committee has met six times via Microsoft TEAMS and physical meetings.
- Sample wind farm SCADA data is being uploaded to IMD and NCMRWF ftps with a granularity of 15 minutes.
- The data reaches their ftp with about 3 to 4 minutes latency and uptime is >90%.
- Scientists have been looking at the data.
- Whatever clarifications needed have been provided.

Progress This far

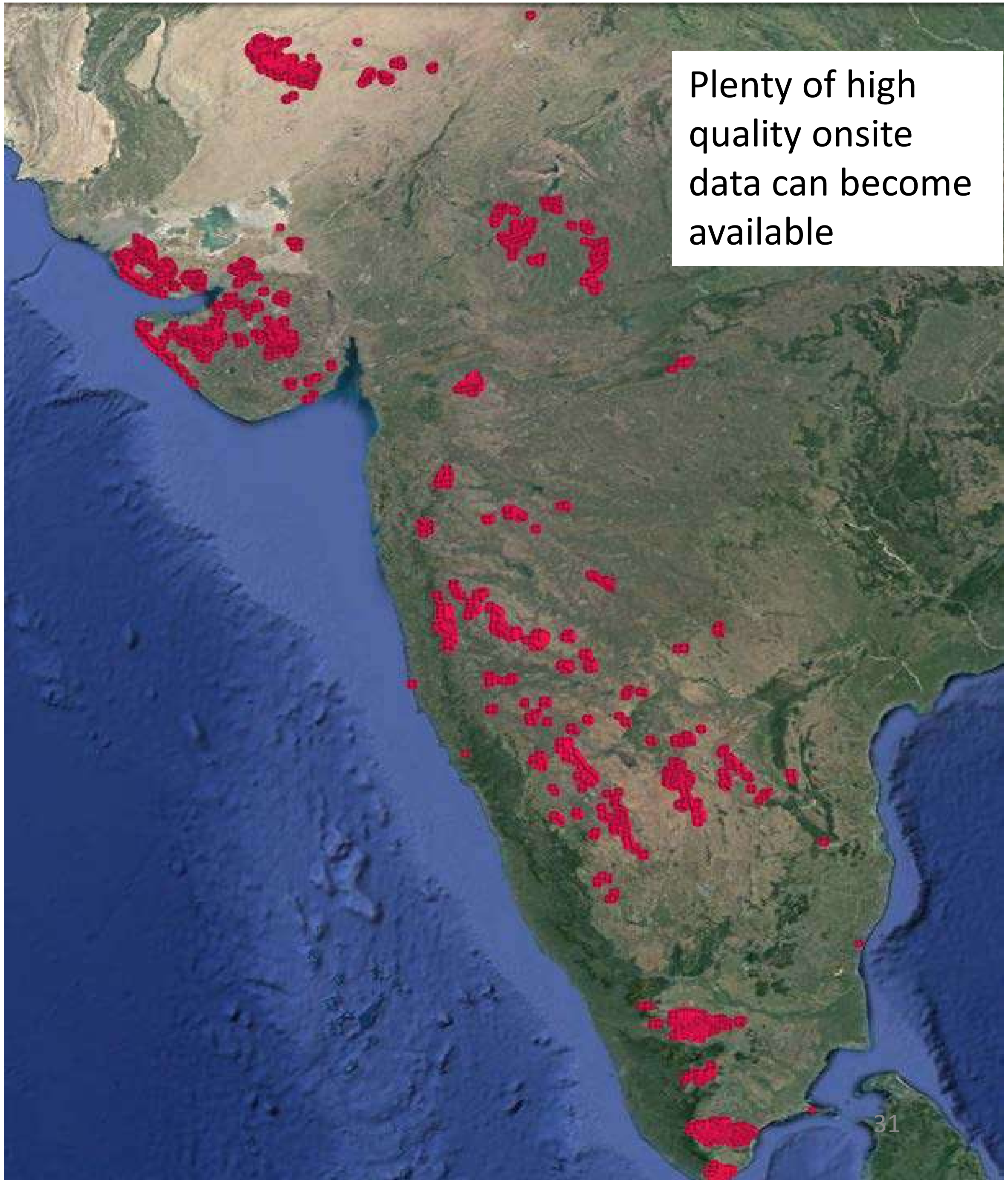
- Discussions and follow up actions have resulted in
  - Agreeing that this data, if available from all wind farm sites can make a difference in improvement of NWP results.
  - The need for other meteorological data continues to be an issue if we wish to employ them in data assimilation.
  - Some meteorological data is being collected at POSOCO substations and these data must also be ported to NCMRWF
  - For this to happen, Automatic Weather Stations also need to be installed at strategic locations, continuously monitored and maintained.
  - The data from AWS also must reach the modelers in time so that it could be used at the assimilation level to obtain better results.
- It was also proposed that we should run a pilot study in Gujarat and Rajasthan & subsequently expand to the entire country

Progress this far

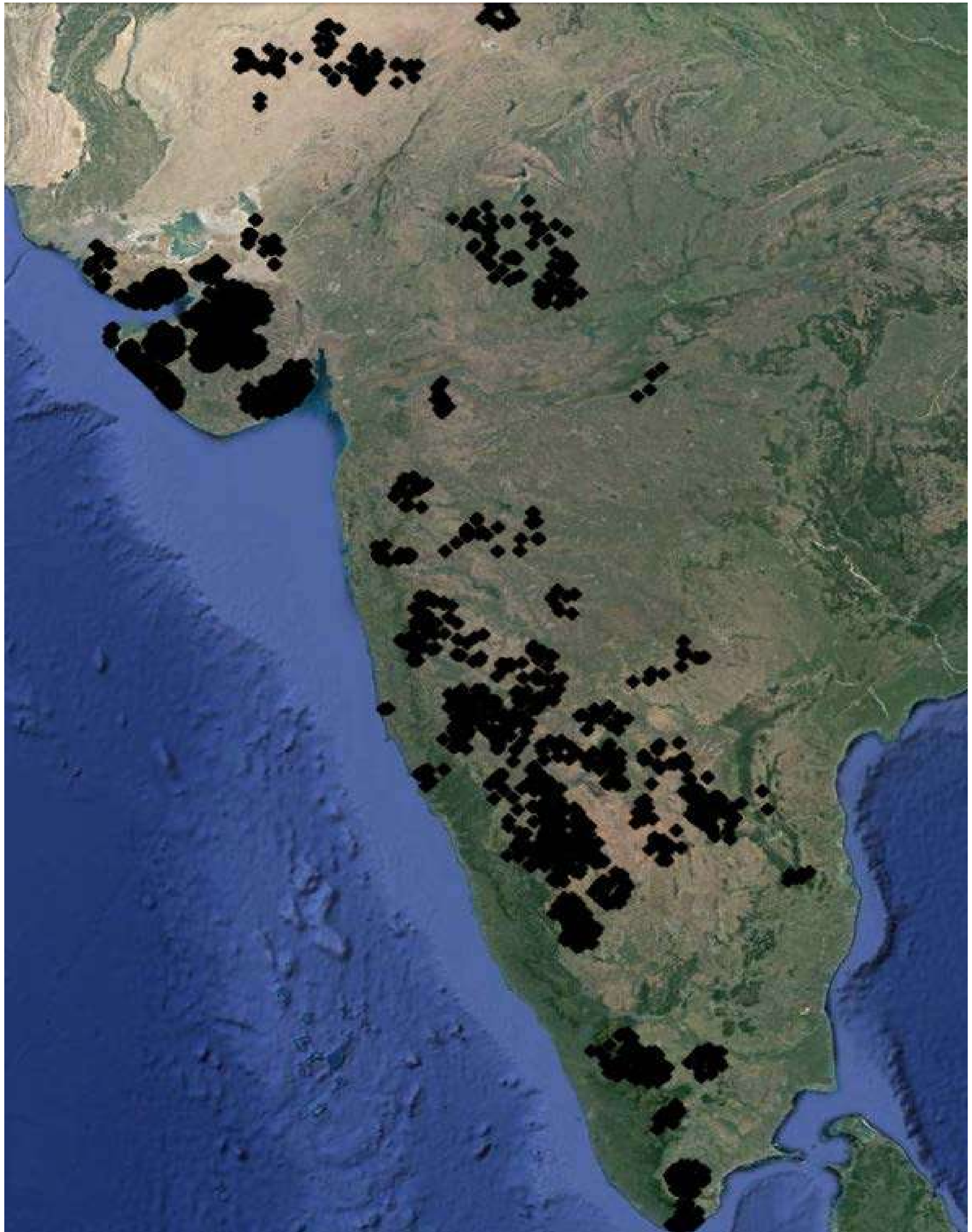
- We have tried to put together the wind farms and corresponding Substations.
- Initial estimates of number of wind farm specific substations is about 3200 substations.
- It is assumed that one substation of 33 kV/66/132/220/400 serves wind turbines with in a radius of 25 to 30 km.
- The meteorological parameters captured at the respective sub stations are expected to be representative for the wind farm area.
- It should be understood that this is much better than having no data at all
- The wind speed and direction information captured by Wind farm SCADA will provide good scaling and possibly used in assimilation.

Windfarms across India

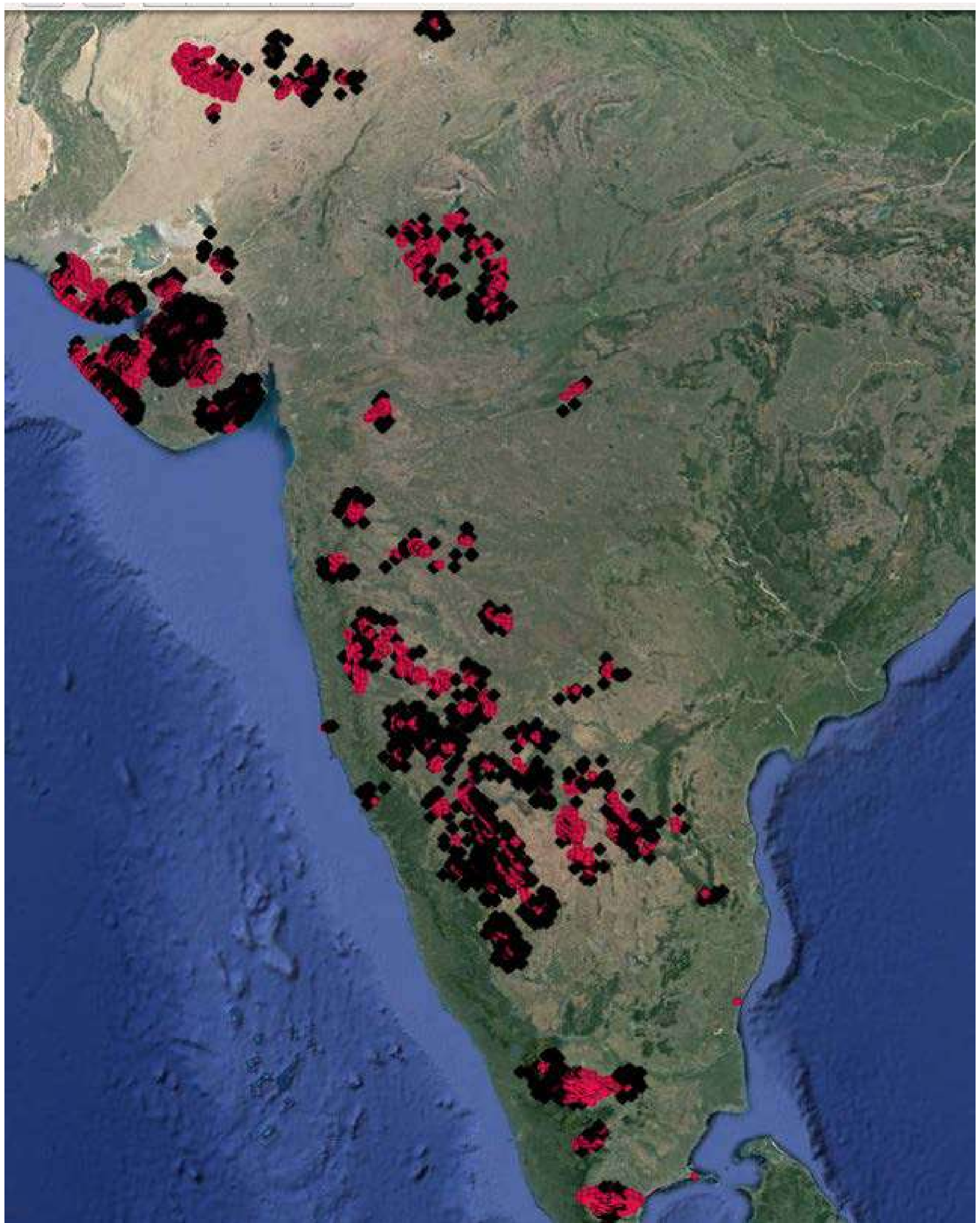
We have windfarms at remote areas and the farm data (including some meteorological data is available in near real time.
This data is going abroad to the so called forecast service providers in bits and pieces.
A dialogue with IMD was started a couple of years back and some sample data is being shared with them for study in near real time.
They have evinced serious interest in this as a possible data source at INPUT level. This approach can be a game changer.
It will need full support from the respective ministries.
It is to be hoped that the major departure from current carrot & stick policy, with no carrot of course.



Substation distribution

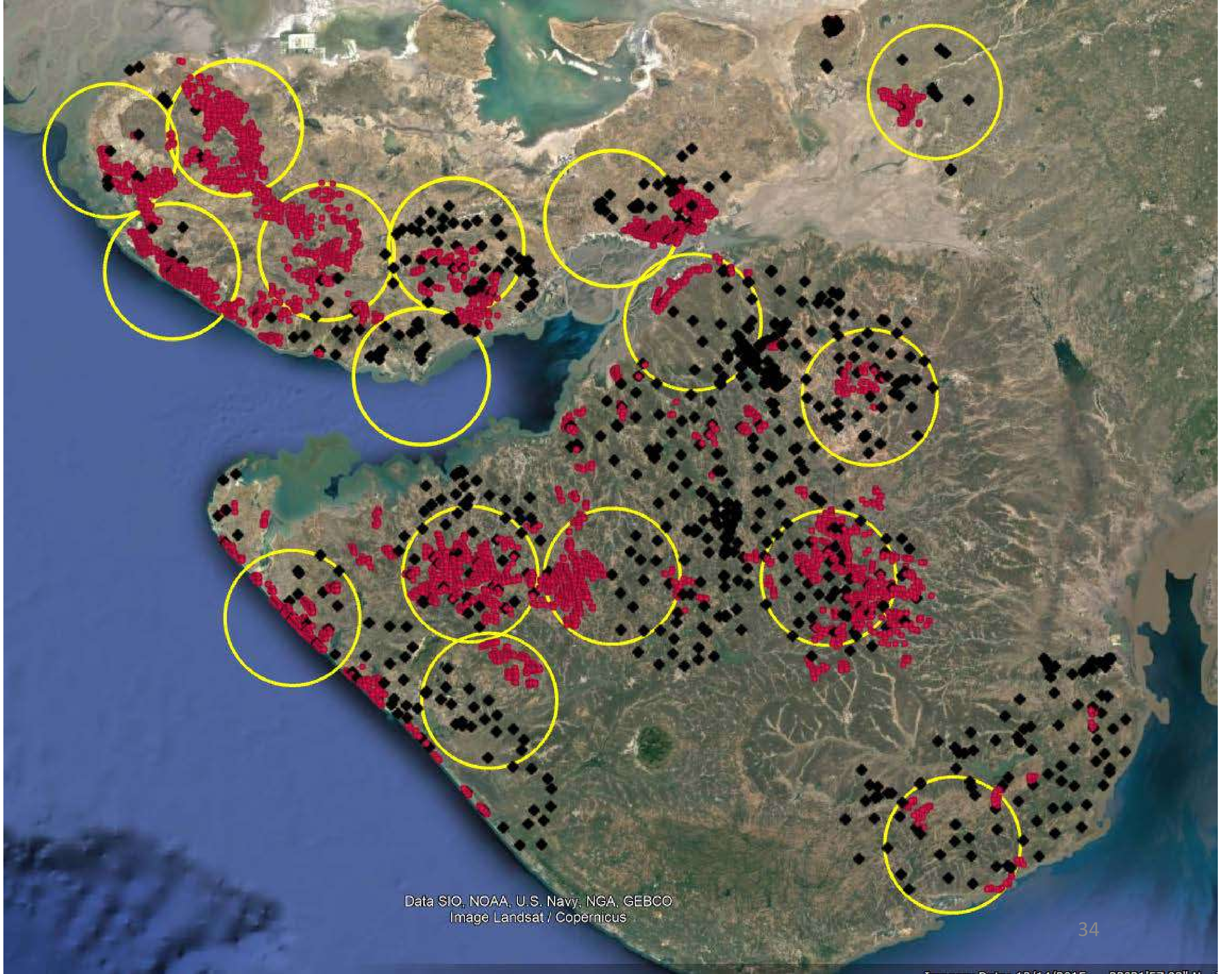


Wind turbines & Substations super-imposed



Pilot study in Gujarat

25 km radius circles showing possible distribution of AWS
For Gujarat we envisage about 23 AWS deployment at the Substations
A similar exercise can be carried out for other states.
There is a possibility of porting met data collected at PGCIL and other substations if they are available.



Some considerations

- In plain terrain the meteorological parameters can have a spatial distribution of about 25 km radius.
- For Gujarat we would need about 23 AWS'es.
- All over India we may think of about 100/150 AWS'es for this purpose.
- We need to see how best to deal with this aspect.
  - These AWS need to be GPRS enabled.
  - They would need security & some routine O & M.
  - There should be a system to manage them properly.
- Typically they would cost 3 to 4 lacs/station and perhaps some central assistance will help.

Structuring the project

- There has to be a structured system in place that will take care of roles and responsibilities to see that there is no break in service.
- IMD/NCMRWF may decide the instrumentation needed, finalize requirements. It will be best if they provide the systems under some formal arrangement. Else it should be fully specified and validated. If MNRE/NIWE provides administrative support, it may be ideal.
- Perhaps Wind Generators will take care of installation, commissioning of the instruments. Take care to see that data flow shall not stop.
- Some Governmental Directions will be necessary to push the project further.

Recommendations

- Getting the Wind farm SCADA based wind speed and direction information to NCMRWF.
- Finalizing economic but effective AWS specs and modalities of deployment.
- Testing the concept in Gujarat & Rajasthan.
- Creating a structure for the complete activity with roles and responsibilities for sustained operation.
- We will require suitable directions to all stake holders to make this happen.

Conclusions

- There can be vast improvements in the NWP outputs if the field data from SCADA & on Site meteorological data are used as inputs – after due verification & validation.
- Improved NWP results would automatically improve the forecast accuracy.
- We must consider setting up High Resolution Rapid Refresh forecasting systems that would help the forecasts get refreshed every hour instead of current practice of 6 hour forecasts with low resolution
- The forecasts must be carried out with state level aggregation instead of merely collecting individual forecasts.

Conclusions

- The Indian Grid has to be able to deal with higher variability, storage technologies, reprograming hydro power & development of decision making algorithms. This initiative is a step in that direction.
- This public –private partnership is perhaps one of the best ways of ensuring higher grid integration of wind power without compromising safety.
- It is not a one time effort. It is something that has to be built and sustained in the long run.
- This program has the potential to become a Make in Bharat if all stake holders work towards making this happen.

We may not have it all together..

but Together we have it all

Thank you