VORTEX 3D FARM Remodeling

Accuracy Improvement Using Site Observations

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Mesoscale Modeling for the Wind Industry

The high-resolution numerical modeling of weather conditions provides today sensitive information of unprecedented quality crucial for the development of any wind project, from the early stages of prospection to the wind farm design and long-term adjustments.

In particular, usage of mesoscale modeled downscaled products driven by global Reanalysis databases gained a considerable acceptance among the wind industry community as reliable reference long-term data and resource screening assessment. Mesoscale downscaled products provide realistic localization of the wind regimes and the topography controlled variables which allows more accurate site impact assessment and climatic representation.

Mesoscale modeling technology is be employed by VORTEX to obtain global wind climates at different resolutions and with customized specifications to provide high quality wind resources information to support project development.

The mesoscale model Weather & Research Forecast Model, WRF, developed a NCAR/NCEP is employed as VORTEX mesoscale modeling core. WRF model has a large tracks record on usage and it is employed operational in many weather services, cutting-the-edge research activities and different industry applications.

WRF development has engaged a wide community of users which meant large peer-review validations analysis and upgrading of advances in the different components of the weather & climate modeling science.

VORTEX has based their modeling expertise in the optimized and automated use of WRF for wind industry applications. The experience gained in the last 8 years guarantees a stable and robust model configuration which has been tested and verified by VORTEX.

More information on VORTEX technology can be found at http://www.vortexfdc.com

3D FARM Remodeling

The main purpose of Farm 3D Remodeling technology is to improve the estimation of the wind conditions characteristics for a given area combining wind observations at the site within the FARM product postprocessing streamflow.

A recurrent question is how to optimize the combined usage of in-site measurements and mesoscale wind flow model products. Different approaches can be envisaged but particular care is required to not degrading the quality of the information that each source, model and observation, provides independently.

Different statistical approaches can be followed to merge mesoscale model and windmast data. Standard methods are based on obtaining correction factors for sectorised wind speed distributions. This approach presents the following limitations:

- Reduction of wind resource conditions to a wind speed and wind direction binned representation;
- Relying on Weibull-fitted wind distributions information as for example WRG files
- Usage of a single correction factor, with no time-dependency

VORTEX investigations and analysis underline the necessity to define efficient statistical methods which spatially propagates the information from the wind mast location through the rest of the model domain, preserving spatial consistency and including the time dependency of model and observations relationship.

Approach

Vortex approach follows an adaptive multivariate geostatistical methodology, which ensures strong coherence in the spatial propagation of available observed information through the modeled domain. The geospatial statistics engine behind is based on a selection of different time dependent predictors that in combination with spatial covariance/correlation patterns boost an intelligent reprojection of measurements/modeling relationship to each point the FARM model domain.

FARM 3D Remodeling is an extension of our technology that has been successfully applied to facilitate long-term modeled SERIES with site observation for climate variability uncertainty assessment. A comprehensive analysis of the statistical methods can be found on Tortosa et al 2014 (http://www.vortexfdc.com/assets/docs/EWEA2014_Atortosa.pdf)

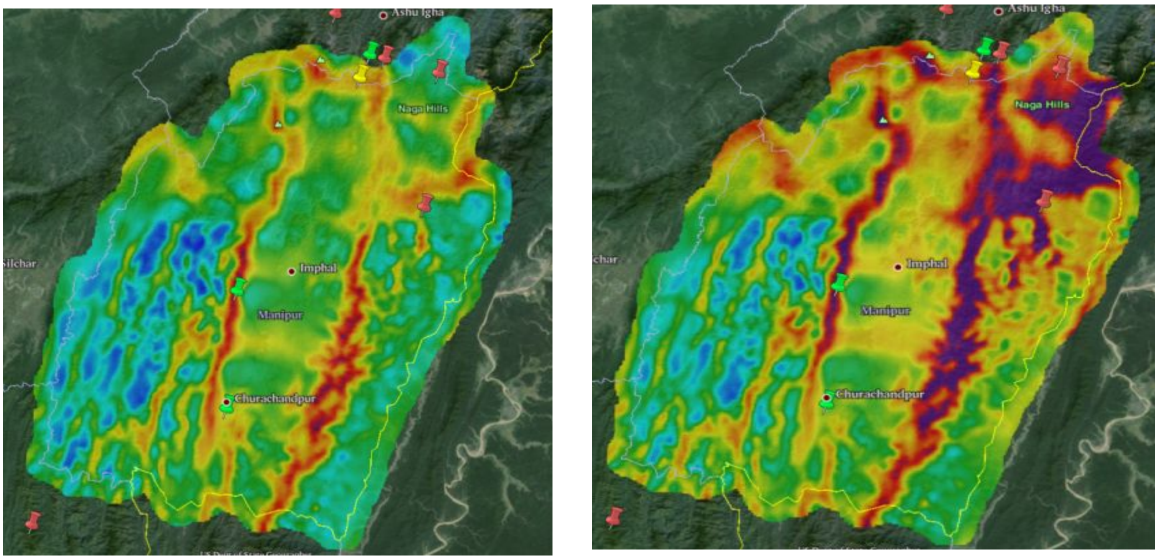


Figure 1: Wind mean field for a selected project for standard FARM (left) and 3D FARM Remodeling (righ0.

Vortex 3D Remodeling ensures that:

- ➔ Consistent correction factors in time and space domain are applied;
- ➔ Avoiding to use Weibull fittings;
- ➔ No need to rely on sectors & bins simplification;
- ➔ Obtained correction factors are time dependent and synchronized with observations;
- ➔ Multiple observation points with different heights can be employed ;
- ➔ Results are long term representative ;
- ➔ Localized spot influence of the point of measurements is mitigated;

Input data

Vortex 3D FARM Remodeled product use the following input:

1. Wind speed and direction hourly time series for one or several locations across the target domain
2. VORTEX time SERIES at 3Km resolution to extend observed data
3. High resolution time series of wind conditions derived from VORTEX FARM product
4. High resolution terrain altimetry and land classification from SRMT (90 m) and ESA GlobCover data bases

Steps

Vortex 3D FARM Remodeling is divided in three steps to prepare all the required input observations, modeled data and to obtain the final corrected wind resources output. The steps are summarized in the following schemes.

STEP 1:
Extension of observations on time using VORTEX REMODELING

Aim: Obtain a long-term represenation of observations consistent with modeled data

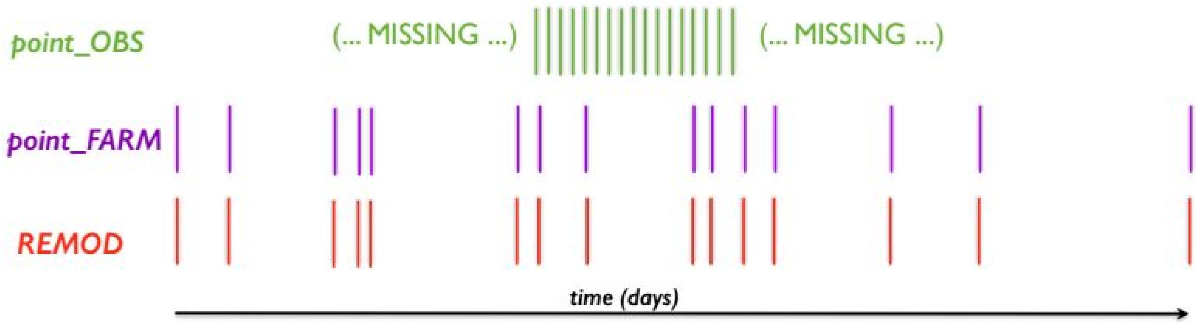
STEP 2:
Times series of modeled data at very high resolution (500m or 100m *) are computed

*** depending on the domain complexity and extension**

STEP 3:
Calculate correction factors for vector components (U-zonal, V-meridional) of wind speed in space (x,y,z) and time using adaptive statistical methods

<u>STEPS 1:</u>

- ➔ The target of the step is to consistently extend observed wind speed and direction data in time to cover all the long-term period covered by the modeled data ;
- ➔ Vortex Remodeling technology is employed to efficiently connect observed and modeled data for the concurrent period and to provide a long-term calibrated times series spanned over the long-term reference period (20 years)



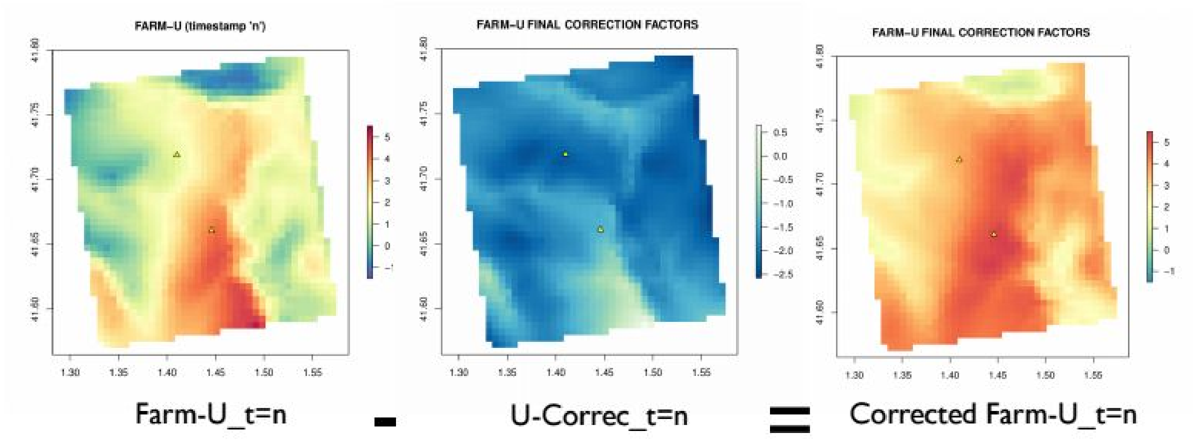
Re-modeling technology is used to extent the observations in order to match the FARMs days.

STEPS 2:

- ➔ High resolution modeled time series of wind conditions for each grid point of the target domain a is obtained from operational VORTEX FARM product
- ➔ Resolution of modeled time series is set to 100 m or 500m depending on the complexity and extension of the target domain

STEPS 3:

- ➔ Times series of zonal and meridional wind components from modeled (step 2) and extended observation (step 1) are employed as input for the final modeling stream in conjunction of terrain descriptive variables;
- ➔ Individual correction for each hourly time steps are obtained and associated to different classes
- ➔ Universal kriging techniques are employed for propagating the correction across the domain
- ➔ Aggregated new wind speed and direction are obtained applying the corrections to the complete high resolution modeled time series



For each wind component and FARM timestamp we obtain a correction factor map that is applied to the original farm in order to adjunt/correct it based on the measures.

Validation

A selection of case studies, representing different degrees of modeling complexity, were selected and analyzed to assess the benefit and gained FARM accuracy after data merging and 3D remodeling.

Assessment of 3D Farms Remodeling improvements have been done for 10 sites, which have each two wind-mast available for a concurrent period of at least 12 months. For each site, a FARM simulation was conducted with standard specifications and a domain large enough to cover both windmast, allowing enough distance to domain boundaries. A cross-validation analysis was conducted using both measurement points.
Improvement results are measured as percentual difference between 3D Remodeling FARM and Standard FARM Mean Errors. An accuracy improvement of 3D Remodeling FARM is therefore associated to higher positive values.

We present in the table 1 results for the cross-validation for mean average speed. The table shows geographic location indicator, distance between wind masts, site complexity, wind mast anemometer and model height above ground, mean error for FARM and FARM 3D Remodeling and differences.

SITE	REGION	Wind Mast Distance [KM]	Terrain Type	HEIGH [m]	FARM Standard Mean Error [m/s]	FARM 3D Remod Mean Error [m/s]	Diff [m/s]
1	Chile	2	Complex dessert	30	1.11	0.61	0.50
2	Chile	2	Complex dessert	30	1.28	0.58	0.70
3	France	4	Flat	60	1.01	0.21	0.80
4	France	4	Flat	60	0.95	0.15	0.80
5	Turkey	11	Complex forest	70	0.63	0.03	0.60
6	Turkey	11	Complex forest	70	1.15	0.65	0.50
7	France	5	Flat	50	0.97	0.17	0.80
8	France	5	Flat	50	1.77	1.47	0.30
9	Canada	8	Complex coastal	80	1.25	0.95	0.30
10	Brasil	3.5	Complex forest	100	0.90	0.70	0.20

Table 1. Results of the improvement assessment validations exercices

Summary

Mesoscale model products can benefit of new methods to spatially propagate information for available site measurements leading to a new generation of consistent site enhanced modeled wind conditions, hence lowering resource uncertainty and increasing project feasibility success.

VORTEX 3D FARM Remodeling offer a effective and validated procedure to automatically integrated users observations in the post-processing modeling stream to reduce wind conditions uncertainty by consistently minimize model bias across the windfarm domain

More information on FARM and other VORTEX developments can be obtained directly from our website or by getting in touch with us:

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Annex: FARM Description

VORTEX FARM product has been developed to support AEP analysis, windfarm layout design and site suitability impact studies facilitating the decision making process at the windfarm pre-construction stage.

FARM product provides the following features:

- Fully selectable areas in size, location and orientation.
- Up to 100 m resolution.
- Any height between 50 and 150 m.
- Unlimited points within the selected area.
- Wind speed histograms with their Weibull fits.
- 16 sectors wind direction rose.
- 50 years extreme wind (Vref) via 30 years Gumbel fit.
- Characteristic turbulence intensity spectra.
- Sector-wise inflow angle and vertical shear.
- Exportable to Google Earth KML, ESRI grid and WAsP WRG files for WindPro, WindFARMer, OpenWind...

VORTEX FARM products has been designed based on the following technical specifications:

A. **Windfarm effective Resolution**:
VORTEX FARM is designed to downscale climate wind conditions up to 100m horizontal with 8 levels in the first 150 m . Downscaling is made in a nesting down procedure where atmospheric flows are refined with enhanced physics options adequate to each scale;

B. **Physics**:
The mesoscale model include a full physics package to describe mechanical and thermal drivers of wind regime turbulence and speed-up effects affecting the flow. Physics and dynamics specification are based on operation VORTEX WRF setup, which benefits of gained experience and cumulated validation exercises and feedback from different VORTEX products users;

C. **Climate representativity**:
Mesoscale model is integrated to span over representative climate period, 20 years backwards from current year ;

D. **Turbulence**:
Mesoscale model is configured to output standard deviation at 10' sampling to effectively derive turbulence intensity. Mesoscale model at final 100m nest is configured to use boundary layer parameterization that takes into account computation of turbulence kinetic energy, allowing a more realistic estimation of turbulence for site assessment.

E. <u>Input data</u>:

Topography data comes from the Shuttle Radar Topography Mission (SRTM) which obtained elevation data on a nearglobal scale to generate the most complete high-resolution digital topographic database of Earth. SRTM consisted of a specially modified radar system that flew onboard the Space Shuttle Endeavour during an 11-day mission in February of 2000. SRTM is an international project spearheaded by the National Geospatial-Intelligence Agency (NGA) and the National Aeronautics and Space Administration (NASA).

Land cover data comes from ESA GlobCover Land Cover1 product derived by an automatic and regionally-tuned classification of a time series of MERIS FR mosaics. Its 22 land cover global classes are defined with the UN Land Cover Classification System (LCCS). Each mosaic product is available in the Hierarchical Data Format-EOS2 (HDF) and is organised on a 5° by 5° tiling without any overlap. The entire Earth is therefore covered by 2592 tiles (72 horizontal tiles x 36 vertical tiles). Only tiles including land cover are processed, which reduces the number of available tiles. The Figure 1 gives the geographical repartition of tiles over the world for the Plate- Carrée projection. The global and regional Globcover Land Cover V2.2 products (Figure 2) are delivered in GeoTIFF format and stored in a zip archived enriched with additional files. The GlobCover products are based on ENVISAT's Medium Resolution Imaging Spectrometer (MERIS) Level 1B data acquired in Full Resolution mode with a spatial resolution of 300 meters. For the generation of the Level 1B data, the raw data acquisitions have been resampled on a path-oriented grid, with pixel values having been calibrated to match the Top Of Atmosphere (TOA) radiance.

Large scale meteorological drivers are prescribed by NCEP latest generation of Reanalysis product: Climate Forecast System (CFS) which spans from 1979 to current month, with a latency of 5 days. The CFS was designed and executed as a global, high resolution, coupled atmosphere-ocean-land surface-sea ice system to provide the best estimate of the state of atmosphere, land and ocean variables. CFS global atmosphere resolution is ~38 km (T382) with 64 levels extending from the surface to 0.26 hPa.

F. <u>Extremes:</u>

As the FARM focus on site suitability, Vref is required. Vref is computed within VORTEX modeling chain by selecting the 30 last years highest wind candidate events at a mesoscale level to launch the downscaling 100m resolution. Standard extreme theory analysis applied based on Gumbel distribution.