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Incorporating Weather Analysis in Performance Assessment

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Introduction

With over 90 GW of worldwide wind capacity up and running, detailed performance data for these wind farms are now rolling in. As owners and financial partners review these results, they are often confronted with actual generation that differs significantly from project pro formas. Several factors affect these variances, with wind variability playing a large part in the equation.

Project stakeholders may be tempted to draw quick conclusions by comparing the observed production with that projected during project planning. However, a detailed understanding of the weather patterns encountered during the performance period is frequently missing from the analysis, which limits the usefulness of the assessment. This approach would be similar to evaluating the performance of a mutual fund without taking into account market fluctuations.

Careful meteorological analysis coupled with comprehensive long-term site or portfolio analysis is essential for setting realistic expectations when assessing production performance. This process yields perspective for evaluating the relative wind resource for a given period and makes it possible to assess other operational factors more accurately. This multi-faceted, operational reassessment approach specifically identifies meteorological patterns and pattern anomalies influencing the wind resource, utilizes meteorological downscaling for generating long time series of wind farm data from quality-controlled actual wind farm data (production or meteorological tower), and incorporates other locally available wind data where possible.

Meteorological Pattern Analysis

A comprehensive analysis of the meteorology for a given performance period provides a physical understanding of factors influencing the available wind resource that cannot be realized from pure statistical analysis for a given site or set of sites. Meteorological pattern analysis involves the identification of jet stream patterns that control the development and propagation of weather systems responsible for driving much of the wind resource in mid- and high latitude regions.

These jet stream locations are often called storm tracks, with “storm” in this case being a pseudonym for an extra-tropical cyclone (i.e., low pressure system). In the summer months, this pattern analysis also extends to examining the seasonal evolution of large persistent pressure systems like the Bermuda High or southwestern United States thermal low.

Requirements. Meteorological pattern analysis requires a few key datasets and capabilities. The first of these involves access to a comprehensive assimilation of three-dimensional atmospheric observations for an area of at least several thousand kilometers. Ideally, the time resolution of this data would be hourly. For the contiguous United States, southern Canada and northern Mexico, the hourly analysis data from the Rapid Update Cycle (RUC) model from the National Centers for Environmental Prediction (NCEP) are well-suited for this task.

The second essential dataset type is one that provides a long record of assimilated three-dimensional tropospheric data for establishing mean upper-level and near-surface conditions for the periods of interest. These mean conditions can be used to find the degree to which an analysis period’s atmospheric state differs from

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climatological expectation. The global reanalysis (RNL) dataset from the National Center for Atmospheric Research (NCAR) and NCEP is appropriate for this task as it provides data at 6-hour intervals dating back to 1948.

Finally, the analyst must be proficient in applying principles of synoptic-dynamic meteorology in developing associations between jet stream patterns, anomalies and tropospheric weather systems. A final capability involves understanding the seasonal climatology of storm tracks and seasonally persistent pressure systems.

Process. The first step in analyzing meteorological patterns is identifying seasonally-dependent mean storm track positions for comparison. With these in mind, animations of the visualized three-dimensional RUC data are then examined to interpret coherent dynamically-connected upper and lower tropospheric patterns for the performance assessment period.

The assessment period could range from one month or one financial quarter to several years. Breaking the data up into individual months for characterization keeps the analysis tractable. Shown in Figure 1 is an example visualization of RUC data that indicates the upper-level storm track, the lower tropospheric wind resource, and surface pressure systems. For illustrative purposes, the capacity factors for a portfolio of 12 proxy wind farms created from 80-m RUC wind speed data are also shown.

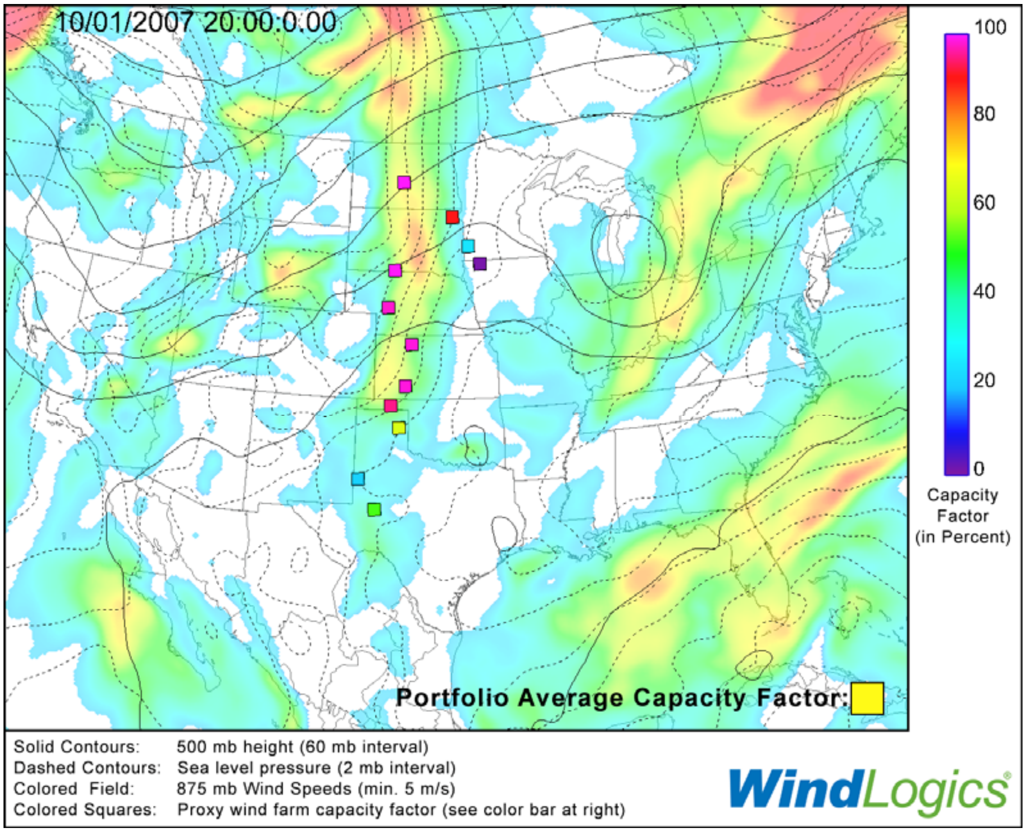

Figure 1. Meteorological analysis for 2000 UTC on 1 October 2007 depicting 500 mb geopotential height, 875 mb wind speed, mean sea level pressure, proxy wind farm capacity factor, and portfolio average capacity factor. The color bar quantifies the capacity factor.

As the monthly RUC data and farm capacity factors are animated, farm/portfolio performance relationships with the meteorological patterns are readily established. This can be a valuable tool for both analyst and wind farm/portfolio operator/owner.

Once the monthly RUC animations are created, the month can be subdivided into dominant jet stream patterns or set of transient patterns. While the jet stream pattern establishes the storm track and provides a valuable qualitative indication of the likely wind resource, not all similar looking patterns have a roughly equivalent wind resource. Each pattern can be further examined to ascertain the number and strength of atmospheric "short waves" which are responsible for cyclones propagating along the jet stream. In much of the mid-latitudes, it is the number and strength of the cyclones (and anti-cyclones) that establishes the pressure gradient that drives the wind resource. In other cases, examination of storm track influences on seasonally persistent and quasi-stationary pressure systems is undertaken. Modifications to these large pressure systems can markedly alter the region-relative surface pressure gradient and associated wind resource.

A valuable technique for ascertaining the degree to which a storm track pattern departs from the assessment period's long-term mean involves using RNL data to develop the climatic mean long-term upper-level pattern using 500 mb analysis as shown in Figure 2. The mean 500 mb pattern for the specific RUC-derived pattern period can then be contrasted with the climatic pattern. This process tests the pattern designations from the RUC analysis, and through anomaly analysis, provides additional information leading to physical explanations for wind resource departures from expectations.

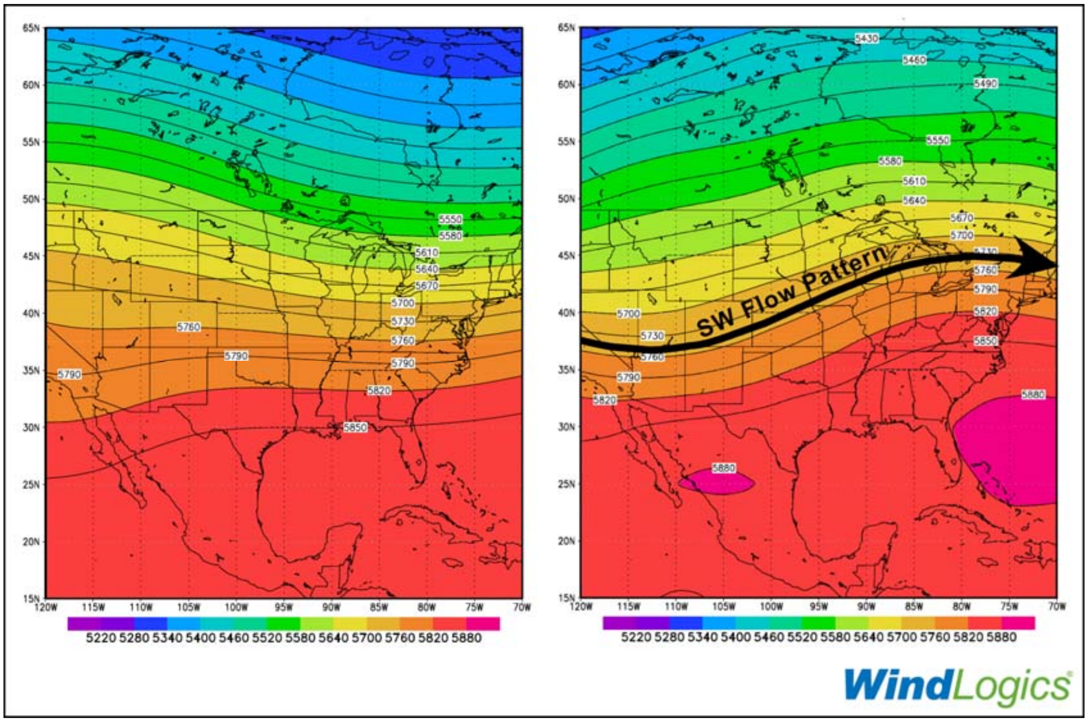

Figure 2. RNL-derived 500 mb geopotential height for long-term mean (left panel) and specific period mean (right panel) for the dominant 2007 pattern. The southwest flow pattern departure of the storm track from climatology can be readily seen.

Upon completion of the storm track pattern analysis, an annotated summary of the dominant or transient jet stream patterns is made that depicts both the track and implications for the wind resource. As shown in Figure 3 (following page), the track summary can provide a tangible vehicle by which to efficiently convey a qualitative understanding of the meteorological drivers of the wind resource. This type of summary information can be presented from a national perspective or specifically annotated for regional assessment.

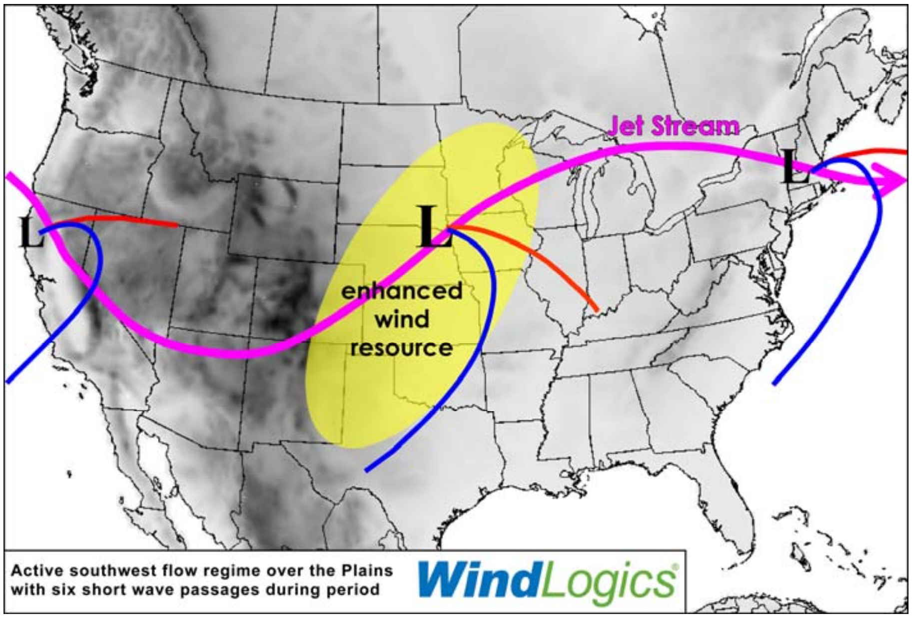

Figure 3. Annotated dominant storm track pattern for October 2007.

Establishing Realistic Wind Resource Long-Term Expectations

Developing realistic expectations for the production of a wind farm or portfolio of wind farms is paramount if operational reassessment is to have any value. The application of meteorological downscaling can be effective in forming production expectations.

Requirements. In this technique a long-term coarse resolution atmospheric dataset is used in conjunction with short duration wind farm production dataset to produce a long-term record of the wind farm production. The NCAR/NCEP RNL data is well-suited for use as the long-term dataset.

Process. To facilitate this process, a computational learning system (CLS) is applied to learn relationships between the datasets in overlapping time periods. Support Vector Machine (SVM) is a powerful type of CLS that applies non-linear regression techniques to develop relationships between datasets. The more training data (i.e., the short-term dataset) that are available, the more robust the SVM-developed relationships. This particular analysis uses the WindLogics patented enhanced measure/correlate/predict (EMCP) methodology [2]. Once the statistical relationships are established, they can be applied to the long-term dataset to generate a long-record wind production dataset.

With EMCP results for a wind farm or portfolio of wind farms guiding the expectations of owners/operators, proper perspective is brought to operational reassessment. An example of EMCP production analysis is shown below for two months in 2007. In this case, a 30-year monthly time series of energy production was generated for a generic 100 MW wind farm on the Great Plains. As one can see from Figure 4, drastic production performance differences exist with respect to the long-term mean for July and October of 2007.

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[2] U.S. Patent No. 7,228,235.

While October production was moderately above normal, consistent with the meteorological pattern analysis shown in the previous section, July 2007 was clearly the lowest performing July in the entire record. Although not shown, meteorological pattern analysis for July clearly demonstrated the physical reasons why the background wind resource was so anomalously weak. Time series such as that shown provide long-term perspective to setting expectations for the assessment period, while additionally affording information on year-to-year variability of the monthly resource.

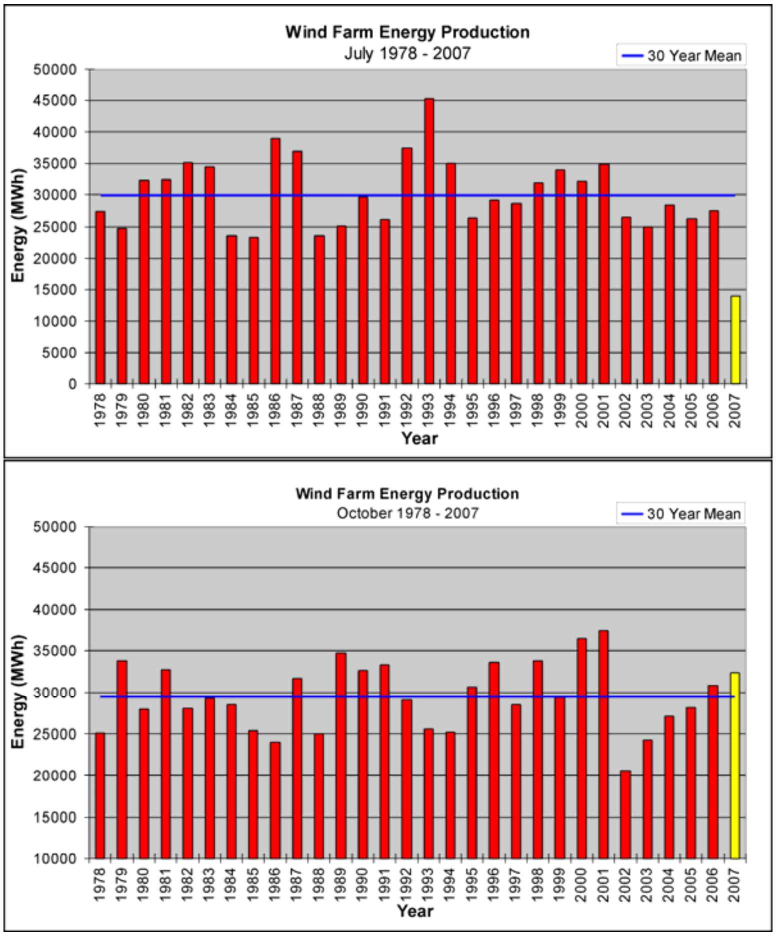

Figure 4. Thirty-year time series of wind farm energy production for July (top panel) and October (bottom panel) from the EMCP process. They yellow bar represents respective July or October actual wind farm production fro 2007.

EMCP output can easily be formulated in different ways to display long-term monthly production expectations and variability is in the box and whiskers format as shown in Figure 5 (following page). In this format, one can readily interpret production expectations for all months and track a given year's wind farm performance against the statistical long-term reference.

Much latitude exists in techniques for examining wind farm or wind portfolio performance. One method worth mention, the regression analysis of farm/portfolio energy production with long-record climate indices, includes aspects of long-term site/portfolio analysis and meteorological pattern analysis on a much larger scale. Indices associated with the El Nino-Southern Oscillation (ENSO) and the Pacific Decadal Oscillation (PDO) can be used; however, other climate indices could also be useful. Potential associations between farm/portfolio performance and atmospheric-ocean climate indices may prove useful for operational assessment, and additionally could provide wind farm/portfolio predictive value.

Integrating Local Data

Analysis of METAR airport weather observations from one to several sites provides a medium-term reference for comparison with both the wind resource implications of the pattern analysis and the inferences drawn from the long-term EMCP analysis. METAR sites used for comparison should be judiciously selected based on the distance from the wind farm and on geographic criteria that ensures that the regional meteorology of the two sites are similar. While some METAR records date back several or more decades, the applicable portion of the METAR record generally extends back to the mid-1990's due to instrument and/or location changes. This record is long enough to provide useful insight on both the departure of the wind resource from this medium-record based expectation and the year-to-year variability in the monthly wind resource.

Pulling it All Together

Armed with information from the comprehensive meteorological pattern analysis, the long-term EMCP wind resource analysis and local/regional METAR analysis, the owner/operator is in a position to both understand the meteorological drivers of the wind resource for a given assessment period and establish the proper expectations for the site/portfolio wind resource.

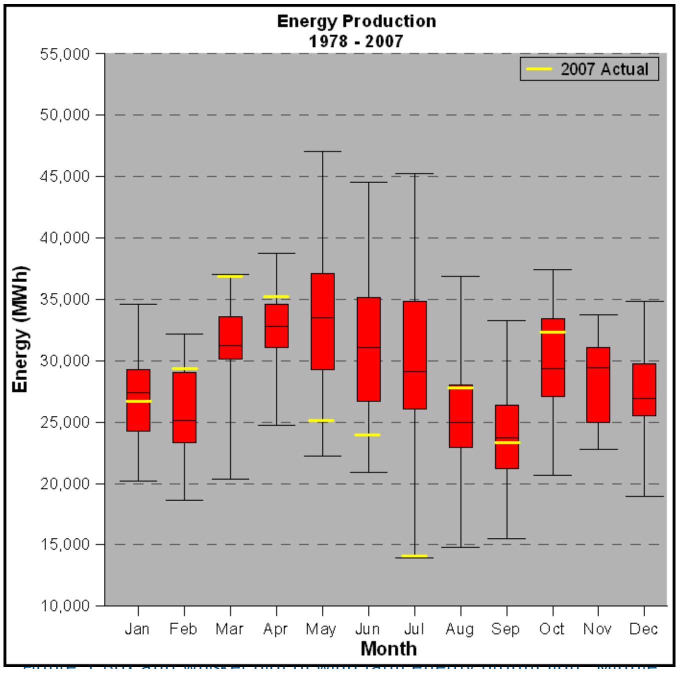

Figure 5. Box and whisker plot of wind farm energy production. Middle 50 % of sample in red box. Upper and lower quartiles shown as whiskers. Median and actual assessment month production values are shown in the black and yellow lines, respectively.

The analysis allows for the creation of an assessment for the wind farm that addresses the degree to which the facility performance can be attributed to departures of the wind resource from the climatic mean during the evaluation period. Further refinements to the assessments can be made to delineate the portion of actual performance anomalies that can be attributable to the variations in the wind resource.

Based largely on the EMCP analysis, moving forward in time from the initial training period, a quantifiable expectation for the assessment period can be compared to actual performance. Since the EMCP analysis for the training period is essentially without bias, the development of a statistically significant bias over time will be due to a departure from the downscaling relationship, which may be indicative of degradations in the farm performance. In this way changes in wind farm performance characteristics will be more easily detected against a backdrop of ever changing weather characteristics. The owner/operator has strong indication that other operational factors contributing to the under-performance may need to be addressed. Analysis from a number of wind farms can be accumulated to provide portfolio perspectives on performance.

In many cases, pre-development wind resource assessments are based on inappropriate or inadequate duration climatological information. The operational reassessment as addressed here, especially the EMCP-based time series wind plant production reconstruction based on real performance, can be utilized as an important update of the pre-built estimate for the farm.

As a result of these efforts, wind farm owners and financiers will be able to move forward with well-informed asset management decisions leading to improved plant output, effective service and warranty, and financial returns for stakeholders. And these improvements will lead to a healthier, more profitable wind industry over all.