Vaisala 3TIER Services COVENANT Process:

Methods Validation Update Report

Methods Change

Numerical Weather Prediction Updates

DATE

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Process Versioning	
Most Recent Validated Version	7.0
Process Updates Version	8.0

Contents

1 PROCESS BACKGROUND

In 2015, Vaisala conducted a significant validation study [1] of its due diligence wind energy assessment methodology. The study was based on 127 years of energy from commercial operations at 30 different wind farms in the United States, Europe, and Asia. Pre-construction assessments were performed with Vaisala's current methodology in a blind retrospective forecast framework. This validation, which demonstrated calibration of methods, was the basis for broad industry acceptance of Vaisala's methods.

Since the December 2015 release of our wind energy assessment validation paper, we have continued to evolve our methodology. Today, Vaisala uses a ground-breaking continuous validation process as a bridge between the need for both innovation and stability. This approach provides an ongoing view into how we are performing, so that we can innovate while at the same time monitor the effects and benefits of each innovation to guard against sudden shifts in accuracy.

In essence, each time a proposed innovation is introduced, a standard test suite is set up, which is designed to completely recreate the energy estimates used in our original validation study. Once the test suite is executed, the results are analyzed to evaluate the corresponding impact on errors and uncertainty. The process effectively tests the innovation against our entire validation database.

If sudden changes in our error or uncertainty values are uncovered during our testing process, either we investigate and address the cause as a result of the new innovation or it is simply not implemented. If the final results show a decreased uncertainty, with no significant change in mean bias error, the result demonstrates that the innovation is a genuine improvement, and it is incorporated into our methodology. By following this approach and showing transparency, we maintain stakeholders' confidence in our process while incrementally benefiting from new innovation and the improved results it delivers to our clients. This methodology evaluation is known as Vaisala's COVENANT process (COntinuous Validation of ENergy AssessmeNT).

Vaisala's most recently validated version of our methods, prior to the currently proposed new version, is Version 7.0. This Version 7.0 showed mean bias error for all wind farm years (where "error" is defined as actual energy produced minus the pre-construction long-term estimate, expressed as a percent) was +0.07%, with a 95% confidence interval of +/- 4.3%. The standard deviation of the 1-year errors was 8.89%, somewhat lower than Vaisala's mean estimated 1-year uncertainty on energy of 10.73%, indicating that Vaisala's estimated uncertainties have been somewhat conservative.

2 OVERVIEW OF CURRENT UPDATES

This section describes the method change(s) that were tested for this iteration of COVENANT.

2.1 Numerical Weather Prediction Updates

Vaisala's standard procedure is to perform a 365-day fine-scale ($500\,m$) Weather Research and Forecasting (WRF) simulation to map out the project-scale wind resource (the "spatial run"), and an approximately 40-year coarser scale ($4.5\,km$) simulation to capture the long-term variability of the wind resource (the "temporal run"). The temporal run is actually an ensemble of runs using three different reanalysis data sets (ERA-I, NCEP/NCAR and MERRA-2) for initial, boundary, and nudging conditions, but a "primary temporal run" is chosen for use in time-series calculations, which best matches on-site observations. Until now, Vaisala's approach has been to use the same reanalysis data set for the spatial run as was selected for the temporal primary run. However, with the reasoning that the most modern and highest resolution reanalysis data set would likely yield the best spatial mapping WRF simulation at project scale (currently MERRA-2), Vaisala is updating its method to always use MERRA-2 for the spatial run.

Vaisala's implementation of the WRF model, and all WRF pre-processing code, was updated from version 3.5.1 to version 3.9.1.1. While no significant changes were made to Vaisala's model configuration choices, each release of WRF generally provides changes, improvements, and bug fixes that can affect the performance of existing model physics schemes.

In addition, two foundational data sets for running WRF were changed. Vaisala migrated from the Shuttle Radar Topography Mission (SRTM) digital elevation data set to the Advanced Land Observing Satellite (ALOS) data set provided by the Japan Aerospace Exploration Agency (JAXA) for model domains located outside of the USA. Vaisala still uses SRTM to fill any gaps or aberrations in the ALOS data. Also, Vaisala migrated US land classification source from National Land Cover Database (NLCD) 2001 to NLCD 2011, and implemented support for the Coordination of Information on the Environment (CORINE) data set in Europe.

3 PROCESS CHANGE ACCEPTANCE

In order to accept a methods change into standard practice, Vaisala has imposed acceptance criteria that must be met within the test. Table 1 describes the tests employed and the results from this test. In the event that a particular test fails, either the method is rejected or further analysis is performed on the projects generating the failed criteria and acceptance is granted with an exception.

The "blue curve" referenced in Table 1 is a normal distribution that matches the mean and standard deviation of the wind farm year percent errors. The "orange curve" referenced in Table 1 is a normal distribution with a mean of 0 and a standard deviation equal to the average model-estimated 1-year uncertainties of all the wind farm years in the validation study.

The "blue curve" and "orange curve" results from the currently proposed method changes can be found in Figure 1 of Section 4.

Category	**Test**	**Result**
Center (or Mean) of Error Distribution	The absolute value of change should be no more than 0.5% from the last mean	Passed
Center (or Mean) of Error Distribution	The mean itself (the center of the histogram or the deviation of the blue vertical line) should be less than +/- 1% from the center	Passed
Uncertainty (or Standard Deviation) of Error Distribution	Change from the prior iteration (i.e. the narrowing or widening of the blue bell curve) should be within 1.9% of the width from the previous iteration	Passed
Uncertainty (or Standard Deviation) of Error Distribution	The difference between the error distribution uncertainty and the average model-estimated uncertainty (i.e. the difference between the widths of the blue and orange bell curves) should be less than 2.0%	Failed
Uncertainty (or Standard Deviation) of Error Distribution	Change from prior iteration of the average model-estimated uncertainty (i.e. the narrowing or widening of the orange bell curve) should be less than +/- 1%	Passed
Change for Individual Projects	Change of the P50 energy estimate for any one project relative to the prior iteration should be less than +/- 2.5%	Failed
Change for Individual Projects	Change in the model-estimated 1-year uncertainty for any one project relative to the prior iteration should be less than +/- 2.5%	Failed

Table 1: Criteria for acceptance. (Colors refer to schema in Figure 1)

3.1 Exceptions To Test Criteria

Discussion regarding criteria failures shown above in Table 1.

3.1.1 Change For Individual Projects - P50 Failure

There were three projects that failed the test that requires all individual project's P50 to vary less than 2.5% when compared to the prior iteration. Vaisala performed an investigation into each of these projects.

For one of the projects that failed, it was determined that the change was caused by a difference in the chosen number of years utilized from the long term climate data sets. As this is not related to the NWP model update, this variance was accepted.

The investigation revealed that the second project failed for reasons caused by a change in NWP modeling. This project is in very complex terrain and there was a real difference in the wind flow patterns that were modeled across the site in the current version when compared to the prior. It is expected that the NWP updates would generate changes, most likely improvements. Indeed, the predictive bias at this site was improved and so this variance was accepted.

For the third project that failed, investigation revealed that there were several reasons. These were a combination of the same reasons as to why the first two mentioned projects failed. First, there was a difference in choice for the number of years that define the long term wind resource. Also, this project did have a complex wind flow model with few observations. The spatial relationship of the project to the single predicting met tower did change, affecting the results. This project's prediction improved and it is assumed the spatial change was an improvement.

Vaisala accepted the results of these changes as caused by either different assumptions not related to this method change or to actual improvements caused by this change and accepts this test in spite of these exceptions.

3.1.2 Change For Individual Projects - Uncertainty Failure

There was one project that failed the change for individual project uncertainty test. For this project, there was an update in inter-annual variability caused by a change in the number of reference years assumed from the long term climate data set. This caused a difference in the 1-year uncertainties beyond the 2.5% threshold. As this change was not related to the NWP methods change, this failure was considered acceptable.

3.1.3 Difference Between Width of Error Distribution

Vaisala's test suite requires the theoretical distribution to be within 2% of the observed distribtion. This criteria is loosely tied to the 95% confidence interval of uncertainty values, as derived in the original validation study [1]. From the original study, the difference between these two curves was 1.9%, barely passing the existing criteria. With several changes to individual projects' long-term reference lengths and inter-annual variability, as discussed in Sections 3.1.1 and 3.1.2, the difference between the theoretical 1-year uncertainty and the actual error distribution width grew to 2.9%.

Since the criteria failure was not caused by the current NWP modeling method change, Vaisala is accepting this test exception. Vaisala will address the differences between the theoretical distribution and actual error distribution widths in an upcoming COVENANT process that evaluates the long-term reference length selection as well as tuning of the uncertainty models.

3.2 Conclusion

On the basis of the above test criteria, including consideration of the test exceptions, Vaisala has accepted this methods change into standard practice and is calling the version incorporating this change as Version 8.0.

4 RESULTS

The resulting histogram after the Numerical Weather Prediction Updates were implemented is shown below. Process versioning has been updated from 7.0 to 8.0.

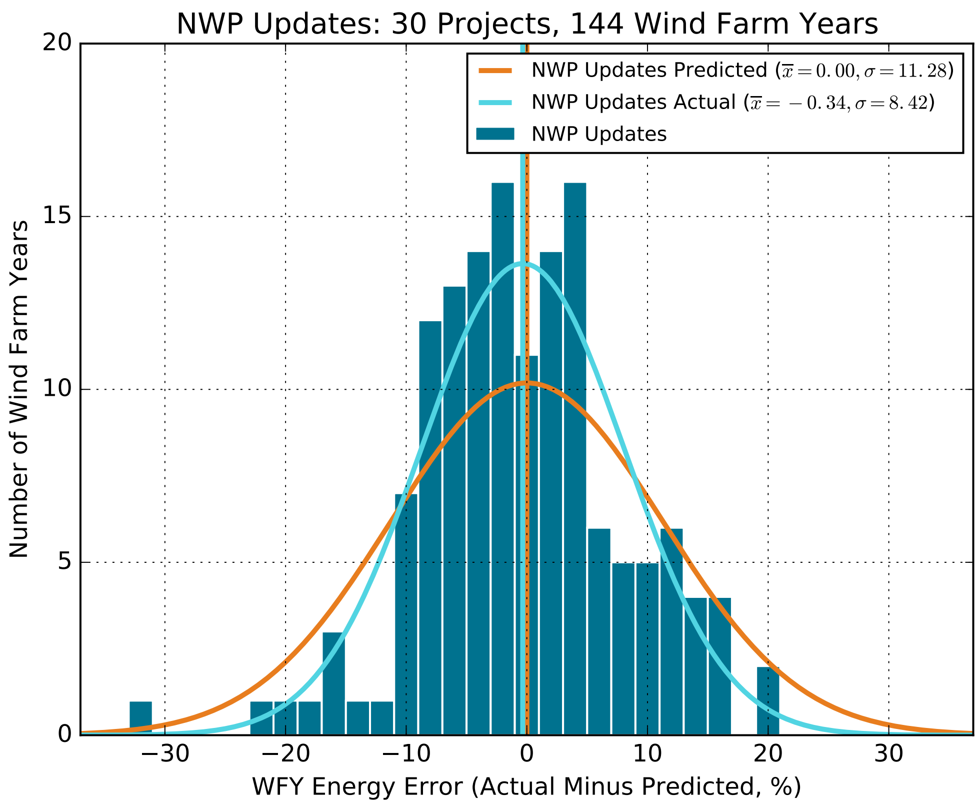

Figure 1: Resulting mean error histogram after Numerical Weather Prediction Updates

	Version 7.0	**Version 8.0**
Mean Bias Error	+0.07%	−0.34%
Actual Standard Deviation	8.89%	8.42%
Model-Estimated Standard Deviation	10.73%	11.28%

Table 2: Changes in mean error and standard deviation of the WFY error distribution histogram from Version 7.0 to Version 8.0.

REFERENCES

[1] M. Stoelinga and M. Hendrickson, "A Validation Study of Vaisala's Wind Energy Assessment Methods," tech. rep., Vaisala, 2015.