Results of Industry & Government Roundtable on Atmospheric Science Research Needs for Renewable Energy

**DOE A2e Mesoscale to Microscale Coupling and
Offshore Wind Atmospheric Coupling Team**

1. Introduction

As the U.S. moves toward very high penetration of renewable energy, the atmospheric sciences are becoming increasingly important. Understanding and predicting renewable fuels (such as wind, solar irradiance, and hydrological resources) and their changes at many scales is important for planning and managing a renewable energy grid. In planning for its atmospheric science research needs for the next 5 to 10 years, the Department of Energy's (DOE) Office of Energy Efficiency and Renewable Energy (EERE) wishes to consider the needs of stakeholders and to connect with other government entities with similar interests. The Mesoscale to Microscale Coupling (MMC) and Offshore Wind Atmospheric Coupling (OWAC) team that emphasizes atmospheric science research for wind energy took the lead in planning and hosting a roundtable discussion held on June 17, 2021. This roundtable discussion was held to promote conversation between government officials and industry representatives to better understand the challenges regarding the atmospheric sciences in large scale deployment of renewable energy and how we need to approach research to address them.

Representatives from various renewable energy commercial sector concerns were invited to present their opinions, as well as representatives from DOE's Office of Science, the National Oceanic and Atmospheric Administration's (NOAA's) Environmental Modeling Center (EMC) , and the National Center for Atmospheric Research (NCAR), which is sponsored by the National Science Foundation. The invitees who were able to participate were:

- Shannon Davis - DOE Wind Energy Technologies Office (WETO)
- Philippe Beaucage - Underwriters Laboratories (UL)
- Julie Pullen – Jupiter Intelligence
- Gary Geernaert – DOE Office of Science
- Greg Oxley – Siemens Gamesa
- Bill Mahoney – NCAR
- Mike Farrar – NOAA National Centers for Environmental Prediction (NCEP)
- Jing Li – General Electric (GE) Global Research
- Javier Sanz Rodrigo – Siemens Gamesa
- Ben Borsch – Duke Energy
- Andreas Knauer – Equinor
- Shreyas Ananthan - Siemens Gamesa

These invited speakers were asked to prepare brief initial statements to introduce a discussion of key aspects of atmospheric science research to facilitate broad deployment of wind energy. This was meant to be a conversation that will inform EERE on prioritization of research needs and opportunities over the next 5 to 10 years. The suggested scope of these statements included atmospheric research needs for resource assessment (including installing wind in lower wind speed environments such as the southeast U.S.), grid integration (including wind power and hybrid plant forecasting), long term outlooks (including impacts from a changing climate), impact of turbulence and hydrometeors on turbine performance, special issues related to deploying offshore wind (including ocean-wave-atmosphere interactions), and other aspects of the environment that are important for wind plant optimization and operation. Specifically, the following questions were posed for guidance:

1. What are the most critical shortfalls in our capabilities to model, predict, and understand the evolution of the atmosphere (from turbulence to climate scales) that are likely to impact deployment of a 100% renewable electrical grid?
2. Given the likely 5-6 times expansion of land-based wind in support of the President's 2035 goal, what are the additional research needs to address deployment in land-based systems, considering issues such as tall towers for low winds and challenges of complex terrain?
3. What improvements are needed in advanced instrumentation, observational infrastructure, and integration of modeling and observations to improve wind energy power prediction forecasting?
4. How can the large DOE computing resources and expertise enable transformative research for renewable energy?
5. How can we best leverage Big Data applications, including machine learning for renewable energy and climate needs?
6. What capabilities are needed in a new generation of wind simulation and prediction tools and what will be the role of AI in all relevant scales to improve computational costs and accuracy?
7. If you had additional funds for research in atmospheric/oceanic science for renewable energy, how would you direct its use to go above and beyond existing research investments?
8. How should environmental justice concerns impact/prioritize the atmospheric R&D research portfolio investment in wind energy?
9. How do you imagine the various roles and connections between government offices in atmospheric research should evolve to achieve the current goals for renewable electricity and climate change mitigation?

Shannon Davis, Atmospheric Science Technology Manager in the Wind Energy Technology Office of EERE, led off by framing the conversation in terms of DOE's wind energy and climate goals. The White House goals are to have a carbon pollution-free power sector by 2035 and a net zero emissions economy by no later than 2050. These goals lead to wind energy goals to increase land-based wind deployment by a factor of five by 2035 and to deploy 30 GW offshore by 2030. To accomplish these goals implies that land-based deployment will include tall towers in lower wind resource areas and in complex terrain, and offshore deployment will occur in both the shallow Atlantic waters and the deeper waters of the Pacific. Deployment must be environmentally mindful. Atmospheric research must broaden scales to encompass climate scales to microscale. Partnerships between agencies and industry are needed to advance the science and technologies behind wind energy development. Thus emerges the central, strategic role for the atmospheric sciences. Wind plant developers tell us that uncertainty in the resource costs millions of dollars. Renewables are becoming a strategic national resource. Therefore, the atmospheric sciences are foundational and must be understood and predicted to the same degree as our other strategic fossil and nuclear energy reserves.

With this framing, the other invited speakers each expressed their point of view for critical research in their opening statements, then participated in a moderated conversation. The results of this discussion are synthesized below.

2. Roundtable Discussion - A Synthesis

The invited speakers each talked to different points that are important to their organizations or themselves. Many excellent points of view were expressed. Here we summarize those comments in terms of the questions posed above.

2.1 Critical Challenges

Addressing the most critical shortfalls in our capabilities to model, predict, and understand the evolution of the atmosphere (from turbulence to climate scales) that are likely to impact deployment of a 100% renewable electrical grid will require increased collaboration between government research and industry. Researchers are challenged with bridging the scales of mesoscale to microscale while integrating climate forecasts, as well as improving the physics and performance of atmospheric models, specifically the atmospheric boundary layer and improving predictability at a seasonal scale and beyond. Industry is tasked with considering what is affordable for clients as well as what conditions are actually predictable. In the context of a shifting environment due to climate change, concerns exist surrounding the viability and longevity of the resources currently being built, as well as a concern for how the current climate assumptions, and the uncertainty attached, direct decision-making. Having more abundant, accurate data is a consistent concern, particularly in areas of low wind resources, offshore, and at the upper levels. These datasets, along with model training frameworks from research to industry, deserve attention. It is suggested that what is provided to industry holds a dual focus: that traditional numeric simulation should be considered in tandem with accurate datasets and comprehensive training frameworks. Balancing, as well as defining, the roles and responsibilities of the private and government sectors also deserves consideration to provide clarity and prevent overlap.

2.3 Research Needed for Land-Based Wind Deployment

Given the likely expansion of 5 to 6 times of land-based wind in support of the President's 2035 goal, additional research is needed to aid deployment of land-based systems in areas of low winds (requiring tall towers) and in complex terrain. Requirements include probabilistic forecasts. These are crucial for understanding the lower and upper bounds of production. There is also the need to improve model performance in complex terrain and during complex atmospheric conditions. Observation data is needed from areas of low wind and complex terrain to support these modeling efforts.

A better understanding of wake impacts is required, not simply within a single farm, but also from multiple nearby farms that impact each other. Improved understanding of the wake effect is necessary, particularly as turbine blades increase in size, as the length scales over which wake effects are important are typically found to scale with rotor diameter.

Turbine lifespan is another important consideration as well as anticipating turbine design in the coming decades. A better understanding of the changing climate at a local scale is needed. While on average the global temperature is rising, climate at a finer scale is shifting differently depending on location. Are the deviations from climatology at these scales temporary, or are they a fundamental shift in the climate? The answers to this question inform our knowledge and understanding of how the current climate assumptions feed into predictions five to ten years from now, and what is and is not predictable. The accessibility of the datasets required to address these questions are somewhat politicized. Attention should be given to balancing the private and government sector, as well as to addressing the role of for-profit data.

2.3 Advanced Instrumentation and Observations

Increased remote sensing capabilities for more observations, specifically at higher levels, is a necessary improvement in advanced instrumentation and observational infrastructure. Ideally, there would be more highly instrumented testbeds. More observations in general are needed, particularly off-shore and in locations with lower winds. The data currently available and generated by these advancements would ideally be shared openly in an organized, concise platform. With this in mind, possible contributions from, as well as impacts on, the private sector should be taken into consideration. Additionally, it is important to match the observations with load, as assuring that observations are available at the times of the highest load is critical.

2.4 Leveraging DOE's Computing Resources

The DOE's large computing resources and expertise can support the high penetration of wind energy by enabling continued innovation in developing and using atmospheric models of various kinds. Specifically, ensemble models could be used in tandem with artificial intelligence to create probabilistic predictions, which are crucial to planning. Computing resources are needed for the development of very high spatio-temporal models, as well as physical models that consider complex terrain and dynamic atmospheric conditions.

Continued evaluation and open benchmarking of current models (both physical and data-grounded) are necessary to assess models' limitations and identify areas in need of improvement. More understanding is needed of the capabilities in the arena of machine learning, particularly with respect to how and why resulting predictions are made. This is necessary for model improvement and for communicating results.

2.5 Leveraging Big Data and Machine Learning

Big Data applications, including machine learning, for renewable energy and climate needs should be used to blend results from multiple physical models for the development of critical probabilistic forecasts. It is important that the resulting forecasts are comprehensive. Machine learning should also be used to reduce the cost and improve the usability of high resolution physical models. Big Data applications could also be used to maintain shared benchmark case datasets.

2.6 High Fidelity Microscale Predictive Tools

There is a need for a new generation of high-fidelity microscale prediction tools that are coupled to the larger scales and leverage AI to improve fidelity and accuracy. Such tools would help provide a better understanding of wake and shear effects, as well as the impact of turbine positioning and farm layout on overall wind power. Turbine positioning and wake/sheer effects can have a drastic impact on the farm performance; thus a better understanding of these effects is critical. In concert with observational data that consider the increasing height of turbines, High-fidelity prediction tools would provide insight into the increasingly complex effects of taller turbines and larger blades at the microscale and would help to inform future turbine design.

2.7 Using Research Funds Well

In the context of modeling, additional funds for research in atmospheric science for renewable energy would best be used to understand uncertainty; improve mesoscale to microscale coupling; and to simplify costly, complicated models to make them more accessible to industry. Funds should be used to develop solutions for balancing offshore and onshore wind and power with load; increasing observations in space and time, especially offshore; as well as investigating the integration of wind energy with other renewables and energy storage.

2.8 Addressing Environmental Justice

Several of the initiatives outlined above intersect with concerns of environmental justice. The atmospheric R&D portfolio investment in wind energy should consider vulnerability to location-specific disturbance events and an understanding of how indicative fluctuations in current climate are of longer-term climate change. Datasets, benchmarking results, and details of the science and development of tools are needed, along with access to the models themselves, and all must be made readily available and transparent. A focus on an equitable transition to renewable resources also includes building community with a diverse set of contributors.

2.9 Roles of Government and Industry

The various roles and connections between government offices should evolve in atmospheric research to achieve a fully integrated renewable electricity grid through the promotion and development of open benchmarking. Accessible, reliable, and comprehensive observational and simulated datasets, as well as consistent collaboration and communication between research and industry, are necessary for the progress articulated in the administration's goals.

3. Summary

We have heard clearly from industry that uncertainty around atmospheric flow has major real-world costs. The need for better, broader observational datasets and benchmarking is clear. In particular, data describing low wind and offshore conditions are required for developing the wind resource in those arenas. For the sake of model development, transparency, and collaboration, these datasets must be readily available.

More synergy between industry and government-funded research is needed in general. Increased interaction would undoubtedly improve communication and maintain a collective consensus regarding which research initiatives will be most impactful for utilities. LES and mesoscale models are complicated to develop, test, and validate, in addition to being costly to run, which is not ideal for operational usage. Room certainly exists for AI/ML to reduce the cost and complexity of the models.

Further research into probabilistic forecasting will also be critical for load balancing and grid reliability. A combination of additional reliable data and benchmarks along with a synthesis of models would be advantageous. An understanding of how conditions are changing with respect to climate will help determine what atmospheric conditions are predictable, in addition to informing future needs in infrastructure and turbine design. Concurrently, it is important to keep the needs of the private sector at the forefront of planning for future research if that research is to be actionable.

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