Lessons Learned From the Planning of Recent Wind Energy Technologies Office Field Campaigns

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1 National Renewable Energy Laboratory
2 Sandia National Laboratories
3 Pacific Northwest National Laboratory
4 University of Wyoming

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August 2024

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List of Acronyms

AWAKEN	American WAKE experimeNt
CRADA	cooperative research and development agreement
DOE	U.S. Department of Energy
FAA	Federal Aviation Administration
FOA	Funding Opportunity Announcement
FTP	file transfer protocol
NDA	nondisclosure agreement
NEPA	National Environmental Policy Act
NOAA	National Oceanic and Atmospheric Administration
RAAW	Rotor Aerodynamics, Aeroelastics, and Wake
SME	subject matter expert
WETO	Wind Energy Technologies Office
WFIP3	Third Wind Forecast Improvement Project

Executive Summary

The U.S. Department of Energy's Wind Energy Technologies Office has funded several wind-energy-focused field campaigns in recent years. Although essential to advancing our understanding of the interactions between the atmosphere and wind turbines, the planning of those campaigns has presented several challenges to the institutions involved in these efforts.

In this report, the authors focus on the planning phases and lessons learned from the recent American WAKE experimeNt (AWAKEN; Moriarty et al. 2020, forthcoming), Rotor Aerodynamics, Aeroelastics, and Wake (RAAW), and Third Wind Forecast Improvement Project (WFIP3) field campaigns. We cover several aspects and propose a methodological pipeline that should be followed when future similar endeavors are planned.

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1 Introduction

In the realm of wind energy and atmospheric science, the planning and execution of field campaigns are essential yet challenging tasks. Over the past decade, several campaigns have been funded by the U.S. Department of Energy's (DOE's) Wind Energy Technologies Office (WETO) to offer insights into the complex interactions between renewable energy sources and atmospheric dynamics. Not only have the scientific successes of the recent American WAKE experimeNt (AWAKEN), Rotor Aerodynamics, Aeroelastics, and Wake (RAAW) project, and Third Wind Forecast Improvement Project (WFIP3) served as catalysts for groundbreaking research, several key lessons have also been learned from the planning of those large projects, therefore underscoring the importance of meticulous planning, project management, and collaboration for successful field campaigns.

This report serves as a comprehensive reflection on best practices for planning field campaigns within the domain of wind energy and atmospheric science. By analyzing the unique aspects of WETO-funded initiatives, the authors aim to distill key insights that can inform future projects and enhance the efficacy of field campaign planning. At the heart of the considerations described in this report lies two of the most distinctive aspects of WETO-funded campaigns—a robust emphasis on data collection for model validation and a strategic alignment with industry and academic partners. However, we also include a variety of other practical considerations—ranging from project-funding mechanisms to team compositions and scientific goal identification—to show how they all shape the trajectory of a field campaign.

2 Project-Funding Mechanism

One of the crucial initial decision points for WETO lies in determining the project type that will lead to the field campaign, as this choice sets the approach for project leadership, funding, and organization. Drawing from the wealth of experience gained through more than 10 years of WETO field campaigns, two predominant models emerge: government laboratory-led initiatives and those steered by nonlaboratory entities, such as universities, industry partners, or other research institutions. The latter often materialize through Funding Opportunity Announcements (FOAs), which entail a competitive bidding and subcontracting process, with laboratory support. FOAs can be associated with cost-share initiatives, where partners provide part of the project funding. Each approach has a complex set of advantages and disadvantages that should be carefully considered before funding allocation. For example, laboratory-led projects allow for flexibility in scope and budget during execution, as they are not constrained by timelines dictated under FOA contracts. Conversely, FOA-driven initiatives may have fewer regulatory constraints than laboratories associated with planning and construction contracts often required for field campaigns. Often the advantages and disadvantages of the funding mechanism approach are dictated by the lead project entity and the required scope of work, and some effort should be made to optimize the chosen approach for the work required.

Regardless of the U.S.-funding mechanism, DOE and laboratories should seek domestic and international partners to leverage local or foreign investments toward shared scientific objectives. Because the scope of field campaigns is often constrained due to funding limitations, aligning with other agencies or countries pursuing similar observations can offer opportunities for joint funding and yield mutually advantageous outcomes. Such coordination not only amplifies the impact of research efforts but also promotes collaboration and knowledge exchange on a global scale. Because funding decisions are often made years before field campaigns occur, one of the first tasks for any new project should be to encourage other funding entities to join in the larger project scope.

3 Team Composition and Roles

Contributions from many individuals are needed to ensure a successful campaign, especially when multiple institutions are involved in the overall effort. It is helpful to provide clear roles and associated expectations to participants and to establish lines of communication within and between institutional teams and across different constituencies within the project (i.e., between instrument experts and field logistics team members, or between modelers and observationalists), as detailed in Table 1. We note that a single individual may play multiple roles within the same project.

Table 1. Recommended Composition and Roles of Teams Responsible for Planning and Managing a Field Campaign

Category	Role	Responsibilities
Project Leadership	Overall principal investigator (often called “uber PI”)	Leading and directing the overall project. Ensuring alignment with overall project objectives. Coordinating activity among labs. Serving as the primary interface with DOE.
	Principal investigator for each participating institution	Representing each institution's interests. Coordinating the institution's contributions to the project. Contributing to the definition of the project scope. Managing the institution's partnerships and contracts.
Project Management	Project managers	Planning, organizing, and overseeing project activities. Monitoring progress and ensuring deadlines are met. Ensuring the execution of partnership agreements.
	Finance	Handling financial transactions and budgeting. Ensuring financial compliance.
	Business support	Providing administrative support. Facilitating communication and coordination within the team.
	Partnership manager	Tasked with monitoring progress and coordinating activities related to the instantiation, execution, and close out of agreements with external partners.
Compliance and Legal	Environment, Safety, Health and Quality representatives	Providing training and certification in environmental, safety, health, and quality requirements.
	Legal team	Handling contracting and agreements (cooperative research and development agreements, nondisclosure agreements, etc.) with external partners, vendors, and subcontractors. Ensuring legal compliance.
	Land leases and real estate	Managing land leases and real estate matters. Ensuring compliance with regulations.

Category	Role	Responsibilities
	Contracting	Managing contracts with vendors and subcontractors. Ensuring quality and compliance with contract terms.
	Construction	Overseeing construction activities. Ensuring construction meets project requirements.
	National Environmental Policy Act (NEPA) review	Conducting environmental impact assessments. Ensuring compliance with NEPA regulations.
	Federal Aviation Administration (FAA) compliance review	Ensuring all planned field activities are compliant with FAA regulations.
Scientific and Technical Expertise	Atmospheric scientists	Providing expertise in atmospheric science and meteorology.
	Wind engineers	Providing expertise in wind turbine and wind plant design and operation.
	Instrumentation and measurement team	Providing expertise in scientific instruments used in the project. Overseeing instrument operation and ensuring data quality.
	Simulation team	Conducting simulations to support project goals. Defining simulation parameters and methodologies.
	Data scientists	Analyzing, processing, and performing quality control for large volumes of measurement and simulation data.
Data Management	Data team	Managing data archiving, storage, and access. Ensuring data quality and documentation.
Field Team and Technicians	Electrical experts	Providing expertise in electrical systems and components.
	Telecommunications experts	Providing expertise in telecommunications systems.
	Engineering design experts	Providing expertise in engineering design relevant to the project.
	Deployment and maintenance experts	Overseeing deployment and maintenance of project equipment. Ensuring equipment is operational and safe.
Communications and Public Relations	Communications	Developing and implementing communication strategies and promotional material. Managing project communications and public relations.
	Graphic specialist	Developing special graphical materials (e.g., logo, sketches for proposals and publications)
	Project review	Reviewing project progress and outcomes.

Category	Role	Responsibilities
Advisory Roles	DOE/WETO managers	Providing guidance and alignment with DOE priorities. Ensuring that project goals align with administrative priorities.
	Industry technology area experts	Providing expertise in specific technology areas relevant to the project.
	Scientific advisory panel	Meaningfully commenting on the scope and trajectory of the project at a high level.
Local Support	Site managers	Serving as the primary contacts for project activities at specific sites.
	Site technicians	Providing technical support at project sites.
	Safety officers	Ensuring safety compliance at project sites.
	Shipping/receiving	Managing the shipping and receiving of project equipment and materials.

4 Science Goal Identification

When identifying and prioritizing science goals for wind energy research, it is recommended to recognize that the scientific priorities and timelines of internal researchers from DOE laboratories, academic partners, researchers from other laboratories, and external stakeholders may diverge. To best reconcile and harmonize these diverse interests, it is helpful to host large-group brainstorming sessions involving as many subject matter experts (SMEs) and potential project partners as possible, creating an environment conducive to collaboration. Expert elicitation is critical to ensuring that science goals address industry needs, cover known gaps in scientific understanding, and remain aligned with administrative priorities. The science goals will then inform the search for suitable sites.

To ensure that the final scientific objectives cover as broad a range of interests as possible, it is recommended to make concerted efforts to integrate input from modeling experts and from the experimental community. These efforts typically involve translating model validation needs into well-defined physical phenomena and measurable quantities, thereby integrating the underlying physics into the consideration of science goals and the validation status of a broad range of numerical tools. For determining and prioritizing technical goals, phenomena identification and ranking tables can be helpful (Maniaci et al., 2020, 2024). By refining input from a diverse group of stakeholders, including current and past collaborators, academic institutions, industry partners, and national laboratories, the prioritization of science goals can better reflect the collective expertise and insights of the wind energy community.

Scoping large projects must also include determining the minimum duration of observations required to effectively address each science goal. This step is particularly important because of potential shifts in campaign timelines, necessitating a thorough evaluation to determine the continued feasibility of achieving all identified goals within the available time frame. For projects driven by DOE development priorities or expert elicitation from industry partners, scientific objectives for large-scale field studies are selected to encompass a valuable cross section of incompletely understood physical processes, social and environmental constraints, model validation needs, long-term industry needs, and administrative priorities.

The process of refining the set of scientific objectives can vary based on the scope and focus of each project. For instance, the AWAKEN project targeted a large-scale field campaign, requiring multiple international partners across various sectors, and focused on a wide variety of science goals. Given this nature, the planning of AWAKEN convened a large, open-format meeting facilitated by the National Renewable Energy Laboratory, bringing together a community of wind energy experts. Through presentations, breakout sessions, and collaborative discussions, the national-laboratory-researcher-led team systematically categorized research priorities and open scientific questions into a set of testable hypotheses and topic areas that included a wide range of specific questions offered by the community.

Conversely, the RAAW campaign was a more concentrated scientific effort, with focus on a single turbine, and a limited number of pre-defined project partners. In this case, the research group engaged a smaller group of experts to refine goals focused specifically on aerodynamic and aeroelastic interactions from a set of known research needs. While the science goals and research areas for RAAW initially came out of phenomena identification and ranking tables, the targets for the program were focused through discussions within the team of national laboratory researchers. We then refined the list of science questions based on available instrumentation, model validation needs, and shared interests with industry partners. This targeted approach allowed for a more streamlined assessment of feasibility, budget considerations, and other pertinent factors, enabling efficient prioritization of scientific objectives.

5 Partnerships and Agreements

Partnerships generally have the longest lead time and are the most critical part of any project where non-DOE assets are central to the field campaign; however, partnerships are also critical for gaining access to utility-scale systems and ensuring the relevance of the project goals.

5.1 Assigning a Partnership Manager

It is strongly recommended that a project management specialist is assigned to the project during the planning stage to assist throughout the process of creation of partnerships (ranging from land use agreements to non-disclosure agreements to university subcontracts). They should be able to pursue partnerships regularly and see partnership-related challenges through to completion. Their responsibilities might include:

- Learning and staying updated on the roles and interests of each partner
- Developing template agreements and obtaining legal approval in parallel as technical teams agree on scope
- Setting up and leading meetings across institutions
- Assisting in negotiations of terms, anticipating roadblocks, and proposing solutions
- Serving as a liaison between the technical team, procurement team, and legal team when needed
- Understanding the required process and timeline to partnership establishment.

This decoupling of agreement negotiation and technical discussion is beneficial economically, as it greatly reduces the number of hours that the technical team would otherwise spend trying to set up agreements and understand procedures. It is also beneficial diplomatically, as it reduces the risk of disputes between the technical teams when firm deadlines need to be set and agreement terms must be discussed.

5.2 Setting Up Agreements

The following are best practices for setting up agreements within the DOE laboratory system:

- It is never too early to start, especially when international parties are involved. Assume everything will take 6–12 months longer than you think.
- The presence of international parties in an agreement can delay DOE approvals by another 6 months due to the additional approvals required.
- Different national labs have different approval processes, especially regarding international partnerships. Find out how long approvals will take at the local DOE office. This should be added to the time required by DOE to approve the international partnership.
- The greater the number of parties, the longer the approval process will take. This applies to the initial establishment of the agreement and any modifications that might follow. Include only those partners absolutely needed for the success of the project within a given agreement.
- Project partnership templates should be outlined for each of the national labs well ahead of any field campaign to speed up the contracting phase. The templates could include

acceptable terms for liability, ownership of data, and confidentiality. A common approach across all labs is encouraged ahead of time to speed up the execution process.

- Consider arranging early on backup plans in case the execution of an agreement takes longer than anticipated (e.g., temporary power solutions if agreements with local utility companies are slow to be executed).

5.3 Cooperative Research and Development Agreement

Cooperative research and development agreements (CRADAs) are used when a partnership is needed to collaborate and share the results of a jointly conducted research and development project. First, we recommend working with the technology transfer office of the lead laboratory to determine if a CRADA is required. Be mindful of how long it might take to execute a CRADA—it will take much longer than a nondisclosure agreement (NDA). It is recommended to designate the CRADA execution as a milestone in annual operating plans to add urgency and importance to its timely completion.

When writing out the scope of work for the technical teams, assign clear responsibilities and deliverables. It is recommended to determine which CRADA parties will be responsible for each task and subtask, when the completion date is (shown in a Gantt chart), and what constitutes completion of the CRADA. Ensure that all CRADA parties have specific responsibilities in the work statement so that all parties are equally invested in advancing the work. Be realistic with the scope, deliverables, and timeline. At the end of the project, it will be necessary to demonstrate the completion of each task and subtask in a written final report.

If some aspects of the project scope remain uncertain or unknown, move ahead without them. In other words, finalize the first version of the CRADA with the information available for the sake of getting it executed in time. When things change, the CRADA can be modified accordingly. This includes, for example, the addition or removal of instrumentation or changes in the scope of work. Adding assets to an existing CRADA is easier than modifying the scope of work, but both are possible.

Once the CRADA is executed, meet with the technical team to designate what will be marked as CRADA-protected information or proprietary information and what does not need to be marked. Apply markings as data are produced. This can easily be done by saving the data into separate folders marked as CRADA-protected information, proprietary information, or public. It is much easier to do this at the beginning of the project than to sort and back-mark all data after they have accumulated.

5.4 Nondisclosure Agreement

Nondisclosure agreements (NDAs) are used to protect specific proprietary information and protect against public disclosure. Always favor NDAs over CRADAs when possible, as the former are much simpler to implement. NDAs are also often needed when parties outside the agreement want to be involved in a project defined by a CRADA. Note that NDAs can become complicated and require substantially more time if three or more parties are involved. Also, execution times of at least 6 months are not uncommon with international partners; shorter durations may be possible with domestic-only agreements between a few partners.

5.5 Subcontracts

Subcontracts are used to procure external resources or expertise needed when the work cannot be performed in-house. Be as specific and detailed as possible when drafting work orders or subcontracts for specific activities. Anticipate risks to timely completion of the work, to the work scope, and to the cost of the activity. It is recommended to perform a risk analysis that identifies the risk classification (cost, delay, scope), probability (low, medium, high), and response (accept, avoid, mitigate). Risks and responses should be discussed and agreed upon with the contracting party.

A subcontract can be established using a request for proposal, a competitive subcontract with preferred suppliers, or a sole-source subcontract. Sole-source subcontracts substantially reduce the time required to execute a subcontract and the risk involved. As an example, if interested in procuring an instrument that the lab has already obtained, a sole-source subcontract can be used. A sole-source scenario is also possible if the subcontract is strategic (e.g., when looking for a buoy contractor) and can be included within the lab annual operating plan.

Subcontracts can also be established with universities. University requests for proposals can get cumbersome, and a specific rating methodology needs to be devised to ensure impartiality. The specific rating would highly depend on what is being requested from the university (e.g., instrument support vs. analysis support). Laboratories need to be aware of their policies for sharing budget proposals with other partners if the partners are going to be included in the evaluation process. Additionally, for university contracts, be aware of the contract process once a university subcontractor is chosen. The process can be surprisingly lengthy (more than 3 months) in the contracting phase, both on the university and the laboratory side; however, it can be sped up if a contract between the university and laboratory has recently been executed. Joint appointments of university faculty with national laboratories can reduce the complexity of university contracts. Also, be aware of the safety documentation and planning needed if universities are conducting field work, which can extend the contracting phase.

Note that for construction contracts, in particular, there are safety and process requirements that are not typically required for non-DOE contracts, and the contractor may not be equipped to respond to such requirements. Finding a contractor that has a profile in the System for Award Management registry means that they have some experience with government processes, which may speed up final execution.

5.5.1 Tips on Efficient Data Management Within Partnerships

When there is potential for sharing proprietary data, set up clear expectations on publications: for conference presentations, journal publications, and any other public appearance of the data, determine what the expectation of each party is regarding their participation in the process, the time they will need for review and approval, and who will be responsible for the approval.

6 Project Budget Planning

Field campaigns have a high level of uncertainty with regards to budget, schedule, and scope, as unexpected costs and challenges often arise. Applying project management best practices can help in discovering and addressing risks before they become significant issues.

During project planning, it is important to quantify risks, and a risk assessment should be conducted using a tool such as the risk assessment matrix (Figure 1) to understand the impact of each risk and the likelihood of occurrence. As shown in Figure 1, for risks that are likely or probable to occur and have a moderate or severe impact, a risk response plan should be developed.

		Impact		
Likelihood		Minor 1	Moderate 2	Severe 3
	Unlikely 1	Low	Low	Medium
	Likely 2	Low	Medium	High
	Probable 3	Low	Medium	High

Figure 1. Risk assessment matrix

For example, instrumentation failure can be identified as a likely risk that could have a severe impact on the project. Because this risk falls into the "high" category, it is important to understand the cost implications by calculating the expected monetary value, which is equal to the probability times the impact. For example, if there is a 50% likelihood that an instrument will unexpectedly fail, and the cost of repair is $10,000, then the expected monetary value is calculated as 0.50 x $10,000 = $5,000.

Once the potential cost impacts are assessed, it is recommended to evaluate whether to include these costs in the project budget as contingency reserves. Calculating the expected monetary value of known risks can help in understanding and planning for cost overruns instead of course correcting during project execution by descoping, which can be a major project challenge.

In addition to risk management, it is important to record and review lessons learned from past projects and communicate with those who have previously conducted field campaigns to better understand the challenges faced and the strategies that were successful in improving the situation.

Another consideration is resource planning. Identify opportunities where more senior staff can delegate tasks to junior staff and balance as needed. Provide a clear schedule to the project team that highlights the critical path; tasks that are necessary for project completion should be prioritized.

As an NREL best practice, the principal investigator and project manager review financial reports on a monthly basis but meet more often if the project is at risk of overspending. Additionally, the principal investigator and project manager meet with the lab program manager monthly to discuss the progress of the project, focusing on scope, schedule, and budget. When financial risks are present, there should be direct communication from the financial analyst to the principal investigator and project manager if the project is projected to go over budget in the next 90 days. This window allows the principal investigator and project manager to address these issues with the project team and management, keeping the project sponsor informed early and often.

These practices should be considered on all projects but especially those with a high degree of uncertainty. While not every risk can be avoided, we can use these strategies to help mitigate severe disruptions to the project.

7 Field Campaign Target Area Scouting

Thoughtful selection of the field campaign site is essential for a successful project. The main takeaways from past campaigns are as follows:

- For the AWAKEN project, we conducted several online meetings with potential project partners to identify the best site. The selection of the final location (i.e., northern Oklahoma) was mainly dictated by the proximity of several closely spaced wind farms (including one with modern wind turbines), the presence of the Atmospheric Radiation Measurement observational network, and the relatively simple topography.
- For RAAW, the industrial partner of the project provided access to one of their research turbines, so the site scouting was more straightforward.

Based on these two experiences, we recommend following a constrained optimization approach (Figure 2). Although it is hard to define a formal process for this task given project-specific considerations, the three main objectives can be defined as follows:

- Fitness to the science goal. This is a measure of how likely a given site will allow successfully capturing the physics relevant for the project goals. The presence of previous local observations and performing preliminary high-fidelity simulations are both important to facilitate instrumental planning.
- Expected costs. In general, the more money is saved in the preparation process, the more money will be available to address the inevitable unscheduled expenses (e.g., instrument repairs, travel) and invest in data analysis.
- Accessibility. Surveying potential target areas on Google Earth will easily lead to a simplification bias, so early exploratory visits to the candidate sites are essential to assess firsthand their accessibility and suitability for the project. Existing facilities with power, concrete foundations, telecom, and security, when available, will make the deployment much faster.

Optimization of the aforementioned aspects should be done under the following non-negotiable constraints:

- Presence of an appropriately sized airport within 100 miles
- Presence of a local airport if instrumented flights are planned as part of the field campaign
- Presence of a hardware store, hospital or other health facility, and food supply stores within 20 miles
- Presence of law enforcement
- Presence of power lines within 1 mile
- Available internet speed faster than 5 megabytes per second or a local area network (Starlink may allow more remote sites to be available)
- Full support from site personnel if the experimental site includes an existing facility
- For offshore sites, proximity to ports and access to on-water transport.

Other aspects to consider that are not necessarily scientific requirements but can really make the difference in terms of engagement of the project partners are the following:

- Diversity and inclusivity of the local community: DOE researchers come from very diverse backgrounds, and it is imperative that they are safe during their field work (Zhang et al., 2023).
- Local amenities: Field work can be hard and frustrating; having a pleasant stay and connecting with the other researchers at the end of the workday can enhance the morale of the team.

As mentioned, a formal mathematical framework for the process of site selection is hard to define; however, it is helpful to use a qualitative diagram like the one shown in Figure 2 to guide the discussion during the early phases.

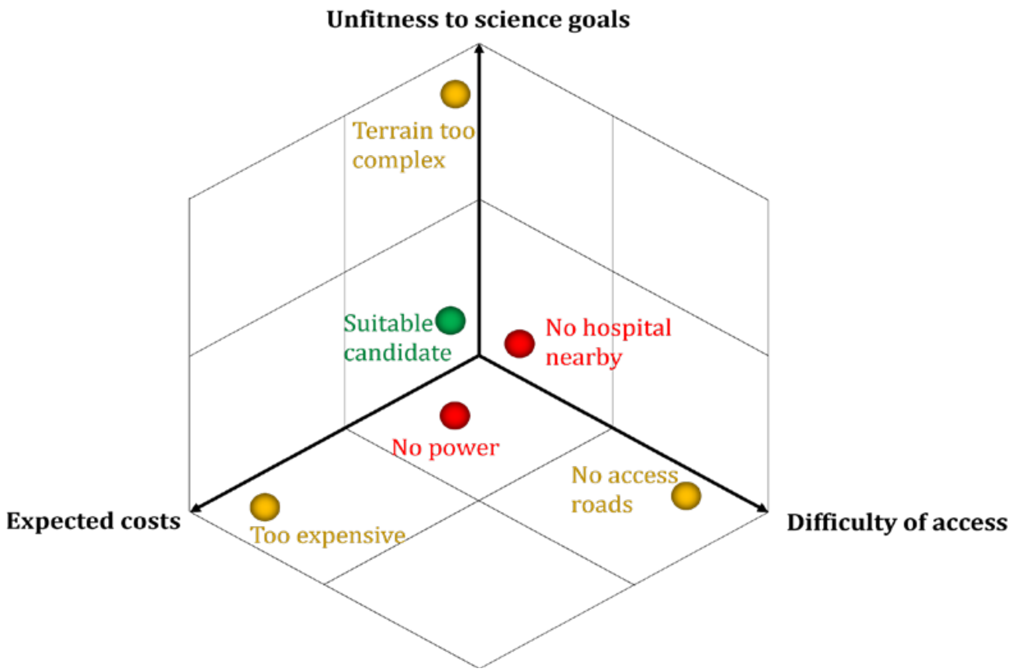

Figure 2. Schematic of the optimization process for field campaign site selection

8 Identification of Instrumented Sites

Once the field campaign target area has been identified, the specific locations for the instrumented sites need to be chosen. Determining the optimal placement of instruments involves a delicate trade-off between science goals and practical constraints, which will vary based on the specifics of each field campaign.

For small-scale experiments where only a single instrumented site is envisioned and in an area where facilities exist (e.g., the case of the RAAW campaign), the specific placement of the sensors can closely follow the ideal scientific plan as long as power and physical access to the equipment are guaranteed and the personnel/owners of the existing facility agree on the desired locations.

For larger-scale campaigns (e.g., AWAKEN, WFIP[s]), when instruments need to be deployed at multiple sites over a larger area, exclusively relying on the scientific needs in the preparatory phase while neglecting some logistical constraints can result in important changes, delays, and/or additional costs in the final layout. The following workflow (see also Figure 3) is therefore suggested:

1. As soon as the target area is identified, plan a site visit with the largest possible number of project partners (it can coincide with a community event to limit costs). There are several practical nuances that only an SME can capture when visiting a site. The goal of the visit is to identify potential locations for instrumented sites. It is recommended that at least two to three options for each instrumented site are identified.
2. After the site visit, it is worth scheduling a plenary meeting where early impressions, science goals, and local climatology data can be discussed. A set of areas of interest for the deployment should be summarized during the meeting, with an associated site visit report.
3. In the following weeks, technical breakout groups led by SMEs in different areas can be formed to fine-tune the placement of the instruments as needed. Examples of such groups are as follows:
    a. Inflow characterization: The SME should be an atmospheric scientist with experience in atmospheric boundary layer profiling and sounding.
    b. Turbine response: The SME should be a wind engineer with experience in turbine control and operation.
    c. Wake impact: If turbines are present, they will impact the flow in the wake region; hence, the SME should be a simulation expert or experimentalist with expertise in wakes.
4. In parallel with the technical groups, a logistical team should start surveying the areas of interest to confirm that the candidate sites are suitable to install instruments. This process includes identifying the landowners, establishing a dialogue with them, and reaching out to local utility companies to determine power needs as appropriate. The logistical team should communicate with the technical team as soon as new constraints come up.

5. Iterations on the choices of instrumented sites are to be foreseen if the technical groups and/or the logistical teams deem some candidate sites to be inadequate.
6. The ideal setup resulting from the combination of the recommendations from the technical team and the constraints of the logistical team should be combined into a final experimental layout. The completion date for this should be 6 months after the first site visit.

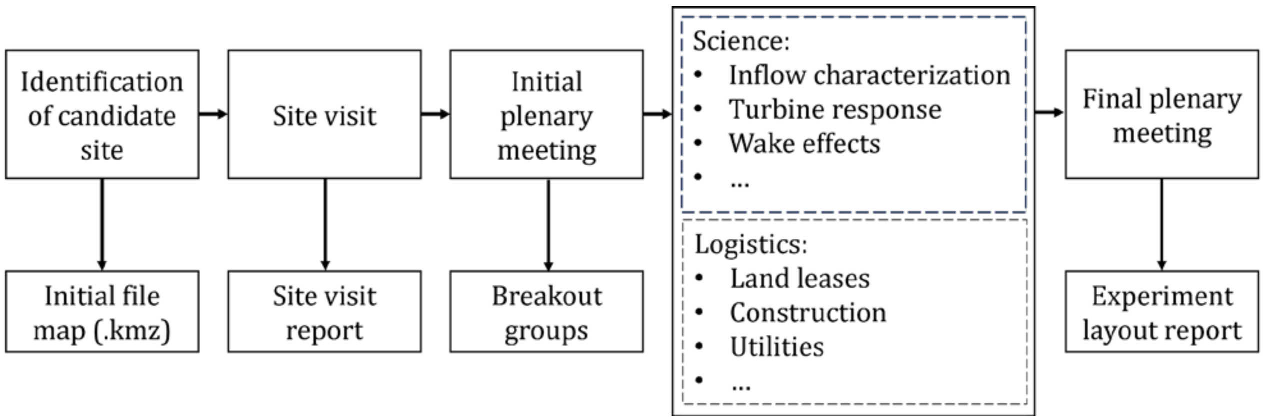

Figure 3. Suggested workflow for the identification of instrumented sites

9 Local Community Engagement

It is highly recommended to establish healthy relationships with the local communities as early as possible whenever a field campaign is expected to have any detectable impact on the local landscape, traffic, security, and so on. Local people can impact the success of a campaign in several ways:

- Landowners need to agree to host instruments on their land parcels, and in the AWAKEN project, face-to-face conversations turned out to be the only way to get land leases executed in a reasonable timeline.
- Personnel from local partner companies/institutes can provide safety training and logistical support.
- Law enforcement representatives can help ensure the safety of field workers and instruments during deployment and throughout the campaign.
- Local schools may greatly benefit from the exposure to research staff and research activities happening in their surroundings.
- Local residents can help monitor the integrity of the deployed equipment.

Engagement with the local community was of primary importance for the AWAKEN project, which had a significant impact on a rural community given the large number of long-term instrumented sites and connected visits from various research teams. Building healthy relationships with local communities was at first neglected but turned out to be one of the most important aspects to speed up the campaign preparation once properly handled. For the RAAW project, local community engagement was more limited because all the deployments were confined at a site owned by a private company. Nevertheless, all the tests were possible thanks only to the extremely supportive and prepared site engineers and technicians; hence, establishing and maintaining healthy relationships with them was essential.

Based on the experience with the AWAKEN campaign, we recommend that all the following people are made aware of the project as early as possible:

- **Landowners**. If instruments need to be placed on privately owned land, initiate conversations with landowners at least a year before the planned deployment. Real estate agents, while useful for navigating property maps and other bureaucratic aspects, should not be the sole point of contact. Still, whenever a real estate agent is engaged, it is essential that they are either local or willing to travel locally. Phone calls are not an effective way to establish productive relationships with landowners, especially in rural communities. Project representatives with scientific insight should personally engage with landowners to provide high-level information about the project, dispelling assumptions that they may not be interested in the scientific aspects. This proactive approach minimizes delays in lease execution.
- **Local site engineers and technicians**. Whenever available, involve local site engineers and technicians from partner institutions early in the project. Especially in the case of large private companies, it is crucial not to assume that the willingness of the company's management to participate in the project automatically extends to their local employees. Addressing the motivation of local personnel and acknowledging them in scientific publications or other means of recognition can facilitate collaboration.

- **Law enforcement**. Engage with local law enforcement, including the sheriff and deputies, prior to the deployment. This approach provides an opportunity for project scientists to express concerns (e.g., leaving costly instruments unattended) and for law enforcement to seek clarification. For AWAKEN, a small team of project representatives was asked to present a high-level project overview at a county meeting, with law enforcement officers in attendance.
- **Larger local community**. Plan an outreach event 3–6 months before the deployment to ensure awareness among residents. Involving communication experts from national laboratories can make the event both entertaining and informative. Alternatively, organize a local community event during the campaign itself. Such activities, especially in small and remote communities, can significantly increase the project's acceptance.
- **Local schools**. Engaging with local schools during wind energy field campaigns in rural communities is also a unique opportunity for fostering community support and inspiring the next generation of scientists. By involving students in hands-on activities and providing educational resources, researchers can create a positive impact, bridging the gap between advanced scientific research and local interests.

10 Instrumentation

The technology of atmospheric instrumentation is advancing rapidly; hence, it is imperative to plan to deploy the most modern instruments for a future campaign as the budget allows. At the same time, it must be ensured that the higher sophistication does not come at the cost of excessively high complexity and therefore reduced reliability and increased downtime (Herges et al. 2020). Several delays occurred during the planning of the AWAKEN campaign. However, these delays allowed for more time to test new instruments. The unintended additional preparatory work turned out to be extremely useful, and similar efforts should be included in future campaigns systematically as follows:

1. **Instrument identification**. As soon as the experiment layout is finalized and science goals are defined, an instrumentation catalog should be created listing instrument models, owners, available dates, and the electrical and construction needs of each instrument. If brand-new instruments are needed, the manufacturers must be contacted to get quotes and lead times (which can be a few months). Arranging shipping from international companies may take up to six weeks. Contracting delays and supply chain interruptions may additionally extend the timeline for receipt of new instruments.
2. **Data collection strategy planning**. Each instrument has different needs and capabilities. Passive, in situ sensors require little in the way of data collection planning, whereas advanced remote-sensing tools require a large number of fine-tuned or tailored strategies. Remote-sensing platforms are also the most expensive and complex class of instruments commonly used in wind energy research, and it is imperative that their operation is carefully optimized based on the specific science goals to maximize their cost-effectiveness. Up to 6 months of dedicated effort could be necessary to identify an optimal operation strategy, and that strategy should be based on published work. As much as possible, the operation strategy of the remote-sensing fleet should be agreed upon by all members of the field campaign team. Moreover, changes to the original schedule should be made only if strictly necessary and with unanimous consensus, as every change results in hours of work on the instrument, new metadata, a new data processing code, more complex data structures, possible errors, and so on.
3. **Testing.** With the instruments available and the operation strategy drafted, it is recommended that at least 1 month of preliminary data are collected to
    a. Get familiar with new hardware and ensure it works as expected
    b. Identify and correct biases in the raw measurements; performing simultaneous and co-located measurements from similar instruments before and after a test will help in quantifying these biases and any potential drift that occurred during deployment
    c. Estimate sources of uncertainty and quantify differences with reference instruments
    d. Develop and test any advanced retrieval methods (e.g., virtual towers, innovative profiling techniques, and inverse methods for retrievals, such as the Tropospheric Remotely Observed Profiling via Optimal Estimation algorithm)
    e. Set up and test instrument data transmission and remote control

f. Stress-test the equipment against, e.g., power outages, weather exposure, and wildlife to improve its reliability.

11 Permitting and Site Development

Once the desired experimental layout has been completed, a significant effort is needed to complete all the permitting required to gain access to the sites and permission to deploy the instruments. Sites for instrumentation placement can include various locations with different landowners and constraints. Moreover, constraints for public and private landowners can vary. At least 6–9 months should be expected for site development activities prior to campaign execution.

- **Land leases**. Securing the land leases, where needed, is the first step toward instrument deployment.
    - The laboratories and DOE have a process for determining fair local rental rates. Assessing rent based on space used rather than number of instruments installed might be easier.
    - Land leases are considered DOE property; therefore, all DOE rules and regulations for working at these sites apply.
    - As stated earlier, on-site in-person visits with landowners make things move a lot faster. Trust can be established much more easily in person than over the phone or via email. Hiring a local champion for this effort would be useful and speed up the process. Landowners may be offline and not always available via email, so in-person meetings may be needed to negotiate and complete agreements. Also, it should be noted that opposition to or at least ambivalence toward renewable energy may be a consideration with some landowners.
- **Federal Aviation Administration approval**. A specific Federal Aviation Administration (FAA) approval is required for tall (greater than 200 ft) meteorological towers and any radars that will be deployed. Permits are also required for airborne technology such as aircraft, tethersondes, and drones. Radiosonde launches do not require FAA approval, although they may require approval from other governing bodies, such as DOE's Aviation Management program. FAA approval can take over 180 days. The lead national laboratory should refer to guidance from their aviation safety office.
- **National Environmental Policy Act**. National Environmental Policy Act (NEPA) needs depend on the specific project characteristics, so it is recommended to discuss those needs with the laboratory permitting team. A lead time of 6 months for a NEPA review is good practice.
- **Site development: construction**:
    - Construction activities at the instrumented sites might be needed, generally for instruments requiring special foundations. Such instruments and their needs should be identified early in the process.
    - Construction is strictly limited under Bayh-Dole regulations that forbid government contractors from performing construction activities beyond more than $2,000 of work. Therefore, it is recommended to identify available construction contractors early in the planning phases. Nine months is a reasonable timeline between sending out a request for proposal and completion of construction work for a project comparable to AWAKEN.

- **Site development: electrical power.** Instruments require electrical power to operate. While some instruments might be able to run off of solar panels, many require more substantial power sources. An accurate list of power requirements for all instruments should be compiled as soon as an experimental plan is available. Once the power needs for each site have been identified, it is recommended to work with local utilities to set up power poles and lines and to determine the correct voltage and amperage needed for each site that does not already have the required power available. In some cases, paperwork must be completed by landowners, which can require additional travel. In the event of delays in securing permanent power, explore temporary options such as diesel generators or solar trailers. Note that diesel generators are expensive and require high maintenance for periods longer than a month. Landowner approval must be obtained for any temporary power solutions.

12 Precampaign Logistics

Following the identification of the site and development of an experimental layout, it is crucial to address several lower-priority practical issues that may impact the timeline of field campaign activities. The list below outlines key considerations based on challenges encountered in previous campaigns:

- **Site addressing**
  - Ensure that each instrumented site is assigned a 911 address.
  - Collaborate with local counties to establish ad hoc addresses for remote locations lacking a designated 911 address.
- **Location of utilities**
  - Determine the location of utilities at all instrumented sites where any sort of digging activity is expected; this process usually requires a few weeks to complete.
- **Fencing for remote sites**
  - Provide fencing for all instruments at remote, unprotected locations to keep out larger animals and deter people.
  - Facilitate a collective discussion to establish fencing requirements, considering factors such as maximum allowable height, based on individual instrument owner necessities and preferences.
  - Note that cattle panels are good for smaller sites (~50 feet by ~50 feet), whereas a chain-link fence should be considered for larger sites.
- Need for shipping containers
  - Take ground water into consideration to avoid damaging equipment and electrical connections. Elevated platforms such as shipping containers can provide protection for instruments off the ground and can be used to store on-site equipment needed for data collection and transfer. The most advanced containers have temperature control to ensure year-round operation of equipment.
- Site security
  - In a multiparty experiment, security needs vary depending on the instrument, site, and comfort level of the instrument owner, so consider installing a site security system with alarms or shock sensors for each instrument, particularly in remote locations.
  - Because security sensors can often inadvertently trigger and result in a nuisance for local authorities, another alternative is to consider installing security cameras, both as an additional deterrent and as a basic instrument troubleshooting asset; fake cameras and security system signs also serve as effective deterrents.

- **Private patrol agent**

    - Consider hiring a private patrol agent, and provide training for the basic troubleshooting of instrumentation, especially when a local partner institution is not part of the project.
- **Facilities for field workers**
    - Provide portable bathrooms or office trailers to accommodate field workers.
    - If possible, find a location with an indoor shop for on-site fabrication and staging of materials for deployment.
    - Preferably, have a shipping container on-site somewhere to serve as a base of operations, which has been crucial for long-term campaigns such as AWAKEN, and keep the container stocked with common tools, sundries, and safety equipment.
- **Environment, safety, and health compliance**
    - Ensure compliance with environment, safety, and health requirements for both the field campaign institutions and local partners.
    - Verify the availability of the right personal protective equipment before every visit.
    - Make sure workers are up to date on their training records and that project partners have a copy of those records.
    - Ensure that first-aid supplies are available for each deployment crew (e.g., automated external defibrillator, first-aid kit), along with a fire extinguisher.
    - Identify local wildlife hazards (e.g., snakes) and discuss mitigation strategies with the environment, safety, and health team.
    - Identify team members' allergies (including allergies to wildlife) and discuss options with the environment, safety, and health team.
- **Lightning protection**
    - For relevant sites, arrange for double, triple, or quadruple lightning protection systems to protect instrumentation against static discharge. Consider activating a monitoring system to warm team members about potential lightning hazards when they are in the field.

By addressing these practical considerations, the field campaign activities can be executed more smoothly, mitigating potential delays and helping ensure the overall success of the project.

13 Campaign Operations and Maintenance

This section delves into the essential practices and considerations involved in deploying, maintaining, and managing instrumentation in the field. From initial deployment strategies to ongoing instrument maintenance, and from pest control measures to site restoration efforts, meticulous planning and execution are essential to ensuring smooth operations and optimal data collection throughout the campaign life cycle.

- **Before initial deployment**
    - When deploying instrumentation in the field, previous experience in setting up similar systems proves invaluable. With a new instrument, it is helpful to have a representative from the manufacturer walk through setting up the instrument with staff at the home office.
    - During this setup phase, meticulous notes or videos should be taken regarding the tools needed and any routine maintenance tasks required to ensure smooth operation of the instrument.
- **Initial deployment**
    - Walk through each step of the deployment, determine what tools/materials are needed, and create a bill of materials to pack.
    - Bring all of the diagnostic tools that you will need to troubleshoot the instrument if you start it up and it is not working.
    - Have redundancy in your diagnostic tools, as multiple troubleshooting methods can be indispensable when faced with unforeseen challenges.
    - For more complicated deployments (e.g., instrumentation on top of a wind turbine), physically rehearse the installation with the personnel conducting the work to ensure smoother installation in the field.
    - Calibrate instruments according to written procedures, and document calibration parameters, some of which may change with time during deployment. Comparison to post field-campaign calibration is important to ensure that quality data have been collected.
    - Document how the installation went. Make notes of what might be failure points along the way. Take plenty of close-out photos of the installation, and also photos of the instruments in context. Open up power and communication enclosures, and photograph their final state before leaving the site.
- **Instrument monitoring**
    - Regularly (at least weekly) monitor all the deployed instruments to ensure they are working and transferring data as expected.
    - Sending an automated weekly reminder to all the instrument owners is helpful to ensure regular instrument monitoring by all parties involved.
- **Instrument maintenance**

- Before the field experiment commences, a plan should be developed regarding how frequently each instrument should be checked on to determine if the instrument is operating normally.
- It is critical to be able to remotely power-cycle the instrument as a basic step in troubleshooting it. It is important to understand the instrument in advance of the deployment to determine how to safely power-cycle the instrument.
- It is important to have equipment to determine if the instrument loses its connection with the internet and to have a way to automatically reboot networking equipment (such as a modem).
- Having redundant systems leads to a longer deployment period without needing maintenance.
- Local help is needed for simple troubleshooting of instruments, such as rebooting or refilling washer fluid. Local partners such as universities may be useful for this.
- If it is necessary to travel to maintain the instrument, have detailed instructions from the manufacturer on what it will take to conduct the maintenance. Come up with a plan for the work to be done, and from that plan, figure out a bill of materials that needs to be packed to get the work done.

- **Landscaping**
  - Arrange landscaping services to maintain each instrumentation site at the experiment's outset while remaining mindful of DOE regulations, particularly regarding silica exposure.
- **Pest control**
  - Pests pose risks to both instrument operation and maintenance personnel. Collaborate with the environment, safety, and health office to identify local pests and develop mitigation plans to address potential risks, such as rodents chewing on cables, tick exposure, and snake bites.
  - Place cabling in a conduit to deter rodents from damaging cables.
- **Site restoration**
  - All sites must be returned to their original condition once the experiment is completed, and project funds must be reserved for this purpose. Depending on what was built at the site, the restoration cost may be similar to the cost of constructing the site in the first place.

14 Long-Term Data Archiving and Management

WETO-funded field projects should use DOE's Wind Data Hub (wdh.energy.gov) as the main portal for data archiving. The Wind Data Hub team at the Pacific Northwest National Laboratory is the best resource for guidance on campaign-specific archival needs, but as a reference, the stages needed to achieve proper data archiving are also outlined here:

1. **Wind Data Hub account creation**
   First, a Wind Data Hub account, which can be created for free, is required.
2. **Two-factor authentication**
   Next, a user needs to be logged into the Wind Data Hub with two-factor authentication.
3. **Project page creation**
   The Wind Data Hub team will then create a project-specific page (listed at https://wdh.energy.gov/projects), which will be filled out with all relevant general information about the field campaign, including relevant key members of the research team.
4. **Metadata creation**
   For each instrument, a metadata page needs to be created. The process is described at https://wdh.energy.gov/metadata and involves specifying information about the instrument, its location, its mentor, and the variables being observed. If a given instrument (or a similar one) was deployed in a previous campaign, metadata can be copied over to the new deployment. For each instrument, it is recommended to create metadata for different data levels, similarly to what established in the DOE ARM program:
   a. The .00 data level is used for raw measurements, typically in the format provided by the instrument.
   b. The .a0 data level is used for processed data.
   c. The .b0 data level is used for reviewed data.
   d. The .c0 data level is used for derived data.
5. **Project-specific uploader creation**
   The Wind Data Hub team will create a project-specific executable file, which will be used on each instrument to transfer observations from the instrument to the Wind Data Hub. Once available, the uploader can be downloaded from https://wdh.energy.gov/upload (Figure 4) by selecting the relevant field project and, on a later screen, the operating system it will be used on.

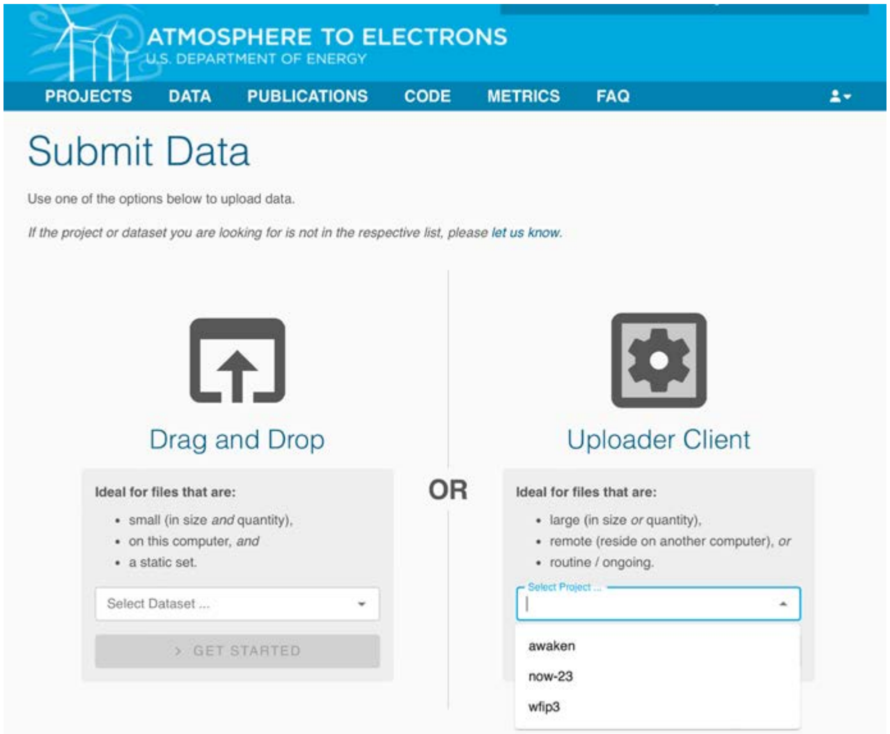

Figure 4. Wind Data Hub uploader setup. *From https://wdh.energy.gov/upload*

6. **Uploader usage**
   For instruments with a Windows PC that can be controlled remotely, the easiest way to transfer the observations to the Wind Data Hub is by running the project-specific uploader on the local computer. If the instrument setup either is too obsolete to run the uploader or does not include a PC but has instead a file transfer protocol (FTP), a possible workaround is to first create an FTP server and then use the pysftp Python package to transfer data.

7. **Ingest for reviewed data**
   Whereas the .00-level data directly come from the files stored by an instrument, all higher-level data files need to be created by the instrument mentor. To do so, appropriate ingest pipelines need to be developed in cooperation with the Wind Data Hub team so that the data can be reformatted, quality checks can be applied, and so on.

15 Communications

Effective communications are essential to a successful and impactful field campaign with benefits that extend to groups well beyond the direct participants. A multipronged communications campaign is essential for broadly disseminating data and knowledge from the campaign to the wider wind energy industry. Regular update meetings, including those at research and industry conferences, are valuable. Also, a webpage with connections to important publications and the Wind Data Hub will ensure that people have access to the latest information. Timely (at least one every quarter for a long-term field campaign, more frequent for projects of shorter duration) newsletter articles and social media postings are also a good way to inform the community. Project leads should consider making a campaign logo and a PowerPoint template early on and provide it to all members to create an effective brand around the project.

16 Offshore-Campaign-Specific Considerations

When planning an offshore wind energy field campaign, additional considerations apply. Based on our experience planning the WFIP3 field campaign, the following key points should be considered:

- **Permitting timeline for offshore wind energy projects**
    - Offshore project permitting unfolds on a longer timeline, typically commencing at least 1 year before deployment initiation.
    - Pre-NEPA prerequisites include cultural resources review, National Historic Preservation Act consultation, Endangered Species Act consultation, Magnuson-Stevens Act Essential Fish Habitat consultation with the National Oceanic and Atmospheric Administration's National Marine Fisheries Service, a U.S. Army Corps of Engineers permit, and Private Aid to Navigation applications.
    - Many of these consultations need to be concluded before NEPA documentation. In WFIP3, a project-specific categorical exclusion expedited the permitting, yet the process still spanned 1 year.
- **Buoy validation with lidar**
    - Offshore buoy deployments necessitate validation using a reference lidar, a process requiring approximately 2–3 months based on Carbon Trust guidelines (Carbon Trust 2018); this validation phase should be factored into the timeline planning stages.
    - If interested in wind energy industry usage of these data, it would be helpful to certify the buoy using DNV or similar. The DOE buoy is now a stage-3 (full commercial use) buoy; therefore, validation is not essential. However, if additional new sensors are added to the DOE buoy (such as a new flux sensor or a ceilometer), a temporary validation or deployment near a reference site would be helpful to make sure that any issues with instrument behavior due to buoy motion are sorted out prior to actual deployment.
- **Offshore deployment challenges**
    - Weather-related delays should be anticipated, and deployments should be conducted when winds are less than 10 knots at the deployment location and wave heights are less than 4 feet with a period greater than 7–8 seconds (i.e., calm weather). Studying the climatology of the site would also be helpful in planning for such deployments.
    - In addition to the weather being favorable during deployment, it needs to be favorable when towing the buoys to the sites. Therefore, it is recommended that at least 2–3 days of calm weather be required.
    - Most buoys also need to undergo a swing test to calibrate their internal inertial measurement unit, which provides each buoy's location and heading. This swing test also requires safe operating conditions (in terms of both weather and location).

- **Maintenance challenges**
    - Maintenance of offshore assets poses substantial time, cost, and logistical challenges.
    - Redundancy for instruments is essential.
    - Vessel availability must be meticulously coordinated with subcontractors conducting offshore work on behalf of DOE.
    - If DOE personnel are involved in offshore deployments (e.g., on wind turbines or buoys), extensive training and internal paperwork are prerequisites.
    - Advanced discussions and planning are imperative for seamless integration of DOE personnel into offshore activities.
- **Instrument marine-proofing**
    - Certain instruments require marine-proofing before offshore deployment, incurring additional costs and potentially necessitating several months for completion. This may include building water-tight power and communication enclosures, and/or sending the instrument to the manufacturer to increase water protection near instrument seams.

Navigating these considerations is critical for the success of offshore wind energy field campaigns, ensuring compliance with regulations, validation of equipment, and the efficient deployment of resources.

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