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Fig. 1 Typical environmental sensor deployment with science, support, and communication systems. Photo 2013 Scotty Strachan, NevCAN Sheep Range Blackbrush station

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Overview

Selection of exactly where and how to acquire data via in-situ sensing efforts is a crucial point in the science process where environmental research is concerned. Decisions made when choosing sites, sensor packages, and support infrastructure in turn place boundaries on what the final science deliverables can be. Data types, quantity, and quality are more or less set in stone during this process. Initial costs, timeframes, and sustainability are also determined by these choices. Selections need to be made based on the desired science products, but also in consideration of a wide array of variables including land ownership, access, equipment budget, long-term maintenance capability, previous research, and construction/deconstruction logistics.

Setting up terrestrial sensing systems is a major infrastructure/personnel commitment with budgetary and environmental concerns, and every effort towards maintaining a robust, low-impact, and long-term data stream should be made. Because each region possesses unique geography, there is no “one size fits all” solution. Instead, a series of decisions needs to be made, with the goals and capabilities of the research team defined in the context of clearly-articulated science questions and objectives.

Introduction

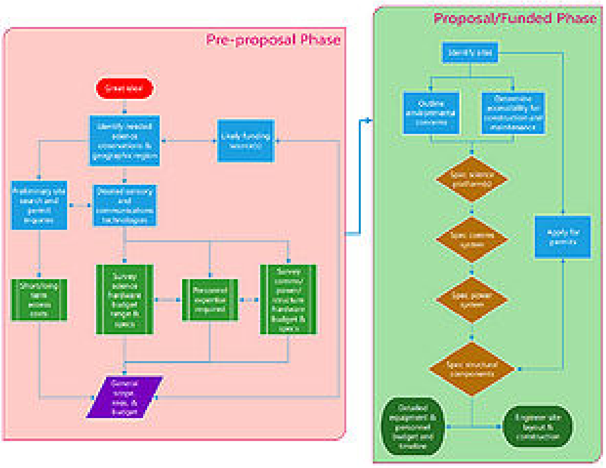

Fig. 2 Progression of work in selecting a site and designing a science deployment.

Identifying both the deployment strategy (site, process) as well as the physical hardware (sensor platforms and support infrastructure) for environmental sensing is usually a daunting task. A key objective of the research team should be to keep the science context in view during this process, as logistic realities will often clash with "ideal" scientific conditions. Very often the decision tree for choosing exact locations and deployment schemes is dependent on interacting factors (such as permitting/geography/access; Fig. 2). There is also a vast array of possible sensor/hardware packages available for a multitude of science applications.

It is critical that Principal Investigators (PI’s), logistical techs, and sensor specialists work together to develop specific deployment plans and alternatives, ideally in the pre-proposal stage. Planning topics must include science objectives, operating budgets, proposed locations, seasonal weather patterns, power sources, communications options, land ownership, distance from managing institutions, available personnel/expertise, and potential expansion/future-proofing. All of these categories are equally critical for discussion as proposed instrumentation projects move towards implementation.

Methods

Site visits, permit/agreement negotiations, equipment specifications, and deployment timelines need to be initiated concurrently because all phases of deployment are interdependent (Fig. 2). The P.I., together with the technical personnel, should identify sites for sensor and equipment deployment based on science needs, local topography, permit/agreement availability, logistical access, and availability of services (such as power and communications). Portions of the plan (such as some purchasing decisions) should remain flexible until the precise sites, permits/agreements, and data flow plan have been positively determined.

Environmental concerns

Environmental conditions have considerable bearing on science application, platform design, construction logistics, access restrictions, equipment reliability, and maintenance cost/longevity. Conditions for in situ sensing can vary tremendously from region to region; therefore, site and equipment selection must be concidered on a case-by-case basis.

- Local topographic variables include: northern versus southern exposure, which can affect hours of direct sunlight and snow persistence; and valley/sink versus ridgeline settings, which can affect daily temperature cycle and wind characteristics. The differences in airflow, wind exposure, cold sinks, snow drifts, sky exposure for solar panels, and possible radio/communications pathways are all important variables when selecting a site and what type of equipment will be deployed.

- Dominant vegetation conditions and potential long-term growth can alter sensor readings via shading effects, affecting temperature, radiation, and snow-related measurements. Radio communications are also affected by vegetation, with most microwave frequencies used by high-speed data radios being strongly attenuated by trees and brush. Vegetation can also be a long-term hazard in the forms of fire fuels and deadfalls.

- Visibility and the visual impact of deployments should be considered for both security and aesthetic considerations. Sometimes reduction of visual impact is required by landowners, but in general it is simply good practice. Metal structures can be camouflaged with paint to reduce visibility, structure heights may be reduced to blend with vegetation, and ground disturbance can be kept to a minimum to avoid biasing certain types of measurements and erosion.

- Dominant weather conditions determine what levels of seasonal access are available, what structural designs should be used, and what sort of equipment should be purchased. Extreme temperatures, tropical storms, lightning, snow depth, riming/ice, UV exposure, high humidity, wind speeds, salt water exposure, flooding, and stream depth variation are all examples of conditions which will influence design and deployment plans.

- Wildlife can provide hazard considerations or be affected by proposed deployments. Bird perching and flight paths, cattle, soil invertebrates, rodents, and large mammals can all disturb or be affected by sensors and equipment installed in the field. Landowners will have regulations or preferences concerning these factors, and proactive steps are necessary on the part of the science team to minimize these hazards.

- Sensitivity to local political and social issues need to be considered, as objective science data should constructively serve the local populations as well as the scientists and funding agencies.

- Site security is a primary concern when planning to deploy sensors and equipment into the field. Human theft/vandalism is a potential cause of sensor disturbance or failure. While remote deployments are nearly impossible to secure physically, measures such as camouflaging, informative signs, fencing, and lockboxes may be employed to mitigate hostile or irresponsible passers-by.

- Hazards to sensors include natural disturbance/disasters such as wildfire, flooding, extreme winds, and mass wasting. Planners should be aware of all these possibilities and at least examine the likelihoods of these event at sites which have been evaluated from the scientific point of view.

Site accessibility

Fig. 3 Seasonal access may vary highly depending on location, limiting the types of maintenance possible at any given time.

Locations for in-situ sensing must be accessed for data collection, survey, construction, and maintenance over the life of the project. Seasonal conditions, roads, and topography determine what types of access may be used during different times of the year. Categorical considerations include:

Vehicular access. Commercial vehicle/equipment, 2WD auto, 4x4 truck, ATV, snow machine, boat, helicopter.
Non-motorized access. Hiking, skiing, pack animals, snowshoeing.
Access improvements. Road building, trail building, trail demarcation, safety rails, harness anchor points.
Seasonal access. Define access by spring/summer/fall/winter seasons. This is directly related to local weather/topographical conditions.
Construction access. Heavy equipment, special equipment, heavy loads, and heavy foot traffic are all likely possibilities depending on monitoring design.
Minimal impact considerations. Can traffic/access be directed in a way to minimize environmental impact (e.g. erosion, vegetation)? Solutions include boardwalks, bridges, raised steps, delineated pathways.

Science platform selection

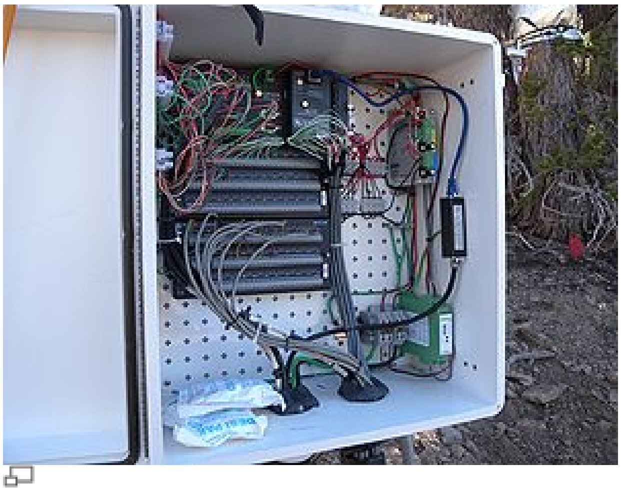

Fig. 4 Science instrumentation specification must be driven by science questions and

environmental/logistical constraints.

Once the science questions have been established and site conditions are known, an itemized list of sensor and support system platforms/hardware may be assembled that best fits the application and budget. Primary considerations include reliability, comparability with other similar field systems, technological (e.g. programming) requirements, budget, and system flexibility (e.g. upgrades, expansion, telemetry options). Accuracy, precision, and expected period of use prior to calibration or replacement may also be a consideration. In some fields of study, there are only one or two alternatives to choose from in terms of scientific instrumentation, whereas in others there can be many choices. Options can be narrowed by researching what equipment/standards are used by existing installations to which comparability is desired. Once a data acquisition platform and sensor array is chosen, remaining support systems are then designed around this core equipment.

Support system specification

The subsystems of infrastructure, electrical power supply, and data communications should all be designed to best support the science platforms in all seasons over the long term. While some vendors offer "all-in-one" packages supplied with standard instrumentation, it is best for the research team to assess whether these solutions are adequate for their chosen site and objective. Quite often several science questions are being addressed in larger deployments, and multiple hardware solutions from several vendors must be combined into one deployment. The support systems should be specified and scaled appropriately.

- Physical infrastructures – these are the building-blocks of any remote data acquisition site, including tripods, towers, poles, buoys, solar panel racks, storage boxes, fencing, concrete pads, and the like. Quite often a single tripod or tower does not have adequate space or structural integrity to support all of the sensors, antennas, solar panels, batteries, and other items, so a typical site design incorporates multiple structural components.

- Power generation and storage – for sustaining long-term reliable data streams, power independence is critical. Stations should be capable of generating and storing their own power locally, as well as taking advantage of any grid or other available power that is within budget and design criteria. Because the majority of related electronics are ultimately powered by DC voltage, having a power generation system and DC battery bank for every site (and sometimes discrete subsystems) is recommended to minimize the loss of power and the resulting data gaps. Independent generation sources are most commonly PV arrays (solar), wind, or water turbines. For reasons of cost, reliability, and maintenance issues, PV (solar) is recommended as the primary on-site generation source if environmental conditions allow. Incorporating simplicity, redundancy, and excess capacity is important for long-term reliability.

- Data communications – Use of real-time communication (in addition to local storage capacity) is desirable in order to transmit data, monitor system health performance, troubleshoot problems, and minimize data gaps. This is usually performed using radio communications (whether vendor-specific or building a general-purpose field IP network). Communications systems need to be robust, secure, and should have low power requirements (refer to "Data Acquisition and Transmission" Best Practices for further detail).

- Construction details – When selecting and designing the sensor and support systems, many details need to be considered when generating specifications and purchasing hardware. Wires should be protected in conduit and storage enclosures to avoid exposure to damage and seasonal degradation. Wire lengths, enclosure sizes, and mounting locations should be planned for accordingly. Anchoring for support structure should be designed to withstand worst-case weather/environmental conditions. Use of corrosion-resistant metals for structure and hardware such as galvanized steel and aluminum will greatly reduce failure or ongoing maintenance problems.

Site layout

Fig. 5 Carefully planning a site layout in advance can prevent surprises and setbacks during installation.

Site layout at first might seem trivial, but is very important when considering interactions of the various subsystems that can influence sensor/equipment reliability and data quality. Science questions/objectives should drive the placement/separation of sensors to optimize measurement quality, followed by placement of support systems and additional structure. Solar arrays need to be angled for sun exposure, minimal shading, and snow shedding. The impacts of site structure on measurements such as wind eddies, incoming/outgoing radiation, camera viewsheds, or precipitation catch zones need to be considered as well as aesthetic impacts if located in a region that is frequently visited by the public. Power and data cable runs should be protected and kept as short as possible; voltage drop over long runs can be a consideration in layout and design. Stipulations in site permits may be drivers of site layout and construction. Once the site layout is designed and mapped, specification of construction materials, sensor cables, and other supplies may be optimized.

Best Practices

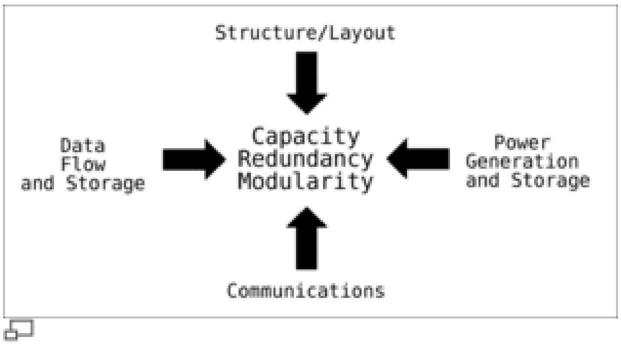

Fig. 6 The approach to deployment should be as durable, reliable, and flexible as possible to accommodate unforeseen conditions and changing science questions or technology improvements over the long term.

Selection of deployment sites, sensor packages, and support systems are interacting processes which can require some iteration before arriving at the final determinations. Unless the science questions are extremely narrow or exceptional in nature, it is unlikely that any one of these decisions can be made in a vacuum without considering the others. With this in mind, the following overarching recommendations should be emphasized:

- P.I. consultation with system/hardware/construction specialists while in the proposal phase will minimize budget surprises or platform compromise later in the process.

- Data quality and longevity should be the ultimate goals when designing the deployment. Making choices for more robust and widely-used core systems and sensors will ensure that data comparability is maximized and hardware problems corrupting data or creating gaps are minimized. Purchase of reliable and known equipment is not as expensive as repairing/replacing equipment halfway through the study or losing valuable data.
- When data quality and continuity is paramount, use of replicate sensors or stations may be required.
- Planning for real-time connectivity is crucial for reducing field maintenance time and data gaps.
- Optimal site selection to answer science questions can often be impeded by permit requirements and landowner preferences. Starting the conversation with landowners early in the process may improve the chance of getting the locations/deployment types that are desired.
- Standardizing sensor and support hardware, software/programming, and structural designs across multiple sites minimizes maintenance issues as well as construction costs and design time.
- Assessing access capabilities to the sites will allow for planning of emergency maintenance access, procedures, and costs.
- Overbuilding structure, power capacity, and site infrastructure (e.g. cabling, networking) will prevent problems in the case of unforeseen events or site expansion.

Common Points of Failure

- Power problems are one of the most frequent causes of total system failure. Battery fatigue, loose connections, and electrical shorts need to be anticipated and prevented where possible. Power systems need to be protected, over-engineered, and replicated wherever possible.
- Temperature extremes of heat or cold can cause electronic or mechanical failure of individual sensors and systems. Insulating enclosures, ventilating enclosures (active or passive), and placement of equipment in sheltered zones can help alleviate these problems.
- Humidity and condensation can be a serious issue for electronics longevity and circuit performance (including accuracy). In zones of high average humidity, sealing enclosures and providing some means of reducing humidity (e.g. desiccant packets) is desirable.
- Sensors can be disrupted by wildlife. Hardening of sensor systems (e.g., armoring cables, fences) can help with some problems. Near-real time data feeds allow rapid detection of problems that will occur.
- Lightning strikes or near-misses are a common problem at exposed or mountainous sites. Extensive grounding (e.g. exposed copper wire network) and use of surge protection throughout the power system and at ends of long power and data cable runs will compartmentalize the site electrically and protect as many components as possible.
- Lack of data storage replication can cause loss of data. Incorporating high capacity storage on-site (datalogger) as well as off-site (database), this problem can be mitigated.
- Personnel turnover coupled with lack of process and hardware documentation can lead to data discontinuity or equipment failure (see Sensor Management and Tracking for additional details).

Case Studies

- NevCAN Transects or Walker Basin (Scotty) --- To be completed, will include a station design and systems, maintenance/access plan, data flow, and some photos/diagrams.
- Andrews Research Sites (Adam) --- To be completed
- Sevilleta - Renee to complete with multiple case study examples