Arnold Schwarzenegger
Governor

WIND ANEMOMETER LOAN PROGRAM PROTOCOL

PIER INTERIM PROJECT REPORT

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"Research Powers the Future"

Prepared For:
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Wind Anemometer Loan Program Protocol

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Abstract

The factors involved to implement an anemometer loan program in California are investigated. An anemometer loan program in California would allow the compilation of large, publicly accessible, state-wide dataset of wind conditions gathered specifically for wind energy development uses. Anemometry equipment has become both more reliable and less expensive in recent years. Sonic anemometers are found to be more reliable and provide higher quality data at a higher price than conventional cup anemometers, although prices are coming down. A prototype system is deployed and evaluated, with satisfactory results. The operation of existing anemometer loan programs in other states is described. The factors to be considered in implementing an anemometer loan program in California are discussed, and recommendations for implementation are given.

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1. Introduction

A lack of good wind data is one of the greatest obstacles to the development of wind energy at new sites in California. On-site evaluation of wind conditions is a necessary step in both large and small scale wind resource development. Currently in California, there is a lack of publicly-accessible data on wind conditions in the types of terrain where wind turbines would be located. While private wind developers have extensive databases of the conditions at their sites, this data is considered too sensitive for most companies to release to outsiders. The recent completion of maps predicting the wind resource potential across the state of California needs to be evaluated for accuracy using wind information recorded at potential wind sites. And landowners interested in installing small wind turbines are often discouraged by the difficulty of evaluating their own wind resource. A viable anemometer loan program would address all of these cases, providing quality wind resource information from sites across the state to any and all interested parties.

This document describes research conducted on anemometry and anemometer loan programs, and gives a preliminary outline of the workings of a Wind Anemometer Loan Program, to be established in order to provide high quality wind information for sites in California. To achieve this goal, a number of steps have been undertaken, including surveying and evaluating wind information recording equipment, developing a protocol for the operation of an anemometer loan program, and assessing the anemometry and data needs of industry and other information users in the wind energy field. It has been found that it is feasible to set up and operate an anemometer loan program in California, that there a variety of ways in which such a program could be operated, depending on the priority of the program goals and the availability of financial and other resources to the program.

2. Equipment to Measure the Wind Resource

2.1 Components of a Wind Information Recording System

A practical wind information recording system (WIRS) involves more than the measurement instruments. Generally, a WIR system is composed of the following components:

Measurement Instruments
: At least one anemometer, plus air temperature (AT), relative humidity (RH) and barometric pressure (BP) sensors to observe the site wind conditions.

Datalogger
: Stores the information produced by the sensors. Generally averages instantaneous data over short time intervals (1-10 minutes). May also perform some initial calculations on data.

Communication System
: Allows checking of sensor operation and downloading of data from remote sites without requiring site visits. May consist of a landline or cellular phone system,

radio transceiver or satellite uplink. A base station is also needed to communicate with remote sites.

Power Supply

Provides electrical power for the other systems. If no on site supply is available, a combination of solar panels and batteries are generally used.

2.2 Anemometers

The heart of any wind speed recording system is the anemometer, which is the instrument that records the wind speed and direction on site. An anemometer must be sturdy enough to withstand the long term exposure to climatic extremes while reliably measuring wind speed and direction. The anemometer must have low power consumption for remote applications where the only power available is from solar panels. For the purposes of the Anemometer Loan Program, it must also be relatively inexpensive and readily available.

There are two types of anemometer systems commonly used to measure wind speed and direction. The most common and least expensive method incorporates a series of cups on small arms that can rotate freely (fig. 1). Aerodynamic forcing by the wind causes the cup to rotate at a speed roughly proportional to the wind speed. A magnet on the rotating cup assembly and a Hall effect sensor on the fixed base produce an electrical pulse each time the cup assembly completes one revolution. The wind speed measurement is made by counting the number of rotations in a certain time span (typically one second or less). Wind direction is determined by a separate vane that is free to rotate and is shaped in a manner that causes it to turn into the prevailing wind. A potentiometer attached to the vane produces an electrical output that varies with the direction the vane is pointing.

Fig. 1: Cup and vane system: RM Young Windsentry

Sonic anemometers (fig. 2) are the next most common method of measuring wind speed. Sonic systems use the principle of Doppler shifting in sound waves to determine wind speed. Three or more transducers are mounted on fixed posts that project into the air stream. At a regular time interval, typically once per second, each transducer sends out an acoustic pulse that is picked up by the other transducers. Electronics within the instrument analyze the variation in the signals to determine wind speed and direction. Depending on the number and arrangement of the transducers, sonic anemometers are capable of resolving either horizontal wind speed and direction, or full three dimensional wind velocity. Some systems also estimate potential temperature, essentially temperature corrected for the standard atmosphere lapse rate.

Fig. 2: Sonic anemometer: Vaisala 425

Sonic anemometers are generally considered preferable to traditional cup and vane systems because they lack moving parts that are susceptible to damage in the field. As a result, sonics are less likely to experience data inaccuracy, such as drift in measurements, or data loss due to the wearing out of mechanical components such as bearings. In light winds (<1-2 m/sec) cup and vane systems are often unresponsive because the wind does not provide enough force to overcome the turning resistance of the bearings. (See fig. 7 for an example of this.) The main drawbacks of sonic systems are cost, although these have come down significantly in recent years. Cup and vane instrument combinations are available for as little as $260 (from NRG) and a variety of instruments are available for less than $600 (e.g. Met One, RM Young). The least expensive sonic anemometer found was a 2D model by Met One with a list price of $1350. Other sonic anemometer prices include $1750 (2D, Vaisala), $4150 (3D, Metek) and $8600 (3D, Campbell Scientific).

2.3 Barometric Pressure, Temperature and Humidity Instruments

The amount of energy available at a wind turbine, to first order, is $E = 0.5\rho U^3$, where U is the wind speed at hub height and ρ is the air density. The amount of power generated by a turbine will be a function of both wind speed and air density. Denser air contains more energy than less dense air for a given wind speed. The density of air varies inversely with temperature. (From the ideal gas law, $\rho = P/RT$). For example dry air at 30°C has a density of $\rho = 1.16$ kg/m^3, while dry air at 0°C has a density of $\rho = 1.29$

kg/m^3, a 10% difference. Humidity also affects the density of air, with increasing humidity resulting in a lower air density. (Water vapor is less dense than air.) For example, dry (0% humidity) air at 20°C has a density of ρ = 1.20 kg/m^3, while air with 100% humidity at 20°C has a density of 1.16 kg/m^3. Air density can be determined directly from the barometric pressure, or estimated from temperature and humidity.

Reliable air temperature (AT) and relative humidity (RH) sensors are available from all major suppliers for $500-$1000. Barometric pressure sensors are available from all major suppliers: Campbell Scientific's CS105 lists for $575.

2.4 Additional Measurements: Wind Shear and Atmospheric Stability

In addition to the wind velocity at hub height, it is important to know the wind "shear," or change in velocity with height, when siting a wind turbine. In most cases, in the lower few hundred meters of the atmosphere, mean wind speeds increase with height above ground. This information is needed in order to optimize tower height with turbine size. Also, as the turbine blades rotate, they will encounter higher wind speeds at the top of the rotation than they will at the bottom. Since more wind speed means greater loads on the blades, the blades will be subject to cycling stresses, with the magnitude of the cycling dependent on the wind shear. Characterizing wind shear requires measuring wind velocities at two or more different heights, suggesting that ideally, a WIRS would have several anemometers installed over a range of heights on the tower.

Atmospheric stability is an important contributor to the wind speeds at a site, as well as the wind shear. Stability refers to the amount of "stratification" in the atmosphere. Generally, stable flow occurs when cooler air is found below hotter air, such as sometimes occurs at night when the air adjacent to the cool ground is cooler than warmer air aloft. The degree of atmospheric stability has a strong effect on the local wind field near complex terrain: stable flow is characterized by predominantly horizontal movements of air, while unstable flow exhibits significant vertical air movement. The non-dimensional Richardson number (Ri) is the similarity parameter used to quantify stability:

$$\mathrm{Ri} = \frac{g\frac{\partial T}{\partial z}}{T\left(\frac{\partial U}{\partial z}\right)^2} \qquad (1)$$

where g = 9.81 m/sec^2 is the gravitational constant, z is height above ground, T(z) is absolute temperature in Kelvin and U(z) is the wind speed. Ri is the ratio of buoyancy which generates vertical motion, to shear in the flow which produces vertical mixing. A Richardson number of zero indicates neutral stability. Ri > 0 indicates stable flow, while Ri < 0 indicates unstable conditions. In order to calculate a Richardson number, it is necessary to estimate the vertical temperature and wind speed gradients, which requires temperature and wind speed measurements at a minimum of two different heights.

3. The CWEC Prototype Wind Information Recording System

3.1 Description of the CWEC Prototype System

A prototype WIRS was assembled for the purpose of obtaining experience deploying and operating wind measurement equipment. Because the prototype system was intended to gain experience in the operation of a WIRS, the equipment specified for the prototype may be somewhat different than what would be used on systems intended for field deployment. The system was also installed on a 6 ft tripod instead of a taller tower in order to facilitate access to the instruments.

Most of the components for the prototype system were sourced from Campbell Scientific. This company was found to offer competitive pricing on most components, and the various components were well-integrated with each other and with supporting software. Other researchers reported few problems with Campbell Scientific equipments and good customer service.

The prototype system included both a 2D sonic anemometer (Vaisala 425A) and a cup and vane anemometer (RM Young Windsentry). An air temperature and relative humidity sensor (Vaisala 435E) was also included. A Met One 2D sonic anemometer was later loaned to us by the California Air Resources Board for evaluation purposes. A Campbell CR10X-2M datalogger serves as the heart of the system. An analog cellular phone communication system, solar power supply, and tripod, mount and enclosure were also included in the system, as was supporting base station software. (See Appendix A for complete information.) Final price for all components, including a small educational discount and ground shipping to Davis, California came to $7855. Availability of components varied, with delivery times ranging from two weeks to two months after ordering.

Fig. 3: Prototype WIRS installed adjacent to UCD/NOAA Climate Station (in background).

The prototype system components were received from the manufacturer, and the components were added to the system in phases. An initial lab test consisted of the RM Young cup and vane anemometer coupled to the CR10X datalogger. The CR10X began recording data on Sept. 6 2002, and has done so continually since then, with the exception of a few (planned) power-off events. The Vaisala sonic anemometer was subsequently incorporated into the system. The equipment was next mounted on the tripod, the solar power supply and cellular phone systems were incorporated and the prototype was placed on the roof of Bainer Hall at UC Davis, where it successfully recorded wind information for one month. The system was then returned to the lab for wind tunnel testing of the anemometers, and additional troubleshooting of the communication system. The full system was deployed to a field site adjacent to the UCD/NOAA climate station west of the main UC Davis campus in early December, 2002 (fig. 3). This site is surrounded by flat fields with no obstructions and experiences less interference than the roof site, which was adjacent to walls and stacks on the roof. Siting adjacent to the UCD/NOAA climate station was to allow for independent verification of recorded data, however, their reporting system went down in mid-December 2002 and at this time has not been returned to service. After additional troubleshooting of the flow control settings, the cellular communication system became consistently functional at the end of January 2003. Automated downloading of system data was started at this time. For demonstration purposes, a custom-written application was implemented to post-process the downloaded data and upload it to a simple web page on the CWEC web site (http://cwec.ucdavis.edu/anemometer). Although the current implementation is a basic proof-of-concept, additional sophistication could be easily incorporated.

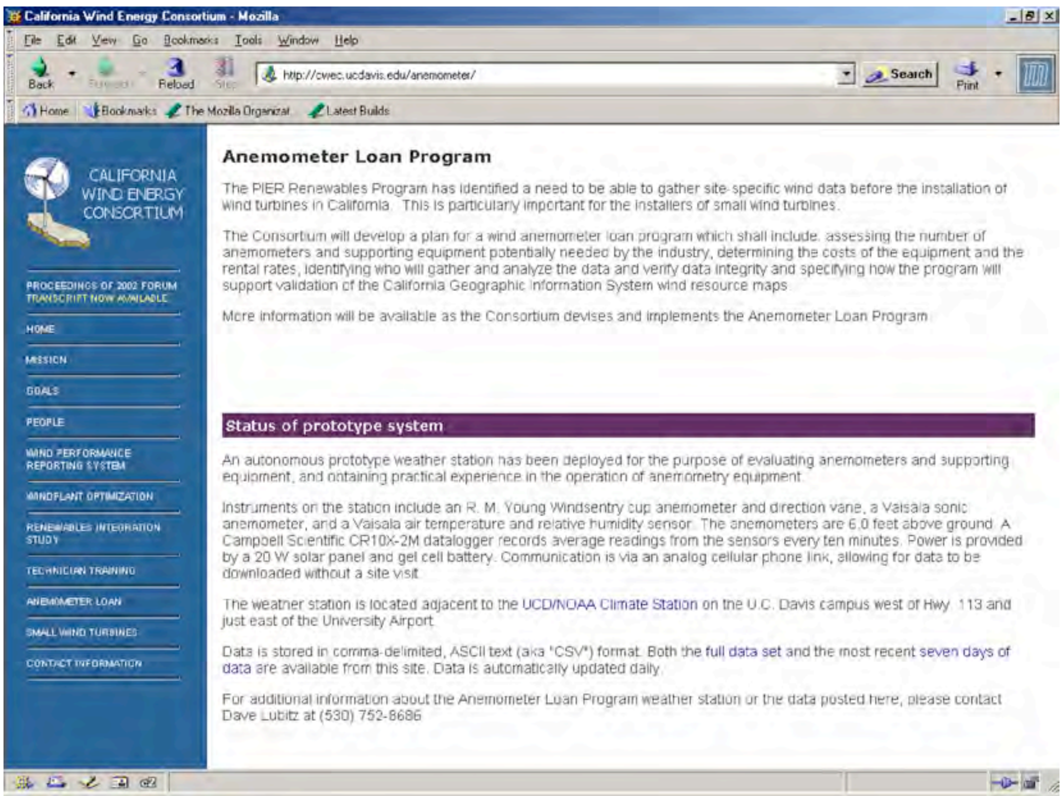


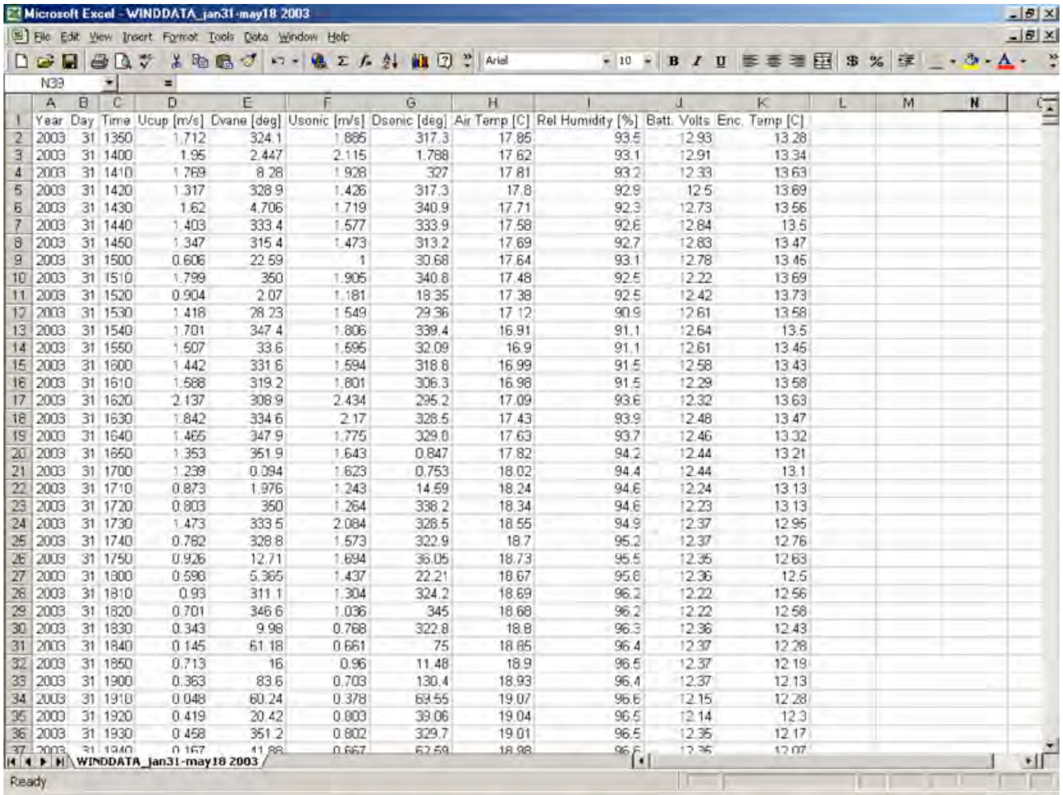
Fig. 4: Anemometer Loan Program web page containing links to view data from prototype WIRS.

Based on our own experience and feedback from stakeholders, future systems should replace the humidity sensing capability with a barometric pressure sensor. Barometric pressure, which correlates directly to air density, is more useful than humidity, from which density can only be indirectly determined.

3.2 Prototype System Performance

All systems have worked well, with no unanticipated difficulties, except for the communications system. Cellular (and to a lessor degree, landline) telephone communication proved problematic. Dropped connections due to system noise appear to be the primary problems. At times, the cellular network also becomes overloaded and calls do not go through reliably. Although the datalogging system is forgiving of dropped calls and data has never been corrupted or lost, it can be difficult to reliably download large amounts of data over the phone link. (Downloading data by directly connecting the datalogger to a lap top computer has, by comparison, proven to be extremely reliable.) Significant trouble-shooting of the communication system was required, until it was determined that data flow control between the various components of the system was the problem. Adjusting the flow control settings for the various communication components resulted in a very reliable system. The remaining reliability issues appear to be due to poor capacity in the cellular service provider's network, and are beyond our control. The automated downloading is successful roughly 50% of the time. Downloading can also be started manually, and this has generally been satisfactory.

Both anemometer systems (Vaisala sonic and RM Young cup/vane) have performed reliably during the preliminary testing phase, both in the field and the wind tunnel. The Vaisala and RM Young anemometer systems were tested in the UC Davis Atmospheric Boundary Layer Wind Tunnel (ABLWT) to confirm that measurements were within factory supplied specifications (fig. 6). Wind tunnel testing speed was approximately 3.2 m/sec, constrained the use of a low speed wind tunnel. Each instrument was mounted on a turntable in the center of the tunnel so that the instrument sensors were 23.5 inches above the tunnel floor. Wind speed and turbulence information was provided by a hot wire anemometer positioned directly upwind of the instruments. The hot wire is considered accurate to within ±2% of the measured wind speed. The hot wire readings were considered to be the true tunnel wind speed at sensor height. Both systems were found to be accurate to within ±1 m/sec for wind speed and ±2° for wind direction. (See Appendix C for full results.)



Microsoft Excel - WINDDATA_jan31-may18 2003

	Year	Day	Time	Ucup [m/s]	Dvane [deg]	Usonic [m/s]	Dsonic [deg]	Air Temp [C]	Rel Humidity [%]	Batt. Volts	Enc. Temp [C]
2	2003	31	1350	1.712	324.1	1.885	317.3	17.85	93.5	12.93	13.28
3	2003	31	1400	1.95	2.447	2.115	1.788	17.62	93.1	12.91	13.34
4	2003	31	1410	1.769	8.28	1.928	327	17.81	93.2	12.33	13.63
5	2003	31	1420	1.317	328.9	1.426	317.3	17.8	92.9	12.5	13.69
6	2003	31	1430	1.62	4.706	1.719	340.9	17.71	92.3	12.73	13.56
7	2003	31	1440	1.403	333.4	1.577	333.9	17.58	92.6	12.84	13.5
8	2003	31	1450	1.347	315.4	1.473	313.2	17.69	92.7	12.83	13.47
9	2003	31	1500	0.606	22.59	1	30.68	17.64	93.1	12.78	13.45
10	2003	31	1510	1.799	350	1.905	340.8	17.48	92.5	12.22	13.69
11	2003	31	1520	0.904	2.07	1.181	18.35	17.38	92.5	12.42	13.73
12	2003	31	1530	1.418	28.23	1.549	29.36	17.12	90.9	12.61	13.58
13	2003	31	1540	1.701	347.4	1.806	339.4	16.91	91.1	12.64	13.5
14	2003	31	1550	1.507	33.6	1.695	32.09	16.9	91.1	12.61	13.45
15	2003	31	1600	1.442	331.6	1.594	318.8	16.99	91.5	12.58	13.43
16	2003	31	1610	1.588	319.2	1.801	306.3	16.98	91.5	12.29	13.58
17	2003	31	1620	2.137	308.9	2.434	295.2	17.09	93.6	12.32	13.63
18	2003	31	1630	1.842	334.6	2.17	328.5	17.43	93.9	12.48	13.47
19	2003	31	1640	1.465	347.9	1.775	329.8	17.63	93.7	12.46	13.32
20	2003	31	1650	1.353	351.9	1.643	0.847	17.82	94.2	12.44	13.21
21	2003	31	1700	1.239	0.094	1.623	0.753	18.02	94.4	12.44	13.1
22	2003	31	1710	0.873	1.976	1.243	14.59	18.24	94.6	12.24	13.13
23	2003	31	1720	0.803	350	1.264	338.2	18.34	94.6	12.23	13.13
24	2003	31	1730	1.473	333.5	2.084	328.5	18.55	94.9	12.37	12.95
25	2003	31	1740	0.782	328.8	1.573	322.9	18.7	95.2	12.37	12.76
26	2003	31	1750	0.926	12.71	1.694	36.05	18.73	95.5	12.35	12.63
27	2003	31	1800	0.598	5.365	1.437	22.21	18.67	95.8	12.36	12.5
28	2003	31	1810	0.93	311.1	1.304	324.2	18.69	96.2	12.22	12.56
29	2003	31	1820	0.701	346.6	1.036	345	18.68	96.2	12.22	12.58
30	2003	31	1830	0.343	9.98	0.768	322.8	18.8	96.3	12.36	12.43
31	2003	31	1840	0.145	61.18	0.661	75	18.85	96.4	12.37	12.28
32	2003	31	1850	0.713	16	0.96	11.48	18.9	96.5	12.37	12.19
33	2003	31	1900	0.363	83.6	0.703	130.4	18.93	96.4	12.37	12.13
34	2003	31	1910	0.048	60.24	0.378	69.55	19.07	96.6	12.15	12.28
35	2003	31	1920	0.419	20.42	0.803	39.06	19.04	96.5	12.14	12.3
36	2003	31	1930	0.458	351.2	0.802	329.7	19.01	96.5	12.35	12.17
37	2003	31	1940	0.167	41.88	0.667	62.59	18.98	96.6	12.35	12.07

WINDDATA_jan31-may18 2003

Ready

Fig. 5: Sample of data from prototype WIRS. Data is uploaded to the site nightly.

Fig. 6: Wind tunnel test of Vaisala sonic anemometer

The CR10X-2M datalogger was programmed and began recording data on Sept. 6, 2002. Since then, it has recorded data continually in the lab, in the wind tunnel and in the field with no unplanned outages. The datalogger samples each instrument once per second, and can record averaged, sampled or maximum/minimum observed values. It can be programmed to perform additional calculations on the incoming data before storing it. Programming can be either done directly, or utilizing user-friendly software supplied by Campbell Scientific. The frequency of data storage is programmable. For testing purposes, data was initially stored once per minute. This results in a large amount of data being generated, which is good for testing the equipment, but may be excessive for collecting field data. Communication with other researchers revealed most field studies of wind speed record data in ten minute averages instead of one minute, and an averaging time of ten minutes was implemented.

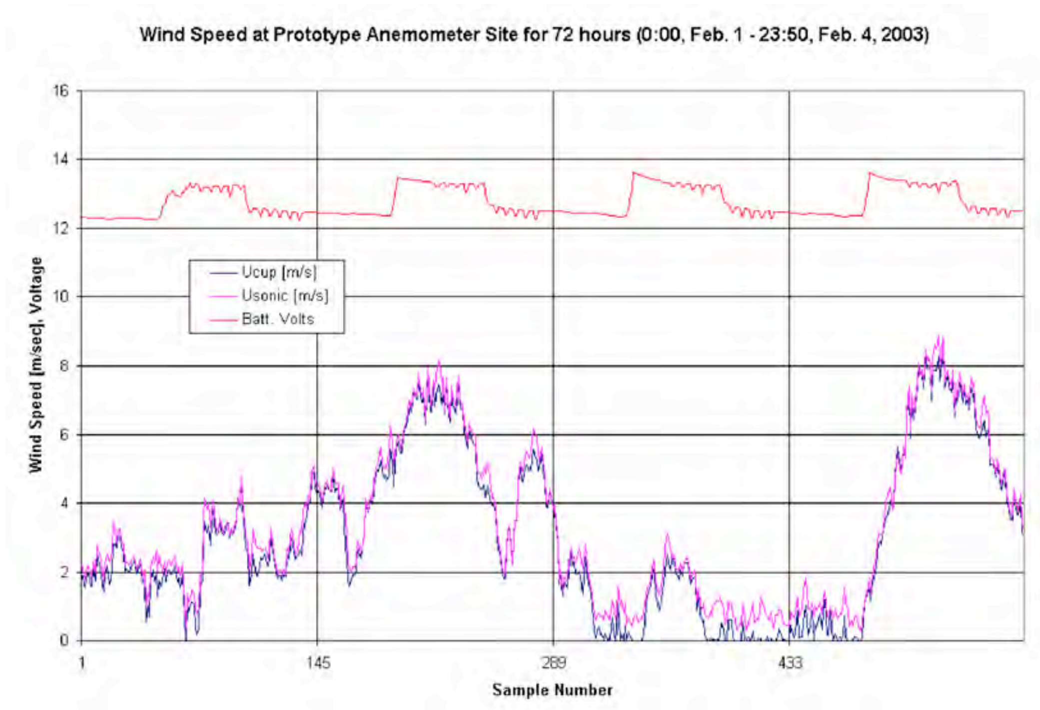


Fig. 7: Example of data from prototype WIRS. The two anemometers track each other reasonably well. During the third day, the cup anemometer underreports wind speed because it stops turning in very light winds. The solar power system kept the battery well-charged even in winter.

The solar power system, consisting of a 20W solar panel, voltage regulator and gel cell battery, has performed well. Very little diurnal variation of voltage was observed (fig. 7), and the system appears to have excess capacity, even during winter storms.

4. Existing Anemometer Loan Programs

Although California has not had an operational anemometer loan program since the mid 1980s, anemometer loan programs currently exist in a number of states, or for targeted populations (such as the Native American Anemometer Loan Program). Most these programs have similar mission statements and function in a similar manner. Most anemometer loan programs exist to assist the people of a specific state or community evaluate the potential of specific sites for wind power (or pumping) development. Therefore, the primary focus is to inexpensively acquire an initial impression of the wind resource at a given site. As a result, the anemometers used are basic systems that are inexpensive and easy to use. Only wind speed and direction information is measured. Any large development being considered would perform a more detailed resource assessment if the results from the a loan anemometer indicated promising wind conditions: current loan programs therefore use their resources to acquire data from more sites, at the cost of the thoroughness of that data.

The Department of Energy, through the Wind Powering America project, provided some or all of the anemometer systems for most current loan programs. NRG Systems anemometer systems (such as the NRG-NOW) are used almost exlcusively. These systems are relatively inexpensive, include all components (instruments, datalogger, solar power supply and tower) and have been generally reliable. The most common system configuration is a single cup and vane anemometer on a 20 m tower, although programs may have taller towers and/or multiple anemometers, and acknowledge that both of these are desirable.

Anemometers are loaned to interested parties (usually landowners) who have completed an application specifying the site of anemometer placement, the purpose for which data is being collected and the borrower's background. The borrowers include people interested in small wind development, as well as developers considering larger projects, landowners interested in their own resource, and farmers considering wind-powered water pumping. Often, the applicant must demonstrate on the application that if the wind resource proves good, some form of wind power development is likely. Generally, demand for anemometers exceeds availability, especially for the first year or two of program operation. Anemometers are loaned for a period of 12-14 months: enough time to install the anemometer, collect one year of data and recover the anemometer. Installation and recovery of anemometers generally requires site visits by program staff to ensure proper handling and installation of the anemometer. (The time and travel expenses associated with this are generally the largest costs experienced by a program.) Borrowers are responsible for changing data storage plugs monthly and mailing the plugs to the program administrator. There have been few problems encountered with this arrangement, especially if sufficient time is allocated for training of the borrower during anemometer installation and pre-addressed mailers are provided by the program. Data collected is public-domain, and is usually posted to a web site (or "will be soon") after processing by program staff. At the conclusion of a loan, the borrower is mailed a copy of all wind data, plus analysis that generally includes wind roses, wind speed ranges and anticipated power production. Returned anemometer systems are inspected, and often anemometers are replaced every other year.

Program staff are required to perform several functions. Installing or recovering an anemometer often requires a full day, or even two when travel time to and from the site is included. The time and travel costs associated with installing and recovering anemometers are usually the single most expensive cost for an anemometer loan program. Office staff are required to publicize the program, evaluate applications, download and process data, compile reports and maintain a web site. Additionally, each returned anemometer must be inspected, tested and overhauled if necessary.

The main costs of operating the form of anemometer loan program outlined above are labor, travel to install and recover anemometer systems, and purchase and maintenance of the anemometer systems. Under the right circumstances, a program as outlined above can be run very inexpensively, with the award for "most economical" program going to the Virginia State-Based Anemometer Loan Program, which has 17 anemometers and operates on a budget of $5000 per year, all of which goes towards transportation expenses. Program staff consists largely of students at James Madison

University who earn class credit for working on the program. Most anemometers were provided by DOE, except for two purchased using outside grants.

5. Anemometer Calibration

After field deployment, it is common for an anemometer to become less accurate over time, due to mechanical wear and tear. The Utah Wind Anemometer Loan Program replaces all cup and vane anemometers after two years for this reason. It is desired to have a method of calibrating anemometers available to the anemometer loan program, both to check older anemometers and to confirm that new anemometers are functioning properly.

In conjunction with the California Wind Energy Collaborative, the U.C. Davis Aeronautical Wind Tunnel is to be certified for cup and vane anemometer calibration, in compliance with the protocol outlined in I.E.C. (International Electrotechnical Commission) publication 61400-121 "Wind Turbines - Part 121: Wind Turbine Power Performance Testing" Annex F.

6. An Anemometer Loan Program for California

6.1 The Goals of a California Anemometer Loan Program

Before deciding on the operational details of a California anemometer loan program, it is necessary to prioritize the goals that this program will have, as there are a number of goals to be accomplished by any anemometer loan program implemented in California. It should be decided whether local landowners will be used to suggest sites and monitor WIR systems in the field, or if this will be done entirely be program staff. The number, type and location of program staff should be determined. Will students or part time workers be used? Will the staff be dedicated to the program or shared with other projects? Where will the program be based? Will the program have one central base or several regional ones?

6.2 Use of local landowners or stakeholders

The most significant decision to make is whether to include local landowners in the operation of the anemometers. The advantages of doing this are that there is a person present on or near the site who can check on the anemometer regularly, do simple, routine maintenance tasks (such as changing data plugs) and alert the program to unexpected events in the field. The communication system has been the least reliable component of the prototype system; regular on-site inspections of the anemometer system would therefore be preferred if possible. To ensure the landowners are sufficiently motivated to carry out their tasks, current programs have application procedures that require an investment of time and energy by the landowner to complete, and require the landowner to demonstrate that they have a serious interest in determining the wind energy potential of their property. This approach also makes site acquisition relatively straightforward, since the landowners suggest the sites where anemometers will be deployed and arrange access. Provided the application process is rigorous, current programs have reported few problems with landowners failing to fulfill their obligations.

Incorporating landowners in the program operation does have complications. Program staff must invest significant amounts of time evaluating landowner applications for anemometers, and communicating with landowners about the program. Landowners must also be thoroughly educated about the tasks they are to perform, and anemometer operation in general. More complicated anemometer systems would require significantly more time to educate landowners about system operation and signs of equipment failure. While site acquisition is simplified for the program staff, only sites that landowners have a specific stake in would be considered for program anemometers. Without a local person regularly checking the anemometer system, a communication system must be relied on to regularly confirm the proper functioning of the anemometer system. There are large areas of California, including many potential wind resource sites, with little population, and therefore it is unlikely that these sites would ever be evaluated by a landowner-centered loan program. This would be a significant problem if the primary goal of the program is a survey of the wind resources of California in general, or using the loan program data to improve California's wind resource maps.

6.3 Program Initiation

It is recommended that the program be started slowly, with just a few WIR systems for the first year. This would allow the program staff to learn their tasks and develop protocols with only a few anemometer systems. Current anemometer loan programs all reported that the initial learning curve was steep when their programs started. Tasks such as setting up the anemometer systems took two to five times more time than an experienced staff required. It is anticipated that after the initial learning period, additional anemometer systems could be added to the program.

It is suggested that anemometers be phased in "one at a time" instead of in large groups. Some existing programs reported difficulties when, for example, all of their anemometer systems were scheduled to be returned from the field in the same month.

6.4 Program Location

California is a very large state, and the anemometer loan program must provide coverage to the entire state. It has already been observed that travel-related costs to install and recover anemometer systems are the greatest non-avoidable expense. To minimize the distances that program staff must travel, it is suggested that several bases be established across the state for anemometer service, storage, maintenance and handling. Preferably, most sites would be close enough to a base that expensive overnight travel between any potential site and the nearest base could be avoided. Having staff at multiple locations across the state would also increase possibilities for local outreach. Functions such as data processing and web site maintenance could be centralized at one of these bases.

Locating the anemometer loan program on college or university campuses is suggested in order to maximize the availability of inexpensive, motivated part time workers, while keeping overhead low. Universities and colleges generally have knowledgeable technical resources that could be accessed for communication system and web page support. It is also anticipated that the program's wind information database would be utilized by academic researchers. It is anticipated that the labor and space demands of the program will vary significantly over the course of a year. An academic location allows greater labor and space flexibility than hiring full time employees and acquiring space in the private sector. For example, part time student employees could be hired when anemometer systems need to be installed or recovered. It is anticipated that the same employees could be hired repeatedly, on an as-needed basis, without the overhead of maintaining their employment during times of low labor needs, such as when all the anemometers are in the field and functioning normally.

Using additional casual student labor as needed, it is anticipated that a single half-time employee, such as a graduate student, could manage a small program of perhaps five anemometer systems, while a full time employee could manage a program of 10-20 anemometers. (Exact numbers depend on too many variables, such as equipment type and reliability affecting setup, recovery and maintenance times, or the amount of time needed to publicize the program and communicate with stakeholders, to be able to predict with any greater precision.) A small amount of office space, enough storage space to simultaneously hold several disassembled anemometer systems and towers and a working area for instrument checkout, maintenance and calibration would also be needed on an on-going basis, at each program base.

6.5 Wind Information Recording System Recommendations

The anemometer system, or Wind Information Recording System (WIRS), is the key component for the Wind Anemometer Loan Program. The WIR system used should be as reliable as possible, and suitable for use throughout California. It should be transportable and easy to set up in the field with a minimum of specialized knowledge or skills. It should have low operating costs, and ideally, a low purchase price.

The following equipment recommendations are based on the idea that the initial purchase price of the equipment, although initially high, will be less than costs for ongoing maintenance and operation of the loan program, especially if equipment failures require many site visits and maintenance. It is also motivated by the realization that the event of undetected equipment failures and the large loss of data that would result would be very costly, since transportation to the site and installation of the equipment are likely to be the highest ongoing expenses.

These recommendations are also based on information gathered from operating anemometer loan programs. Operators of these programs consistently desired more than one anemometer on each tower, as well as taller towers.

A minimum of two anemometers, mounted at two or more different heights on the tower, should be included. This provides both wind shear information and redundancy in case of anemometer failure. Sonic anemometers are desirable over cup and vane systems, in order to minimize possible failure modes. Cup and vane anemometer could be partially or fully substituted if equipment cost must be minimized and regular site checks are possible.

Two temperature sensors should be mounted at different heights on the tower adjacent to anemometers. In addition to allowing the assessment of atmospheric stability, one program operator mentioned that temperature readings would be useful for troubleshooting whether individual anemometers had temporarily failed due to icing.

A barometric pressure sensor is considered to be the most straight-forward method of determining air density, which is necessary to properly characterize the power potential of the wind resource, and one should be included in the system.

An onsite datalogger should be used. Communicating raw data directly to a remote base station is not considered feasible. Wind data should be averaged over ten minute or greater time spans to reduce data storage/communication needs unless there is a specific need for more detailed information on turbulence at a site. A good datalogger can also track other useful quantities, such as maximum observed wind speeds and variance of wind speeds without too much difficulty.

A communication system should be incorporated to allow frequent (ie daily) confirmation of system functioning without site visits. This system is essential if a local landowner or other stakeholder is not available to periodically check on the system. Ideally, wind data could also be downloaded via the communication link, so that site visits would only be required for periodic checks of the equipment. The choice of communication system will depend on the remoteness of the site the WIRS is to be placed at. Digital or analog cellular telephone may be used at sites with the appropriate coverage. (It should be noted that federal regulators have given cellular service providers permission to shut down their analog networks in 2007 and most providers have expressed intentions to do so. In this eventuality, cellular coverage will be discontinued to many remote areas that receive coverage only via analog networks.) If cellular coverage is not an option, packet radio or GOES satellite communication may be implemented.

Even with the presence of onsite power, a back-up solar/battery power system is suggested to maintain data integrity in the event of primary power failure.

The tower used should be as tall as possible. Modern multi-megawatt turbines can be 100 m tall or more at hub-height. Portable tower systems up to 60 m tall are available from multiple vendors. It should be noted that the tower price increases rapidly as tower height is increased. For example NRG Systems quotes $800 for a 20 m tilt up tower, while the 40 m version is $3700. Their tallest tower is 60 m, selling for $8400. To the extent possible, "piggy-backing" on existing towers should be considered in order to economically place instruments as high as possible.

It is suggested that a single vendor be used for component sourcing to the maximum extent possible. Most vendors provide information and troubleshooting only on the use of their components together. Support is also difficult for systems with components from multiple vendors. Supporting software is also tailored to the vendor's own components. As a result, it is significantly easier to integrate the sensors from a given vendor to the datalogger and communication system of the same vendor, than it is to integrate these components when supplied by multiple vendors.

6.6 Proposed Standard for Wind Information Measurement and Storage

A consistent standard should be used for measuring and recording wind data from all WIR systems. The standard should include the sampling frequency of the instruments, averaging times and other calculations to be performed, the frequency of data storage, data file formats, and reporting methods. The following preliminary suggestions are based on experience with the prototype system and communication with other researchers:

Sampling frequency of anemometer:

1 Hz. Once per second sampling is frequent enough to gather useful turbulence data. Sampling frequency could be reduced if power consumption is too high.

Sensor specifications:

Sensors should meet the following minimum performance specifications:

	Anemometer	Wind Vane	Temperature	Pressure	Humidity
Measurement Range	0 – 50 m/s	0° – 360° (<8° deadband)	-40° – +60°C	94 – 106 kPa (sea level equivalent)	0% – 100%
Starting Threshold	≤ 1.0 m/s	≤ 1.0 m/s	N/A	N/A	N/A
Operating Temperature Range	-40° – +60°C	-40° – +60°C	-40° – +60°C	-40° – +60°C	-40° – +60°C
Operating Humidity Range	0% – 100%	0% – 100%	0% – 100%	0% – 100%	0% – 100%
Max. Measurement Error	≤ 3%	≤ 5%	≤ 3°C	≤ 1 kPa	≤ 2%
Min. Measurement Resolution	≤ 0.1 m/s	≤ 1.0°	≤ 1°C	≤ 0.2 kPa	≤ 5%

Averaging period for data storage:

10 min. Recording data once every 10 minutes gives 6 data points per hour, or 144 points per day. For a system recording ten data types, this produces 1440 data points a day. This is a small enough amount of data to be downloadable via all types of communication systems, while providing reasonable data resolution.

Suggested information to record:

Date and time of observation, average wind speed at two or more heights, standard deviation of wind speeds, maximum wind speeds, sampled wind directions, sampled air temperature, barometric pressure, and voltage level of battery.

Frequency of system checks via remote call-in: Daily.

Length of loan: Minimum of 12 months.

Verified data file format:

Each file should contain one day of data in time series with each set of samples being one row in a comma-delimited ASCII text file. Compile into monthly files for archiving.

Reporting method:

Initial: Post data files to FTP site as verified data becomes available.
Final: Interactive web-accessible database capable of providing user-specified datasets.

7. Estimates of Labor and Costs for an Anemometer Loan Program

Estimates of costs and labor involved in operating an anemometer program were made based on several assumptions. It was assumed that ten anemometer systems are operated by the program, and that each anemometer is deployed at a site for a one year period. Estimates were made for two types of WIRS. The first system is one based on Campbell Scientific equipment that is fully self-contained, communications enabled and includes several anemometers including sonic anemometers, temperature sensors and a barometer. The second system is based on NRG Systems equipment and intended to represent minimal capital costs. It is instrumented with cup and vane anemometers only, is not communications enabled and requires on-site power. The cooperation of a landowner is required to visit the site monthly, swap data plugs and send them to the program. The details of the cost estimates for these two systems are included below.

It is apparent that the initial cost of anemometry equipment is highly variable, depending on the type of system chosen. It is recommended that the best possible equipment be purchased, as this will provide much more extensive data, allow more flexibility in site selection and be more reliable.

Several significant capital and operating costs, such as those for office and work space, were not estimated, since the cost of these items will vary significantly depending on how the program is implemented.

On-going operating expenses are expected to consist primarily of labor, communications and mailing costs, miscellaneous office expenses and routine replacement parts. For communications enabled systems, there are costs associated with maintaining the communications systems (e.g. cell phone subscriptions for each system), while there are mailing and processing costs associated with systems that must have data plugs manually changed and mailed. Overall, communications enabled systems will increase the operating costs of the program relative to non-communications enabled systems.

It was assumed that the program operator would transport anemometer systems to and from the site and assist in installing and removing the system at the site. Two site visits per year per anemometer system are expected, one for installation and one for recovery. Transportation costs were assumed to be $0.35/mile and no allowance was made for overnight trips or overtime. Transportation costs are therefore highly dependent on the travel distances required.

It is estimated that support for ten anemometer systems would require about 1000 hours of labor per year, the equivalent of a single person working half-time on the program.

Projected Anemometer Program Costs July 18 '03
Program based on Campbell Scientific, communications-enabled systems.
(Communications enabled, fully instrumented, stand-alone systems.)

Capital Costs

Quantity	Item	Unit Price	Cost
10	Campbell Scientific-Based Anemometer System	9000	90000
10	20 m Tower	800	8000
2	Tower Installation Kit	750	1500

Capital Costs	99500

Annual Operating Costs

Quantity	Item	Unit Price	Cost
10	Replacement Parts (cups, vanes, misc. every 2 years)	150	1500
10	Cellular Phone Line Subscriptions ($55/month)	660	6600
20	Transportation for Site Visits to Install / Remove Systems		
	Average distance 100 miles	*70*	*1400*
	Average distance 200 miles	*140*	*2800*
	Clerical Supplies		500
	Office Phone		600

Operating Costs	10600 to 12000

Labor Estimates

Quantity	Annual Labor	Unit Hours	Hours
10	System Checks	0.5 h/unit/w	250
10	Site/Landowner Selection	8 h/site	80
	Public Relations		150
10	Data Processing	5 h/site	50
	Web Site Maintenance	3 h/wk	150
10	Labor for Site Visits (Time at site)	6 h onsite	120
10	Labor for Roundtrip Travel to Site Visits		
	Average distance 100 miles	*4 h travel*	*80*
	Average distance 200 miles	*8 h travel*	*160*
10	System Maintenance / Overhaul / Testing	10	100

Total Annual Hours	980 to 1060

Additional Requirements Not Listed Above
Office Space and Furniture
Office Phone
Workshop / Storage Space
Hand Tools Necessary For Routine Anemometer Mainenance
Computer Base Station with Internet
Recalibration of Anemometers Every Two Years

Notes
Transportation costs assume roundtrips at $0.35/mile
Each system is assumed to have 2 site visits per year for installation and removal.
Transportation costs assume no overnight travel and no overtime expenses.
"Quantity" refers to number of anemometer systems operated by program.
Hours listed above assume experienced laborer. During program start-up, tasks will take longer.

Projected Anemometer Program Costs July 18 '03
Program based on minimizing capital costs of anemometers.
(Requires on-site power, no communication, only cup anemometers.)

Capital Costs

Quantity	Item	Unit Price	Cost
10	NRG-NOW 20 m Systems	1700	17000
1	Datakit 2	1000	1000
2	Tower Installation Kit	750	1500

Capital Costs	19500

Annual Operating Costs

Quantity	Item	Unit Price	Cost
10	Replacement Parts (cups, vanes, misc. every 2 years)	150	1500
20	Transportation to Install/Remove Systems		
	Average distance 100 miles	*70*	*1400*
	Average distance 200 miles	*140*	*2800*
	Clerical Supplies		500
	Office Phone		600

Operating Costs	4000 to 5400

Labor Estimates

Quantity	Annual Labor	Unit Hours	Hours
10	Site/Landowner Selection	8 h/site	80
	Public Relations		150
10	Data Processing	5 h/site	50
10	Processing Data Plugs	1 h/m/site	120
	Web Site Maintenance	3 h/wk	150
10	Labor for Site Visits (Time at site)	6 h onsite	120
10	Labor for Roundtrip Travel to Site Visits		
	Average distance 100 miles	*4 h travel*	*80*
	Average distance 200 miles	*8 h travel*	*160*
10	System Maintenance / Overhaul / Testing	10	100

Total Annual Hours	850 to 930

Additional Requirements Not Listed Above
Office Space and Furniture
Office Phone
Workshop / Storage Space
Hand Tools Necessary For Routine Anemometer Mainenance
Computer Base Station with Internet
Recalibration of Anemometers Every Two Years

Notes
Transportation costs assume roundtrips at $0.35/mile
Each system is assumed to have 2 site visits per year for installation and removal.
Transportation costs assume no overnight travel and no overtime expenses.
"Quantity" refers to number of anemometer systems operated by program.
Hours listed above assume experienced laborer. During program start-up, tasks will take longer.

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APPENDIX A: Purchased Components of Prototype Wind Information Recording System

	Campbell Scientific w/ Vaisala Components	
Sonic Anemometer	425A 2D Sonic Anemometer (Vaisala)	1,700.00
Cup and Vane	03011-L12 RM Young Wind Sentry	465.60
RH/Temperature	435E RHAT Sensor (Vaisala)	712.00
Radiation Shield	442C Solar Shield (Vaisala)	216.00
Datalogger	CR10X-2M Datalogger	1,296.00
Cell Com. System	COM100 Analog System	624.00
	COM210 Telephone Modem	379.20
	10530 8 dB Yagi	153.60
	13366 Cellular Handset	135.00
	SC32A RS-232 Interface	139.20
Solar Power System	MSX20 20W solar panel	398.40
	CH12R 12V Charger/Regular	177.60
	BP12 12AHr Sealed Battery	91.20
Tower	CM6 6 ft tripod and grounding kit	331.20
Crossarm	UT108	91.20
Enclosure	ENC 16/18	321.60
Cables	9661 12 ft cable	3.12
	9720 12 ft cable	6.72
	1017 hard crossover	12.48
	6880 Wind Sentry bracket	57.60
Software	Loggernet Software	379.20
Shipping	UPS Ground	165.00
Total Cost		**7,855.92**

Notes

Better priced than competing sonic systems.
Sonic anemometer and temp/RH reliable and field tested.
Campbell dataloggers used and recommended by other researchers.
Industry-standard for atmoshpheric science.
Includes educational discount.

APPENDIX B: Cost Comparisons of Other WIR Systems

	Met One		**Vaisala** (based on RAWS system)		**NRG Systems**	
Sonic Anemometer	50.5 2D Anemometer	1,350.00	425A 2D Sonic Anemometer	1,650.00	None Available	
Cup Aneomemeter	014A Wind Speed	225.00	430A Wind Speed	468.00	1899 NRG #40 Cup Anemometer	97.00
Wind Direction	024A Wind Dir.	337.50	431A Wind Dir.	645.00	1904 NRG #200P Direction Vane	165.00
RH/Temperature	083D-1-35 humidity/temp.	675.00	HMP45AH	712.00	1906 NRG #110S Temp w/ Rad Shield	195.00
Radiation Shield	073B Naturally Aspirated	157.50	442A Convection Aspirated	174.00	2047 Relative Humidity Sensor	275.00
Datalogger	466A Weatherproof	1,417.50	555B DCP MET Painted Steel	2,256.00	3147 Symphonie Logger	1,250.00
			555-7007 Met Configuration Panel	1,354.00	3158 Symphonie MMC Reader	50.00
Cell System	MX-911 Cell w/ phone, ant.	1,295.00	Vaisala Cell Phone Module	add'l	3162 AMPS iPack	1,105.00
Modem			555-7019 Modem	635.00		
Antenna					3163 AMPS 6 dB Antenna	125.00
Solar Power	30W Panel w/ 36 Ahr battery	850.00	540-7037 20W Panel unregulated	500.00	3160 5W PV Panel	125.00
			Battery/regulator	add'l		
Tower			403A 20 ft Tower	2,443.00		
Crossarm	191-1 crossarm assembly	135.00				
Enclosure					3159 Symphonie Shelter Box	105.00
Mounts	Orientation fixture for 50.5	67.50				
	2x 193 univ. tower mount	135.00				
Cables	40 ft cable for 50.5	63.00	425-3492 cable 425A/555B	187.00	1930 11m 2C Sensor Cable	13.00
	40 ft cable for wind speed	63.00	540-3428 28 ft WS/WD cable	559.00	1935 11m 3C Sensor Cable	13.00
	40 ft cable for wind dir.	63.00	550-3310 10 ft RH/AT cable	232.00	3153 SCM Card for 110S	25.00
	40 ft cable for temp/RH	63.00			3156 SCM Card for RH5	25.00
Software						
Shipping					Ground shipping complimentary	0.00
	(Tower not included)		(Not all components included in price)		(Tower not included)	
Total Cost		**6,897.00**		**11,815.00**		**3,568.00**

Notes

Met One	Vaisala	NRG Systems
Delicate sonic anemometer which must be factory recalibrated	Sonic anemometer, temp/RH reliable and field tested.	Specialize in wind energy specific, "turn-key" systems.
Less field tested than Campbell, Vaisala equipment	Components more expensive than competing systems	Do not offer sonic anemometer
50.5 has same resolution and accuracy as 425A	Does not include shipping	
Does not include shipping		

APPENDIX C: Wind Tunnel Calibration Results for Vaisala and RM Young Anemometers

Comparison of RM Young Wind Sentry and Vaisala Sonic Anemometer to Hotwire Measurements in UCD ABLWT on Oct. 21 '02

Each case below was run for 5 minutes. Datalogger (CR10X) ouput is once per minute. All recorded data for each five minute period is presented below.

Vaisala — Wind from 270

Hotwire	CR10X						Uavg [m/s]	Dir [deg.]								Hotwire Uavg	Anemometer Uavg	% Difference
Uavg = 3.299	101	2002	294	1656	0	140	3.302	264.8	-2.059	41.09	12.28	0	26.13	0	3.598	3.299	3.293	-0.181873
Urms = 0.168	101	2002	294	1657	0	140	3.272	266.5	-2.059	41.12	12.31	0	26.16	0	3.496			
Turb Int % = 5.09	101	2002	294	1658	0	140	3.293	266.2	-2.059	41.12	12.28	0	26.16	0	3.691			
	101	2002	294	1659	0	140	3.308	266.2	-2.06	41.05	12.32	0	26.16	0	3.506			
	101	2002	294	1700	0	140	3.29	267.7	-2.056	40.99	12.32	0	26.16	0	3.487			

Vaisala — Wind from 180

Hotwire	CR10X						Uavg [m/s]	Dir [deg.]								Hotwire Uavg	Anemometer Uavg	% Difference
Uavg = 3.277	101	2002	294	1621	0	140	3.093	178.8	-1.661	41.65	12.29	0	25.99	0	3.469	3.277	3.1044	-5.267013
Urms = 0.168	101	2002	294	1622	0	140	3.098	179	-1.66	41.58	12.32	0	25.99	0	3.349			
Turb Int % = 5.14	101	2002	294	1623	0	140	3.108	178.8	-1.675	41.58	12.32	0	25.99	0	3.358			
	101	2002	294	1624	0	140	3.122	177.6	-1.722	41.58	12.32	0	25.99	0	3.487			
	101	2002	294	1625	0	140	3.101	178.9	-1.728	41.45	12.29	0	25.99	0	3.478			

Vaisala — Wind from 90

Hotwire	CR10X						Uavg [m/s]	Dir [deg.]								Hotwire Uavg	Anemometer Uavg	% Difference
Uavg = 3.277	101	2002	294	1635	0	140	3.154	87.4	-1.86	41.38	12.32	0	26.05	0	3.478	3.277	3.1462	-3.991456
Urms = 0.17	101	2002	294	1636	0	140	3.16	89	-1.862	41.32	12.32	0	26.05	0	3.385			
Turb Int % = 5.2	101	2002	294	1637	0	140	3.129	88.9	-1.862	41.32	12.32	0	26.05	0	3.339			
	101	2002	294	1638	0	140	3.127	90.4	-1.866	41.25	12.32	0	26.05	0	3.376			
	101	2002	294	1639	0	140	3.161	88.9	-1.915	41.25	12.32	0	26.05	0	3.487			

Vaisala — Wind from 0

Hotwire	CR10X						Uavg [m/s]	Dir [deg.]								Hotwire Uavg	Anemometer Uavg	% Difference
Uavg = 3.307	101	2002	294	1644	0	140	3.081	353.5	-1.964	41.18	12.32	0	26.07	0	3.358	3.307	3.0844	-6.731176
Urms = 0.172	101	2002	294	1645	0	140	3.087	-1.504	-1.988	41.12	12.28	0	26.07	0	3.358			
Turb Int % = 5.21	101	2002	294	1646	0	140	3.091	354.3	-1.993	41.05	12.32	0	26.1	0	3.487			
	101	2002	294	1647	0	140	3.077	1.222	-1.992	41.05	12.32	0	26.1	0	3.478			
	101	2002	294	1648	0	140	3.086	1.786	-1.993	40.92	12.32	0	26.1	0	3.284			

RM Young — Wind from 270

Hotwire	CR10X						Uavg [m/s]	Dir [deg.]								Hotwire Uavg	Anemometer Uavg	% Difference
Uavg = 3.232	101	2002	294	1401	2.912	267.2	0.599	295	-0.995	41.48	12.28	0	25.02	3.2	1.008	3.232	2.9046	-10.12995
Urms = 0.166	101	2002	294	1402	2.9	271.9	0.487	302	-1	41.42	12.32	0	25.02	3.2	0.768			
Turb Int % = 5.14	101	2002	294	1403	2.912	268.7	0.458	295	-1	41.45	12.32	0	25.04	3.2	0.786			
	101	2002	294	1404	2.887	268.6	0.549	274.4	-1.032	41.38	12.32	0	25.04	3.2	0.879			
	101	2002	294	1405	2.912	270.4	0.611	310.6	-1.066	41.32	12.32	0	25.07	3.2	1.008			

RM Young — Wind from 180

Hotwire	CR10X						Uavg [m/s]	Dir [deg.]								Hotwire Uavg	Anemometer Uavg	% Difference
Uavg = 3.213	101	2002	294	1409	2.95	180.8	0.574	319.9	-1.176	41.25	12.28	0	25.13	3.2	0.916	3.213	2.9524	-8.1108
Urms = 0.169	101	2002	294	1410	2.925	181.4	0.552	266.3	-1.199	41.12	12.32	0	25.15	3.2	0.888			
Turb Int % = 5.26	101	2002	294	1411	2.962	181	0.519	307.6	-1.253	40.99	12.32	0	25.15	3.2	0.897			
	101	2002	294	1412	2.95	180.1	0.506	314.5	-1.265	41.19	12.32	0	25.18	3.2	0.879			
	101	2002	294	1413	2.975	181.4	0.59	303.3	-1.32	40.92	12.32	0	25.18	3.2	0.999			

RM Young — Wind from 90

Hotwire	CR10X						Uavg [m/s]	Dir [deg.]								Hotwire Uavg	Anemometer Uavg	% Difference
Uavg = 3.244	101	2002	294	1418	2.875	88	0.501	293.7	-1.463	40.72	12.32	0	25.26	3.2	0.999	3.244	2.8824	-11.14673
Urms = 0.171	101	2002	294	1419	2.875	88.9	0.527	284	-1.463	40.79	12.32	0	25.26	3.2	0.999			
Turb Int % = 5.26	101	2002	294	1420	2.9	88.9	0.507	307.6	-1.5	40.72	12.32	0	25.29	3.2	1.008			
	101	2002	294	1421	2.887	89.5	0.544	314.5	-1.53	40.82	12.32	0	25.29	3.2	0.897			
	101	2002	294	1422	2.875	88.8	0.54	314.5	-1.53	40.72	12.32	0	25.32	3.2	0.999			

RM Young — Wind from 0

Hotwire	CR10X						Uavg [m/s]	Dir [deg.]								Hotwire Uavg	Anemometer Uavg	% Difference
Uavg = 3.218	101	2002	294	1425	2.812	0.94	0.589	300.7	-1.593	40.66	12.32	0	25.35	3.2	1.129	3.218	2.8222	-12.29956
Urms = 0.169	101	2002	294	1426	2.812	0.094	0.545	300.9	-1.644	40.66	12.32	0	25.38	3.2	1.008			
Turb Int % = 5.25	101	2002	294	1427	2.825	0.188	0.584	324.2	-1.662	40.69	12.32	0	25.38	3.2	1.018			
	101	2002	294	1428	2.825	0.094	0.562	289.6	-1.662	40.66	12.32	0	25.4	3.2	0.897			
	101	2002	294	1429	2.837	1.222	0.598	295	-1.707	40.59	12.32	0	25.4	3.2	1.008			