Wind Energy Resource Evaluation on Venezuela: Part I

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***Abstract*—This paper is a first step of the wind energy resource evaluation on Venezuela, and show the main results of this. Two sets of data were analyzed, one set was obtained directly from ground measures of wind speed, and this was used to found the local wind resource. Several tables and maps were developed, for some different scale of times: annual, season, monthly diary and hourly. Four zones was found with sufficient potential to be exploited with commercial purpose, and this research recommend local ground measures of wind speed for this and another places candidates to be evaluated.**

***Index Terms*— Average speed, wind energy, wind resource, wind speed.**

I. Introduction

VENEZUELA is a country on the northern tropical Caribbean coast of South America. Venezuela borders Brazil to the south, Guyana to the east, and Colombia to the west. North of the Venezuelan coast lie the islands of Aruba, the Netherlands Antilles, and Trinidad and Tobago. With 916.050 km^2, Venezuela is home to a wide variety of landscapes, such as the north-easternmost extensions of the Andes Mountains in the northwest and along the northern Caribbean coast, of which the highest point is the Pico Bolívar at 4,981 m. The center of the country is characterized by extensive plains known as the llanos, and the south are found the dissected Guayana Highlands.

Recently the Venezuelan government has begun a more aggressive policies and incentives on renewable energy resources. An important fact is the Venezuela incorporation on Kyoto Protocol and his ratification on December 7 of 2004. Over last two years, special concern on wind energy has been important by the Venezuelan Government. The Business Planning 2005-2012 of the most important Venezuelan petroleum company, *Petróleos de Venezuela S.A.* (PDVSA), include several energetic projects with wind resources, solar energy and fuel cell on transport application. Project for installation of five wind farms in the archipelagoes Los Roques and Los Monjes and in the islands La Tortuga, La Ochila and La Blanquilla [1]. This wind farms, will be added to two project of wind farms to be developed on La Guajira and La Peninsula de Paraguaná[2]. Some preliminary studies indicate the possibility of installations of some wind farm up to 100 MW on La Peninsula de Paraguaná [3]. Although, a wind speed atlas or a full evaluation of the wind resources in Venezuela is necessary.

Fig. 1. Wind Farm to be installed on La Península de Paraguaná [3].

This paper shows a first step on the development of full evaluation of the wind resources for Venezuela. A wide variety of data types and analysis techniques may be utilized in performing the regional wind energy resource assessments and ultimately producing a wind energy atlas. In this first step, we use two sets different of data.

One data set is provided by the NASA Earth Science Enterprise (ESE) program's satellite and reanalysis research data [4], and the second data set is obtained from ground measurement data provided by Meteorology Service of Venezuelan Air Force.

II. Data Collection and Treatment

This paper is the first step to make an atlas to estimate wind energy resource for the Venezuela. The main idea is indicate general areas where a high wind resource may exist. This information is valuable to wind energy developers and potential wind energy users because it allows them to choose a general area of estimated high wind resource for more detailed examination.

This wind energy resource atlas is a synthesis and update of specific resource assessments that were performed by two different sources: (1) NASA Earth Science Enterprise (ESE) program's satellite and reanalysis research data [4], and ground measurement data provided by Meteorology Service of Venezuelan Air Force.

A. Meteorology Service of Venezuelan Air Force

The needs of meteorological information to guarantee major safety to the air operations motive the creation of the Service of Meteorology of the Air Force, on October 10, 1947. This military institution provides information and climatological advice in support to the activities of the armed force and organizations that like that need it. To collect, summarize, process and make forecast, the Meteorology Service of Venezuelan Air Force (VAF), have a network of weather stations located in both rural and urban setting, mainly in airports and military bases (see Table I and Fig. 2).

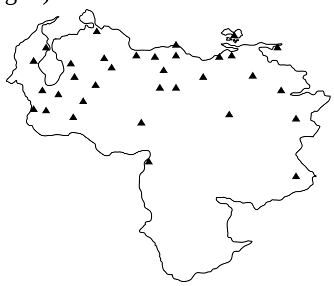

Fig. 2. Meteorology Service of Venezuelan Air Force weather stations network location.

These wheatear stations are provided by devices to collect information of: temperature, wind speed, wind direction, humidity, precipitation, isolation, and other climatic variables.

TABLE I
UNITS FOR MAGNETIC PROPERTIES

Station	*State*	*Longitude, Latitude*
Acarigua	Portuguesa	09º 33'N, 69º 14'W
Barcelona	Anzoátegui	10º 07N, 64º 41'W
Barinas	Barinas	08º 37N, 70º 13'W
Barquisimeto	Lara	10º 07N, 69º 32'W
Calabozo	Guárico	8º 92N,-67º 42'W
Carrizal	Guárico	10° 2'N, 64° 27"W
Cdad. Bolívar	Bolivar	08º 09N, 63º 33'W
Colon	Táchira	08º 07N, 71º 02'W
Colonia Tovar	Aragua	10º 15N, 67º 40'W
Coro	Falcón	11º 25N, 69º 41'W
Cumaná	Sucre	10º 27N, 64º 11'W
Guanare	Portuguesa	09º 01N, 69º 44'W
Guasdualito	Apure	07º 14N, 70º 48'W
Güiria	Sucre	10º 67N, 63º 33W
La Aguada	Mérida	8º 63N, 69º 83W
La Cañada	Zulia	10º 35N, 71º 44W
La Carlota	Dtto. Federal	10° 30' N, 66° 56' W
La Montaña	Mérida	08º 40N, 71º 11'W
Loma Redonda	Mérida	08º 41N 071º 12'W
Maiquetía	Dtto. Federal	9º 65N, 69º 89'W
Maracaibo	Zulia	10º34N, 71º 44'W,
Maracay	Aragua	10º 15N, 67º 39'W
Maturín	Monagas	9º 45N, 63º 11'W
Mene Grande	Zulia	10º33N, 71º 43'W
Mérida	Mérida	8º 36N, 71º 11'W
Palmichal	Carabobo	10º 09N, 67º 55'W
Pico Espejo	Mérida	8º 33'N, 71º 00' W
Porlamar	Nva. Esparta	10º 55N, 63º 59'W
Pto. Ayacucho	Amazonas	5º 36'N, 67º 30'W
San Antonio	Táchira	7º 51'N, 72º 27'W,
San Fernando	Apure	7º 54'N, 67º 25'W
San Juan	Guárico	9º 55'N, 67º 20'W
Santa Elena	Bolívar	4º 52' N, 60º 39' W
Santo Domingo	Táchira	7º 35'N, 72º 04'W
Temblador	Monagas	09º 55'N, 64º 11'W
Tumeremo	Bolívar	7º30'N, 61º45'W
Valencia	Carabobo	10º 10N, 67º 56W
Valle De La Pascua	Guárico	9º 13'N, 66º 01'W

B. NASA Earth Science Enterprise (ESE) program's

The purpose of NASA's Earth Science Enterprise (ESE) is to understand the total Earth system and the effects of natural and human-induced changes on the global environment [5]. The Office of Earth Science comprises an integrated slate of spacecraft and in situ measurement capabilities; data and information management systems to acquire process, archive and distribute global data sets; and research and analysis projects to convert data into new knowledge of the Earth system. The NASA Earth Science Surface meteorology and Solar Energy (SSE) [4] data set contains parameters formulated for assessing and designing renewable energy systems. This contains on-line plotting capabilities allow quick evaluation of potential renewable energy projects for any region of the world. The SSE data set is formulated from NASA satellite- and reanalysis-derived insulation and meteorological data for the 10-year period July 1983 through June 1993. Results are provided for 1° latitude by 1° longitude grid cells over the globe. Average daily and monthly measurements for 1195 World Radiation Data Centre ground sites are also available.

C. Time Scales Considerations

Several time scales are used in the wind resource evaluation: annual, seasonal, monthly, diurnal, and hourly. Annual mean values are based on an average of the one hourly observations of wind speed in the period of record.

However, a complete calendar year's data (covering January 1 to December 31) is used for calculating individual yearly means. On Venezuela, there are not four stations. Although two pseudo-stations are evident, rainy station (May to October) and summer or dry station (November to April). These two seasons are defined by two sets of six month each. The phrase *seasonal trend* refers to the change in monthly mean values over the course of the two seasons. Monthly mean values are based on as many hours of data as are available for that month in each year of the period of record. The daily or diurnal cycles of variation in the hourly mean wind power or speed are referenced to local standard time on a 24-hour clock. Midnight is both 00 and 24.

III. RESULTS

This section presents a summary of the Venezuela wind energy resource.

The first approach is a global analysis using meteorology parameters calculated from ground measurements have been used for determining the viability of Renewable Energy Technology (RET) projects [4].

In contrast to ground measurements, the SSE data set is a continuous and consistent 10-year global climatology of insolation and meteorology data is interpolated on a 1 longitude by 1 degree latitude equal-angle grid covering the entire globe (64,800 regions). Although the SSE data within a particular grid cell are not necessarily representative of a particular microclimate, or point, within the cell, the data are considered to be the average over the entire area of the cell.

Knowledge of the wind regime is crucial to the implementation of any type of wind energy system. The principal descriptive parameter of a wind regime is the annual average wind speed. For this reason, twelve maps was plotted (Figure 3 and 4), one for each month, representative of the average wind speed in m/s for terrain similar to airport (10m) with data from July 1983 to June 1993.

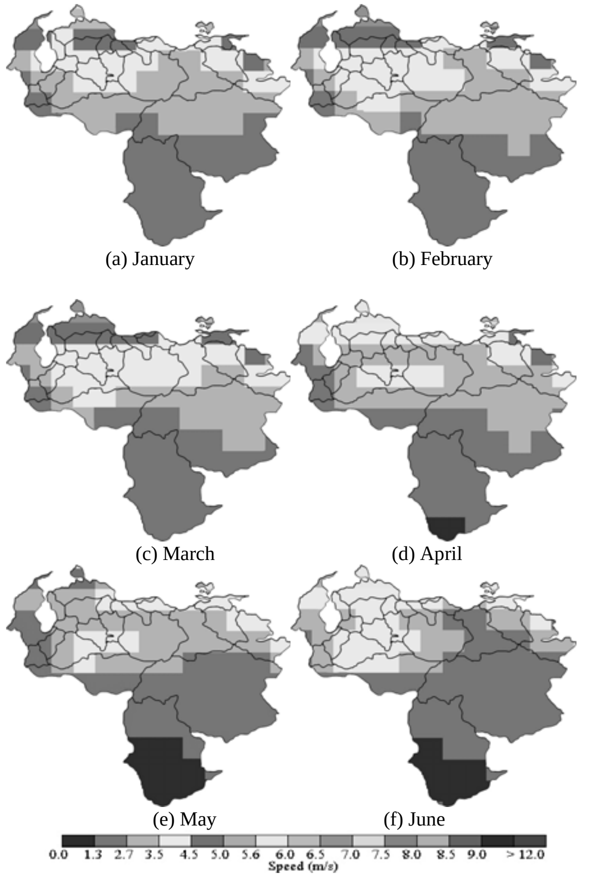

Fig. 3 Monthly Averaged Wind Speed At 10 m (m/s) plotted for January to June

January to July are the months with highest average wind speed in Venezuela (slightly over 3m/s, wind class 3 @ 10,), nevertheless there are valuable differences in monthly average wind between states of north and south of the country. Falcon state, Zulia state and Margarita Island, All coastal places to the north of Venezuela exhibit the highest average wind speed (over 5m/s class 3 or 4 in nine months @ 10m, see Fig. 5), but places states on the south of the country, at more over of 800 km from the coast, like Bolivar and Amazonas state, have the lowest average wind speed (between 0 to 2.7m @ 10m, see Fig. 6) all year.

The anemometer height above the surface rarely was at either the 10-m (33-ft) or 50-m (164-ft) reference levels chosen for the presentation of the wind resource. The power law was used to adjust the long-term mean wind speed or power density to the reference level. Some particular sites, on Venezuela exhibit average wind speed over 6 m/sec (at 50 m) moderate wind–see Table II.

The wind direction is other important component of the wind. In Venezuela the wind direction is mostly constant over all year, measured clockwise from true North, 80º degrees is the direction the wind is coming from typically, with a deviation of ±20º, this is specially true in northern states, on the Southerners places, the wind directions is more changeable, but mainly comes from 80º at 100º.

TABLE II. WIND ENERGY RESOURCES IN SOME PLACES OF VENEZUELA

Location Name	*Latitude/ longitude*	*Average Wind Speed m/s at 50 m*
Cabure	11º 08' N / 69º 38' W	6.18
Capatarida	11º 11' N / 70º 37' W	6.16
Coro	11º 25' N / 69º 41' W	6.18
La Asunción	11º 02' N / 63º 53' W	6.31
La Vela	11º 27' N / 69º 34' W	6.18
Pueblo Nuevo	11º 58' N / 69º 55' W	6.18
Puerto Cumarebo	11º 29' N / 69º 21' W	6.18
Punto Fijo	11º 42' N / 70º 13' W	6.16
San Juan de los Cayos	11º10' N / 68º 25' W	6.23
San Luis	11º 07' N / 69º 42' W	6.18
Paraguaipoa	11º 21' N / 71º 57' W	6.18

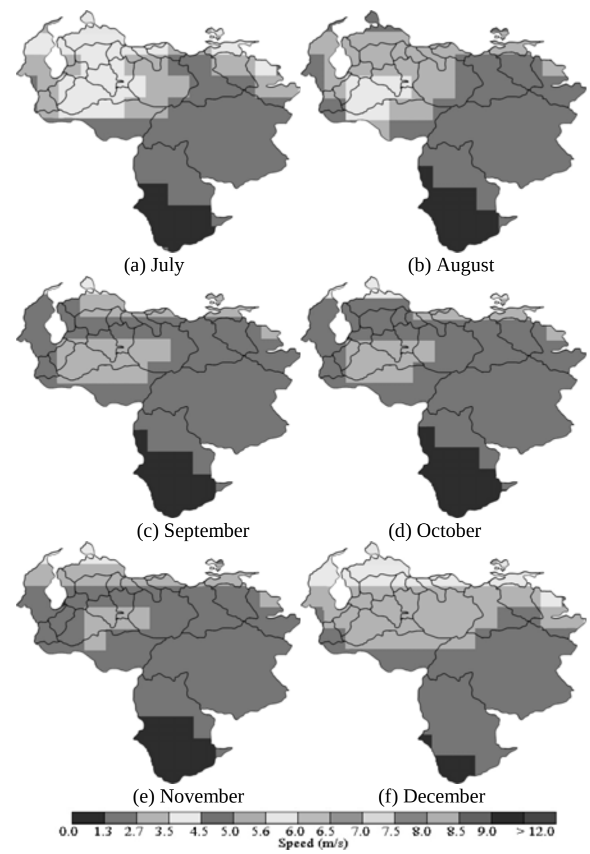

Fig. 4 Monthly Averaged Wind Speed At 10 m (m/s) plotted for July to December

One of the characteristics of wind is that its speed at any moment cannot be estimated based on its speed some moment earlier; that is, wind follows a basically random pattern from in moment to the next. Nevertheless, measured over longer periods of time, winds speeds tend to display a generally predictable frequency distribution. The Weibull distribution has been found to conform well to the distribution of observed wind speeds. A overview of the Weibull distribution permits to describe the variation of wind speeds on Venezuela, average wind speed results over 3 m/s, with high probability (60%) to 3m/s. Again, the northern places have better wind speed profile, and more high speed probabilities than southern places. In Falcon, Zulia and Margarita Island, over 60% probability occurs with average wind speed between 3-10m/s (see fig. 7). In addition, proper evaluation of the wind energy resource also requires that measurements of the air temperature and the atmospheric pressure be taken since this information is also important in determining the energy content in the wind and the appropriateness of the equipment being considered.

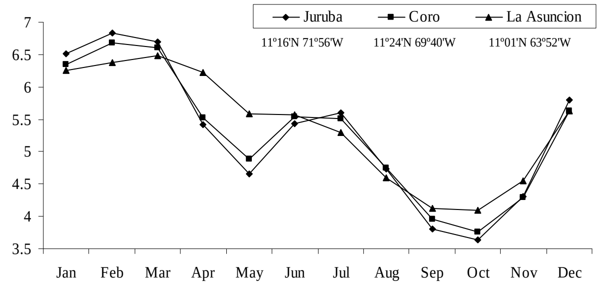

Fig. 5. Monthly Averaged Wind Speed At 10 m Above The Surface Of The Earth For Terrain Similar To Airports (m/s), for three places on north of Venezuela

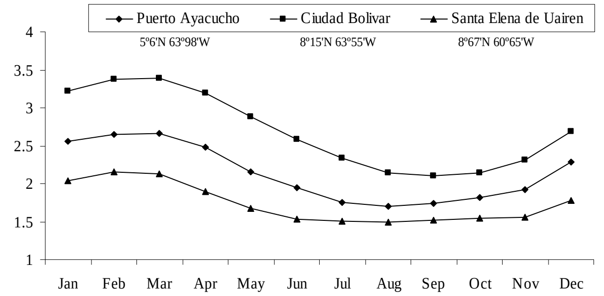

Fig. 6. Monthly Averaged Wind Speed At 10 m Above The Surface Of The Earth For Terrain Similar To Airports (m/s), for three places on south of Venezuela

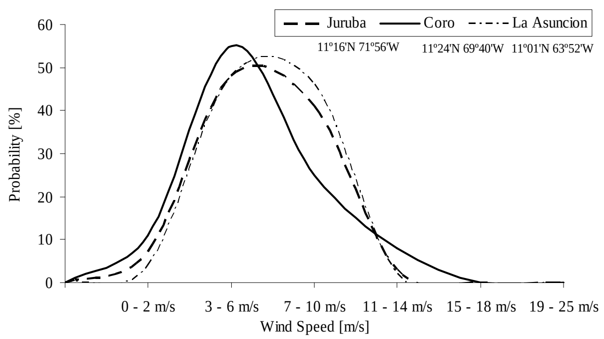

Fig. 7. Weibull Distribution of Wind Speed At 10 m for three places on north of Venezuela

Results of detailed evaluation of each state on Venezuela were realized considering the main meteorology variables. For reasons of space, the results of the analyses affected to every state are not showed here. As example, three places, with wind class 4 are shown: Juruba (Zulia), Coro (Falcon), and La Asunción (Margarita Island), see Figures 7, 8 and 9 respectively.

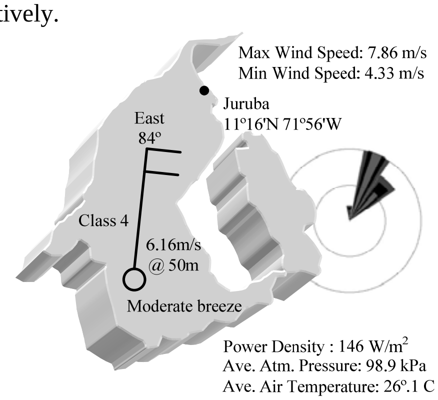

Fig. 7. Summary of main meteorology variables for wind energy resource on Juruba, Zulia.

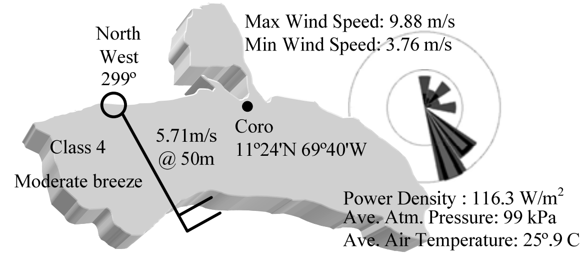

Fig. 8. Summary of main meteorology variables for wind energy resource on Coro, Falcon.

As we known the wind resource evaluation is a critical element in projecting turbine performance at a given site. The class of wind power density is a good indicator for adequate use of the wind resource.

Areas designated class 3 or greater are suitable for most utility-scale wind turbine applications, whereas class 2 areas are marginal for utility-scale applications but may be suitable for rural applications. Class 1 areas are generally not suitable, although a few locations (e.g., exposed hilltops not shown on the maps) with adequate wind resource for wind turbine applications may exist in some class 1 areas. The degree of certainty with which the wind power class can be specified depends on three factors: the abundance and quality of wind data; the complexity of the terrain; and the geographical variability of the resource.

TABLE III. CLASSES OF WIND POWER DENSITY AT 10M AND 50M[(A)]

Wind Power Class	*10 m (33 ft)*		*50 m (164 ft)*	
	Wind Power Density (W/m^2)	*Speed[(b)] m/s (mph)*	*Wind Power Density (W/m^2)*	*Speed[(B)] m/s (mph)*
1	<100	<4.4 (9.8)	<200	<5.6 (12.5)
2	100 - 150	4.4 (9.8)/5.1 (11.5)	200 - 300	5.6 (12.5)/6.4 (14.3)
3	150 - 200	5.1 (11.5)/5.6 (12.5)	300 - 400	6.4 (14.3)/7.0 (15.7)
4	200 - 250	5.6 (12.5)/6.0 (13.4)	400 - 500	7.0 (15.7)/7.5 (16.8)
5	250 - 300	6.0 (13.4)/6.4 (14.3)	500 - 600	7.5 (16.8)/8.0 (17.9)
6	300 - 400	6.4 (14.3)/7.0 (15.7)	600 - 800	8.0 (17.9)/8.8 (19.7)
7	>400	>7.0 (15.7)	>800	>8.8 (19.7)

(A) Vertical extrapolation of wind speed based on the 1/7 power law

(B) Mean wind speed is based on the Rayleigh speed distribution of equivalent wind power density. Wind speed is for standard sea-level conditions. To maintain the same power density, speed increases 3%/1000 m (5%/5000 ft) of elevation.

A more detailed evaluation of wind energy resource is presented for Margarita Island (Fig. 9).

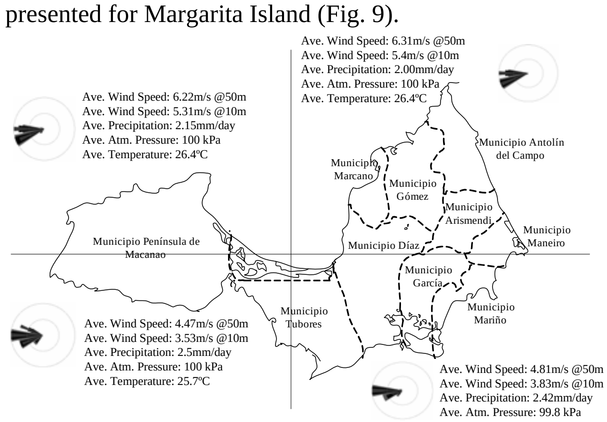

Fig. 9. Summary of main meteorology variables for wind energy resource on Margarita Island.

Four zones are clearly defined on Margarita Island by metrological variables, two northern with average wind speed is over 6m/s @ 50m, class 3 of wind power density, suitable for most utility-scale wind turbine applications, and the wind rose shown a good distribution of this wind, and the Weibull distribution indicate a high probability of wind between 3 and 12 m/s.

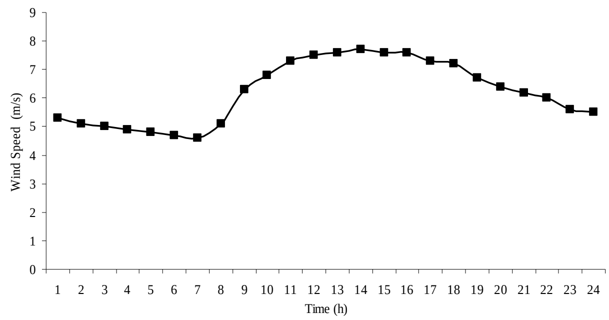

Fig. 10. Hourly Averaged Wind Speed At 10 m Above The Surface Of The Earth For Terrain Similar To Airports (m/s), for Margarita Island

Using a ground measure of wind speed, we plot the hourly average wind speed (Fig. 10). Between 11 and 18 hours, the average speed result over 7m/s, with a maximum speed of 7.7 m/s, and minimum of 4.9 m/s before 1 hour.

A simple analysis considering the variability hourly of the wind speed, atmospheric pressure and temperature, permit infer about 3.9 kWh/m^2 during a typical average day on Margarita Island, over a 1.3 MWh/m^2 during a typical year. As consequence, of this approach, the north of Margarita Island have wind energy resources suitable to utility-scale wind energy application.

IV. Conclusion

This paper result novelty for some things, but the most important result, are three well defined sites on Venezuela with sufficient wind resources to develop preliminary studies for wind farm, with locally ground measures. These places are: the Venezuelan Guajira at Zulia, La peninsula de Paraguaná on Falcon, and Margarita Island. In this paper was demonstrated with a simple approach, that places on the north of Margarita Island have wind energy resources suitable to utility-scale wind energy application. A collection of data, tables, maps, are products of this research, and we recommend a further research to impulse a wide network of weather stations, with remote capacity of measure and data transfer.

The type of wind data which ideally would be available include: average wind speed, frequency distribution, height scaling factor (roughness index), directional distribution, distribution of wind speeds over time, turbulence, extremes, surrounding topography. Further work, will develop and include more of this data.

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