PRELIMINARY STUDY ON ISLAND-WIDE MODELING OF WIND POWER OVER JAMAICA

Dharmaratne Amarakoon[*], **A. Anthony Chen**

Climate Studies Group, Department of Physics
University of the West Indies, Kingston 7, Jamaica

ABSTRACT

A preliminary simulation of wind (speed and power) by computer modeling over Jamaica has been performed, on a grid having a resolution of 1 km x 1 km, using the software *Wind*Map v 2.21 which is designed for use with geographical information systems (GIS). This software provides an estimate of wind speed and power at any site from a knowledge of average prevailing wind speeds and directions, terrain elevation, slope, and vegetation or surface roughness. Annual average wind data from three surface stations Munro, Manley and Sangster were used to initialize the software. Elevation and surface roughness parameters were supplied from digitized satellite maps. Results indicate that (i) *Wind*Map predicts annual mean wind speeds reasonably well, deviations in tested cases lie between 1 and 14%, and also the influence of elevation and surface roughness seem to be represented well, (ii) there is a variability in annual mean wind speed and power from parish to parish with Portland, St. Thomas, Manchester and St. Elizabeth recording high values in that order, and Manchester appear to have the largest extent of wind field, and (iii) inland sites are more favorable for wind power utilization than coastal sites.

Keywords: *Annual mean wind speed and power, elevation, grid resolution, simulation of wind, surface roughness, wind turbine.*

INTRODUCTION

Since the energy crisis of the 1970's, there have been on and off efforts (Chen, 1980; Chen et al., 1990; Wright, 1998) to find suitable sites for wind power generation in Jamaica, mainly for electricity generation and irrigation. While these efforts have located several good potential sites for irrigation, there have been few identifiable sites for electricity generation. One of the problems of site prospecting in Jamaica is that it has been impossible to cover the entire island. This is because site prospecting as done in Jamaica involves selecting sites from map surveys, mainly based on elevation, and visiting the site and possibly setting up anemometers and wind vanes to measure the wind power for a period, preferably of at least one year. This process is necessarily time consuming and costly. As a result survey of sites, island wide, has been less than comprehensive.

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*Corresponding Author. Tel: (876) 927 2480; Fax: (876) 977 1595
E-mail: amarak@uwimona.edu.jm

Computer simulation (mapping) of wind (speed, power and turbine output) by modeling over Jamaica on a suitable grid is a possible solution to part of the problem. The problem of in situ site measurements still remains. But the advantage of simulation is the fact that it helps to identify potential sites, without detailed field measurements, thus avoiding time consuming and costly procedures. Also simulation can easily provide an estimate of the extent of the wind field, an aspect that is difficult to accomplish without recourse to laborious procedures.

This paper reports the preliminary results of such a computer simulation done using the software *Wind*Map v 2.21 (Brower and Co., 2000). The software is designed to use with geographical information systems (GIS). It has the ability to simulate (map) wind across an entire region at levels greater than 10 m, irrespective of the complexity of the region (Brower et al., 1996; Brower, February 1997; Brower, September 1997). The surface grid resolution associated with *Wind*Map is 1 km x 1 km and the input data required to initialize it and map wind are: prevailing wind speeds and directions from surface stations, horizontal cartesian (x and y) coordinates (referenced to a suitable origin) of the surface stations, and elevation and roughness parameters of the region defined on a 1 km x 1 km grid scale. In this work, prevailing wind data available at the Meteorological Office, Physics Department of the Mona Campus, UWI, and Petroleum Corporation of Jamaica were used in the analysis. Digitized satellite maps purchased from Brower and Company, Andover, MA, USA supplied the required elevation and roughness parameters on a 1 km x 1km grid scale.

MEASUREMENTS AND DATA ANALYSIS

The surface stations used in the analysis were Munro, Manley, Sangster, Mona and Blenheim. Wind data (speed and direction) from Munro, Manley and Sangster along with a wind rose having 12 sectors were used to initialize *Wind*Map and map the wind field across the island. Data from Mona and Blenheim together with annual mean wind speeds predicted by *Wind*Map at Munro, Manley and Sangster were used to evaluate the applicability of the software. The instruments used at the stations were conventional cup anemometer and wind vane systems. Table 1 presents the physical characteristics of the surface stations; wind measuring heights, period of data collection, mean wind speed and predominant wind direction from North. The term 'mean' as used in this work refers to the mean of any quantity that was obtained after averaging over the period of data collection. In this regard, except Blenheim, mean quantities are annual means. Wind speed and direction used in the analysis were hourly values. Raw data from Munro, Manley and Sangster were 10-minute values. These were reduced to hourly values using software WinSite (Second Wind Inc., 1995) and Excel. Raw data from Mona and Blenheim were hourly values.

Data analysis comprised of executing *Wind*map under different scenarios, performing in-house calculations to determine percentage deviations of the predicted results from the measured values and creating wind maps that predict mean wind speeds and power. Different scenarios were possible because of the options available. Options considered were: atmospheric stability (neutral and unstable), the choice of a reference station in the initialization, weighting of stations used in the initialization and minimizing of root mean square error. Stability was considered because studies (Chen et al., 1987) have shown that atmosphere in the vicinity of Mandeville is unstable and the station Munro is in the proximity of Mandeville. Overall, model results tested did not show significant difference under neutral and unstable scenarios and the results reported here were obtained under neutral stability scenario. The selection of one station as the reference station is an important requirement in the use of the software. Primary reason is to optimize execution time that has to accommodate many iterations. Reference station is the one that provides frequency of wind by direction to all the stations used in initializing the model. A problem that encountered in our work because of associating the frequencies of the reference station with the other stations was the fact that at some stations there was significant difference, greater than about 15%, between the measured annual mean wind speeds and the weighted means based on the reference frequencies. Mean wind speeds are required to create the initial wind field. The problem encountered was resolved by comparing the measured mean and the weighted mean based on the reference frequencies for a station, and adjusting the speed (Brower, 2001) for each direction so as to restore the correct mean. Since only three stations (Munro, Manley and Sangster) were used in this work, simulations of annual mean wind speeds were done using these stations as reference stations in turn. However, since Munro was an inland site and the anemometer-vane system at 30 m was well exposed to wind, the results for wind power across the island and the parish based results for speed and power given in the results section are referenced to Munro. Weighting of stations is another aspect that has to be considered in running the model. Weighting is required for the model to account for all the variations (due to elevation, roughness, slope) among the stations. In the analysis it was observed that when all the initializing stations are of equal weight, the model is stable (iterations converge) and the results appear better. Therefore the results reported correspond to equally weighted stations. GIS software ILWIS 2.1 (IIASES, 1997) was used to edit the digitized maps of wind speed and power produced by *Wind*Map.

RESULTS, DISCUSSION AND CONCLUSION

Tables 2 to 3 and figures 1 to 5 present the results obtained in this study. From the predicted mean wind speeds for Munro (at 30 m), Blenheim (at 40 and 20 m) and Mona (at 16 m) appearing in table 2 it is clear that *Wind*Map extrapolates wind speed, vertically, fairly well. Three different scenarios of initializing are given in table 2. One is initializing with 10 m Munro data, other is with 20 m Blenheim data and the next is 30 m Munro, 10 m Manley and 10 m Sangster data with Munro as the reference station. Percentage deviation at Munro is 12.3%, at Blenheim 9.8, 14 and 9.3% and at Mona 8.6%. Percentage deviations of the order of 14% in any quantity are acceptable in our work when the uncertainties in the measured wind speeds, directions and surface parameters (coordinates, elevation and roughness) are all considered. Under neutral atmospheric conditions, model assumes the logarithmic wind profile for extrapolation, which is acceptable. Results are further appealing when one considers the annual mean wind speeds for Munro, Manley and Sangster recorded in figures 1, 2 and 3. These were the values predicted by *Wind*Map. A comparison of these with the measured means given in table 1 reveal that the predicted values are within a few percent (0.6 to 7%) of the measured means. Table 3 presents a sample of results to illustrate the ability of *Wind*Map to account for elevation and roughness. Under normal conditions, in the absence of severe events such as hurricanes, strong gusts etc., large roughness values produce large wind shear and hence low wind speeds at low elevations, and higher elevations for a given roughness are associated with higher winds. Generally, these features were seen in the wind speeds simulated by *Wind*Map of which a sample is given in table 3. Thus, it appears that the software has the ability to represent the influence of elevation and roughness well. This aspect is important as topography of Jamaica based on elevation and local roughness is fairly complex.

Figures 1 to 3 present the mapped mean wind field (mean speed distribution) across Jamaica with Munro, Manley and Sangster as the reference station selected in that order. The speeds given are at 30 m height from the surface. In the maps, the darker the shade the higher is the wind speed. A closer look at the three maps yields the following observations. (i) There is considerable overlap among the wind regimes shown in the maps. That is to say, for example an area shown as a high wind regime in one map is more or less the same high wind regime shown in the other maps or a low wind regime shown in one map is the same as that in other maps. This is encouraging as the dependency of the final results on the directional frequency distribution of the reference station can be treated as tolerable, if not minimal. (ii) Highest wind speeds are seen in Portland/St. Thomas parishes, but wind fields (with speeds greater than about 4.5 ms^{-1}) larger in extent are seen in the parish of Manchester followed by St. Elizabeth. (iii) Simulation done with Munro referenced appear to represent the average results of the three simulations. One simulation is Munro referenced, other one is Manley referenced and the next is Sangster referenced.

Figure 4 presents the simulated mean wind power (at 30 m) distribution across Jamaica and figure 5, the extremes of speed and power on a parish basis. Because of (iii) above and also Munro was an inland site with the measuring system at 30 m well exposed to wind, estimates of mean wind power across Jamaica as given in figure 4 and the parish based results for speed and power given in figure 5 were simulated using Munro as the reference station. The wind power at 30 m at the three stations are also recorded in the map (figure 4). The results for wind power shows that inland sites have more power than coastal sites with the parishes Portland/St. Thomas, Manchester and St, Elizabeth again dominating which is apparent from the results in figure 5 also. The second quantity in MWh (673 MWh) at Munro (see figure 4) represents the energy that can be expected, based on simulation, if a turbine Vestas V29-225 kW operates at Munro for one year (August 1, 1996 to July 31, 1997). This energy value agrees closely (within 2%) with the value that can be obtained using the software WinSite. The expected energy calculated for Vestas V29-225 kW turbine using WinSite was 689 MWh. Assuming the same turbine at Munro, the expected energy simulated with Manley and Sangster referenced were 639 MWh and 638 MWh, respectively. These values agree with the WinSite value to within 8%. WinSite is a software that is being used for single-station calculations rather than for simulation over large regions. These agreements are encouraging as they justify the validity of the simulated wind power values. Furthermore, simulated power, at 20 m, compares roughly with the power estimated by Chen et al. (1990). A limitation in the study is the fact that only 3 surface stations were used to initialize the model. Use of more stations, when available may provide better magnitudes for wind speed and power.

In conclusion we may state that the preliminary results presented in the preceding section, based on computer simulation, show that Jamaica has potential for wind power utilization, which supports the previous studies (Chen et al., 1990). Parishes Manchester, St. Elizabeth and Portland/St. Thomas appear quite suitable for in-depth exploration in relation to electricity generation by wind power. The extent of the wind fields seen in Manchester and St. Elizabeth indicate that the areas are suitable for wind farming. It is a pleasure to state that the exploration activities that are presently being conducted in Manchester by the Petroleum Corporation of Jamaica are in the right direction. This work primarily dealt with annual means of speed and power. From the magnitudes of the simulated means it is apparent that during summer months (a period in which supplementary power is required) one can expect higher speeds and power over most parts of the island.

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TABLE 1. Names of the surface stations, their physical characteristics (elevation and roughness), period of data collection and number of data hours, wind speed and direction measuring heights, Mean wind speed, and predominant direction from North.

Station	Elevation (m)	Roughness (m)	Period of data collection and data hours	Measuring heights (m)	Mean wind speed measured (m/s)	Predominant direction from North (degrees)
Munro	766	0.2	August, 1996 to July, 1997 (8750 hours)	10 30	5.51 7.17	90 90
Manley	0 (sea level)	0.001	January, 1998 to Dec., 1998 (8340 hours)	10	4.06	120
Sangster	0 (sea level)	0.001	September, 1996 to August, 1997 (7925 hours)	10	3.82	30
Mona	186	0.06	January, 1996 to Dec., 1996 (8248 hours)	16	1.85	90
Blenheim[a]	609	0.66	May, 1998 to Dec., 1998 (4247 hours)	20 40	3.88 5.83	300 300

[a] Blenheim data set was from Dr. Raymond Wright, Petroleum Corporation of Jamaica.

TABLE 2. Part of the results obtained and used to evaluate the applicability of the software *Wind*Map v 2.21.

Scenario	Initializing station or stations	Predicted mean wind speed and height (m/s)	Percent deviation from measured mean
1	Munro, 10 m	8.05 at 30 m, Munro	12.3
2	Blenheim, 20 m	6.40 at 40 m, Blenheim	9.8
3	Munro[a], 30 m	5.01 at 40 m, Blenheim	14.1
	Manley, 10 m	4.24 at 20 m, Blenheim	9.3
	Sangster, 10 m	2.01 at 16 m, Mona	8.6

[a] Munro was the reference station in this scenario.

TABLE 3. A sample of results used to examine the ability of *Wind*Map to account for elevation and roughness variations.

X Coordinate[a] (m)	Y Coordinate[a] (m)	Elevation[b] (m)	Roughness[b] (m)	Mean wind speed[c] at 30 m, (m/s)
209000	1998000	281	0.20	6.38
214000	2036000	80	0.375	3.54
216000	1983000	766	0.20	7.14
218000	1980000	605	0.06	6.77
257000	2005000	221	0.06	3.52
347000	1991000	1026	1.125	5.85
356000	1988000	384	1.125	3.59

[a] X and Y map coordinates are referenced to North Negril point (146000 m, 2033000 m). [b] Elevation and roughness values are from the digitized satellite maps; Brower and Co., Andover, MA 01810, USA. [c] These are simulated speeds using Munro, Manley and Sangster to initialize the model with Munro as the reference station.

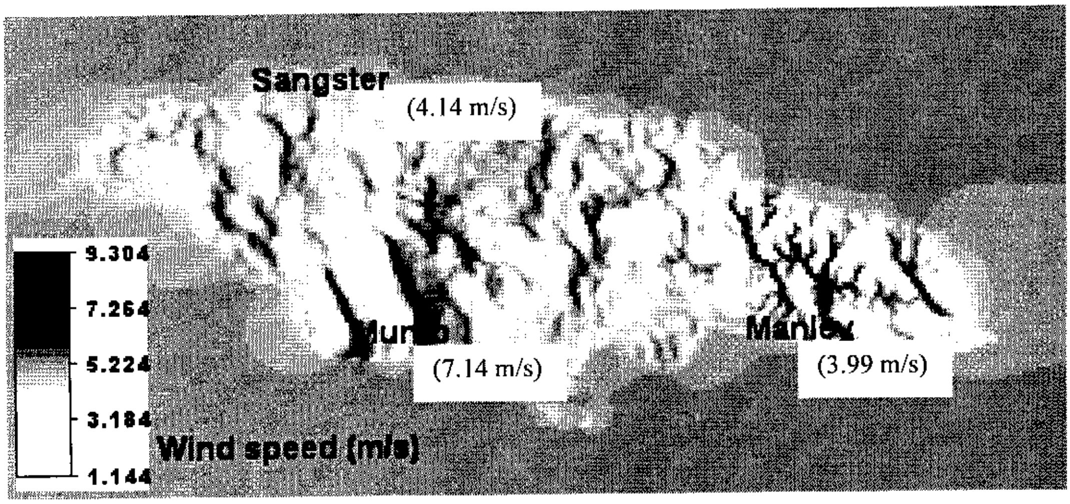

Figure 1 Annual mean wind speed distribution produced by *Wind*Map at 30 m, using Munro, Manley and Sangster as initializing stations with Munro as the reference station

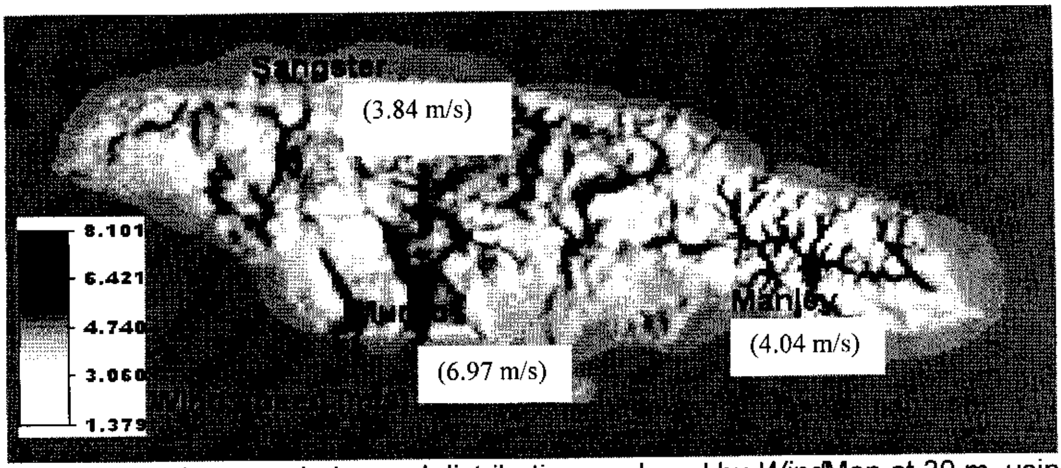

Figure 2 Annual mean wind speed distribution produced by *Wind*Map at 30 m, using Munro, Manley and Sangster as initializing stations with Manley as the reference station

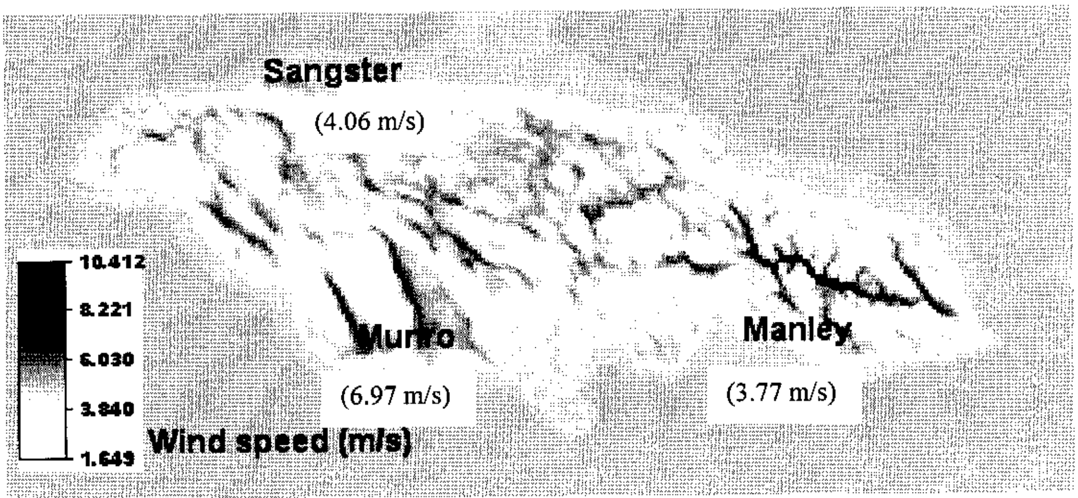

Figure 3 Annual mean wind speed distribution produced by *Wind*Map at 30 m, using Munro, Manley and Sangster as initializing stations with Sangster as the reference station.

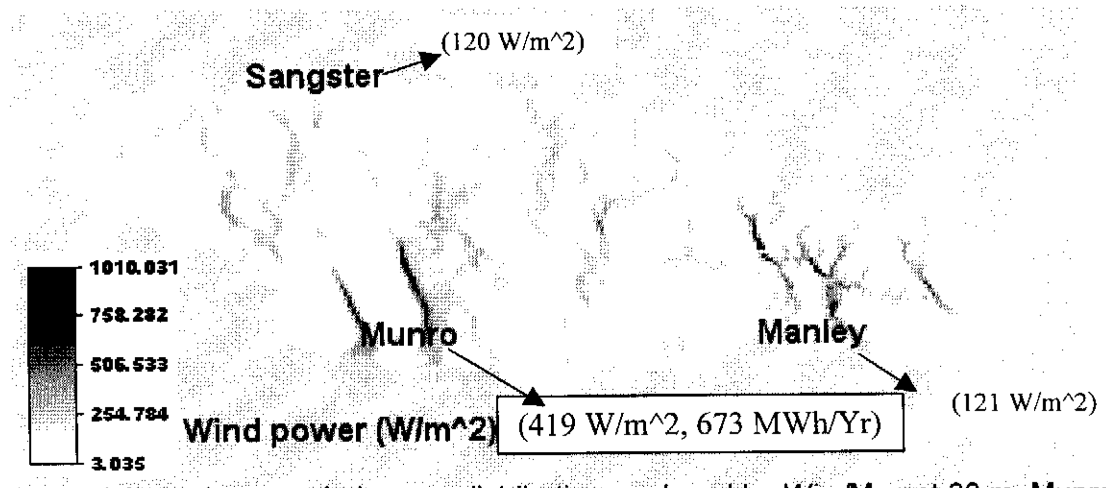

Figure 4 Annual mean wind power distribution produced by *Wind*Map at 30 m, Munro, Manley and Sangster as initializing stations with Munro as the reference station

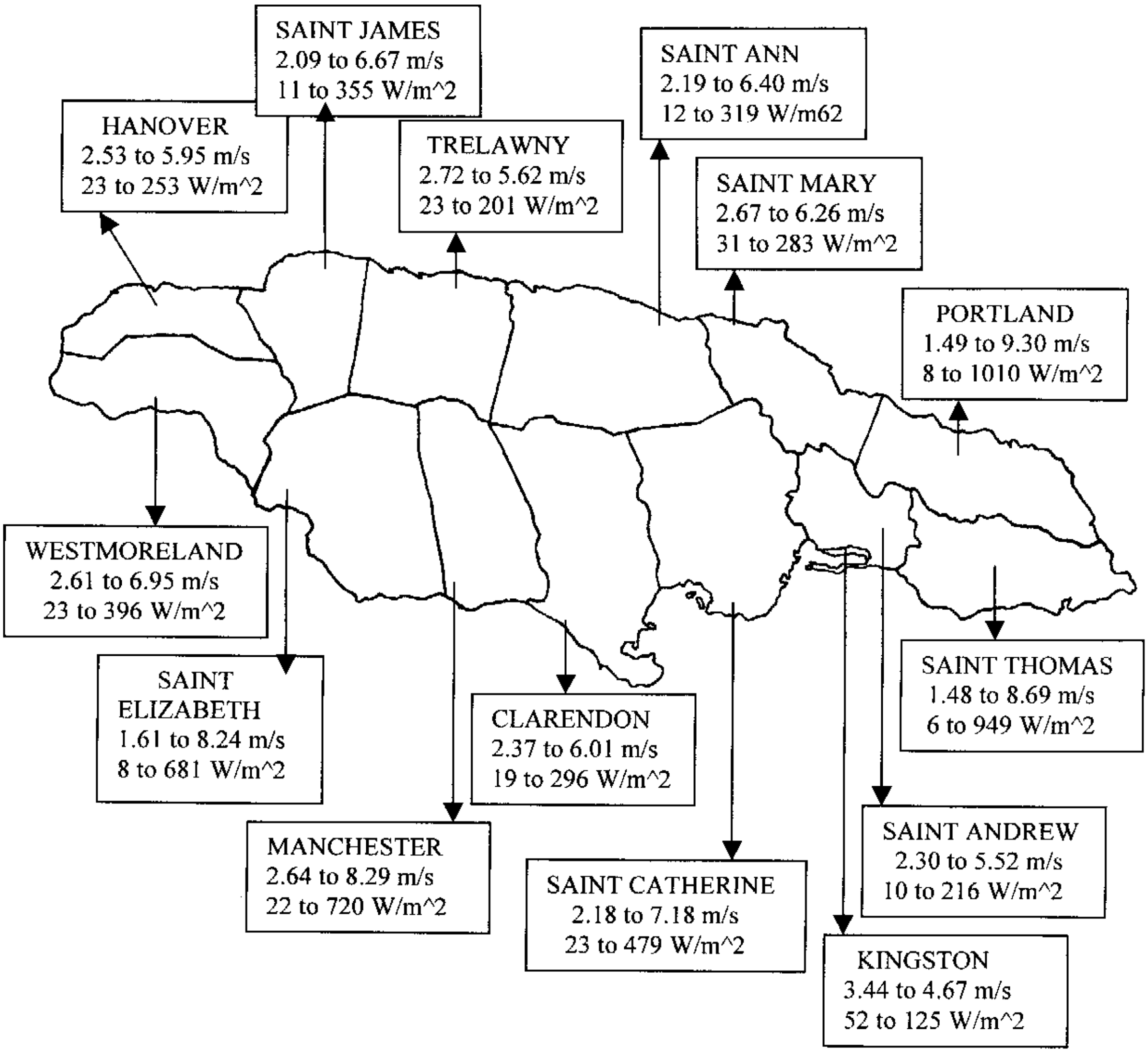

Figure 5. Extremes of annual mean wind speed and power on a parish basis, at 30 m. Results appearing in this figure are from the simulation based on Munro, Manley and Sangster initializing combination with Munro as the reference station.