WIND RESOURCE MAPPING OF PATAGONIA, ARGENTINA

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Abstract

The Patgonian region of Argentina has been recognized as an area with an enormous wind resource potential since the early 1980s. The portion of the region covered in this study lies near the southern tip of South America between latitudes 42^o and 51^o south and covers an area of 320,000 square km (125,000 square miles). The region is a vast coastal high plain (altiplano) with an average elevation ranging from 200 to 1,000m. It lies on the eastern side (downwind) of the Andes Mountains, which have peaks between 3,000 and 4,000m. The area is characterized by very low population density with 100 to 200 km between settlements.

Recognizing the enormous potential in the region and the need for additional wind measurements to validate and delineate the resource, the FloWind Corporation funded a wind resource study of the region in the mid 1990s. A total of 12 meteorological towers were installed ranging in height from 27 to 60 meters with two or three measurement heights. The towers were installed in the provinces of Chubut and Santa Cruz and were spread out over the entire region, with about 200 km between towers. Most of the tower sites were chosen to be representative of large areas that could support huge windfarm developments. Wind speed, turbulence, wind direction, atmospheric pressure and temperature data were collected for a period of about nine to twelve months.

A map has been prepared showing the geographical distribution of the high wind area. Typical mean annual wind speed estimates at 50m are 9 mps, and the best and worst sites were 11 and 7 mps. The highest winds were found in a long north-south belt about half way between the Andes Mountains on the west and the Atlantic coast in the east. The high wind zone appears to stretch for about 900 km from north to south, by about 200 km in the east-west direction. The area could support roughly 900,000 MW of wind capacity, if transmission lines were available.

Climatic features of the wind in Patagonia, Argentina

The southern part of the South American continent (i.e. south of about 40^o S) resembles a narrow tongue of land within a predominantly oceanic hemisphere. Geographic and climatic uniformity characterizes the entire region known as Patagonia. The Cordillera de los Andes, which runs along the western side of the continent, is the major topographic feature, and is oriented perpendicular to the prevailing westerly winds characteristic of such latitudes. Between the eastern slope of the Andes and the Atlantic Ocean coast, Patagonia shows a typical meseta - plateau landscape with its grass and shrub steppe.

While the Chilean part of Patagonia is almost uninhabited, the Argentinean Patagonia (which includes the three southernmost provinces: Neuquén, Chubut, and Santa Cruz) extends over 767,720 square km with a population density of about 2 inhabitants per square kilometer. As Prohaska precisely stated [1], “in few parts of the world as in Patagonia the climate of a region is so determined by a single meteorological element: the constancy and strength of the wind.”

The circulation is characterized by a strong north-south surface pressure gradient between the semi-permanent subtropical high-pressure centers (cells) in the subtropical Pacific and Atlantic oceans and the subpolar belt of low-pressure centered approximately on the Antarctic Circle. The small seasonal variation of these pressure centers has a slight effect on the otherwise prevailing westerly flow throughout the year.

In summer, a low-pressure trough intensifies over the continent (65° W, 25° S) between the oceanic high-pressure cells. The center of the Pacific high-pressure area is located farther south and close to the western coast of South America. Then, the pressure gradient is more pronounced over western Patagonia and oriented in the northwest to southeast direction, giving a southerly component to the westerly winds. In winter, on the other hand, a pressure trough sets up over the continent connecting both the Atlantic and Pacific high-pressure centers. Isobars become almost parallel to latitude circles. Hence, westerly and northwesterly winds prevail during the cold season.

Observations at individual stations indicate an annual mean direction frequency of 50 to 70% from the west sector. North and east winds can occur occasionally due to the intensification of the Atlantic high-pressure cell, which inhibits the characteristic zonal circulation. Furthermore, in summer, during sunny days, a sea breeze circulation develops quite regularly along the eastern coast of Patagonia, penetrating as far as 100 km inland.

A regional surface wind of 7 m/s has been estimated in correspondence with the annual mean pressure gradient between 40° and 60° S. Interannual wind velocity variability observed over Patagonia stations is within 10 to 20%. Local orographic features, resulting in mean values much higher than indicated can significantly modify this regional wind pattern. In longitudinal valleys and canyons traversing the Patagonia plateau in the east-west direction and over low hills, the wind accelerates reaching mean annual values well above 9 m/s at 10 m above the ground.

Brief history of the wind energy assessment at the Centro Nacional Patagónico

Since its foundation in 1972, the Centro Nacional Patagónico - CONICET, located in Puerto Madryn, Chubut, has fostered research on wind energy applications in its Environmental Physics Area (EPA). This research team has been permanently involved in programs and studies of the wind in Patagonia. Since the energy crisis in the 1970s, wind power assessment and related studies have grown at EPA. Field experiments and long-term measurement campaigns started on a regular basis at several sites in Chubut province. Additionally, reanalysis of the historical observations in Patagonia obtained from the NWS and other sources was performed by Dr. Vicente Barros, the pioneer of wind energy studies in Argentina, leading to the first edition of the Wind Energy Atlas of Southern Argentina in 1983 [2].

Simultaneously, the scarce and scattered data in Patagonia motivated the research on new methodologies aiming to optimize the use of short time series of observations, like the Multiple Climatic Reduction Technique [3].

During the 1980s, four towers between 30 and 90m height equipped with data-loggers, anemometers and wind vanes at several levels were deployed along an east-west 100-km line over Pampa del Castillo plateau, near Comodoro Rivadavia city (68° W, 46° S). This field experiment provided a unique set of wind measurements representative of an extended and homogeneous region [4]. In the mid-1980s, the measurement campaign intensified in the area. The Pampa del Castillo 90m tower was equipped with anemometers, vanes and temperature sensors at four levels. Surface pressure was also measured. Observations were used to study the distribution of extreme winds as well as other surface layer wind characteristics [5].

South of Comodoro Rivadavia, two 30m portable towers and five 10m masts with anemometers and vanes were distributed over a 150 km^2 surface. Then, a mass-consistent model of the airflow over complex topography was applied to simulate the three-dimensional wind field all over the region, using the observed data set as input. The results allowed an objective selection of sites with maximum wind power availability [6].

At the beginning of 1990s, and within a more profitable regulatory framework of the energy market, co-operative utilities, which manage electricity generation and distribution in several towns throughout the country, and independent power producers have found a good business opportunity in wind energy investment. During this period, the managers of the electric power generation co-operative of Gobernador Costa, Chubut, contacted EPA for a preliminary wind energy assessment and site selection in the area surrounding the village. A one-year wind measurement program was performed using a portable 30m mast.

Finally, EPA and FloWind Corp. carried out a joint measurement campaign in Southern Argentina, which is described below.

Site description of the EPA-FloWind campaign

The EPA-FloWind joint survey in Southern Argentina (Patagonia) concentrated almost exclusively over the central-occidental plateau in Chubut and Santa Cruz provinces. Measurement sites were selected in several steps. First, a preliminary site selection was performed based on available topographic information and visual inspection. A few geographic strategies were employed. About half of the towers were installed on east-west cross sections of Patagonia. Second, there are several large lakes in the foothills of the Andes that form east-west oriented drainage areas in the mountain chain. A few of the towers were sited downwind of these lakes. Finally, during the equipment installation phase, adjustments were made to the siting, based on site accessibility and exposure.

Three of the twelve monitoring systems were installed on pre-existing towers including Pampa del Castillo, which was subsequently used as a reference for correlation. The others were mounted on 27m NRG tilt-up towers. Six of the sites were in Chubut Province and six were in Santa Cruz Province. Due to the lack of cellular coverage and the enormous distances between the sites, data were retrieved every third month or less frequently. The data retrieval process required several thousand kilometers of driving. The reliability of the Second Wind, Inc. Nomad data loggers produced high data recovery, in spite of the infrequent site visits. Local personnel assisted with battery changes at some of the more remote sites.

Table one lists a number of pertinent characteristics of the 12 monitoring sites, including elevation, highest sensor level, terrain type and areal representation. The table shows that about half of the sites are representative of very large areas; 100s to 1000s of square kilometers. Site 5 is Pampa del Castillo, which was used as a reference site, since it has been used in several previous studies by CONICET.

TABLE 1 - SITE CHARACTERISTICS

Chubut sites ID	Elevation (m)	Sensor Height (m)	Terrain type	Areal Representation (sq. km)
1	169	60	coastal plateau, altiplano	2,500
2	1,150	24	ridgeline	10
3	1,129	27	sub-Andean ridgeline	4
4	914	27	hilltop	2
5	706	60	plateau, altiplano	2,500
6	598	27	coastal plateau, altiplano	400

TABLE 1 - SITE CHARACTERISTICS

Santa Cruz sites

7	480	27	hilly, near lake shore	400
8	620	27	gentle hill, near river valley	4
9	808	27	plateau, altiplano	100
10	462	27	plateau, central altiplano	25
11	238	27	plateau, near lake shore	1,000
12	341	40	coastal plateau, altiplano	2,500

Vegetation at all the sites was typical of the Patagonian steppe climate, consisting of small bushes and shrubs, mostly lower than one meter in height. The table shows that many of the towers were installed on plateaus, referred to as altiplanos in Argentina, with an areal representation of hundreds or even thousands of square kilometers. The ridgeline sites were generally less than 100m higher than the surrounding terrain.

Wind Characteristics

The Pampa del Castillo site had been the subject of several studies before the FloWind program [4, 5]. It is the only site with several years of wind data available. Pampa del Castillo is located near the center of the study region and has characteristics such as mean speed and direction that are very typical of most of the sites. For these reasons, it shall be the focus of several analyses. Figure one shows the monthly mean speeds at the 60m level. The figure shows that the highest winds occur in the late spring and early summer and the lowest winds occur in the fall. However, all 12 months have high monthly mean speeds and there is no low wind season. Figure two shows the diurnal mean speeds at four levels of the tower. At the 15m level there is a distinct diurnal peak in the mid-afternoon hours. At the top level of the tower the diurnal cycle is much less pronounced, but it still exhibits the afternoon peak. Essentially, figures one and two show a lack of either a strong diurnal or seasonal pattern, i.e. the winds blow quite consistently, day and night, all year around.

Figure three is a wind speed frequency distribution in one-mps bins for a typical one-year period at the 60m level. The mean speed was about 9 mps and the Weibull factors were 10.04 and 2.29. The graph shows the actual distribution as bars and the Weibull distribution as a line. The Weibull is a fairly good fit, although it underpredicts the 7 and 8 mps bins and overpredicts the 10 and 11 mps bins. The shape factor is slightly higher than 2.0 and is fairly typical of all the sites. The modal wind speed is 7 mps, and there are less than ten hours above 23 mps.

Figure four is a wind energy rose. The upper portion of the figure shows the percent time and percent energy in the 16 compass directions. Below the graph the same data are listed in tabular form, along with the mean wind speed for each direction. The summary shows that 70% of the annual energy budget comes from the three sectors centered on the westerly direction. Seasonal wind roses show a slight variation as discussed in the climate summary. The summer season wind rose shows more west-southwest winds and the winter wind rose shows more west-northwest and northwest winds.

Estimated mean speeds and wind map

Wind speed data were collected at the 12 sites for periods of nine to twelve months. Estimates of long-term mean speed and power density were made based on regression/correlation and speed ratios between 11 of the sites, relative to the reference tower at Pampa del Castillo. The estimates are only as reliable as the correlation coefficients, and at some of the sites, separated by large distances, the correlations were fair at best. Therefore the long-term estimates should be considered preliminary. The mean speed estimates have been rounded off to the nearest one-half meter/second to reflect this uncertainty. Wind power density estimates have been rounded to the nearest 50 Watts/m^2. The wind speeds were extrapolated to 50 meters above ground level (AGL) based on the measured vertical shear at each tower. Table two lists the sites, the estimated mean speed at 50m, the measured vertical shear exponent, the measured turbulence intensity at the 27m level, the Weibull shape factor (k) and the estimated wind power density at 50m. The turbulence intensity is based on the 15-mps bin and 1-minute standard deviations.

TABLE 2 - WIND STATISTICS

Site	Estimated 50m Speed	Shear Exponent	Turbulence Intensity	Weibull Shape factor	Wind Power (50m) Density (W/m^2)
1	7.0 mps	0.18	.112	2.38	400
2	11.0	0.11	.083	2.18	1,250
3	9.5	0.06	.064	e2.0	900
4	8.0	0.10	.111	2.02	550
5	9.0	0.13	.089	2.56	800
6	9.0	0.18	.097	2.47	800
7	8.5	0.14	.095	1.82	700
8	10.0	0.09	.074	2.28	1,050
9	9.0	0.13	.078	2.24	800
10	9.5	0.15	.084	2.08	950
11	7.0	0.23	.094	1.57	400
12	8.5	0.08	.070	2.13	700
Mean	**8.8 mps**	**0.13**	**.088**	**2.16**	**775**

The table shows that seven of the 12 sites have estimated annual mean speeds between 8.5 and 9.5 mps at the 50m level. The lowest estimated mean speed was 7.0 and the highest was 11.0 mps. The sitewide average was 8.8 mps. The vertical shear exponents at most of the sites were slightly lower than the so-called normal 1/7th value. The turbulence intensity at most sites was quite low, below 10%. The Weibull shape factor generally exceeded 2.0, the value associated with the Rayleigh distribution. Wind power density ranged from 400 to 1,250 Watts/m^2 and the average was 775 W/m^2. The average power density is equivalent to a wind power class 6 using the U.S. DOE class system.

The mean wind speed estimates listed in table two have been plotted on figure five, a map of Patagonia. The values have been plotted at the location of the monitoring stations. The large star shows the location of Pampa del Castillo. The nine-mps isotach has been plotted on the map. Isotachs are a bit dangerous because they can lead to mis-interpretation. It should not be assumed that all areas within the isotach are at or above nine mps, and vice-versa. With these caveats in mind, the nine-mps isotach is a hot-dog shape running north-south through the entire latitude of the study area. The highest wind speeds were found about half way between the Andes and the Atlantic coast. The two sites on the eastern shore line of the large lakes (7 and 11) did not experience exceptionally high winds. This suggests that drainage flows were not enhanced by the presence of the lakes.

Perspective

Figure five shows that a large area of Patagonia falls within the 9 mps isotach. This is equivalent to a wind power density of 800 W/m2 or a wind power class 6. The size of the area within the isotach is about 900 km by 200 km or 180,000 square km. The area might be larger, but the study area included only two Provinces. If we assume that one-half of the land within this 9 mps isotach has a wind resource of 9 mps or better (a reasonable assumption, based on the fairly homogeneous terrain) we are left with 90,000 square km. Using today’s technologies, with 1 MW wind turbines, one could install 10 MW of capacity per square km. This would result in 900 GW of capacity. This is a staggering amount of wind power capacity. The current installed capacity worldwide is 10 GW of which 2 GW is in the United

States. Of course, there are the obvious problems of a lack of electric transmission lines and other infrastructure in Patagonia associated with the extremely low population density. And in addition, electric power rates are very low in Argentina, although recent legislation to promote renewables will help this situation.

In 1991, Elliott, et. al. [7] estimated the amount of windy land in the contiguous United States. These estimates were updated in 1992 but remained nearly the same. In the 1991 report, the total amount of land in the contiguous U.S. with a wind power class of 6 or better was 37,000 square km. Wyoming had the largest share with 18,350 square km. After eliminating lands with environmental and other constraints, the amount of land left in the contiguous U.S. with wind power class 6 or better was 17,500 square km and in Wyoming it was 11,800.

By comparison, the land in the class 6 area in Patagonia appears to have few or no environmental constraints, urban areas, national parks or wilderness preserves. Based on a superficial review, it would appear that most or all of the land within the high wind zone in Patagonia would be available to develop. Thus the land available in Patagonia with a class 6 resource is equivalent to about five times the class 6 area within the contiguous U.S. Patagonia, Argentina may very well be the largest potential wind resource area in the western hemisphere.

References

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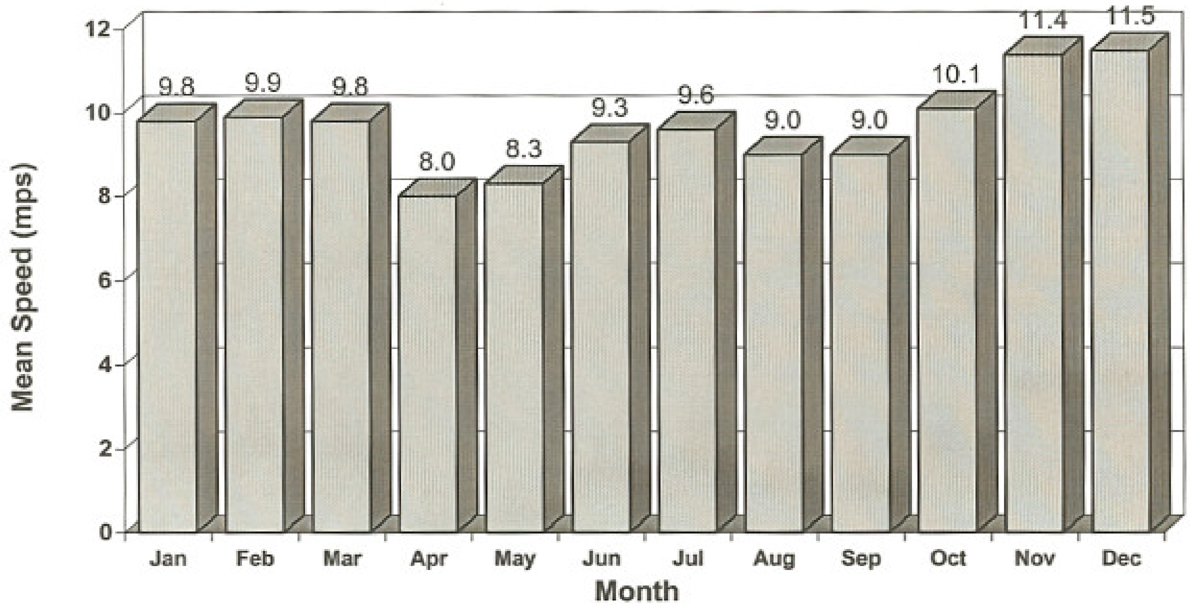


FIGURE 1. MONTHLY MEAN SPEEDS (MPS)
PAMPA DEL CASTILLO, 60M LEVEL

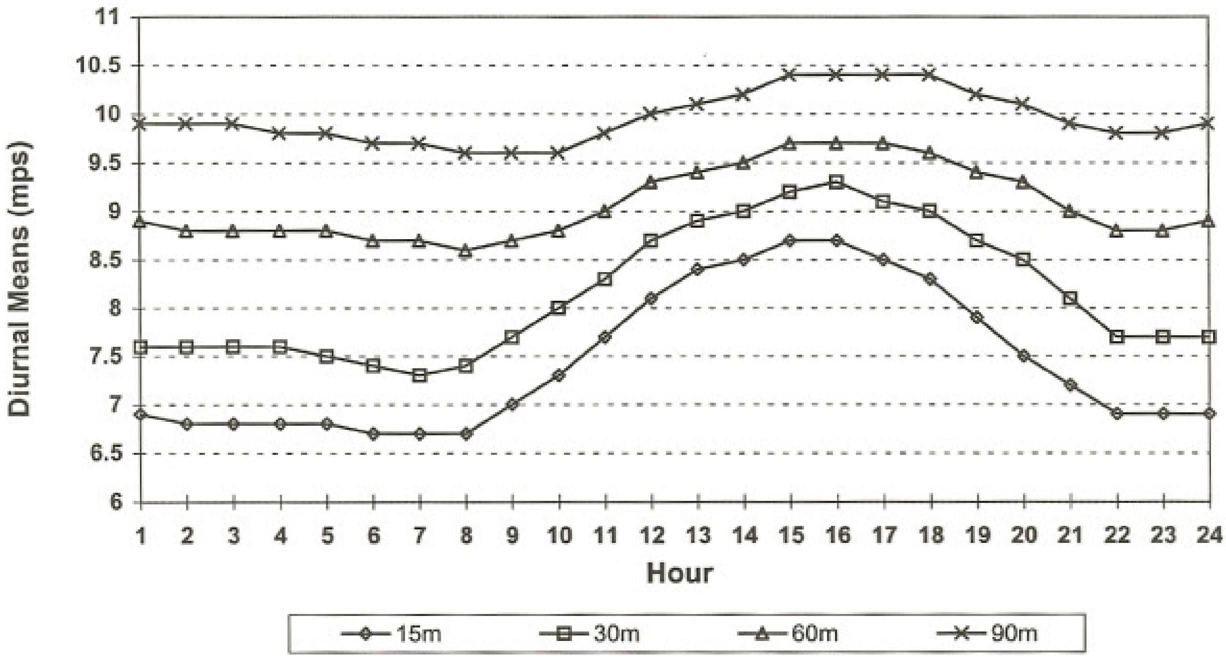


FIGURE 2. DIURNAL MEAN SPEEDS (MPS)
PAMPA DEL CASTILLO, PATAGONIA

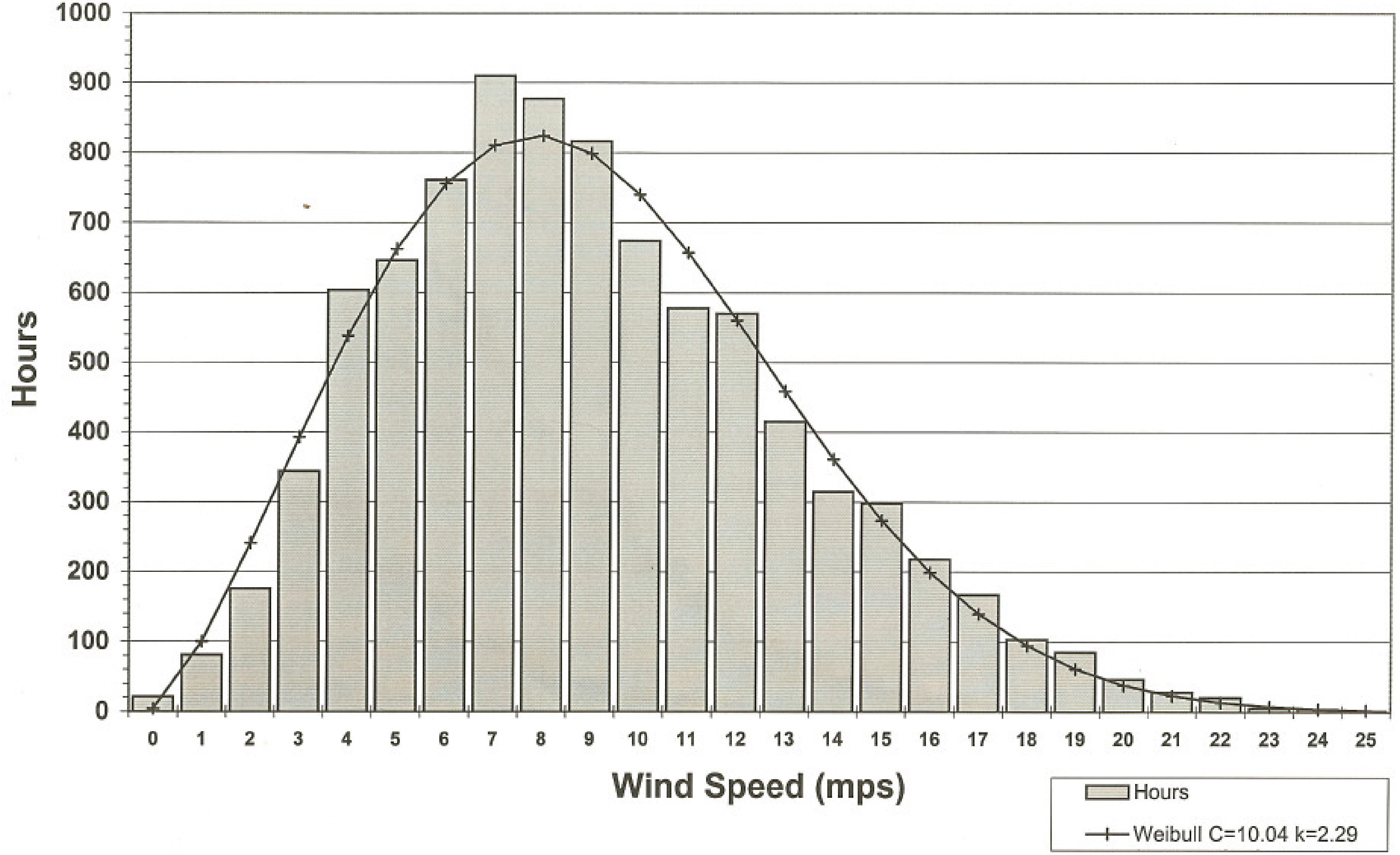
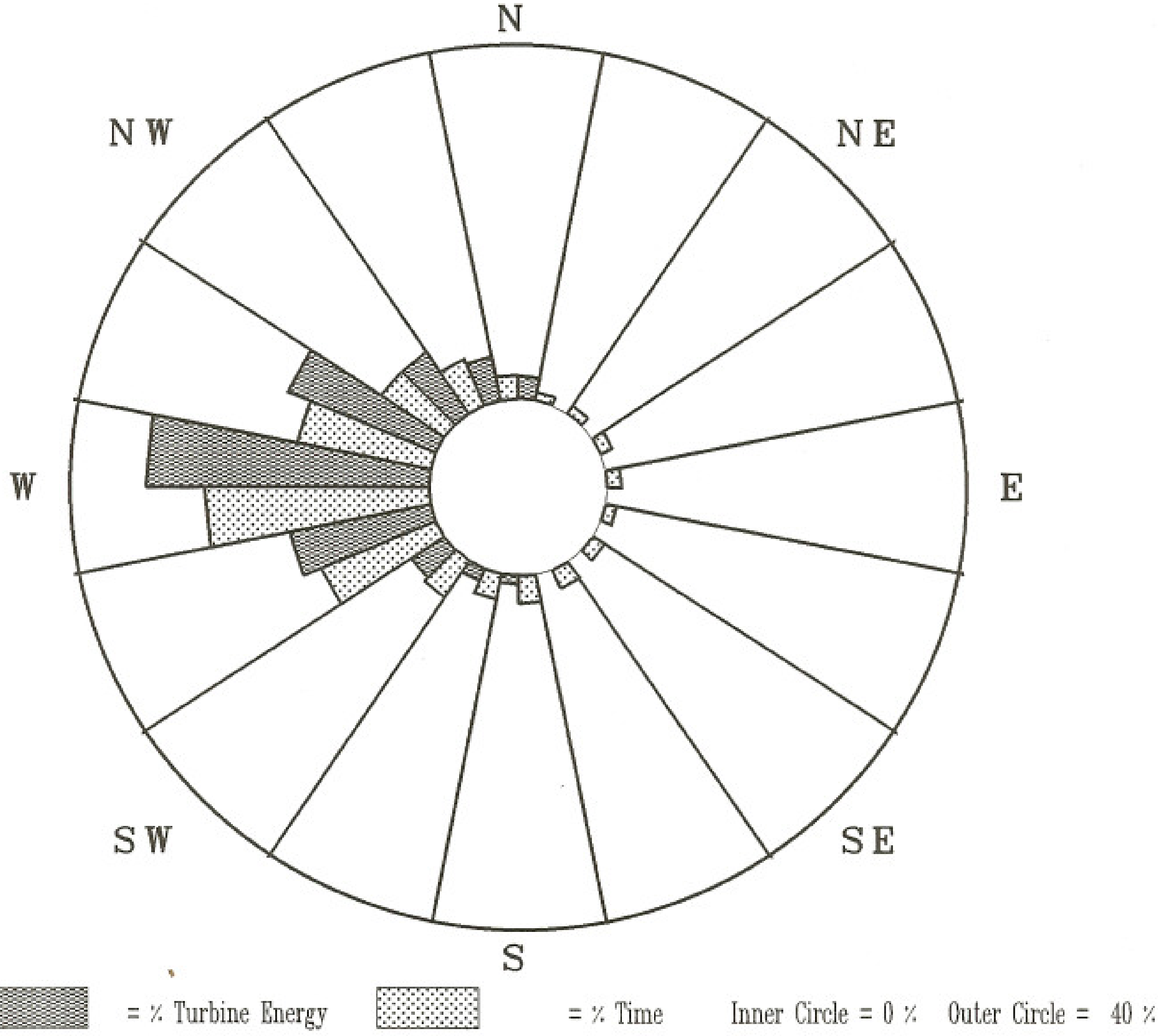


FIGURE 3. WIND SPEED FREQUENCY DISTRIBUTION
PAMPA DEL CASTILLO 60m LEVEL

WIND ENERGY ROSE

Chubut, Patagonia, Argentina
60-m Pampa del Castillo wind speed
03-01-1980 to 03-31-1996



Compass Direction		% Time	% Turbine Energy	Mean Speed (MPS)
N	349 - 11	2.9	2.8	9.0
NNE	11 - 34	1.0	0.5	6.9
NE	34 - 56	1.1	0.3	5.6
ENE	56 - 79	1.6	0.6	6.4
E	79 - 101	1.7	0.4	5.5
ESE	101 - 124	1.3	0.5	6.2
SE	124 - 146	1.7	0.9	7.1
SSE	146 - 169	2.5	0.8	5.7
S	169 - 191	3.4	1.1	6.0
SSW	191 - 214	3.3	1.7	7.1
SW	214 - 236	5.5	4.9	8.9
WSW	236 - 259	15.0	17.3	10.7
W	259 - 281	27.1	34.1	11.4
WNW	281 - 304	16.4	19.3	10.8
NW	304 - 326	9.2	9.2	9.8
NNW	326 - 349	6.2	5.5	9.0

FIGURE 4. WIND ROSE

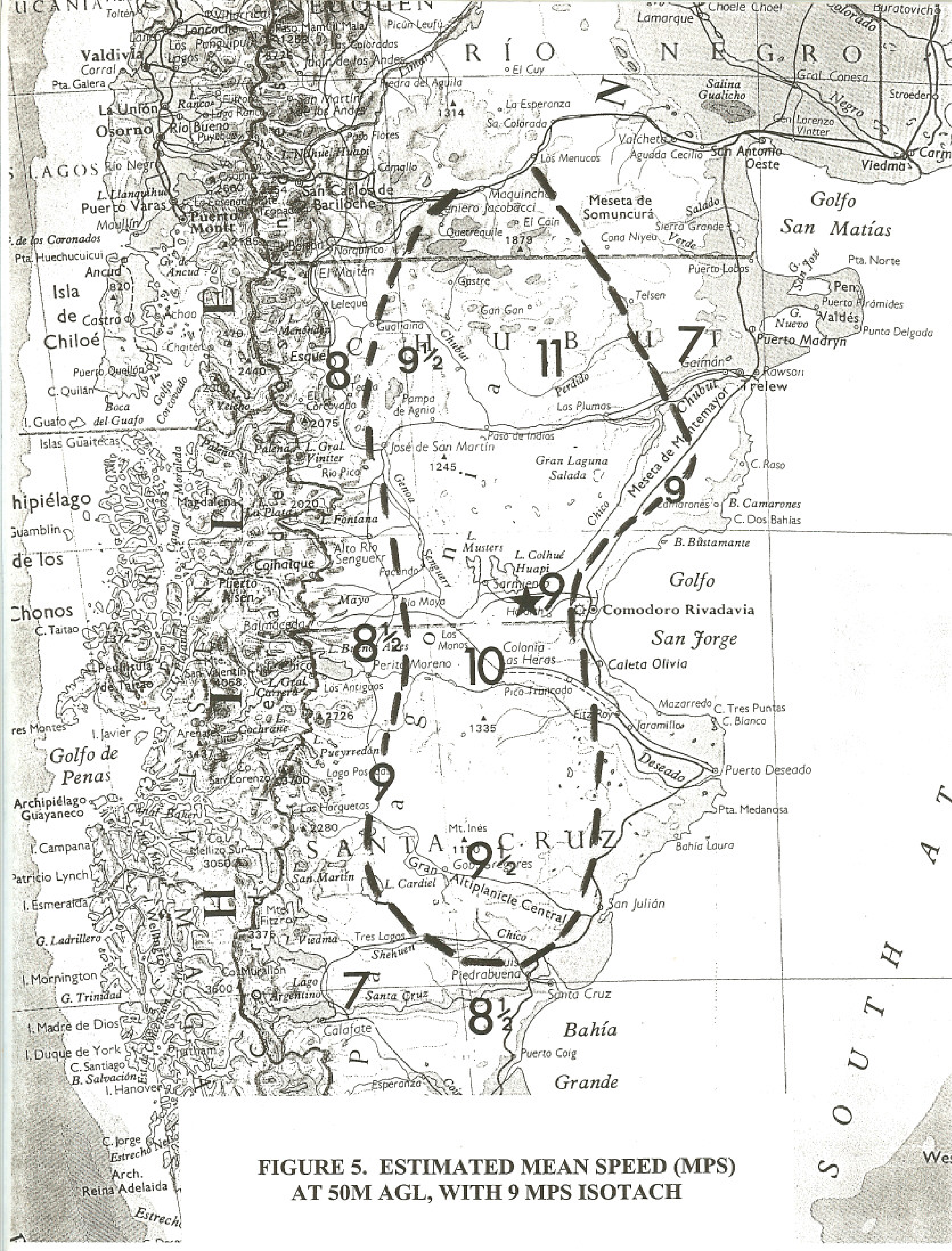


FIGURE 5. ESTIMATED MEAN SPEED (MPS)
AT 50M AGL, WITH 9 MPS ISOTACH