8.0 Wind Resource Characteristics of the Maldives

8.1 Introduction

This section discusses the approach, wind mapping results, and the wind power density estimates for the Maldives. The wind resource in exposed areas has relatively little variation in the Maldives, but it is important to emphasize the regions of the country where the better resource occurs. A simple wind classification with small wind power intervals scheme is used to represent the wind resource and is presented in Table 8.1. The Maldives is suited for village and resort wind turbine applications provided trees or other obstacles do not shelter the particular site. For this atlas, small-scale applications refer to 50 kW or less of installed capacity and large-scale applications have more than 50 kW. Economic and social factors in addition to the available resource will determine the feasibility of any wind energy project in the Maldives.

Table 8.1. Wind Power Classification

Resource Potential Large	Resource Potential Small	Wind Power Density (W/m^2) @ 50 m agl	Wind Speed [(a)] (m/s) @ 50 m agl
Fair	Moderate	225 – 250	5.8 – 6.0
Fair	Moderate	250 – 275	6.0 – 6.2
Fair	Moderate	275 – 300	6.2 – 6.4
Moderate	Good	300 – 325	6.4 – 6.5
Moderate	Good	325 – 350	6.5 – 6.7

[(a)] Mean wind speed is estimated assuming a sea level elevation and a Weibull distribution of wind speeds with a shape factor (k) of 2.0. The actual mean wind speed may differ from these estimated values by as much as 20 percent, depending on the actual wind speed distribution (or Weibull k value) and elevation above sea level.

8.2 Approach

The ocean module of NREL's wind mapping system was the basis of the wind power map of the Maldives. This module takes the ambient wind power at 50 m above the open ocean surface and adjusts it on the size of an affected island or coastal region. However, for the Maldives the individual atolls and islands are too small and the distance between the atolls too large to have a significant effect on the available resource. Therefore, the wind resource at 50 m for the atolls and islands are the same for the surrounding ocean areas. Surface roughness data for the Maldives islands were not available, but any trees or buildings will minimally affect the 50-m wind power values on the small islands. However, treed or other areas with obstructions will have considerably reduced resource at 20 m or 30 m compared to the 50 m values.

The open ocean values were based on two data sets. The most important data were the ocean satellite data that calculates the wind speed and power at 10 m above the surface. This information was converted to 50-m values based on a wind shear value commonly estimated for oceanic regions. The satellite data was supplemented by Reanalysis data that estimated the Weibull k values for the Maldives. Finally, the estimates of the open ocean values were referenced against surface data from the Male' airport and upper-air observations from Male' and Addu Atoll (Gan Island) to ensure the accuracy of these values.

8.3 Wind Resource Distribution and Characteristics

8.3.1 Annual Wind Resource Distribution

Figure 8.1 shows the wind resource map and the atoll names for the Maldives. The highest wind resource is found between 4.5^{o} N Lat and approximately 6.5^{o} N Lat. North Maalhusmadulu, South Maalhusmadulu, North Miladhunmadulu, South Miladhunmadulu, and Faadippolhu Atolls are estimated to have the best resource in the Maldives. This level of resource is estimated to be good for small-scale applications and moderate for large-scale applications. North and south of this area the wind resource is slightly lower but still considered good for small-scale and moderate for large-scale wind applications. These areas include the North Thiladhunmathi and South Thiladhunmathi Atolls at the northern end of the Maldives, and North Ari and Male' Atolls near 4^{o} N Lat. Male', the capital of the Maldives, is included in this wind resource area. The wind resource gradually decreases from Male' southwards with the lowest resource found on the atolls south of 1^{o} N Lat. However, the wind resource is still considered moderate for small-scale applications and favorable locations for wind energy projects may still be found as far south as Addu Atoll.

The Maldives is influenced by monsoon flows but the annual and seasonal patterns vary from north to south because strengths of the monsoon flows change with proximity to the equator. The strongest west monsoon occurs in the extreme north of the Maldives while the strongest northeast monsoon occurs in the north-central part of the country. The highest wind resource in the Maldives is located where the northeast monsoon is strongest. The west monsoon weakens in the southern part of the Maldives but still is of moderate strength down to Addu Atoll. The northeast monsoon decreases rapidly in strength south of Male' and is barely present at Addu Atoll. In fact, west winds predominate all year at Addu Atoll so it can be said that the monsoon flows stop somewhere north of that location. The weakening of the west and northeast monsoons results in a pronounced shift of the high wind resource months from the northern to the southern parts of the country, but the moderate west winds across the southern part of the Maldives keeps the variation in the overall resource in the Maldives relatively small.

The extreme northern part of the Maldives has a wind climate featuring a strong west monsoon from May through August and a moderate northeast monsoon from December through February. The ocean wind speeds during June, July, and August are strong with wind speeds from 6 m/s to 7.5 m/s at 10 m above the surface. The northeast monsoon is of moderate strength (4 m/s to 5 m/s) from December through February. Although the other months of the year can be considered inter-monsoon months, there is a prevailing northwest wind direction at this time. September and October have significantly stronger northwest winds than March and April.

The highest resource area in the Maldives that extends from just north of Male' to the North Miladhunmadulu Atoll experiences a stronger northeast monsoon from December through February than areas to its north and south. The stronger northeast monsoon has its origins in the accelerated flow around the southern tip of India. The west monsoon lasts from May through October with November being a transition month with characteristics of both monsoon flows. The northwest winds are not as evident as they are further north, with April, September, and October having the most northwest winds. March and April are the months with the lowest winds.

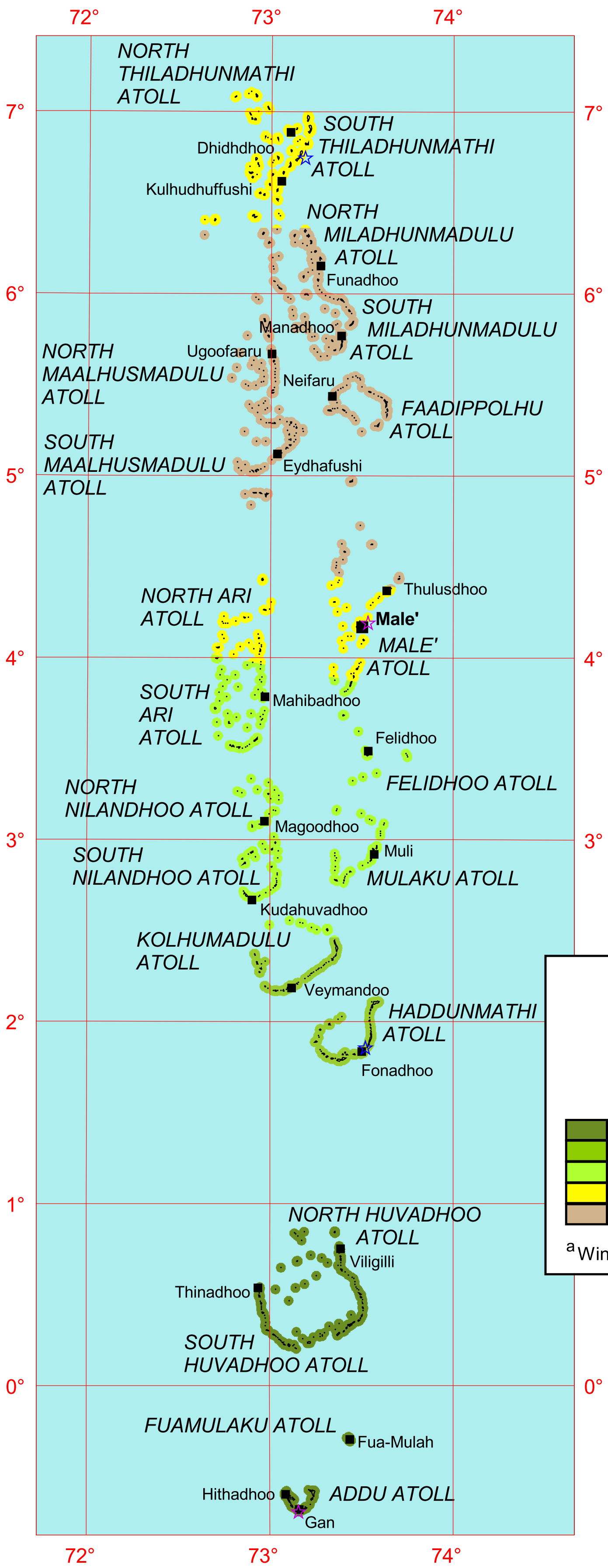
The northeast monsoon weakens south of the Male' area and by Addu Atoll at the southern extreme of the Maldives the prevailing direction is westerly most of the year. During December through March the winds are from the northwest replacing the northeast winds observed further north. The northwest winds also re-appear in July and August, though in some years southerly winds prevail during these months. Winds more from the due west prevail from April through June and in October and November. September is a transition month with characteristics of the westerly and northwesterly flow. The strongest winds occur during the months the winds are most westerly.

8.3.2 Seasonal Wind Resource Distribution

The extreme northern part of the Maldives has a distinct resource maximum from May through October during the west monsoon with the highest resource in June and July. The resource during the rest of the year is significantly lower and reaches the lowest resource during March and April. The seasonal distribution changes as you move south. The highest wind resource area between Male' and North Miladhunmadulu Atoll has a more even distribution throughout the year. Several factors contribute to this change in the seasonal distribution. The resource in July and August decreases compared to northern part of the Maldives, but the strengthening of the northeast monsoon between December and February and the west monsoon in September and October compensates for the decrease. The net result is a seasonal distribution with broad resource maximums from May through October, slightly peaking in June, and a secondary resource maximum in December and January. The trend of decreasing resource in July and August continues as one moves south and the northeast monsoon disappears. At Addu Atoll, the seasonal distribution is bimodal. There are wind resource maximums in April and May and from September through November. The peak wind resource month at Addu Atoll is October instead of June as is found in the central and northern Maldives. June and July have a relative minimum of resource in the southern Maldives instead of a maximum of resource in these months in the northern Maldives. Figure 8.2 shows the seasonal wind pattern from the satellite ocean data covering the northern through the southern regions of the Maldives. The Appendices contain tables and plots of wind characteristics from stations in the Maldives (Appendices A and B), upper-air data from Minicoy Island (India), Male', and Gan Island (Appendix D), and ocean satellite data maps for the area (Appendix E). As shown by the interannual plots of the ocean satellite data included in Appendix E, not all years have close to the long-term average wind resource. For example, the year 1997 was an abnormally low wind resource year throughout the Maldives with little spatial variation. This shows that long-term ocean satellite wind data can be used to examine whether short-term data (such as one year) from measurement sites are truly representative of the long-term wind resource.

Because the ocean influence is so strong in the Maldives the diurnal pattern at 50 m will be typical of marine locations. The diurnal speed and power profiles will be flat with a tendency for the maximum speed and power to occur at night.

Maldives
Wind Resource Map



This wind resource classification is specific for large scale and small scale applications.

Wind Power Classification

	Resource Potential Large	Resource Potential Small	Wind Power Density at 50 m W/m²	Wind Speed[a] at 50 m m/s
(dark olive)	Fair	Moderate	225 - 250	5.8 - 6.0
(green)	Fair	Moderate	250 - 275	6.0 - 6.2
(light green)	Fair	Moderate	275 - 300	6.2 - 6.4
(yellow)	Moderate	Good	300 - 325	6.4 - 6.5
(tan)	Moderate	Good	325 - 350	6.5 - 6.7

[a] Wind speeds are based on a Weibull k value of 2.0

50 0 50 100 150 200 Kilometers

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Figure 8-1

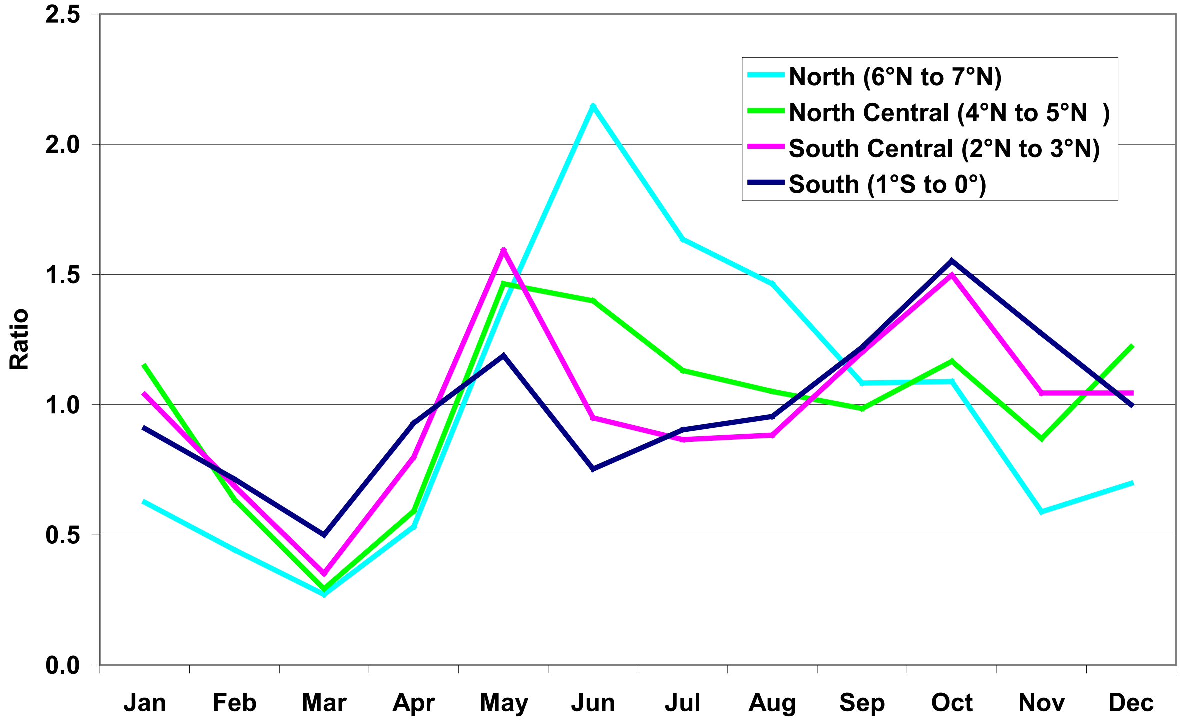

Figure 8.2 Maldives – Monthly Ratio (Month/Annual) of Wind Power Density.