Meteorological Conditions Report
Morro Bay and Diablo Canyon Offshore Wind Energy Call Area

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June 26, 2019

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1.0 INTRODUCTION

This report provides an analysis of the meteorological conditions associated with the Morro Bay and Diablo Canyon Offshore Wind Energy Call Areas, which BOEM is evaluating for possible offshore wind energy leasing. The call area is located off the coast of Central California in the general vicinity of the City of San Luis Obispo. Metrics associated with prevailing meteorology and with visibility that will influence views of the call area. The report will assist in understanding the meteorological conditions experienced in this area and how they may influence the visibility of a wind energy project. The analysis used existing meteorological information from a measurement site within the area where the call area is located. Data for visibility at the measurement site is reported to a distance of up to 10 nautical miles (nm) and therefore, visibility beyond 10 nm was calculated as described further below.

2.0 DATA COLLECTION

The meteorological assessment utilized hourly meteorological surface data collected at National Weather Service (NWS) measurement site located at the San Luis County Regional Airport in San Luis Obispo, California (Figure 1) over the 10-year period of January 1, 2009–December 31, 2018. Surface observations for the site were obtained from the National Climatic Data Center (now referred to as National Center for Environmental Information).

The hourly observations in the data sets include wind speed, wind direction, cloud cover, cloud ceiling height, visibility, weather codes denoting precipitation, ambient, dew point temperatures, and precipitation amounts.

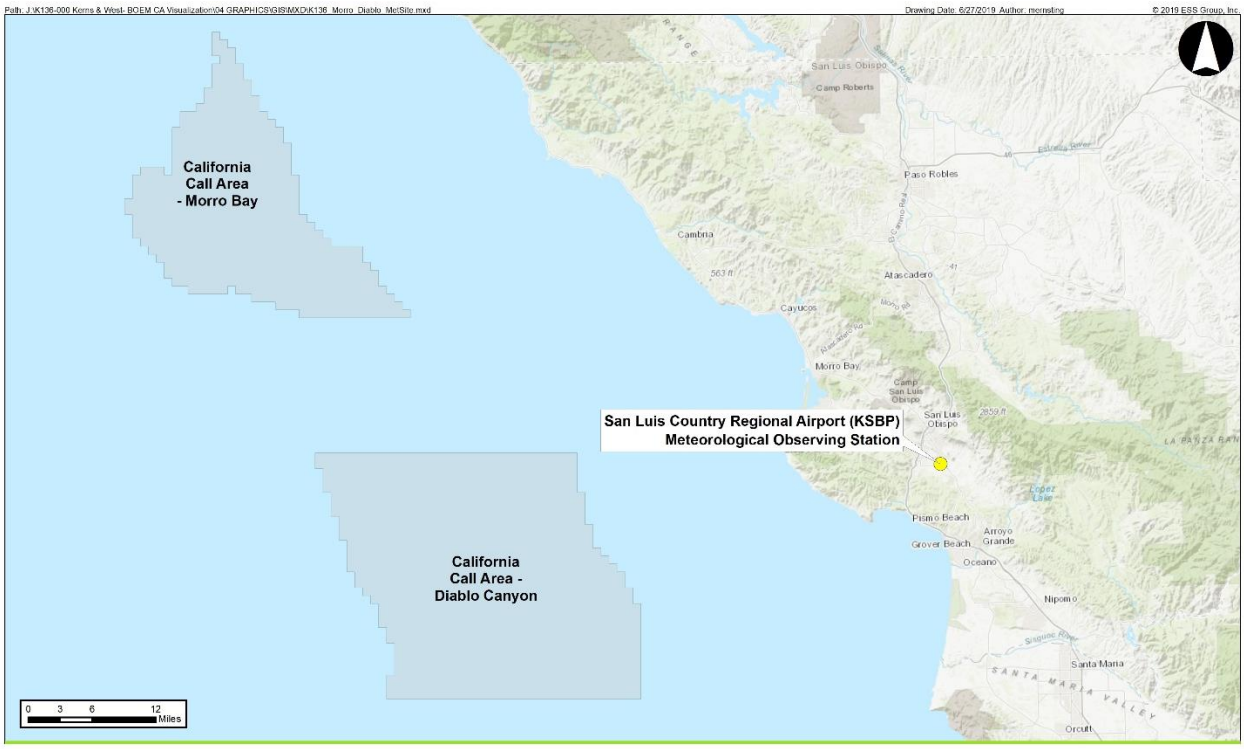

Figure 1: Location of Meteorological Measurement Site

3.0 METEOROLOGICAL CONDITIONS AND VISIBILITY ASSESSMENT

Hourly surface observations were evaluated to determine the following meteorological conditions and visibility.

Meteorological Condition

- Average number of days when it is clear, cloudy, foggy, rainy and hazy during daylight hours in each of the four seasons,
- Average number of days when it is clear, cloudy, foggy, rainy and hazy for 50% of the daylight hours in each of the four seasons,
- Average percent of daylight hours when it is clear, cloudy, foggy, rainy and hazy in each of the four seasons, and
- Average percent of nighttime hours when it is clear, cloudy, foggy, rainy and hazy in each of the four seasons (i.e. the average conditions for nighttime during each of the seasons).

Visibility

- The average number of days that there is visibility to 10 nm, 20 nm and 30 nm.
- The average number of days that have visibility to 10 nm, 20nm and 30nm for at least 50% of the day in each of the four seasons.
- The average number of days that there is visibility to 10 nm, 20nm and 30nm for at least 75% of the day in each of the four seasons.
- The average distance that visibility is reduced (from clear conditions) on each day that haze is reported in each of the 4 seasons.
- The average visibility distance in each of the four seasons.

3.1 Definition of Data Parameters

Since the analysis covers daylight and nighttime conditions, it was important to define what constitutes daylight, as it changes in duration over the year. Sunrise, sunset and civil twilight times were obtained from timeanddate.com. Civil twilight is period where there is sufficient light to start, or continue, outdoor activities without lighting. This corresponds to civil dusk, when the sun is 6 degrees, or less, below the horizon.

NWS stations provide excellent data capture; however, it is not 100% complete and missing data periods do occur. Only daylight and nighttime periods with data capture at or better than 50% for the 24-hour data period were included in the analysis, avoiding possible biases in considering periods of a few hours.

The data was evaluated for clear, cloudy, rainy, foggy and hazy conditions during daylight and nighttime hours based upon the following criteria:

- Clear conditions were defined as having an unlimited cloud ceiling height. Unlimited ceiling heights are associated with clear and scattered sky cover (up to 50% of the sky).
- Cloudy conditions were defined as broken or overcast sky cover, greater than 50% of the sky.
- Rainy conditions were defined as any “trace” or measurable precipitation (rain, snow, sleet, etc.) amount. The Integrated Surface Database (ISD) data set includes weather codes that define the type and intensity of different weather conditions. Examples of the codes are RA (rain), SN (snow), FZRA (freezing rain). A complete code list can be found in “Integrated Surface Database (ISD) Documentation” (ncdc.noaa.gov).

- Foggy and hazy conditions are defined only by weather codes. Fog has a weather code of FG. Haze has a weather code of HZ.

Each individual daylight period was characterized as being clear, cloudy, rainy, foggy or hazy. When examining the five meteorological conditions, it is possible to have multiple conditions occurring concurrently. For example, haze can occur when it is sunny. Fog and rain occur when it is cloudy or there can be light rain during fog events. In order to avoid 'double counting' any of the conditions and maintaining a 100% count, conditions were assigned based on the following:

1. An hour is either clear or cloudy.
2. If clear or cloudy conditions occur for 50% or more of the daylight hours, assign the day based on visibility restriction.
3. Clear conditions are based on unlimited ceiling height and can include haze. A day was counted as hazy before being counted as sunny.
4. Cloudy conditions are based on limited ceiling height and can also include rain and fog. The day classification order was foggy, rainy and finally cloudy.
5. If clear and cloudy conditions each account for 50% of the daylight hour, the clear condition (sunny, hazy) was assigned 0.5 day as was the cloudy condition (fog, rain, cloud).

This prioritization was also used for evaluating individual hours.

Seasons were defined as follows:

- Winter = December 22–March 21
- Spring = March 22–June 21
- Summer = June 22–September 21
- Autumn = September 22–December 21

4.0 METEOROLOGICAL CONDITIONS AND VISIBILITY RESULTS

4.1 Meteorological Conditions

Table 1 presents representative seasonal and annual meteorological conditions observed at the San Luis County Regional Airport and the frequency of occurrence and distribution of clear, foggy, rainy, hazy and cloudy conditions. The data has been rounded to a whole day value. The topmost data group presents the average number of days per season/year that each of the five conditions was observed to occur at least for one hour during the daylight period. These numbers are independent of each other and should not be summed as multiple tallies could occur in any single daylight period. For example, clouds and fog could occur in the early morning giving way to clear skies later in the morning. A thunderstorm could occur in the late afternoon. In that case, clear, cloudy, rainy and foggy conditions would all occur for at least one hour.

The second data grouping characterizes days where each day is clear, cloudy, rainy, foggy or hazy and only a single tally is made for any daylight period. This characterization is based on which of the five meteorological conditions occur for at least 50% of the hours in the daylight period. These numbers can be summed to equal to the number of valid daylight periods occurring during the year.

The third data group presents the distribution of the five meteorological conditions during daylight hours as a percentage. Each hour is characterized as clear, foggy, rainy, hazy or cloudy. The percentages of the five meteorological conditions can be summed to equal 100%.

The fourth data group presents the distribution of the five meteorological conditions during nighttime hours as a percentage. Each hour is characterized as clear, foggy, rainy, hazy or cloudy. The percentages of the five meteorological conditions can be summed to equal 100%.

Table 1 Summary of Meteorological Conditions

	Winter	Spring	Summer	Autumn	Annual
Days/Year with 1 or More Daylight Observations					
Clear	79	85	86	80	331
Foggy	11	9	9	14	40
Rainy	18	8	2	10	38
Hazy	2	4	7	2	16
Cloudy	49	64	76	49	237
Days/Year with 50% or More Daylight Observations					
Clear	60	52	41	61	214
Foggy	2	<1	<1	3	5
Rainy	6	<1	<1	2	9
Hazy	<1	<1	<1	<1	<1
Cloudy	22	36	36	20	125
Distribution of Hourly Daylight Observations (%)					
Clear	66	57	50	65	59
Foggy	3	2	1	4	3
Rainy	6	2	2	2	3
Hazy	<1	<1	1	<1	<1
Cloudy	25	38	46	28	35
Distribution of Hourly Nighttime Observations (%)					
Clear	70	78	86	78	77
Foggy	<1	<1	<1	<1	<1
Rainy	5	2	1	3	3
Hazy	<1	<1	<1	<1	<1
Cloudy	25	20	12	18	19

Clear conditions occur at least one hour during daylight 331 days per year with seasonal values ranging from 79 days during winter to 86 days during summer. Cloudy conditions occur 237 days per year, with seasonal values ranging from 49 days in autumn and winter to 76 days in summer. Fog occurred 40 days per year. Seasonal values range from 9 days in spring and summer to 18 days in winter. Rain, without associated fog, occurred 38 days per year. Seasonal values range from 2 days in summer to 18 days in winter. Haze occurred about 16 days per year, ranging from 2 days in winter and spring to 9 days in autumn.

Days were characterized as clear, cloudy, foggy, rainy or hazy based on an occurrence of the meteorological condition 50% or more of daylight hours. Clear days occurred 214 days per year, with seasonal values ranging from 41 days in summer to 61 days in autumn. Cloudy days occurred 125 days per year, ranging from 20 days in autumn to 46 days in summer. Foggy days occurred 5 days per year, with seasonal values ranging from less than one day in the spring and summer to 3 days in autumn. Rainy days occurred 9 days per year, ranging from less than one day in spring and summer to 9 days in winter. Haze occurred less than one day both annually and seasonally.

Clear conditions occurred 59% of the daylight hours over the course of the year, with seasonal values ranging from 57% in summer to 66% in winter. Fog occurred 3% of the time, with seasonal values ranging from 1% in summer to 3% in autumn. Rain, without associated fog, occurred 3% of the time, with seasonal values ranging from 2% in spring, summer and autumn to 6% in winter. Cloudy conditions, without

associated fog or rain, occurred 35% of the time, with seasonal values ranging from 25% in winter to 46% in summer. Haze occurred 1% of the time with seasonal values ranging from less than 1% in winter, spring and autumn to 1% in summer.

Clear conditions occurred 77% of the nighttime hours over the course of the year, with seasonal values ranging from 70% in winter to 86% in summer. Fog occurred less than 1% of the time, north annually and seasonally. Rain, without associated fog, occurred 3% of the time, with seasonal values ranging from 1% in summer to 5% in winter. Cloudy conditions, without associated fog or rain, occurred 19% of the time, with seasonal values ranging from 12% in summer to 25% in autumn. Haze occurred less than 1% of the time both annually and seasonally

4.2 Visibility

Visibility observations in the NWS surface data are limited to a maximum of 10 statute miles and therefore in order to evaluate visibility at the 20 nm and 30 nm distances, a methodology was developed using the observed visibility (out to 10 statute miles) and a relational algorithm. The algorithm was developed by Egan Environmental and has been used in other analysis and calculates the visibility distance based on relative humidity.

Hourly surface observations from San Luis County do not include calculated relative humidity values. Relative humidity is calculated from ambient and dew point temperatures, which were also included in the data record. Relative humidity is calculated from the following equation:

$$RH = 100 * ((112 – 0.1 * TA + DP) / (112 + 0.9 * TA)) ^8$$

Where,

RH = relative humidity

TA = ambient temperature (ºC)

DP = dew point temperature (ºC)

As previously stated, relative humidity values are not provided in the data record. These values are calculated using the temperature observations. There were some missing relative humidity values, however, in every case, this appears to be because there was insufficient temperature data to perform the relative humidity calculation.

The visible distance algorithm was developed from a regression analysis of Martha's Vineyard visibility and relative humidity observations[1]. Visibility distance was calculated as:

$$VIS = 69.9 – 0.742 * RH$$

Where,

VIS = visibility distance (statute miles)

The calculated statue miles were then converted to nautical miles by applying a factor of 0.86839.

Visibility calculations were performed for each hour with a valid relative humidity. The calculated distance was compared to the observed distance to determine which value to carry forward in the analysis.

[1] The algorithm was developed under work conducted by ESS for BOEM and reported in "Visualization Simulations for Offshore Massachusetts and Rhode Island Wind Energy Area Meteorological Report" under Task Order M13PD00044, January 15, 2014

Observations up to 10 statute miles used the observed value. Observations at 10 statute miles used the greater of the observed or calculated values.

As mentioned above, there can be occurrences of multiple weather conditions within the same hour. Throughout all four seasons, there were reports of fog occurring within the same hour as a 10-mile visibility observation. Hours when these conditions occurred were not considered in the visibility analysis.

The following table presents representative estimated visibility distances and the frequency of occurrence of visibility greater than 10, 20 and 30 nautical miles, along with the average visibility for clear, foggy, rainy, hazy and cloudy conditions. The topmost data group presents the average number of days per season/year that there was at least one hour when visibility was at least 10, 20 and 30 nautical miles during a daylight period. The count for the 20 and 30 nm entries are also contained in the 10 nm entry. The count for the 30 nm entry is also contained in the 20 nm count.

The second and third data groups present the number of days per season/year that visibility exceeded 10, 20 and 30 nautical miles at least 50% and 75% of the daylight hours. As is the case with the topmost data group, the 20 nm and 30 nm values are subsets of the 10 nm values. The 30 nm values are subsets of the 20 nm values.

The last two data groups present the average seasonal and annual visibility distance for clear, foggy, rainy, hazy and cloudy conditions for daylight and nighttime hours. The annual and seasonal averages were determined by taking a weighted average of the five meteorological conditions.

Observations up to 10 statute miles used the observed value and observations reported as 10-statute mile in the data used the greater of the observed or calculated values, resulting in a conservative estimate of visibility. Table 2 presents a summary of the visibility results.

Table 2 Summary of Visibility

	Winter	Spring	Summer	Autumn	Annual
Days/Year with 1 or More Daylight Observations					
10 nm	70	89	88	70	317
20 nm	42	76	74	49	249
30 nm	21	36	29	28	114
Days/Year with 50% or More Daylight Observations					
10 nm	33	27	12	36	108
20 nm	14	7	3	17	41
30 nm	4	2	<1	8	15
Days/Year with 75% or More Daylight Observations					
10 nm	25	16	7	28	76
20 nm	9	4	1	13	28
30 nm	2	1	<1	6	10
Average Daylight Visibility (nm)					
Clear	15	17	15	18	16
Foggy	<1	<1	<1	<1	<1
Rainy	5	6	5	5	5
Hazy	8	4	5	7	5
Cloudy	10	9	8	9	9
Average	13	13	11	14	13
Average Nighttime Visibility (nm)					
Clear	25	23	23	27	25
Foggy	1	NA	NA	<1	<1
Rainy	6	7	14	5	6
Hazy	8	5	10	12	10
Cloudy	16	16	17	16	16
Average	22	21	22	24	22

NA - Due to fog occurring within the same hour as a 10-mile visibility as described in text above.

Visibility of at least 10 nm occurred for at least one hour during daylight 317 days per year, with seasonal values ranging from 70 days during winter and autumn to 89 days during spring. Visibility to 20 nm occurred 249 days per year, with seasonal values ranging from 42 days in winter to 76 days in spring. Visibility extended to 30 nm 114 days per year. Seasonal values range from 21 days in winter to 36 days in spring. Visibility extended to 10 nm for 50% or more of the daylight hours 108 days per year, with seasonal values ranging from 12 days in summer to 36 days in autumn. Visibility to 20 nm occurred 41 days per year, ranging from 3 days in summer to 17 days in autumn. Visibility to 30 nm occurred 15 days per year. Seasonal values ranged from less than one day in summer to 8 days in autumn.

Visibility extends to 10 nm for 75% or more of the daylight hours 76 days per year, with seasonal values ranging from 7 days in summer to 28 days in autumn. Visibility to 20 nm occurred 28 days per year, ranging from 1 day in summer to 13 days in autumn. Visibility to 30 nm occurred 10 days per year. Seasonal values ranged from less than one day in summer to 6 days in autumn.

The average daylight visibility for clear conditions was 16 nm, with seasonal values ranging from 15 nm in winter and summer to 18 nm in autumn. Cloudy conditions reduce the average visibility to 9 miles, ranging from 8 nm in summer to 10 nm in winter and autumn. Rainy, hazy and foggy conditions have an average visibility of 5, 5, and <1 nm, respectively. These visibilities are consistent through the year. The average

daylight visibility in winter, spring, summer and fall, regardless of meteorological condition, is 13, 13, 11, and 14 nm, respectively.
The average nighttime visibility for clear conditions is 25nm, with seasonal values ranging from 23 nm in spring and summer to 27 nm in fall. Cloudy conditions reduce the average visibility to 16 miles, with little seasonal variability. Visibility for rainy conditions is 6nm, with seasonal values ranging from 5 nm in winter to 14 nm in summer. Visibility for foggy conditions is less than 1 nm, with seasonal values consistent throughout the year. Visibility for hazy conditions is 10 nm, ranging from 5 nm in spring to 12 nm in autumn. The average nighttime visibility in winter, spring, summer and fall, regardless of meteorological condition, is 22, 21, 22 and 24 nm, respectively.

5.0 EFFECT OF HAZE ON VISIBILITY

As shown in the table above, haze can reduce visibility. Clear skies, on average, result in daytime visibilities of 15 to 18 nm, whereas hazy skies result in an average visibility of 4 to 8 nm. This represents approximately a 50% reduction in visibility.

Nighttime hazy skies result in average visibilities of 10 nm compared to 25 nm for clear conditions. In winter, clear skies have an average visibility of 25 nm compared to 8 nm for hazy skies. This represents approximately a 67% reduction in visibility. In spring, visibility decreases from 23 nm for clear conditions to 5 nm for hazy conditions, a reduction of approximately 78%. In summer, the average visibility for clear skies is 23 nm compared to 10 nm for hazy skies, representing a 57% reduction in visibility. In autumn, clear skies have an average visibility of 27 nm, compared to 12 nm for hazy conditions, an approximately 56% reduction in visibility.