Meteorological Conditions Report
Humboldt Offshore Wind Energy Call Area

PREPARED FOR:
Kearns & West
233 Sansome Street, Suite 400
San Francisco CA 94104

PREPARED BY:
ESS Group, Inc.
10 Hemingway Drive, 2nd Floor
East Providence, Rhode Island 02915

ESS Project No. K136-000

June 26, 2019

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1.0 INTRODUCTION

This report provides an analysis of the meteorological conditions associated with the Humboldt Offshore Wind Energy Call Area, which BOEM is evaluating for possible offshore wind energy leasing. The call area is located off the coast of Northern California in the general vicinity of the City of Eureka. 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 Arcata-Eureka Airport in Eureka, 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.

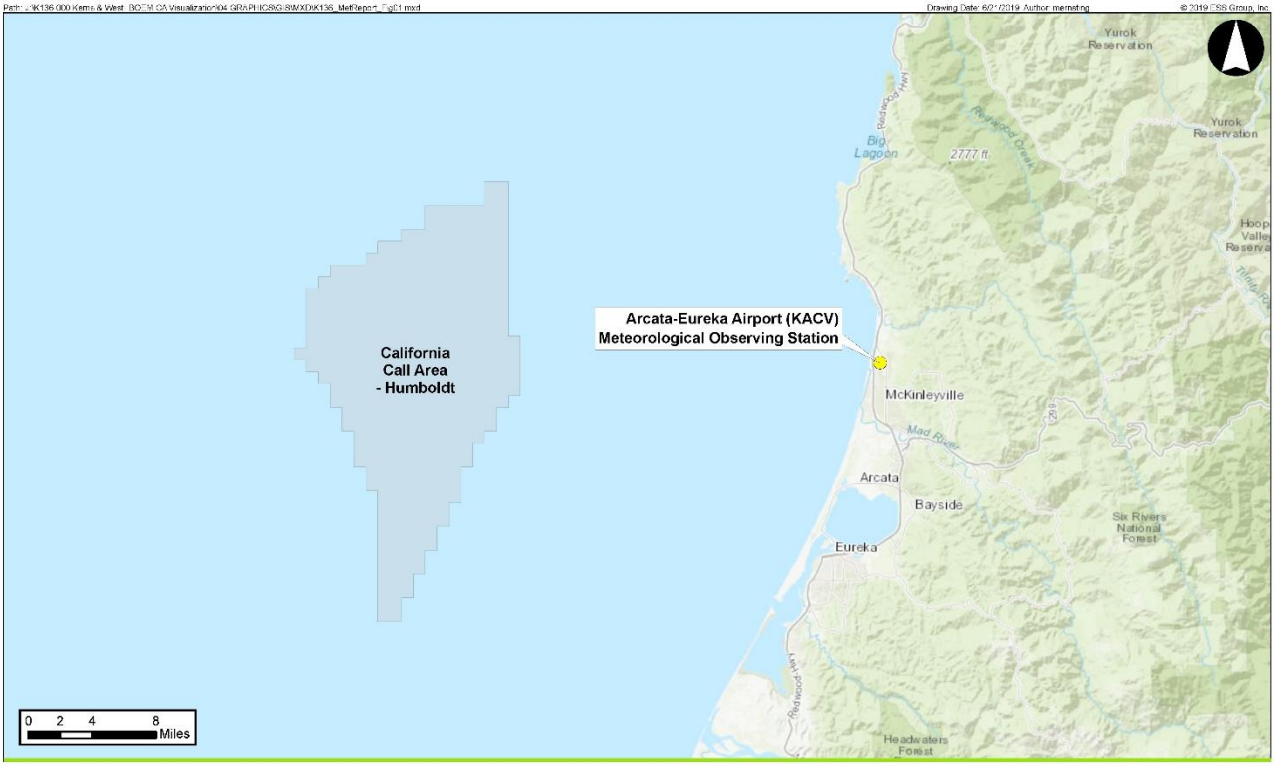

Figure 1: Location of Meteorological Measurement Site

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 the 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 Arcata-Eureka 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	66	70	59	70	266
Foggy	11	10	34	15	71
Rainy	30	22	13	27	91
Hazy	3	7	8	4	22
Cloudy	66	81	85	63	295
Days/Year with 50% or More Daylight Observations					
Clear	40	33	22	42	137
Foggy	2	<1	6	4	13
Rainy	10	4	<1	6	20
Hazy	<1	<1	<1	<1	<1
Cloudy	27	47	58	28	161
Distribution of Hourly Daylight Observations (%)					
Clear	44	37	27	48	38
Foggy	4	2	10	6	6
Rainy	19	10	3	13	10
Hazy	<1	<1	1	<1	<1
Cloudy	33	50	60	33	46
Distribution of Hourly Nighttime Observations (%)					
Clear	48	56	55	50	52
Foggy	2	<1	4	4	3
Rainy	16	8	1	11	10
Hazy	3	1	2	3	3
Cloudy	31	33	38	31	33

Clear conditions occur at least one hour during daylight 266 days per year with seasonal values ranging from 59 days during summer to 70 days during autumn and winter. Cloudy conditions occur 295 days per year, with seasonal values ranging from 63 days in autumn to 85 days in summer. Fog occurred 71 days per year. Seasonal values range from 10 days in spring to 34 days in summer. Rain, without associated fog, occurred 91 days per year. Seasonal values range from 13 days in summer to 30 days in winter. Haze occurred about 22 days per year, ranging from 3 days in winter to 8 days in summer.

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 137 days per year, with seasonal values ranging from 22 days in summer to 42 days in autumn. Cloudy days occurred 161 days per year, ranging from 27 days in winter to 58 days in summer. Foggy days occurred 13 days per year, with seasonal values ranging from less than one day in the spring to 6 days in summer. Rainy days occurred 20 days per year, ranging from less than one day in summer to 10 days in winter. Haze occurred less than one day both annually and seasonally.

Clear conditions occurred 38% of the daylight hours over the course of the year, with seasonal values ranging from 27% in summer to 48% in autumn. Fog occurred 6% of the time, with seasonal values ranging from 2% in spring 10% in summer. Rain, without associated fog, occurred 10% of the time, with seasonal values ranging from 3% in summer to 19% in winter. Cloudy conditions, without associated fog or rain,

occurred 46% of the time, with seasonal values ranging from 33% in autumn and winter to 60% in summer. Haze occurred 3% of the time with seasonal values ranging from 1% in autumn to 6% in summer.

Clear conditions occurred 60% of the nighttime hours over the course of the year, with seasonal values ranging from 57% in autumn to 63% in winter. Fog occurred 2% of the time, with seasonal values ranging from less than one percent in summer to 2% in spring. Rain, without associated fog, occurred 19% of the time, with seasonal values ranging from 18% in summer to 20% in autumn and winter. Cloudy conditions, without associated fog or rain, occurred 17% of the time, with seasonal values ranging from 14% in summer to 20% in autumn. Haze occurred less than 1% of the time with seasonal values ranging from less than one percent in autumn, spring and winter to 1% in summer.

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 Eureka 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.

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	43	56	34	38	171
20 nm	17	17	8	17	58
30 nm	6	5	4	7	23
Days/Year with 50% or More Daylight Observations					
10 nm	9	5	<1	9	24
20 nm	3	<1	<1	3	6
30 nm	<1	<1	<1	<1	1
Days/Year with 75% or More Daylight Observations					
10 nm	5	2	<1	5	12
20 nm	1	<1	<1	<1	2
30 nm	<1	<1	<1	<1	<1
Average Daylight Visibility (nm)					
Clear	10	10	9	10	10
Foggy	<1	<1	<1	<1	<1
Rainy	6	6	4	6	6
Hazy	4	4	4	4	4
Cloudy	9	8	6	9	8
Average	9	9	6	8	8
Average Nighttime Visibility (nm)					
Clear	14	14	10	14	13
Foggy	<1	<1	<1	<1	<1
Rainy	6	6	5	6	6
Hazy	4	5	4	4	4
Cloudy	10	10	8	10	9
Average	11	12	9	11	11

Visibility of at least 10 nm occurred for at least one hour during daylight 171 days per year, with seasonal values ranging from 34 days during summer to 56 days during the spring. Visibility to 20 nm occurred 58 days per year, with seasonal values ranging from 8 days in summer to 17 days in the other seasons. Visibility extended to 30 nm 23 days per year. Seasonal values range from 4 days in summer to 7 days in autumn.

Visibility extended to 10 nm for 50% or more of the daylight hours 24 days per year, with seasonal values ranging from less than one day in summer to 9 days in winter and autumn. Visibility to 20 nm occurred 6 days per year, ranging from less than one day in summer to 3 days in winter and autumn. Visibility to 30 nm occurred one day per year. Values were less than one day in all four seasons.

Visibility extends to 10 nm for 75% or more of the daylight hours 12 days per year, with seasonal values ranging from less than one day in summer to 5 days in winter and autumn. Visibility to 20 nm occurred 2 days per year, ranging from less than one day in spring, summer and autumn to 1 days in winter. Visibility to 30 nm occurred less than one day per year. Values were less than one day in all four seasons

The average daylight visibility for clear conditions was 10 nm, with little variability seasonally. Cloudy conditions reduce the average visibility to 8 miles, ranging from 6 nm in summer to 9 nm in winter and autumn. Rainy, hazy and foggy conditions have an average visibility of 6, 4, 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 9, 9, 6, and 8 nm, respectively.

The average nighttime visibility for clear conditions is 13 nm, with seasonal values ranging from 10 nm in summer to 14 nm in winter, spring and fall. Cloudy conditions reduce the average visibility to 9 miles, with little seasonal variability. Rainy, hazy and foggy conditions have an average visibility of 6, 4 and <1 nm, respectively. These visibilities are consistent through the year. The average nighttime visibility in winter, spring, summer and fall, regardless of meteorological condition, is 11, 12, 9 and 11 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 9 to 10 nm, whereas hazy skies result in an average visibility of approximately 4 nm, with little seasonal variability. This represents approximately a 60% reduction in visibility.

Nighttime hazy skies result in average visibilities of 4 nm compared to 13 nm for clear conditions. In winter, clear skies have an average visibility of 14 nm compared to 4 nm for hazy skies. This represents approximately a 71% reduction in visibility. In spring, visibility decreases from 14 nm for clear conditions to 5 nm for hazy conditions, a reduction of approximately 64%. In summer, the average visibility for clear skies is 10 nm compared to 4 nm for hazy skies, representing a 60% reduction in visibility. In autumn, clear skies have an average visibility of 13 nm, compared to 4 nm for hazy conditions, an approximately 69% reduction in visibility.