NATIONAL RENEWABLE ENERGY LABORATORY

Interagency Agreement M16PG00038

MEMO

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To: Daniel O'Connell, Bureau of Ocean Energy Management

CC: Darryl Francois, Frank Pendleton, Bureau of Ocean Energy Management (BOEM); Suzanne Tegen, Corrie Christol, National Renewable Energy Laboratory (NREL)

From: Caroline Draxl, Walt Musial, George Scott (NREL)

Subject: Offshore Time Series Development for the US Atlantic, Pacific and Gulf of Mexico

This memo documents the creation of time series data from the Wind Integration National Dataset (WIND) Toolkit to produce geo-databases of statistics summarizing key wind resource parameters for each BOEM aliquot in the Pacific and Atlantic offshore regions, as well as for BOEM lease blocks in the Gulf of Mexico. The geo-database and this accompanying memo are deliverables for Interagency Agreement M16PG00038.

Wind Integration National Dataset (WIND) Toolkit

The WIND Toolkit, which was developed by NREL, is an update and expansion of previously available wind datasets, and is intended to support the next generation of wind integration studies. The Weather Research and Forecasting (WRF) model version 3.4.1 was used to create an underlying meteorological dataset, using re-analysis weather data as inputs. The meteorological dataset has a spatial resolution of 2x2 km and 5 min temporal resolution. It covers 7 years (2007–2013) and is available for the outer continental shelf (OCS) over the contiguous 48 U.S. states. Unlike the hybrid dataset used on the initial Pacific geodatabase, the WIND Toolkit is a spatially and temporally consistent data set that is well suited to describe the wind resource off the US coast. It is freely available, and has the advantages of being reproducible, extendable geographically and in time, and its creation is fully documented. Furthermore, the data are available over the whole continental US – which provides the advantage of allowing one consistent methodology to be used when conducting national offshore studies across the United States. It allows for physical and statistical interpretations of data as a data set resulting from chronological physical model runs.

The WIND Toolkit has been used by various research centers worldwide, within NREL, and by universities in multiple studies. A validation report is available for 6 onshore sites and 3 offshore sites (Draxl, Hodge, Clifton, 2015). A validation study and gaps analysis for the WIND Toolkit for offshore waters is planned by DOE in FY 2017.

Wind Resource Statistics

NREL generated summary statistics to convey an understanding of the wind resource for planning purposes.

Time-series wind data can be approximated using a two-parameter Weibull distribution function fitted to the actual distribution of hourly values; however, there is no physical relationship that causes wind speed values to follow a Weibull distribution resulting in some uncertainty between the Weibull approximation and the actual observations. Conveniently though, a large number of cases of time-series wind speed data fit the Weibull distribution function quite well making the Weibull approximations acceptable for most applications.

The probability density function of the two-parameter Weibull distribution is given below in Equation (1). The parameters that define this Weibull function are the shape parameter *k*, and the scale parameter *c*. For lower values of *k*, there is more variation in wind speed.

$$f(v) = \left(\frac{k}{c}\right)\left(\frac{v}{c}\right)^{k-1} \exp\left[-\left(\frac{v}{c}\right)^{k}\right] \qquad (1)$$

To approximate wind speed distributions for a large number of points, NREL uses an “energy-conserving” Weibull approach. A Weibull distribution function conserves energy relative to a time-series distribution when the total wind energy potential in the Weibull distribution is the same as that in the corresponding time-series distribution. There can be many energy-conserving values of *k*, but only one will have the same average wind speed as the corresponding time-series distribution.

The potential of a specific wind power plant to provide for time-varying energy demand is often summarized by plotting the hourly energy production on a monthly basis. Such a summary is known as a 12 x 24 production report. These reports combine the distribution of wind speed values with power curve data to calculate production estimates for each hourly and monthly bin. To enable the broad evaluation of a site’s potential to provide for energy demand without having a specific wind plant design, NREL generated a database that can be used to create 12 x 24 production reports of mean wind speed and Weibull function parameters for each aliquot. These statistics are stored in the accompanying geodatabase in separate feature classes (by month).

The overall long-term characteristics of the wind resource are represented by mean wind speeds. In addition, the distribution of the wind speed on various time scales (long term, monthly, hourly, and hourly by month) is of key importance and is represented by the Weibull curve parameters calculated for the time scale of interest. NREL generated these statistics which are stored in the geo-databases in the accompanying feature class for each aliquot in the US offshore area of the Pacific and Atlantic, as well as for the Gulf of Mexico lease blocks.

Results in the geo-database are reported on the existing 1.2 km x 1.2 km aliquot grid defined by BOEM for the Pacific and Atlantic coastal region. Wind speed statistics are reported at the center point of each aliquot grid, but represent the mean values over the entire area of each grid cell. In the Gulf of Mexico, lease blocks were used as no aliquot grid was available.

Wind speed values in the geodatabase were obtained by finding the closest WIND Toolkit point to a given aliquot (or lease block) and assigning all wind statistics from that point to the aliquot.

In the Atlantic and Pacific, where the aliquot spacing is smaller than the WIND Toolkit spacing, multiple aliquots may use the data from the same WIND Toolkit point.

Geo-database Format

The data set delivered to BOEM is a geo-database consisting of 14 shape files—one for each GIS layer. There is one layer for each month, one layer for the long-term statistics, and one polygon layer of aliquots covered by the data. The long-term shape file includes mean wind speed and Weibull parameters to capture the long-term wind speed distribution of the entire 7-year WIND Toolkit time series. Each monthly shape file contains mean wind speed and Weibull parameters for that month overall and for each hour of the day. The parameters included in the geo-database shape files are shown in Table 1 and Table 2. The geo-databases were delivered in local time: Pacific Time for the US West Coast, Eastern Time (EST) for the Atlantic, and Central Time (CT) for the Gulf of Mexico. Note that the waters west of Florida belong to EST (Figure 1) near shore, but the majority of the OCS west of Florida would actually fall in the Central time zone. For simplicity CT was used for the whole Gulf.

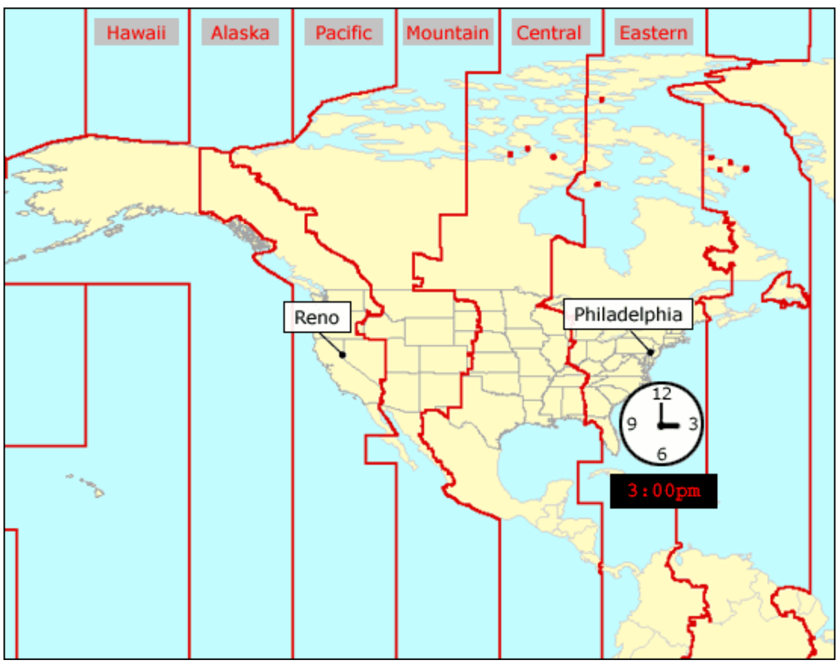

Figure 1 – Map showing time zones over North America (source: https://www.quora.com/How-many-time-zones-does-the-US-have)

Table 1. Long-Term Statistics Layer Parameters

Parameter	Description
Aliquot	Aliquot identifier
Longitude	Longitude of aliquot center
Latitude	Latitude of aliquot center
WS	Long-term wind speed (m/s)
WC	Long-term Weibull scale parameter
WK	Long-term Weibull shape parameter
H00_WS	Hour zero wind speed (m/s) (midnight to 1 a.m.)
H00_WC	Hour zero Weibull scale parameter
H00_WK	Hour zero Weibull shape parameter
↓ ↓	↓ ↓ ↓ ↓ ↓ ↓ ↓
H23_WS	Hour twenty-three wind speed (m/s)
H23_WC	Hour twenty-three Weibull scale parameter
H23_WK	Hour twenty-three Weibull shape parameter

Table 2. Monthly Statistics Layer Parameters

Parameter	Description
JAN_WS	Long-term January wind speed
JAN_WC	Long-term January scale parameter
JAN_WK	Long-term January shape parameter
JAN_H00_WS	January hour zero wind speed (m/s)
JAN_H00_WC	January hour zero Weibull scale parameter
JAN_H00_WK	January hour zero Weibull shape parameter
↓ ↓	↓ ↓ ↓ ↓ ↓ ↓ ↓ ↓
JAN_H23_WS	January hour twenty-three wind speed (m/s)
JAN_H23_WC	January hour twenty-three Weibull scale parameter
JAN_H23_WK	January hour twenty-three Weibull shape parameter

Table 3 is an example of how these hourly statistics by month for a single aliquot could be used to generate a 12 x 24 output report. Note that Table 3 contains data for aliquot NL09-02-6951E centered at 47.1283 N, 124.2647 W. Data such as the contents of this table can be accessed directly from the geodatabase.

Table 3. 12 x 24 Average Hourly Wind Speed in UTC by Month (m/s) at 47.1283 N, 124.2647 W

Hour	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
0000	8.78	8.09	8.25	7.16	6.75	6.13	7.34	6.27	6.08	6.81	8.74	8.96
0100	8.97	8.23	8.43	6.99	6.47	5.99	7	6	5.9	6.79	8.87	8.79
0200	8.95	8.12	8.64	6.94	6.34	5.78	6.71	5.66	5.84	6.82	8.85	8.88
0300	8.97	8.27	8.5	6.9	6.05	5.51	6.39	5.39	5.8	6.74	8.92	8.8
0400	9.1	8.25	8.45	6.89	5.93	5.3	6.08	5.22	5.73	6.76	9.03	8.61
0500	9.29	8.41	8.47	6.76	5.74	5.22	5.83	4.97	5.65	6.89	9.12	8.78
0600	9.27	8.55	8.42	6.78	5.58	5.03	5.45	4.79	5.68	7.09	9.18	8.83
0700	9.29	8.73	8.43	6.75	5.48	4.99	5.15	4.54	5.49	7.06	8.94	8.82
0800	9.28	8.78	8.16	6.52	5.39	4.81	5.09	4.43	5.4	7.09	8.9	8.73
0900	9.12	8.53	8.01	6.61	5.39	4.84	5.11	4.37	5.03	6.87	8.98	8.83
1000	8.72	8.17	7.86	6.66	5.54	5	5.24	4.5	4.93	6.59	8.71	8.64
1100	8.4	7.97	7.71	6.81	5.85	5.32	5.47	4.81	4.9	6.48	8.37	8.48
1200	8.32	7.94	7.96	7.07	6.38	5.85	5.89	5.21	5.2	6.47	8.3	8.29
1300	8.24	7.82	8.09	7.34	6.69	6.13	6.29	5.56	5.55	6.78	8.32	8.19
1400	8.31	7.7	8.27	7.5	6.98	6.39	6.59	5.93	5.95	6.86	8.14	8.26
1500	8.43	7.6	8.34	7.66	7.25	6.6	6.98	6.2	6.17	7.07	8.26	8.39
1600	8.84	7.59	8.54	7.7	7.48	6.72	7.29	6.39	6.31	7.19	8.64	8.46
1700	9.23	7.87	8.42	7.76	7.55	6.83	7.56	6.61	6.41	7.22	8.56	8.75
1800	9.28	8.06	8.42	7.64	7.6	6.83	7.79	6.77	6.54	7.17	8.69	8.71
1900	9.48	8.31	8.35	7.69	7.59	6.86	7.93	6.93	6.6	7.37	8.66	8.72
2000	9.22	8.33	8.22	7.74	7.6	6.86	8.05	6.97	6.65	7.29	8.73	8.61
2100	9.05	8.13	8.02	7.34	7.45	6.69	8.02	6.87	6.47	7.21	8.61	8.73
2200	8.98	8.17	8.25	7.25	7.21	6.53	7.86	6.66	6.39	6.97	8.74	8.72
2300	8.89	8.15	8.24	7.06	6.96	6.32	7.66	6.49	6.24	6.87	8.7	8.97

Specific information about the geo-databases for the Atlantic, Gulf of Mexico, and Pacific

Data set for the Atlantic

The geo-database for the Atlantic contains values at each Atlantic aliquot (Figure 2) out to the 200 nm exclusive economic zone (EEZ). There are 513,227 aliquots in continental U.S. waters, covering longitudes -83.000 to -66.917 and latitudes 23.821 to 44.765. Each aliquot lies in one of 58 protractions. Protractions can have as many as 14,997 aliquots. Protractions have names like NJ19-01 and each aliquot has a 4-digit block number followed by a letter code 'A' through

'P' (there are 16 aliquots per block). So a full aliquot identifier might look like this: **NJ19-01 6002C**. Aliquot data were downloaded as shapefiles from the BOEM GIS website: https://www.boem.gov/Oil-and-Gas-Energy-Program/Mapping-and-Data/ATL_ALIQUOTS.aspx

Since the WTK grid is roughly half the resolution of the aliquots, many WTK points will have their values assigned to multiple (almost always 2, 3 or 4) aliquots. Near the edges of the aliquot or WTK grids, there may be higher numbers of aliquots using data from a single WTK point.

Figure 3 shows the annual average wind speed for the Atlantic aliquots over the entire offshore wind resource area analyzed.

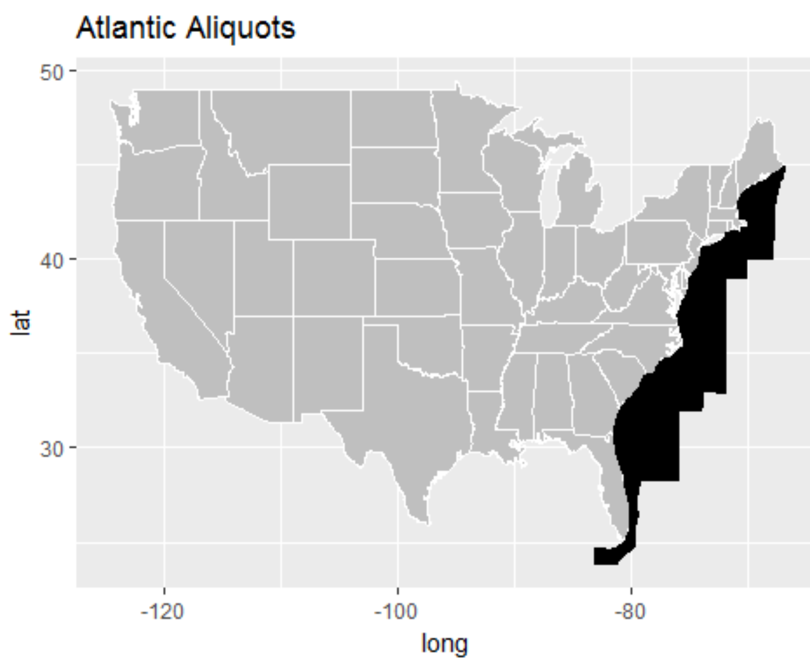

Figure 2: Atlantic wind resource area covered by analysis in black

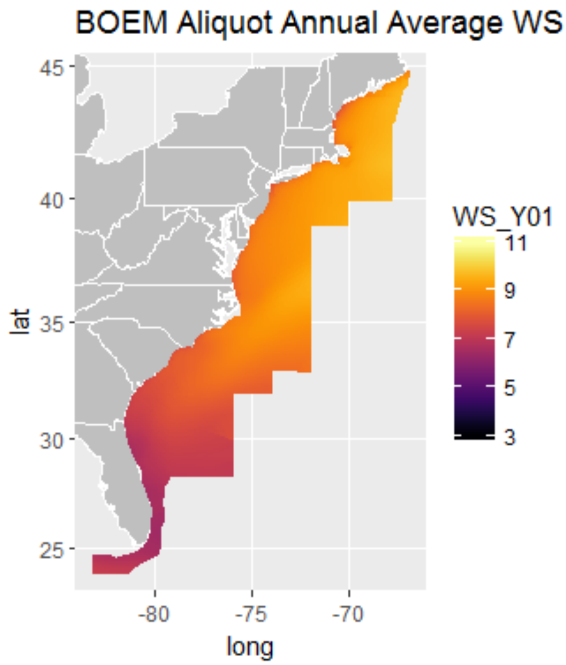

Figure 3: Annual average wind speed in the Atlantic aliquots.

Data set for the Gulf of Mexico

In the Gulf of Mexico, aliquots are not defined. Therefore, values are given at each GOM lease block (4.8 km x 4.8 km). There are 29,101 blocks, covering longitudes -97.214 to -81.194 and latitudes 23.802 to 30.267. This domain is plotted in Figure 4. Each block lies in one of 94 protractions. Protractions can have as many as 989 blocks. Most protractions have names like NF17-01 and each block has a 4-digit block number. So a full block identifier might look like this: **NF17-01 151**. There are 2305 blocks that have been assigned to Texas protractions (beginning with **TX**), and 3393 blocks in Louisiana protractions. There are also 11 blocks that did not have a protraction. All of these have zero area in the shapefile and can probably be ignored (although they are included here).

Block data were downloaded as shapefiles from the BOEM GIS website: https://www.data.boem.gov/homepg/pubinfo/repcat/arcinfo/zipped/blocks.zip

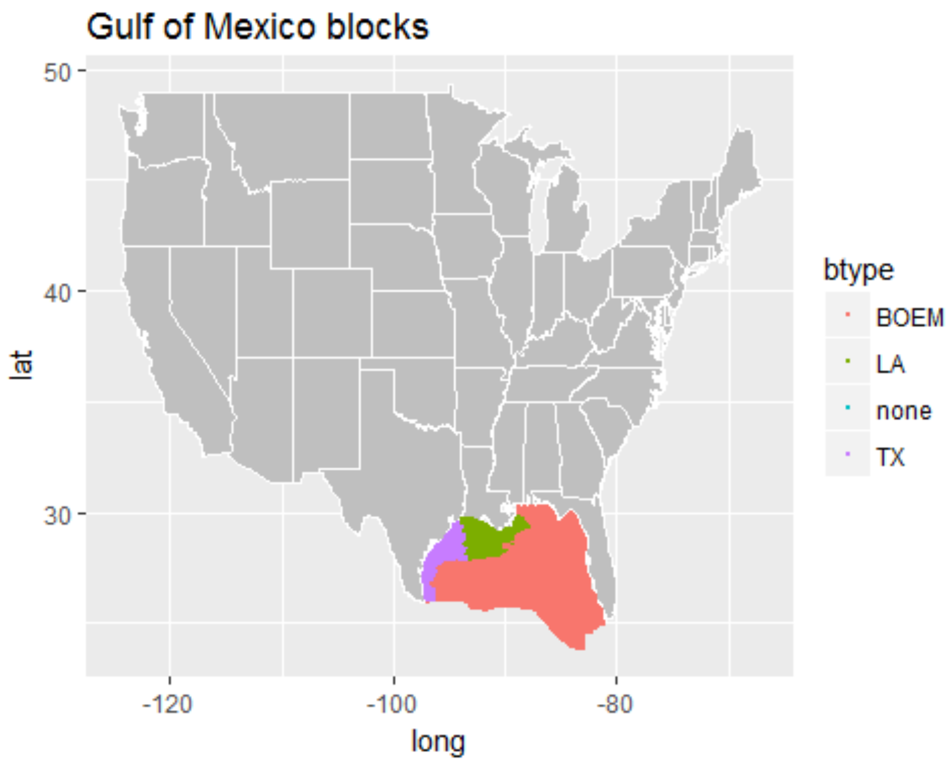

Figure 4: Offshore wind resource area covered by analysis in the Gulf of Mexico. Green denotes Louisiana protractions, purple denotes Texas protractions and red denotes BOEM protractions.

Since the WTK grid is finer than the resolution of the blocks, each block is associated with the WTK point nearest to the block center. Near the edges of the block or WTK grids, there may be multiple blocks using data from a single WTK point. Figure 5 shows the annual average wind speed in the Gulf of Mexico over the analysis area for each lease block.

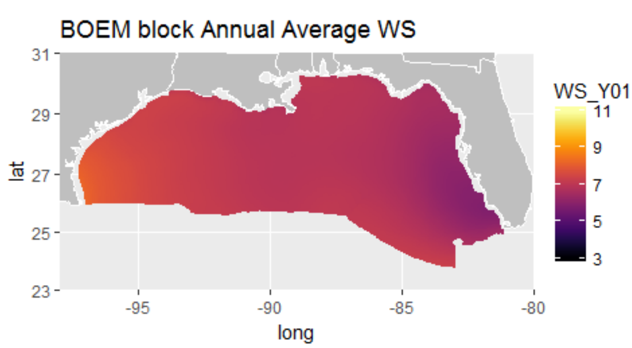

Figure 5: Annual average wind speed in the Gulf of Mexico over analysis area

Data set for the Pacific

We updated the geo-databases for the Pacific with WIND Toolkit data, which were previously created using the hybrid MERRA-AWS dataset. New WTK values are given to replace the previous hybrid values at each Pacific aliquot. There are 163,052 aliquots, covering longitudes -126.000 to -117.189 and latitudes 31.851 to 48.503. The extent of the area analyzed is shown in Figure 6. Each aliquot lies in one of 38 protractions. Protractions can have as many as 12,207 aliquots. Protractions have names like NL09-05 and each aliquot has a 4-digit block number followed by a letter code 'A' through 'P' (there are 16 aliquots per block). So a full aliquot identifier might look like this: **NL09-05 6001A**. Aliquot data were downloaded as shapefiles from the BOEM GIS website:
https://www.boem.gov/uploadedFiles/BOEM/Oil_and_Gas_Energy_Program/Mapping_and_Data/Pacific_files/PC_ALIQUOTS.zip

Since the WTK grid is roughly half the resolution of the aliquots, many WTK points will have their values assigned to multiple (almost always 2, 3 or 4) aliquots. Near the edges of the aliquot or WTK grids, there may be higher numbers of aliquots using data from a single WTK point. Figure 7 shows the annual average wind speed in the Pacific region over the analysis area for each aliquot.

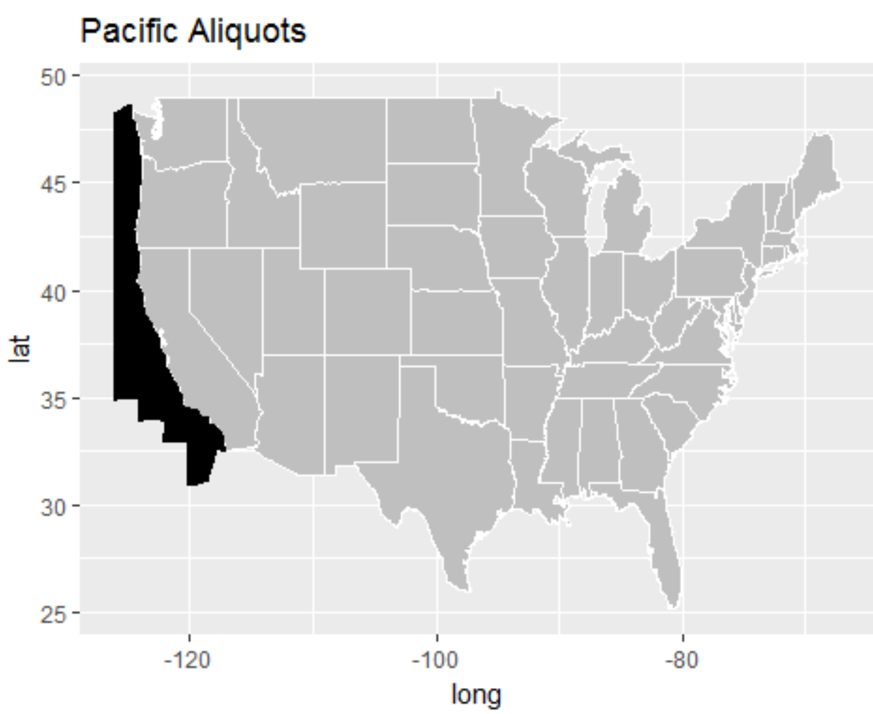

Figure 6: Extent of Pacific analysis region

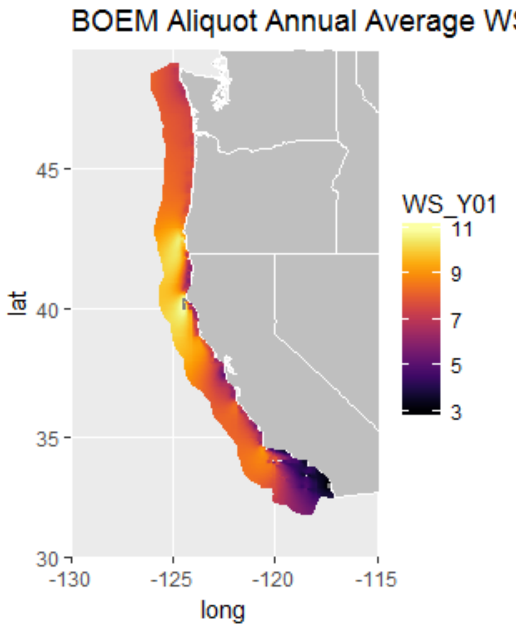

Figure 7: Annual average wind speed in the Pacific for the analysis area

Summary and Conclusion

NREL delivered a preliminary geo-database that was created using the WIND Toolkit dataset on a GIS grid corresponding to the existing BOEM aliquot and lease block grid. The WIND Toolkit is considered the best available data that meet BOEM's requirement for time-varying wind speed data. It is useful for the broad planning and development of overall integration strategies for offshore wind energy technologies. Assessments for specific locations require further study and investment in detailed measurement campaigns. NREL recommends that this data be used by BOEM and its partners with this documentation as guidance. The WIND Toolkit data are publicly available, and the geo-databases will be made public in the same way the hybrid MERRA-AWS data are available online.

References

C. Draxl, A. Clifton, B-M. Hodge, J. McCaa, 2015: The Wind Integration National Dataset (WIND) Toolkit. Appl Energy, http://dx.doi.org/10.1016/j.apenergy.2015.03.121

C. Draxl, B-M. Hodge, A. Clifton, 2015: Overview and Meteorological Validation of the Wind Integration national Dataset (WIND) toolkit. NREL Tech report, http://www.nrel.gov/docs/fy15osti/61740.pdf