# TECHNICAL REPORT

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|---|---|---|---|
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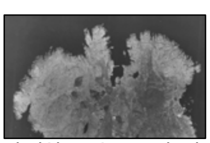
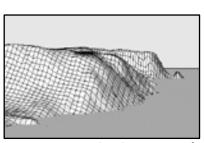
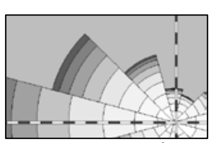
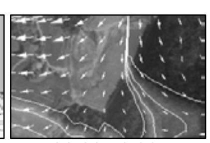
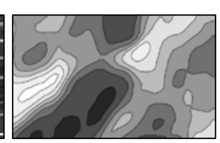


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This report, to the best of our knowledge, represents the state-of-art in wind assessment methods, and the efforts have been made to secure reliable results, WindSim AS cannot in any way be held responsible neither to the use of the findings in the report nor for any direct or indirect losses arising from such use or from errors of any kind in the contents.

Wind measurements were not under the responsibility of WindSim AS, therefore WindSim AS cannot be responsible for the accuracy of data provided as input to our analysis.

## KEY TO DOCUMENT CLASSIFICATION

| | |
|---|---|
| Strictly confidential | For disclosure only to named individuals within the Client's organization |
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| For Public | Available for information to public |

# REVISION HISTORY

| version | date | Summary |
|---|---|---|
| A | 27/04/2025 | Original issue |
| | | |

# EXECUTIVE SUMMARY

The 3 second extreme wind in 50 return year at XXX Solar Park Point 1 is assessed as 108.0mph at 10m, 88.2mph at 4.6m and 68.4mph at 2m.
From the north, the 3 second extreme wind in 50 return year is assessed as 100.8mph at 10m, 83.7mph at 4.6m and 65.7mph at 2m.
From the south, the 3 second extreme wind in 50 return year is assessed as 97.2mph at 10m, 81.0mph at 4.6m and 63.9mph at 2m.
The probability is 85% that the actual value will be less than those assessed value. The directional extreme wind is shown as below.

| **Sector** | **From** | **To** | **Extreme wind (mph), 3sec, 50 yrs** | | |
|---|---|---|---|---|---|
| | | | **2m** | **4.6m** | **10m** |
| **1** | **345** | **15** | **65.7** | **83.7** | **100.8** |
| **2** | 15 | 45 | 58.5 | 74.7 | 90.0 |
| **3** | 45 | 75 | 59.4 | 75.6 | 90.9 |
| **4** | 75 | 105 | 63.9 | 81.0 | 98.1 |
| **5** | 105 | 135 | 66.6 | 84.6 | 101.7 |
| **6** | 135 | 165 | 66.6 | 84.6 | 101.7 |
| **7** | **165** | **195** | **63.9** | **81.0** | **97.2** |
| **8** | 195 | 225 | 60.3 | 77.4 | 92.7 |
| **9** | 225 | 255 | 62.1 | 80.1 | 98.1 |
| **10** | 255 | 285 | 65.7 | 85.5 | 105.3 |
| **11** | 285 | 315 | 68.4 | 88.2 | 108.0 |
| **12** | 315 | 345 | 65.7 | 84.6 | 103.5 |
| **Total** | | | **68.4** | **88.2** | **108.0** |

***Table Extreme wind by direction at Benz Solar Park as 3-sec peak gust in mph for 50 return years***

For ASCE 7-10/16 Category I, the 3 second extreme wind in 300 return year at Benz Solar Park Point 1 is assessed as 129.6mph at 10m, 105.8mph at 4.6m and 82.1mph at 2m.
From the north, the 3 second extreme wind in 300 return year is assessed as 121.0mph at 10m, 100.4mph at 4.6m and 78.8mph at 2m.
From the south, the 3 second extreme wind in 300 return year is assessed as 116.6mph at 10m, 97.2mph at 4.6m and 76.7mph at 2m.
The probability is 85% that the actual value will be less than those assessed value. The directional extreme wind is shown as below.

| **Sector** | **From** | **To** | **Extreme wind (mph), 3sec, 300 yrs** | | |
|---|---|---|---|---|---|
| | | | **2m** | **4.6m** | **10m** |
| **1** | **345** | **15** | **78.8** | **100.4** | **121.0** |
| **2** | 15 | 45 | 70.2 | 89.6 | 108.0 |
| **3** | 45 | 75 | 71.3 | 90.7 | 109.1 |
| **4** | 75 | 105 | 76.7 | 97.2 | 117.7 |
| **5** | 105 | 135 | 79.9 | 101.5 | 122.0 |
| **6** | 135 | 165 | 79.9 | 101.5 | 122.0 |
| **7** | **165** | **195** | **76.7** | **97.2** | **116.6** |
| **8** | 195 | 225 | 72.4 | 92.9 | 111.2 |
| **9** | 225 | 255 | 74.5 | 96.1 | 117.7 |
| **10** | 255 | 285 | 78.8 | 102.6 | 126.4 |
| **11** | 285 | 315 | 82.1 | 105.8 | 129.6 |
| **12** | 315 | 345 | 78.8 | 101.5 | 124.2 |
| **Total** | | | **82.1** | **105.8** | **129.6** |

***Table Extreme wind by direction at Benz Solar Park as 3-sec peak gust in mph for 300 return years (For ASCE 7-10/16 Category I)***

For ASCE 7-10/16 Category II, the 3 second extreme wind in 700 return year at Benz Solar Park Point 1 is assessed as 139.3mph at 10m, 113.8mph at 4.6m and 88.2mph at 2m.
From the north, the 3 second extreme wind in 700 return year is assessed as 130.0mph at 10m, 108.0mph at 4.6m and 84.8mph at 2m.
From the south, the 3 second extreme wind in 700 return year is assessed as 125.4mph at 10m, 104.5mph at 4.6m and 82.4mph at 2m.
The probability is 85% that the actual value will be less than those assessed value. The directional extreme wind is shown as below.

| Sector | From | To | Extreme wind (mph), 3sec, 700 yrs | | |
|---|---|---|---|---|---|
| | | | 2m | 4.6m | 10m |
| **1** | **345** | **15** | **84.8** | **108.0** | **130.0** |
| **2** | 15 | 45 | 75.5 | 96.4 | 116.1 |
| **3** | 45 | 75 | 76.6 | 97.5 | 117.3 |
| **4** | 75 | 105 | 82.4 | 104.5 | 126.5 |
| **5** | 105 | 135 | 85.9 | 109.1 | 131.2 |
| **6** | 135 | 165 | 85.9 | 109.1 | 131.2 |
| **7** | **165** | **195** | **82.4** | **104.5** | **125.4** |
| **8** | 195 | 225 | 77.8 | 99.8 | 119.6 |
| **9** | 225 | 255 | 80.1 | 103.3 | 126.5 |
| **10** | 255 | 285 | 84.8 | 110.3 | 135.8 |
| **11** | 285 | 315 | 88.2 | 113.8 | 139.3 |
| **12** | 315 | 345 | 84.8 | 109.1 | 133.5 |
| **Total** | | | **88.2** | **113.8** | **139.3** |

***Table Extreme wind by direction at Benz Solar Park as 3-sec peak gust in mph for 700 return years (For ASCE 7-10/16 Category II)***

# CONTENTS

# 1 Introduction

The purpose of this project is to analyse the extreme wind conditions at a solar park.

The design of the solar panel rack in USA follows the national standard, named ASCE 7 Minimum Design Loads for Buildings and Other Structures, issued by American Society of Civil Engineers (ASCE) /1/.

In chapter 26.5.3 of ASCE 7-16, Estimation of Basic Wind Speeds from Regional Climatic Data, it is defined that in areas outside hurricane-prone regions, regional climatic data shall only be used in lieu of the basic wind speeds given in Fig. 26.5-1 when

(1) approved extreme-value statistical-analysis procedures have been employed in reducing the data; and
(2) the length of record, sampling error, averaging time, anemometer height, data quality, and terrain exposure of the anemometer have been taken into account.

Reduction in basic wind speed shall be permitted.

In hurricane-prone regions, wind speeds derived from simulation techniques shall only be used in lieu of the basic wind speeds given in Fig. 26.5-1 when approved simulation and extreme value statistical analysis procedures are used.

Following the requests, for non-hurricane region, WindSim AS applied the statistical and physical models in the analysis in the following steps:

- Nearby regional reference wind conditions
- On-site wind conditions
- On-site extreme wind conditions
- Uncertainty of the assessment

for hurricane region, WindSim AS applied the statistical and physical models in the analysis in the following steps:

- Return period for landfall hurricane wind
- Sea land transition
- On-site extreme wind conditions
- Uncertainty of the assessment

## *1.1 Site*

XXX Solar Park is located near XXX, XXX, United States with coordinates XXX"N, XXXW. The location of solar park is shown in Figure 1.1. The site is located in the hurricane region, methodology for hurricane applies.


*Figure 1.1 The location of the solar park*

# 2 Methodology

The territory of US is divided into two regions, non-hurricane region and hurricane region, which is in line with ASCE) /1/. When the site is located in the non-hurricane region, the methodology for non-hurricane region applies, and when the site is located in the hurricane region, the methodology for hurricane region applies.

## *2.1 Methodology for non-hurricane region*

The extreme wind analysis has four major steps.

### 2.1.1 Step 1, analysis of nearby regional reference wind conditions

The regional reference wind near the solar park is the starting point for extreme wind analysis. The accuracy of the assessment may depend largely on the availability and the quality of the reference wind nearby.

In this step, the area of 100km x 100km, cantering solar park is examined to identify reference wind nearby. The reference wind comes mostly from two sources.

The first source is Standardized Extreme Wind Speed (SEWS) database /2/. The database is processed and managed by Statistical Engineering Division from National Institute of Standards and Technology (NIST). The raw data is from National Climatic Data Centre (NCDC). Integrated Surface Hourly (ISH) Data Set 3505 is used from the raw data. The raw data is recorded by the weather stations, which are Automated Weather Observing System (AWOS), operated mostly by Federal Aviation Administration (FAA), and Automated Surface Observing System (ASOS), which are operated and controlled cooperatively in the United States by the National Weather Service (NWS), Federal Aviation Administration (FAA), and Department of Defence (DOD).

The data is processed by NIST for standardization of elevation, averaging time, terrain roughness, with quality control. The final dataset includes 1865 sites in the United States, representing the time series of 3 second averaging extreme wind at 10m height at roughness of 0.03. The length of the record depends on the data, and it may range from several years to more than 30 years.

The selected data has been verified and quality controlled by WindSim AS. Typically, the extreme wind events over 70mph are compared with reports for storm paths, deaths, injuries, and property damage, from Storm Data Publication from National Centres for Environmental Information (NCEI), from National Oceanic and Atmospheric Administration (NOAA) /3/.

The second source is Modern Era Retrospective Analysis for Research and Applications (MERRA-2) /4/, MERRA-2 is a reanalysis for the satellite era using a major new version of the Goddard Earth Observing System Data Assimilation System Version 5 (GEOS-5), from Global Modelling and Assimilation Office (GMAO) from National Aeronautics and Space Administration (NASA).

The data is regularly distributed in USA, at resolutions of 0.5 degree latitude and 0.625 degree longitude (around 50-60km to each other). It gives average wind speed and direction at the time step of 1 hour at 50m for about 37 years.

Usually one or more SEWS and 4 MERRA-2 are located in the area of 100km x 100km.

The quality of SEWS is investigated, by comparing nearby SEWS points in case the data period is less than 10 years, and by comparing Storm Data Publication when the wind speed record is over 80mph.

### 2.1.2 Step 2, analysis of on-site wind conditions

Wind is correlated to each other within the micro scale wind pattern zone. The ratio between wind speed at two locations nearby from one direction is roughly a constant, independent to the wind speed.

The purpose of this step is to transfer the regional reference wind condition to the solar park by WindSim flow modelling. Thus, the basic assumption is that the extreme wind at solar park is correlated with the regional reference wind nearby.

Because the wind flow is affected by the local terrain, the digital terrain model including elevation and roughness is set for the simulation.

The elevation data comes from National Elevation Dataset (NED), which is the primary elevation data by United States Geological Survey (USGS). NED data are available in USA at resolutions of 1 arc-second (about 30 meters) and 1/3 arc-second (about 10 meters), and in limited areas at 1/9 arc-second (about 3 meters) /5/.

The roughness is converted mainly from National Land Cover Database 2011 (NLCD 2011) /6/, created by Multi-Resolution Land Characteristics (MRLC) Consortium. It has multiple-class land cover classification scheme that has been applied consistently across the United States at a spatial resolution of 30 meters.

Near the US border area, when the NLCD 2011 is not available, Global Land Cover 30 (GLC30) dataset, which is managed by National Geomatics Center of China (NGCC), is complemented /7/.

Based on the digital terrain model, the simulation domain is generated covering the air above it. The entire large simulation domain is then further divided into small boxes, and each small box is represented by a node. Boundary conditions are applied to the nodes on the surfaces of the simulation domain, and Reynolds Averaged Navier-Stokes (RANS) equations are applied to each node within the simulation domain, before the numerical simulation started by iteration to solve the wind flow from each wind direction /8/.

Once the flow model is completed, the wind speed and direction at any point within the simulation domain is known. Then the speed-up ratio and direction shift between reference wind place and solar park point can be calculated. As the reference wind is created in the first step, the on-site wind condition at solar park is generated.

### 2.1.3 Step 3, analysis of on-site extreme wind conditions

In this step, a time series of wind speed and direction at the solar park from step 2 is used for analysis, and Method of Independent Storm (MIS) /9/ is applied to estimate the extreme wind. MIS has two steps. First, the peak wind value from each storm event is picked from the time series. The storm event is usually defined by the period of 48 - 72 hours and the 3 second wind speed is over 20 - 40mph, or the hourly averaging wind speed is over 9 – 11mph, and it is around 20 storms per year.

The Gumbel distribution is used for modelling the probability of the extreme wind speeds. The Equation 2.1 gives the cumulative probability distribution function of the Gumbel distribution:

$$F(x) = \exp\left\{-\exp\left[\frac{-(x-\mu)}{\beta}\right]\right\}$$

***Equation 2.1 Cumulative probability distribution function of the Gumbel distribution***

Where, x is the extreme value, beta is a scale parameter, and mu is a mode parameter. Both parameters have the same units as x.

The equation can be further linearized as Equation 2.2.

$$-\ln[-\ln F(x)] = \left(\frac{1}{\beta}\right)x - \frac{\mu}{\beta}$$

***Equation 2.2 Linearized cumulative probability distribution function of the Gumbel distribution***

That is in the form y = mx + b, when plotting -ln(-ln(F(x))) versus x, a straight line can be found with a slope of 1/beta and an intercept of -mu/beta.

A highest few extreme values are used in the curve fit /10/ to calculate scale parameter beta and model parameter mu.

The return period is defined as the reciprocal of the probability of exceedance. A given Gumbel distribution represents the distribution of annual extreme wind speeds, and when x takes a value of 80 mph, for example, the cumulative distribution function F(x) gives a value of 0.98. That means that there is a 98% probability that in any one year, the annual extreme wind speed x will be equal to or less than 80 mph. The probability of exceedance of 80 m/s is therefore 100% - 98% = 2%. The resulting return period is 1 / 0.02 = 50 years. That means that, on average, we would expect a wind speed of 80mph once in 50 years.

The Equation 2.3 gives the annual extreme value for a specified Gumbel distribution and a return period of R years:

$$x = \mu - \beta \cdot \ln\left[-\ln\left(1 - \frac{1}{R}\right)\right]$$

***Equation 2.3 Annual extreme wind for a return period of R years***

In the case that MERRA-2 is used in the first step, the time step, then, is 1 hour, the further unit and time step conversion are needed.

Based on the internal validation study /12/ on 21 sites across US, there are discrepancy in the result between method driven by MERRA-2 and method driven by SEWS. The reason is that extreme wind mostly happens during the thunderstorm, which tends to be very short and local, MERRA-2, however, tends to fail to record those events. The study recommended that when the MERRA-2 is the sole source, the correction factor should be applied.

### 2.1.4 Step 4, analysis of assessment uncertainty

Uncertainty in extreme wind assessment is a vital part of the result. It gives the confidence analysis to the accuracy of the extreme wind estimate. The uncertainty is divided by four categories.

1. Wind record
2. Long term representativeness
3. Flow model
4. Extreme wind model

**Wind record:** This is the uncertainty in the wind speed as measured by anemometers after data validation and adjustments. It reflects not only the uncertainty in the sensitivity of the instruments when operating under ideal wind conditions, but also their performance in the field. When SWES is used, it is assumed that the equipment has high accuracy, well calibrated, the installation is according to the standard, and the maintenance is well conducted, the data collection and treatment is free of error. The total uncertainty for extreme wind is 3.0%. When MERRA-2 is applied, uncertainty of 10.0% is assumed.

**Long term representativeness:** The uncertainty is associated with the length of the recording period, historical data availability, representativeness of the long-term wind regime. Based on the study for 21 sites /12/, it is calculated that yearly variability of the annual extreme wind is 15%, then the uncertainty of the period of X years is calculated as 15%/sqrt(X).

**Flow model:** The uncertainty is associated with the WindSim flow modelling. It depends on suitability of the flow model to the flow pattern, model gridding, governing equations, boundary conditions, flow similarity, terrain similarity, and distance between reference wind and on-site wind locations. The uncertainty is estimated as 0.1% per km for simple terrains, and 0.15% per km for complex terrains.

**Extreme wind model:** It relies on the mathematical expression of the extreme wind. The uncertainty is estimated as 2.0% by applying current method.

Each uncertainty is assumed to be independent, and the total uncertainty is calculated by root-sum-square basis. The extreme wind estimation is assumed to follow a normal distribution, and the probability of non-exceedance is estimated as

Extreme Wind (P85) = Extreme Wind (P50) x (1 + 1.04 x Uncertainty);
Extreme Wind (P90) = Extreme Wind (P50) x (1 + 1.28 x Uncertainty);
Extreme Wind (P95) = Extreme Wind (P50) x (1 + 1.65 x Uncertainty).

The expected Extreme Wind PXX implies that there is a probability of XX% that the outcome will be less than PXX and a probability of (100-XX)% that the outcome will be more.

## *2.2 Methodology for hurricane region*

The extreme wind analysis has four major steps.

### 2.2.1 Step 1, Return period for hurricane wind

The radius of maximum wind (RMW) is the distance between the center of a cyclone and its band of strongest winds.

The calculation of the RMW is based on the National Hurricane Center Risk Analysis Program (HURISK) /13/. RMW is directly proportional to latitude and inversely proportional to storm intensity. The effect of latitude on RMW is greater than the effect of storm intensity. The inverse relationship between RMW and storm intensity increases rather rapidly with increasing storm intensity.

The historical hurricanes database is used, and it is International Best Track Archive for Climate Stewardship (IBTrACS) /14/ data set, from NOAA. It has more than 6000 tropical cyclones, ranging from 1842.

Within range of the incoming directions of the hurricanes, the distance between each coastline to the solar park is measured. When the distance is within 150km, the routes are considered as possible hurricane route passing the coastline and hitting the solar park.

At coastline, two return periods are read from HURISK program /13/. The method is established in 1987, the data is through 2010. They are the return years for hurricanes over and including Saffir-Simpson /15/ Category 1 passing within 50 nautical miles, and the return periods in years for hurricanes over and including Saffir-Simpson Category 3 passing within 50 nautical miles.

For Saffir-Simpson Category 1, the sustained wind speed is 74-95 mph, and for Saffir-Simpson Category 3, the sustained wind speed is 111-129 mph. Sustained wind is defined by averaging winds over a period of one minute, measured at 10 metres height.

HURISK /13/ model is used for assessing the long-term vulnerability of coastal areas to tropical cyclone events. One of the output is return periods for any coastal or near-coastal site over the Atlantic tropical cyclone basin. For input, the program access NHC files of historical tropical cyclone data which begins with the year 1886. For the computing, Mote-Carlo simulation is used as computer random number generator for storm distance, Weibull distribution of the maximum winds, log-normal distribution of RMW for the site. The simulation period is 10000 storms passing a site within 150 nautical miles scan radius.

At each coastline for possible hurricane route, the scan circle 50 nautical miles is used to estimate the percentage of hurricanes passing the coastline and hitting the solar park.

The sustained wind speed for 50 return periods, which passing the coastline and hitting the solar park is calculated, with the consideration of the RMW, scan circle in HURISK, and percentage of hurricane passing the coastline and hitting the solar park.

### 2.2.2 Step 2, analysis of extreme wind inland

The average forward wind speed of hurricane site is calculated by latitude based on the statistics from Hurricane Databases second version (HURDAT2) from NHC. It contains details on tropical cyclones that have occurred within the Atlantic Ocean and Eastern Pacific Ocean since either 1851 or 1949.

The hurricane traveling time is calculated based on the distance between the coastline and solar park and the average forward wind speed of hurricane.

The roughness of the land terrain increases friction, but more critical, once the hurricane is over land, the system is cut off from its heat and moisture sources.

The maximum sustained wind speed at the place with flat terrain and low roughness, at the same distance between the solar park and the coastline is calculated based on Equation 2.4, which is generated from the work of Johan Kaplan and Mark DeMaria /17/.

$$U_{!} = (U_{"} - U_{\#})e^{\$\%.'\%(} + U_{\#}$$

***Equation 2.4 Decay function of inland wind speed after landfall by time***

Where $U_i$ is the inland sustained wind speed in mph at at the place with flat terrain and roughness is 0.03m, $U_l$ is the landfall sustained wind speed in mph, $U_c$ is constant as 34.5 mph, t is hurricane traveling time from the coast to inland in hour.

Gust factor between 3 second extreme wind and sustained wind speed as 60 seconds is XX after 2 times RMW, linear at the distance between RMW and 2 times RMW, XX within RMW to the coastline, modified based on the work from WMO /11/. The 3 second extreme wind 50 return year at site with flat area and low vegetation is then calculated, serving as reference wind.

### 2.2.3 Step 3, analysis of extreme wind at solar park

Because the wind flow is affected by the local terrain, the digital terrain model including elevation and roughness is set for the simulation.

The elevation data comes from National Elevation Dataset (NED), which is the primary elevation data by United States Geological Survey (USGS). NED data are available in USA at resolutions of 1 arc-second (about 30 meters) and 1/3 arc-second (about 10 meters), and in limited areas at 1/9 arc-second (about 3 meters) /5/.

The roughness is converted mainly from National Land Cover Database 2011 (NLCD 2011) /6/, created by Multi-Resolution Land Characteristics (MRLC) Consortium. It has multiple-class land cover classification scheme that has been applied consistently across the United States at a spatial resolution of 30 meters.

Near the US border area, when the NLCD 2011 is not available, Global Land Cover 30 (GLC30) dataset, which is managed by National Geomatics Center of China (NGCC), is complemented /7/.

Based on the digital terrain model, the simulation domain is generated covering the air above it. The entire large simulation domain is then further divided into small boxes, and each small box is represented by a node. Boundary conditions are applied to the nodes on the surfaces of the simulation domain, and Reynolds Averaged Navier-Stokes (RANS) equations are applied to each node within the simulation domain, before the numerical simulation started by iteration to solve the wind flow from each wind direction /8/.

Once the flow model is completed, the wind speed and direction at any point within the simulation domain is known. Then the speed-up ratio and direction shift between reference wind place and solar park point can be calculated. As the reference wind is created in the second step, the 3 second extreme wind for 50 return year period at solar park is generated.

For 3 second extreme wind for 500 return year period, the conversion factor XX is used /19/.

### 2.2.4 Step 4, analysis of assessment uncertainty

Uncertainty in extreme wind assessment is a vital part of the result. It gives the confidence analysis to the accuracy of the extreme wind estimate. The uncertainty is divided by four categories.

1. Landfall wind speed
2. Sea land transition
3. Flow model
4. Extreme wind model

**Landfall wind speed:** This is the uncertainty for return period at landfall. It reflects the uncertainty in the HURISK study, and the sensitivity of hurricane wind direction distribution at landfall. The uncertainty of HURISK is estimated as X.0%. The hurricane wind direction distribution at landfall is calculated based on data from several selections at the coastline.

**Sea land transition:** The uncertainty is associated with the sea land transition decay function. It's based on the validation study for 100 hurricanes, and it's calculated as X%.

**Flow model:** The uncertainty is associated with the WindSim flow modelling. It depends on suitability of the flow model to the flow pattern, model gridding, governing equations, boundary conditions, flow similarity, terrain similarity, and distance between reference wind and on-site wind locations. The uncertainty is estimated as 0.1% per km for simple terrains, and 0.15% per km for complex terrains.

**Extreme wind model:** It relies on the mathematical expression of the extreme wind. The uncertainty is estimated as 2.0% by applying current method.

Each uncertainty is assumed to be independent, and the total uncertainty is calculated by root-sum-square basis. The extreme wind estimation is assumed to follow a normal distribution, and the probability of non-exceedance is estimated as

Extreme Wind (P85) = Extreme Wind (P50) x (1 + 1.04 x Uncertainty);
Extreme Wind (P90) = Extreme Wind (P50) x (1 + 1.28 x Uncertainty);
Extreme Wind (P95) = Extreme Wind (P50) x (1 + 1.65 x Uncertainty).

The expected Extreme Wind PXX implies that there is a probability of XX% that the outcome will be less than PXX and a probability of (100-XX)% that the outcome will be more.

# 3 Wind Conditions

The site in at the latitude between 41 to 42 degrees, the average RMW for category one hurricane is calculated as 66.3km. The average radius of maximum wind for category three hurricane is calculated as 63.7km, shown in Table 3.1.

| Hurricane Category | RMW -km |
|---|---|
| **1** | 68.0 |
| **3** | 65.4 |

***Table 3.1 Radius of Maximum Wind (RMW) in km for Hurricane category 1 and 3 at site***

Within the scan circle and the distance between the solar park to the coast is within 200km, there are possible routes below for hurricane hitting the solar park:

- 50km from XXX coast with direction 180 degree;

The landfall maximum sustained wind as one-minute average for 50 return years passing the XXX county and hitting the site are calculated as 81.4mph from XXX shown in Table 3.2.

| Direction | Coastline county | Distance -km | Landfall maximum sustained wind speed as one-minute average for 50 return years -mph |
|---|---|---|---|
| 180 | Suffolk | 50 | 81.4 |

***Table 3.2 Maximum sustained wind speed at landfall as one-minute average for 50 return years passing the XXX county and hitting the site in mph***

The highest wind occurs when the hurricane comes from XXX county with direction of 180 degrees. The extreme wind as 3-second average for 50 return years at site for flat area and low vegetation is 92.9mph, shown in Table 3.3.

| Direction | XXX county | Inland extreme wind as 3-sec average for 50 return years -mph |
|---|---|---|
| 180 | XXX | 92.9 |

***Table 3.3 Extreme wind as 3-second average for 50 return years at site for flat area and low vegetation***

# 4 CFD Modelling

The detail of the digital terrain model is shown in Table 4.1, Table 4.2, Table 4.3 and Figure 4.1.

| **Parameter** | **Information** |
|---|---|
| Extension | .gws |
| Type | Grid |
| Projection | UTM Zone 18 |
| Horizontal Datum | WGS 84 |

***Table 4.1 Geo information of the digital terrain model***

| **Corner** | **Easting (m)** | **Northing (m)** |
|---|---|---|
| Northeast | XXX | XXX |
| Southwest | XXX | XXX |
| | **East-West (m)** | **North-South (m)** |
| Distance | 50000.0 | 50000.0 |
| Resolution | 100.0 | 100.0 |

***Table 4.2 Coordinates and distance of digital terrain model (UTM Zone 18, WGS 84)***

| Land Cover | Roughness length (m) |
|---|---|
| Open Water | 0.0003 |
| Perennial Ice/Snow | 0.0010 |
| Developed, Open Space | 0.0300 |
| Developed, Low Intensity | 0.0300 |
| Developed, Medium Intensity | 0.3000 |
| Developed, High Intensity | 0.5000 |
| Barren Land (Rock/Sand/Clay) | 0.0100 |
| Unconsolidated Shore | 0.0500 |
| Deciduous Forest | 0.4000 |
| Evergreen Forest | 0.4000 |
| Mixed Forest | 0.4000 |
| Dwarf Scrub | 0.0500 |
| Shrub/Scrub | 0.1000 |
| Grassland/Herbaceous | 0.0500 |
| Grassland/Herbaceous | 0.0500 |
| Lichens | 0.0020 |
| Moss | 0.0020 |
| Pasture/Hay | 0.0300 |
| Cultivated Crops | 0.0300 |
| Woody Wetlands | 0.2000 |
| Palustrine Forested Wetland | 0.3000 |
| Palustrine Scrub/Shrub Wetland | 0.1000 |
| Estuarine Forested Wetland | 0.3000 |
| Estuarine Scrub/Shrub Wetland | 0.1000 |
| Emergent Herbaceous Wetlands | 0.1000 |

***Table 4.3 Roughness table for digital roughness model***

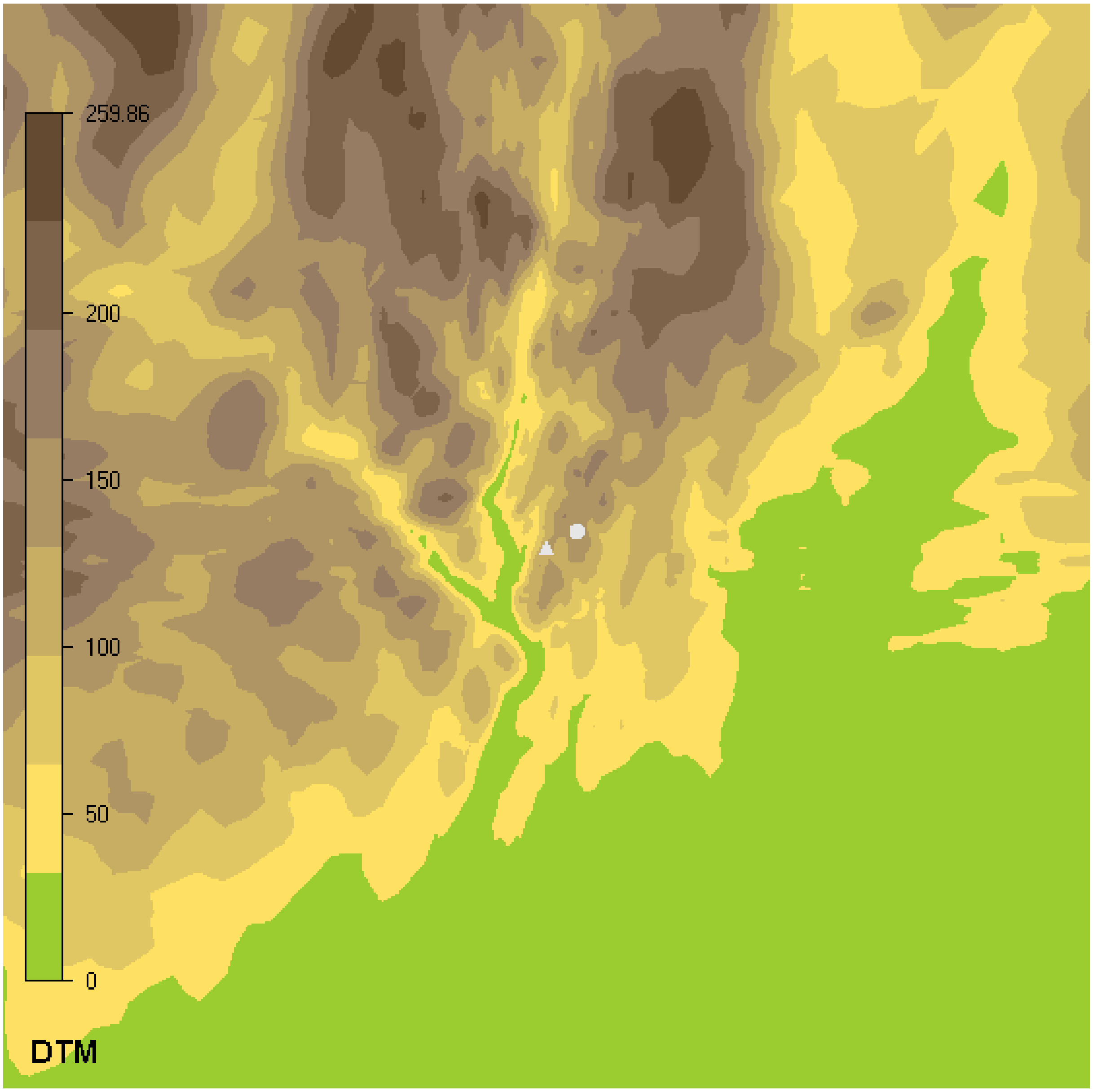


***Figure 4.1 Digital elevation model (triangle is the solar park, dot is the reference wind)***

# 5 Extreme wind analysis by hurricane methodology

The results are generated at one point within the solar park. The coordinates are shown in Table 5.1, and Figure 5.1.

| Name | Easting (m) | Northing (m) | Height (m) |
|---|---|---|---|
| XXX Solar Park Point 1 | XXX | XXX | 10.0 |

***Table 5.1 Extreme wind result points (UTM Zone 18, WGS 84)***


***Figure 5.1 Extreme wind result points***

The extreme wind as 3-sec peak gust in mph for 50 return years by direction at site results for XXX Solar Park Point 1 are shown in Table 5.2.

| Sector | From | To | Extreme wind (mph), 3sec, 50 yrs | | |
|---|---|---|---|---|---|
| | | | 2m | 4.6m | 10m |
| **1** | **345** | **15** | **65.7** | **83.7** | **100.8** |
| **2** | 15 | 45 | 58.5 | 74.7 | 90.0 |
| **3** | 45 | 75 | 59.4 | 75.6 | 90.9 |
| **4** | 75 | 105 | 63.9 | 81.0 | 98.1 |
| **5** | 105 | 135 | 66.6 | 84.6 | 101.7 |
| **6** | 135 | 165 | 66.6 | 84.6 | 101.7 |
| **7** | **165** | **195** | **63.9** | **81.0** | **97.2** |
| **8** | 195 | 225 | 60.3 | 77.4 | 92.7 |
| **9** | 225 | 255 | 62.1 | 80.1 | 98.1 |
| **10** | 255 | 285 | 65.7 | 85.5 | 105.3 |
| **11** | 285 | 315 | 68.4 | 88.2 | 108.0 |
| **12** | 315 | 345 | 65.7 | 84.6 | 103.5 |
| **Total** | | | **68.4** | **88.2** | **108.0** |

***Table 5.2 Extreme wind as 3-sec peak gust in mph for 50 return years by direction at site.***

The uncertainty analysis result is shown in Table 5.3 and Table 5.4.

| | Item | Unit | Uncertainty |
|---|---|---|---|
| | **Total Uncertainties** | % | 14.7 |
| 1 | Landfall wind speed | % | 6.9 |
| 2 | Sea land transition | % | 12.8 |
| 3 | Flow model | % | 0.2 |
| 4 | Extreme wind model | % | 2.0 |

***Table 5.3 Uncertainty analysis for extreme wind as 3-sec peak gust in mph for 50 return years***

| Extreme Wind (mph) | 2m | 4.6m | 10m |
|---|---|---|---|
| P85 | 68.4 | 88.2 | 108.0 |
| P90 | 70.5 | 90.9 | 111.4 |
| P95 | 73.8 | 95.1 | 116.5 |

***Table 5.4 Extreme wind with probability of non-exceedance analysis for extreme wind as 3-sec peak gust in mph for 50 return years***

The extreme wind as 3-sec peak gust in mph for 300 return years by direction at site results for XXX Solar Park Point 1 are shown in Table 5.5.

| Sector | From | To | Extreme wind (mph), 3sec, 300 yrs | | |
|---|---|---|---|---|---|
| | | | 2m | 4.6m | 10m |
| 1 | 345 | 15 | 78.8 | 100.4 | 121.0 |
| 2 | 15 | 45 | 70.2 | 89.6 | 108.0 |
| 3 | 45 | 75 | 71.3 | 90.7 | 109.1 |
| 4 | 75 | 105 | 76.7 | 97.2 | 117.7 |
| 5 | 105 | 135 | 79.9 | 101.5 | 122.0 |
| 6 | 135 | 165 | 79.9 | 101.5 | 122.0 |
| 7 | 165 | 195 | 76.7 | 97.2 | 116.6 |
| 8 | 195 | 225 | 72.4 | 92.9 | 111.2 |
| 9 | 225 | 255 | 74.5 | 96.1 | 117.7 |
| 10 | 255 | 285 | 78.8 | 102.6 | 126.4 |
| 11 | 285 | 315 | 82.1 | 105.8 | 129.6 |
| 12 | 315 | 345 | 78.8 | 101.5 | 124.2 |
| Total | | | 82.1 | 105.8 | 129.6 |

***Table 5.5 Extreme wind as 3-sec peak gust in mph for 300 return years by direction at site. (For ASCE 7-10/16 Category I)***

The extreme wind as 3-sec peak gust in mph for 700 return years by direction at site results for XXX Solar Park Point 1 are shown in Table 5.6

| Sector | From | To | Extreme wind (mph), 3sec, 700 yrs | | |
|---|---|---|---|---|---|
| | | | 2m | 4.6m | 10m |
| 1 | 345 | 15 | 84.8 | 108.0 | 130.0 |
| 2 | 15 | 45 | 75.5 | 96.4 | 116.1 |
| 3 | 45 | 75 | 76.6 | 97.5 | 117.3 |
| 4 | 75 | 105 | 82.4 | 104.5 | 126.5 |
| 5 | 105 | 135 | 85.9 | 109.1 | 131.2 |
| 6 | 135 | 165 | 85.9 | 109.1 | 131.2 |
| 7 | 165 | 195 | 82.4 | 104.5 | 125.4 |
| 8 | 195 | 225 | 77.8 | 99.8 | 119.6 |
| 9 | 225 | 255 | 80.1 | 103.3 | 126.5 |
| 10 | 255 | 285 | 84.8 | 110.3 | 135.8 |
| 11 | 285 | 315 | 88.2 | 113.8 | 139.3 |
| 12 | 315 | 345 | 84.8 | 109.1 | 133.5 |
| Total | | | 88.2 | 113.8 | 139.3 |

***Table 5.6 Extreme wind as 3-sec peak gust in mph for 700 return years by direction at site. (For ASCE 7-10/16 Category II)***

# 6 Conclusions and Recommendations

1. The solar park is located in the hurricane region. The methodology of extreme wind for hurricane region applies. P85 value is used in the result.

2. The 3 second extreme wind in 50 return year at XXX Solar Park Point 1 is assessed as 108.0mph at 10m, 88.2mph at 4.6m and 68.4mph at 2m. The 3 second extreme wind in 300 return year is assessed as 129.6mph at 10m, 105.8mph at 4.6m and 82.1mph at 2m. The 3 second extreme wind in 700 return year is assessed as 139.3mph at 10m, 113.8mph at 4.6m and 88.2mph at 2m.

3. From the north, the 3 second extreme wind in 50 return year is assessed as 100.8mph at 10m, 83.7mph at 4.6m and 65.7mph at 2m. The 3 second extreme wind in 300 return year is assessed as 121.0mph at 10m, 100.4mph at 4.6m and 78.8mph at 2m. The 3 second extreme wind in 700 return year is assessed as 130.0mph at 10m, 108.0mph at 4.6m and 84.8mph at 2m.

4. From the south, the 3 second extreme wind in 50 return year is assessed as 97.2mph at 10m, 81.0mph at 4.6m and 63.9mph at 2m. The 3 second extreme wind in 300 return year is assessed as 116.6mph at 10m, 97.2mph at 4.6m and 76.7mph at 2m. The 3 second extreme wind in 700 return year is assessed as 125.4mph at 10m, 104.5mph at 4.6m and 82.4mph at 2m.

5. The uncertainty of the extreme wind estimation is 14.7%. The probability is 85% that the actual value will be less than those assessed value. The closely correlates with the 15% probability of exceedance as mentioned in note 5 per Figure 26.5-1C & 26.5-1A per ASCE 7-10 and ASCE 7-16, respectively.

6. The extreme wind (mph) provided in Table 5.2 represents an Occupancy/Risk Category II wind velocity (50 year return period) at 2m & 10m height, at varying probabilities of non-exceedance (highlighted below). To convert the 50 year return extreme wind to a Risk Category I design wind to be used for ASCE 7-10 or ASCE 7-16, the extreme wind must first be multiplied by the square root of the ASCE 7-05 importance factor, sqrt(0.87) = 0.93 and then divided by the square root of 0.6 (IBC Equation 16-33). Therefore, 0.93* Extreme Wind (mph)/sqrt(0.6) = 1.2*Extreme Wind (mph).

| ASCE Code Reference | Risk/Occupancy Category | Return Period (yrs) | Conversion Factor | Design Wind (mph): Extreme wind*Conversion Factor |
|---|---|---|---|---|
| ASCE 7-05 | I | 25 | 0.93 | 0.93*Extreme Wind |
| ASCE 7-05 | II | 50 | 1 | 1.00*Extreme Wind |
| ASCE 7-10/16 | I | 300 | 1.2 | 1.20*Extreme Wind |
| ASCE 7-10/16 | II | 700 | 1.29 | 1.29*Extreme Wind |

7. For comparison, from Figure 6.1 in ASCE 7-16, the 3 second extreme wind in 50 return year is 91mph at 10m. ASCE 7 may under-estimate the extreme wind at site.

8. Simulation and extreme value statistical analysis procedures are used to calculate wind speed.

# 7 Deliverables

The deliverables of this project are:

- 250427_XXX_100: Project report

# 8 References

/1/ ASCE/SEI 7-16 Minimum Design Loads for Buildings and Other Structures (7-16), American Society of Civil Engineers, https://sp360.asce.org/PersonifyEbusiness/Merchandise/Product-Details/productId/233133882

/2/ Standardized Extreme Wind Speed, NIST, http://www.itl.nist.gov/div898/winds/NIST_TN/nist_tn.htm

/3/ Storm Data Publication, NCEI, NOAA, https://www.ncdc.noaa.gov/IPS/sd/sd.html

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/16/ Hurricane Databases second version, HURDAT2, National Hurricane Center, http://www.nhc.noaa.gov/data/

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/18/ Vickery, Peter J., and Peter Irwin. "Ultimate Wind Load Design Gust Wind Speeds in the United States for Use in ASCE7." *Journal of Structural Engineering.* May 2010: p. 623.

/19/ ASCE/SEI 7-05 Minimum Design Loads for Buildings and Other Structures, American Society of Civil Engineers, http://www.asce.org/templates/publications-book-detail.aspx?id=7933

# 9 Appendix

For the engineer applying ASCE 7-10: Minimum Design Loads for Buildings and Other Structures, or ASCE 7-16: Minimum Design Loads for Buildings and Other Structures, the following steps are applied.

The risk category of this study is classified as Occupancy Category I and II according to ASCE 7-10 or ASCE 7-16.

The extreme wind speed in this study is equivalent to Figure 9.1, Figure 9.2, Figure 9.3 and Figure 9.4 on the conditions that Kz=1, Kzt=1. It is because that in this study, the result has considered the basic wind speed, exposure and topographic effect. The extreme wind speed is defined as 3-second gust wind speeds in mph at 10m above ground.

When combinations of loads are used, wind directionality factor, Kd could be calculate based on directional results from this report. For example, if extreme wind speed from 90 degree is 90 mph, and extreme wind speed in total is 100 mph, the directionality is 90/100 = 0.9.

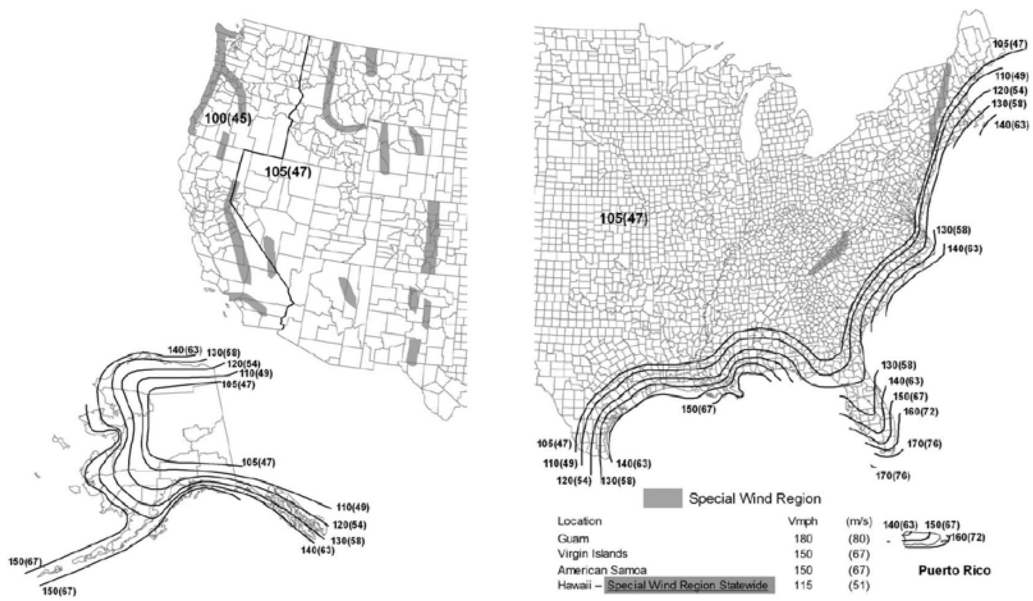


***Figure 9.1 Basic Wind Speed for Occupancy Category I Building and Other Structures from ASCE7-10. Values are nominal design 3-second gust wind speeds in miles per hour (mph) at 33ft (10m) above ground for Exposure C category. Wind speeds correspond to approximately a 15% probability of exceedance in 50 years (Annual Exceedance Probability = 0.00333, MRI = 300 Years).***

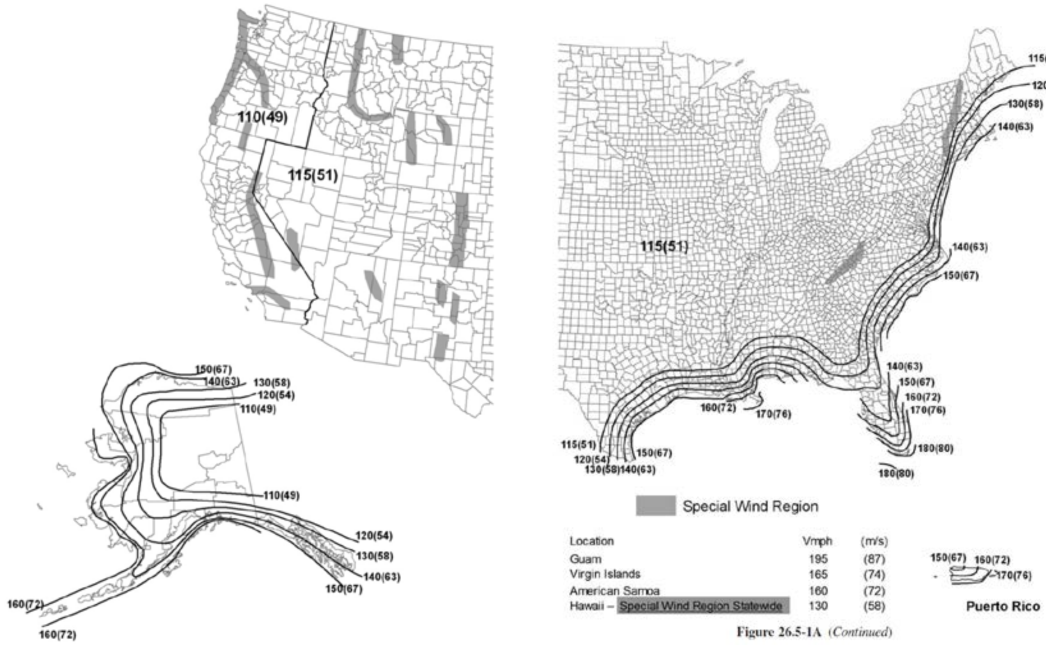


***Figure 9.2 Basic Wind Speed for Occupancy Category II Building and Other Structures from ASCE7-10. Values are nominal design 3-second gust wind speeds in miles per hour (mph) at 33ft (10m) above ground for Exposure C category. Wind speeds correspond to approximately a 7% probability of exceedance in 50 years (Annual Exceedance Probability = 0.00143, MRI = 700 Years).***

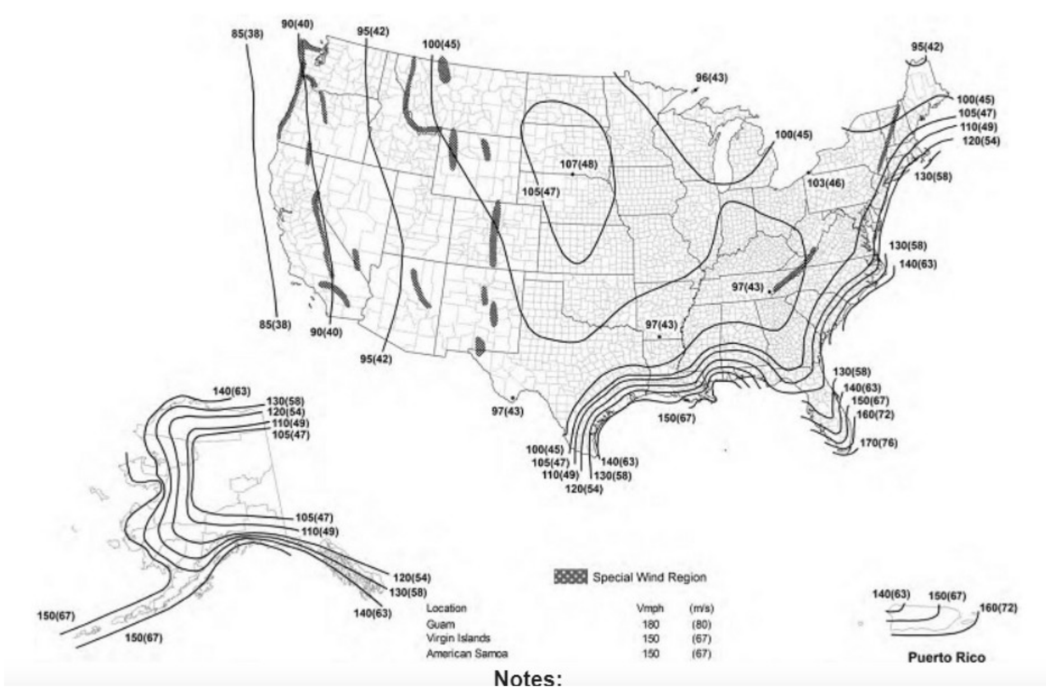


***Figure 9.3 Basic Wind Speed for Occupancy Category I Building and Other Structures from ASCE7-16. Values are nominal design 3-second gust wind speeds in miles per hour (mph) at 33ft (10m) above ground for Exposure C category. Wind speeds correspond to approximately a 15% probability of exceedance in 50 years (Annual Exceedance Probability = 0.00333, MRI = 300 Years).***

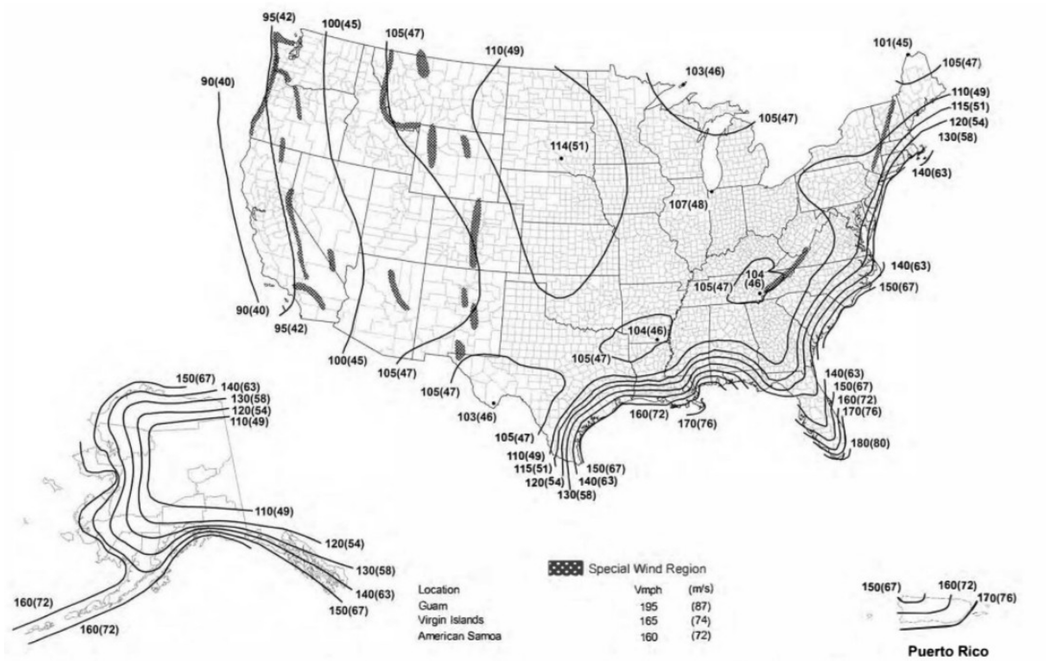


***Figure 9.4 Basic Wind Speed for Occupancy Category II Building and Other Structures from ASCE7-16. Values are nominal design 3-second gust wind speeds in miles per hour (mph) at 33ft (10m) above ground for Exposure C category. Wind speeds correspond to approximately a 7% probability of exceedance in 50 years (Annual Exceedance Probability = 0.00143, MRI = 700 Years).***

Thus, the steps of wind load calculation based on this study are

1. Basic Wind Speed, from this report.
2. Exposure category, Kz =1.
3. Topographic factor, Kzt=1
4. wind directionality factor, Kd:
    a. Option a: Calculated from this report, for combined load only;
    b. Option b: From ASCE, Kd=0.85, for combined load only.
5. Gust-effect factor, from ASCE, for example, G=0.85 for rigid building or other structure
6. Enclosure classification, from ASCE