Analysis of Wind Effects on Vegetation-Related Outages

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Introduction

The San Diego Supercomputer Center (SDSC) at the University of California San Diego (UCSD) is partnering with San Diego Gas & Electric's (SDG&E) Vegetation Management team to analyze factors affecting vegetation-related power outages. These factors can be related to tree features such as tree species and tree height, and also weather variables such as wind speed and soil moisture.

In the study summarized in this report, the focus is on the effects of wind on vegetation-related outages. The goal of this analysis is to uncover any patterns in the observed nature of wind with relation to risk of power outages caused by vegetation. Since the difference between wind patterns leading to outages and those associated with non-outage conditions is important, we also present a comparative analysis between outages and non-outages with respect to statistics of wind speeds and wind gusts.

Data

Data used in this analysis is obtained from SDG&E's vegetation management system and forecast weather. From the vegetation management data, outage locations and timestamps are extracted. The outages are filtered to include only the following vegetation-related outage cause codes:

- 322 - tree/branch/limb fell on line or other electrical equipment
- 426 - tree/branch/limb fell on the line due to storm/high wind
- 324 - palm tree contact
- 428 - palm tree contact due to storm/wind
- 326 - palm frond contact
- 430 - palm frond contact due to storm/wind
- 420 - tree contact due to storm/high wind

Note that code 318 (tree contact as a result of growth / encroachment) is not included in the analysis since this cause code is not related to wind.

Weather data associated with each outage is obtained from the SDG&E's historical GFS003 ensemble of WRF (Weather Research Forecast). The WRF data includes hourly predicted weather conditions through physics-based simulations for 2x2 km spatial grids. This analysis uses outage and weather data from the time period from January 2011 to June 2020. The choice of June 2020 was based on the latest WRF historical data available.

Since this is a wind analysis study, the weather variables used in this report are wind speed and wind gust. Wind speed is based on U and V at 10m height. Wind gust is calculated as follows: wind gust = wind speed + 7.71 * UST, where UST is friction velocity, and the value 7.71 was provided by SDG&E's meteorology team. Note that the UST variable in the WRF data is updated every hour.

Methodology

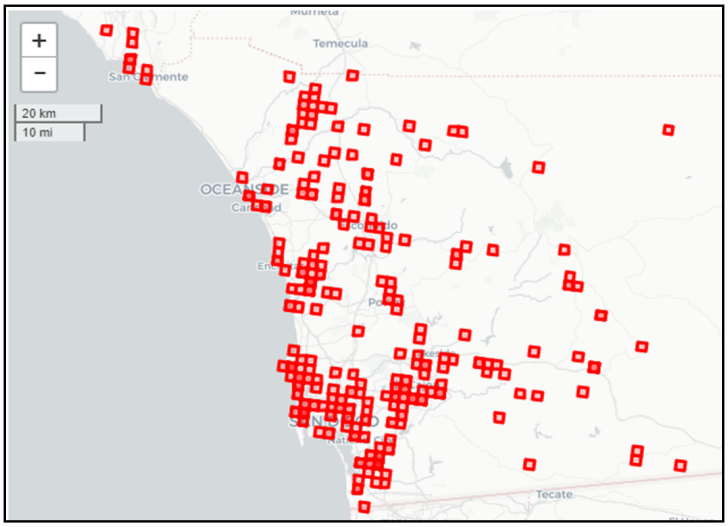

Figure 1. 2km x 2km grids used in the analysis

The red squares in the figure on the left show the 2x2 km grids where a vegetation-related outage occurred from January 2011 to June 2020. Based on SDG&E's vegetation management system, there were 298 vegetation-related outages in the 198 red squares shown in the figure. These red squares are the outage grids. For each outage grid, statistics on wind speed and wind gust values are calculated for that grid based on the timestamp of the outage.

As a control measure, we identify some non-outages for each outage grid. These are defined based on the outage timestamp: a corresponding non-outage will have a timestamp with the same time, same day, same month, but a different year. For example, for an outage with a timestamp of 2014-12-01, one of the non-outage samples is the *same* grid with a timestamp of 2016-12-01 (assuming an outage was not observed on that day). Non-outages are selected this way to capture wind seasonality, and to focus the analysis on the effects of wind and not of other factors such as tree species. Using this information we can perform an analysis to uncover patterns between wind and vegetation-related outages.

Outage and non-outage counts used in our analysis are as follows:

- Total number of grids in analysis: 198
- Total number of outage samples: 298
- Total number of non-outage samples: 2,578

From the WRF model we obtain wind data at hourly increments for each individual grid. We aggregate these hourly raw wind values and calculate statistics at the granularity of **24-hour buckets**. These 24h buckets are chosen around the outage timestamp. For example, if an outage happened at 2:19 pm, the 24h bucket interval would run from 2:19 pm of the previous day to 2:18 pm of the day of the outage (as opposed to 12:00 am to 11:59 pm). This is important since we want to consider wind statistics *leading to* the outage, not wind statistics that occur *after* the outage.

The process for obtaining wind speed data for the analysis is described in the following steps:

1. Obtain raw wind speed values in hourly increments for each grid.
2. Compute aggregated statistics of raw wind speed values for the aforementioned 24h buckets:
    a. max wind speed value across each 24h bucket
    b. mean wind speed value across each 24h bucket
3. Bin aggregated statistics into percentiles
4. Extract aggregated statistics for outage samples only and bin them into percentiles from Step 3. This provides the histogram for the outage samples.
5. Repeat Step 4 for non-outage samples to create the histogram for the non-outage samples.

Notes:

- The above statistics are calculated only within an *individual* grid and not across grids.
- *Percentiles* are used instead of raw wind speeds as wind behavior differs based on geographical location.

For the overall analysis, we obtain the raw wind speed values across all time (all months from all years). For the seasonal and monthly analysis we limit the raw wind speed data to the outage/non-outage timestamp's season or month, respectively, but across all years.

Results are presented below for the following analyses:

- Wind speed overall analysis
- Wind speed seasonal analysis
- Wind speed monthly analysis
- Delta of wind speed and wind gust analysis
- Wind gust analysis

Results - Wind Speed

Overall Analysis

First, we compare across all time for both outages and non-outages. The below boxplot shows the distribution of the percentile of the **max** 24h bucket aggregated values for outages and non-outages:

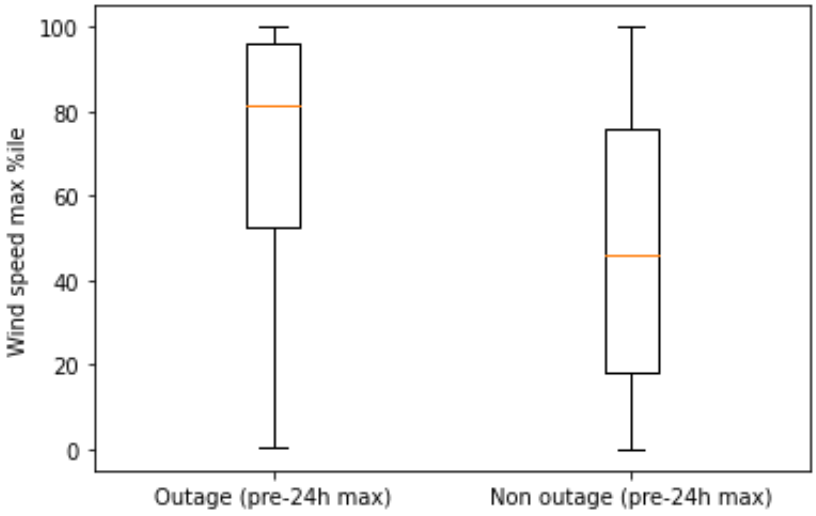

Figure 2. Wind speed max %ile in 24h bucket leading to (non)outage compared to all other 24h buckets

Here we can see that the outages observe much higher wind speeds than non-outages. We illustrate the same with the histograms below for max wind speed:

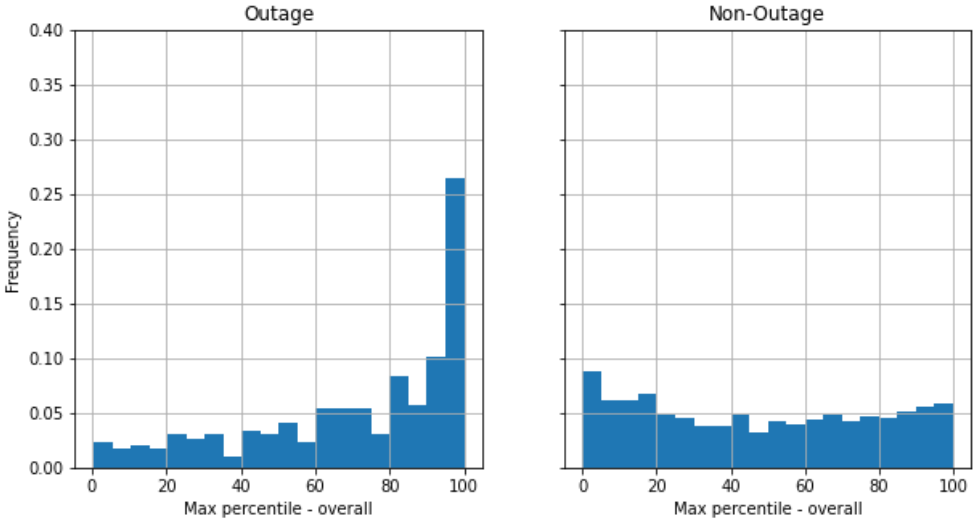

Figure 3. Outage v/s non-outage wind speed max %ile - 24h buckets all time

The histograms show that higher wind speeds are associated with outages. Specifically, more than 25% of the outages occur when the wind speed is at or above the 95th percentile. On the other hand, the wind speed distribution for non-outages is relatively uniform.

With the **mean** aggregation percentiles, we see a similar trend:

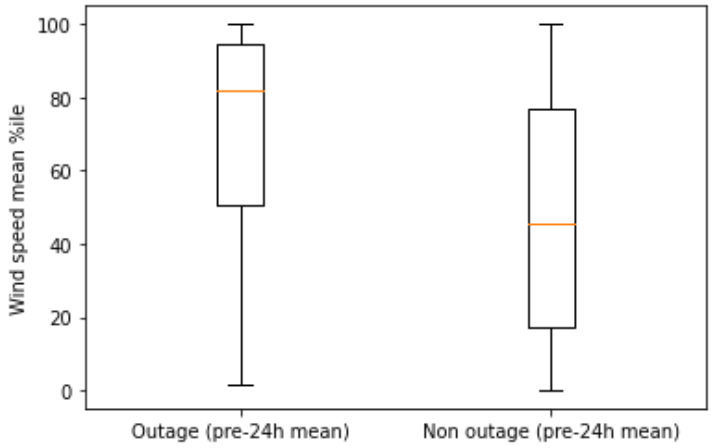

Figure 4. Wind speed mean %ile in 24h bucket leading to (non)outage compared to all other 24h buckets

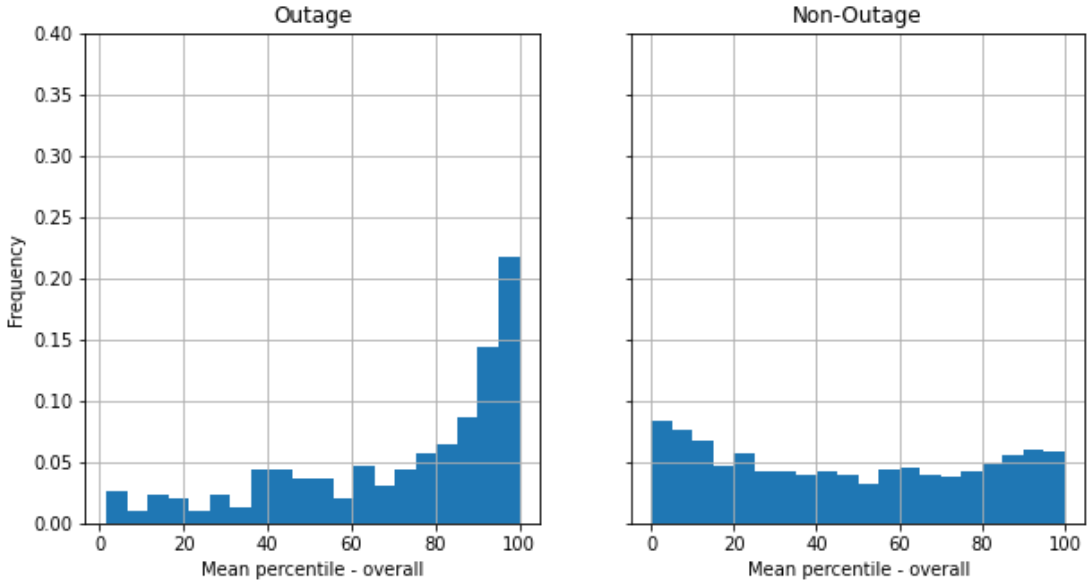

Figure 5. Outage v/s non-outage wind speed mean %ile - 24h buckets all time

Summary of Findings for Wind Speed Overall Analysis

The takeaways from the plots above for wind speed are:

- There is a clear correlation between wind speed and outage events.
- A large number of outages occur when the wind speed is at or exceeds the 95th percentile.

Below, we extend this analysis to seasonal and monthly granularities.

Seasonal Analysis

We extend the above analysis to a seasonal level - the weather data is reduced to a subset of the outage/non-outage timestamp's season.

The distribution of outage and non-outage label numbers across seasons are:
Summer (June, July, Aug) - outages: 40, non_outages: 331
Winter (Dec, Jan, Feb) - outages: 144, non_outages: 1268
Spring (Mar, Apr, May) - outages: 68, non_outages: 611
Autumn (Sept, Oct, Nov) - outages: 46, non_outages: 368

Max: For the 24h **max** aggregation, we observe the general trend to be similar to the **overall** time analysis while plotting all seasons in a single plot:

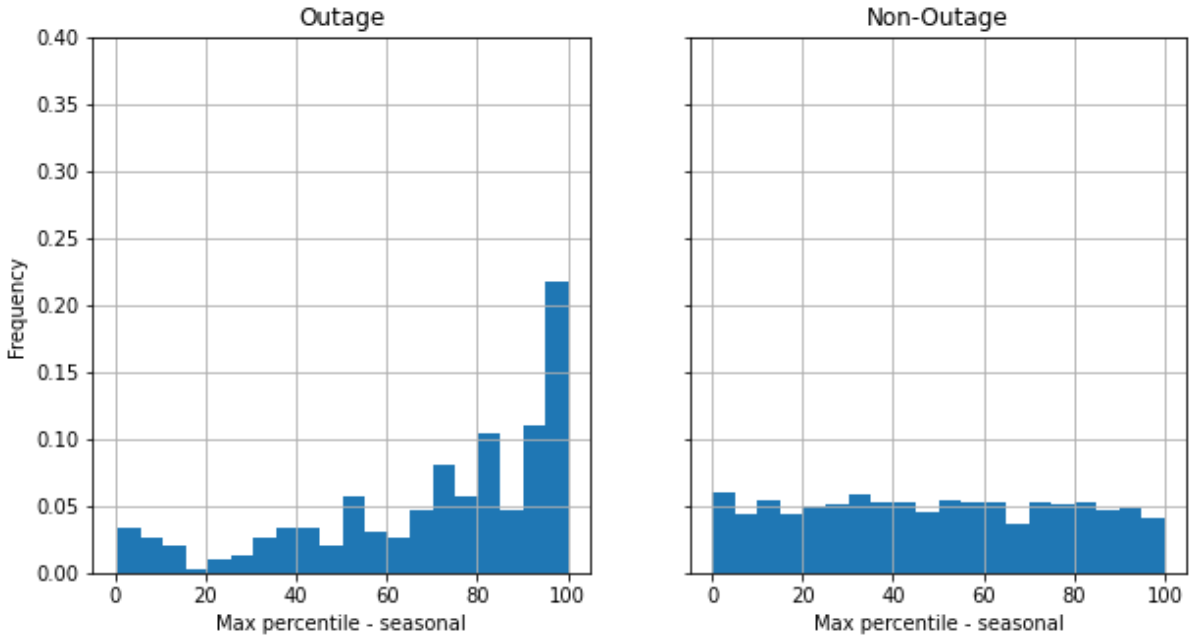

Figure 6. Outage v/s non-outage wind speed max %ile - (ALL SEASONS)

For each of the seasons we see the below plots:

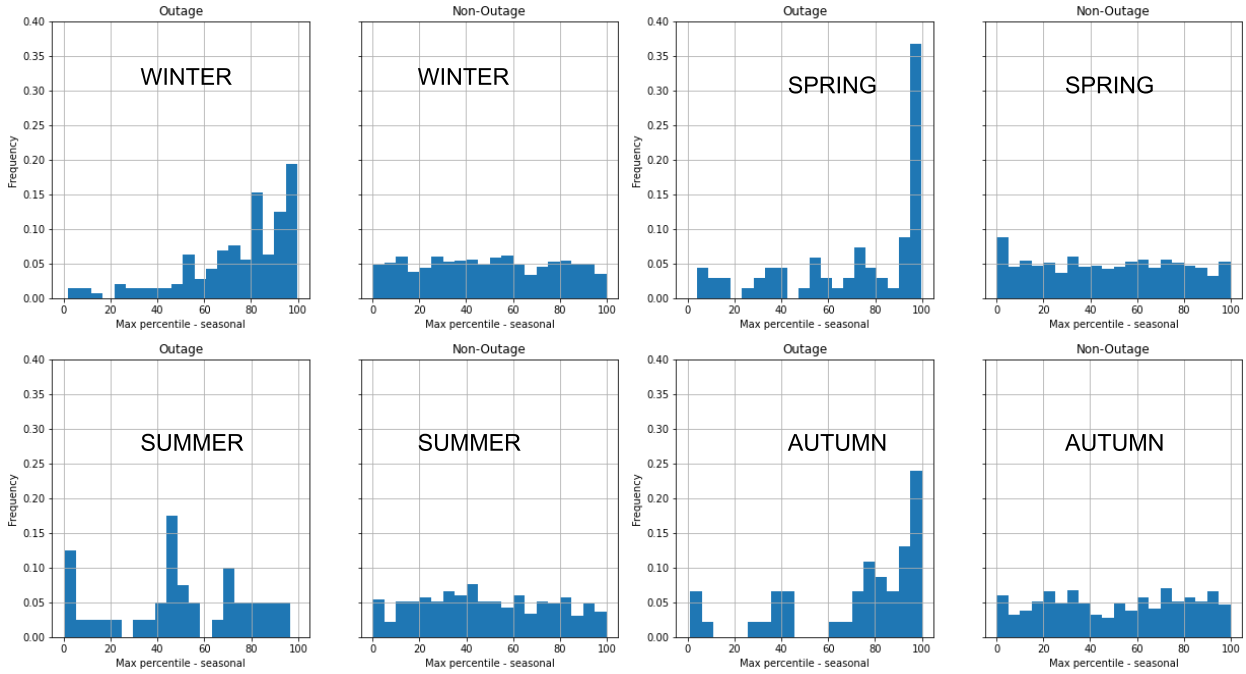

Figure 7. Outage v/s non-outage wind speed max %ile per season

Mean: For the 24h **mean** aggregation we observe the general trend to be similar to the overall time analysis (peak at highest percentile but smaller peak than **max** aggregation percentile for outages):

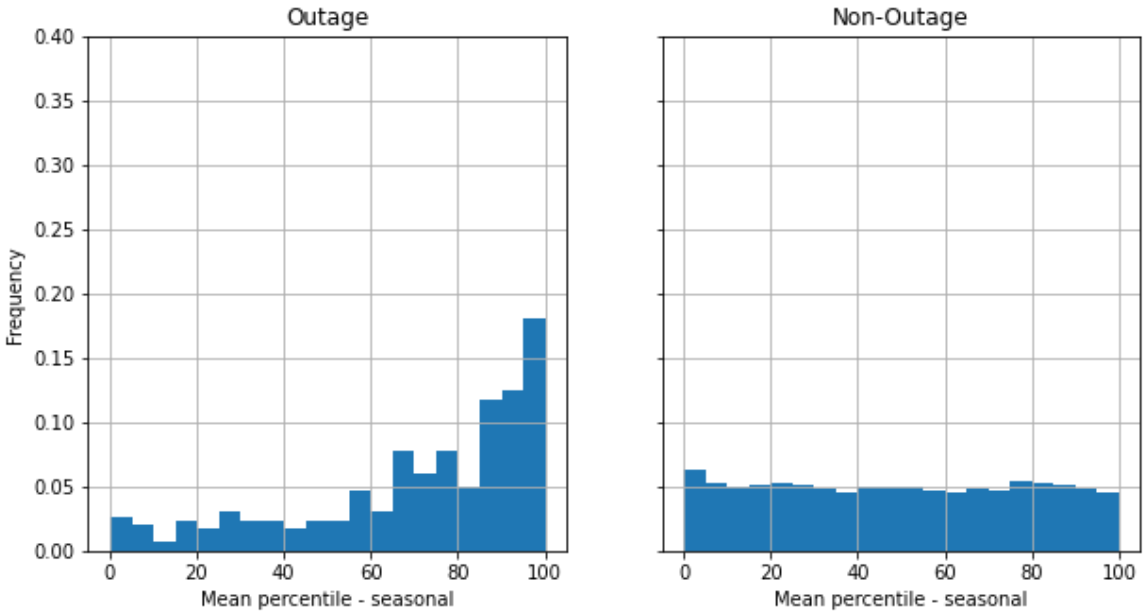

Figure 8. Outage v/s non-outage wind speed mean %ile - (ALL SEASONS)

For each of the seasons we see the below plots:

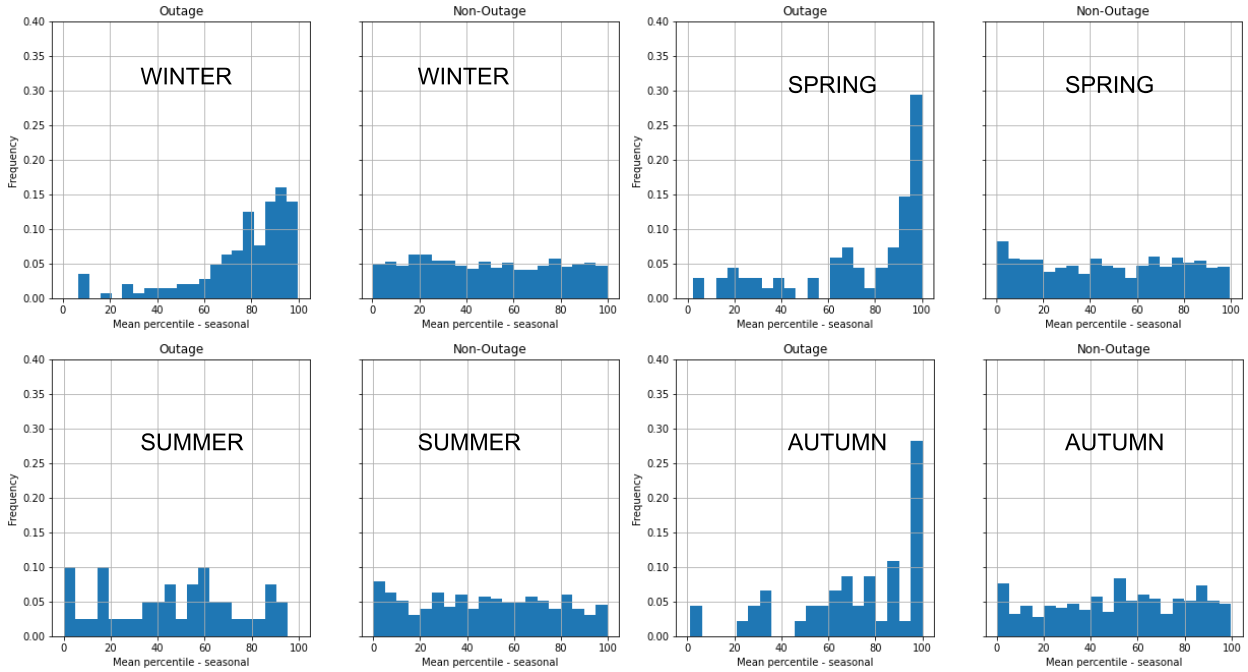

Figure 9. Outage v/s non-outage wind speed mean %ile per season

Summary of Findings for Wind Speed Seasonal Analysis

As seen in the plots above, even while comparing aggregated percentile values across seasons, the trend is very similar to the overall time analysis.

The main interesting takeaways apart from the one above are:

- Non-outages have uniform wind speed percentile observations for all seasons.
- Outages have higher wind speeds than non-outages for all seasons except summer.
- In summer, there is no direct correlation between wind speeds and outage events.

Monthly Analysis

We extend the above analysis to a seasonal level - the weather data is reduced to a subset of the outage/non-outage timestamp's season. The distribution of outage and non-outage label numbers across seasons are:

January - outages: 76, non_outages: 684
February - outages: 43, non_outages: 384
March - outages: 27, non_outages: 243
April - outages: 31, non_outages: 279
May - outages: 10, non_outages: 89
June - outages: 11, non_outages: 99
July - outages: 12, non_outages: 96
August - outages: 17, non_outages: 136
September - outages: 19, non_outages: 152
October - outages: 2, non_outages: 16
November - outages: 25, non_outages: 200
December - outages: 25, non_outages: 200

Max: For the 24h **max** aggregation we observe the general trend to be similar to the overall time analysis and seasonal analysis while plotting all seasons in a single plot:

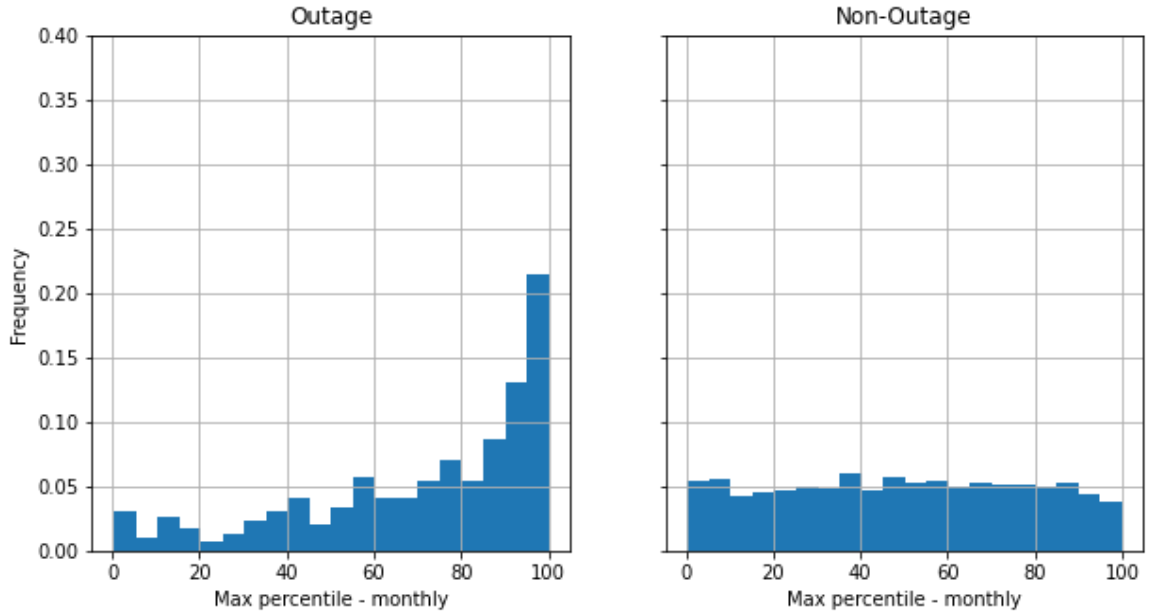

Figure 10. Outage v/s non-outage wind speed max %ile - (ALL MONTHS)

For the monthly analysis we select one month each (Jan, Apr, Jun, Sept) from a season and show the histograms for them:

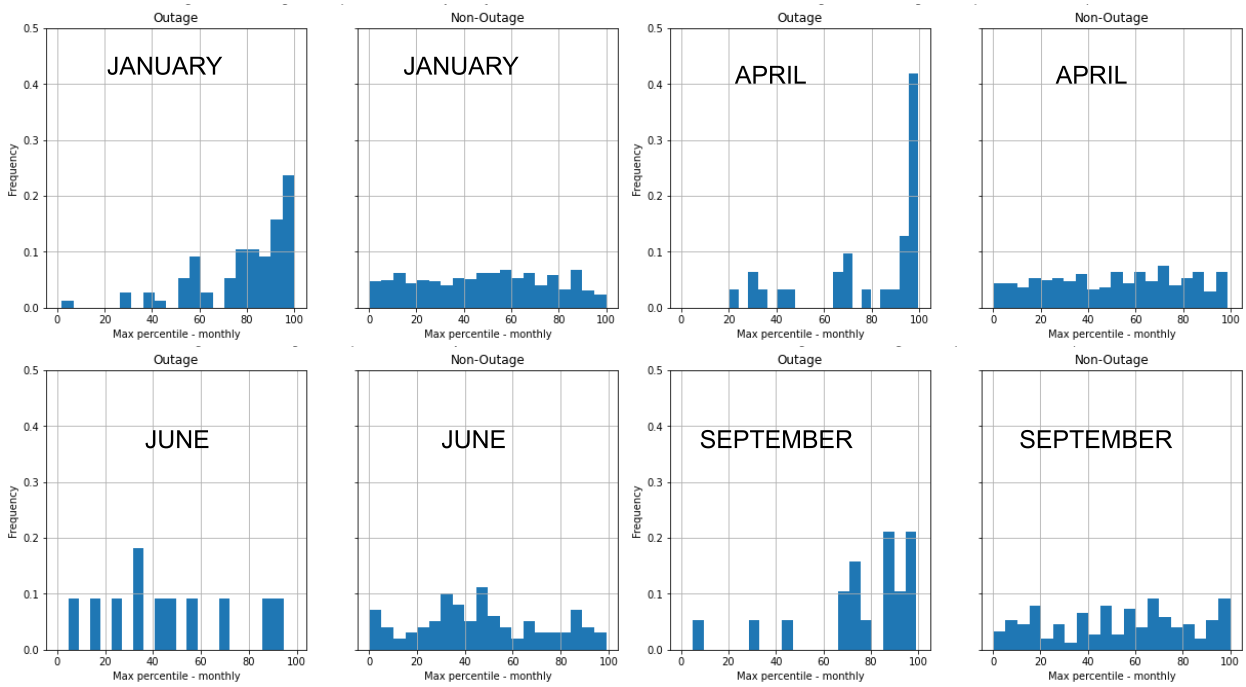

Figure 11. Outage v/s non-outage wind speed max %ile per month

Mean: For the 24h **mean** aggregation we observe the general trend to be similar to the overall time and seasonal analysis (peak at highest percentile but smaller peak than **max** aggregation percentile for outages):

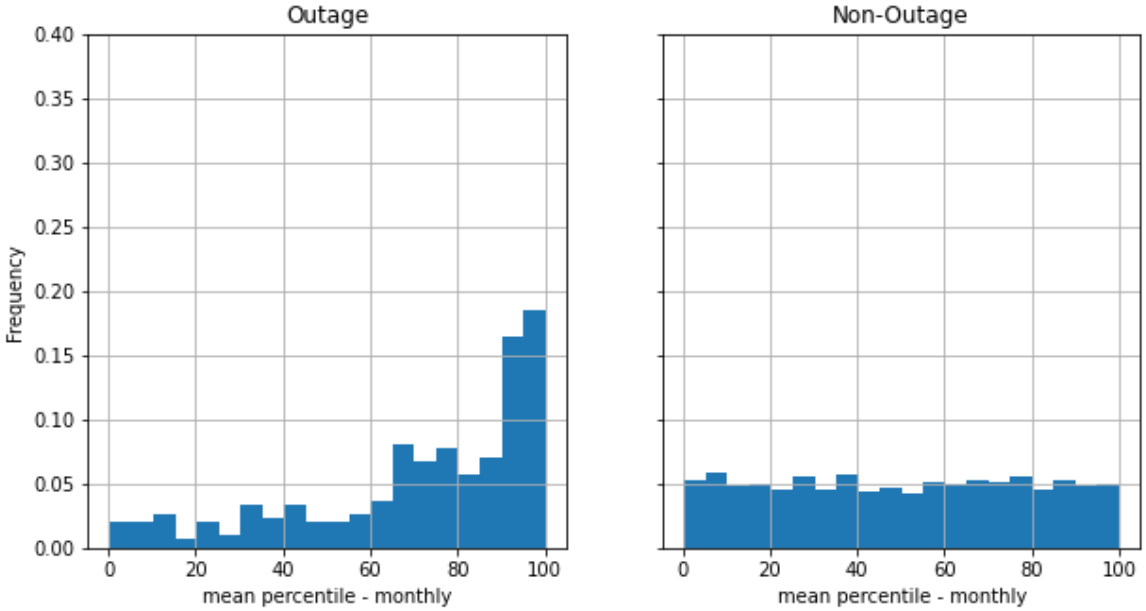

Figure 12. Outage v/s non-outage wind speed mean %ile - (ALL MONTHS)

For the monthly analysis, we select one month each (Jan, Apr, Jun, Sept) from a season and show the corresponding histograms:

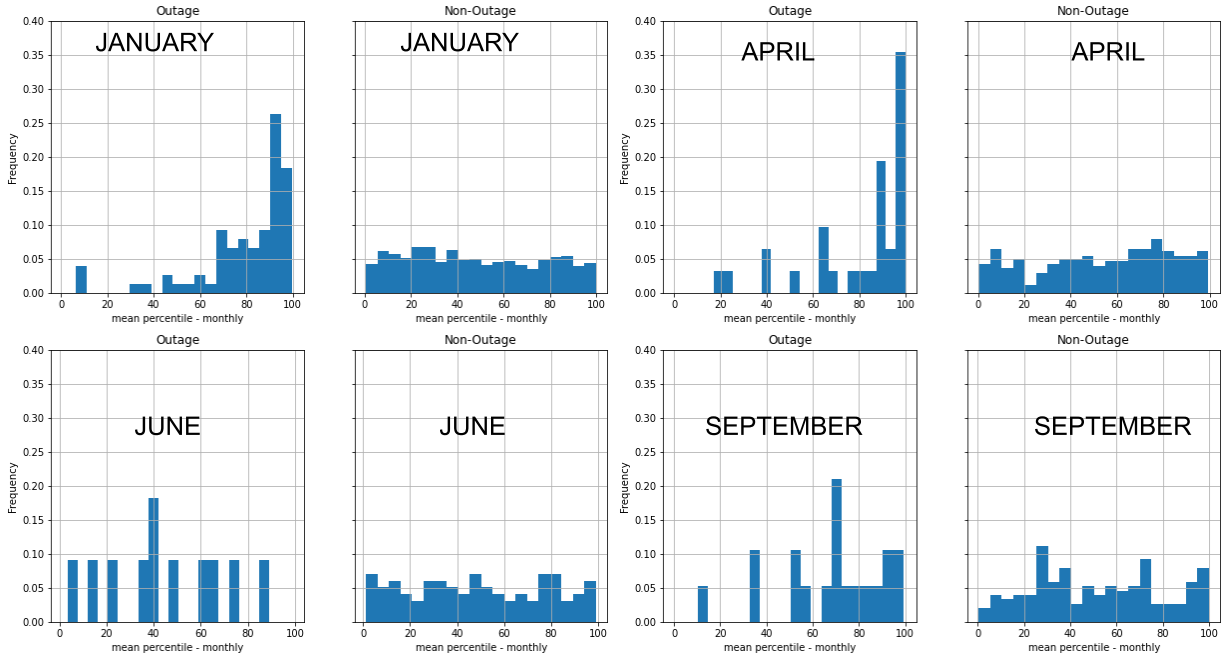

Figure 13. Outage v/s non-outage wind speed mean %ile per month

Summary of Findings for Wind Speed Monthly Analysis

As seen in the plots above, even while comparing aggregated percentile values across months, the trend is very similar to the overall time and seasonal analysis. The takeaways for the month analysis are thus similar to those from the seasonal analysis:

- Non-outages have uniform or noisy wind speed percentile observations for all months.
- Outages have higher wind speeds than non-outages for all months except the summer months.
- In summer, there is no direct correlation between wind speeds and outage events.

Delta (wind speed, wind gust) Analysis

Based on the suggestion of domain experts, we also looked into the delta between wind speed and wind gust to see if that shows us some interesting patterns for outages and non-outages.

We calculate the delta(speed, gust) of the **max** and **mean** aggregations (for each 24h bucket, as explained previously) and get the percentiles of those values across all months and all years.

The output matches the theory put forward by the domain experts that higher deltas should be observed for outages:

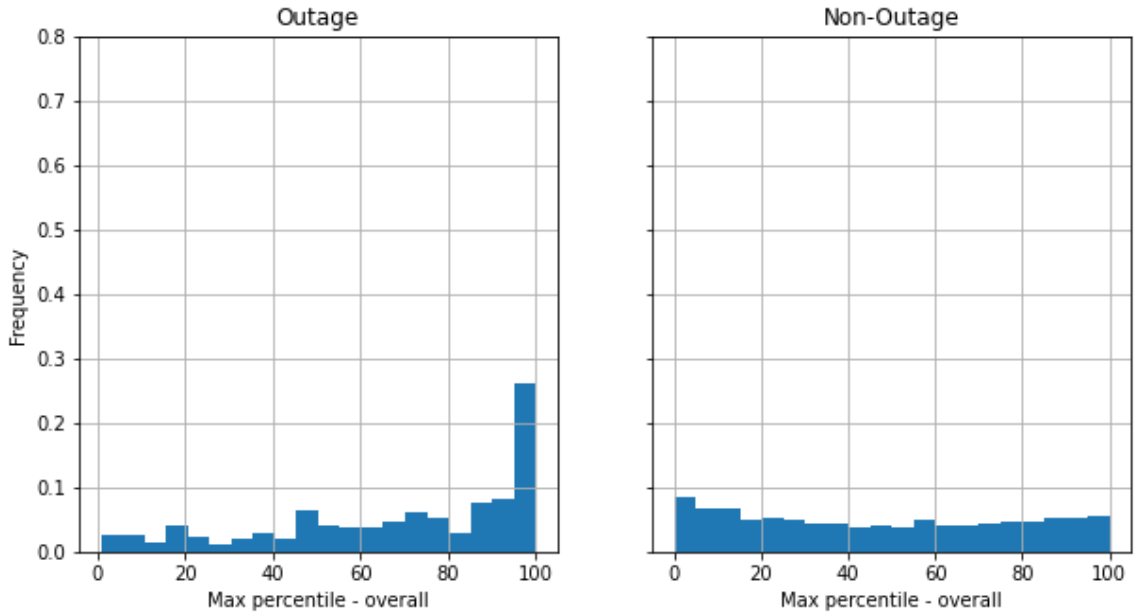

Figure 14. Outage v/s non-outage wind speed gust DELTA max %ile - 24h buckets all time

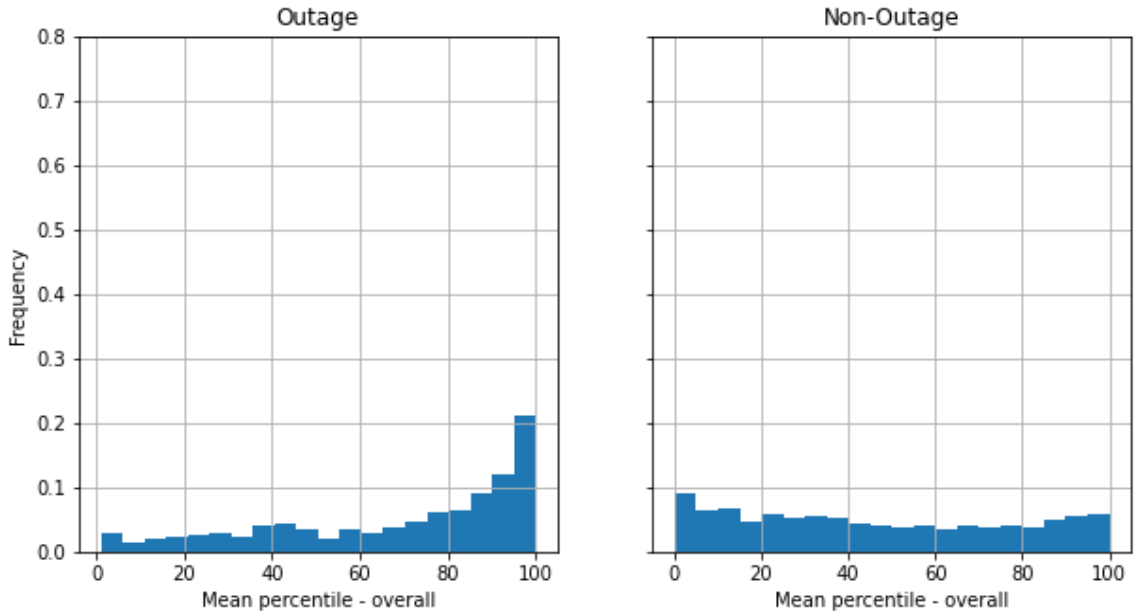

Figure 15. Outage v/s non-outage wind speed gust DELTA mean %ile - 24h buckets all time

Summary of Findings for Wind-Speed-Wind-Gust-Delta Analysis

The main takeaways from the plots above are as follows:

- Higher deltas between wind speed and wind gust are observed for outages.
- For non-outages, on the other hand, the deltas are uniformly distributed. Additionally, we also observe from the plots above that the non-outage distribution has slightly higher peaks for lower delta values, indicating small changes in winds for non-outages.
- A higher delta between wind speed and wind gust therefore indicates a sudden change in wind speed, which can likely lead to branch or tree failure.

Results - Wind Gust

This same analysis of overall, monthly and seasonal has been extended to use the **wind gust** values. The resulting graphs and conclusions are nearly identical to those for wind speed above. We show here the plots from the overall analysis for wind gust, and include the rest in the Appendix.

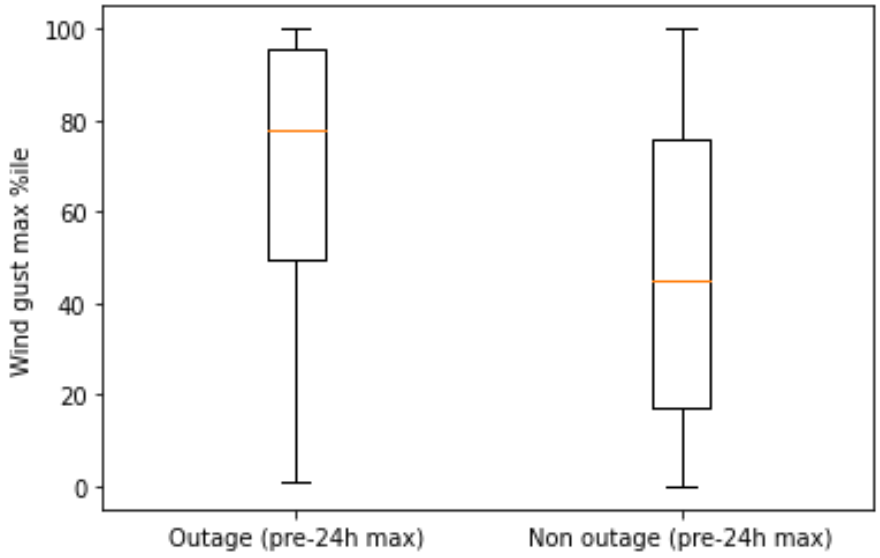

Figure 16. Wind gust max %ile in 24h bucket leading to (non)outage compared to all other 24h buckets

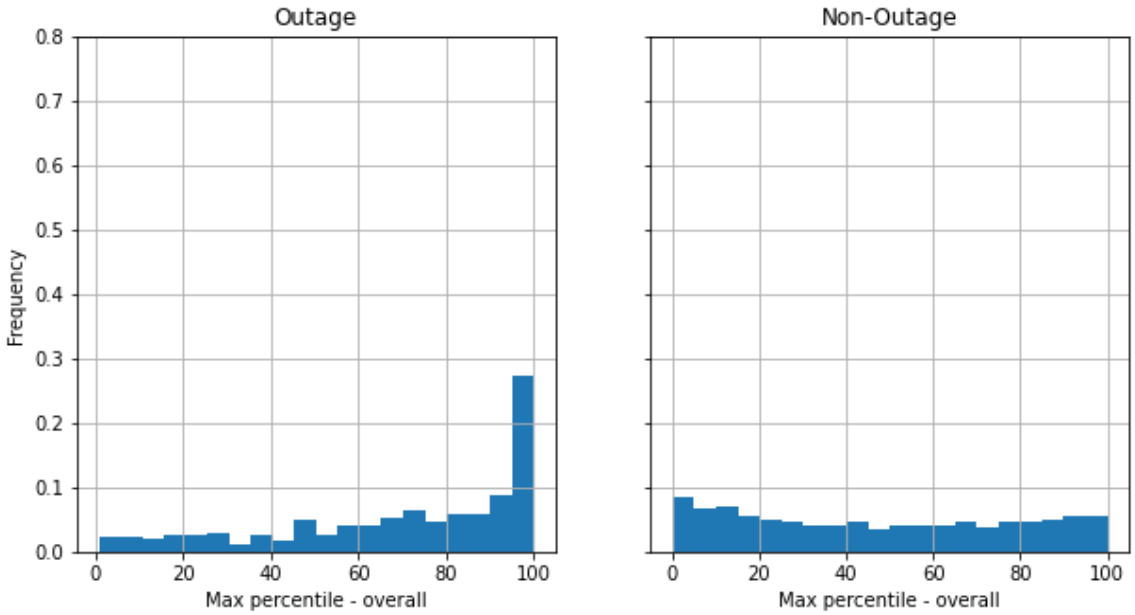

Figure 17. Outage v/s non-outage wind gust max %ile - 24h buckets all time

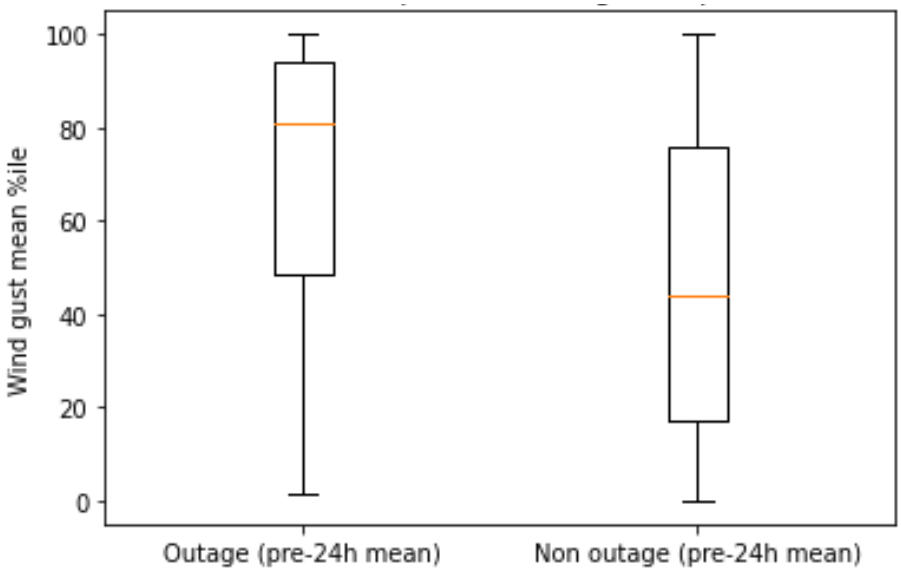

Figure 18. Wind gust mean %ile in 24h bucket leading to (non)outage compared to all other 24h buckets

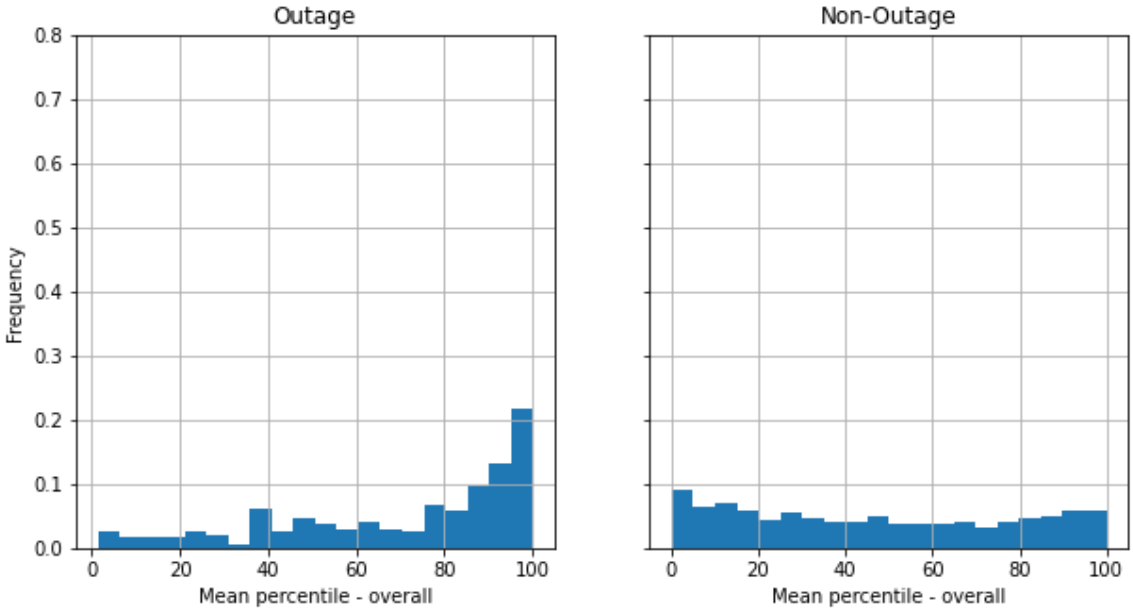

Figure 19. Outage v/s non-outage wind gust mean %ile - 24h buckets all time

Acknowledgment

We would like to thank Landy Cui and Michael Daleo from the Vegetation Management Team, along with Chris Arends and the Meteorology Team at SDG&E for their valuable inputs to this analysis.

Appendix

Max: For the 24h **max** aggregation we observe the general trend to be similar to the overall time analysis and seasonal analysis while plotting all seasons in a single plot:

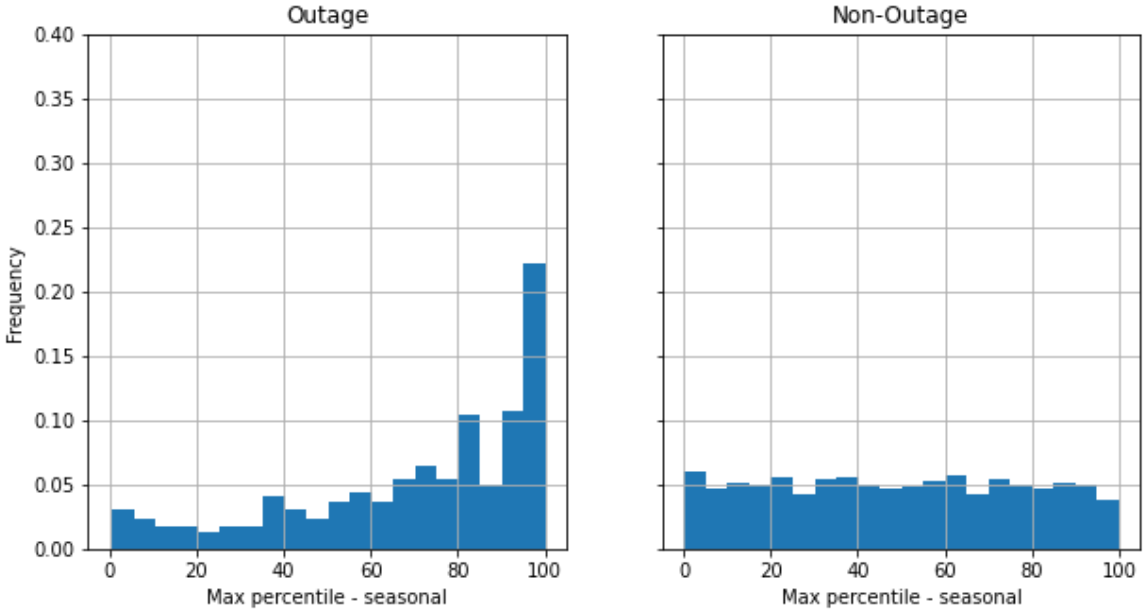

Figure 20. Outage v/s non-outage wind gust max %ile - (ALL SEASONS)

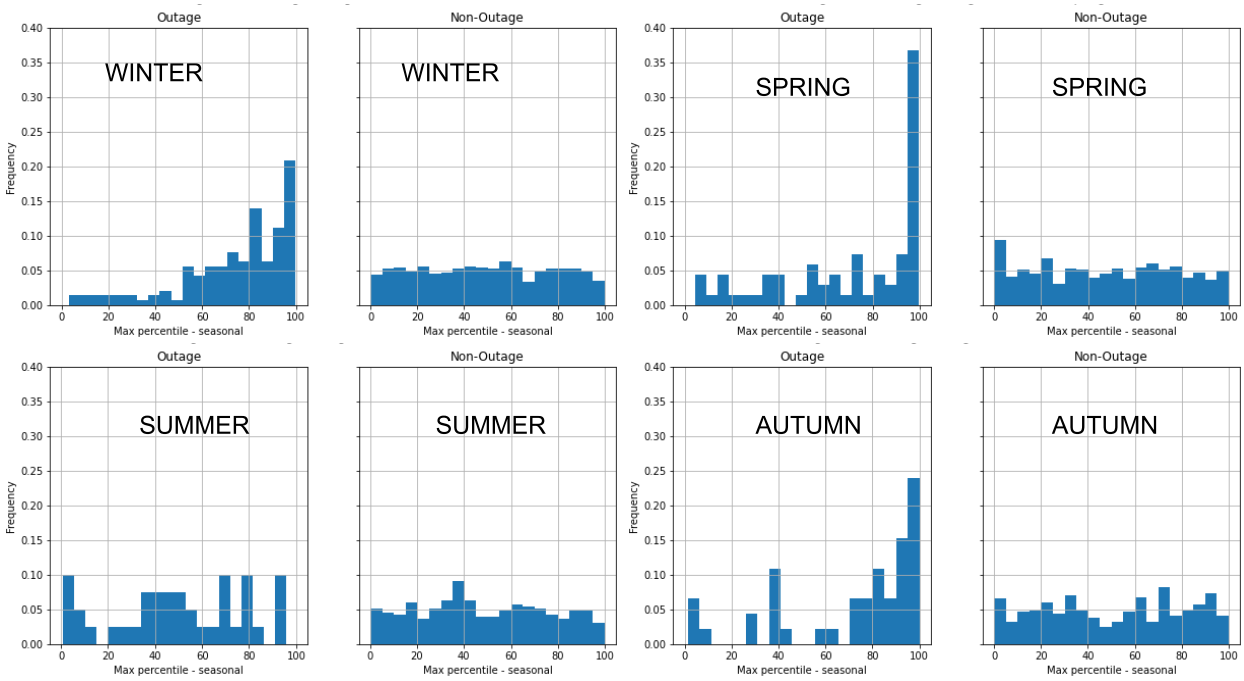

Figure 21. Outage v/s non-outage wind gust max %ile per season

Mean: For the 24h **mean** aggregation we observe the general trend to be similar to the overall time and seasonal analysis (peak at highest percentile but smaller peak than **max** aggregation percentile):

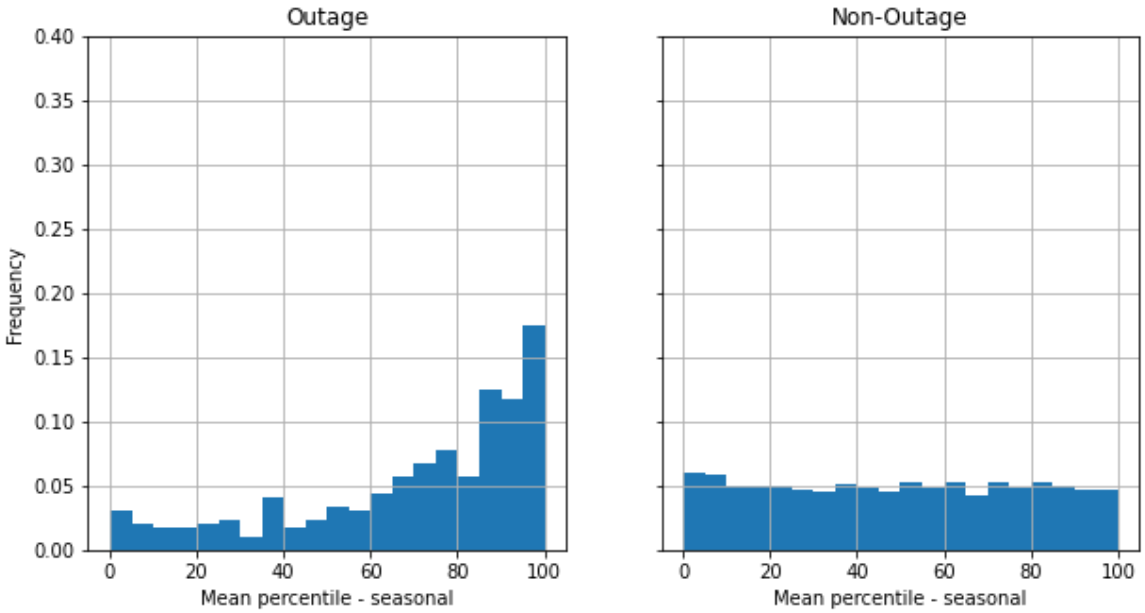

Figure 22. Outage v/s non-outage wind gust mean %ile - (ALL SEASONS)

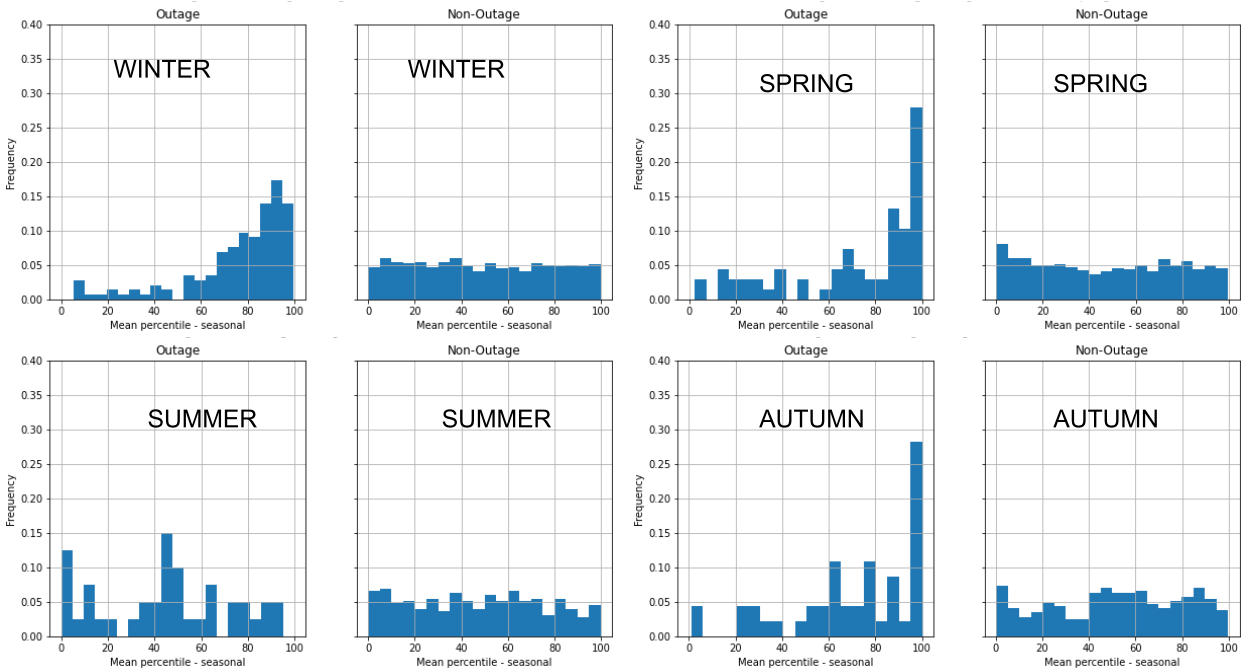

Figure 23. Outage v/s non-outage wind gust mean %ile per season