# Investigation of Wind's Effect on LIGO's Hanford Observatory

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## Abstract

**This investigation aims to measure the impact of wind on the search for burst gravitational waves at LIGO's Hanford detector to determine the potential benefits of a wind mitigation system.** The detector's operational status, glitch rate (Omicron), and accidental events from the main burst search algorithm (Coherent WaveBurst, cWB) were analyzed because these characteristics directly affect LIGO's confidence in a true gravitational wave detection. Based on the effect of wind speed on the omicron trigger (glitch) rate and the cWB accidential trigger population (background), **we observe that reducing wind speed will have a modest positive effect on LIGO's data quality and ability to confidently detect burst gravitational waves**.

The overall mean wind speed during observing mode is 2.666 m/s and the overall mean wind speed while not in observing mode is 2.796 m/s; this difference of 0.123 m/s is significant at >99% confidence. The rate of the Omicron triggers increases with the wind speed, with an average Pearson's correlation coefficient of +0.2048. The accidental cWB triggers were separated based on wind speed and their false alarm rate and probabilities calculated. To reach the same false alarm probability, an event must be about +0.2 in strength (ρ) in order to reach the same significance. A full report of this work is documented in [1].


## Introduction

The Laser Interferometer Gravitational-wave Observatory (LIGO) is composed of two detectors; one in Livingston, Louisiana and the other in Hanford, Washington. Each "L"-shaped interferometer has arms 4 kilometers long and is used to detect gravitational waves [2]. LIGO also has thousands of auxiliary channels constantly recording data about the environment [3].

High winds are prevalent at the Hanford detector. A wind fence has been proposed to help mitigate effects like loss of observing time and higher glitch rates in data. This investigation is meant to inform on the potential effects reduced winds would have on the search for burst (short, unmodeled) gravitational waves.

*Fig. 1b (below): This is a photo of the LIGO Hanford Observatory where the data is collected, and the prototype is built.*

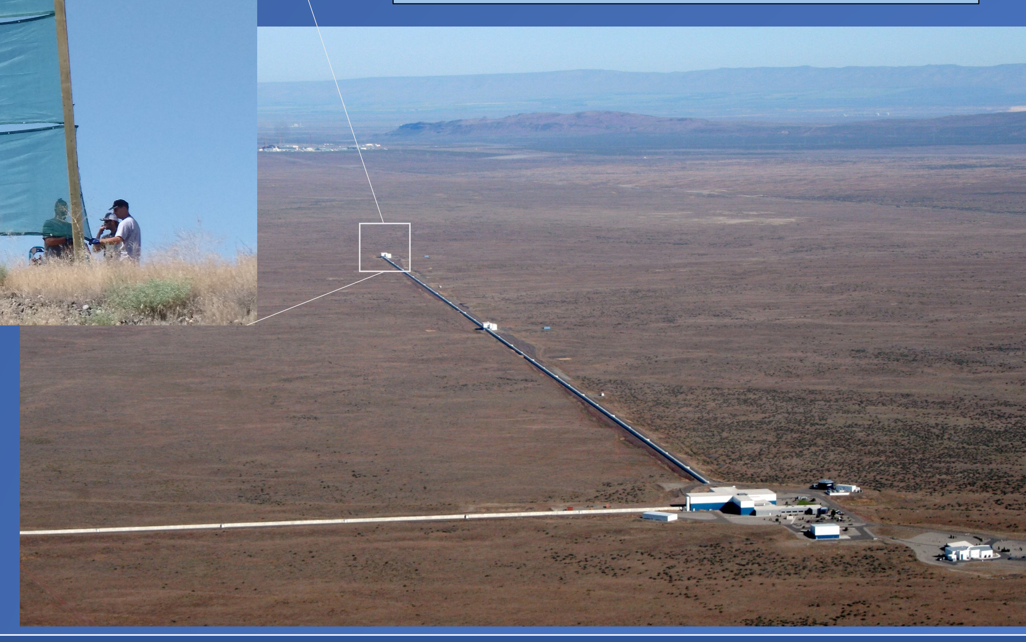

*Fig. 1a (above) This is a photo of the prototype wind fence at the Hanford Observatory. The fence may be built around the entirety of the Hanford site buildings.*

## Hanford Wind Speeds and Directions

The Hanford detector has a set of sensors that measure the maximum wind speed and average wind direction every minute. These can be used to determine both the frequency of any given wind speed or direction, as well as how it affects the detector's operation, i.e. whether it is or is not in observing mode.

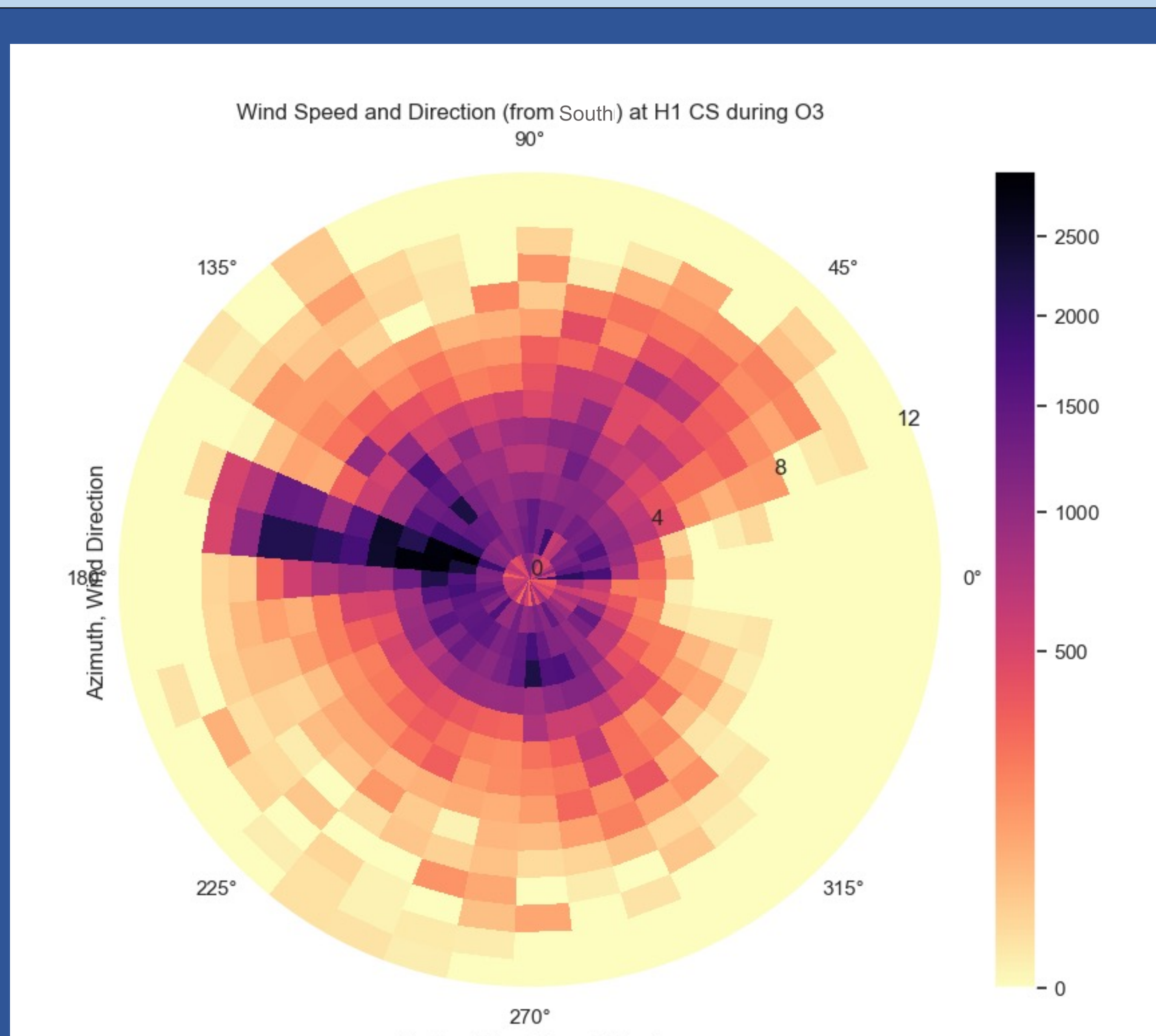


*Fig. 3 (left): This figure shows a 2-D histogram of the average radial direction at which the wind blew every minute, as well as the speed at which it blew. The stronger the gust of the wind, the farther from the center of the plot the data point was placed. The darker sections depict more frequent gusts from a given direction, at a given speed. Thus from this plot, we can observe that the wind at LIGO's Hanford Detector blows most frequently from angles of 160-170° at speeds of 1-9 m/s.*

## Omicron Triggers

Omicron is an algorithm that searches for excess statistical power in gravitational wave data and is particularly sensitive to glitches. In Figure 6, the trigger rate (frequency) was calculated for different signal-to-noise ratio (SNR) ranges. Due to the higher rate of glitches of all SNR ranges, we chose only to consider the epoch after the glitch rates decreased (1240704060, 1 May 2019 00:00:42 UTC) for Figures 7 and 8.

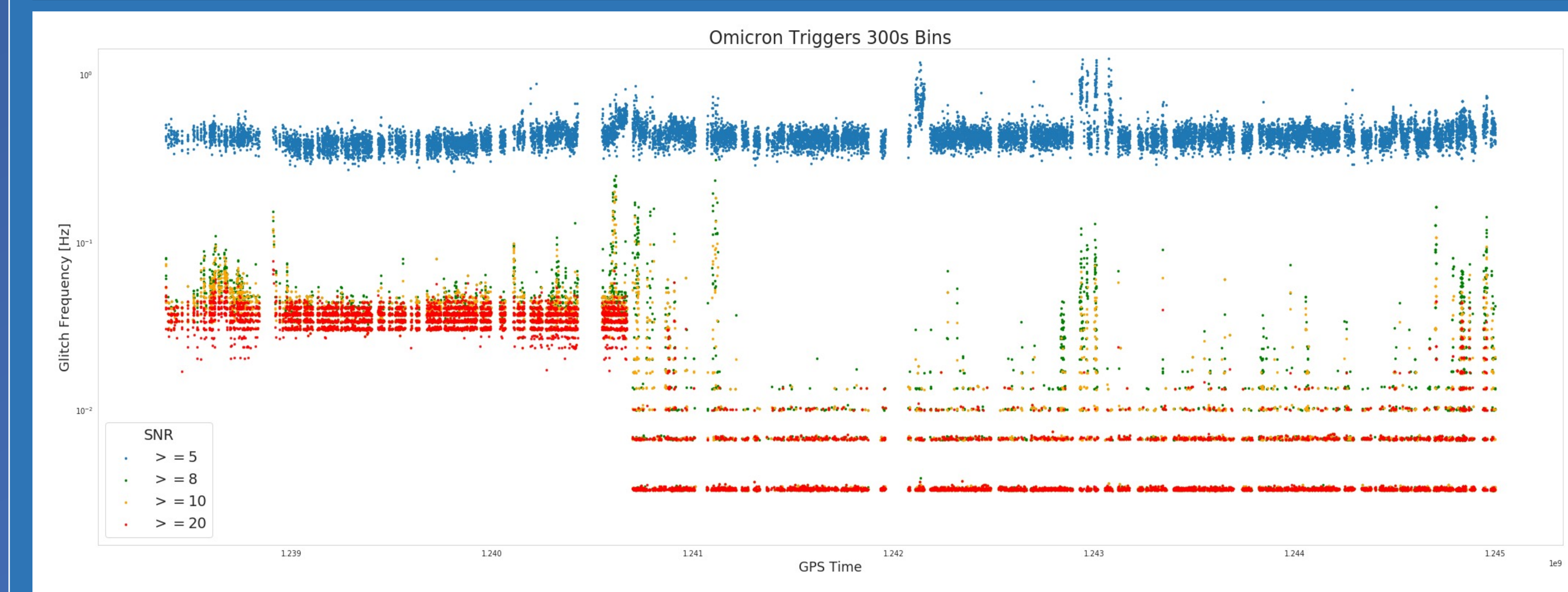


*Fig. 6 (above): This figure shows the Omicron triggers from the start of LIGO's third observing run through June 19th. The points represent the average Omicron trigger rate (frequency) over 300 seconds for different SNR ranges. For each point on this graph the average wind speed for the 300 second bin was calculated.*

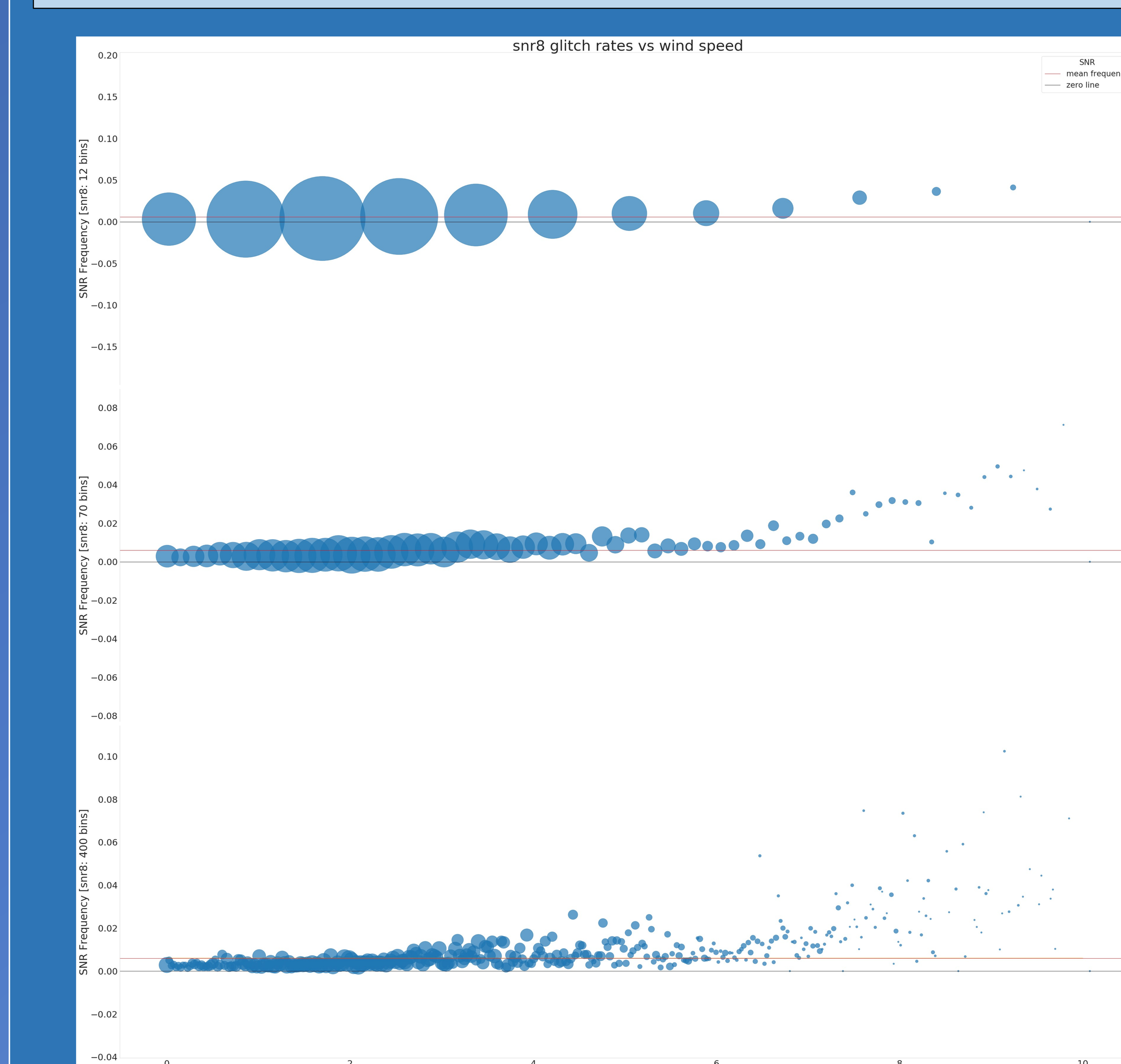


*Fig. 7 (left): This scatter plot shows the relationship between mean wind speed and the frequency of omicron triggers with an SNR >= 8. From top to bottom the bins are 15, 70, and 400 points large. The size of the points represent the amount of data within that given bin. As the wind speed increases, there is a noticeable increase in trigger rates up to 700% for this plot. However, the small number of measurements at high mean wind speed suggest we should expect only a moderate overall effect.*

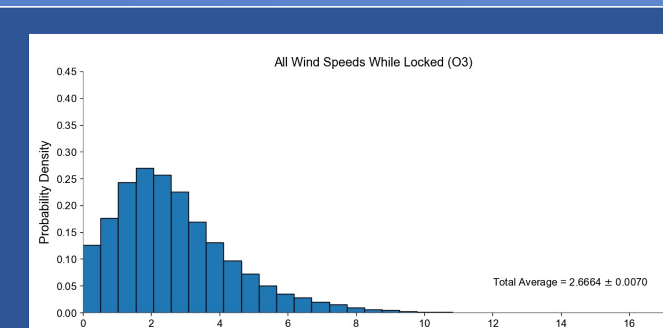


*Fig. 4 (above): This figure is a histogram of the normalized mean wind speeds detected, every minute, while the detector is in observing mode (locked). The total mean wind speed was then calculated to be 2.666 ± 0.007 m/s.*

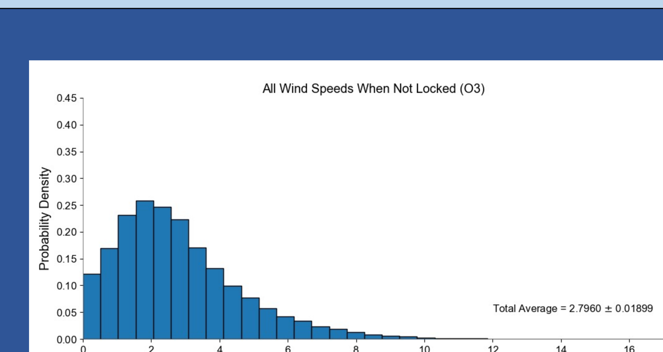


*Fig. 5 (above): This figure is a histogram of the normalized mean wind speeds detected, every minute, while the detector is **not** in observing mode (not locked). The total mean wind speed was then calculated to be 2.796 ± 0.019 m/s. The 0.123 m/s difference when the detector is locked vs. not locked is significant with a confidence of > 99%*

| snr8: Wind Speed (m/s) | Average Trigger Rate Before: | Average Trigger Rate After: | After/ Before |
|---|---|---|---|
| 1 | 0.00315 | 0.0063 | 2.0026 |
| 1.5 | 0.00319 | 0.0067 | 2.1190 |
| 2 | 0.00330 | 0.0074 | 2.2619 |
| 2.5 | 0.00351 | 0.0084 | 2.4157 |
| 3 | 0.00403 | 0.0092 | 2.2850 |
| 3.5 | 0.00446 | 0.0100 | 2.2462 |
| 4 | 0.00477 | 0.0110 | 2.3064 |
| 4.5 | 0.00500 | 0.0122 | 2.4400 |
| 5 | 0.00521 | 0.0133 | 2.5672 |
| 5.5 | 0.00537 | 0.0144 | 2.6958 |
| 6 | 0.00542 | 0.0175 | 3.2389 |
| 6.5 | 0.00548 | 0.0209 | 3.8249 |
| 7 | 0.00556 | 0.0259 | 4.5370 |
| 7.5 | 0.00565 | 0.0320 | 5.6737 |
| 8 | 0.00574 | 0.0337 | 5.8671 |
| 8.5 | 0.00581 | 0.0383 | 6.5918 |
| 9 | 0.00587 | 0.0416 | 7.1000 |
| 9.5 | 0.00590 | 0.0326 | 5.5287 |
| 0 | 0.00592 | 0 | 0 |

*Table 1: This table quantitatively describes the data shown in Fig. 7; The table shows the average trigger rate below (before) and above (after) different wind speeds. Both the table and Fig. 7 show an increase in Omicron trigger rates with an increase in wind speed.*

## Coherent WaveBurst Background

Coherent WaveBurst (cWB) is the flagship search for burst gravitational waves. Its "background" is composed of triggers from the 2 LIGO detectors time-shifted more than the light travel time between them so that any coincident triggers are accidental. This background is used to determine the confidence of candidate gravitational wave detections. We computed the background false alarm rate and probability separating those triggers that were above and below threshold wind speeds to measure the effect of wind on cWB.

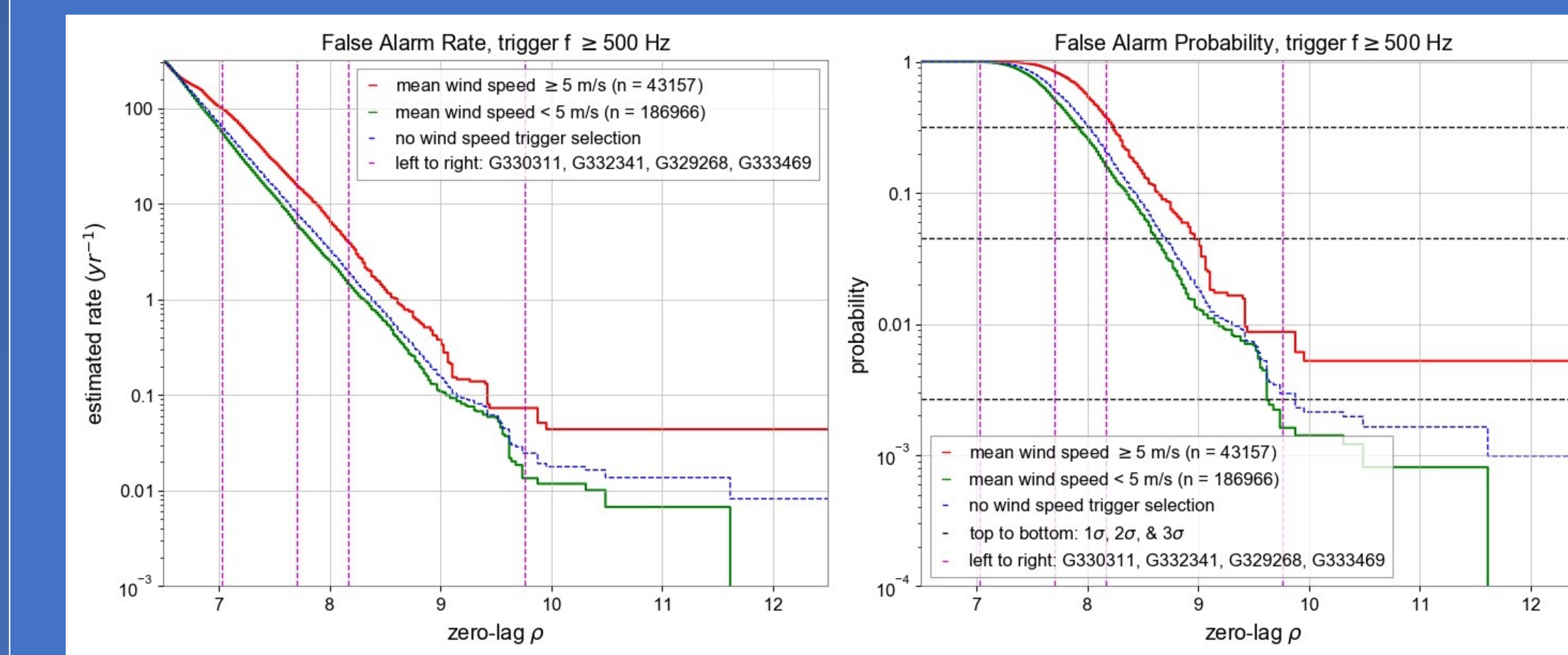


*Fig. 8 (above): The false alarm rate (FAR) (left) and false alarm probability (FAP) (right) are affected by the wind speeds. The blue dotted line shows the rate and probability for all of the triggers, the red solid line is for the triggers that occurred when the wind speed was ≥5 m/s, and the green line for the triggers when the wind speed was <5 m/s. Only triggers with a central frequency of >500 Hz were used here since they were more likely to be glitches caused by the wind. For a given detection strength $\rho$, the FAR and FAP are greater for higher wind speeds. The effect of the wind on the FAR and FAP is clear but modest.*

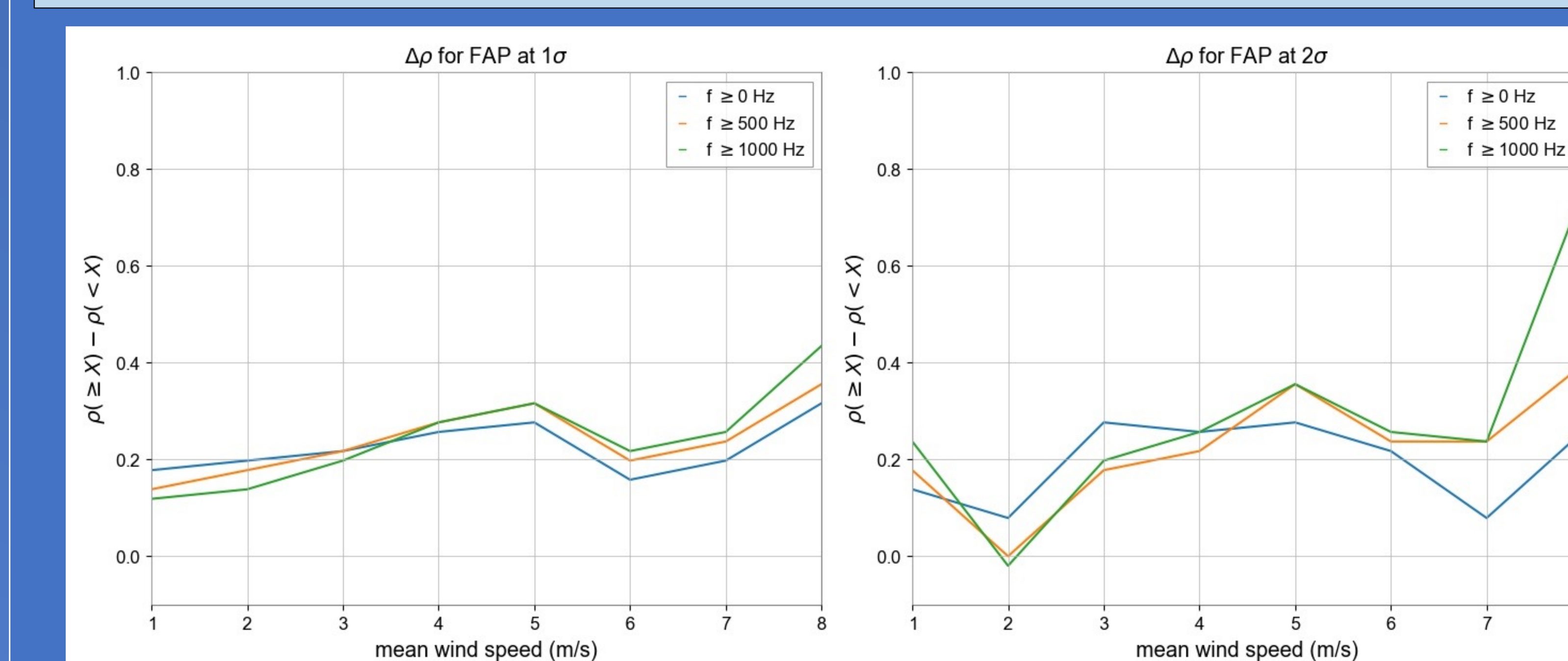


*Fig. 9 (above): For a constant FAP, we can see the difference in $\rho$ when the wind speed is high compared to when it is low (threshold speeds on x-axis). In general an additional 0.2 of $\rho$ is required, with the increase amplified when the wind speed is ≥7 m/s.*

## Conclusions

**Wind Characteristics**

- Higher wind speeds observed when **not** in observing mode.
- Average wind speed difference in and out of observing mode was of 0.123 m/s, p > 0.99.

**Wind Effect on Omicron**

- An increase in wind speed produces a higher Omicron (glitch) rate.
- Average Pearson correlation coefficient between wind speed and Omicron trigger rates is 0.2048

**Wind Effect on cWB**

- For a given detection strength *p*, the FAR and FAP are greater for higher wind speeds.
- In general, when the wind speed is high, a trigger will need to have a ρ+0.2 to reach the same FAP compared to when the wind speed is low.


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## Sources


[1] A. Stuver, R. Dean, M. Caesar, "Impact of Wind Speed at LHO on the Burst Search in Early O3," LIGO Document T1900412-v2.

[2] "What Is LIGO?" *LIGO Lab | Caltech*, www.ligo.caltech.edu/page/what-is-ligo

[3] L. Nuttall, J. McIver, *"Understanding the characteristics of the LIGO Detectors,"* **LIGO Magazine**, issue 8, p. 38 (3/2016) https://www.ligo.org/magazine/LIGO-magazine-issue-8-extended.pdf