EVLA Memo No. 220
OST logs 2011-2022: weather and forecast

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Abstract

The objective is to better understand the weather forecast role in the VLA Observation Scheduling Tool (OST). For this a series of analysis are done using twelve years of OST observation logs, as well as two an half years of weather forecast data. Typical values of weather conditions and predictions are presented. The weather results confirm that the forecasts are adequate to improve the sequence of VLA observations. Some comments are made on how to optimize the use of these predictions.

Introduction

The analysis of the OST logs from 2011 to 2022 was divided in two EVLA Memos. This report focuses on weather conditions and forecasts, as well as day and night variations. Memo #221 focuses on temporal and sidereal coverage of the observations.

It is noteworthy that this report only takes into account the time that the VLA operated with the OST, and theses operations were recorded in its logs. Hereafter, the expression "observed hours" is a short for "observed hours with OST". Detailed information on how the observation time was spent can be found in the VLA Operation reports.

Observatios logs

The weather conditions (wind speed and API) at the start of an observation come directly from the OST logs. More specifically, from the `scheduler.log` file. Log data starts on 2010-3-22 ("LST day" 62001). These wind speed ("Wind") and API values are the ones that are effectively considered for the creation of the schedule – and the choice of the Scheduling Block (SB) for the observation.

Note: prior to 2022-4-22 (LST 66425) some executions came from OST-test (not OST-production). However, even these test observations used updated weather station data, and therefore will not be filtered out.

OST Scheduler logs are stored at `/home/mchost/evla/logs/scheduler`.

OST-Weather logs

OST forecast data is retrieved from NOAA's XML query service. NOAA updates its forecast every hour, and offers hourly predictions.

OST weather retrieves four forecast data points from eight specific hours (MT timezone): 3, 6, 9 and 12 am/pm. Example: at 1pm, it retrieves the forecast for 3, 6, 9 pm and 12 am. Then OST interpolate the weather conditions to the next twelve hours from these 3h spaced data.

Prior to August 2022, data retrieval script was running hourly and was not handling errors (a new attempt was expected only in the next hour). The logs show that retrieval failures are common (once or twice a day), but hardly occur consecutively (ie., the forecast could be outdated on more than 1h, but hardly more than 2h). The errors occur due to problems in the NOAA server (HTTP 503 response). In August 2022 a change was make and in case of failure it makes new tries every 15 minutes.

The forecast (interpolated) data starts on 2020-02-21.

OST Weather logs are stored at `/home/mcmonitor/mcmonitor.evla.nrao.edu/content/evla/ostweather/logs`.

OST scheduler filters

In the process of creating the schedule, the OST Scheduler gets the wind speed and API values from the "param database" and applies them to all elegible blocks. Then, it applies the forecast values for the next twelve hours. If a longer than 12h schedule is generated, no additional constrains are applied after the that time.

It is important to note that the Scheduler does not take into account if the forecast is predicting a weather improvement, since the SBs not matching the current conditions are not considered for the schedule.

Analysis

Observations

OST was used 64% (~2/3) of the time from 2010-03-22 to 2022-08-23 (69,789 of 108,888 hours available for operations).

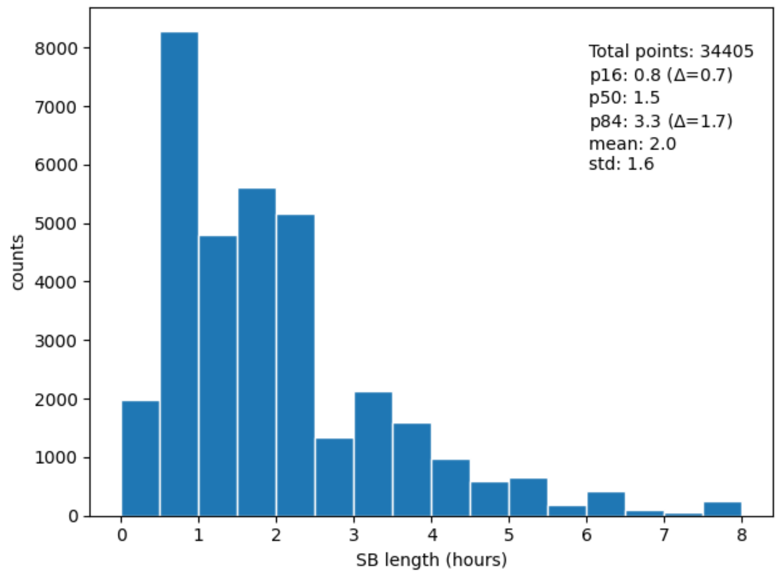

Figure 1: *Histogram of the duration of the Scheduling Blocks (March 2010–August 2022)*

Typical SB duration is in between 30 minutes and 1h, and that 97% of SBs lasts less than 7h (Fig. 1). Number of SBs longer than 6h (from a total of 34405):

- 6–8h: 635
- 8–10h: 174
- 10–12h: 43
- 12–15h: 17
- 15–20h: 4
- >20h: 7

A preliminar assessment of the longest SBs indicate they were all tests.

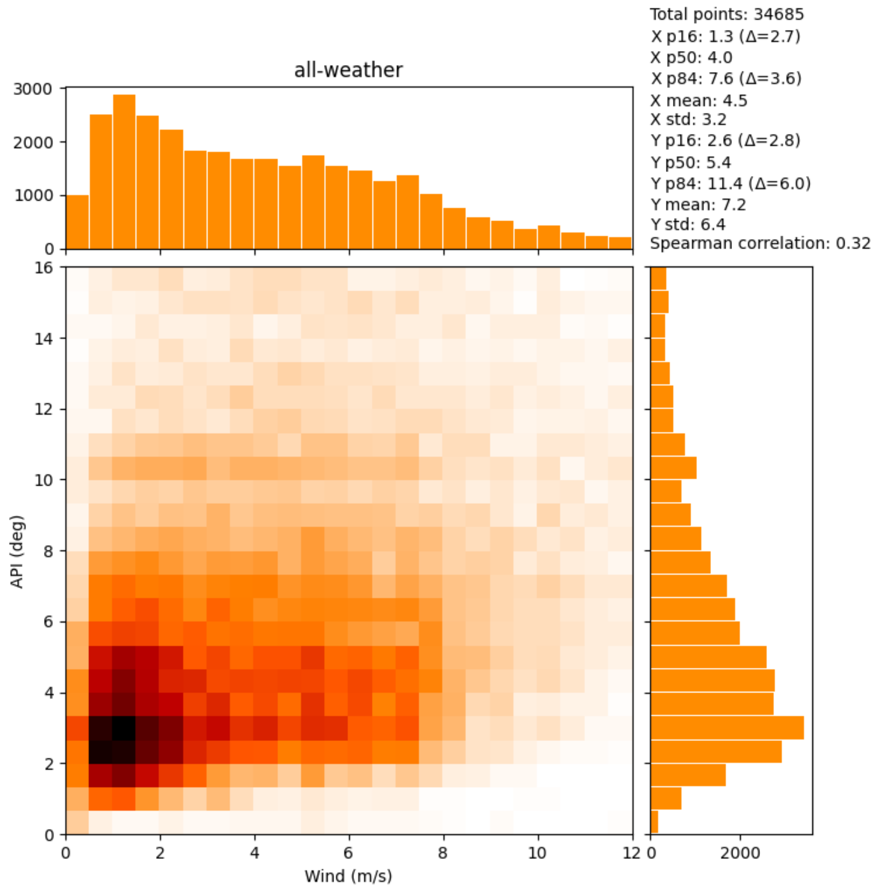

Figure 2: *2D histogram of the Wind Speed and API at the start of the SBs (March 2010–August 2022)*

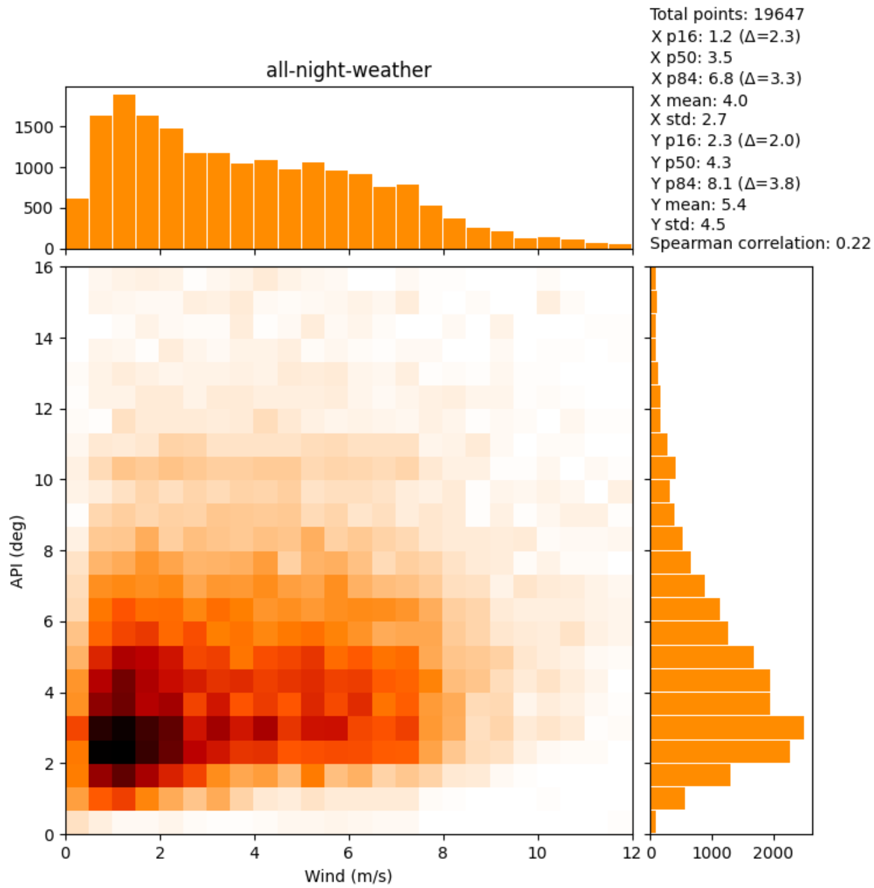

Figure 3: *Same as Fig. 2, for nighttime only*

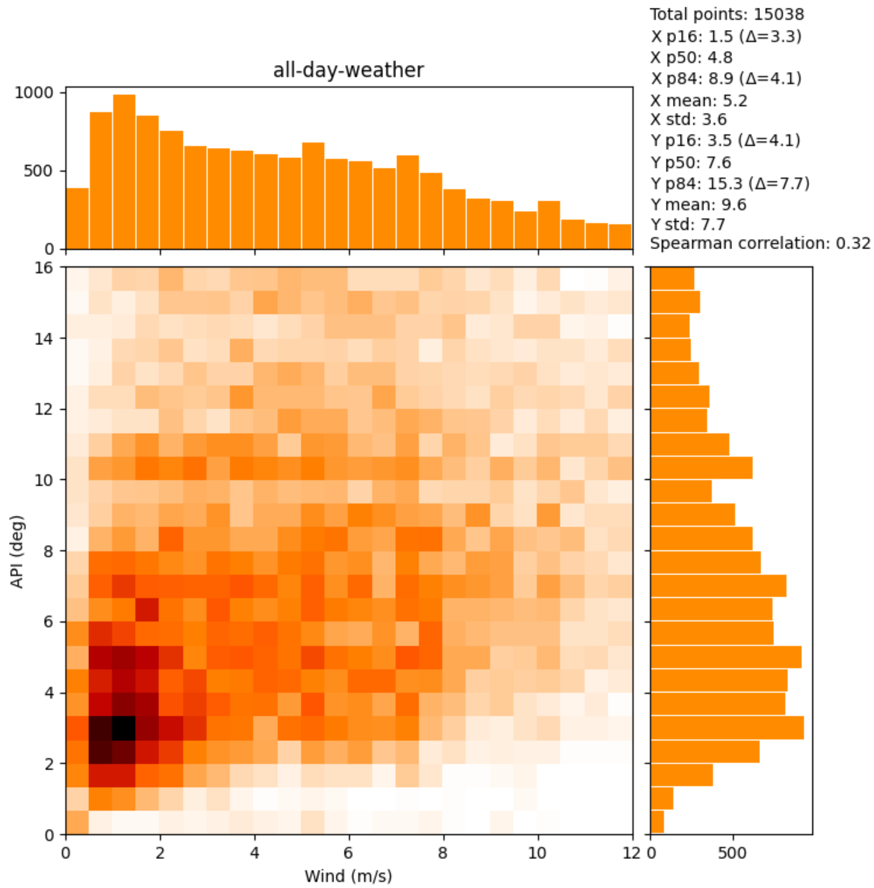

Figure 4: *Same as Fig. 2, for daytime only*

From a total of 34685 runs, 15038 (or 43%) were during the day (top right corner of the 2D histograms contains the total number of points). The lower number of SBs during the day likely indicates time spent on maintenance or test/commissioning. The weak correlation of API and wind speed (`|spearman_r|` <0.32) confirms that wind speed forecast can not be used to predict API values.

The correlation of SB length with wind speed or API are very weak (`|spearman_r|` <=0.03; see appendix). Thus, it is possible to extract the average weather properties directly from the data points (ie, it is not necessary a weighting by the duration of SBs).

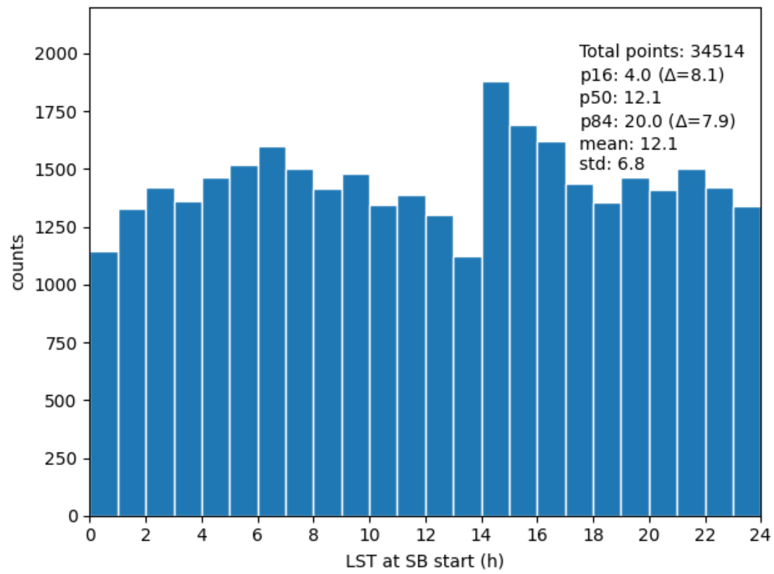

Figure 5: *Histogram of the local sidereal time at the start of the Scheduling Blocks (March 2010–August 2022)*

Given the almost flat distribution of SB over LST (Fig. 5), no weighting is required regarding the Sidereal Time coverage. Note that LST values in Fig. 5 are the local sidereal time at the beginning of the observation (and not the Right Ascension of the sources).

In Memo #221 the observed decrease of SBs at LST 13–14h and the increase at LST 14–15h is investigated in detail.

Seasonal weather values

Table 1: *Seasonal API (deg) and Wind (m/s) values of the Scheduling Blocks (March 2010–August 2022)*

Month	API (night)	API (median)	API (day)	Wind (night)	Wind (median)	Wind (day)
Jan	3.4	3.8	5.1	3.4	3.8	4.6
Fev	3.6	4.2	5.5	4.0	4.7	5.8
Mar	3.9	4.7	6.6	4.0	4.9	6.1
Apr	4.0	5.3	7.7	4.7	5.5	6.8
May	4.0	5.5	8.0	4.1	4.8	5.9
Jun	5.1	6.6	8.9	4.0	4.5	5.1
Jul	6.7	8.5	11.8	3.4	3.6	3.9
Ago	6.4	7.9	11.1	3.1	3.2	3.3
Sep	6.2	7.5	10.4	2.6	3.2	3.9
Out	4.3	5.2	7.7	2.9	3.3	4.4
Nov	3.6	4.0	5.6	3.1	3.4	4.1
Dec	3.4	3.7	4.9	3.1	3.5	4.5

A comparison of Table 1 with the VLA Performance webpage (see References section) indicates that the reference values are better than used by OST ("day" indicates sunrise to sunset values and "night" indicates sunset to sunrise values). In short, observed average values are 1.0 deg higher for API and 1.0 m/s higher for wind speeds. More detailed differences are presented in Table 2.

Table 2: *Seasonal API (deg) and Wind (m/s) comparison with NRAO's website reference. Values are monthly averages and their standard deviation. Negative averages indicated higher values observed than the reference.*

Quantity	**mean diff.**	**std diff.**
API (night)	-0.85	0.32
API (median)	-0.74	0.35
API (day)	-1.11	0.54
Wind (night)	-0.95	0.79
Wind (median)	-0.88	0.61
Wind (day)	-1.12	1.00

Observability of bands

Table 3: *Observability of bands (wind speed and API within constraints; percentage of the time from March 2010 to August 2022).*

Band	**% of time**	**wind (m/s)**	**API (deg)**
Q	31.5%	< 5	< 5
Ka	48.2%	< 6	< 7
K	64.4%	< 7	< 10
Ku	85.7%	< 10	< 15
X	98.2%	< 15	< 30
C	99.7%	< 20	< 45
S	99.9%	< 20	< 60

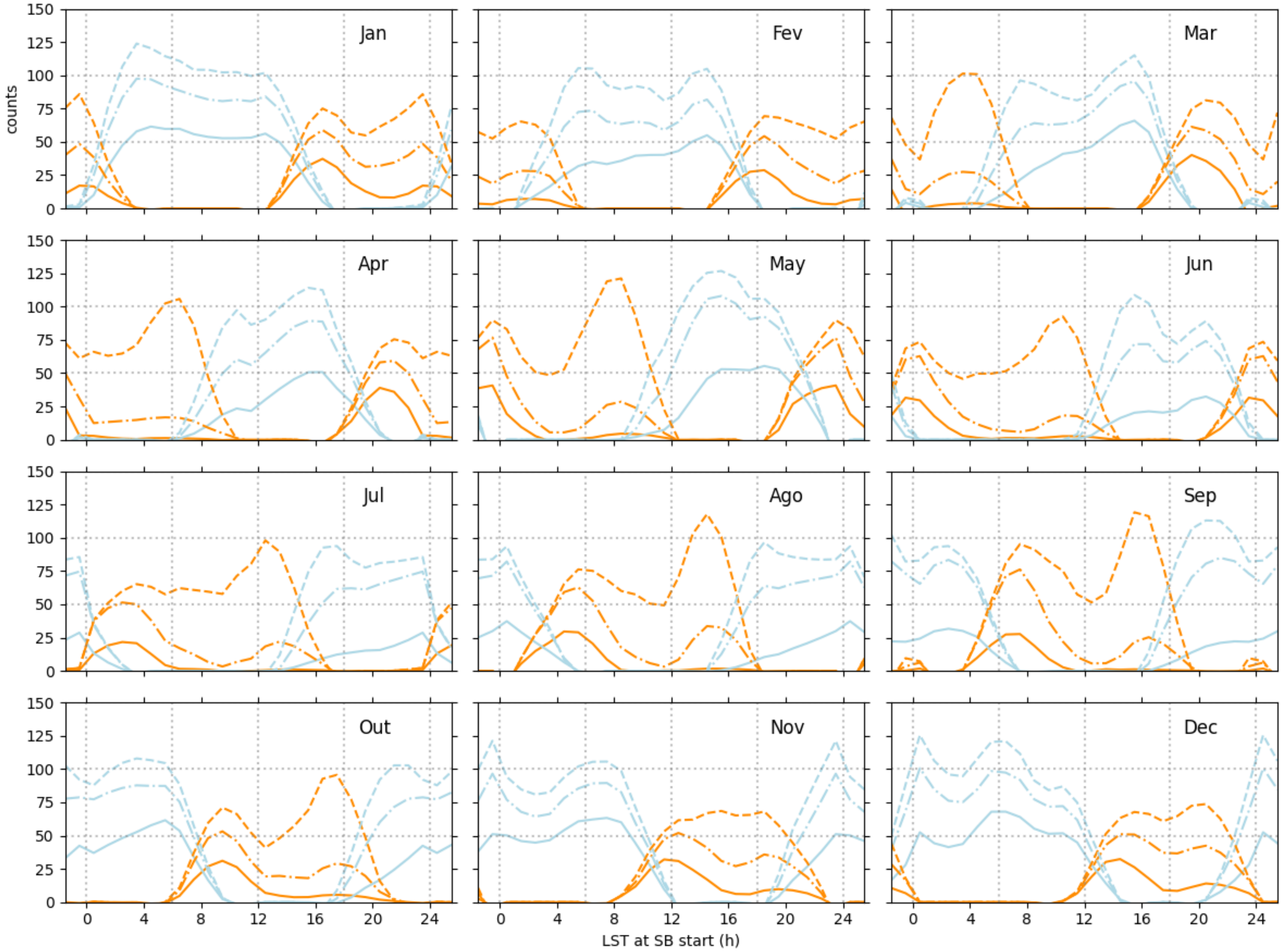

Figure 6: *Monthly number of Scheduling Blocks that matched the observability conditions for the Q band (solid line), K band (dot-dashed line) and lowest frequencies (dashed line). Nocturnal observations are indicated by light blue lines, while diurnal by dark orange. Smoothed curves with from 2014–2021 data.*

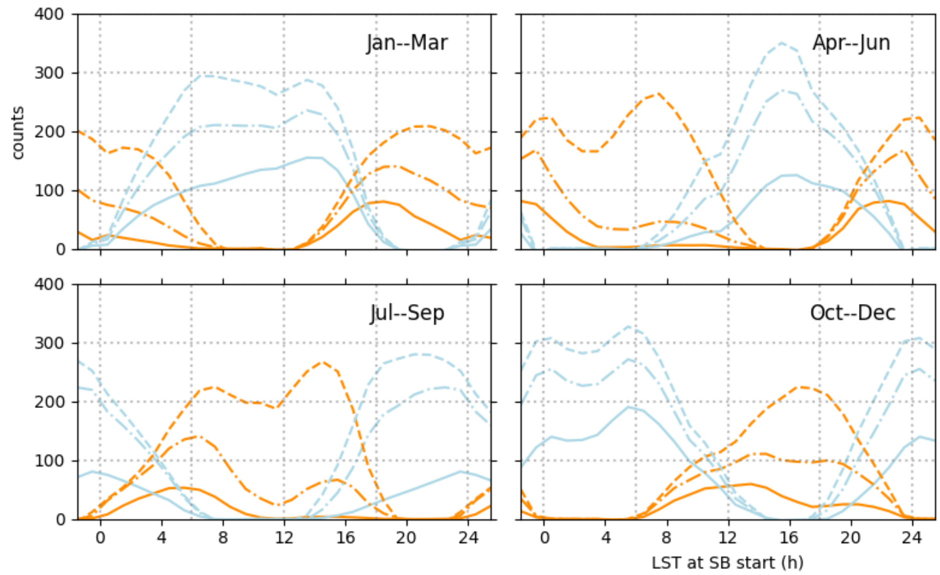

Figure 7: *Seasonal number of Scheduling Blocks that matched the observability conditions for the Q band (solid line), K band (dot-dashed line) and lowest frequencies (dashed line). Nocturnal observations are indicated by light blue lines, while diurnal by dark orange. Smoothed curves from 2014–2021 data.*

Fig. 6 shows the amount of SBs observed monthly (2014–2021 range) satisfying the weather constraints for high (Q-band), medium (K-band) and low frequencies. A Savitzky-Golay filter of order 2 and window 7 was applied to the curves. The raw data are shown in the appendix. Fig. 7 does the same, but for each season of the year (approximately).

The counts can be correlated with the observation time of each of the filters per LST, day and night. The SBs of each of the curves have a mean duration of ~2.0h and a standard deviation of 1.5h (very likely Fig. 1).

Daytime observability

As we have seen in the previous section, daytime weather conditions are considerably better in the morning than in the afternoon. A very useful information for Operations is the typical (local) time when conditions go out-of-spec for high frequency observations.

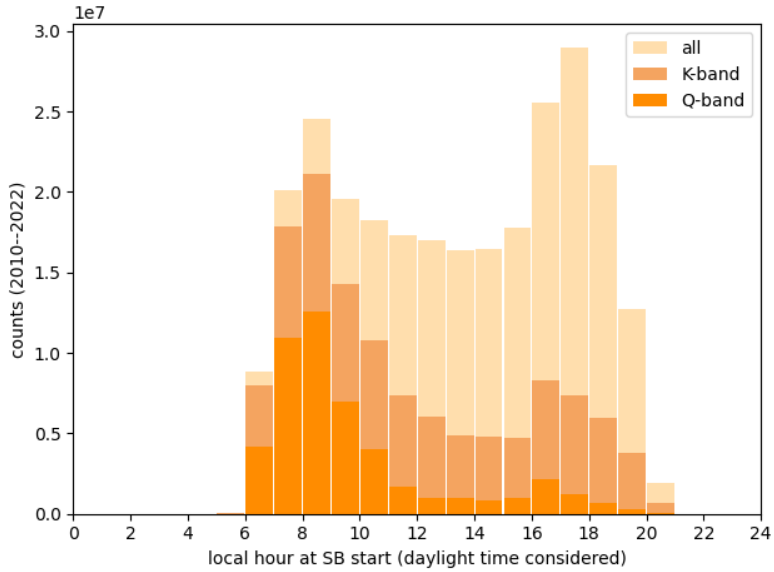

Figure 8: *Daytime SB counts as function of the local time (MST/MDT). The weather conditions satisfying Q, K and all bands are indicated (dark to light colors).*

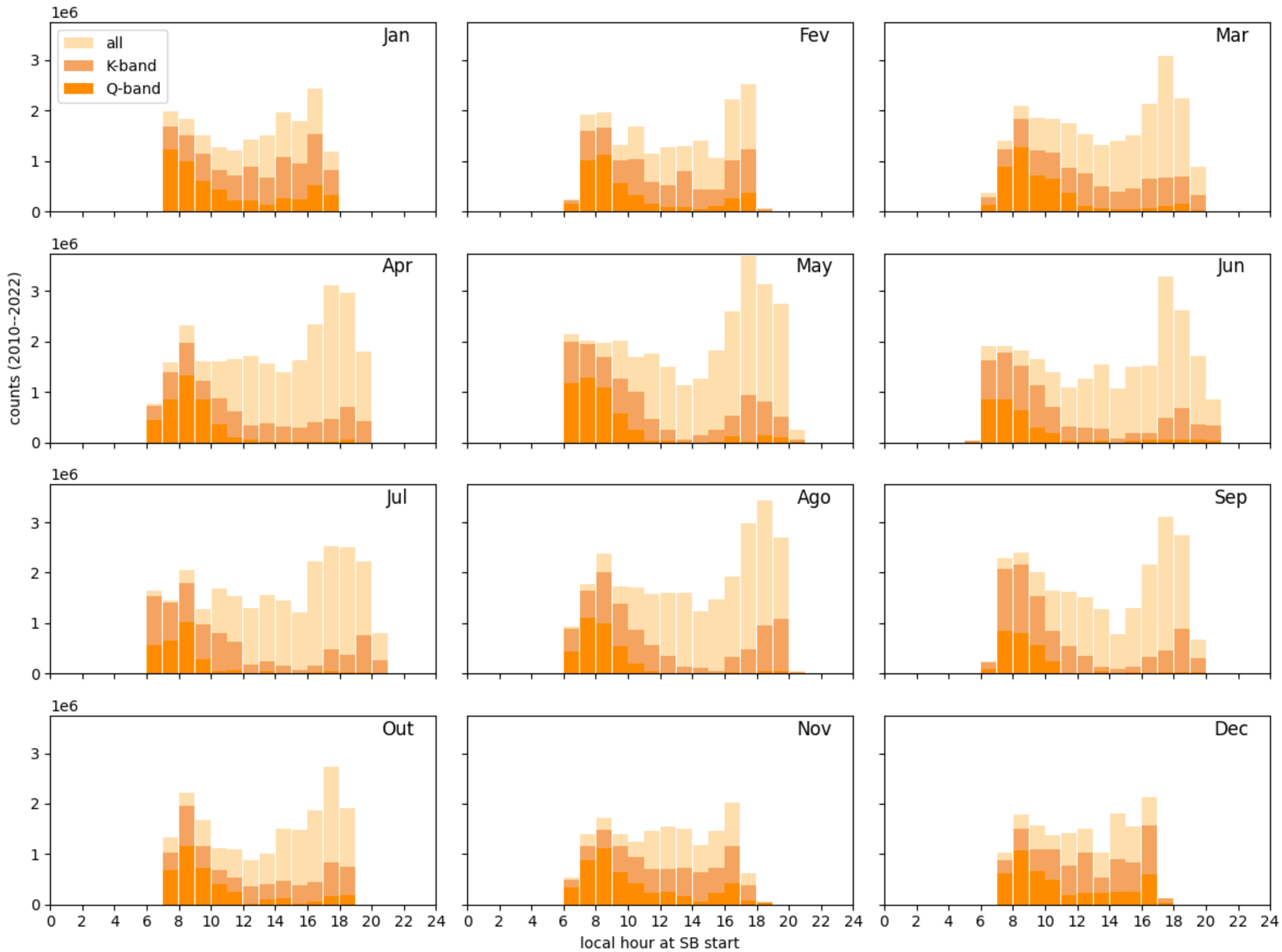

Figure 9: *Same as previous figure, but grouped month by month.*

In Fig. 8 and Fig. 9 it can be seen that after 11 am (local time), the observability of high frequencies is very low. The exception is the coldest months (October to March), where the observation window extends to 12 am (local time); and in December and January, where some favorable conditions are seen throughout the day.

Forecast

In this section, compare the forecast values obtained from the NOAA service with those recorded on the site. The Wind speed read from the "param" database at the start of the SB execution is compared with the predictions made at different intervals, as follows:

- forecast <= 1.5 hour before
- 1.5 < forecast <= 3 hours before
- 3 < forecast <= 6 hours before
- 6 < forecast <= 9 hours before

Note that NOAA's offers two different predictions for the wind speeds: an "average" value (referred here as "wind") and gust values. OST weather can work with both for the schedule filtering.

It is emphasized that the time coverage of the data in this section is shorter than the previous one. It only covers the time the OST weather operates (ie., since February 2020).

The comparison of the wind speed forecast with the values actually measured is shown below, followed by the gust speeds.

Predicted wind speeds up to 1.5h in advance

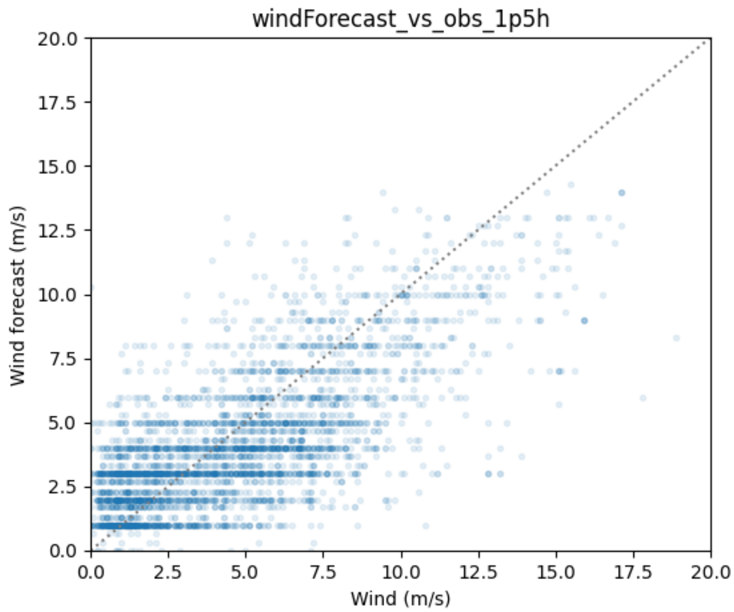

Figure 10: *Wind speed forecast vs values observed up to 1.5 h in advance (Feb 2020 – Aug 2022)*

In Fig. 10, the dotted line corresponds to a one-to-one relationship between the variables (ie., precise forecast wind speeds). Points above the line correspond to overestimated wind speeds; below the line, underestimated speeds. (More statistics in Fig. 12).

The data points are centered along the one-to-one correspondence, confirming the forecast correlation with the observed wind speeds. Most of the values are < 5.0 m/s, which can be taken as the typical dispersion amplitude. The discretization of values on the ordinate axis is a consequence of the discrete forecast values.

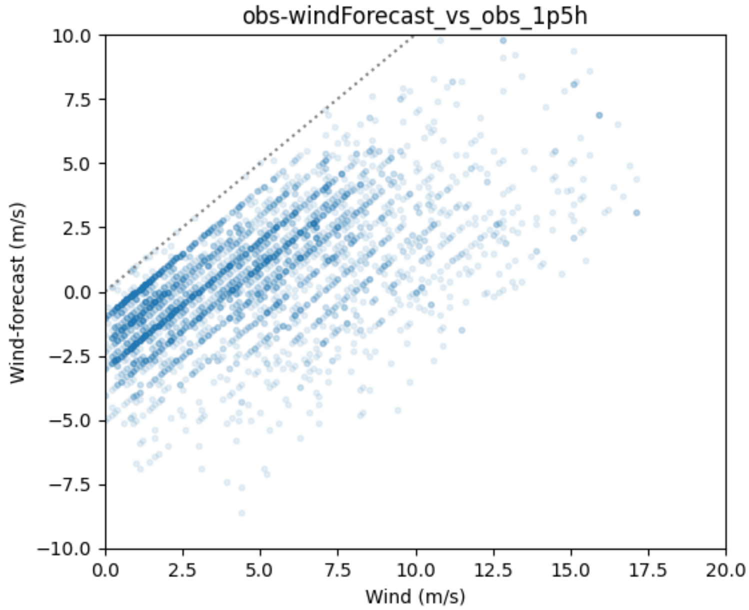

Figure 11: *Wind speed forecast difference vs values observed up to 1.5 h in advance (Feb 2020 – Aug 2022)*

Fig. 12 is the difference of the observed wind speed and its forecast. Thus, the dotted line indicates precise forecast values. This plot shows some interesting features: i) the top-left left corner does not have any data points. This region is equivalent to "negative wind speed" forecasts; ii) the absence of data points along the dotted line (more below).

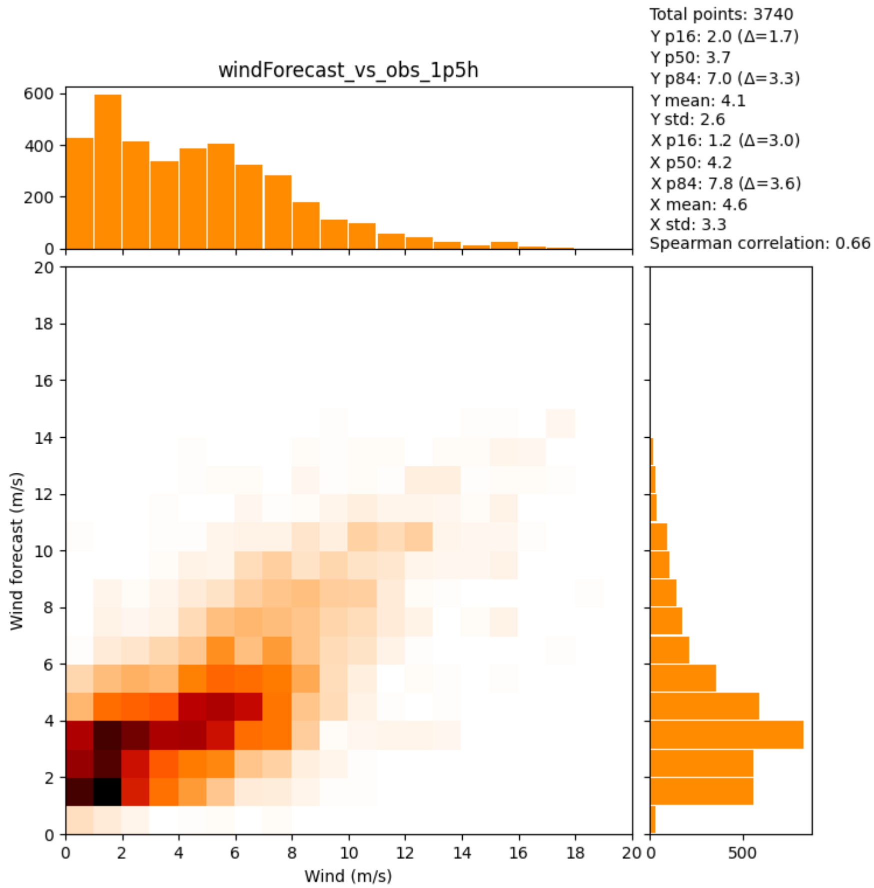

Figure 12: *2D histogram of wind speed forecast vs values observed up to 1.5 h in advance (Feb 2020 – Aug 2022)*

The observed and predicted wind speed histograms in Fig. 12 are different. Observed values have broad dispersion (<= 8/ms), but it is common to observe winds < 1 m/s, with typical values between 1 and 2 m/s. On the other hand, forecast dispersion is narrower (<= 6m/s), with typical winds speeds between 3 and 4 m/s and almost no occurrence of winds < 1 m/s. This last feature explains why it cann't be seen points along the line of the difference between observations and predictions (Fig. 11).

The high correlation value (`|spearman_r|` =0.66) reinforces that the forecasts are adequate in estimating the wind speeds.

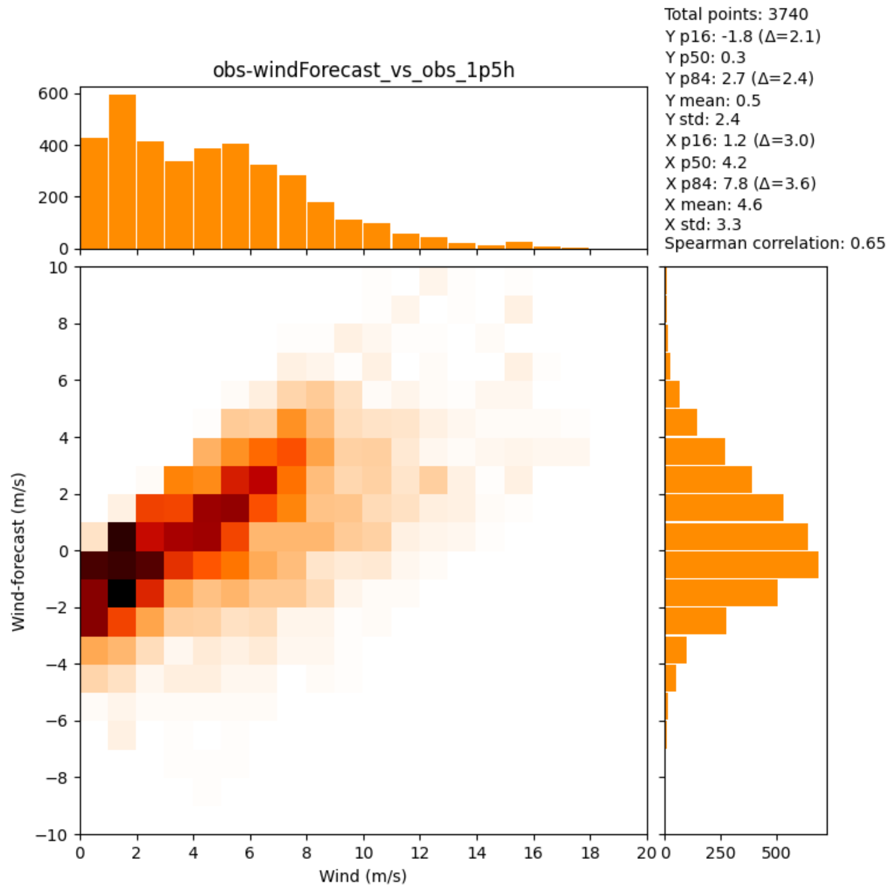

Figure 13: *2D histogram wind speed forecast difference vs values observed up to 1.5 h in advance (Feb 2020 – Aug 2022)*

In Fig. 13 it is shown the quantification of how much the forecasts differs from the wind speeds. A positive median indicates that usually the forecasts underestimate the speed (in this case, by 0.3 m/s). Most winds are overestimated by up to 1.8 m/s (p16) or underestimated by up to 2.7 m/s (p84).

Predicted wind speeds over time

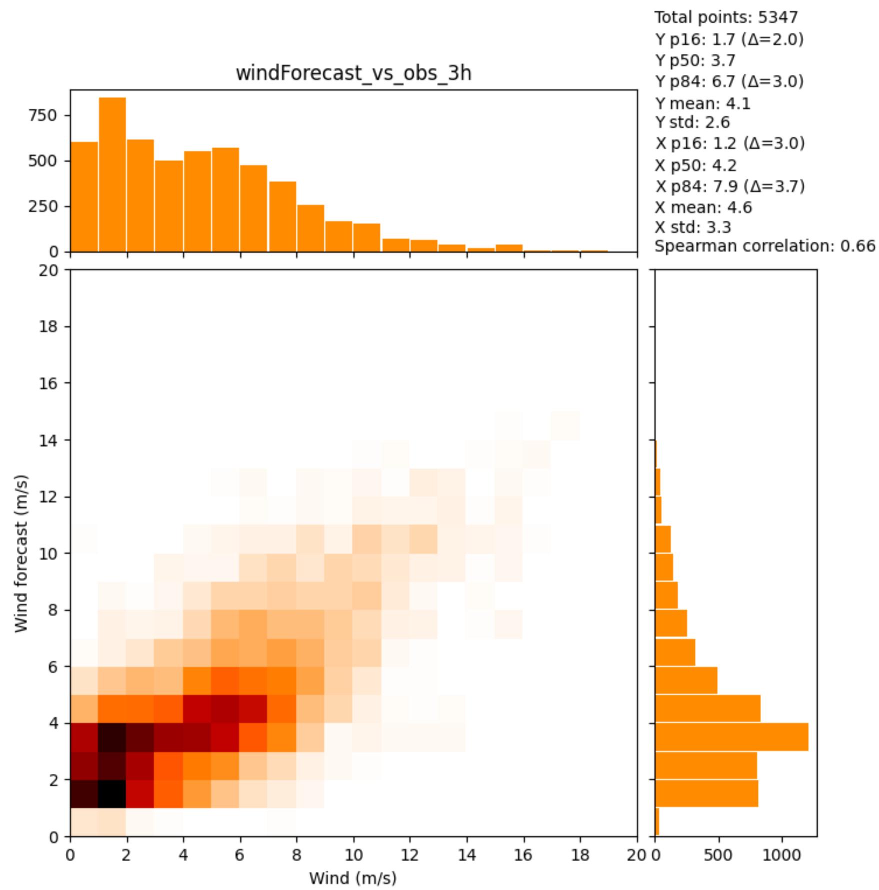

Figure 14: *2D histogram of wind speed forecast vs values observed between 1.5 < t < 3h in advance (Feb 2020 – Aug 2022)*

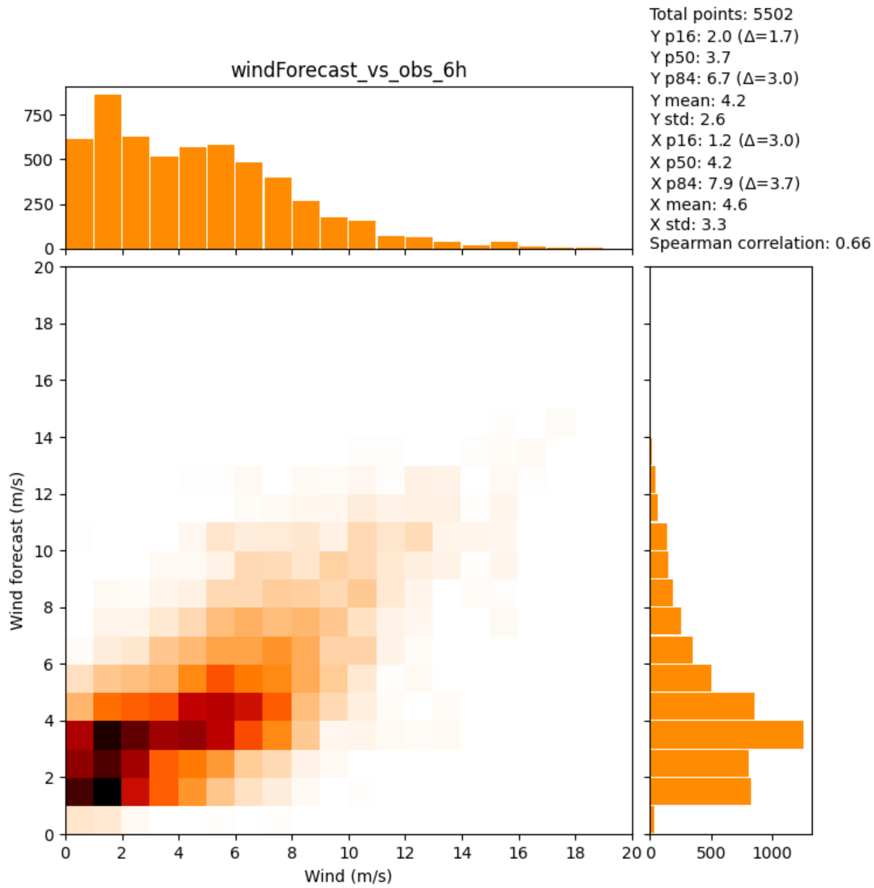

Figure 15: *2D histogram of wind speed forecast vs values observed between 3h < t < 6h in advance (Feb 2020 – Aug 2022)*

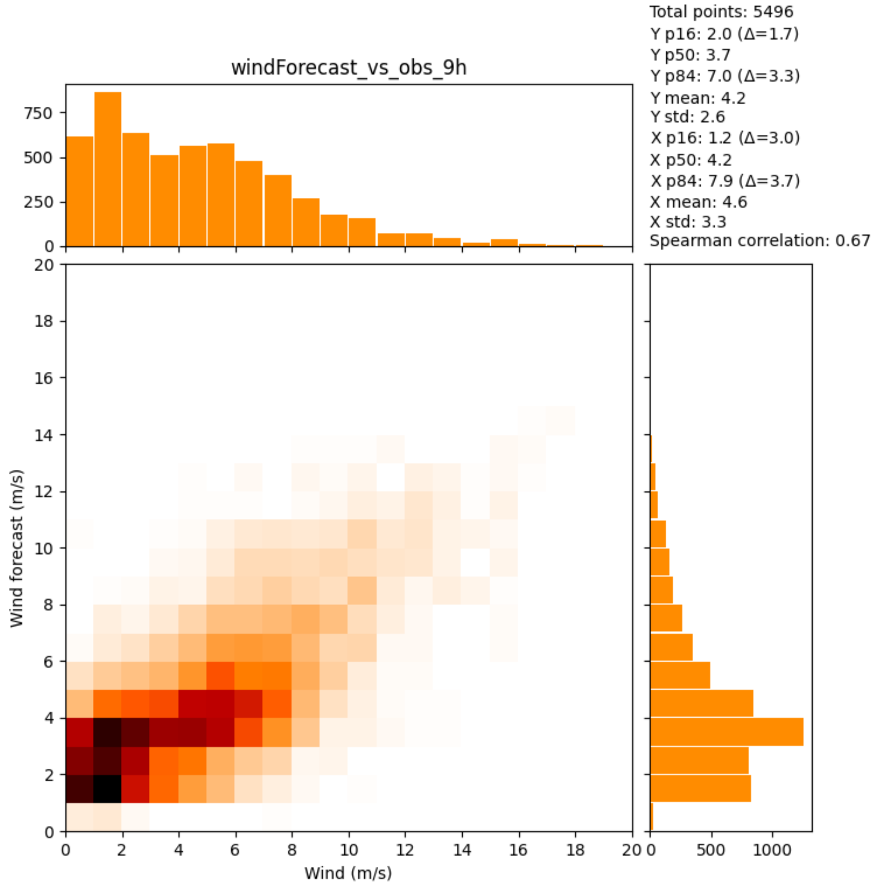

Figure 16: *2D histogram of wind speed forecast vs values observed between 6h < t < 9h in advance (Feb 2020 – Aug 2022)*

Figs. 14 to 16 correspond to Fig. 12 but for forecasts between 1.5h < t < 3h, 3h < t < 6h and 6h < t < 9h respectively.

It can also be seen that the forecast changes very little over time (if it changes at all). The slight variations seen between the figures are to be expected since forecast update failures are common (for example, a forecast obtained 1h before the observation counts for Fig. 12, but this observation would be absent in Fig. 14 if there were failures between 2h and 3h).

This means that delays/failures of a few hours in the forecast retrieval have a negligible impact on the construction of the schedule.

Predicted wind gusts up to 1.5h in advance

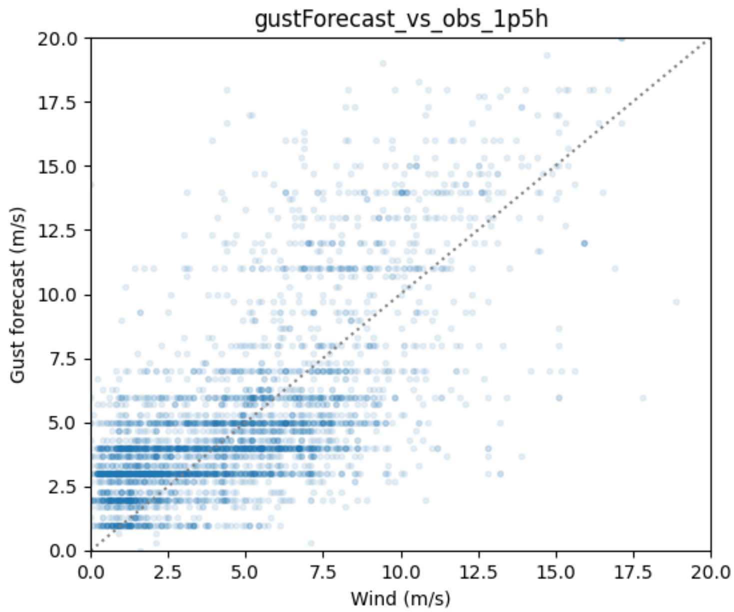

Figure 17: *Wind gust forecast vs values observed up to 1.5 h in advance (Feb 2020 – Aug 2022)*

Fig. 17 and 18 show that the wind gust forecast is systematically higher than the values observed. This also creates a "structure" (points concentration) in addition to the dispersion of higher speed predictions when observed wind speeds are ~7.5 to 12.5 m/s.

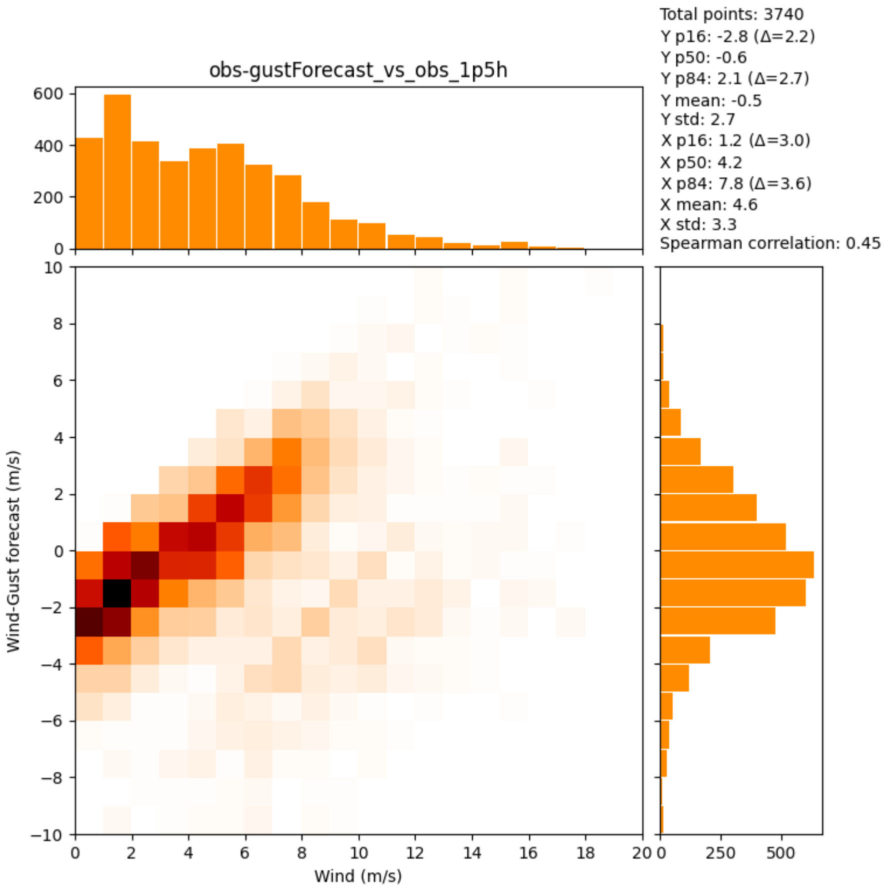

Figure 18: *2D histogram wind gust forecast difference vs values observed up to 1.5 h in advance (Feb 2020 – Aug 2022)*

In Fig. 18 a negative median confirms that the forecast overestimate the values (by 0.6 m/s). Most winds are overestimated by up to 2.8 m/s (p16) or underestimated by up to 2.1 m/s (p84). Correlation value (`|spearman_r|` =0.45) is significantly lower that the one for wind speed forecast.

Predicted wind gusts over time

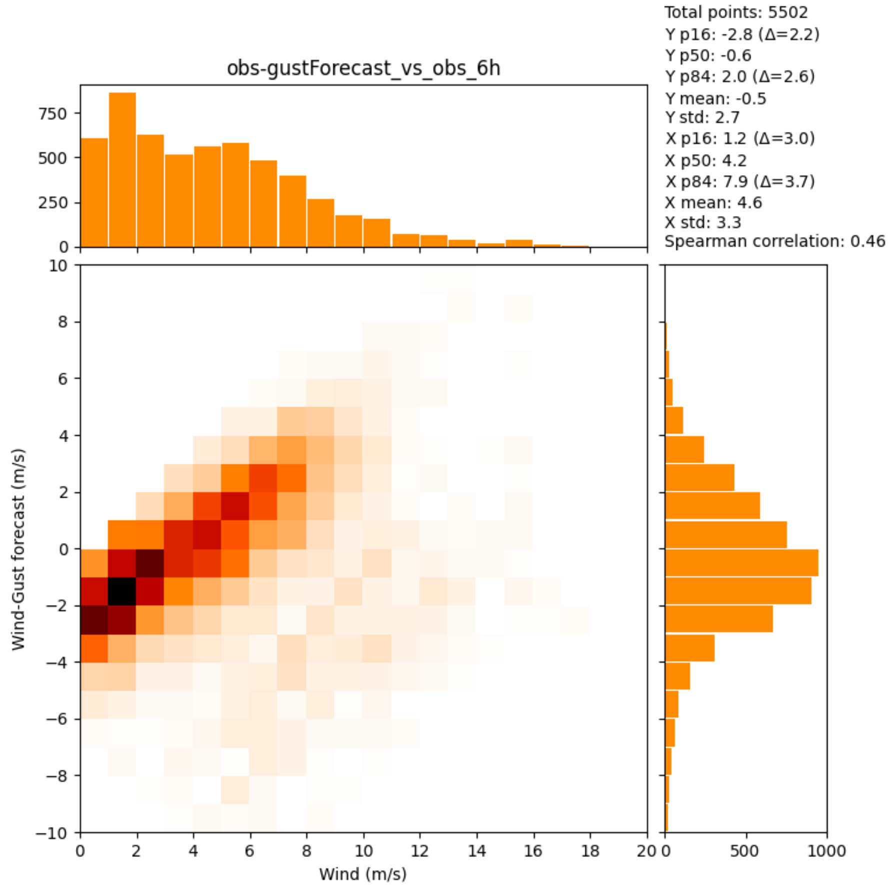

Figure 19: *2D histogram wind gust forecast difference vs values observed up to 6 h in advance (Feb 2020 – Aug 2022)*

As for wind speed, wind gust forecasts changes very little over time (if it does). As an example, Fig. 18 can be compared to Fig. 18. The 3h and 9h difference are in the Appendix.

Conclusions

OST schedule default length of 24h is more than adequate since the median Scheduling Block is 1.5h and 97% of the SBs are < 7h.

Regarding the weather conditions and the observability of filters, a summary of the main trends follows: i) observed wind speed and API values are worst than the reference values currently available at NRAO's website (respectively by ~1.0 m/s and ~1.0 deg); ii) almost 1/3 more sources are observed at night than during the day, with the nighttime offering the best observability at higher frequencies; ii) at night, roughly 2/5 of the observable time is available for the highest frequencies (Q band) and 3/4 for medium frequencies (K band); iii) during the day, 1/6 of the observable time is suitable for Q-band and 3/7 for K-band, especially between sunrise and 11 am (local time); iv) high-frequency observability is considerably reduced from June to September (summertime).

The fact that the webpage reference for winds speeds and those predicted by the NOAA service are lower than those observed (respectively -0.9 and -0.3 m/s) may indicate that there is some bias in readings used in observations. This might be due to the fact that it is measured the wind at the top of the weather station tower (60 ft height), and the forecasts are for the surface. To better determine the nature of this offset, it would be necessary to analyze wind directions and their speeds, something beyond the scope of this report.

This report does not evaluate in detail the favorable conditions for high-frequency daytime observations. The offer of this type of observation requires further investigation, such as the stability/continuous duration of the weather constraints and their seasonal repetition that would allow a regular allocation of SBs.

A bump in the LST coverage at 13h–15h found in the 12 years of OST logs will is analyzed in the EVLA Memo No. 221.

NOAA's predictions for the VLA site change very little in the 9 hours prior to the forecast. This confirms that the OST Weather strategy of data retrieval every hour is adequate.

Having good estimates allows the OST Scheduler to build a sequence that favors priority blocks matching the weather conditions. The high correlation (`|spearman_r|` = 0.66) and the small difference of forecasts (-0.3 m/s) for the entire 12h interval confirm that the wind speed forecasts are good predictions. However the typical forecast deviation of ~2.5 m/s is only adequate to define between low and medium frequency Scheduling Blocks, but insufficient for a choice between the highest frequency bands.

As it was implemented, weather forecast is applied on top of the current conditions filter (ie, the queue is only prepared for worsening weather conditions). In one hand, this minimizes the chances of observing out of specification. On the other hand, this prevents blocks with more restrictive conditions from being scheduled. This filtering feature make it more important for Operators to update the Schedule before the start of each run to not discard blocks unnecessarily.

This study does not allow us to state whether the forecasts are being used optimally. For this, it is necessary to analyze how much of the observations were outside the weather specifications and how much of the high-frequency blocks were successfully observed. To increase the number of high-frequency observations, it is possible artificially make the forecasts to have better values, or not apply the current conditions filter (allowing for weather improvement forecasts). Conversely, if an even more conservative approach is desired, one can artificially worsen the forecast values (or use the wind gust forecast). An addition in wind speed of the typical dispersion value (~2.5 m/s) almost guarantees that all observations would be within specifications.

Acknowledgements

The author thanks P. Beaklini, B. Butler, V. Dhawan, M. Gardiner and A. Mioduszewski for their comments and suggestions on this report.

References

- Seasonal API/wind values at the VLA: https://science.nrao.edu/facilities/vla/docs/manuals/oss/performance/gaincal#RapidPhaseAPI
- VLA API wind page: https://science.nrao.edu/facilities/vla/proposing/VLA-API-wind
- Filter constraints and their monthly observability by LST: https://science.nrao.edu/facilities/vla/proposing/VLA-API-wind/monthly-conditions-at-the-vla
- EVLA Memo No. 221 - OST logs 2011-2022: temporal and sidereal coverage
- Sunset and sunrise times: https://pypi.org/project/suntime/

Appendix

VLA Operations date format

"LST day" is a quantity created by Barry Clark for convenience in the earliest days of the VLA and it is still used to this day. One can use the following relation to convert between MJD (UTC) and LST (both MJD and LST have day + fraction):

```
        LST - c
MJD = ------- + lon
          sid
```

or, conversely,

```
LST = sid * (MJD - lon) + c
```

where `c=6572.1557060185187`; `lon=1.87828367838904/(2*pi)` (the VLA longitude), and `sid=1.002737909350795` (relationship of sidereal to actual day length).

The *Time Calculator* tool is available at the the VLA OPS page (https:/ops.vla.nrao.edu) for these conversions, including from/to the Gregorian calendar. Below are two examples.

Example 1:

- UTC: 2022-08-09 19:00:00.0
- MJD: 59800.79166667
- LSTday: 66536 09:02:32.411

Example 2:

- UTC: 2020-05-30 12:00:00.0
- MJD: 58999.5
- LSTday: 65732 21:23:22.565

Extra Observation Figures

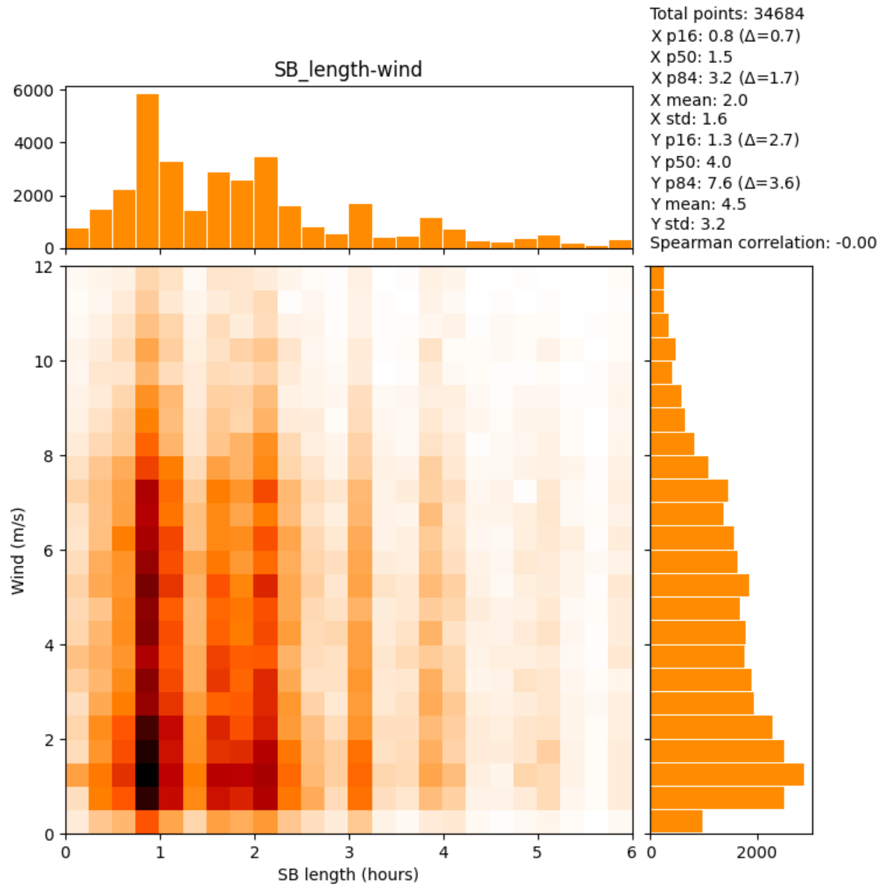

Figure 20: *2D histogram of the Scheduling Blocks length and wind speed (Mar 2010 – Aug 2022)*

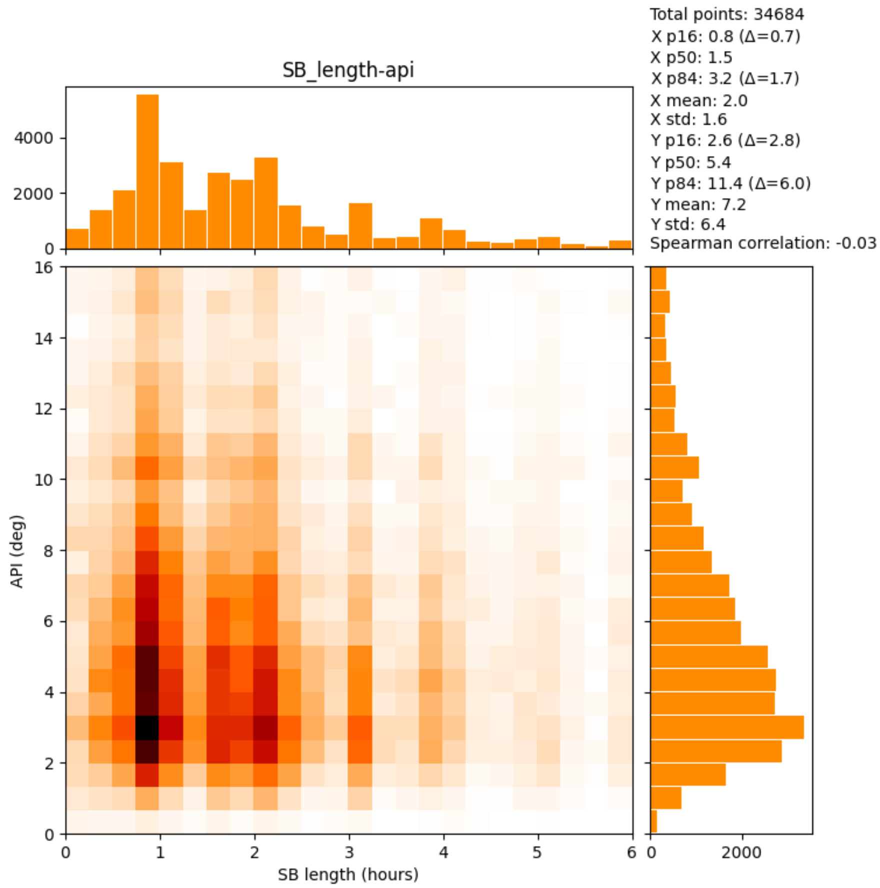

Figure 21: *2D histogram of the Scheduling Blocks length and API (Mar 2010 – Aug 2022)*

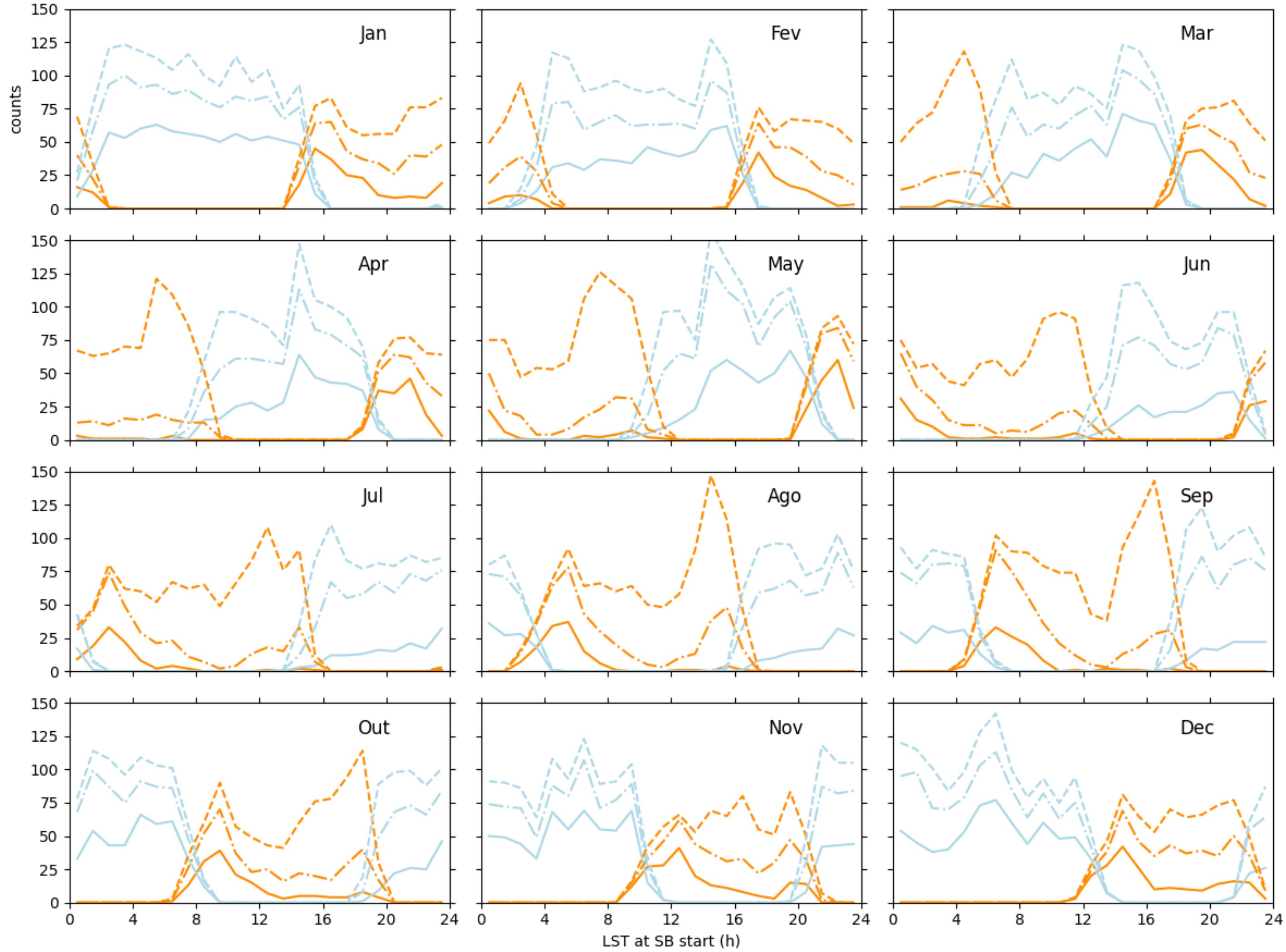

Figure 22: *Monthly number of Scheduling Blocks that matched the observability conditions for the Q bands (solid line), K (dot-dashed line) and lowest frequencies (dashed line). Nocturnal observations are indicated by light blue lines, while diurnal by dark orange. Data from 2014–2021.*

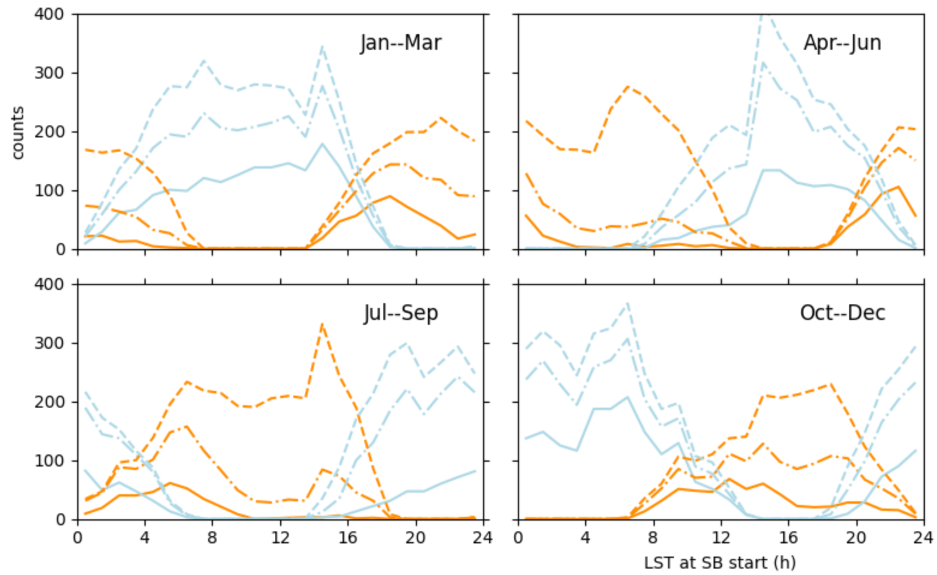

Figure 23: *Seasonal number of Scheduling Blocks that matched the observability conditions for the Q bands (solid line), K (dot-dashed line) and lowest frequencies (dashed line). Nocturnal observations are indicated by light blue lines, while diurnal by dark orange. Data from 2014–2021.*

Extra Forecast Figures

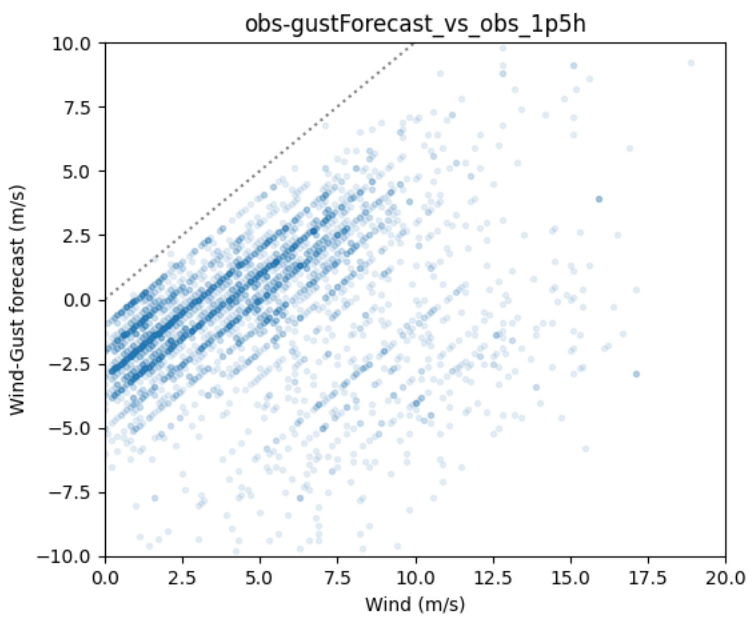

Figure 24: *Wind gust forecast difference vs values observed up to 1.5 h in advance (Feb 2020 – Aug 2022)*

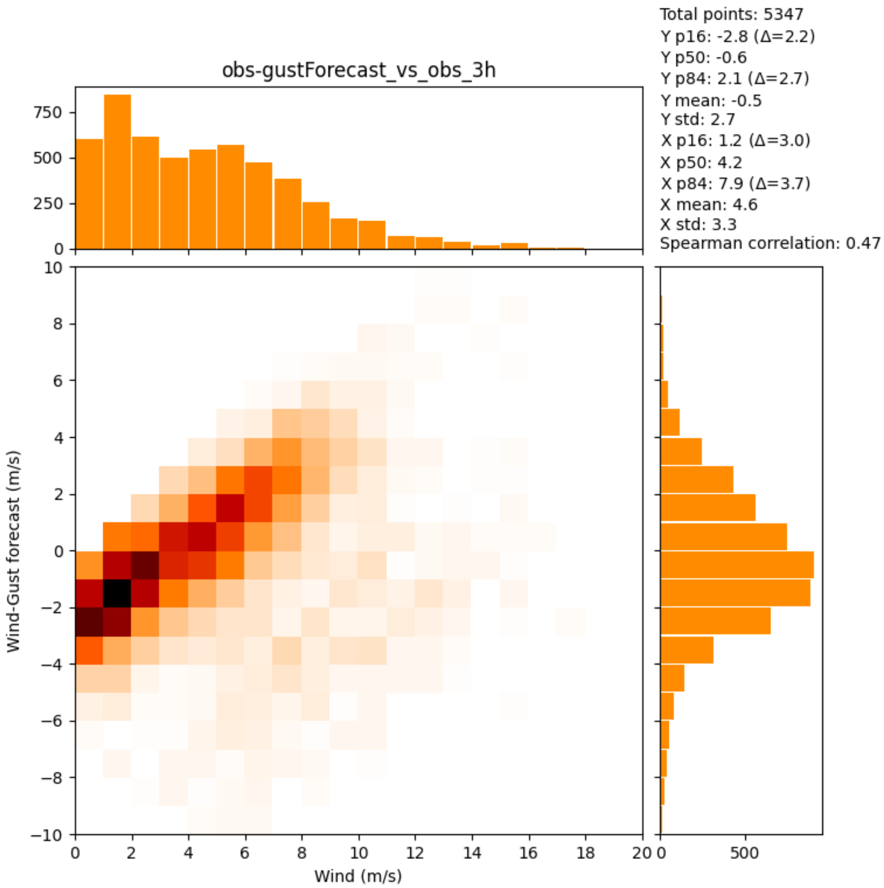

Figure 25: *2D histogram wind gust forecast difference vs values observed up to 3 h in advance (Feb 2020 – Aug 2022)*

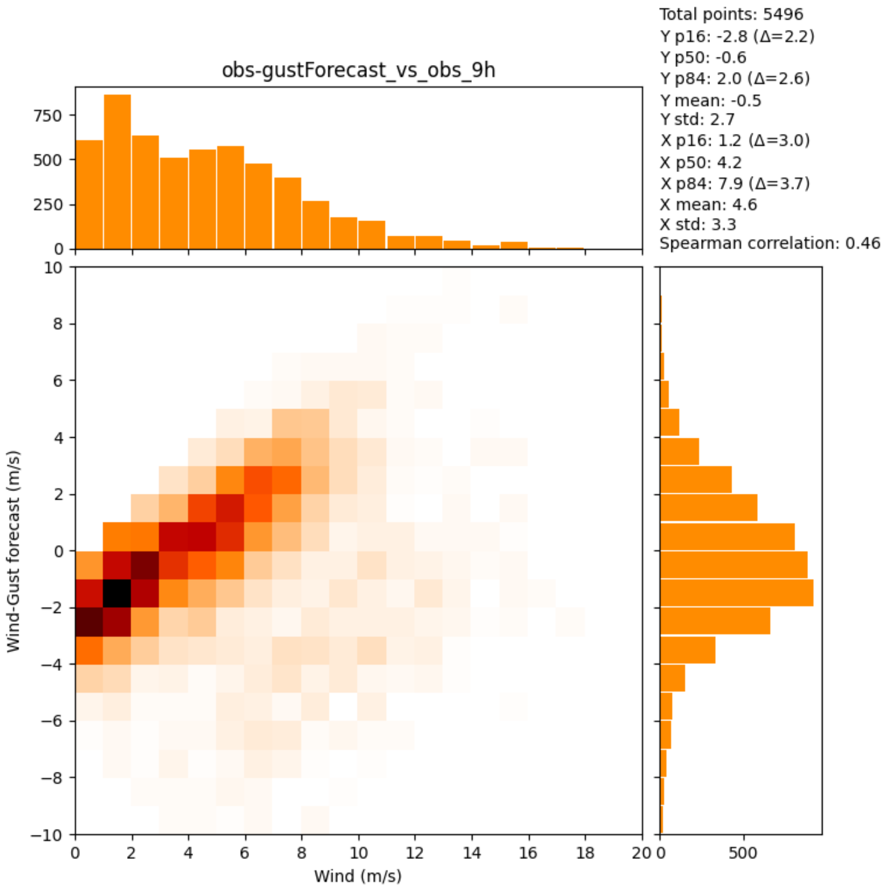

Figure 26: *2D histogram wind gust forecast difference vs values observed up to 9 h in advance (Feb 2020 – Aug 2022)*

Table 4: *Average hours observed monthly for different bands. Data from 2014–2021.*

Month_Band	0h	1h	2h	3h	4h	5h	6h	7h	8h	9h	10h	11h	12h	13h	14h	15h	16h	17h	18h	19h	20h	21h	22h	23h
Jan | Q_day	3.7	2.8	0.2	0	0	0	0	0	0	0	0	0	0	0	4.1	10.3	8.5	5.7	5.3	2.3	1.8	2.1	1.8	4.4
Jan | Q_night	2.1	6.9	13.5	12.5	14.2	14.9	13.7	13.2	12.8	11.8	13.2	12	12.8	12	11.3	2.6	0	0	0	0	0	0	0	0.2
Jan | K_day	9.2	5.1	0.2	0	0	0	0	0	0	0	0	0	0	0	7.4	14.7	14.9	9.9	8.5	7.8	6	9.2	9	11
Jan | K_night	5	13.9	22	23.6	21.5	22	20.3	21	19.1	18	19.8	19.1	19.8	15.8	18	4.5	0	0	0	0	0	0	0	0.5
Jan | all_day	15.9	7.6	0.2	0	0	0	0	0	0	0	0	0	0	0	8.7	17.7	19.1	14	12.6	12.9	12.9	17.5	17.5	19.1
Jan | all_night	6.4	18.4	28.4	29.1	27.9	26.7	24.6	27.4	23.6	21.7	26.9	22.4	24.6	17.7	22	5.4	0	0	0	0	0	0	0	0.9
Fev | Q_day	0.9	2.1	2.3	1.6	0	0	0	0	0	0	0	0	0	0	0	0.2	4.4	9.6	5.5	3.9	3.2	1.8	0.5	0.7
Fev | Q_night	0	0	1	3.3	7.9	8.7	7.4	9.4	9.2	8.7	11.7	10.7	9.9	11	15	15.8	6.6	0	0	0	0	0	0	0
Fev | K_day	4.4	7.1	9	6.4	0.9	0	0	0	0	0	0	0	0	0	0	0.2	7.6	14.7	10.6	10.6	9	6.4	5.7	4.1
Fev | K_night	0	0	1.8	7.9	20.1	20.4	15	16.6	17.8	15.8	16	16	16.3	15.3	24.5	22.2	8.4	0.3	0	0	0	0	0	0
Fev | all_day	11.3	15.2	21.6	12.9	2.5	0	0	0	0	0	0	0	0	0	0	0.2	9.6	17.5	13.3	15.4	15.2	14.9	13.8	11.3
Fev | all_night	0	0	3.8	12	29.8	28.8	22.4	23.2	24.5	22.9	22.2	22.9	20.9	19.6	32.3	27.8	11.5	0.5	0	0	0	0	0	0
Mar | Q_day	0.2	0.2	0.2	1.5	1	0.5	0.2	0	0	0	0	0	0	0	0	0	0	2.7	10.4	10.9	8.1	5.4	1.7	0.5
Mar | Q_night	0	0	0	0	0	0.8	3	7.3	6.2	11.1	9.7	12.1	14	10.5	19.2	17.8	17	10	0.8	0	0	0	0	0
Mar | K_day	3.5	4.2	5.7	6.4	6.9	6.4	1.5	0	0	0	0	0	0	0	0	0	0	5.2	14.8	15.6	13.6	12.1	6.7	5.7
Mar | K_night	0	0	0	0	0.3	5.7	12.1	20.5	14.6	17	16.2	18.9	20.8	17	28.1	26.2	23.2	14.8	1.6	0	0	0	0	0
Mar | all_day	12.3	15.8	17.8	24	29.1	22.2	6.7	0	0	0	0	0	0	0	0	0	0	6.2	16.3	18.5	18.8	20	15.8	12.6
Mar | all_night	0	0	0	0	0.5	13.5	22.1	30.2	22.1	23.5	21	24.8	23.2	20.2	33.2	32.1	26.7	18.9	1.6	0	0	0	0	0
Apr | Q_day	0.8	0.3	0.3	0.3	0.3	0	0.8	0	0	0	0	0	0	0	0	0	0	0	2	9.3	8.8	11.6	4.8	0.8
Apr | Q_night	0	0	0	0	0	0	0	0.3	4.1	4.3	6.8	7.6	6	7.6	17.3	12.7	11.6	11.4	10	2.2	0	0	0	0
Apr | K_day	3.3	3.5	2.8	4	3.8	4.8	3.8	3.3	3.3	0.5	0	0	0	0	0	0	0	0	2.5	12.9	16.2	15.6	10.9	8.3
Apr | K_night	0	0	0	0	0	0	0	2.2	9.7	14.3	16.5	16.5	16	15.4	30.6	22.5	21.4	19.2	16.8	3.5	0	0	0	0
Apr | all_day	16.9	15.9	16.4	17.7	17.4	30.5	27.5	21.7	13.1	1	0	0	0	0	0	0	0	0	2.8	14.6	19.2	19.4	16.4	16.2
Apr | all_night	0	0	0	0	0	0	0	5.7	16	26	26	24.6	23	19.2	39.8	28.4	27.1	24.9	18.9	4.3	0	0	0	0
May | Q_day	5.4	1.5	0.2	0	0	0	0.7	0.5	1	1.7	0.5	0.2	0	0	0	0	0	0	0	0	5.7	11.1	14.8	5.9
May | Q_night	0	0	0	0	0	0	0	0	0	0.5	1.2	2.1	3.5	5.4	12.2	14	12.2	10.1	11.7	15.7	11	2.8	0	0
May | K_day	12.4	5.4	4.5	1	1	2	4.2	5.7	7.9	7.7	2	1	0	0	0	0	0	0	0	0.2	9.9	19.8	20.8	14.6
May | K_night	0	0	0	0	0	0	0	0	0	0.9	4.2	12.2	15.2	14.3	30.9	26.2	23.9	16.4	21.5	24.3	16.4	4.4	0	0
May | all_day	18.6	18.6	11.6	13.4	13.1	14.6	26.2	31.2	28.7	26.2	13.1	2.5	0	0	0	0	0	0	0	0.2	10.9	20.8	23	17.8
May | all_night	0	0	0	0	0	0	0	0	0	2.1	10.8	22.5	22.7	17.5	36.7	31.6	27.1	20.3	25	26.7	18.5	5.1	0	0
Jun | Q_day	7.3	3.6	2.4	0.5	0.2	0.2	0.5	0.2	0.2	0.2	0.5	1.2	0.2	0	0	0	0	0	0	0	0	0.5	6.2	6.9
Jun | Q_night	0	0	0	0	0	0	0	0	0	0	0	0	0.7	1.8	3.9	5.9	3.9	4.8	4.8	5.9	7.9	8.2	3.4	0.2
Jun | K_day	15.4	9.5	7.1	3.6	2.6	2.6	1.2	1.7	1.4	2.8	4.7	5.2	2.8	0.2	0	0	0	0	0	0	0	0.9	10.4	13.7
Jun | K_night	0	0	0	0	0	0	0	0	0	0	0	0	2.7	5.7	16.1	17.5	16.1	12.9	12	13.2	19.1	17.9	8.4	0.9
Jun | all_day	17.8	12.8	13.5	10.4	9.7	13.5	14.2	11.1	14.4	21.5	22.7	21.5	8.5	2.1	0	0	0	0	0	0	0	1.2	11.4	15.9

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Table 4: *Average hours observed monthly for different bands. Data from 2014–2021.* (... continued)

Month_Band	0h	1h	2h	3h	4h	5h	6h	7h	8h	9h	10h	11h	12h	13h	14h	15h	16h	17h	18h	19h	20h	21h	22h	23h
Jun | all_night	0	0	0	0	0	0	0	0	0	0	0	0.2	6.4	10.7	26.3	26.8	22.2	16.8	15.4	16.6	21.8	21.8	10.7	1.4
Jul | Q_day	2.1	4.4	7.7	5.1	1.9	0.5	0.9	0.5	0	0	0	0	0.2	0	0.5	0.2	0	0	0	0	0	0	0	0.2
Jul | Q_night	4.3	0.3	0	0	0	0	0	0	0	0	0	0	0	0	0.8	1	3	3	3.3	4.1	3.8	5.3	4.3	8.1
Jul | K_day	7.2	10.5	17.3	11.4	6.8	4.9	5.4	2.6	1.6	0.5	0.9	3	4.2	3.5	7.7	1.6	0	0	0	0	0	0	0	0.7
Jul | K_night	10.7	1.8	0	0	0	0	0	0	0	0	0	0	0	0.3	3	8.4	17	14	14.7	17	15	18.5	17.3	19.3
Jul | all_day	7.9	11	18.7	14.5	14	12.1	15.6	14.5	15.2	11.4	15.4	19.4	25.2	17.7	21.3	2.8	0	0	0	0	0	0	0	0.7
Jul | all_night	10.9	2	0	0	0	0	0	0	0	0	0	0	0	0.3	8.9	21.3	27.9	21.1	19.5	20.6	20	22.1	20.8	21.6
Ago | Q_day	0	0	1.7	4.3	8.2	8.9	3.6	1.4	0.2	0	0	0	0.2	0.2	0	1	0.2	0	0	0	0	0	0	0
Ago | Q_night	9.7	7.3	7.6	4.9	0	0	0	0	0	0	0	0	0	0	0	0	0.3	2.2	2.7	3.8	4.3	4.6	8.7	7.3
Ago | K_day	0	0	3.4	8.7	15.4	18.8	10.4	7.2	4.8	2.7	1.2	0.7	2.4	3.1	9.2	11.6	4.1	0	0	0	0	0	0	0
Ago | K_night	19.7	19.2	15.4	7.6	0.3	0	0	0	0	0	0	0	0	0	0	0.5	8.9	16	16.8	18.4	15.4	16.2	24.1	17
Ago | all_day	0	0	3.9	9.2	16.6	22.2	15.4	15.9	14.5	15.4	12.1	11.6	14	22	35.5	27.5	11.1	0.2	0	0	0	0	0	0
Ago | all_night	21.6	23.5	16.5	7.6	0.3	0	0	0	0	0	0	0	0	0	0	1.1	16.2	24.9	26	25.7	19.5	20.8	27.8	20.5
Sep | Q_day	0	0	0	0	0.9	5	7.5	5.9	4.5	1.8	0	0.2	0	0.5	0.2	0.2	0	0.5	0	0	0	0	0	0
Sep | Q_night	7.3	5.3	8.5	7.3	7.8	3.3	0.8	0	0	0	0	0	0	0	0	0	0	0.5	2	4.3	4	5.5	5.5	5.5
Sep | K_day	0	0	0	0	1.8	10.8	20.6	16.9	12.6	8.1	4.7	2.7	1.1	0.7	2.9	4.1	6.3	7	0.7	0	0	0	0	0
Sep | K_night	18.6	16.6	20.1	20.3	19.8	6.8	1.5	0	0	0	0	0	0	0	0	0	0	4	16	21.6	15.5	20.1	21.3	19.1
Sep | all_day	0	0	0	0	2	11.5	23	20.3	20.1	17.8	16.7	16.7	9.7	8.6	21	26.4	32.3	19.2	1.8	0	0	0	0	0
Sep | all_night	23.3	19.3	22.8	22.1	21.6	7.8	2	0	0	0	0	0	0	0	0	0	0	9.5	26.6	30.8	22.6	25.6	27.1	21.6
Out | Q_day	0	0	0	0	0	0	0.3	3.4	8.2	10.3	5.6	4	1.9	0.8	1.3	1.3	1.1	1.1	2.1	1.1	0	0	0	0
Out | Q_night	8.5	14	11.1	11.1	17.1	15.2	15.8	8.5	3.1	0	0	0	0	0	0	0	0	0	0.3	2.3	5.7	6.7	6.5	11.9
Out | K_day	0	0	0	0	0	0	0.5	6.9	13.8	18.5	9.8	6.1	6.6	4.2	5.8	5.3	4.5	7.7	10.6	4.5	0	0	0	0
Out | K_night	17.6	25.6	22.5	19.4	23.5	22.5	22.2	12.4	4.1	0	0	0	0	0	0	0	0	0	2.1	12.7	17.6	18.9	17.1	21.7
Out | all_day	0	0	0	0	0	0	0.8	9.3	15.9	23.8	15.1	13	11.4	10.9	15.9	20.1	20.7	24.9	30.2	7.9	0	0	0	0
Out | all_night	20.2	29.5	27.9	24.8	28.2	26.6	26.1	15	4.4	0	0	0	0	0	0	0	0	0	4.9	23	25.3	25.6	22.7	26.1
Nov | Q_day	0	0	0	0	0	0	0	0	0	3	6.9	7.1	10.4	5.1	3.3	2.8	2	1.3	0.8	3.8	3.6	0	0	0
Nov | Q_night	12.6	12.4	11.1	8.3	17.2	13.9	17.4	13.9	13.6	17.4	3.8	0.5	0	0	0	0	0	0	0	0	2	10.6	10.9	11.1
Nov | K_day	0	0	0	0	0	0	0	0	0	3.8	8.4	11.7	15.8	11.2	9.4	7.9	8.4	5.6	7.6	11.9	8.1	0.5	0	0
Nov | K_night	18.7	18.2	17.9	12.4	22.2	20.2	27	17.9	19.4	22.5	6.6	0.5	0	0	0	0	0	0	0	0.3	7.6	22	20.7	21.2
Nov | all_day	0	0	0	0	0	0	0	0	0	4.1	10.7	14.5	16.8	13.5	17.5	16.5	20.3	14	13	21.1	12.7	1.8	0	0
Nov | all_night	23	22.7	21.7	16.2	27.3	23.5	31	22.5	23	26.2	8.1	0.5	0	0	0	0	0	0	0	0.3	12.1	29.8	26.5	26.5
Dec | Q_day	0	0	0	0	0	0	0	0	0	0	0	0.7	5	6.9	10.4	6.4	2.5	2.7	2.5	2.2	3.5	4	3.7	0.7
Dec | Q_night	14.2	11.9	10	10.5	14	19.2	20.3	15.8	11.6	15.8	12.6	12.9	8.7	1.8	0	0	0	0	0	0	0	1.1	5.8	6.8
Dec | K_day	0	0	0	0	0	0	0	0	0	0	0	0.7	6	9.4	17.1	11.4	8.7	10.7	9.2	9.7	8.7	12.4	8.7	2.2

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Table 4: *Average hours observed monthly for different bands. Data from 2014–2021.* (... continued)

Month_Band	**0h**	**1h**	**2h**	**3h**	**4h**	**5h**	**6h**	**7h**	**8h**	**9h**	**10h**	**11h**	**12h**	**13h**	**14h**	**15h**	**16h**	**17h**	**18h**	**19h**	**20h**	**21h**	**22h**	**23h**
Dec | K_night	25	25.8	18.7	18.4	20.8	27.1	29.8	22.4	16.9	21.6	16.6	19.8	11.1	2.1	0	0	0	0	0	0	0	1.1	14.5	16.9
Dec | all_day	0	0	0	0	0	0	0	0	0	0	0	1	6.9	11.4	20.1	16.1	13.1	17.4	15.9	16.4	18.1	19.1	12.2	2.5
Dec | all_night	31.6	30.3	26.6	22.1	25.8	33.7	37.4	26.3	20.8	24.5	19.8	24.8	14	2.1	0	0	0	0	0	0	0	1.1	16.1	22.9