Ground-Based Atmospheric Measurements at the Onsala Space Observatory (Sweden): Data & Trends (2009–2025)

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The following color code is used throughout this document:

- Black text: Comments/questions from the Editorial Team and the two referees.
- Blue text: responses to the reviewers and the editorial team
- → Red text: line or page numbers referring to modifications in the revised manuscript

Reply to the comments of the Editorial Team

Thank you for your feedback. We have carefully considered the comments provided and revised the manuscript accordingly.

Please adjust your manuscript files before your next file upload (next round of revision or after acceptance) considering the following requirements:

(i) The map in Figure 4 seems to be taken from a map provider. Please add the appropriate credit or copyright statement according to the guidelines (see https://www.earth-system-science-data.net/submission.html#mapsaerials). Indeed, we had initially omitted the source of the map used in Fig. 4. We note that this was also the case for the large-scale map included in Fig. 1. We have now specified the sources of these maps in the figure captions of Figs. 1 and 4: *vemaps* and *Google Maps*, respectively.
→ The captions of Fig. 1 (p. 3) and Fig. 4 (p. 11) have been updated to include the map sources.

(ii) Your table C1 contains coloured cells or/and coloured values. Please note that this will not be possible in the final revised version of the paper due to HTML conversion of the paper. When revising the final version, you can use footnotes or italic/bold font.
The colours previously used in Tables 2 and C1 have been removed. The highlighted values are now indicated using bold font.
→ The table captions and the associated text have been updated accordingly (captions of Table 2 in p. 16 and Table C1 in p. 23).

(iii) Please ensure that the colour schemes used in your maps and charts allow readers with colour vision deficiencies to correctly interpret your findings. Please check your figures using the Coblis - Color Blindness Simulator (https://www.color-blindness.com/coblis-color-blindness-simulator/) and revise the colour schemes accordingly. → Figs. 2, C1
We have revised the colour schemes in Figs. 2 and C1. In addition, different line styles (solid, dashed, dotted, etc.) and/or distinct markers ('o', '■', '+', and 'x') have been used for each curve to improve readability for readers with colour vision deficiencies.
→ See Figs. 2 (p. 7) and C1 (p. 22).

Reply to the comments of the two referees

First of all, many thanks to the two reviewers for the time devoted to read this manuscript, for help and interesting comments. Below, we provide point-by-point responses (in blue). All changes and clarifications have been incorporated into the revised manuscript.

1   REFEREE #1 (RC1)

The authors are clear that the intention of the paper is to introduce the observations and the site, not the presented analysis of the data. However the presentation of the data reviles insights in interpretations of the description and is thus useful. To be a useful article there are some details about the observations that must be added. For example the placement of the sensors, the resolution of the sensor and how certain variables are defined. The presented analysis and interpretation is a bit trivial, but showcases the data set. I would recommend the article for publication if they clarify it.

We thank the reviewer for this constructive comment. We agree that, for a data paper to be fully useful, a detailed description of the observations is essential. We have therefore expanded the *Instrumentation* section (Sec.2.2) and Table 1 to explicitly describe sensor placement, measurement heights, resolution, and the precise definition of key variables (e.g. wind gust, rain rate, cloud cover). These additions improve the clarity and reusability of the dataset while remaining consistent with the descriptive scope of the paper.

Specific comments:

(i) Figure 1 gives an overview of the location of the instrument mast, but the picture is almost not showing the tower. I would highly recommend a better picture of it. In the text, at line 68, it is referred to as a "concrete tower".

We replaced Figure 1 with a close-up view of the instrumented mast and removed the word "concrete" in the revised manuscript (see revised Fig. 1).

→ Figure 1 on p. 3 has been replaced, and the word "concrete" has been deleted line 70.

(ii) Line 68: Has the sensor been the same for the whole measuring period? It is relevant for the humidity observations where capacitive sensors are known to drift in RHmax value with time.

The Vaisala WXT520 remained installed at the same location for the full record (Aug 2009–Apr 2025). Instrument maintenance logs do not report sensor replacements during this period; sensor drift cannot be fully excluded and this is now mentioned/discussed in the revised manuscript (see Section 5).

→ See Section 5, lines 302–307, for the added discussion on sensor stability and data consistency.

(iii) How is the sensor placed on the tower. I cant tell from the picture. Is it placed on top of the tower or on the side on a boom (in htet case in wich direction?)?

The Vaisala WXT520 sensors are mounted at the top of the instrumented mast ($\sim$16.1 m a.s.l.; see Table 1). The modified Figure 1 shows the sensor location. This information has also been added to the revised manuscript (Section 2.2).

→ Figure 1 on p. 3 has been replaced, and a precision has been added line 70

(iv) Line 70: It is unclear if wind (speed and direction) is measured with the Vaisala weather transmitter WXT520 or with an additional separate sensor. It is also not clear how the Vaisala weather transmitter WXT520 is mounted on the tower.

Wind speed and direction are measured by the Vaisala WXT520's ultrasonic sensor (WINDCAP®) that determines wind speed and direction from the transit time differences of ultrasonic pulses transmitted between multiple transducers. This information has been added to the revised text (Section 2.2). The Vaisala transmitter (including the wind sensor) is mounted at the top of the mast (see modified Fig.1 and Sec.2.2).

→ See revised text in Section 2.2 (Lines 67–78) and the updated Figure 1.

(v) Table 1: It is unclear if the observations are made at 16.1 m above sea level, or at 16.1 meter on the tower. Or is the base of the tower located at sea level?

The elevations in Table 1 are given in meters above sea level (a.s.l.). This includes the observation height on the mast (e.g., 16.1 m a.s.l. for the Vaisala WXT520). We have clarified the text and the table to avoid any confusion.

→ See Table 1 (page 4), Figure 2 caption (page 7), and updated clarifications at lines 70, 101, and 349–350.

(vi) Rain rate (RR [mm/h]): According to the text rain rate is based on minute observations (line 73 and 168). Explain how this is done. Is it the maximum minute value that is used or ..?
Rain24: Accumulated precipitation during 24 can within meteorological data either be 00-24 or morning to morning (06-06 UTC).
The rain rate (RR) is provided at 1-minute resolution by the RAINCAP® impact sensor. For each minute, RR represents the estimated rainfall in mm/h according to the manufacturer's algorithm; it is not the maximum instantaneous value but a minute-averaged estimate. Hourly (R1h) and 24-hour (R24h) accumulations are obtained by summing the incremental minute values over the corresponding periods. For R24h, we use the 06:00–06:00 local (morning-to-morning) convention. These clarifications have been added to the revised manuscript (see Sec. 2.2).
→ → See updated definition in Section 2.2, Lines 81–84.

(vii) The resolution of the sensors are missing in the table.
We thank the reviewer for this suggestion, which is very helpful. Sensor resolutions have now been added to Table 1 as requested.
→ We added a line in the Table 1 (p. 4) indicating the *Output resolution* of each parameter.

(viii) In which direction is the pyranometer mounted on the tower? If it is mounted on the tower it must be shaded by the tower part of the days.
We thank the reviewer for pointing this out. The pyranometer is installed on the ground at 12 m a.s.l., not on the tower, and is therefore not shaded. We have clarified both Figure 1 and the text to prevent any misunderstanding.
→ Fig.1 (p. 3) has been updated with a closer view of the instrument and we change "1.5m above the grass surface" by "12m above sea level" on line 101-102.

(ix) Line 79-80: How are clear and cloudy pixels defined?
Cloudy and clear-sky pixels were identified using the FindCloudsTrinity (FCT) algorithm applied to ASI-16 sky camera images (Schreder CMS, 2025a,b). The method is based on color ratio analysis, in particular the Blue/Red and Blue/Green (BRBG) ratios computed from the RGB channels, which allows discrimination between clouds, haze, and clear sky. Pixels are classified as cloudy or clear-sky using the BRBG-based cloud index, resulting in a binary cloud mask. Cloud cover is then calculated as the fraction of pixels classified as cloudy within each image. This approach has been widely used and validated in previous studies based on sky camera observations for cloud and irradiance analysis (e.g. Song et al., 2023; Nevins and Apell, 2021; Long et al., 2006; Sabburg and Long, 2004). This clarification and the corresponding references have been added to the revised manuscript.
→ See updated definitions and methodology in Section 2.2, Lines 90–96.

(x) Line 84: Here is the additional pyranometer placed. The height is given but not the location (on the mast or on a separate structure)? Line 102: It is unclear which pyranometer the text is referring to.
Line 235: Specify from from which sensor the data comes from (you write that there are two pyranometers).
We thank the reviewer for highlighting this ambiguity. Only one pyranometer is used in this study, and the text has been revised to avoid any confusion. Its location and height are now clearly indicated in Table 1 and Fig. 1.
→ See Table 1 (page 4), Figure 1 (page 3), and revised text at lines 100–102.

(xi) Line 136: I am curious about the very few days of fog in the RH data. Since OSO is located in a costal region I would expect to see at least some occurrence of foggy days. I agree that the drift in RH value is low for most of the time period, but from 2020 it is increasing by about 2% per year. Has the sensor been replaced or recalibrated during the time period?
Line 274: Could the shape of the cure be due to drifting in RHmax value?
We thank the reviewer for raising this important point. According to maintenance logs, no explicit sensor replacement or recalibration for the Vaisala WXT520 transmitter was performed during 2009–2025; therefore, an instrumental drift cannot be fully excluded. It is also worth noting that very few foggy days are observed at OSO overall, consistent with the reported relative humidity data. These points have been clarified and discussed in the revised manuscript (Section 5).
→ See updated discussion on sensor stability and local fog climatology in Section 5, Lines 302–307.

(xii) Figure 2: Is a) showing daily or hourly observations? It is not mentioned in the text. c) What pressure value is plotted? Observed value (at what height above sea level) or as sea level. This might be clearer if table 1 is updated.

Figure 2(a) shows temperature and humidity at 1-minute resolution, while panel (c) displays a 1-minute resolution time series of observed pressure at 16.1 m a.s.l., including monthly means (black dots). The figure caption and Table 1 have been clarified to make this explicit, and the text in Section 4 has also been updated.
→ See updated sensor specifications in Table 1 (page 4), Figure 2 (page 7), and lines 123–125.

(xiii) Line 170: Measurable precipitation needs to be defined. Common resolution of precipitation observations is about 0.1 mm. It thus sounds odd that the measurable precipitation needs to be at least 1 mm/day. Please clarify.
In this study, the term "measurable precipitation" is not used in the sense of the instrumental detection limit, but rather to denote days with an appreciable (non-negligible) amount of precipitation contributing meaningfully to the daily total. The threshold of R24h $\geq$ 1 mm was therefore chosen to identify days that can reasonably be considered as precipitation days at the daily scale, excluding very small amounts that may be detected by the instrument but do not represent a clearly wet day. This choice is consistent with the focus on daily precipitation occurrence and characteristics, rather than on the sensor resolution itself. The definition has been clarified accordingly in the revised manuscript.
→ See updated specifications and terminology in Section 4.4, Lines 189–194 (and footnote).

(xiv) Line 199: If the clouds promote vertical mixing, how can the conditions lead to stable temperature profiles? It more sounds like you have unstable or near neutral (windy) conditions.
Thank you for this comment. We have clarified the sentence: we meant that marine WSW winds enhance vertical mixing in the lower atmosphere, while prevailing anticyclonic ENE conditions maintain a thermal inversion aloft. The text has been revised for clarity.
→ See revised Section 4.5, Lines 223–225.

(xv) Figure 4: What is plotted in the figure? Hourly average wind speed values or daily values?
For Fig. 4, wind speed and wind direction measurements at 1-minute resolution are used to produce the wind roses and histograms. For the seasonal wind roses, the data are divided into four categories (seasons) based on the measurement date (see text for details).
→ See updated details in Fig. 4 caption and lines 217–219.

(xvi) You need to define your wind gust. Max value under what time period. Its also relevant to know the frequency of the measurement.
Wind gusts are defined as the maximum wind speed measured over the internal short averaging interval of 3 seconds, as reported by the WXT520 sensor, following the manufacturer's specifications. Wind speed and gust values are recorded at a temporal resolution of 1 minute. These definitions and the measurement frequency have been added to Section 2.2 of the revised manuscript.
→ Added details on wind gust definition at lines 74–78.

(xvii) Figure 5: What values are plotted? Daily average values, hourly average values or ..?
For Fig. 5, the upper panel shows solar irradiance measured by the pyranometer at 1-minute resolution. The lower panel shows 3D scatter plots combining solar irradiance with cloud cover estimated from the sky camera. For these 3D scatter plots, irradiance values corresponding to the exact dates and times of available sky camera observations are used (i.e., every 15 minutes).
This information has been clarified in the descriptive text and in the figure caption.
→ Text modified on lines 260–262 and Fig. 5 caption.

(xviii) Line 261: Is the "." supposed to show that the values a multiplied by each other?
Thank you for noticing this typographical error. We corrected it ($°C.yr^{-1} \to °C\,yr^{-1}$).
→ Corrected on line 296.

(xix) Line 289: It difficult to talk about trends when you at the same time show that they are not significant!
We agree that the original wording could be interpreted as suggesting trends despite the lack of statistical significance. We have therefore revised the text to adopt a more descriptive formulation and to avoid any implication of significant trends. The revised text now explicitly states that only small, non-significant variations are observed in the frequency of precipitation days.
→ The text has been rephrased (see lines 318–320).

(xx) Line 318: I suggest you specify the observation height. Common meteorological data are from 1,5 or 10 m. So important to

be clear about the heights here!

Thank you for this helpful suggestion. We have added a clear statement in the Instrumentation section and in Table 1 indicating the observation heights (16.1 m a.s.l. for the Vaisala WXT520 meteorological station, 12 m a.s.l. for the pyranometer, and 3 m a.s.l. for the sky camera), and we have reiterated these heights in the conclusion of the revised manuscript (Sec. 6).

The observation heights have been explicitly added to Table 1, Section 2.2 (*Instrumentation*), and relevant figure captions. We have also specified these heights on lines 349–350 in the revised manuscript.

REFEREE #2 (RC2)

The manuscript presents a dataset of potential interest to the journal, as the topic is aligned with the scope of Earth System Science Data, and the effort invested in data generation and collection is evident. If properly documented and clarified, the dataset could represent a valuable resource for future studies.

However, there are numerous flaws in the presentation of this important set of results that could prevent its effectiveness in future impact. Most of them are related to poor level of details relevant to the presented data. I suggest the Authors to re-read their paper and keep in mind whether, for each of the important set of information they are providing, they are detailing all the quantities that are necessary for the Readers to understand their data.

We thank the reviewer for their thorough and constructive assessment. We agree that, for a dataset to be a valuable resource and fully reproducible, a high level of detail and clarity in the documentation is essential. We have therefore carefully revised the manuscript with the reader and data user in mind, expanding the description of all observed variables, sensor placement and heights, measurement resolution, and variable definitions. Sections 2 and 4, as well as Table 1, were substantially revised to ensure that all quantities necessary to understand and reuse the data are now explicitly documented.

(i) A glaring example is already present in Section 2.2, where the sampling frequency for the instrmentation, such as the temperature, relative humidity, pressure, wind sensor, is not provided. Other definitions, such as the gust wind velocity, is not provided. How is that defined ?A similar example concerns the Rain Rate, how is that defined ?

We thank the reviewer for this point. Sampling frequencies and variable definitions have now been clarified in Section 2.2, Table 1, and the figure captions.

Pressure, temperature, relative humidity, and wind measurements are provided at 1-minute resolution (see Sec. 2.2 and Table 1).

Wind measurements from the Vaisala WXT520 are based on an ultrasonic sensor (WINDCAP®), with wind gust defined as the maximum wind speed observed over a 3-second internal averaging interval.

Rain rate (RR) is provided at 1-minute resolution by the RAINCAP® sensor and corresponds to the estimated mm/h for that minute.

→ The measurement resolution has been specified at multiple points throughout the text (e.g., lines 69, 76, 82, 123, 218, 280) and in the captions of Figures 2, 4, and 5. Additionally, a row has been added to Table 1 (p. 4) specifying the output resolution.

The definitions for gust wind velocity and rain rate have also been clarified on lines 77–78 and 81–84.

(ii) Fig. 1 may contain a better close-up of the tower, with the location of the sensors.

We replaced Figure 1 with a close-up view of the instrumented tower in the manuscript (see revised Fig.1).

→ Figure 1 on p. 3 has been replaced with a better close-up of the tower showing the location of the sensors.

(iii) Fig 2a, b, c: is the resolution of the data used for this subplots always the same ? It is not clear from the text.

Panel (a) shows temperature and humidity at 1-minute resolution; panel (b) presents monthly averages derived from these data; and panel (c) shows a 1-minute resolution time series of atmospheric pressure at 16.1 m a.s.l., including monthly means (black dots). The figure caption has been clarified to make this explicit, and the text in Section 4 has also been updated.

→ The data resolution for each panel has been explicitly stated in the updated caption of Figure 2 (p. 7) and on lines 123–125.

(iv) Fig. 4/5 and relevant description: it is not clear which type of data are plotted in the graphs.

For Fig. 4, wind speed and wind direction measurements at 1-minute resolution are used to produce the wind roses and histograms. For the seasonal wind roses, the data are divided into four categories (seasons) based on the measurement date (see text for details). For Fig. 5, the upper panel shows solar irradiance measured by the pyranometer at 1-minute resolution. The lower panel shows 3D scatter plots combining solar irradiance with cloud cover estimated from the sky camera. For these 3D scatter plots, irradiance values corresponding to the exact dates and times of available sky camera observations are used (i.e., every 15 minutes).

This information has been clarified in the descriptive text and/or in the figure captions.

→ The data types and temporal resolutions used for both figures have been clarified in the revised captions (p. 11 and p. 14) and the corresponding text. Please refer to lines 218–219 for Figure 4 and lines 260–263 for Figure 5.

Additional changes in the revised manuscript

In addition to the responses above, we have made the following minor corrections and clarifications to the text:

- Abstract: Line 7
- Introduction: Lines 15–16
- Data availability: Lines 111–115
- Conclusions: Lines 358–359

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