Response to comments from reviewer 1

Manuscript: A satellite-based analysis of semi-direct effects of biomass burning aerosols on fog and low cloud dissipation in the Namib Desert # EGUSPHERE-2024-1627

General comments

Fog is an important source of moisture in arid regions, and thus, the question of when and where fog is present is of high importance. This well-written paper investigates how biomass- burning aerosols (BBA) influence the (diurnal) dissipation time of fog/low cloud (FLC) events in Namib. Various satellite data and reanalysis data serve to analyze differences between high and low biomass burning conditions revealing significant differences also in respect to the meteorological conditions. Finally, a statistical model is built to predict the dissipation time from meteorological fields, showing the difficulty of disentangling aerosol and meteorological effects. The paper is certainly interesting for ACP and of high quality, however, I have several comments/ideas for further improvement.

First of all, we would like to thank the reviewer for the positive comments and for providing very helpful and constructive feedback. We thank the two reviewers in the acknowledgments of the updated version of the manuscript as follows "We are also grateful to the two anonymous reviewers for their careful and constructive feedback, which has helped improve the manuscript."
The comments and suggestions from reviewer 1 are incorporated in italics and addressed by the authors in blue.

The area of investigation is rather void of observations. Therefore, reanalysis highly depends on satellite data, which have problems in resolving the boundary layer, and the underlying NWP model. Because the 4D-Var data assimilation uses 12-hour windows (from 09 UTC to 21 UTC), jumps can occur at these times in parameters (such as water vapor) that are not constrained strongly by observations. This might influence the results in Fig. 6 as the largest changes exactly occur around the 9 UTC time. As an example, you can find the diurnal cycle of total column water vapor for Iquique, Chile, at the coast of the Atacama. Here the 21 UTC jump is most pronounced. I find the physical explanation for the behavior sound, but it would be good to check the consistency of your data and mention ERA5 limitations in the manuscript.

Figure 3 (in this document) shows the diurnal TCWV anomalies for the Namib desert so it is possible to compare it to the data over Iquique. The jumps related to the data assimilation schemes are present, with the 21 UTC jump being the most pronounced. But the jumps over the Namib have a smaller amplitude in comparison with Iquique. Figure 4 (in this document) presents the same plot for T2M anomalies. Although jumps are still present, they are more difficult to discern compared to TCWV. Larger discontinuities probably occur at higher hPa layers. However, in Figure 6 of the manuscript, the impact of the 9 UTC jump is certainly small compared to the effect of sunrise on air temperatures.
It's a good point a should be mentioned as an ERA5 limitation:
- Added in Section 2.3: "An additional limitation of the data is related to the assimilation scheme of ERA5, which uses 12-hour windows from 09 UTC to 21 UTC (Hersbach et al., 2020). In regions with sparse observations, such as the Namib Desert, the reanalysis heavily relies on satellite data and the underlying numerical weather model, which can result in discontinuities during these times."

I like the classification into low and high BBA conditions, which have, by definition of the percentiles, the same number of members. However, I am wondering whether one could be even more successful with an event-based approach, as I suspect that the BBA effect is most effective during selected episodes when filaments of moist and polluted air arrive in the target regions. Especially for the southern CN region satellite total column water vapor images sometimes hint at this. Therefore, it would be good to see the frequency distribution of CAMS BCAOD to illustrate how the 25 and 75 percentiles are derived and also how they differ for both regions.

For the classification into the low and high BBA conditions, before using a percentile approach we tried to define common AOD thresholds across the two regions. However as the distributions are quite different between the Angolan Namib (AN) and the Central Namib (CN), it was not possible to define reliable thresholds with approximately the same number of members in both groups and both regions. The event-based approach is a good idea but it will lead again to issues with the number of data points as we need a relatively high and similar number of data points between the different groups to have significant results.
- We added a figure in Appendix A (Figure 1 in this document) in Appendix A showing the distribution of CAMS BCAOD.
- Added in Section 2.2: "In the CN, the first quartile is characterized by a high density, followed by an almost exponential decrease into and throughout the third quartile. In contrast, the AN exhibits a more linear increase in density within the first quartile, followed by a gradual decline as BCAOD increases (see Appendix A). These differences are attributed to the distance from emission sources."

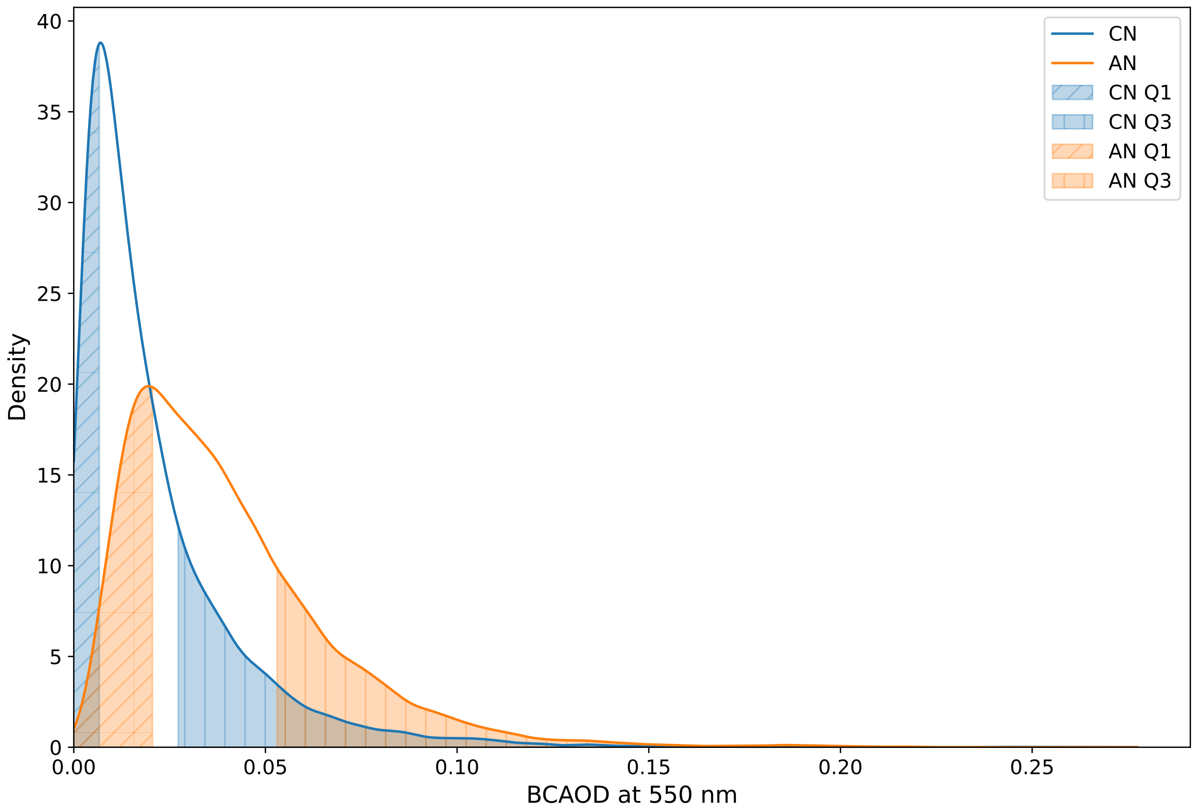

Figure 1: BBA season mean climatology (2004–2018) of the BCAOD probability density distribution in the AN and CN, along with their respective 1st and 3rd quartiles.

Coming back to my suspicion that the strong pollution mainly occurs as episodes. This counteracts the assumption of a linear model to predict FLC times. Why didn't the authors perform trajectory calculations (such as in Andersen et al. (2020) to check the meteorological similarity of the different BBA events?

Trajectory calculations were indeed the original plan for this study, but long-term issues with large-scale data storage at our institution made it impossible to work with back trajectories. As a result, we adapted our approach and opted for a statistical framework, which has been successfully applied in this region for different predictands. Additionally, using a linear model facilitates the interpretation and visualization of coefficient fields; however, it requires a linearity assumption that is rarely fully achieved in real life, as you pointed out. In the end, due to differing synoptic conditions during high and low BBA days, similar trajectories are sparse. Therefore, statistically modeling the dynamical contribution to fog dissipation may be a more appropriate method after all.

The target of the study is the dissipation time. Therefore, it would be good to provide more information on its variability, not only the aggregated statistics (boxplot) from Fig.3, especially as this variability is not well reproduced by the regression model (Fig.7). For these figures and all further analysis two geographical regions (AN, CN) are considered over which averages are provided. Even after looking at the study by Anderson and Cermak (2018) the motivation to put everything together in the two regions was not clear for me. Why not look at continuous development as a function of latitude and similarly as a function of distance from the coast (which the authors themselves mention to have a strong influence)? Maybe this information could be shown graphically to motivate the choice of the two regions. In this respect, it is also not clear to me how clear sky days are treated, e.g. coastal clearings.

Working with continuous development as a function of latitude and distance to the coastline is interesting but it entails training a ridge regression for each gridpoint of the dataset. It would exponentially increase the computational time and then there is the question of how to communicate the results. It would not be possible to show the coefficients maps we produced in this study for each cell of the dataset. In this approach some form of data aggregation would still be required. By selecting these two regions (AN and CN) we focus on the two regions with the most frequent FLC events, so with the most number of data points and with contrasting characteristics in terms of aerosols: AN is closer to the emission sources.
Any absence of FLC events such as clear sky days, coastal clearings, or FLC events too brief to derive dissipation time are discarded and are treated as missing data:
- Added in Section 2.1: "Additionally, any absence of FLC events, such as during clear sky days, is discarded and treated as missing data"
- Added more information about the disisaption time in Section 2.1: "The dissipation of FLC features a main phase that begins around 6 UTC and reaches a maximum at 8 UTC in both regions, followed by a decrease until a daily minimum is observed around 13 UTC; this decline begins slightly earlier in the CN region. A secondary phase of dissipation begins at 16 UTC in the AN and at 18 UTC in the CN, continuing throughout the night, though it involves a considerably smaller number of occurrences in both regions."

The last paragraph of the introduction contains the hypothesis states that BBA events modify the inversion and the early morning development of the planetary boundary layer. Partly, this is nicely shown in Fig. 6) but what about other parameters, such as boundary layer height or water vapor (as Q975 is so important in the ridge regression)? Vicencio et al. (2023, Fig. 10) showed that the Namib has an especially high variability in boundary layer height in austral summer. Therefore

Q975 might sometimes be in the BL and sometimes not.

In Fig. 10 of Vicencio et al., the authors used daily averages for the BLH values. In this study, all meteorological fields are taken at 08 UTC, which corresponds to the most frequent dissipation time. By focusing on this specific time, we avoid a significant source of variability observed in Vicencio et al. On a typical day, we can expect the Q975 to be within the boundary layer, as the boundary layer has already started developing by this time. While exceptions are possible, they are likely to be rare.

- We added a figure in Appendix B (Figure 2 in this document) showing the hourly development of the boundary layer height in the two region on high and low BBA groups.
- Added in Section 3.2: "Additionally, the morning development of the boundary layer height (see Appendix B) indicates that the planetary boundary layer (PBL) deepens slightly more until noon on low BBA days. In the CN, the PBL is marginally lower on high BBA days; however, the differences are minimal, as shown by the largely overlapping standard deviation areas."

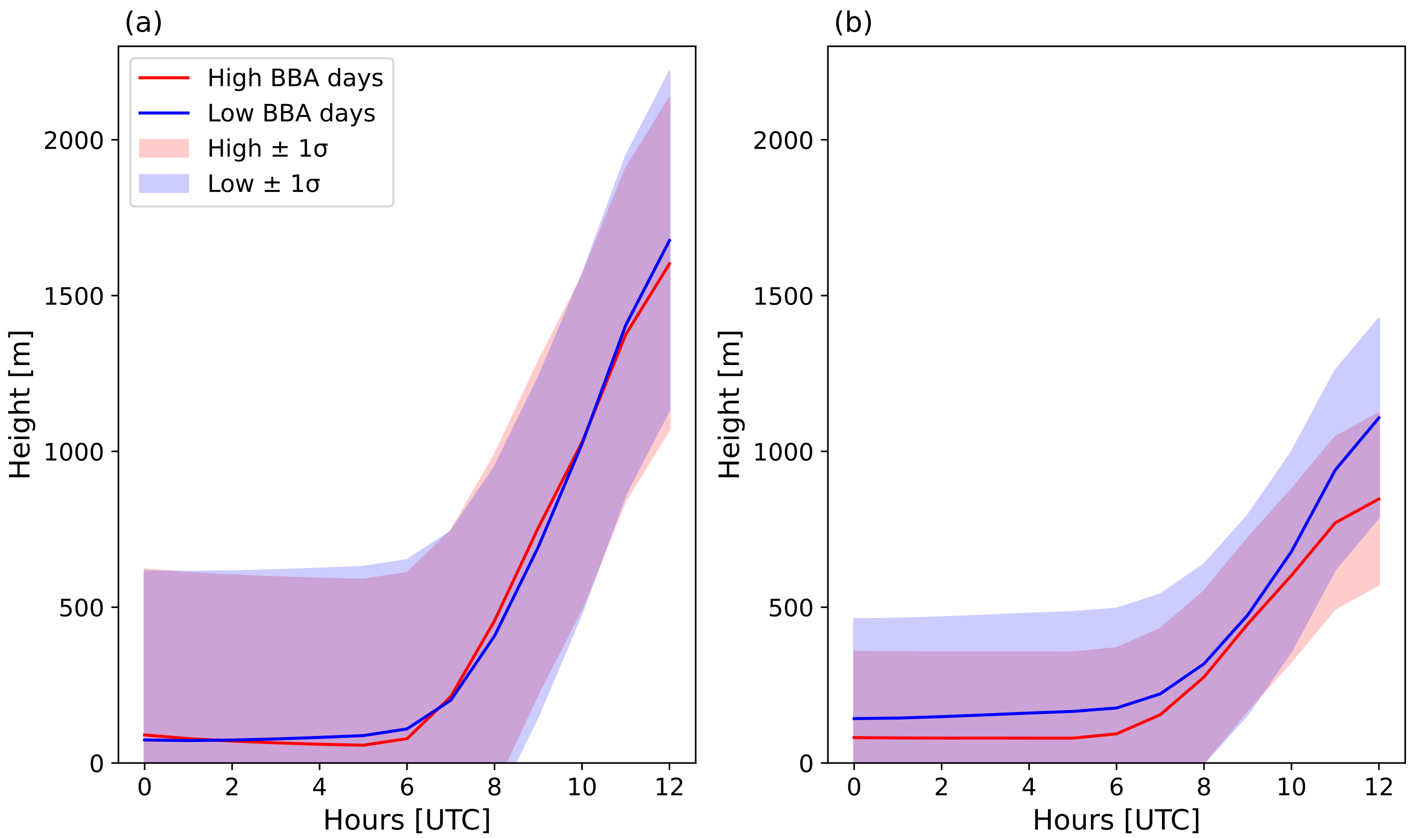

Figure 2: BBA season mean climatology (2004–2018) of the mean hourly boundary layer height in the AN **(a)** and the CN **(b)**.

Specific Comments

Abstract: Mention that you are looking at the time of day when the fog is dissolving. The reader could also think that dissipation time is the duration of a fog event.

Modified in the Abstract: "This is done by investigating both **the time of day when FLCs are dissolving** and synoptics depending on BBA loading."

Introduction: please briefly explain the diurnal coastal circulation

Added in the Introduction: "The diurnal coastal circulation in the region features sea breezes during the day as cooler ocean air moves inland and land breezes at night as cooler air flows from land to sea (Lindesay and Tyson, 1990)"

L25 better represent instead of resolve

Changed in the text.

L74 define semi-direct

Added in the introduction: "Semi-direct effects in this study refer to the "large-scale" semi-direct effects, as defined in Diamond et al. (2022), involving atmospheric thermodynamic and stability adjustments resulting from the absorption or scattering of solar radiation by aerosols."

L74-79: Here, it would be good to mention briefly how you want "to disentangle the BBA effects from other meteorological covariates."

Added : "... and used in a statistical learning framework to quantify **and disentangle** meteorological and BBA influences on FLC dissipation time."

L97: Does 97% mean the hit rate excluding false positives? Or the CSI?

The 97% is the Percent Correct so the correct predictions, both true positives and true negatives, to the total number of predictions made. The hit rate excluding false positives is 94% and the CSI is 83%.
- We added more information in Section 2.1: "Extensive validation against surface observations has shown a good performance (**probability of detection of 94%, a false-alarm rate of 12% and an overall correctness of classification of 97%.**)"

Section 2: I had difficulties to extract information on data amount and resolution.
Amount of data: June to October is roughly 150 days; with 15 years, this makes 2250 days. However, you have about 200 samples in one quartile, making the total sample about 800 days. What about the rest?

Resolution of SEVIRI: My assumption is that each area has a grid (about 6 pixels in longitudinal and many in latitudinal direction). For each gridpoint, you have (at most) one dissipation time per day. Is this correct? If yes, then it may help to delete the 15- minute resolution in line 109. It would also help to say in Fig. 3 how many data points are going into each bar. have: are available

Amount of data: You're are right but there are two steps where we drop NaN values. Because of the CAMS resolution, there are very few pixels per region (CN and AN). We chose a rather aggressive approach by discarding every day where at least one pixel is outside the defined quartiles to have a consistent number of CAMS pixels per region. This leads to approximately 300 days per quartile as written in Section 2.2. From these 300 days we discard again around 100 days with missing data in the FLS dataset (for example during clear sky days) and we end up with around 200 days per group in Fig.3 as written in Section 3.1.

- Added in Section 2.2 : "They are referred to as 'high BBA days' and 'low BBA days,' **each containing around 300 days after discarding those where at least one pixel of the region is outside the defined thresholds.**"
- Added in Section 3.1: "Then, the data is separated into two groups of high and low BBA loading with around 200 days in each group **after discarding days without FLC events, which had no data on FLC dissipation time.**
- Figure 3 modified to show the number of datapoints per bar.

Resolution of SEVIRI: Yes exactly we have a dissipation time per gridpoint. But because of the temporal SEVIRI resolution, there are "only" 96 possible different dissipation times: from 00:00 to 23:45 with a time step of 15 minutes.
- Modified in Section 2.1: The resulting dataset provides the daily UTC time of FLC dissipation for the period of 2004–2018, **with a 15-minute temporal step (allowing for 96 possible dissipation times from 00:00 to 23:45)** and a 3x3 km spatial resolution.

Fig.2 Why don't you show this separately for the high and low BBA situations? This would strongly help to better understand the differences between the AN and CN region.

It's a good idea, and we considered it, but the issue is that the current plot (Fig. 2 in the manuscript) already shows some artifacts due to the spatial sparsity of the CALIPSO observations. By selecting data only from the 200 high and low BBA days, the artifacts become more pronounced, which is why we chose to present these plots. However, despite this issue, the data still reveal interesting information that should be mentioned in the paper:
- Added in Section 3.1: "In both regions, the aerosol plumes are located higher during high BBA days, around 550 hPa, whereas on low BBA days, they are situated around 750 hPa. This pattern is likely due, for the most part, to the large-scale atmospheric processes responsible for the transport of the aerosol plumes into these regions."

L117: Please motivate why early morning. – this only comes later in L128. At this time the reader does not know that early morning is the most frequent dissipation time

Added in Section 2.2: "Half-day averages from 00:00 to 12:00 UTC are used to capture BBA that may influence the morning dissipation of FLCs**, which is the most frequent dissipation time (Andersen and Cermak, 2018).**"

L139: Please explicitly say in contrast to all other data another time range is used due to…-

Added in Section 2.4: "In contrast to all other data in this study, 13 June 2006 is the earliest available date because CALIPSO was launched in April 2006."

L170: Is the area large enough to encompass the important transport aspects? To make it easier for the reader, It would be good to mark the two regions in Fig. 4

A tradoff is necessary when defining the spatial extent for the predictor fields: the area must be large enough to capture relevant information while remaining small enough to minimize noise and reduce the risk of overfitting. The areas defined in this study were selected after several iterations to find the best possible compromise. While they may seem small for fully encompassing all aspects potentially affecting aerosol transport, we argue that this information is indirectly represented in the contribution maps (Fig. 9) due to the separation into high and low BBA days.
We are concerned that marking the spatial extent used for the ridge regression in Fig. 4 may cause confusion, as we are not discussing or utilizing ridge regression at this point in the results section.

L163: What is actually the resolution of your predictand. Is it the average FLC in one region per day or do you do it for each satellite pixel? I assume the average as you compare it in Fig.7 with the observed medium dissipation time? Still, this could have effects on the variability of FLC, which is poorly predicted.

Yes, your assumption is correct; the resolution is the median FLC dissipation in one region per day. While this could have some effects on the predicted variability, these effects are likely relatively small compared to the other reasons cited in the manuscript. Because, as you mentioned, we compare it to the observed median dissipation times shown in Figure 3 of the manuscript, which, although averaged, exhibit a significantly larger spread than the predicted times, as illustrated in Figure 7.
- Added in Section 2.5: "However, the rescaling of the predictand is unnecessary because a spatial **median** of dissipation times is calculated **for each region** at each time step.

L164: It might be lengthy, but it is good to have the list of variables of the "spatial fields of ERA5 meteorology" used as predictors. Is subsidence included?

- Added in Section 2.5: "The predictors are the spatial fields of MSLP, Z650, T2M, SST, Q650, Q975 and EIS (as defined in Section 2.3) from ERA5 and BCAOD from CAMS"
While subsidence is not included in our analysis, we first utilized boundary layer height (BLH), which is related to the subsidence. However, the coefficient fields were quite noisy, making it difficult to extract useful information. Although subsidence might yield better results than BLH, we do not expect significant differences in the model's performance by including it.

L198: Mention the definition of variability, IQR?

Added in Section 3.1: "While the variability of dissipation times, **measured by the interquartile range**, does not change with BBA in the AN"

L206: Motivate 650hPa. It is done later but before wrote that the transport is highest in 650 hPa

- Moved: "the typical altitude of the BBA plumes" from line 212 to the beginning of Section 3.2
In Section 3.1 when describing Figure 1, we now provide a range of pressure layers where the BBA plumes are located. However, 650 hPa is the midpoint, where BBA plumes are most likely to be found.

L247: grid cell is better than pixel here

Changed in the text.

L183. Z and Q are not defined.
L231: T2M not defined

All the ERA5 acronyms are defined in the Section 2.3. But we also chose to not use the acronyms in the captions of the figures so a reader could understand the parameters of the figures without needing the next.

L275: A correlation coefficient of 0.58 (explained variance 0.34) is not too bad. Did you try to identify the cases when especially poor predictions were made, e.g. by colouring scatter diagrams etc?

It's a good question. Examining the extreme values reveals a relatively big spread. For AN the worst model has a R^2 of 0.22, while the best model has a R^2 of 0.41 (and a similar spread for CN). This can largely be attributed to the choice of using a random split for the training and test groups. In some cases, models may encounter days with vastly different synoptic situations in each group, causing them to fail to generalize and resulting in low R^2 values. Conversely, random splits can also lead to temporal autocorrelation when neighbouring days appear in both the training and test groups, which may affect the robustness of the model. By creating an ensemble mean of 50 different models, we effectively average out these issues. For comparison, we ran a single model using time series cross-validation, thus avoiding temporal autocorrelation, and found similar R^2 values for both regions, with nearly identical patterns in the coefficient fields.

L323:"These contributions are due to a negative SST anomaly close to the coastline which may be explained by the greenhouse warming in the free troposphere". Not clear to me..

Modified to "These contributions are the product of a negative coefficient field and a negative SST anomaly near the coastline (not shown), which could partly be explained by reduced incoming solar radiation due to absorption in the free troposphere. However, since the ocean surface responds only slowly, other factors, such as the changed circulation possibly contributes as well.

Conclusions: Wouldn't radiative sensitivity studies also be helpful in disentangling water vapor and BBA contributions?

That's a good idea yes, but it would probably be more oriented towards direct aerosol effects rather than semi-direct.
- Added in the conclusion: "Additionally, radiative sensitivity studies such as Obregón et al. (2018), could also be useful in

disentangling aerosol direct effects from meteorological covariates."

Technical corrections

L 160: Greek letter for lambda.

Changed in the text.

I find that the readability of the text is degrading when figure caption information (that is not important for following the text) is repeated in the test. My recommendation would be to remove -statements such as in L210 (Additionally, in the Q975 fields (Fig. 5c and d) the subsurface regions at this pressure level are masked). Or statements such as like "are shown in the third panel.", "dashed lines"

The highlighted sentences were deleted, as well as similar ones throughout the manuscript.

L330. Blank missing

Fixed in the text.

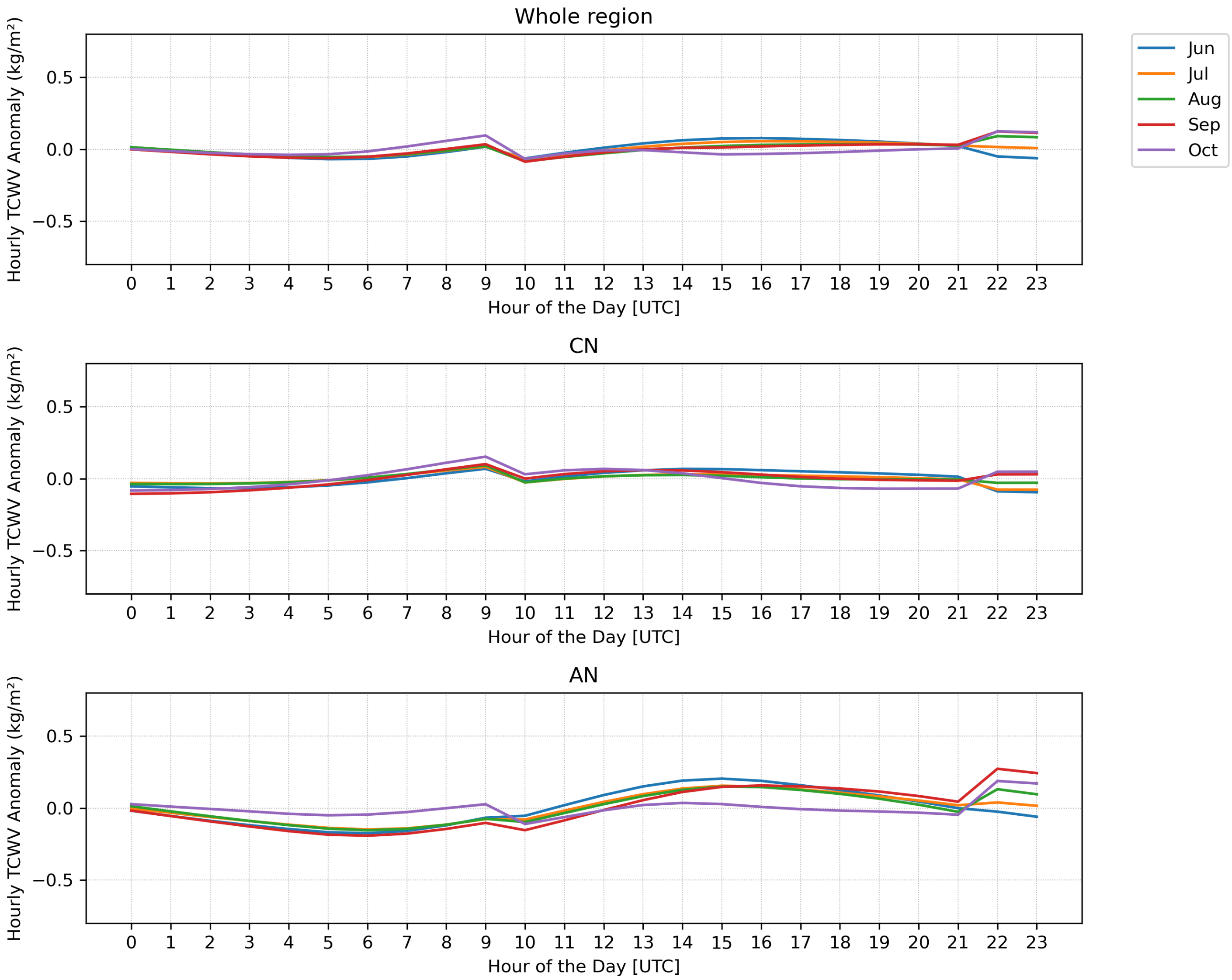

Figure 3: ERA5 TCWV anomaly (hourly average minus daily mean) from 2004-2018 in the Namib desert.

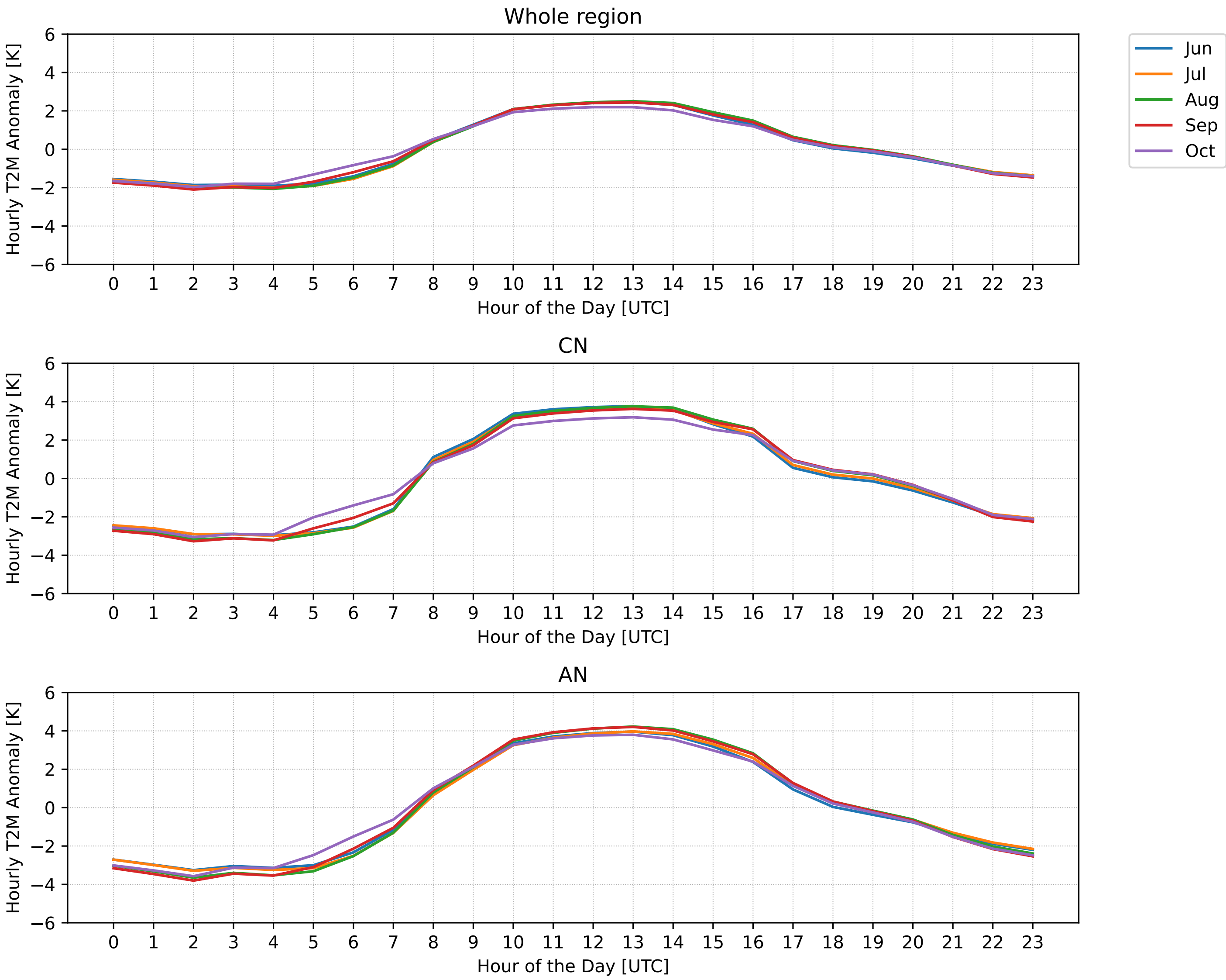

Figure 4: ERA5 T2M anomaly (hourly average minus daily mean) from 2004-2018 in the Namib desert.