Referee #2:

Summary:

Lang et al. present an expansion of their earlier study, Lang et al. 2022, where they used a convolutional neural network to identify open and closed mesoscale cellular convective clouds in the Southern Ocean. This study adds clouds in an additional region, the North Pacific, that have been identified with their algorithm (applied to the geostationary Himawari satellite and using brightness temperature, which enables identifications over the full diurnal cycle). Maps of cloud occurrence frequency are contrasted with maps of stability metrics in the two regions annually and seasonally. Visual relationships to regional environmental factors (e.g., Kuroshio current, oceanic polar front, storm track) are documented. The diurnal cycle is also presented for these regions annually and seasonally. Differences in behavior in the North Pacific are qualitatively documented and contrasted with the previously published Southern Ocean behaviors.

General comments:

The premise of this study is exciting, and the data developed as part of this and Lang et al. 2022 is quite valuable. It is especially noteworthy and novel to examine the diurnal cycles of MCC cloud types in these two hemispheres. The figures developed in this analysis are very well done, clear and compelling. However, the analysis is limited to qualitatively documenting the behaviors in these regions along with their visual correspondence to stability metrics and sea surface temperature. This provides some insights about regional differences but without quantitative analysis the conclusions are limited, similar to those presented in previous studies, and ultimately not as substantive as they have the potential to be. However, I think the authors can develop this analysis into a valuable contribution to the field and fully realize the potential of this work.

1. My main recommendation is to add quantitative comparisons to bolster the qualitative comparisons and help with interpreting/establishing the differences between the NP and SO regions. “Correlations” are currently discussed but they are based on visual comparisons and not calculated/provided. Actual correlations, between occurrence frequency and meteorological variables, could be calculated at many scales (e.g., within spatial map grid boxes, for annual and seasonal relationships, for composite differences, for diurnal cycles, etc.). By quantifying the relationships that you suggest here, you would greatly strengthen your results and better support your conclusions.

R: We appreciate the valuable feedback and agree with the suggestion. In response, we have conducted a thorough analysis in the revised manuscript, including the calculation of correlation maps (new Figure 4). These correlation maps ensure consistency in evaluating the relationship between both categories of MCC and the meteorological indices *M* and EIS. Furthermore, we have expanded our investigation to encompass correlation maps for near-surface wind speed and sea surface temperature (SST). These quantitative analyses provide insights into the associations between monthly MCC cloud frequency and monthly averages of *M* index, EIS, SST, and near-surface wind speed in both study regions. The correlations were computed using the monthly mean MCC cloud frequencies in each grid box and exhibit statistical significance at a 95% confidence level for a 36-point correlation. We have incorporated this quantitative analysis throughout the results and discussion sections, as suggested by the referee. By including these correlation maps, we have gained a deeper understanding of the relationships between the meteorological variables and both open and closed MCC cloud types, thereby enriching our knowledge of their spatial patterns and behavior. The inclusion of these additional analyses enhances the robustness and significance of our findings, and we sincerely thank the referee for contributing to the improvement of our research.

2. The diurnal cycle analysis in this and Lang et al. 2022 is novel and has a lot of potential. However, these results are currently limited to qualitatively documenting the differences between type, season, and region. There is an opportunity here to add more depth to the analysis by quantifying the connections to the

meteorological environment (as you do qualitatively in the first part of the paper). This would lead to a deeper understanding of what is contributing to these diurnal cycle differences through understanding how these cloud types are responding to their environmental diurnal cycles. Being able to interpret why you see differences between regions, seasons, etc. in the MCC diurnal development cycle would be a very valuable contribution to the field.

R: We greatly value this comment and concur with the potential of a study focused on the influences of the meteorological environment on the diurnal cycle of MCC clouds. This would help in understanding what drives the diurnal cycle for each type of MCC and the differences between each region. As mentioned in the manuscript, our first step would be to expand the number of categories to disorganized MCC clouds and no MCC clouds. This would allow us to consider the entirety of low-level clouds as defined in Wood and Hartmann (2006). Once this is achieved, we believe that a detailed analysis of the diurnal cycle for all categories, considering the meteorological factors used in this study, would provide valuable insights into this diurnal cycle analysis.

For instance, we aspire to conduct a study similar to the one by Vial et al. (2021), which provided a detailed analysis of the influence of meteorological variables on the diurnal cycle of mesoscale clouds over the North Atlantic. However, we believe that an essential first step towards this goal is to enhance and refine our Convolutional Neural Network (CNN) by incorporating additional categories of mesoscale cloud organization.

To enhance our analysis of the diurnal cycle, we have proposed several explanations for the distinct diurnal cycles observed in the two regions. However, it is crucial to understand that these factors are intricately interconnected and complex. Therefore, a more comprehensive and detailed investigation is necessary to accurately determinate their specific influences.

Specific Comments:

Throughout: Please only discuss correlations or variables being “correlated” when you have computed a correlation coefficient and statistically tested whether they are correlated (e.g., p-value ≤ 0.01 for 90% confidence). Visually similar maps and cycle plots are not correlations.

R: We thank you for this comment. We fully agree, and as a result, we have included correlation maps for EIS, *M* index, SST, and near-surface wind speed in the revised manuscript. Additionally, we have incorporated a detailed discussion of the correlations between these variables and both the open and closed MCC categories. This addition provides a comprehensive analysis of the relationships between the meteorological parameters and both cloud types, enhancing the overall findings and understanding presented in the study.

Line 35: I would suggest removing “are most common in” since sub-tropical decks also have a lot of MCC. Agreed that these MCC types dominate the storm tracks (also see Agee et al. 1973, McCoy et al. 2023 for climatology).

R: Thank you for this suggestion. We have removed the phrase “are most common in” in the revised manuscript. We have also included the references of Agee et al. (1973) and McCoy et al. (2023) in the paragraph. These references provide additional context and support to show that MCC types dominate the storm tracks.

Line 37: Fletcher et al. 2016 is for clouds in general, not MCC. Atkinson and Zhang 1997 and Wood 2012 review this MCC-CAO relationship in detail and McCoy et al. 2017 quantified it more recently.

R: We thank you for this comment. We agree that Fletcher et al. (2016) did not study MCC clouds, and it was included as a reference to marine cold air outbreaks. As suggested, we have modified the references, removing Fletcher et al. (2016), and instead added Atkinson & Zhang (1996) and McCoy et al. (2017), which are more appropriate for the context of the sentences.

Section 2.2: I see the rational of only identifying open and closed MCC and throwing everything else into a catch all since it gives you a high quality MCC dataset. However, I do think it would be valuable to at least subdivide the “other” into low, middle, and high clouds and clear sky so that you have an idea of what is happening with the other low clouds (besides the MCC types) in these regions. From the small MCC absolute frequencies that you are working with, there is clearly a lot of the low-cloud behavior that you are missing throughout your analysis and analyzing that could give you valuable context for whether the MCC behaviors are unique and whether their differences are statistically significant from the base behavior.

R: Thank you for your valuable comment. We recognize the significance of analyzing low-level clouds within the category "Other". As previously mentioned in Lang et al. (2020), we are aware of the limitation in our study for not including other low-level cloud types, such as disorganized MCC and no MCC clouds. To address this limitation and improve our CNN, we plan to incorporate more training samples from both regions to include these additional categories. This approach aims to improve the accuracy and robustness of our CNN model, enabling a more comprehensive analysis of marine atmospheric boundary layer clouds.

Nonetheless, we have addressed this limitation by extending our analysis to include the low-level clouds within the category "Others" and comparing them with the open and closed MCC categories using the Himawari-8 cloud products. The Japan Aerospace Exploration Agency (JAXA) provides Himawari-8 cloud products, such as cloud-top height and cloud optical thickness; however, these data are not available during nighttime. Therefore, to define the low-level clouds in the category "Others", we applied a filter that considers only the diurnal cloud product, identifying clouds below 3.5 km and selecting daytime open and closed MCC. The results of this analysis are presented in Section 3.4, where we examine and compare the characteristics of these low-level clouds with open and closed MCC. This additional analysis allows for a more comprehensive understanding of the cloud patterns in the category "Others" and their relationship with open and closed MCC.

Section 2.3: It might be beneficial to expand beyond stability metrics (EIS and M) and SST. Clouds in this region respond to a variety of factors in opposing ways (e.g., Scott et al. 2020) and MCC are thought to be sensitive to more than just stability and SST in their development (e.g., Eastman et al. 2021, 2022). Temperature advection might be especially useful as it would more accurately characterize the surface forcing contribution in these regions. Expanding your meteorological variable space has the potential to quantify novel relationships between MCC (this is a strong dataset for doing this) and the characteristics of these regional environments and could help to better distinguish your analysis from previous work on MCC behavior in these regions (e.g., Muhlbauer et al. 2014, McCoy et al. 2017, Lang et al. 2022).

R: We acknowledge that other variables may have the potential to show a relationship with open and closed MCC morphologies. In our analysis, we have included near-surface wind speed and calculated correlation maps to explore its influence. The decision to include wind speed was influenced by Lang et al. (2022), who speculated on its relationship with the distribution of MCC clouds. Additionally, a recent study by Eastman et al. (2023) established a connection between near-surface wind speed and cloud morphological transitions. While not directly related to temperature advection, wind speed and temperature advection are closely linked in the atmosphere. Temperature advection involves the horizontal movement of air with different temperatures, driven by variations in atmospheric pressure and wind patterns. Wind speed plays a crucial role in determining the rate of air transport, which in turn affects the strength and extent of temperature advection.

Line 134, 158 and Figure 2: Since you use the oceanic polar front as a reference for discussing cloud behavior, it would be useful to have the corresponding annual/seasonal climatological location of the oceanic polar front plotted on these maps. Otherwise, consider citing literature to support these statements and your conclusions.

R: This is a great suggestion. In Section 2.3, we have included pertinent references regarding the location of the oceanic polar front, which has been linked to strong meridional SST gradients, as discussed in Truong et al. (2020) and Dong et al. (2006).

Line 164: It would be very valuable to spatially correlate these figures, as you imply here, and show the results (e.g., as a map of correlation coefficients with significance indicated). As mentioned above, please do not refer to something as "correlated" unless you are providing a correlation coefficient.

R: Thank you for your valuable comment. As we previously stated, we have incorporated correlation maps (new Figure 4) into the revised manuscript to maintain coherence with the discussion of correlations between MCC clouds and the meteorological indices and variables. This inclusion enables to quantitatively evaluate the relationships between various variables and MCC cloud types, facilitating a more comprehensive analysis of their spatial patterns and behavior. We deeply appreciate your input, which has significantly improved the clarity and robustness of our research.

Figure 4 and 5: It might be clearer to see how the regions differ by looking at a difference plot between the NP and SO cases (since you have the data composited to the same space already). You could also consider looking at how the "other-low cloud" category behaves in this space and how it differs from open and closed MCC (e.g., how anomalous the MCC types are from all low clouds).

R: This is a great suggestion. In response, we have included a figure in Section 3.4 of the revised manuscript to compare both regions and the low-level clouds of the category "Other" with open and closed MCC types during daytime. This additional analysis provides valuable insights into the characteristics and behavior of the low-level clouds within the category "Other", enhancing our understanding of their relationships with open and closed MCC. We are thankful for this comment, as it has improved the comprehensiveness of our research.

Line 175: How is the relationship "better"? Please quantify these statements with correlations or other statistics.

R: Thank you for your comment. We agree that a quantitative analysis is necessary to support statements with correlations or other statistics. We have included correlation coefficient maps and conducted analyses based on these correlations to strengthen the validity of our findings. This addition enhances the rigor and reliability of our research.

Line 188-189: Like with the oceanic polar front, it would be helpful to include a corresponding annual/seasonal climatological storm track to show the relationship with the storm track you suggest here. You could also correlate the location with the occurrence frequency and quantify this. Otherwise, please reference literature supporting this statement about the storm track shift and your conclusions.

R: We thank you for this comment. We agree that understanding the location of the storm tracks is vital to ascertain the peak occurrence of open MCC clouds during summertime. Consequently, we have referenced Shaw et al. (2016), which establishes the location of the storm tracks and explains the reasons for their positioning during summer in both hemispheres.

Figure 6: Worth noting somewhere in the text what Figure 6 is showing and adding to the story (it is only mentioned in passing, not explained).

R: Thanks for noticing this. We have rewritten Section 3.2 to complement the analysis with the seasonal two-dimensional histograms of *M* versus EIS for open and closed MCC categories that are shown in Figure 6, new Figure 7 of the revised manuscript.

Line 192-193: It would help for these types of comparisons if they were quantified. How do you know this is "more relevant", hard to know that from visually comparing the plots. Consider checking the regressions of frequency on these variables (e.g., in a multiple linear regression that accounts for correlations between predictor variables) and looking at spatial correlation maps.

R: Thank you for your comment. We have taken your suggestion into account and added seasonal correlation maps for *M* index and EIS as Supplementary Material in the revised manuscript (Figure S2). With the inclusion of these seasonal correlation maps, we can now quantitatively assess the seasonal relationships between both meteorological indices and MCC cloud types, resulting in a more comprehensive analysis of their spatial patterns and behavior.

Line 194 (and throughout): You can say it "corresponds" instead of "correlated", but it would be much better to calculate the coefficients and quantify this (see above comments).

R: We have revised this sentence to reflect the incorporation of new seasonal correlation maps for *M* index and EIS, which can be found in Figure S2 of the revised manuscript. With these additions, we can now quantitatively assess the correlations between MCC clouds and the EIS during the summer season.

Line 199-200: Why does the cooler SST explain the higher open MCC frequency? Please explain and support statement.

R: Thank you for bringing this to our attention. We have revised the sentence in the manuscript to clarify the association between winter SSTs and open MCC clouds.

Line 200-201: What do you mean here? Please explain and support statement.

R: Thanks for noticing this. In the revised manuscript, we have clarified that during wintertime, closed MCCs are more frequently observed at lower latitudes compared to higher latitudes.

Line 206, 215-216, 217: These are very exciting results. Would you be able to extend your meteorological factor analysis to this diurnal cycle analysis as well (something like Vial et al. 2021)? This could really help you to begin interpreting what factors might be driving these cycles (and why they are different between regions).

R: We agree that a comprehensive analysis of the daily cycle, similar to the one by Vial et al. (2021), would be insightful. The question of what drives the diurnal variability in the frequency of MCC cloud occurrences is indeed intriguing. Specifically, understanding the impact of large-scale environmental conditions on the diurnal cycle of MCC clouds is an interesting direction to explore. However, our current methodology does not readily support such an analysis. A crucial step towards this would be enhancing and refining our CNN by integrating additional categories of mesoscale cloud organization. While we recognize the significance of examining the influence of meteorological variables on the diurnal cycle of mesoscale clouds using Himawari-8, such an investigation necessitates a separate study and falls beyond the scope of the current one.

Line 232-233: Also MODIS (Muhlbauer et al. 2014, McCoy et al. 2017, McCoy et al. 2023).

R: Suggested revision made.

Line 249-251, 263-264, abstract: It seems that you are referring to M as if it is surface forcing or an air-sea temperature difference and contrasting it against static stability as measured by EIS. This is confusing since M is also a stability estimate (essentially a modified form of LTS). This is also inconsistent with your earlier discussions. M can be written as a function of EIS and the air-sea temperature difference (McCoy et al. 2017), is that what you are referencing? Please clarify your meaning and be more accurate in your language.

R: We appreciate your keen observation. In response, we have revised the abstract and pertinent sections of the manuscript to clarify that the *M* index is an effective tool for identifying instances of marine cold air outbreaks. It achieves this by integrating considerations of both surface forcing and lower tropospheric stability.

Line 269: Please explain how you come to this conclusion. Hard to tell from comparing Figure 2 and 5, is this based on a different analysis?

R: Thank you for bringing this to our attention. Based on the seasonal correlation maps between closed MCCs and the EIS, we have rephrased the sentence in the revised manuscript to provide further clarification and support for our discussion on the seasonal differences between open and closed MCCs and their association with the EIS.

Line 272-276: Great to include the discussion on lines 272-274 of why you have these diurnal cycle differences. It would be very valuable to extend this further to the intriguing regional differences you document (i.e. to add interpretation to Lines 274-276).

R: We appreciate your comment. We have provided several interpretations for the observed differences in diurnal cycles between the two regions. However, it is important to note that these elements are interconnected and complex, and a deeper, more detailed investigation is needed to accurately discern their specific influences.

Line 277: How are you quantifying "good performance" here? You previously tested and trained on the SO data (and that is presented well in Lang et al. 2022), are you able to similarly check the accuracy for the NP? Or is this from visual inspection?

R: Thank you for your valuable comment. As highlighted in the first paragraph of Section 3 (Results), the training data for the model was exclusively obtained from the SO. However, following an exhaustive visual inspection of the cloud cover over the NP region, we were able to confirm that the algorithm consistently produced robust and reliable results across both hemispheres. However, we recognize that the phrase "good performance" can be ambiguous and potentially lead to confusion. Therefore, to ensure clarity, we have decided to remove this sentence from the revised manuscript.

Line 280-281: Extending this diurnal analysis, either here or in a future paper, would be fantastic. Your results raise so many interesting questions: why are closed MCC NP cycles smaller than SO? Why are they especially small in the summertime? Why are the closed MCC cycles peaking in magnitude in different seasons in the two regions? Why are open MCC cycles much smaller and peaking at different times? What is happening with the remaining contribution of clouds (your "other" type)? You could make a good start at answering these by quantifying the cycle relationships to the meteorological variables you discussed in the first part of the paper.

R: We deeply appreciate your feedback, particularly concerning the expansion of our diurnal cycle study. We are keen to explore the factors influencing the diurnal variability of MCC cloud occurrences and the contrasts between the NP and SO regions. Alongside the referee's insights, we share an interest in understanding the roles of other low-level clouds, including disorganized MCC and no MCC clouds. As we have highlighted, our next step involves enhancing our CNN to encompass a broader range of mesoscale cloud categories. This enhancement will lay the groundwork for a thorough analysis of all mesoscale cloud dynamics and a more in-depth study of the diurnal cycle.

Technical Corrections:

Line 158: “but is relatively”

Line 167: “Figure 4”

Line 185: “considerably”

Line 246: “current in the Kuroshio region”

Line 248: “MCCs than in the SO”

R: All the technical corrections have been made.

References:

Agee, E. and Dowell, K.: Observational studies of mesoscale cellular convection, Journal of Applied Meteorology and Climatology, 13, 295 46–53, doi:10.1175/1520-0450(1974)013<0046:OSOMCC>2.0.CO;2, 1974.

Atkinson, B. W. and Zhang, J. W.: Mesoscale shallow convection in the atmosphere, Reviews of Geophysics, 34, 403–431, doi:10.1029/96RG02623, 1996.

Dong, S., Sprintall, J., and Gille, S. T.: Location of the Antarctic polar front from AMSR-E satellite sea surface temperature measurements, Journal of Physical Oceanography, 36, 2075–2089, doi:10.1175/JPO2973.1, 2006.

Eastman, R., McCoy, I. L., & Wood, R.: Wind, rain, and the closed to open cell transition in subtropical marine stratocumulus. Journal of Geophysical Research: Atmospheres, 127, e2022JD036795. doi:10.1029/2022JD036795, 2022

Fletcher, J., Mason, S., and Jakob, C.: The climatology, meteorology, and boundary layer structure of marine cold air outbreaks in both hemispheres, Journal of Climate, 29, 1999–2014, doi:10.1175/JCLI-D-15-0268.1, 2016a.

Lang, F., Ackermann, L., Huang, Y., Truong, S. C., Siems, S. T., and Manton, M. J.: A climatology of open and closed mesoscale cellular convection over the Southern Ocean derived from Himawari-8 observations, Atmospheric Chemistry and Physics, 22, 2135–2152, doi:10.5194/acp-22-2135-2022, 2022.

McCoy, I. L., Wood, R., and Fletcher, J. K.: Identifying Meteorological Controls on Open and Closed Mesoscale Cellular Convection Associated with Marine Cold Air Outbreaks, Journal of Geophysical Research: Atmospheres, 122, 11,678–11,702, doi:10.1002/2017JD027031, 2017.

McCoy, I. L., McCoy, D. T., Wood, R., Zuidema, P., & Bender, F. A.-M.: The role of mesoscale cloud morphology in the shortwave cloud feedback. Geophysical Research Letters, 50, e2022GL101042. doi:10.1029/2022GL101042, 2023

Shaw, T., Baldwin, M., Barnes, E. et al. Storm track processes and the opposing influences of climate change. Nature Geosci 9, 656–664 (2016). doi:10.1038/ngeo2783

Truong, S., Huang, Y., Lang, F., Messmer, M., Simmonds, I., Siems, S., and Manton, M.: A climatology of the marine atmospheric boundary layer over the Southern Ocean from four field campaigns during 2016–2018, Journal of Geophysical Research: Atmospheres, 125, e2020JD033 214, doi:10.1029/2020JD033214, 2020.

Vial, J., Vogel, R., & Schulz, H.: On the daily cycle of mesoscale cloud organization in the winter trades. Quarterly Journal of the Royal Meteorological Society, 147(738), 2850-2873, doi:10.1002/qj.4103, 2021.

Wood, R. and Hartmann, D. L.: Spatial variability of liquid water path in marine low cloud: The importance of mesoscale cellular convection, Journal of Climate, 19, 1748–1764, doi:10.1175/JCLI3702.1, 2006.