

Manuscript evaluation of “Identifying Synoptic Controls on Boundary Layer Thermodynamic and Cloud Properties in a Regional Forecast Model”

General comments

This paper investigates how marine boundary layer clouds respond to synoptic conditions, particularly in the cold sector of a cyclone, and evaluates how a numerical weather prediction model compares to observational data. This is an important and timely research topic, given the ongoing challenges in accurately representing these clouds in models and their critical role in Earth’s radiative budget. The study’s use of a novel approach—transforming coordinates into a frontal perspective (following Naud et al. 2016)—is a valuable contribution, particularly for the modeling community, as it allows for improved comparisons between simulations and observations.

However, the manuscript has some weaknesses that should be addressed:

- **Clarity and Contextualization:** The introduction lacks clarity in some areas and should define the goals of the paper or contextualize it within existing research more clearly (see SC1 and SC2). The overarching goal of the study is not explicitly stated early on, making it harder to follow the intended contribution. Additionally, the authors should add a stronger connection to previous work, explicitly stating what knowledge gap this study addresses.
- **Interpretation of Figures & Takeaways:** Some figures contain interpretations that are incomplete or potentially incorrect (SC3). Additionally, discussions of figures often lack clear takeaway points (SC5), making it difficult for the reader to track key findings throughout the manuscript. This also affects the conclusion, as it becomes harder to recall where certain results were discussed.
- **PBL Depth Discrepancy:** There is an inconsistency when reporting differences in planetary boundary layer (PBL) depth using two different methods (SC4), and the implications of this discrepancy for commonly used approaches in the field are not discussed.
- **Framing and Significance of Findings:** One aspect not covered in the specific comments is that the authors may be underselling the importance of their results. For example, the discrepancy between open-cellular convection observed in satellite imagery and closed-cellular convection in the model is potentially significant, given its implications for cloud albedo, climate feedbacks, and solar radiation management. The authors should consider whether these aspects deserve more discussion, either through an expanded interpretation of the findings or by referencing relevant literature.

Specific comments

SC1) Adding clarity in the Introduction

The second paragraph of the introduction (lines 24–36) is difficult to follow and would benefit from revision to improve clarity. For instance, the sentence “*this tends to decouple the boundary layer, where mixing between the cloud and surface layers is inhibited*” (line 30) is ambiguous. It raises two questions:

1. What exactly does the boundary layer decouple from?
2. Does the sentence imply that mixing is inhibited because the boundary layer is decoupled, or is the decoupling a result of inhibited mixing?

I suggest rewriting this paragraph to provide clearer explanations of the mechanisms involved and how they interact.

SC2) Make clear the goal of the paper and better contextualize it within current research (Introduction)

The introduction explains the mechanisms relevant to marine low-level clouds and the transitions between different regimes, which are essential points for the reader to understand. However, two critical elements are missing:

1. **The goal of the paper:** It is unclear what the overarching goal of the paper is (is it a proof of concept, are we looking for behaviour that has not yet been analyzed?). For instance, the last paragraph in the introduction alludes to an investigation of multiple “systems” (plural) but as far as I understand it, only a single case study is investigated. The authors should clearly state the aim of the paper upfront to provide readers with a cohesive understanding of the study's purpose and structure. Also consider adding a short sentence regarding these points in the abstract.
2. **Contextualization within current research:** The introduction does not adequately explain what is novel about this study or how it addresses a specific gap in knowledge. For instance:
 - What gap in knowledge is being addressed exactly?
 - What is the primary motivation for evaluating the regional numerical weather prediction model in this context?
 - Are midlatitude baroclinic synoptic systems especially important or poorly understood? This last point should be addressed in the paragraph in line 38 to 56.

SC3) Incorrect/incomplete interpretation of figures

I have the following issues with the analysis of results presented in Figures 5 and 7:

1. Line 285: COAMPS only underestimates the temperature profile throughout the lowest 3 km of the atmosphere from 11:30 on 24.01 to 11:30 on 25.01, not for the time frame stated by the authors.
 2. The line immediately following: COAMPS only overestimates PBL moisture for the first two subplots of Fig. 5 (24.01 05:30 to 24.01 11:30) and not as stated by the authors.
 3. Directly thereafter: to my eyes, the Thompson param. and Kessler param. show similar skill in predicting the decoupling (Fig7c). Please add some sort of metric to support the statement that one is better than the other in this regard.
 4. Line 307: not all COAMPS microphysics sensitivity experiments overestimate stability, because unless I have understood something, there are three data points below the 1:1 line in Fig 7 a).
 5. Line 315: “The Kessler parameterization [...] only [overestimates] decoupling for **one** sounding” → how are you defining an over/underestimation? Because there is definitely **more** than one Kessler data point above the 1:1 line in Fig. 7c).
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SC4) Richardson number vs. best estimate approach

In line 130 the authors state that the best estimate approach results in PBL depths that are **800m** larger than those derived from the Richardson number approach. In line 219 the authors put this number at **400m**. Please revise (or in case this is not a mistake, make clear why the difference is 800m and then 400m).

Please also discuss the implications this discrepancy has for methods commonly used in the field.

SC5) Emphasize main findings

In the paragraph between lines 398 and 409, as well as the following paragraph discussing Figures 11 and 12a, the authors provide a brief summary of what is shown in the figures. However, the key takeaways are only stated briefly.

Clarity would improve if the authors more clearly emphasize the main findings—e.g., by explicitly stating, *'As discussed in Section X, this shows that the model is incapable/capable of [etc.]'* or similar phrasing—to guide the reader and reinforce the significance of the results.

For instance, in Line 415–416 ('*Subsidence dominates [the entire cold sector]*'), could you briefly remind the reader whether this behavior aligns with expectations? The first paragraph in page 14 is a positive example and does a good job at this.

While most of these takeaways should, of course, be reserved for the conclusion, these modifications would still improve readability. These modifications would also help the reader recall where specific findings were discussed when reaching the conclusion.

SC6) Use color deficient friendly color palettes and (perceptually uniform) colormaps

Figures 12b, 13, 14 and 15 use red and green colors on the same plot. This combination is not color-deficient friendly, please a different color palette (see e.g <https://www.nceas.ucsb.edu/sites/default/files/2022-06/Colorblind%20Safe%20Color%20Schemes.pdf> for a sensible choice of colors)

Figure 9 uses a rainbow colormap, which is neither color-deficient friendly nor perceptually uniform. Please change the colormap (viridis, plasma, batlow, etc.).

Technical corrections

- Please add relevant citations in line(s) 18, 20-22, 25.
- Line 309: make sure you are referencing the correct figure. Also in the rest of the paragraph.
- Figure 10: the labels “a) b), ... i)” are missing
- Use either “Fig. X” or “Figure X”