Authors' response to reviewers' comments

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Assessing the skill of high-impact weather forecasts in southern South America: a study on Cut-off Lows

The authors sincerely thank both reviewers for their detailed and constructive feedback, which significantly improved the manuscript. We have carefully considered all the comments and made substantial revisions to address the issues raised. These revisions have strengthened the analysis, particularly in relation to the predictability of Cut-Off Lows (COLs) and their impacts on Southern America during austral autumn. We believe the revised manuscript is now significantly clearer and more impactful.

In this document, the responses to the reviewers' comments are highlighted in red font, and the resulting corrected text is highlighted in green

Reviewer 1

Summary and recommendation

Cut-off lows (COLs) are important circulation systems that can often bring extreme precipitation. Using the Global Ensemble Forecasting System, the authors systematically assess the prediction skill of cut-off lows over Southern America during austral autumn. The showed that the COLs can be successfully predicted 3 days ahead. The model ensemble mean tends to underestimate the intensity and has track bias to the west. This provides a comprehensive assessment of the COL skills by current ensemble forecast systems. The results are clearly stated and I suggest minor revisions.

Minor comments

1. **Minor comment 1:** I think the current manuscript is missing a discussion of the physical processes responsible for the COLs in Southern America. This is important because this may help readers to understand why the models tend to underestimate the COLs and have track bias. For example, does the bias result from the weak eddy-mean flow interaction in the evolution of COLs (e.g., Pinheiro et al., 2022; Nie et al, 2022, 2023)?

   References to minor comment 1:

   - Nie, Yu, Jie Wu, Jinqing Zuo, Hong-Li Ren, Adam Scaife, Nick Dunstone, and Steven Hardiman, 2023: Subseasonal Prediction of Early-summer Northeast Asian Cut-off Lows by BCC-CSM2-HR and GloSea5. *Adv. Atmos. Sci.* 40, 2127-2134.

https://doi.org/10.1007/s00376-022-2197-9

- Nie, Yu, Yang Zhang, Jinqing Zuo, Mengling Wang, Jie Wu and Ying Liu, 2022: Dynamical processes controlling the evolution of early-summer cut-off lows in Northeast Asia. *Clim. Dyn*., 60, 1103-1119.

- Pinheiro, H., T. Ambrizzi, K. Hodges, M. Gan, K. Andrade, and J. Garcia, 2022: Are cut-off lows simulated better in CMIP6 compared to CMIP5? Climate Dyn., 59, 2117−2136, https://doi.org/10.1007/s00382-022-06200-9.

Response to minor comment 1: We thank the reviewer for pointing out this gap in our research. We agree that discussing the physical processes responsible for the COLs in South America is crucial for better understanding the origin of biases observed in the GEFS model. While our focus was on the forecast performance of COLs, we acknowledge that this discussion could help clarify the reason behind the intensity underestimation and the bias in position.

To address this, we have expanded the discussion section to incorporating insights from the literature, including the interaction between transient waves and the mean flow. Specifically, recent studies (Pinheiro et al., 2022; Nie et al., 2022, 2023) point to the weak representation of eddy-mean flow interactions as a key factor leading to forecast biases in COLs. These findings align with earlier work in Southern South America, which identified critical precursors for COL development. For instance, Godoy (2012) emphasizes the role of the jet stream's positioning and intensity, increased wave activity over the South Pacific, and the persistence of mid-latitude stationary wave patterns in shaping COL formation and evolution. These patterns are essential for understanding the forecast errors observed in GEFS predictions. While our current study focused on forecast performance, delving deeper into the simulation of jet streams and wave activity would enhance our understanding of these model biases.

Thus, to address the reviewer's comment, we have expanded the Discussion and Conclusion section to include the following:

"In summary, the GEFS model performs well in predicting the onset of COLs up to three days in advance, but forecast skill diminishes with increasing lead time, with a notable westward bias and underestimation of intensity. This bias likely arises from the model's inadequate representation of eddy-mean flow interactions, as explored by Nie et al. (2022, 2023) and Pinheiro et al. (2022). Furthermore, in our study region, the positioning of the jet stream and

the enhancement of transient wave activity over the South Pacific, identified in previous work (Godoy, 2012), are key to understanding these biases. While a detailed investigation of the physical mechanisms underlying these forecast errors was beyond the scope of this study, we recognize that future work exploring the simulation of jet streams and Rossby wave activity could provide crucial insights. Preliminary research has already shown that specific Rossby wave patterns preceding COLs can be predicted up to a week in advance, although with reduced confidence beyond that period (Choquehuanca et al., 2023)."

We believe that this expanded discussion addresses the reviewer's concern and enhances the manuscript by providing a more comprehensive understanding of the physical processes that influence COL predictability in Southern America.

References of the response to minor comment 1:

- Choquehuanca, B., Godoy, A., & Saurral, R. 2023: Evaluating cut-off lows forecast from the NCEP Global Ensemble Forecasting System (GEFS) in southern South America. Session 27: Hazards and Extreme events in The WCRP Open Science Conference (Kigali, Rwanda)

- Godoy, A. A.: Procesos dinámicos asociados a las bajas segregadas en el sur de Sudamérica. Ph.D. thesis. Universidad de Buenos Aires. Facultad de Ciencias Exactas y Naturales, Argentina. https://hdl.handle.net/20.500.12110/tesis_n5602_Godoy , 2012.

2. **Minor comment 2:** Since the COLs often arise from the internal atmospheric variability similar to blocking high, I am curious about whether the ensemble spread of model is comparable to the variability of observed COLs.

   Response to minor comment 2: We thank the reviewer for this comment. However, in our approach we did not make use of ensemble members from GEFS, and focused our analysis on the ensemble mean. Therefore, we are not able to quantify the ensemble spread and to compare it against the observed variability of COLs.

   Still, it is worth noting that we found a significantly large correspondence between observed and forecast COL events in our dataset, which is indicative of the high skill of the GEFS model to predict these systems over southern South America.

3. **Minor comment 3:** In the abstract (Lines 22-23), the author stated that the depth and intensity of cold core can affect the thermodynamic instability pattern, precipitation and

horizontal temperature advection. I suggest the authors either add more related evidence to support these statements in the manuscript or adjust the statements in the abstract since the current manuscript is missing a detailed corresponding discussion.

Response to minor comment 3: Thank you for this comment. In the revised version, we have included additional references to provide more evidence supporting the influence of cold-core on thermodynamic instability, precipitation patterns and horizontal temperature advection. The discussion and the abstract in the manuscript have been revised and adjusted to reflect these changes.

The Discussion section is now expanded as follows:

"It is well documented that the cold-core of COLs modulates the atmospheric instability response (Pinheiro et al., 2021; Hirota et al., 2016; Nieto et al., 2007; Porcu et al., 2007; Llasat et al., 2007; Palmen and Newton 1969). The dynamical ascent and atmospheric instabilities associated with the cold-core trigger and/or enhance precipitation events (Godoy et al., 2011; Nieto et al. 2007). "

The abstract section is now rewritten as follows:

"Cut-off Lows (COL) are mid-tropospheric cyclonic systems that frequently form over southern South America, where they can cause high-impact precipitation events. However, their prediction remains a challenging task, even in state-of-the-art numerical weather prediction systems. In this study, we assess the skill of the Global Ensemble Forecasting System (GEFS) in predicting COL formation and evolution over the South American region where the highest frequency and intensity of such events is observed. The target season is austral autumn (March to May), in which the frequency of these events maximizes. Results show that GEFS is skillful in predicting the onset of COLs up to 3 days ahead, even though forecasts initialized up to 7 days ahead may provide hints of COL formation. We also find that as the lead time increases, GEFS is affected by a systematic bias in which the forecast tracks lay to the west of their observed positions and intensity. Analysis of two case studies provide useful information on the mechanisms explaining the documented errors. These are mainly related to inaccuracies in forecasting the vertical structure of the two case studies, including their cold core and associated low-level circulation. These inaccuracies potentially affect thermodynamic instability patterns (thus shaping precipitation downstream) as well as the horizontal thermal advection which can act to reinforce or weaken the COLs. These results are expected to provide not only further insight into the physical processes at play in these

forecasts, but also useful tools to be used in operational forecasting of these high-impact weather events over southern South America."

References of the response to minor comment 3:

- Godoy, A. A., Campetella M. C., Possia N. E.: Un caso de baja segregación en el sur de Sudamérica: Descripción del ciclo de vida y su relación con la precipitación. Revista Brasileira de Meteorologia. v.26, n.3, 491 - 502. doi: https://doi.org/10.1590/S0102-77862011000300014, 2011

- Hirota, N., Takayabu, Y. N., Kato, M., & Arakane, S. (2016). Roles of an atmospheric river and a cutoff low in the extreme precipitation event in Hiroshima on 19 August 2014. Monthly Weather Review, 144(3), 1145–1160. https://doi.org/10.1175/MWR-D-15-0299.1

- Llasat, M. C., Martín, F., & Barrera, A. (2007). From the concept of "Kaltlufttropfen" (cold air pool) to the cut-off low. The case of September 1971 in Spain as an example of their role in heavy rainfalls. Meteorology and Atmospheric Physics, 96, 43–60. https://doi.org/10.1007/s00703-006-0220-9

- Nieto, R., Gimeno, L., Añel, J., De la Torre, L., Gallego, D., Barriopedro, D., & Ribera, P. (2007). Analysis of the precipitation and cloudiness associated with COLs occurrence in the Iberian Peninsula. Meteorology and Atmospheric Physics, 96, 103–119. https://doi.org/10.1007/s00703-006-0223-6

- Palmén, E., & Newton, C. W. (1969). Atmospheric circulation systems: Their structure and physical interpretation. Academic Press.

- Pinheiro, H., Gan, M., & Hodges, K. (2021). Structure and evolution of intense austral cut-off lows. Quarterly Journal of the Royal Meteorological Society, 413. https://doi.org/10.1002/qj.3900

- Porcù, F., Carrassi, A., & Medaglia, C. (2007). A study on cut-off low vertical structure and precipitation in the Mediterranean region. Meteorology and Atmospheric Physics, 96, 121–140. https://doi.org/10.1007/s00703-006-0224-5