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Evaluation of Sophie Abramian's PhD thesis

The Ph.D. thesis provides a very good introduction to convection and convective systems, discussing the key role of aggregation of the different feedback that can lead to convective aggregation. Then the PhD student discusses squall lines and the interaction between wind shear and the environment, pointing to historical (1945) observations and the first theoretical model of squall lines (Rotunno et al., 1988). Then some presentation of the optimal wind speed (and shear) in cloud-resolving models is demonstrated.
The introduction then explains the key relationship between organized systems and extreme rainfall, by first defining extreme precipitations and then presenting mesoscale convective systems, and their role in extreme precipitation and the role of organization onto mesoscale convective systems. Extremes of precipitation are then shown to be related to the number of centroids in a domain and not just to the total precipitation area, emphasizing the role of organization in modulating extremes of precipitation. There is a bit of a detour on the role of machine learning to analyze data. This sub-section could be better integrated with the recent introduction, maybe by stating that the datasets coming from DYAMOND and large cloud-resolving models can be very bulky and difficult to analyze. Finally, Sophie presents the role of dynamics on extremes, beyond Clausius-Clapeyron Scaling. I feel that this could be a subsection in its own right as it is very critical for the rest of the PhD thesis.
Overall, this is a good introduction that has the right appropriate details and cites the appropriate historical and recent literature. It would have been nice to have a bit more context initially, with a first section discussing the broader climate system and hydrological cycle and why convection is important.

In the second chapter, which has been published in the literature, Abramian and colleagues investigate using cloud-resolving models, the orientation of squall lines with respect to wind speed to highlight the variations of the angle of the formed squall lines with respect to the wind. They manage to highlight and validate the theory of Rotunno and the key role of cold pools on the definition of a critical wind threshold. They found very good agreement between the theory of Rotunno et al 1988, Robe and Emanuel 2001 and the numerical results. They further try to highlight the role of cold pool intensification on the squall line orientation and how this can lead to a correction term on the orientation. The analysis is sound and very clear, leading to a clear understanding of the role of cold pools in a correction of the RKW theory. I very much enjoyed the paper and since it has already been seen by multiple reviewers I don't feel that there is a need to add much to it or correct anything. I just found a few typos and missing references in the attached document.

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The third chapter of the thesis is dedicated to the study of the growth of MCSs and how it relates to their life cycle. The paper is in preparation. The main focus is to relate the first hours of the evolution of the convective system to its maximum area (which is linked to precipitation). The authors found that there is a strong predictive relationship between the initial stage to the final area. The authors start from a theoretical growth equation inspired by Elsaesser et al. 2022. As large MCS have a strong impact on precipitation intensity and extremes, the authors make the hypothesis that early growth could be an excellent mechanism to predict the maximum area of the MCS. To do so the authors used global cloud-resolving model simulations (DYAMOND) to highlight this process. The first challenge they managed to solve is to track the storms as they travel during the analysis time. To do so they use the TOOCAN algorithm, which employs a Lagrangian tracking algorithm. They focus on the tropical MCS with 30 degrees of latitude. They then use machine learning models (regression tree – random forest, neural networks and in comparison to LASSO) to predict the maximum size. This is a good strategy when physical understanding can be challenging. The authors could have given more details on the hyperparameters and training of those algorithms. They find very high predictive score (R2) using only the first few hours of the system. The three models have similar performance showing that the process is quasi-linear. They could demonstrate that adding more input features to the initial growth improves but does not dramatically impact the prediction, thus building confidence in the capacity of the initial stage (within 1.5 hours) to be a good predictor of the rest of the day. Overall, I found this paper to be well-written. Some additional clarifications on the details of the machine learning fits should be provided as much as possible. I spotted a few small issues in terms of Figure reference in particular.

In the second part of the thesis, Sophie Abramian tries to use to evaluate the implications of her findings on extreme precipitation. In Chapter 4, she focuses on the impact of shear on extreme precipitation in squall lines. This paper was published in JAMES in 2023. The authors focus on the role of shear on extreme rainfall rates and try to dive into the physical mechanisms explaining the findings. They used idealized simulations from cloud-resolving models with various background wind levels. They then compare the intensity of precipitation to the model of Muller and Takayabu 2020, also used by Singh and O'Gorman 2014 to investigate rainfall extremes and the role of dynamics vs thermodynamics. This decomposition indicates that in all simulations, the dominant contribution to changes in extreme precipitation is the dynamic contribution. They then went further by decomposing the dynamics in terms of the role vertical updraft speed and how it relates to changes in cloud base velocity and CAPE and demonstrating the dominant roles of the cloud-base velocity. They note though that this effect saturates in the super-optimal wind background regime, explaining the rainfall peak at critical wind speed.

The last paper was led by Camille Risi and it is a bit more difficult for this reviewer to assess the exact contribution of the Ph.D. student. In addition, the paper has already been published so I abstained from judging it again here.

The conclusion is well-written and provides some interesting ideas for future work including the role of synoptic versus population of cold pools on mesoscale convective systems.

Overall this is an excellent thesis focusing on the understanding of mesoscale convective systems and squall lines in particular, using a combination of modern tools (high-resolution simulations and machine learning) in combination with theory to gain a deep understanding of the physical processes at play. If the thesis is eligible for an award, I would recommend it to such an award given the quality of the science, the clarity of the explanation and the new understanding gained by this thesis.

Sincerely yours,
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