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COMMENTARY
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Key Points:

- Janssens et al. (2025, https://doi.org/10.1029/2024gl112288) find cumulus clustering has a small net radiative effect due to symmetrical offsets
- Cumulus sensitivity to change in environmental conditions is similar regardless of organization
- Further evaluations of the symmetry hypothesis and the other organizational climate impacts are needed

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Does It Matter to the Climate If Trade Cumulus Clouds Cluster?

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Abstract Low, marine clouds cool the Earth system, reflecting sunlight back to space. Low cloud response to environmental change is a key uncertainty in future climate projections. It is especially uncertain how much warming amplification will occur due to tropical cumulus feedback. A potentially important feedback modulator is the ability for cumulus to cluster through mesoscale circulations. Janssens et al. (2025, https://doi.org/10.1029/2024gl112288) demonstrate that moisture convergence in ascending circulation branches organizes clouds into fewer and brighter structures while moisture divergence dries descending branches, reducing cloud and increasing longwave cooling. These offsetting effects result in a small net radiative effect due to organization. Janssens et al. (2025, https://doi.org/10.1029/2024gl112288)'s results imply that the influence of organization on cumulus feedback is insignificant. The proposed offsetting of radiative effects across mesoscale organization patterns, or "symmetry," is worthy of continued research. Observational support and further investigations into whether cumulus organization has other climate impacts is encouraged.

Plain Language Summary Clouds forming low in the atmosphere cool the climate system through reflecting sunlight back to space. Low cloud responses to change in their environment are uncertain. How much low cloud amount reduces in response to a sea surface temperature increase will result in a commensurate increase in the amount of sunlight entering the Earth system. This feedback is especially uncertain for small, plume-like cumulus clouds in the tropics, a region experiencing the most sunlight. Potentially, this feedback may be modulated through clustering of cumulus under mesoscale (on the order of 100 km) circulations. These circulations converge moisture in their ascending branches, organizing clouds into fewer but larger and brighter structures. Simultaneously, atmospheric drying due to the circulations increases the amount of energy radiated back to space, cooling the atmosphere. Janssens et al. (2025, https://doi.org/10.1029/2024gl112288) find that these effects offset each other, resulting in a small net radiative cooling effect due to cumulus organization. Cumulus response to environmental conditions is similar regardless of clustering, indicating organization does not modulate cumulus feedback. These results present an important potential mechanism to help understand cumulus behavior and their radiative influence. Further mechanism evaluation and investigations into whether organization influences other climate system components is encouraged.

1. Introduction

Low clouds are a key component of the Earth system, efficiently reflecting sunlight back to space and helping to cool the climate (Hartmann & Short, 1980). Their response to change in the environment driven by increases in well mixed greenhouse gases is one of the key sources of uncertainty in projecting future climate behavior (Sherwood et al., 2020; Zelinka et al., 2020). Future increases in sea surface temperatures are expected to reduce low, marine clouds, a positive feedback on the climate that reinforces warming. The magnitude of this feedback varies across low cloud regimes and is still uncertain, particularly in the small, plume-like cumulus clouds occurring over the tropical oceans (Cesana & Del Genio, 2021; Myers et al., 2021, 2023). Sunlight impinges on the Earth system preferentially in the tropics before being energetically redistributed across the globe, ensuring that even a small change in tropical cloud amount has the potential to reverberate throughout the climate. Global climate models that parameterize cloud behavior currently project a much stronger trade cumulus feedback than is supported by observational constraints (e.g., Myers et al., 2021; Scott et al., 2020) or by high resolution, small domain simulations that capture turbulent cloud development (e.g., large eddy simulations, LES, Blossey et al., 2013; Bretherton et al., 2013).

The stark disagreement in cumulus feedback projections has re-energized (e.g., Bony et al., 2017; Jansson et al., 2023; Stevens et al., 2021) efforts to understand trade cumulus behavior (Myers et al., 2023). An idea that has recently gained traction is the potential importance of mesoscale organization in controlling cumulus behavior and their response to environmental change. Mesoscale circulations on the scale of ∼200 km (George et al., 2023) act to organize shallow convection, converging moisture into their ascending, cloudy branches and diverging moisture away from their descending, clear-sky branches (Bretherton & Blossey, 2017; Janssens et al., 2023, 2024; Narenpitak et al., 2021). In the trade-wind cumulus regime, mesoscale organization influences the reflectance of low clouds primarily through modulating their coverage (Bony et al., 2020) but, through moisture convergence, the depth and brightness of clouds is also enhanced (Alinaghi et al., 2024; Denby, 2023; Eastman et al., 2024). Environmental conditions control the organization states of cumulus (Aemisegger et al., 2021; Bony et al., 2020; Schulz et al., 2021). Change in environmental conditions may lead to a global shift in the frequency of occurrence of the different organization states, potentially leading to a mesoscale feedback associated with the accompanying shifts in radiative properties (McCoy et al., 2023). Shifts in organization tendency in response to the environment have already been seen in the tropics since 1971 (Eastman et al., 2025). However, strong coupling between cloud behavior and mesoscale vertical velocity (George et al., 2021) suggests that cumulus is relatively resilient to environmental change (Vogel et al., 2022) despite their organization (Radtke et al., 2021; Vogel et al., 2016). Future increases in greenhouse gases may further hinder the effectiveness of mesoscale circulations themselves (Kazil et al., 2024).

2. Janssens et al. (2025)'s Novel Conceptual Framework

It is into this conceptual landscape that Janssens et al. (2025) (hereafter J25) entered with the goal of determining whether mesoscale organization modifies cumulus feedback. The design of their study further seeks to investigate why observational and small domain LES studies agree in their projections of a weakly positive cumulus feedback despite capturing different underlying cloud behavior. Notably, while observations of cumulus feedback inherently contain the influence of mesoscale organization in the underlying data, LES analyses on historically-feasible, small domains do not permit such organization (e.g., Blossey et al., 2013; Bretherton et al., 2013). Larger LES domains facilitate self organization through a mesoscale circulation-convection feedback (e.g., Bretherton & Blossey, 2017; Narenpitak et al., 2021), a concept that Janssens et al. (2024) explored in greater depth. Several case studies bridging this analysis scale gap by using large, organization permitting LES domains also found weakly positive trade cumulus feedback (Radtke et al., 2021; Vogel et al., 2016).

For their investigation, J25 used two sets of idealized tropical trade cumulus LES ensembles developed from Jansson et al. (2023). The first ensemble used a small domain (10 km, run for J25) representative of historical LES studies that have projected a small cumulus feedback without mesoscale organization. The second ensemble used a large domain (150 km, Jansson et al., 2023) that is more akin to real world observations in that they allow mesoscale organization to develop. Each ensemble iterated through ∼100 combinations of initial conditions based on an observationally constrained range of environmental variables (Jansson et al., 2023). In total, 77/103 of the 3-day simulations produced cloud. While the simulations are idealized, utilizing an ensemble of LES realizations drawn from present-day initial conditions is a particular strength of this study, improving the statistical significance of their conclusions.

Comparisons between the small and mesoscale domain ensembles reveal a surprising aspect of how mesoscale organization modulates radiation in the trades. J25 focus on the top of atmosphere (TOA) radiative budget, which quantifies how much incoming solar energy escapes back to space as shortwave (SW, through reflection) and longwave (LW, through absorption and re-emission by the atmosphere). Figure 1 diagrams how the organization of an example cumulus field under mesoscale circulations (a) modifies the outgoing SW and LW. In this example, circulations and organization strengthen with time (right to left in a; c to b) as the cloud field is advected across the Atlantic (a).

Increasing moisture convergence in the ascending circulation branches (right of diagrams, c vs. b) organizes clouds into fewer but brighter cloud structures that are deeper, wider, and have increased liquid. This results in increased outgoing SW per cloud but a reduction in outgoing SW due to loss of clouds. Deeper clouds also precipitate more, eventually removing moisture from the cloud layer and increasing the amount of LW radiation released. Simultaneously, as circulations strengthen, more moisture is exported from the descending branch (left of diagrams, c vs. b). This dries the atmosphere and reduces cloud amount, increasing outgoing LW and reducing

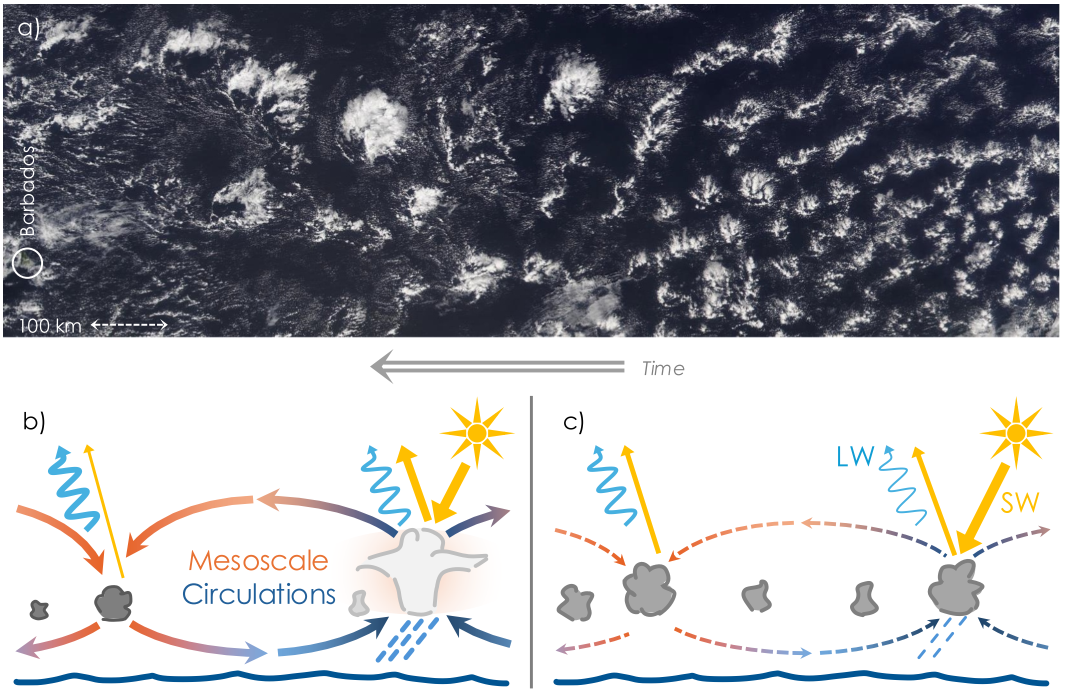

Figure 1. (a) Example image from the NOAA-20/VIIRS satellite on 11 February 2020 showing trade cumulus clouds undergoing mesoscale organization as they advect across the Atlantic toward Barbados. Cloud organization increases as mesoscale circulations strengthen over time (c to b, matching the evolution shown in a). Arrows mark shortwave (SW, yellow), longwave (LW, blue), and mesoscale circulation (blue in the ascending branches, orange in the descending branches) behaviors following Janssens et al. (2025).

outgoing SW. Increased condensation and precipitation in the deeper clouds in the ascending branch also warms the domain-averaged cloud layer. This warming is horizontally communicated through the weak temperature gradient, reinforcing the circulations (Janssens et al., 2024). This may reduce inversion strength leading to further reductions in cloud amount through loss of cloud anvils (e.g., Figure 2f of J25).

The offsetting effects of cloud loss and cloud deepening result in a net SW warming effect while increased atmospheric drying and warming enhances LW radiative cooling. Thus, while organization modifies the TOA radiative budget, the opposing effects largely balance, resulting in a small net radiative cooling (-0.5 W m^{-2}). J25 introduce a new conceptual framework to explain this mesoscale cloud-circulation coupling behavior. Their symmetry hypothesis proposes that the small net radiative effect of organization is a result of the ascending and descending branches of mesoscale circulations being nearly symmetric in their opposing effects on cloud amount and SW cloud radiative effect.

J25 further examine the sensitivity of the leading radiative terms (LW clear-sky cooling and SW cloud radiative effect) to environmental conditions in the small versus mesoscale domains. Their results are telling: the sensitivity to environmental conditions is similar between the small and mesoscale domains. In fact, the radiative sensitivity to variability in large-scale environmental change is far larger than the differences between small and mesoscale domain ensembles. This indicates that mesoscale organization has a very small modulating effect on how cloud systems respond to environmental change. The small contribution of mesoscale organization to the cumulus feedback resolves the apparent discrepancies in underlying cloud behavior between small domain LES and observationally constrained cumulus feedback projections. J25 conclude that even if there is a mesoscale organization feedback modulating the cumulus feedback, it is sufficiently weak that it will not significantly alter the current projections of a weakly positive cumulus feedback.

3. Further Framework Evaluation and Broader Implications

The implications of mesoscale circulations energetically self-regulating the tropical low cloud-climate system, regardless of large-scale environmental change, are critical. Are the offsetting effects of organization unique to trade cumulus or could they influence climatological shifts in organization tendencies in other low cloud regions (e.g., McCoy et al., 2023)? Extending this symmetrical mesoscale cloud-circulation coupling theory to other regimes could help interpret low cloud feedback more broadly.

It is important to continue evaluating this theory through observations, including more in situ samples across mesoscale circulation branches, and a wider array of environmental conditions, including under potential future climate scenarios. Observations will also help to address some of the idealized LES limitations (e.g., J25 Section 5). For example, larger circulations and their cloud systems (growing beyond 700 km, Janssens et al., 2024; Schulz et al., 2021) cannot be captured by the doubly-periodic mesoscale domains. Evaluating the cloud amount versus vertical velocity relationships across varying circulation sizes (e.g., J25 Figure 4b) may assist in defining the scope of this theory. Aerosol is an additional cloud controlling factor that influences present-day trades (e.g., Quinn et al., 2022; Royer et al., 2023) and alters organization by pushing cloud systems to be deeper, fewer, and brighter (Yamaguchi et al., 2019), potentially reinforcing the offsetting effects across circulations. Investigations of how aerosol forcing may influence trade cumulus feedback are beginning to be conducted (Alinaghi et al., 2025; Eastman et al., 2025; Park et al., 2024).

Finally, tropical low cloud organization may influence the hydrological budget by redistributing precipitation (Radtke et al., 2023), which can serve as a preamble to the development of deep, precipitating convection (Wolding et al., 2024). J25's study presents evidence that the organization of tropical low cloud systems has a small net radiative effect but it may have other climatic influences on the current and future climate systems. Fundamentally, these results present a novel conceptual framework for understanding how tropical low cloud systems behave and impact the climate, encouraging re-evaluation of mesoscale organization impacts globally.

Data Availability Statement

The image in Figure 1a is a Corrected Reflectance (True Color) retrieval from NOAA-20/VIIRS on 11 February 2020 (−60 to −43°E, 12 to 18°N) and was downloaded from https://go.nasa.gov/45gPjSb.

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