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Cloud-Radiation Interactions and their contributions to Convective Self-Aggregation

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Numerical models configured in radiative convective equilibrium (RCE) have shown that convection can self-aggregate, where initially randomly distributed convection becomes clustered despite homogeneous initial conditions and forcing. The degree of self-aggregation within a domain has important consequences for weather and climate, and varies considerably between models. Previous studies have shown that interactions between clouds and radiation are crucial drivers and maintainers of aggregation. This study investigates the direct radiative-convective feedbacks that are important to self-aggregation within elongated channel simulations of the UK Met Office Unified Model (UM) version 11.0. Our simulations are configured using three fixed sea surface temperatures (SSTs) following the radiative-convective equilibrium model intercomparison project (RCEMIP) protocol.

Our analysis builds on the vertically-integrated frozen moist static energy (FMSE) variance budget framework that assumes that aggregation increases as FMSE variance increases. The budget shows how interactions between FMSE and radiation, surface fluxes and advection contribute to increasing FMSE variance. This variance is highly sensitive to SST, however, by normalising FMSE between theoretical upper and lower limits based on SST, this sensitivity can be eliminated. This allows the variance of normalised FMSE to be a consistent aggregation metric across all SSTs. By deriving a new budget equation for normalised FMSE, we can see which interactions are important for aggregation and how these interactions are sensitive to SST. By defining cloud types based on the vertical distribution of condensed water, we study the importance of radiative interactions with each cloud type to aggregation, and how they change with SST.

We find that our simulations reach similar degrees of aggregation, despite the contributions of shortwave and longwave interactions decreasing with SST. Surface flux and advective feedbacks with FMSE become less negative with SST, accounting for the decreasing radiative feedback contribution. Longwave interactions with high-topped clouds are the main drivers and maintainers of aggregation, with their influence decreasing with SST as high clouds become less abundant. Longwave interactions in clear regions have significant positive effects in driving aggregation, however their contributions decrease once the convection becomes aggregated. Their longwave contributions to aggregation decrease with SST and can become negative at high SSTs once convection is aggregated. The shortwave interactions with water vapour are one of the key

maintainers of aggregation, becoming more important as aggregation increases. Shortwave interactions are more important at cooler SSTs where there is a greater contrast in shortwave heating between moist and dry regions.

Results presented here are not necessarily representative of real world convection, these are merely results of this model configuration. Applying this technique to other models may highlight key differences in their cloud-radiative feedbacks and may help to explain differences in the degree of aggregation within numerical models.