Sensitivities of Stratocumulus organization to precipitation

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Introduction

In 1975 Arakawa's WMO report, Stratocumulus are identified as one of the Canonical Cloud forms whose representation was essential to accurate simulations of the general circulation. In the intervening decades, work by himself, his students and collaborators have greatly advanced our understanding of this critical cloud regime. Here, we investigate the sensitivity of cloud and flow organization to precipitation.

Methodology

Large-eddy simulations with bulk microphysics parameterization (following Seifert and Beheng, 2001) on large domains (25.5 x 25.5 x 1.5 km^3) with fine vertical resolution are employed. Three 6-h long simulations of nocturnal STBL are analyzed:

- NDS -- Non-precipitating Simulation,
- DS -- Drizzling Simulation, and
- DWES -- Drizzling Without sub-cloud Evaporation Simulation.

Questions

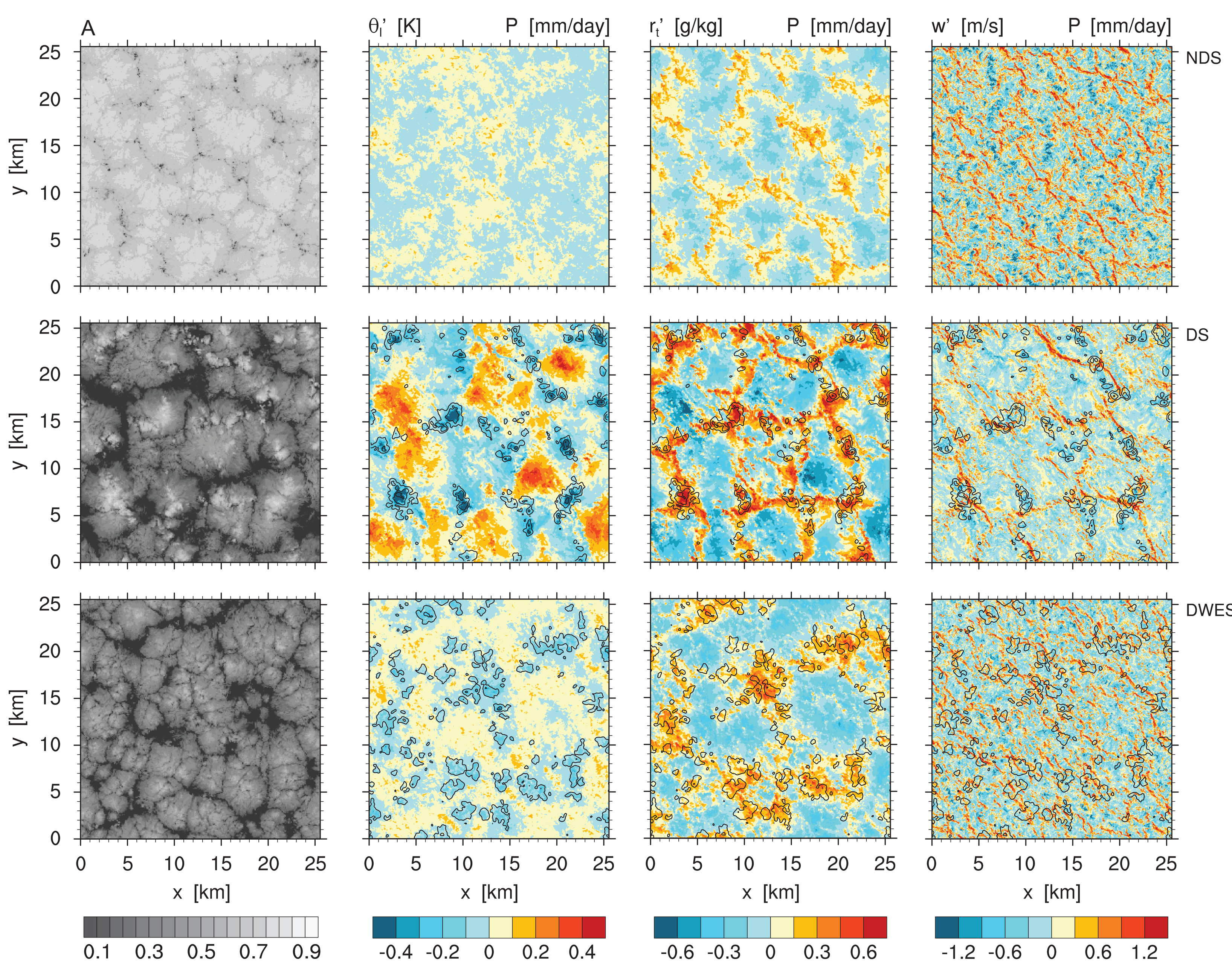
Can drizzle induce a transition in cloud planform from closed cellular circulations, characterized by well mixed boundary layers with significant cloud cover, to open-cellular circulations, characterized by decoupled boundary layers and less cloud cover?

To the extent that there is transition, how is it affected by the sub-cloud-layer evaporation of drizzle?

How do pools of elevated thetae observed in association with drizzle develop?

Cloud and flow organization and evolution

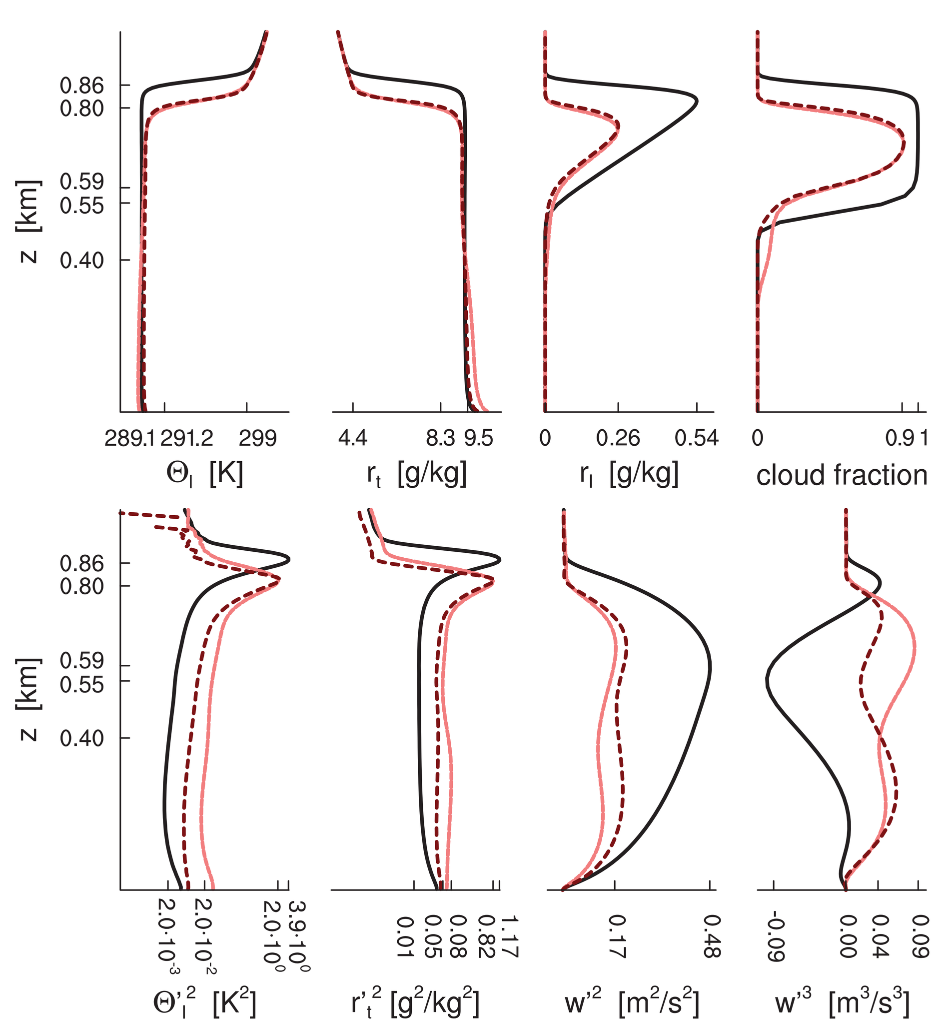
Drizzle leads to much less reflective and topologically distinct cloud layer. Reduced albedo is mostly due to the depletion of cloud liquid water and an increase in the spatial variability of the cloud field. Twomey effect accounts for only about one third of the total albedo reduction.



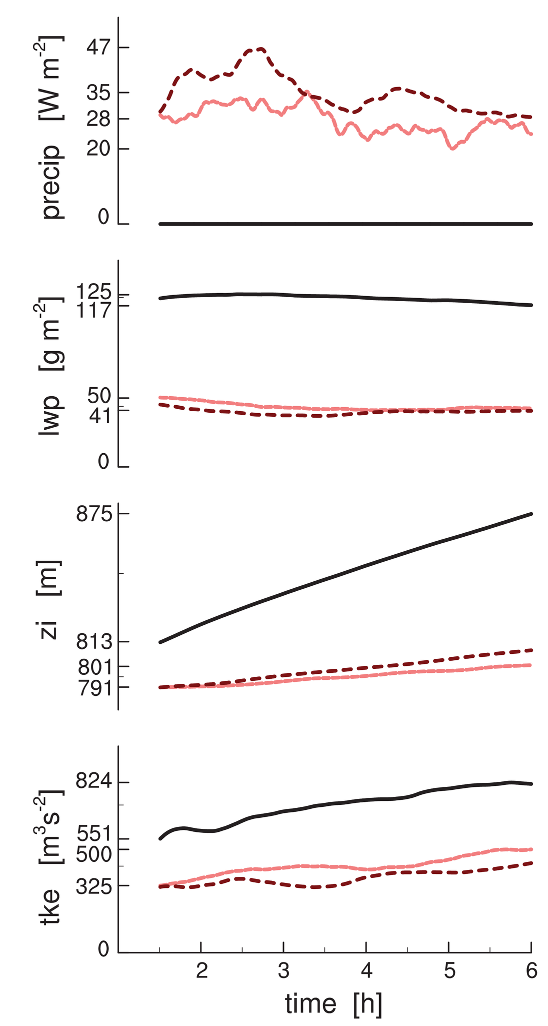
Evaporation of drizzle in the sub-cloud layer aids the development of topological distinction between drizzling and non-drizzling Sc. Although both are organized in the closed cells, drizzling Sc experience development of network of Cu rising into Sc with apparent open-cellular organization. When evaporation is disabled, Cu development is absent.

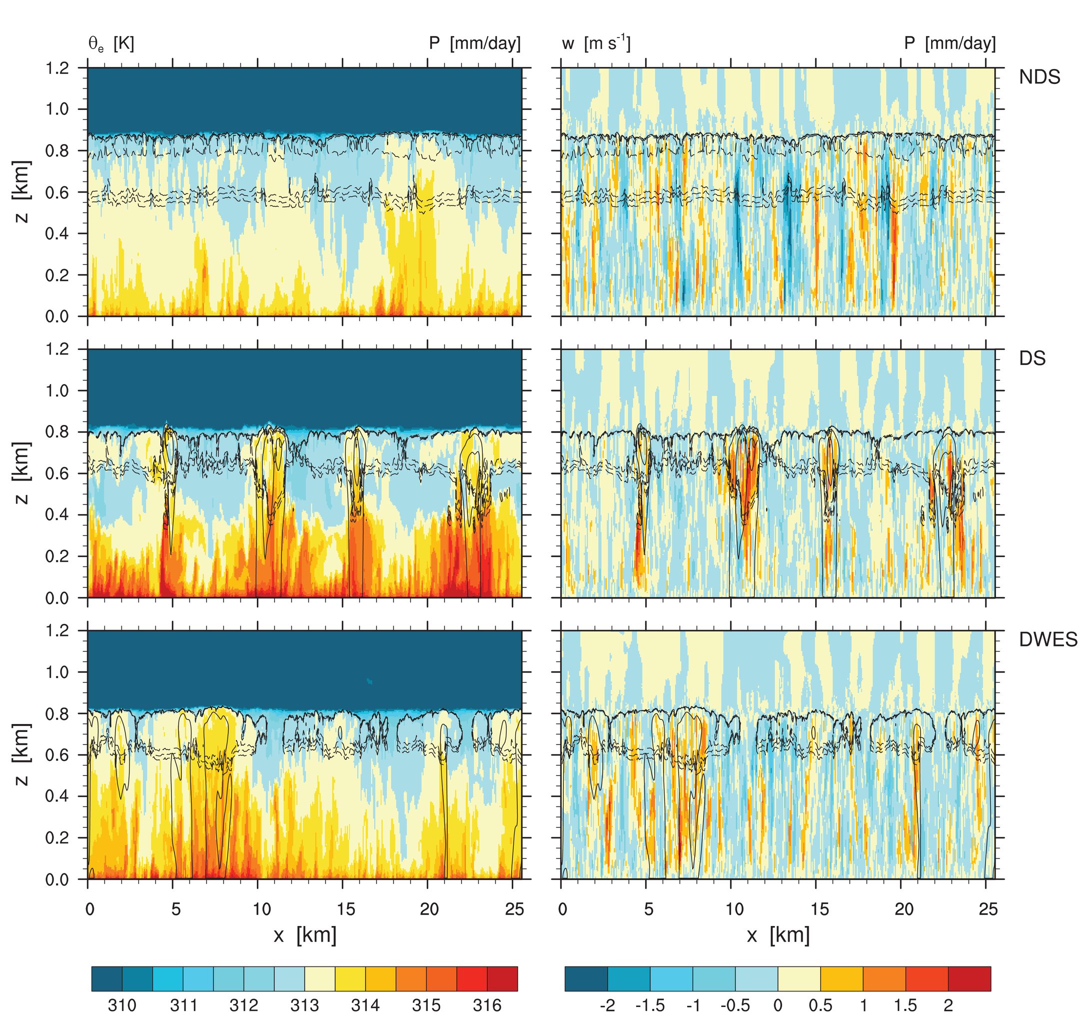
Drizzle also leads to the slower circulations that allow for higher horizontal variability of the scalar fields and couple more strongly to an open-cellular network of surface-bound r_t anomalies. It induces a lack of strong downdraft motion, which, along with the updrafts of the commensurate strength, is characteristic of the non-precipitating nocturnal STBL, and leads to the dominance of strong updrafts.

Drizzle evaporation supports more regular pattern in the precipitating regions, which tend to be concentrated and associated with the strong fluctuations in the sub-cloud thermodynamic structure. In the absence of evaporation, however, drizzling regions tend to be more wide spread and less intense, while the scalar fluctuations are weaker.



Drizzle moreover leads to the accumulation of higher values of θ_e in the sub-cloud layer, with the evaporation being in particular supportive of this aspect of circulation change. Drizzle-induced Cu underlying Sc are localized in the vicinity of the updrafts rich in θ_e and are noticeably associated with locally elevated cloud tops.

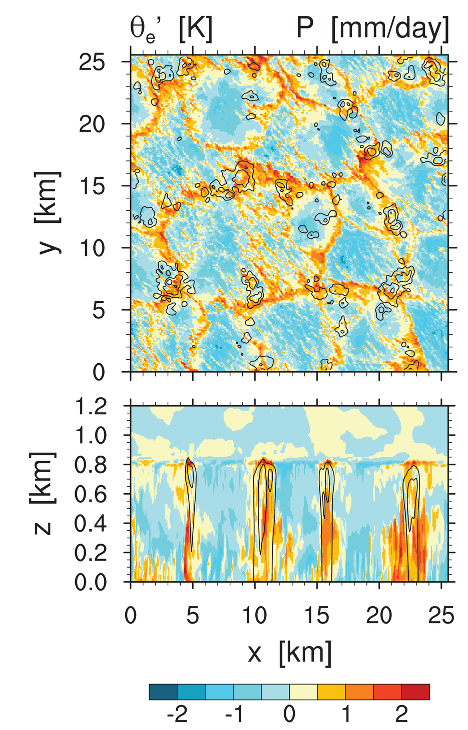




Precipitation leads to shallower BL, reduction in cloud liquid water and cloud fraction, while its evaporation promotes development of Cu. It also induces decoupling and weaker, more surface-forced circulation, which exhibits greater scalar variance. Drizzle evaporation particularly promotes the scalar variability in spite of hardly affecting the w variability, which reflects the existence of topological changes.

Precipitation-induced changes in the flow seem to be persistent, with the evidence of remarkably constant LWP, BL growth rate and domain-averaged TKE. Although precipitation depletes cloud liquid water, it does not lead to the collapse of cloud and BL. On contrary, there is a long-lived, persistently precipitating STBL that, due to the weaker entrainment rates, only grows slower than the compared non-drizzling STBL.

Pools of elevated θ_e

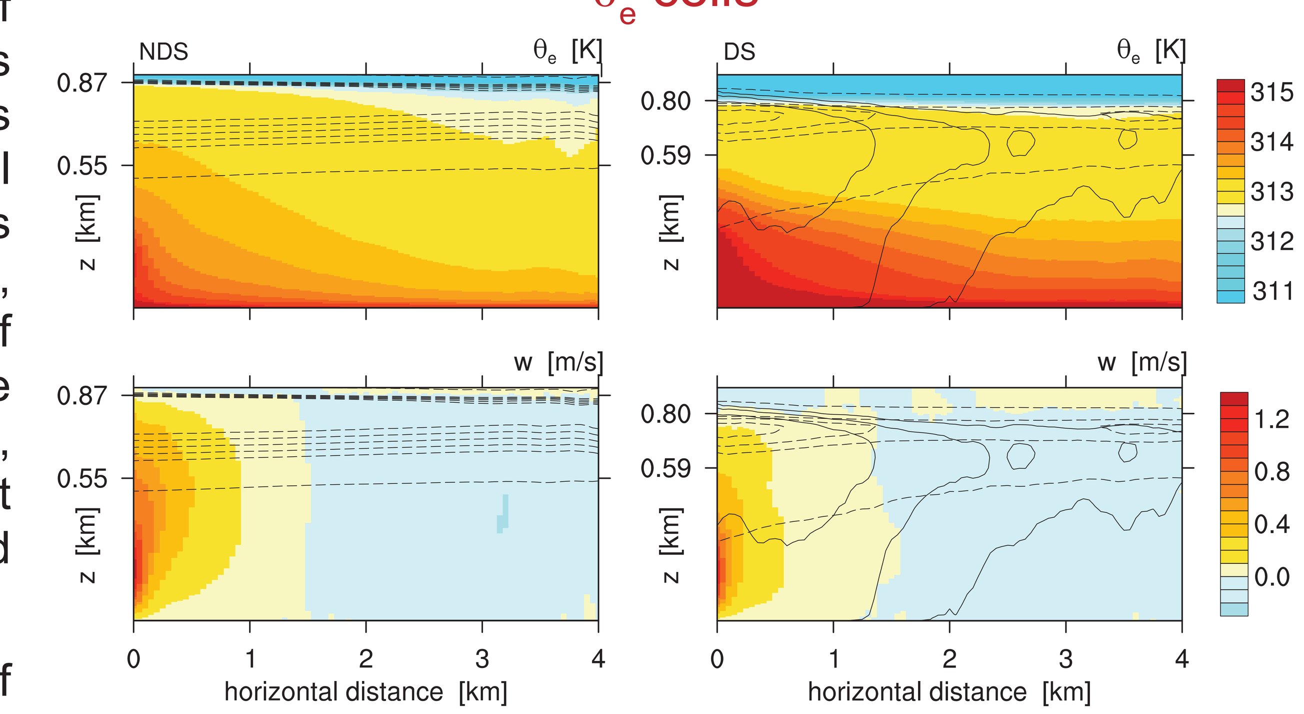


Pools of elevated θ_e have been observed in the sub-cloud layer by vanZanten and Stevens (2005) to be in the regions associated with drizzle. Sub-cloud horizontal cross section of θ_e overlaid with the precipitation contours from DS visualizes presence of drizzle mostly in the areas of elevated θ_e. Vertical cross section of the same variables further depicts that this feature is present throughout the depth of the boundary layer, not only in the sub-cloud layer.

Conditional composites of θ_e and w over the strongest events of elevated θ_e (θ_e cells) evince that θ_e is actually peeled off from the surface. Because of the drizzle-induced weaker circulation, θ_e is more surface bound and the loci where it is peeled off experience stronger increase of θ_e values in the boundary-layer interior for the drizzling than for the non-drizzling STBL.

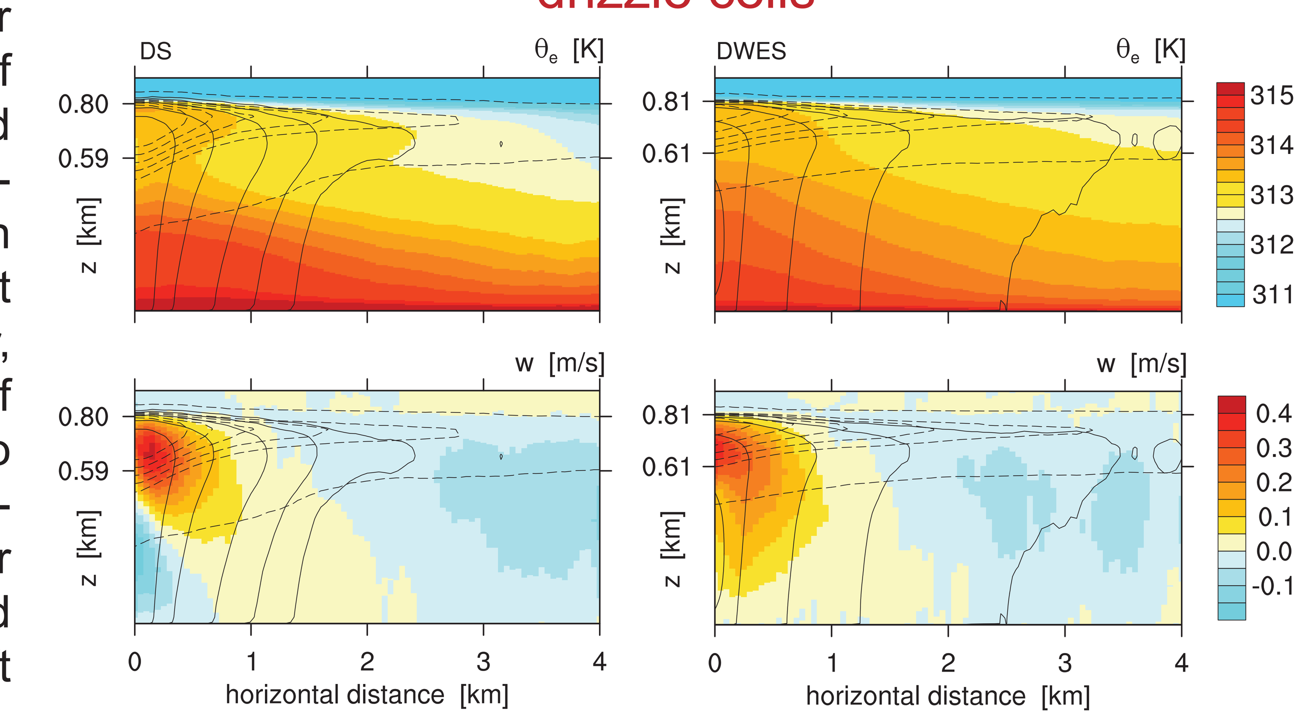
Conditional composites of precipitation in the θ_e cells and conditional composites of θ_e in the drizzle cell reveal that these two cells are not necessarily aligned, but that the peak values of θ_e tend to be just off the center of the drizzle cell, which further suggests that drizzle cells are nourished by the θ_e cells.

θ_e cells



Conditional composites of w and θ_e in the drizzle cells of DS and DWES further support conclusion of evaporation-induced change in the flow organization. Core updrafts in both simulations exhibit similar strength. However, sub-cloud evaporation of drizzle in the DS leads to development of the downdrafts in the sub-cloud layer of drizzle-cell centers and elevation of the updraft core to the cloud layer.

drizzle cells



Additionally, hints of horizontal detrainment of θ_e from the cloud layer of drizzle cell in the DS suggest stronger differentiation between the drizzling cloud and its environment, which seems absent from the DWES.

Conclusions

Presented simulations are shown to support the hypothesis that drizzle can induce a transition in cloud planform. Topology of the cloud field changes toward Cu-coupled open-cellular organization. This transition in topology is particularly supported by sub-cloud evaporation of drizzle.

Drizzle has a long-lasting and locally intense character. It leads to reduced circulation intensity and increased horizontal inhomogeneity of the thermodynamic fields. Evaporation-induced changes in the organization of circulation additionally augment the scalar variability.

Pools of elevated θ_e associated with drizzle seem to be a reflection of the slower circulation that does not mix surface moisture deeper in the layer, and are enhanced by the topological changes induced by evaporation that couples the updrafts to the surface-bound moisture excess.