LES simulation of the shallow cumulus clouds over the chessboard land surface: Influence of the heterogeneity length scale and the background wind speed

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Key Questions

- What are the combined influences of the surface heterogeneity size and the background wind speed on land-PBL-cloud interaction processes?
- What processes contribute to the shallow-to-deep convection transition over the heterogeneous land surface
- How can we generalize such influences?

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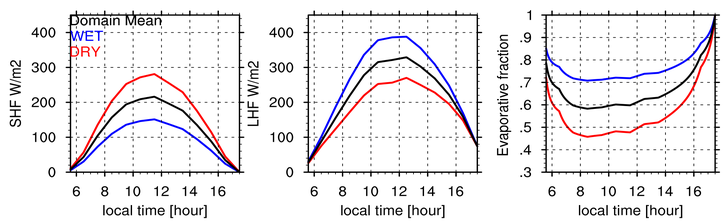
1. Idealized LES over the chess-board pattern surface based on CASS

Large-eddy simulation (LES) model : SAM (System for Atmospheric Modeling)
- Domain size : 28.8 x 28.8 km^2
- Resolution : dx = dy = 50m, dz = 20m below 4km

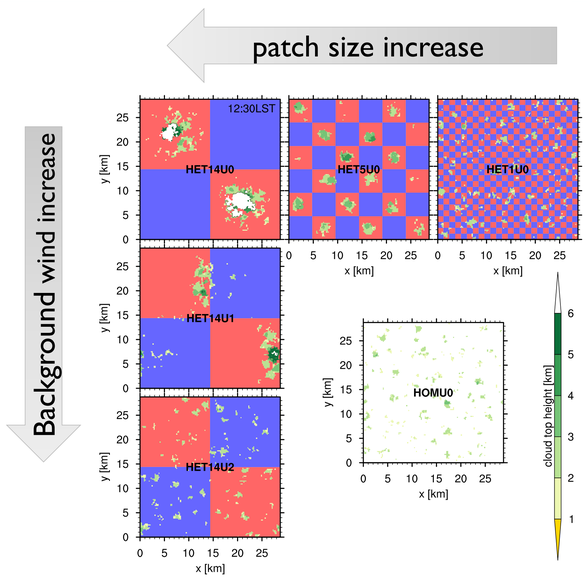
Base case: Continental Active Surface-forced Shallow Cumulus (CASS: Zhang et al., 2017)
- A new composite case of non-precipitating, fair weather shallow cumulus at ARM SGP sites
- Weak large-scale forcing, near surface temperature inversion

Differences from CASS
- Alternating WET/DRY patches with different EF values (non-interactive land surface)
- Pure zonal, vertically constant background wind



Testing the impact of the patch size and background wind speed
- Patch size: 14.4, 7.2, 4.8, 2.4, 1.2 km (hereafter HET14, HET7, HET5, HET2, HET1)
- Background wind speed: 0, 1, 2, 3, 10 m/s (U0, U1, U2, U3, U10)

2. Clouds under the surface heterogeneity influence



Shallow-to-deep convection transition
- HET14U0, HET14U1, HET7U0 and HET5U0
- Clouds over DRY patches with the well defined secondary circulation

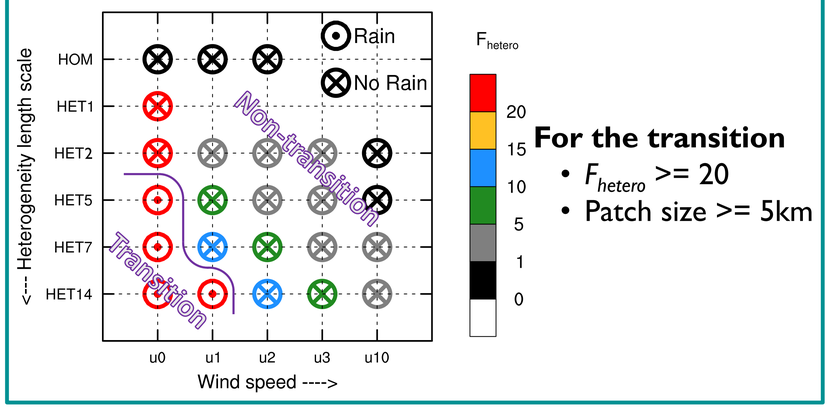
5km patch size threshold for the convection transition

Strong background wind impact
- The secondary circulation hardly survives under the 1 – 2 m/s background wind

3. Criteria for Shallow-to-deep convection transition

Non-dimensional parameter F_{hetero}

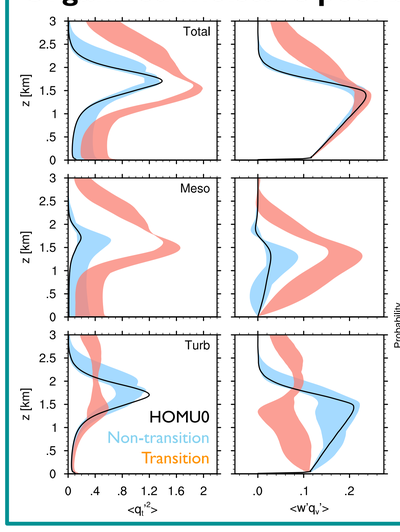
$$F_{hetero} = \frac{L_{patch}/U}{z_i/w_*} = \frac{Flow\ \ advective\ time}{large-eddy\ time\ scale}$$



For the transition
- F_{hetero} >= 20
- Patch size >= 5km

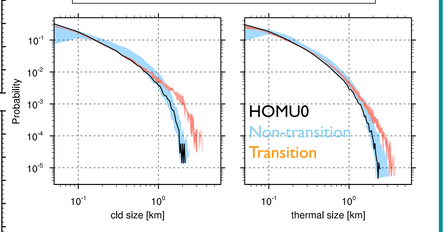
4. Key ingredients for the convection transition during ShCu stage

Organized moisture pool by the secondary circulation



Secondary circulation at mesoscale contributes most to the moisture transport

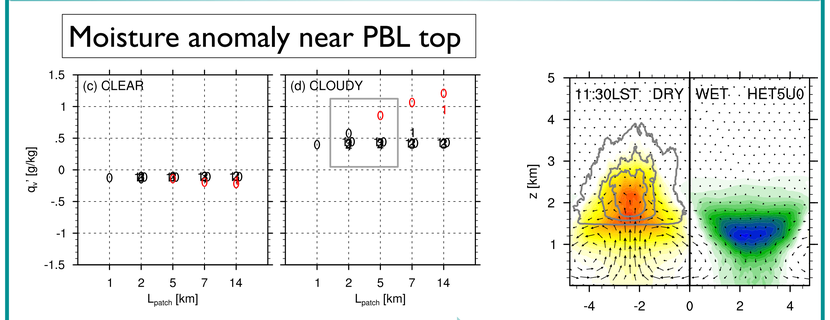
Cloud and thermal size



Larger ShCu

5. Large patch promotes the organization of the moisture pool

Moisture anomaly near PBL top



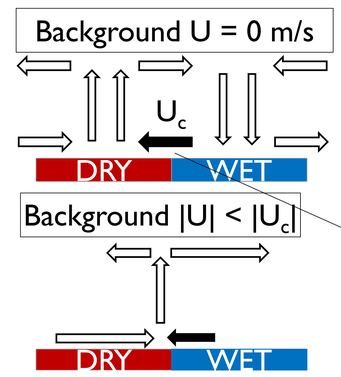
Patch size threshold at 5km. Why?

Similar secondary circulation strength
For smaller patches (< 5km):
Horizontal mixing > moisture advection
=> weaker patch contrast

Summary & Future plan

- Mesoscale secondary circulation and the consequent moisture variability across the PBL top are the key for the convection transition over the heterogeneous surface.
- Secondary circulation weakens itself by reducing the horizontal temperature gradient
- We plan on addressing other factors such as the influence of the heterogeneity amplitude, wind shear, wind direction on the convective clouds
- Land-model coupled LES will be used to examine the characteristics of cold pools over heterogeneous land surface

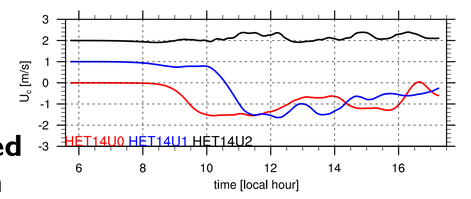
6. Strong interference form the background wind speed



Transition cases

Surface convergence zone and clouds shift downwind but still over DRY patches

Cross-border wind speed

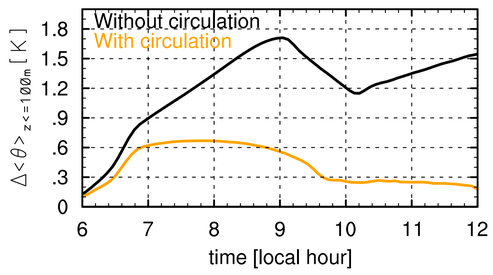


Cross-border wind speed ≒ secondary circulation speed

The secondary circulation can exist if the background wind is weaker than the circulation itself

Why is the induced circulation so weak?

Near surface temperature difference between WET and DRY patches



- Minimal horizontal temperature gradient throughout the day due to the effect of the secondary circulation
- How to formulate temperature (/pressure) gradient and U_c ?

Acknowledgements

Authors would like to acknowlege Department of Energy (DOE) and Early Career Research Program (ECRP) that supported this research. We would like to thank DOE ASR/ARM for providing us the observational data.

This work is supported by the Atmospheric System Research program for the Office of Science of the United States Department of Energy. This work was performed under the auspices of the U. S. Department of Energy by Lawrence Livermore National Laboratory under contract DE-AC52-07NA27344. LLNL-POST-747800