Can we generalize the influence of wind speed and patch size on the development of cumulus clouds over heterogeneous surface?

Jungmin Lee, Yunyan Zhang and Stephen A. Klein
Lawrence Livermore National Laboratory

Effect of surface heterogeneity

Heterogeneous land surface induces surface heating perturbation that can trigger the mesoscale circulation favoring the deep convection over the warm area. Among many factors that control the land heterogeneity effect, we focus on the impact of heterogeneity length scale and wind speed on the life cycle of shallow cumuli. Topics that will be discussed are:

- Generalization of the combined effect of heterogeneity length scale and wind speed on the ShCu development
- Range of patch size and wind speed that triggers the transition to deep convection
- Influence on the PBL structure

Factors controlling the effect of land surface heterogeneity

Land surface Heterogeneity length scale and amplitude	Atmosphere
Soil texture and moisture gradient	Atmospheric stability
Vegetation type transition	Atmospheric moisture
Terrain change	Background wind speed
Urban area	Background wind shear
among many others	Cloud cover

LES Experiment setup

LES model : SAM (System for Atmospheric Modeling) [1]

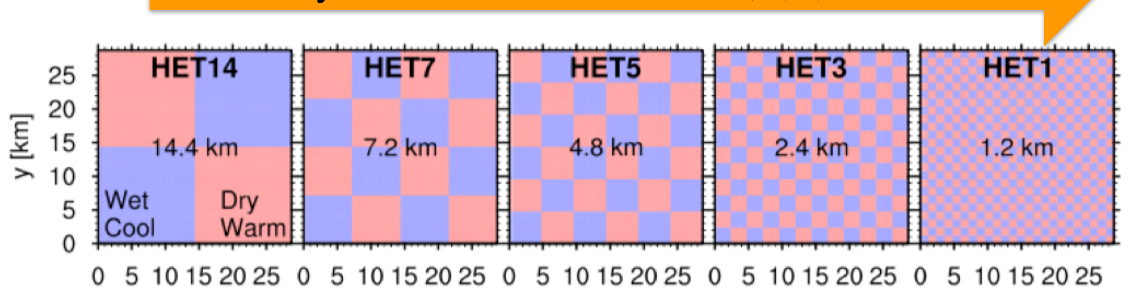
- Domain size : 28.8 x 28.8 km^2
- Resolution : dx=dy=50m, dz = 20m below 4km
- Double moment microphysics scheme [2]

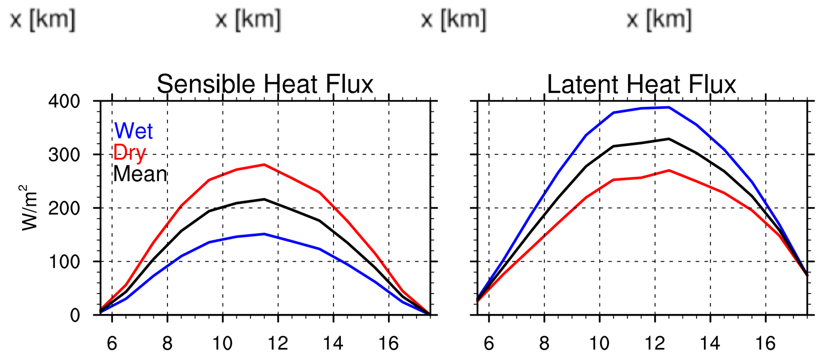
Forcing dataset

- A new composite case of non-precipitating, fair weather shallow cumulus at ARM SGP sites [3]
- Weak large-scale forcing, near surface temperature inversion

Experiment setup

Vertically constant zonal wind : 0,1,2,3 and 10 m/s

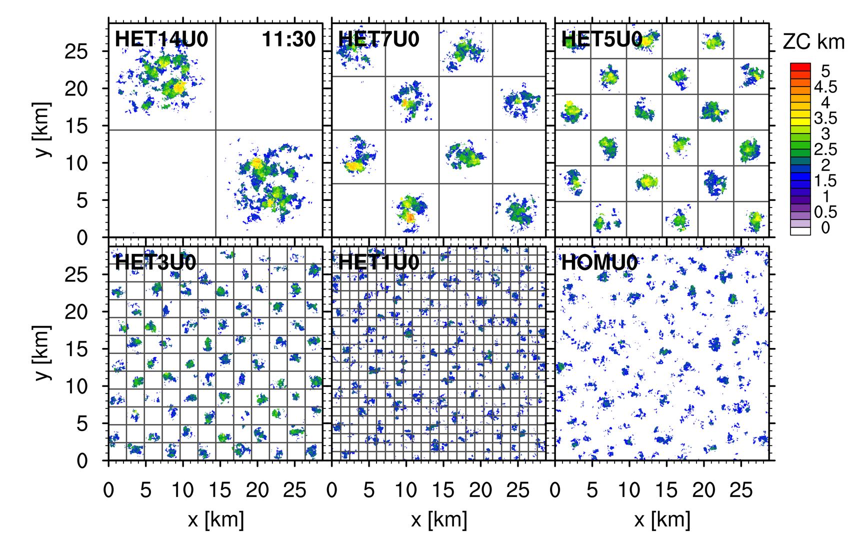




- Patch contrast of the surface fluxes is adjusted from the EBBR/ECOR data over different surface type
- Patches have the same net surface energy (=SHF + LHF)

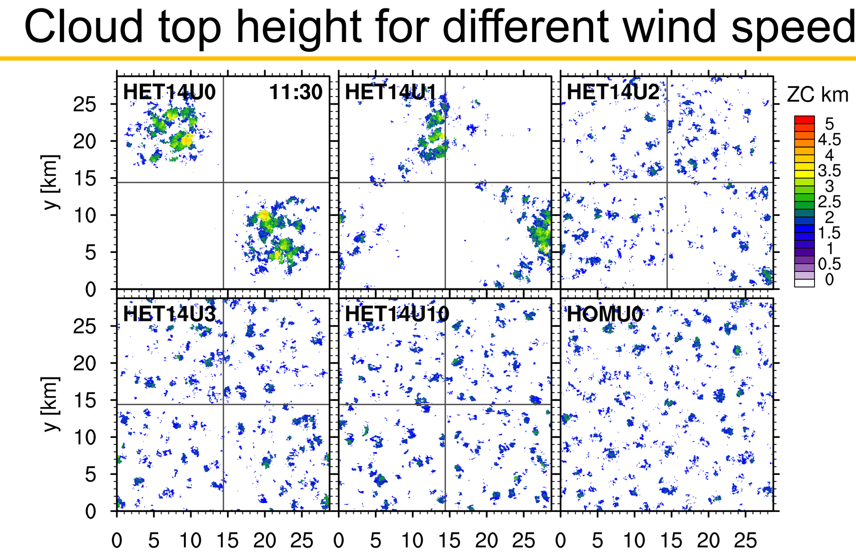
The fate of the shallow cumuli over heterogeneous land

Cloud top height over different patch sizes



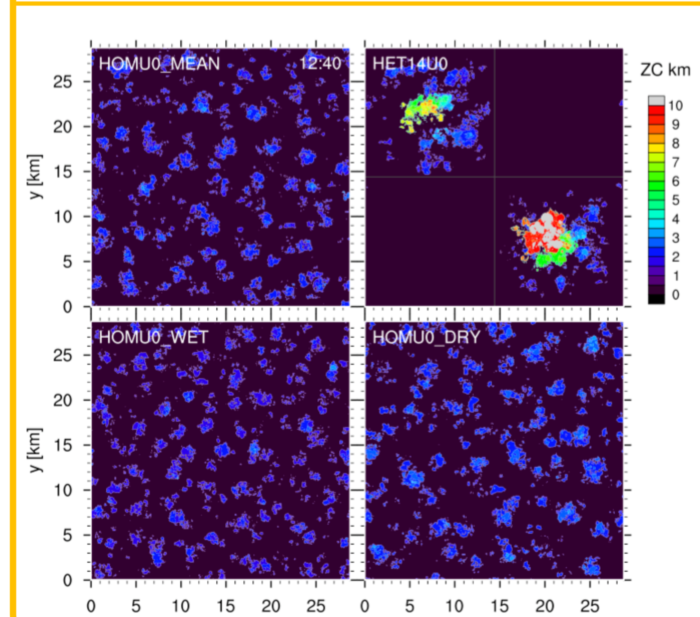
- Clouds form over dry/warm patch with zero wind

Cloud top height for different wind speeds



- Convergence zone shift downwind under weak wind and clouds form over the patch boundaries

Homogeneous cases with different Bowen ratio vs. Heterogeneous surface



Bowen ratio effect can be ruled out for the development of deep convection over heterogeneous land surface

Summary

- Surface heating variation over the heterogeneous land surface can trigger the shallow to deep convection transition.
- For a given heterogeneous length scale and wind speed, F_{hetero} is a good proxy to determine whether there will be a secondary circulation or not, and therefore, a good proxy for the convective regime shift.

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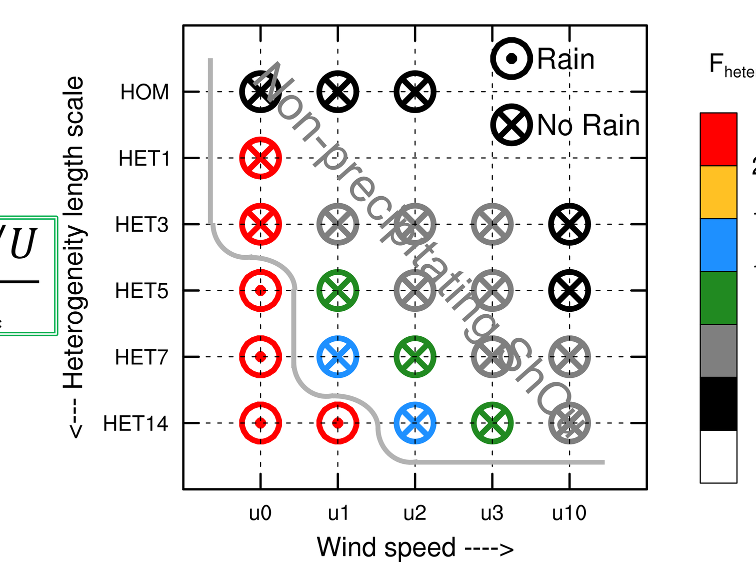
Which condition favors the shallow-to-deep convection?

Combined effect from the heterogeneity length scale and wind speed

Non-dimensional parameter, F_{hetero} is used to quantify the heterogeneity effect from the varying patch size and wind speed. F_{hetero} is equivalent to the ratio of time for flow to cross over the patch to the time for thermals to rise through the PBL

$$F_{hetero} = \frac{L_{patch}/U}{z_i/w_*}$$



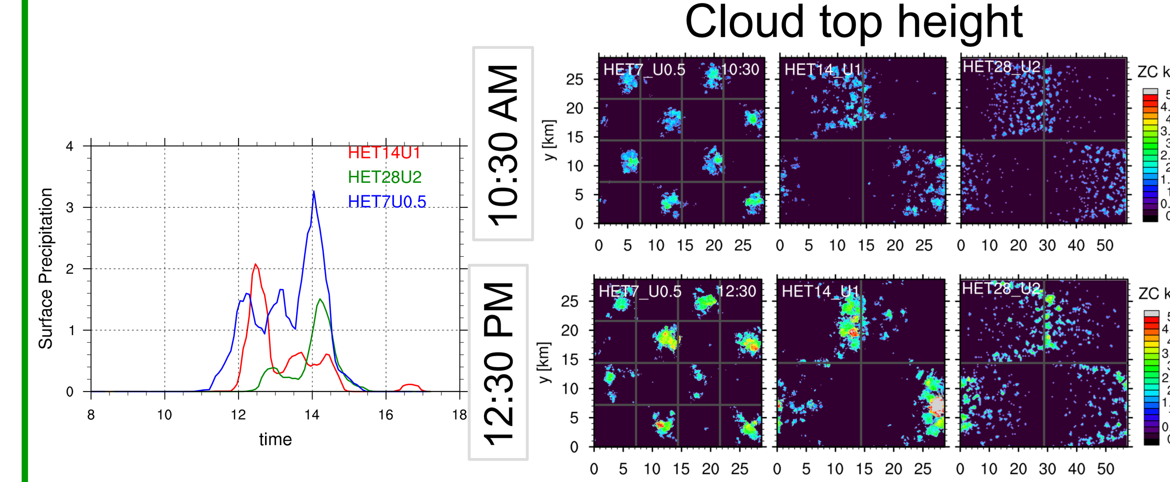
- Patch size and wind speed exerts opposite influence on the heterogeneity effect
- Criteria for convective transition
  - F_{hetero} >= 20 & patch size >= 5km

F_{hetero} as a proxy for the transition

Regardless of wind speed and patch size, cases that satisfy F_{hetero} >= 20 develop precipitating convection

HET7U0.5	HET14U1	HET28U2

Cloud top height



- With non-zero wind speed, the axis of cloud distribution shifts downwind

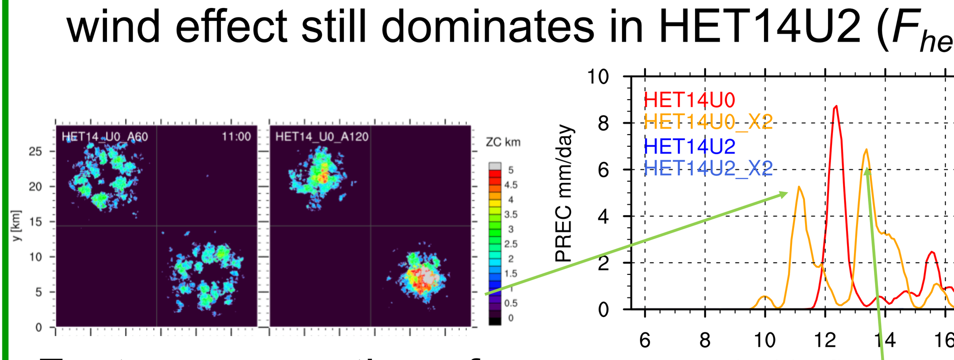
Can the patch contrast offset the wind effect?

- Patch contrast X2 for HET14U0 and HET14U2 cases

	Bowen ratio
Wet	0.37
Dry	1.1

	Bowen ratio
Wet	0.19
Dry	1.8

- Even if the patch contrast doubles, the background wind effect still dominates in HET14U2 (F_{hetero} = 10).



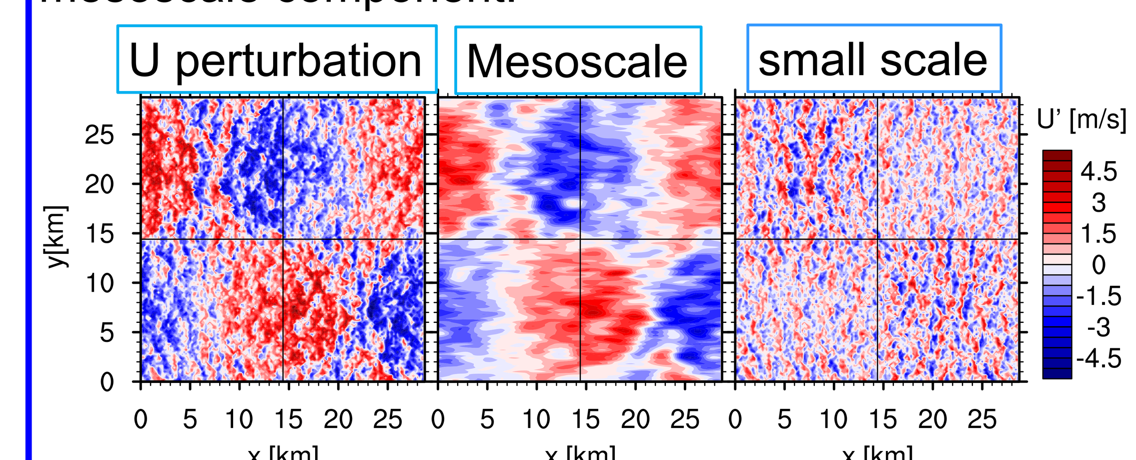
Faster propagation of fronts

Clouds over cold pool edge merge

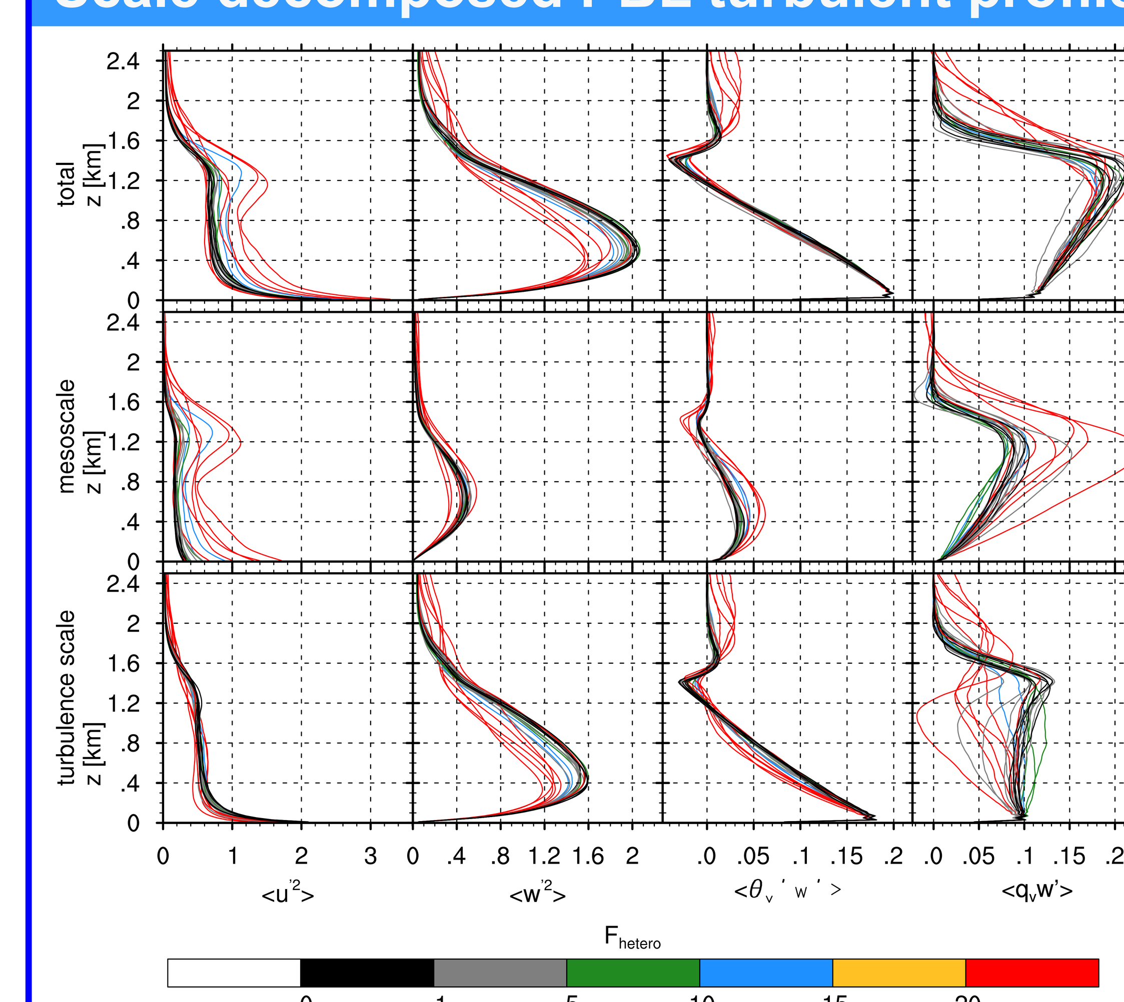
How does the PBL turbulent structure change over heterogeneous land surface?

Scale decomposition method

2D Fast Fourier Transformation is applied with the cut-off wavelength of 4 km to separate the mesoscale and turbulence scale component of the PBL turbulent structure. [4] The secondary circulation triggered over the heterogeneous surface is dominated by the mesoscale component.



Scale decomposed PBL turbulent profiles



- F_{hetero} = 20 separates the transition and non-transition cases
- Transition cases are characterized with the organized mesoscale circulation

Reference

[1] Khairoutdinov and Randall (2006). High-resolution simulation of shallow-to-deep convection transition over land. *J. Atmos. Sci.*, *63*(12), 3421-3436.
[2] Morrison *et al.* (2005). A new double-moment microphysics parameterization for application in cloud and climate models. Part I: Description. *J. Atmos. Sci.*, *62*(6), 1665-1677.
[3] Zhang *et al.* (2017). LES of shallow cumulus over land: A composite case based on ARM long-term observations at its Southern Great Plains site. *Submitted to J. Atmos. Sci.*
[4] Kang and Ryu (2016). Response of moist convection to multi-scale surface flux heterogeneity. *Q. J. Roy. Meteor. Soc.* *142*, 2180-2193.

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