SGP Local Convections and their Coupling with Land Surface from ARM Observations and LES

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Trent Ford, Chris Fiebrich, Pavlos Kollias,
Joe Santanello, Minghua Zhang

Motivation – Diurnal Cycle over Land

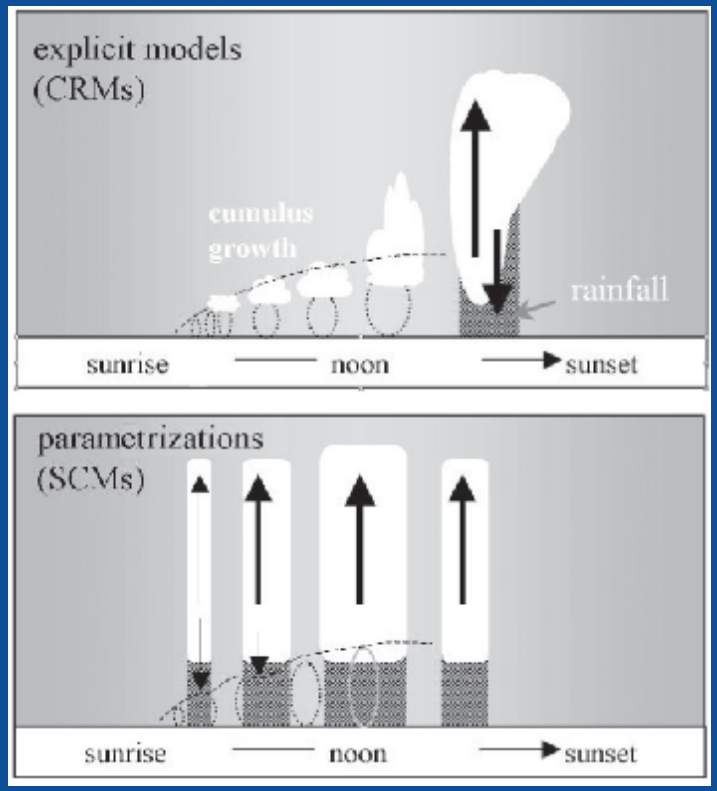
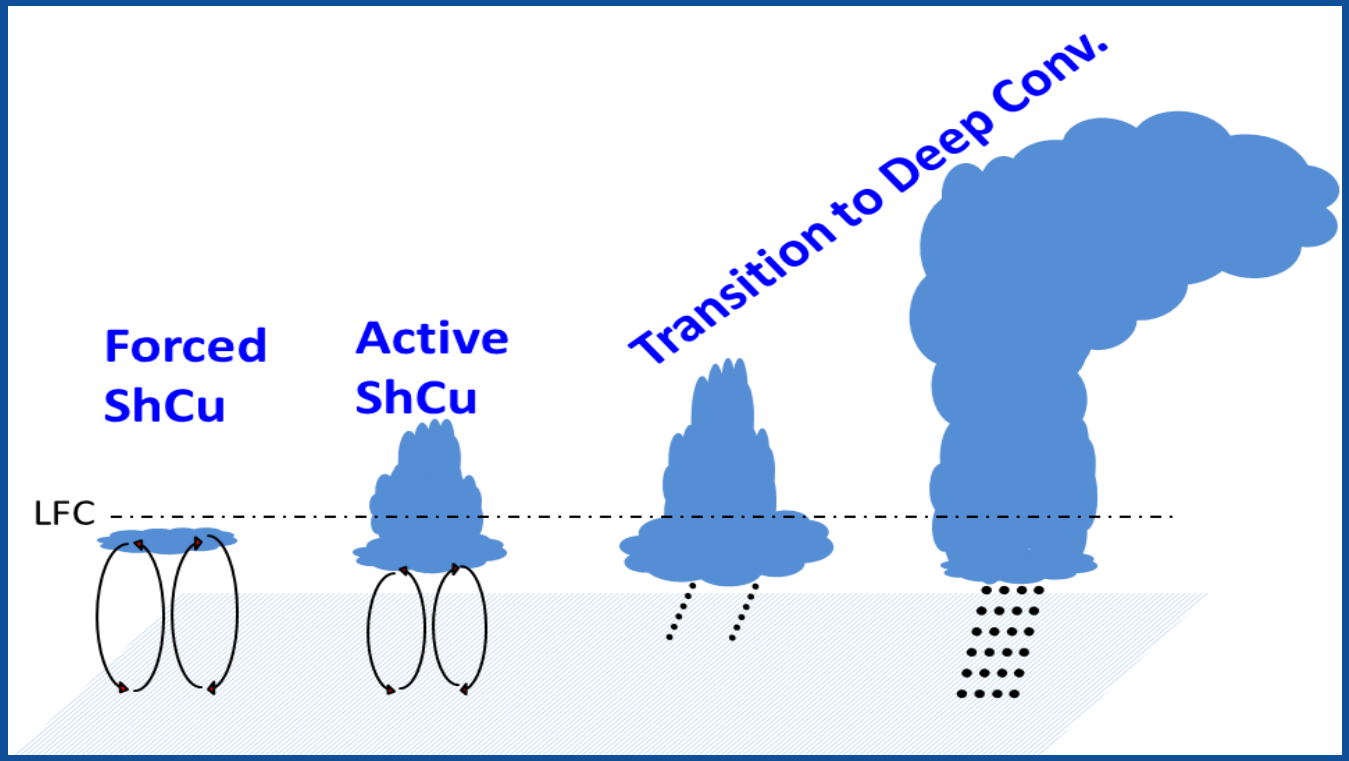


Figure from Guichard et al, 2004

- Convective clouds are important for summertime climate over land
- GCMs poor performance in diurnal cycle largely due to lack of shallow cumulus
- Although GCMs start to resolve mesoscale phenomena, locally-forced convective regimes still need parameterization

Locally generated convection regimes at SGP



Case libraries of different convective days are built upon 13-yr summertime data at SGP
Zhang & Klein, 2010, 2013

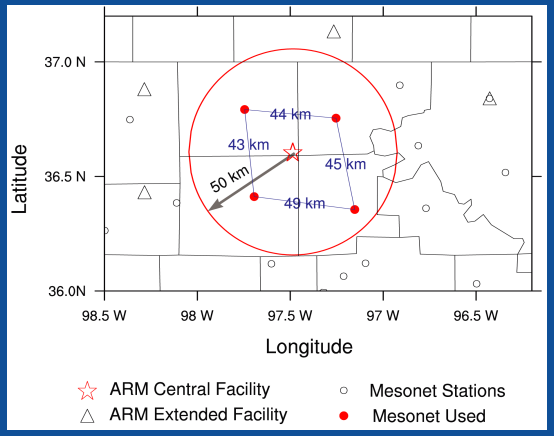
Isolated popcorn-like convections associated with local environmental and land-surface conditions
Excluding mesoscale propagating convection systems and orographic-forced convections

1. What do we learn from ARM SGP observations on continental convections and their coupling with land-surface?

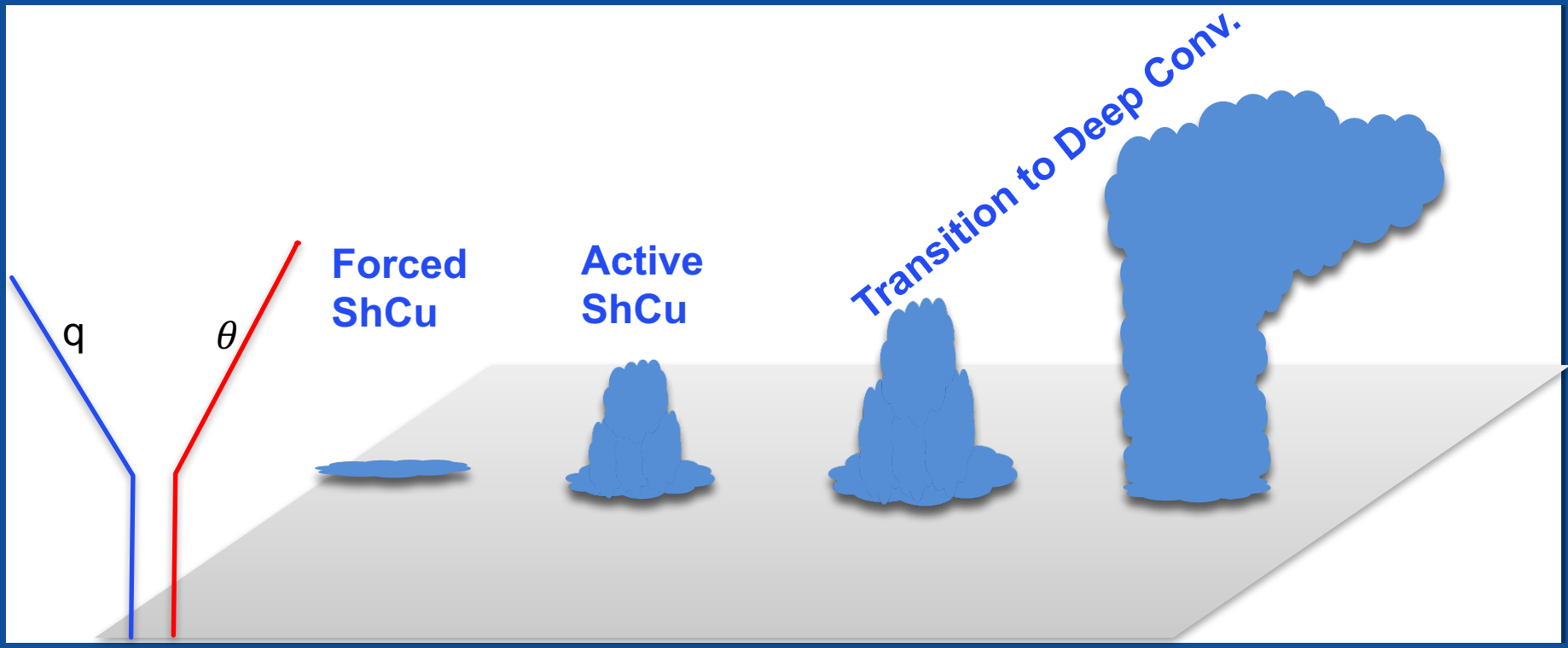
2. What do we learn from LES about ShCu physics including its coupling with land-surface?

1. What do we learn from ARM SGP observations on continental convections and their coupling with land-surface?

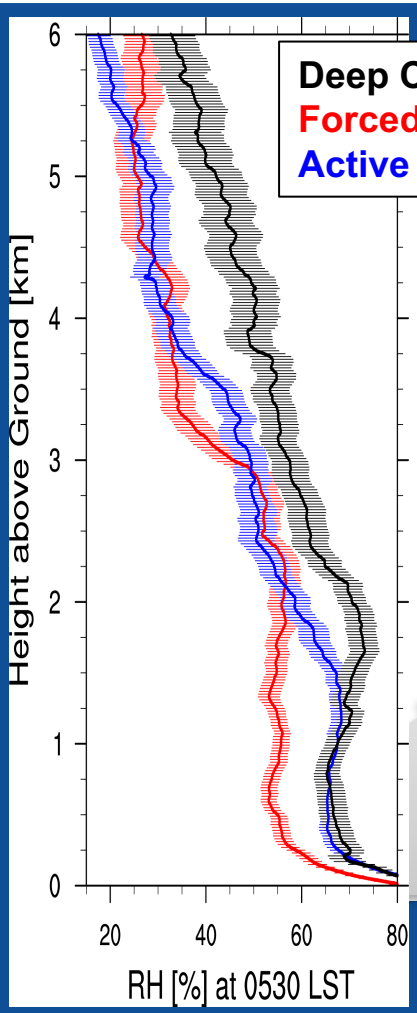
- Atmospheric control
- Surface control
- Boundary layer control



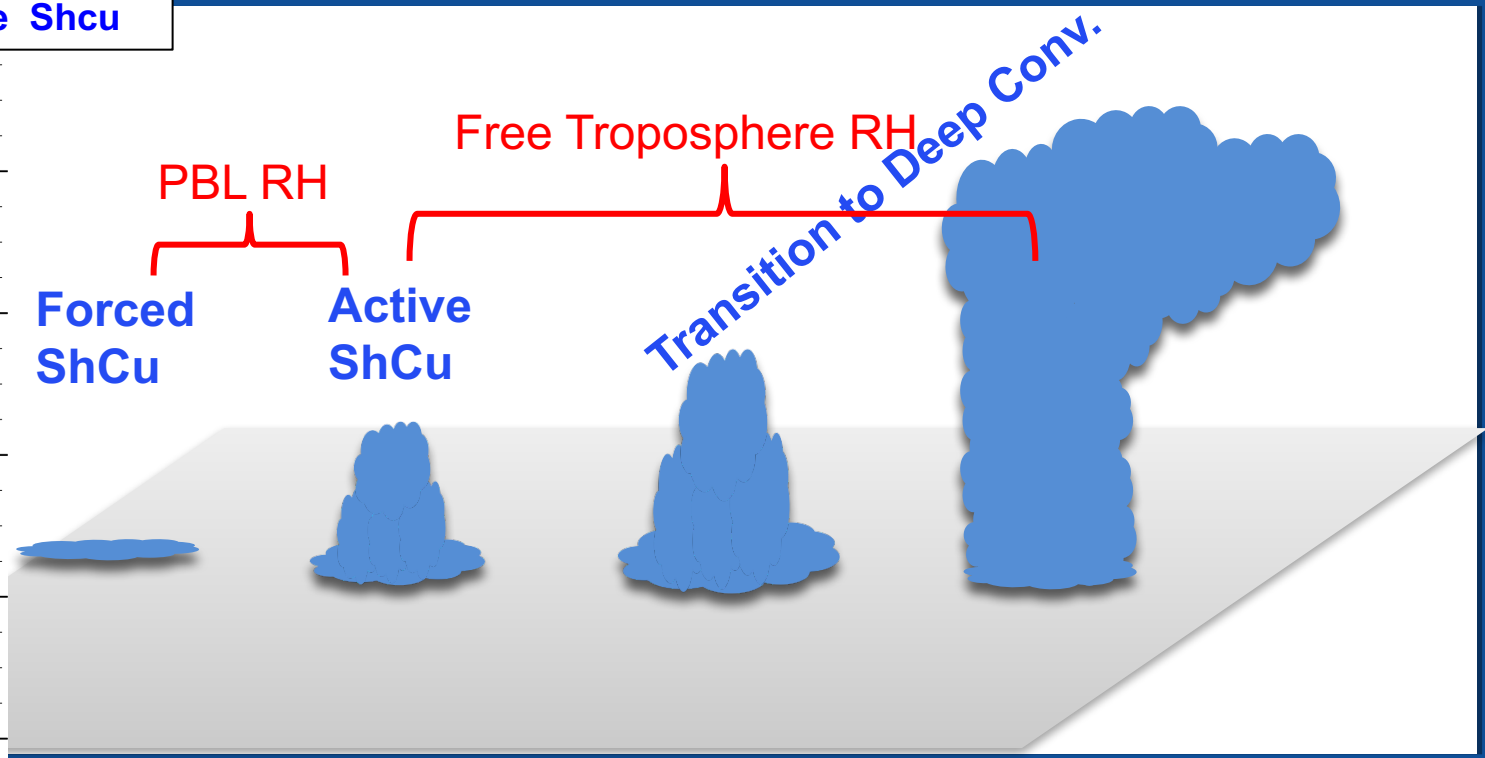
What are the Atmospheric controlling factors?



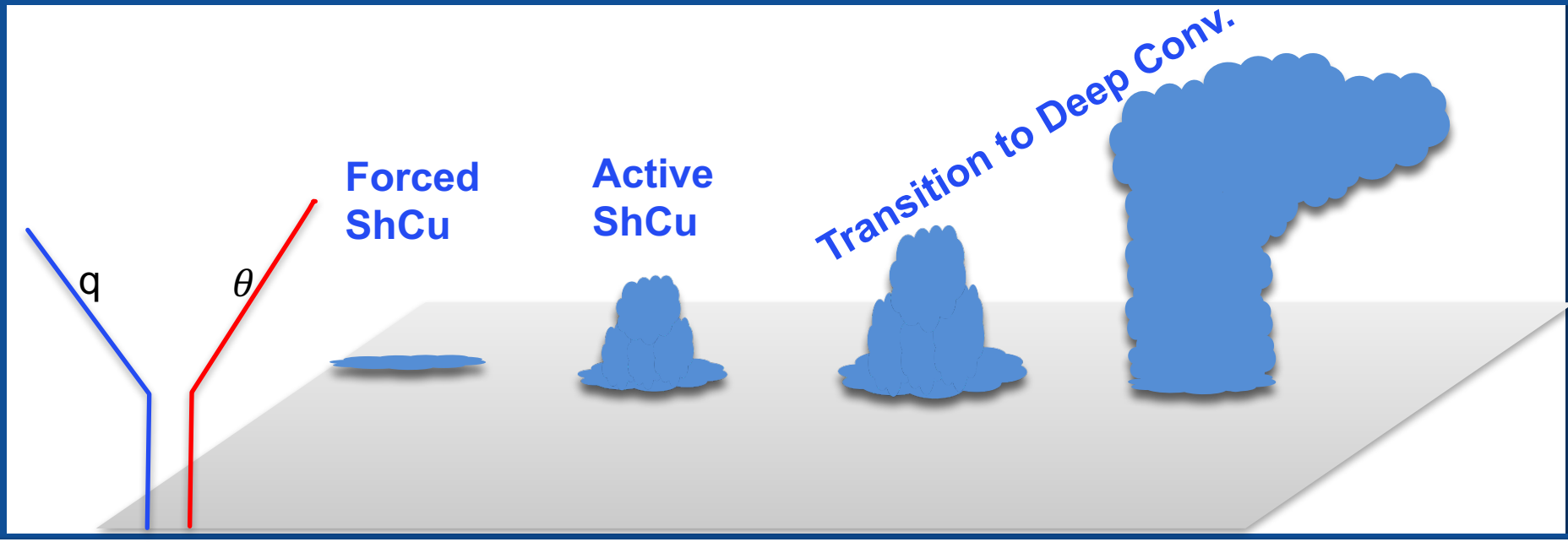
RH is the dominating Atmospheric factor



Zhang & Klein, 2010, 2013



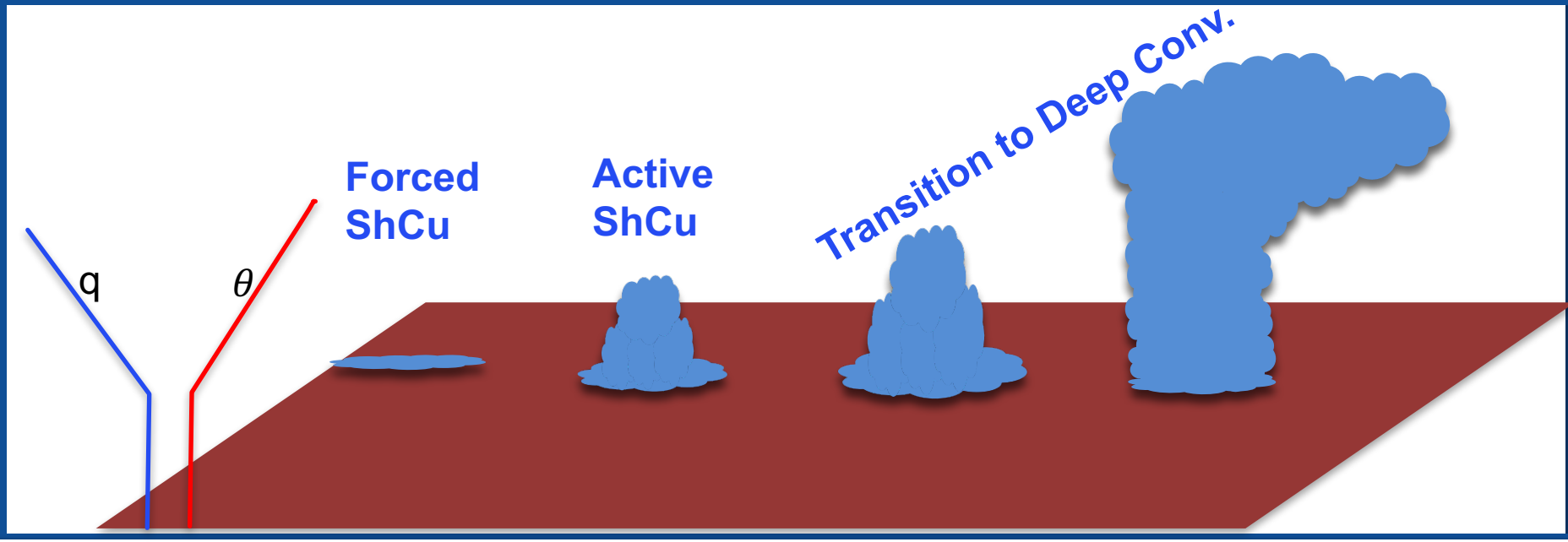
What are the Surface controlling factors?



What is the effect of soil moisture anomaly?

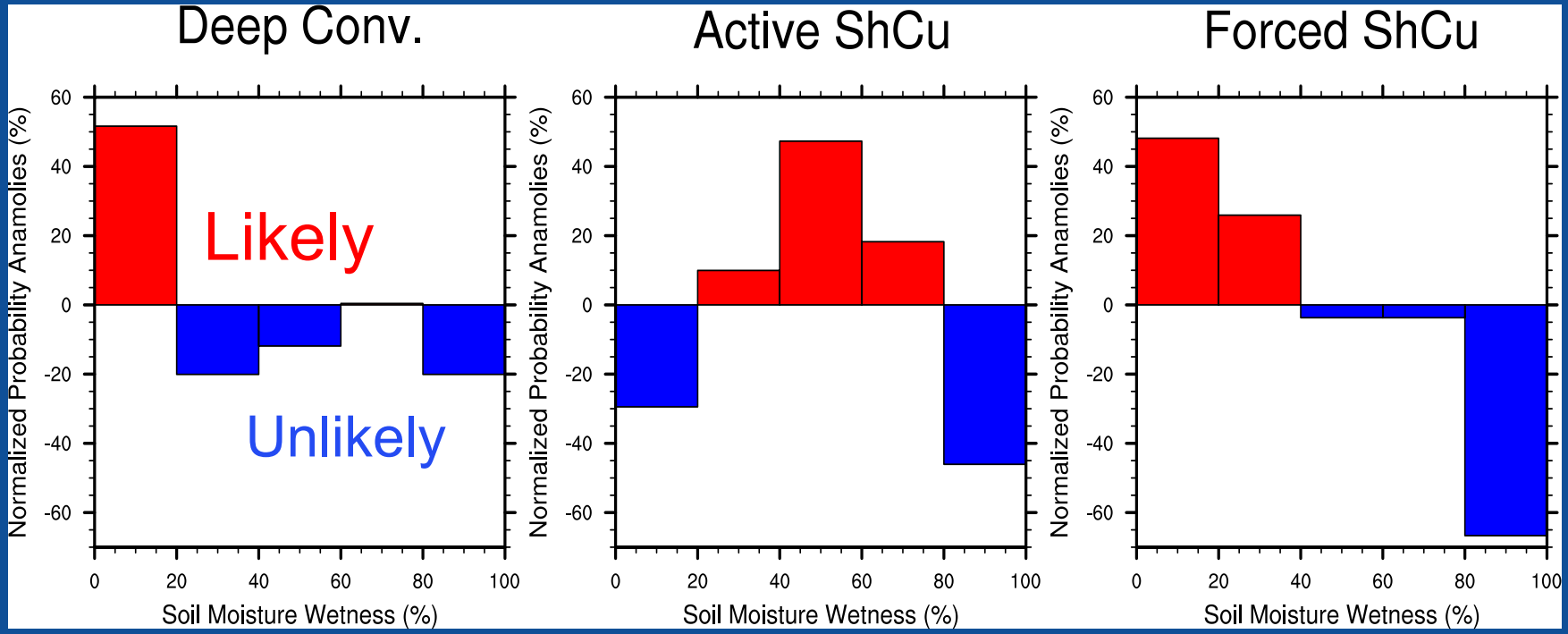
'LoCo Process Chain' $\Delta SM \rightarrow \Delta EF \rightarrow \Delta PBL \rightarrow \Delta ENT \rightarrow \Delta T_{2m}, Q_{2m} \blacktriangleright \Delta P/Clouds$
(a) (b) (c) (d)

Santanello, et al, 2011



Do Convective clouds preferentially occur on the days with dry/wet soil conditions?

Occurrence Probability Anomalies for different convective types



Zhang et al (2017b)

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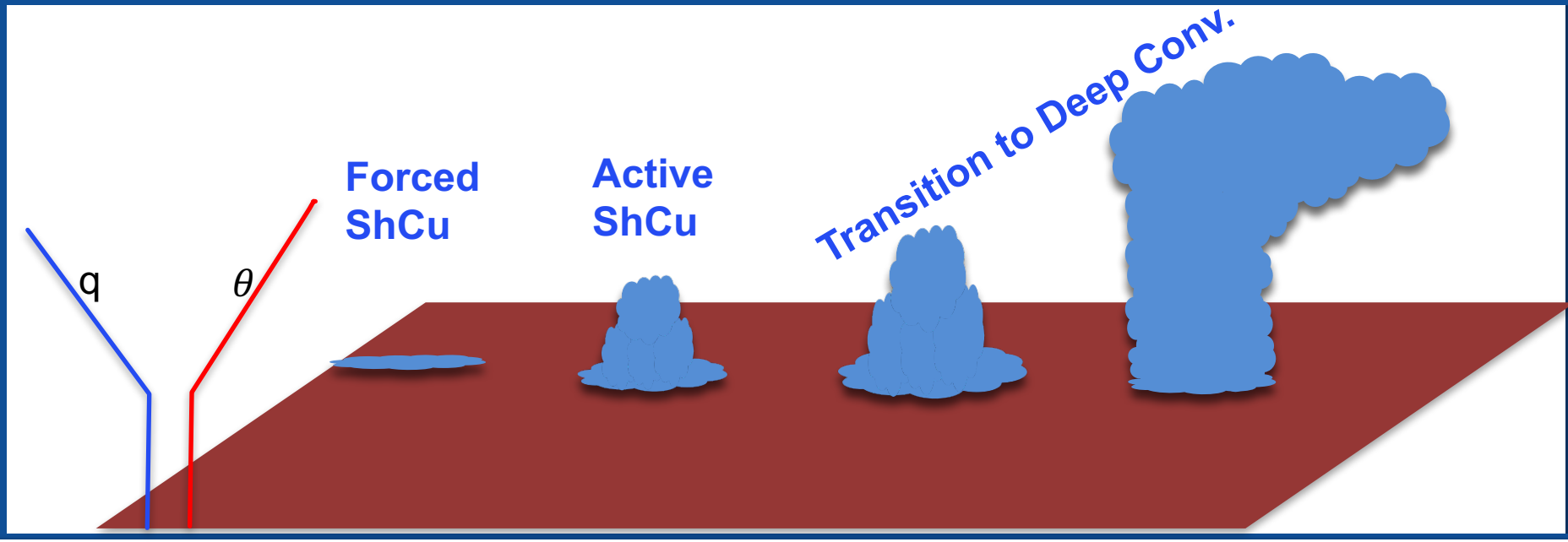
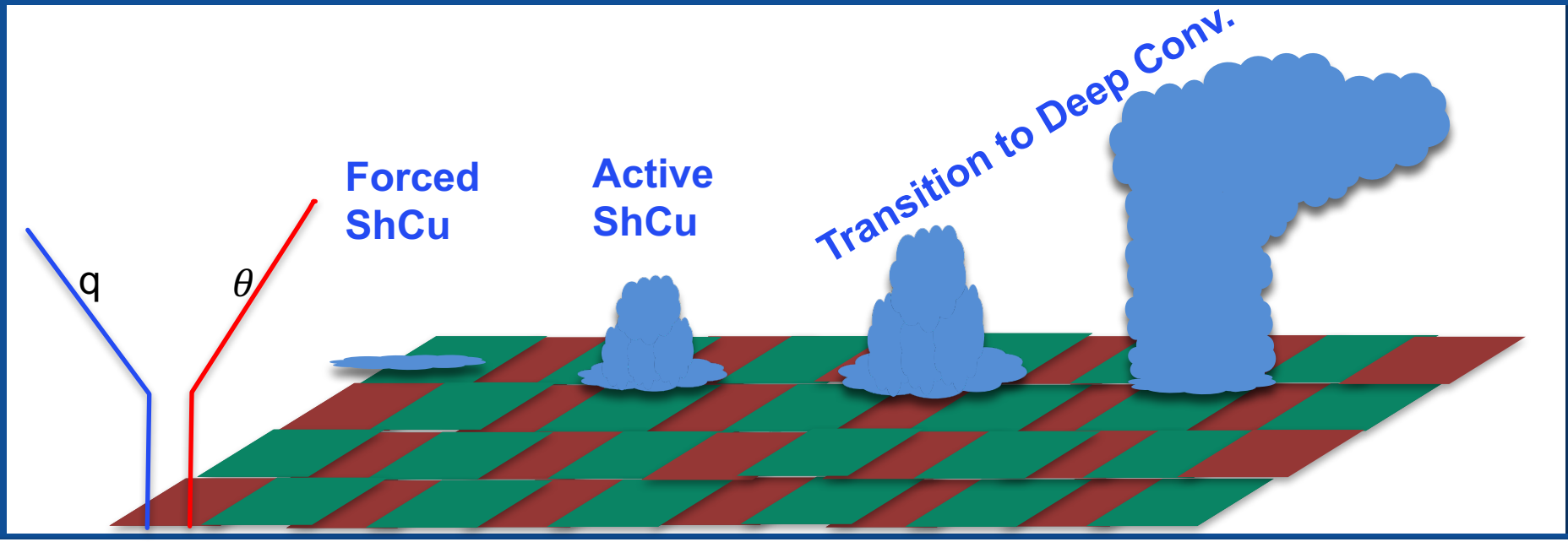


What is the effect of soil moisture heterogeneity?

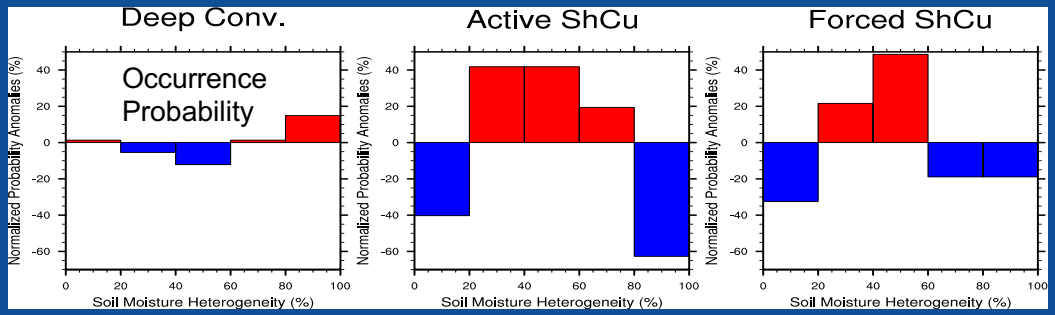
'LoCo Process Chain' $\Delta SM \rightarrow \Delta EF \rightarrow \Delta PBL \rightarrow \Delta ENT \rightarrow \Delta T_{2m}, Q_{2m} \blacktriangleright \Delta P/Clouds$
(a) (b) (c) (d)

Santanello, et al, 2011

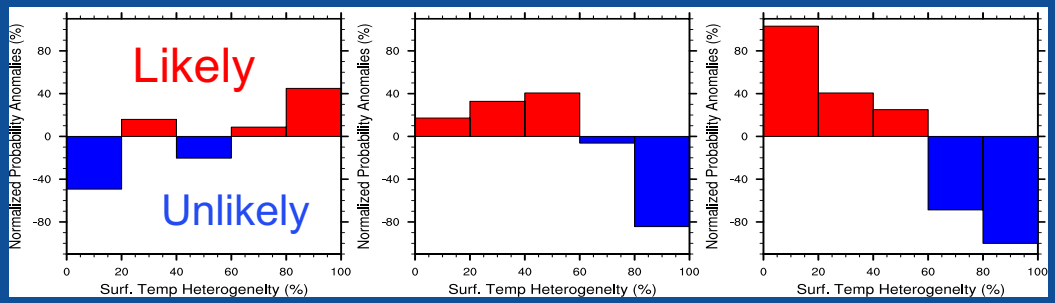
Spatial heterogeneity → **Meso-scale circulation**



Do convective clouds preferentially occur over small/large spatial heterogeneity or wind pattern?

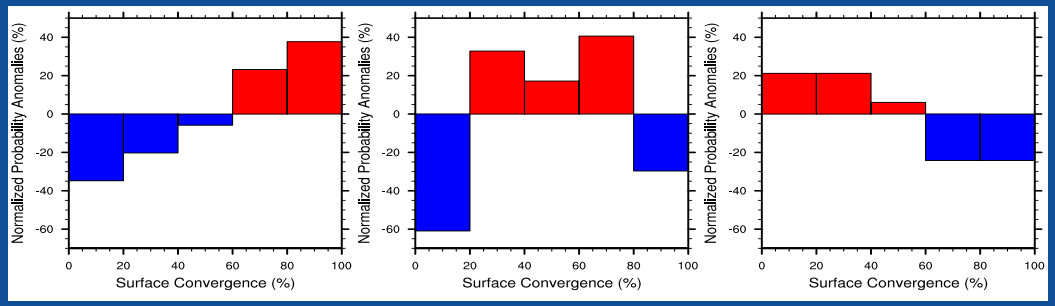


Soil Moisture heterogeneity



Temperature heterogeneity

Heterogeneity Small → Large



Mesoscale Wind convergence

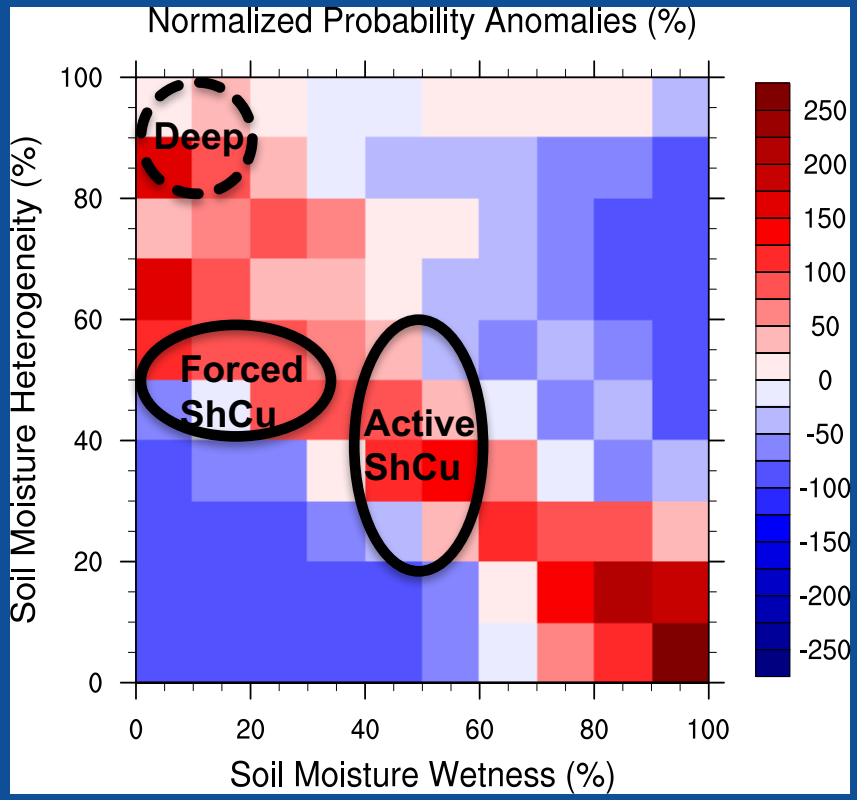
Wind Divergence → Convergence

Zhang et al (2017b)

What is the effect of soil moisture and heterogeneity on convective clouds?

Large

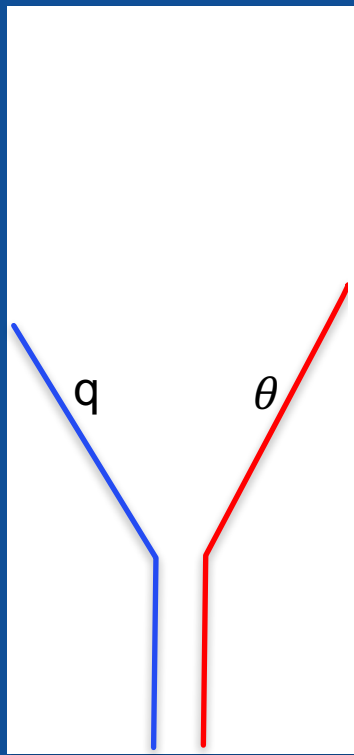
Small Heterogeneity

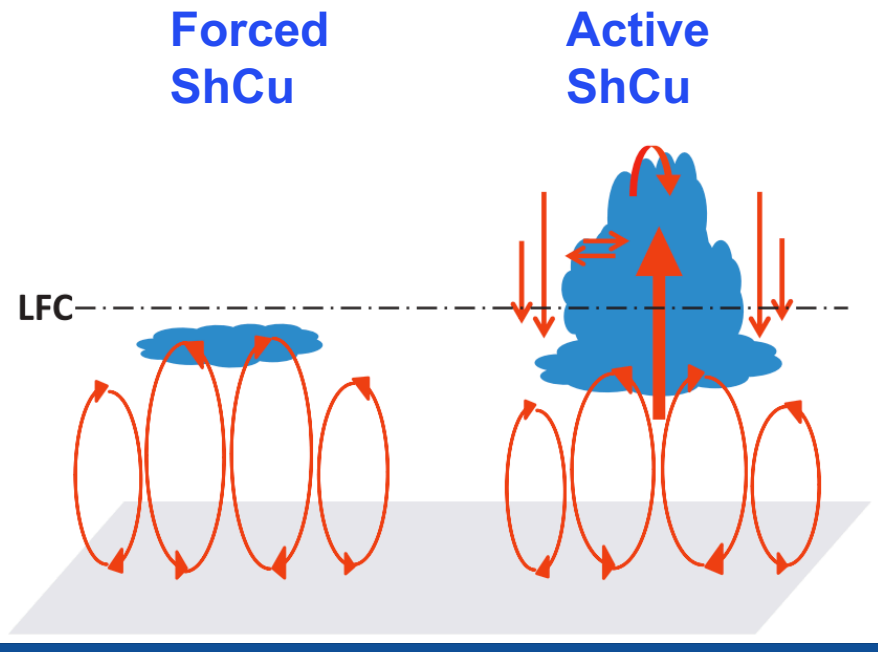


Dry → Wet

Zhang et al (2017b)

What do Doppler Lidar data tell us about the boundary layer control on ShCu?





Doppler Lidar Vertical Velocity 2011-2015
(Rob Newsom)

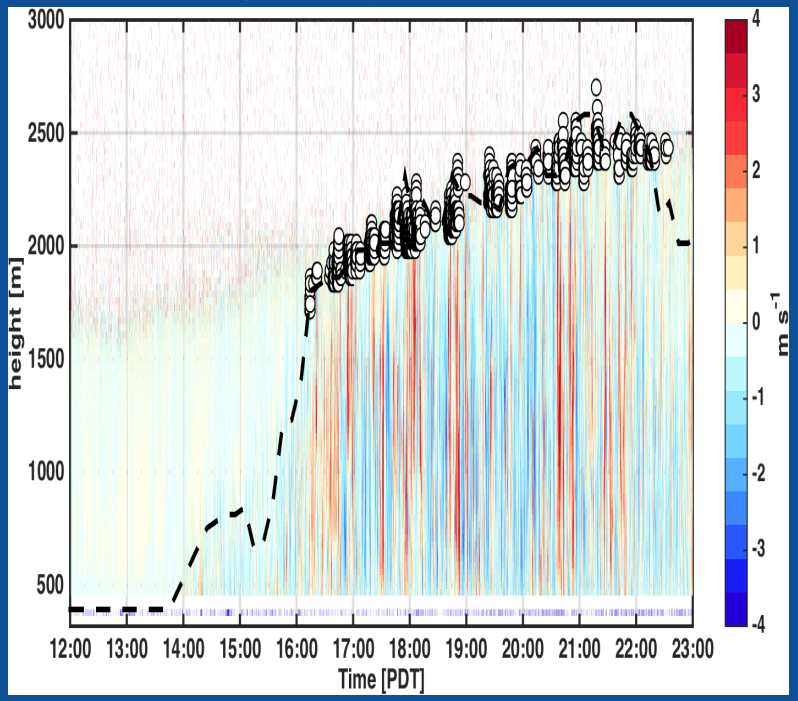
Traditional parameterization is built upon the sub-cloud layer turbulence's influence on shallow convection

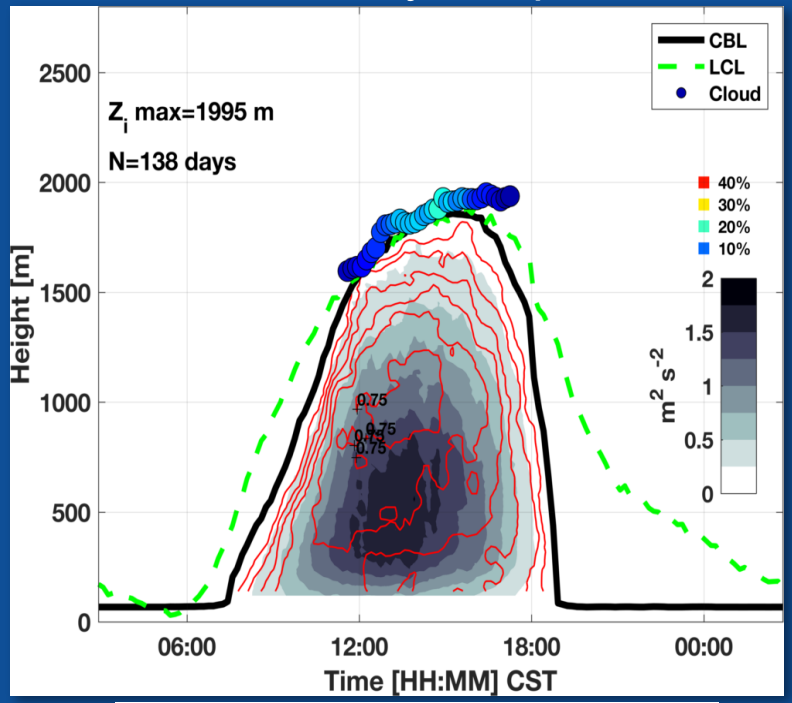
Can we use DL data to characterize ShCu sub-cloud layer turbulence?

Single-day Sample

Multi-day composite

Height





Time

Contour: vertical velocity variance
Red lines: vertical velocity skewness
Green Line: LCL
Black line: PBL top
Colored dots: cloud base & fraction

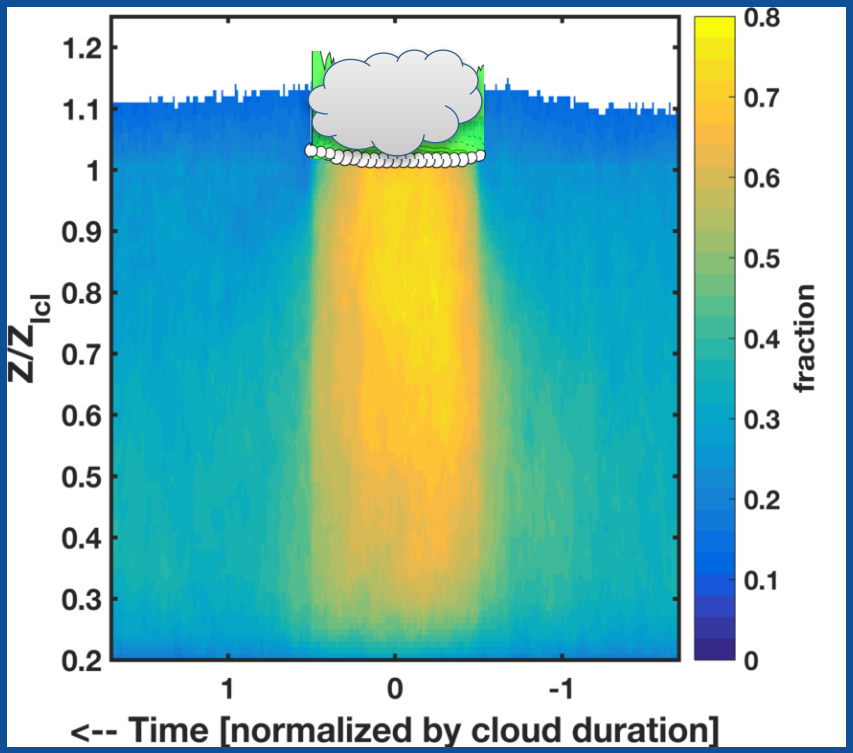
Lareau et al, 2017

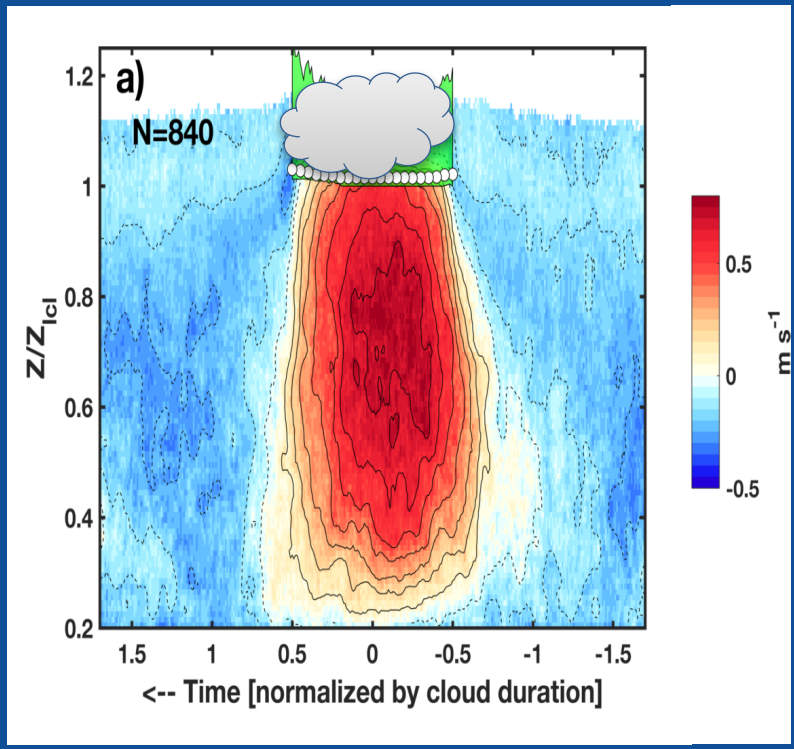
What is the distribution of vertical velocity under active Shallow Cumulus clouds?

Updraft Fraction

Mean Vertical Velocity

Normalized Height





Normalized distance*

Normalized distance*

Lareau et al, 2017

Can we use DL data test cumulus parameter. based on sub-cloud vertical velocity?

$\frac{\sqrt{CIN}}{W_{cb}}$ as a non-dimensional parameter based on DL data, the ability to break CIN barrier

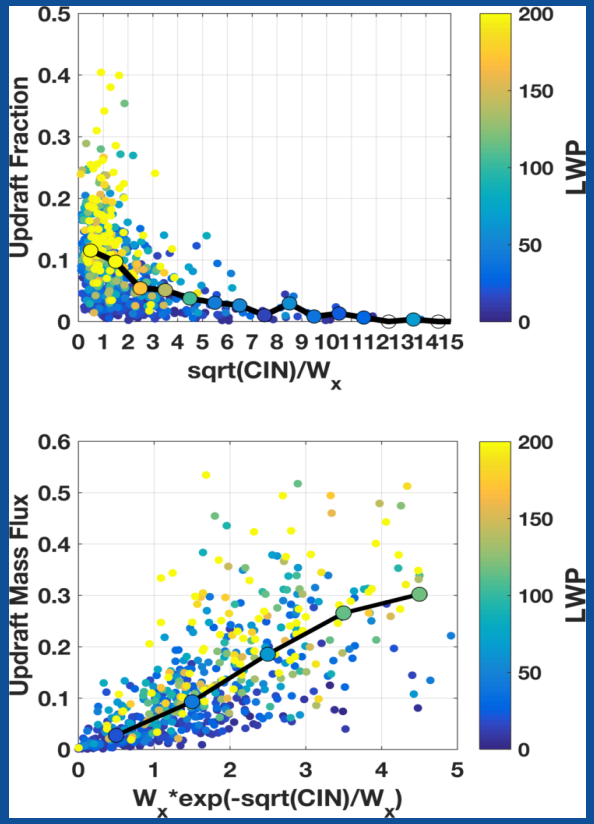
Updraft Fraction:

$$a_{cb} = c_1 \exp\left(-c_2 \frac{\sqrt{CIN}}{W_{cb}}\right)$$

W_{cb} is assumed to be proportional to TKE

Updraft Mass Flux:

$$m_{cb} = c_1 W_{cb} \exp\left(-c_2 \frac{\sqrt{CIN}}{W_{cb}}\right)$$



Similar analysis will be applied to DL data at boundary facilities over different land cover/types

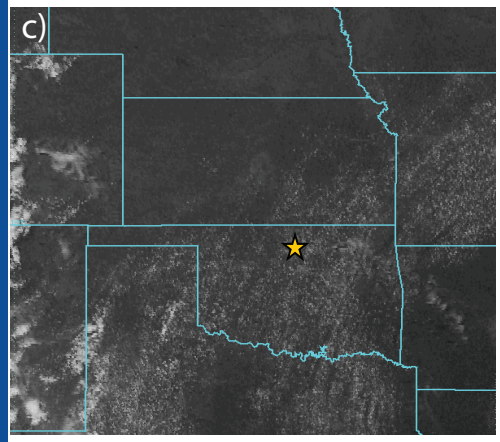
Lareau et al, 2017

1. What do we learn from ARM observations on continental convections and their coupling with land-surface?

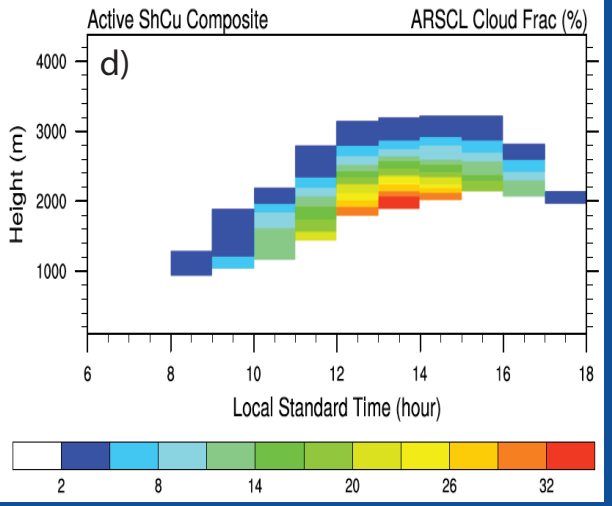
2. What do we learn from LES about ShCu physics including its coupling with land-surface?

A NEW composite case: Surface-forced ShCu

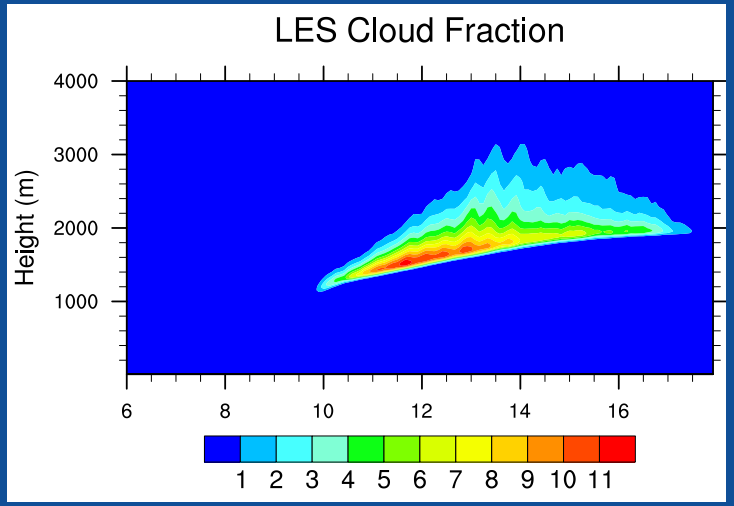
Satellite (one of 76 golden days)



ARM ARSCL composite



LES of the composite case



- A good case of “purely” surfaced-forced case built upon observations
- Consists of 76 ”golden” ShCu days
- Trace back very well to forcing data and numerous validation of cloud observations
- Serve as a starting point and basis for LES and SCM tests
- If interested, contact me!

Zhang et al, 2017a

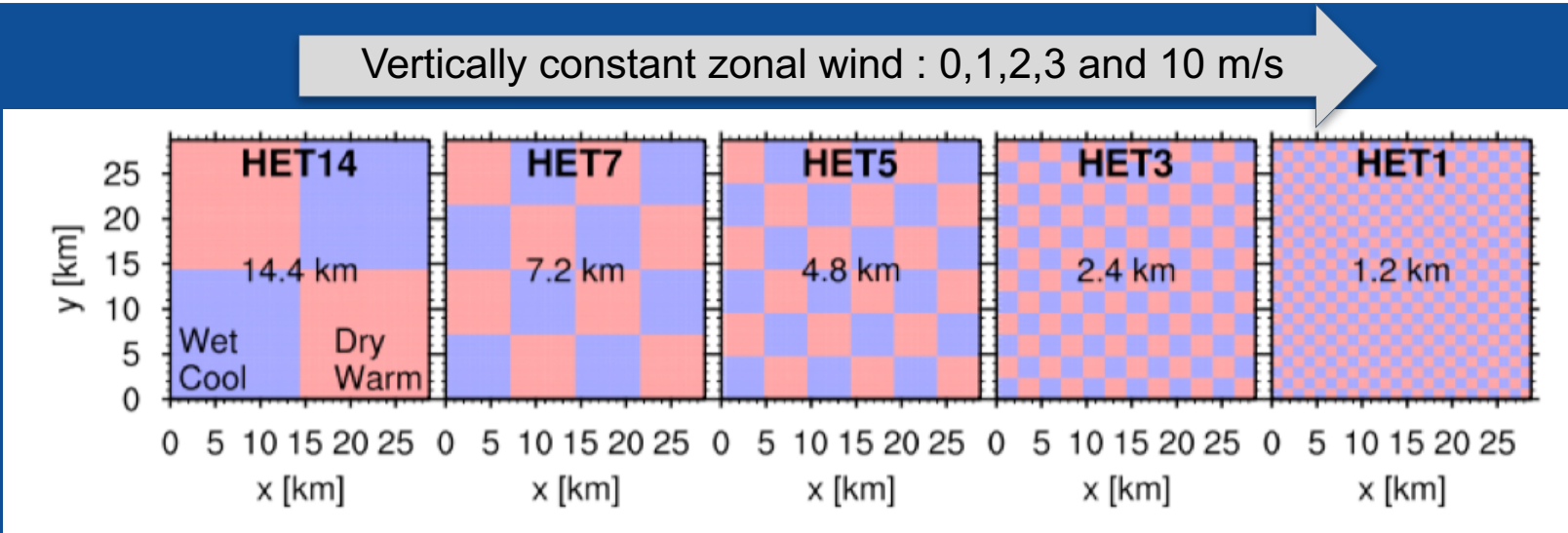
How will land heterogeneity affect ShCu?

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 effect

Lee et al (2017)

Prescribed surface fluxes and wind speed

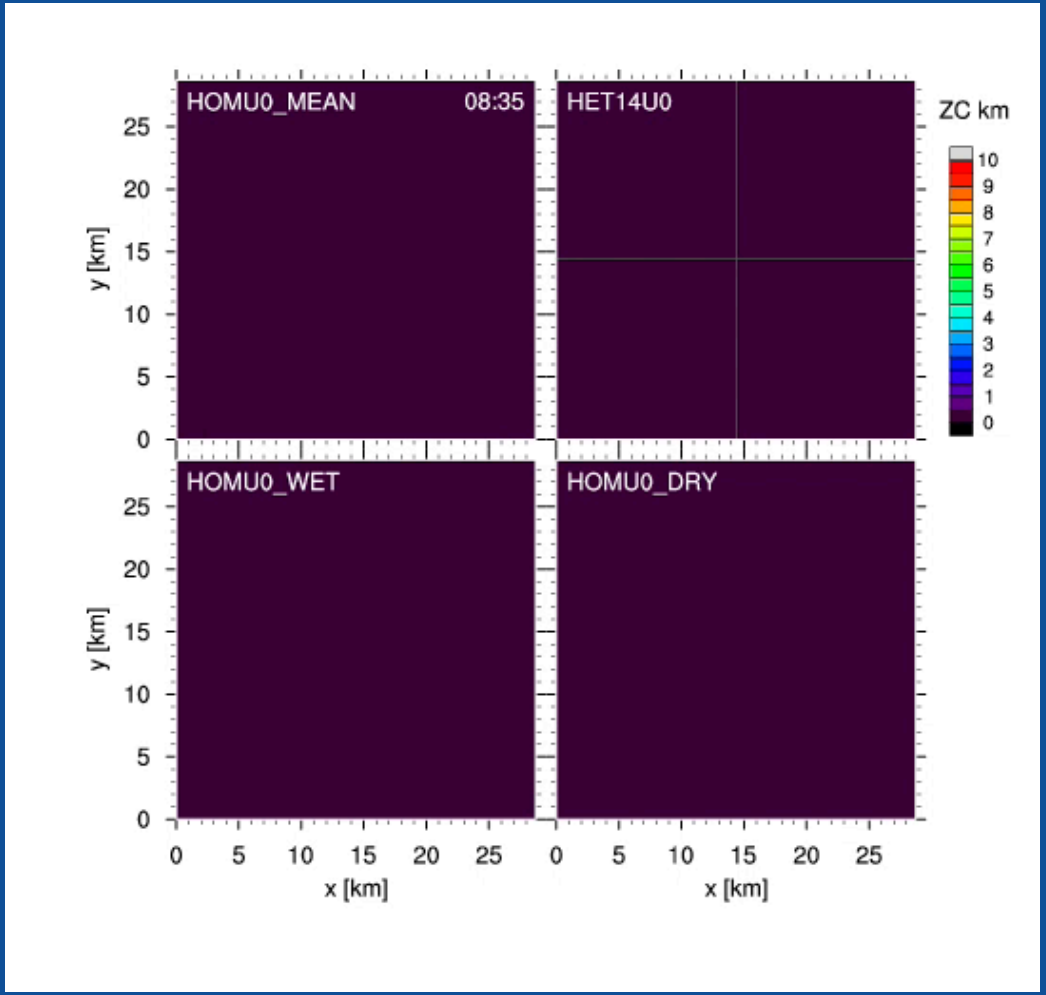


- SAM is used with prescribed surface fluxes (Khairoutdinov and Randall, 2003)
- Patch difference corresponds to the measurements by EBBR/ECOR over different vegetation
- Other model setup follows the composite ShCu case

Lee et al (2017)

Fate of shallow cumulus (zero background wind)

- No transition over homogeneous land under different evaporative fraction
- Surprise!! Shallow-to-deep transition occurs with surface flux heterogeneity

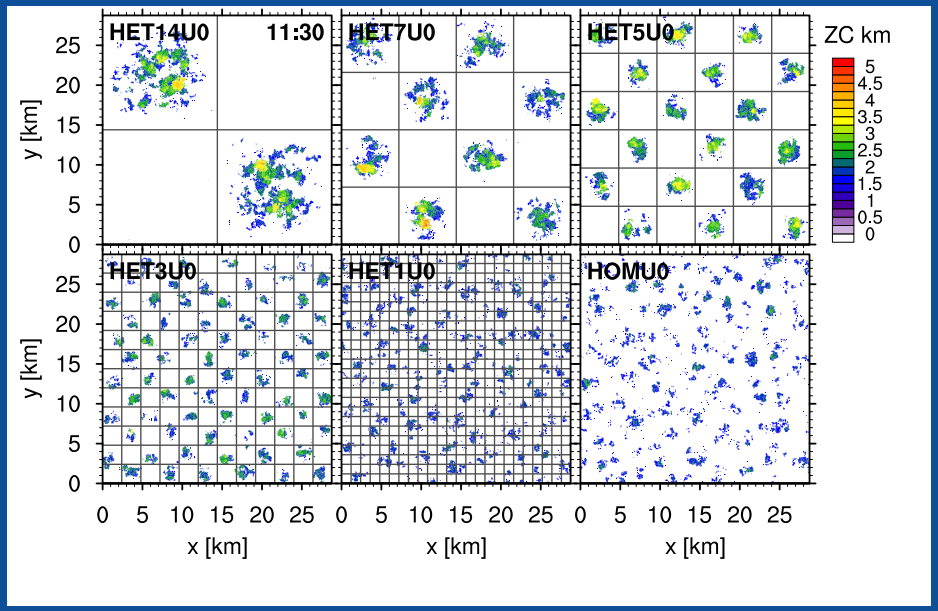


Lee et al (2017)

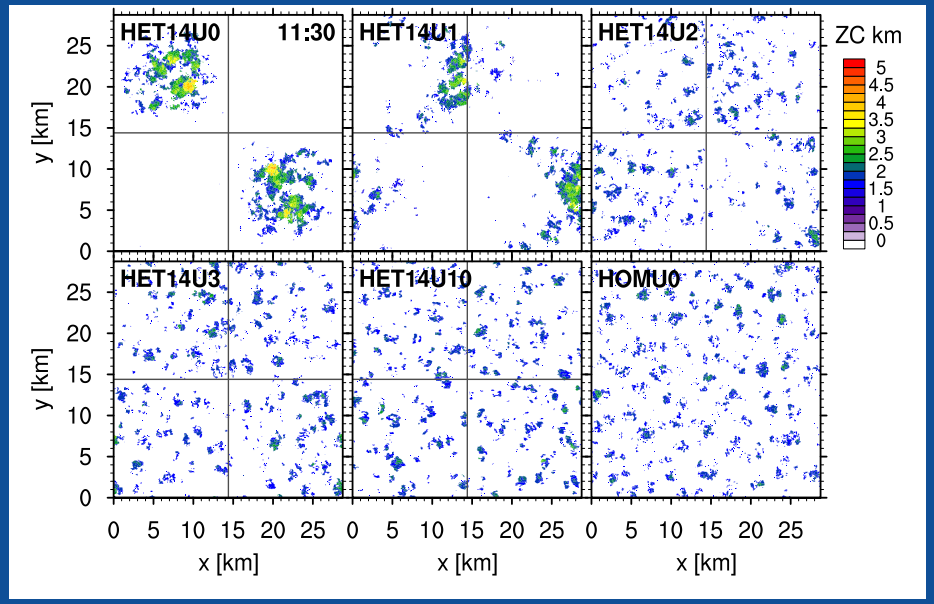
What is the dependence of clouds on the patch size and wind speed?

- Clouds form mostly over warm/dry patch with zero wind
- Clouds form over the patch boundaries with weak wind

Cloud top height over different patch sizes



Cloud top height for different wind speeds



Lee et al (2017)

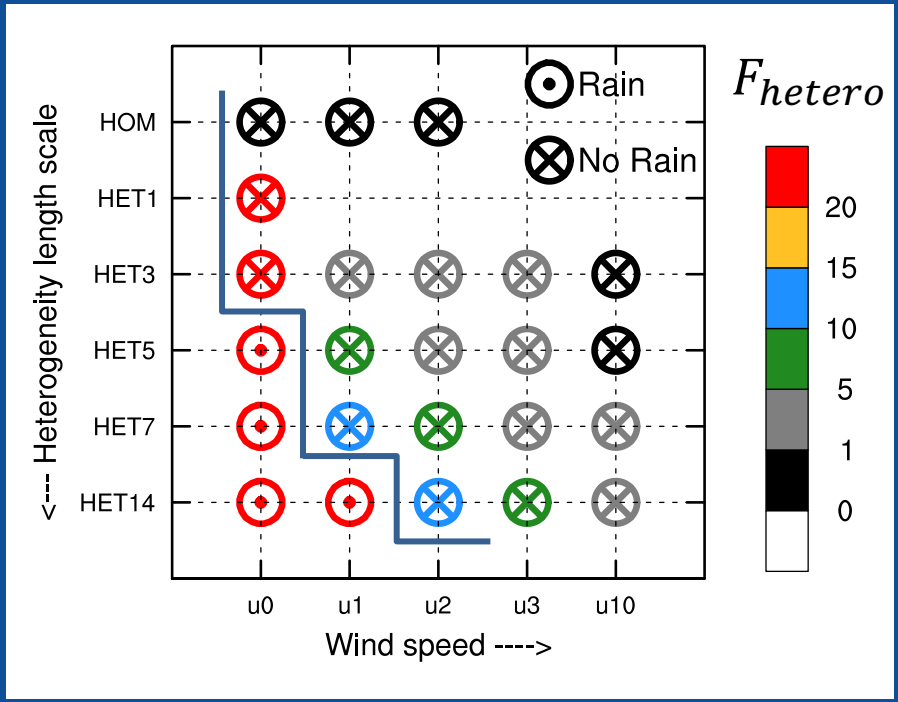
Can we generalize the effect of patch size and wind speed on convection development?

A non-dimensional parameter F_{hetero}

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

$$= \frac{time\ for\ flow\ to\ cross\ the\ patch}{time\ for\ thermals\ to\ rise\ through\ the\ PBL}$$

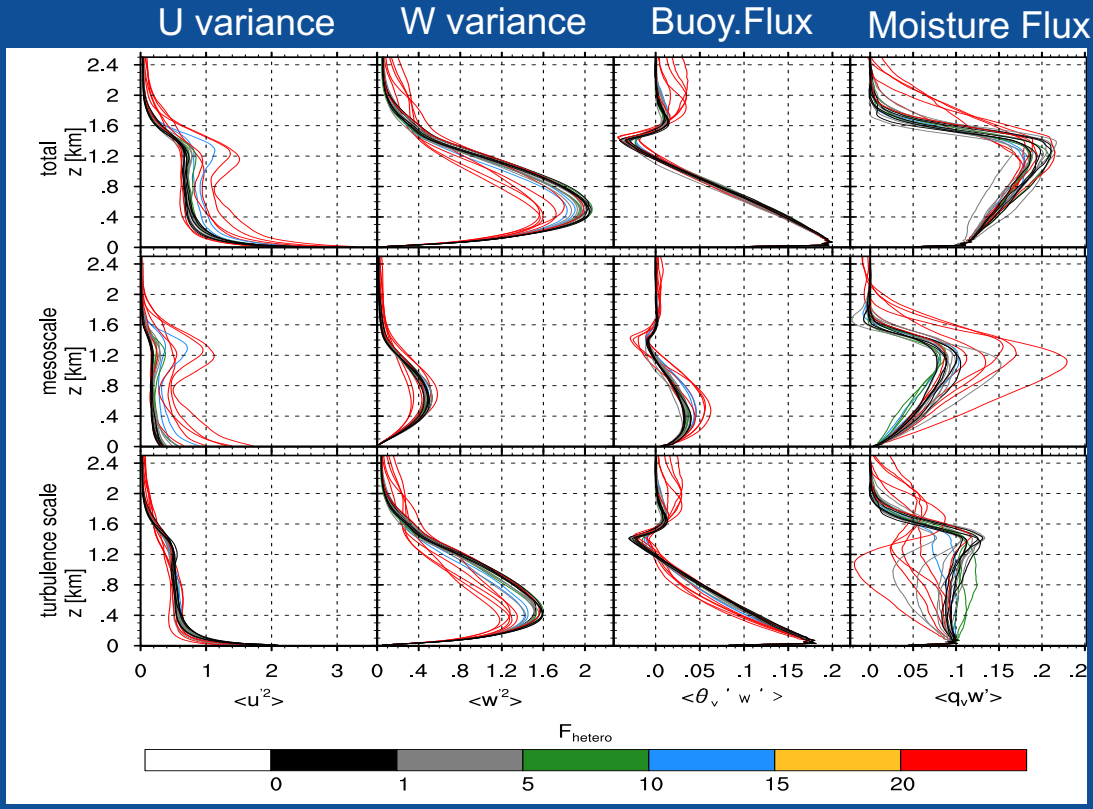
(Mahrt, 2001)



- Transition of ShCu to Deep Cu. : F_{hetero} >= 20 & L_{patch} >= 5km
- Precipitating convection develops when F_{hetero} is 20 regardless of patch size and wind speed, such as HET7U0.5, HET14U1, or HET28U2

Lee et al (2017)

What happens in PBL when F_{hetero} >= 20?



- Shallow-to-deep cases with organized “mesoscale” circulation
- Non-transition cases show similarity to homogeneous case

Lee et al (2017)

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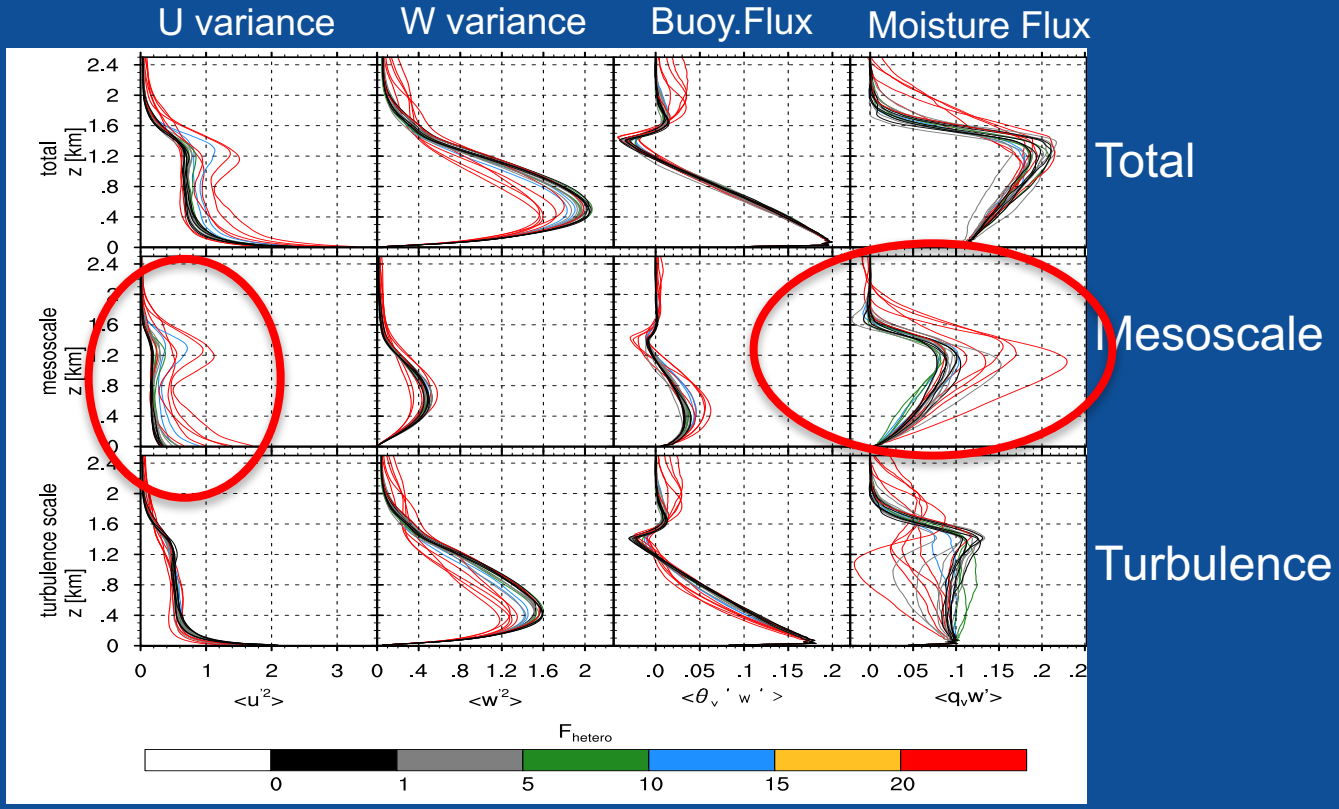

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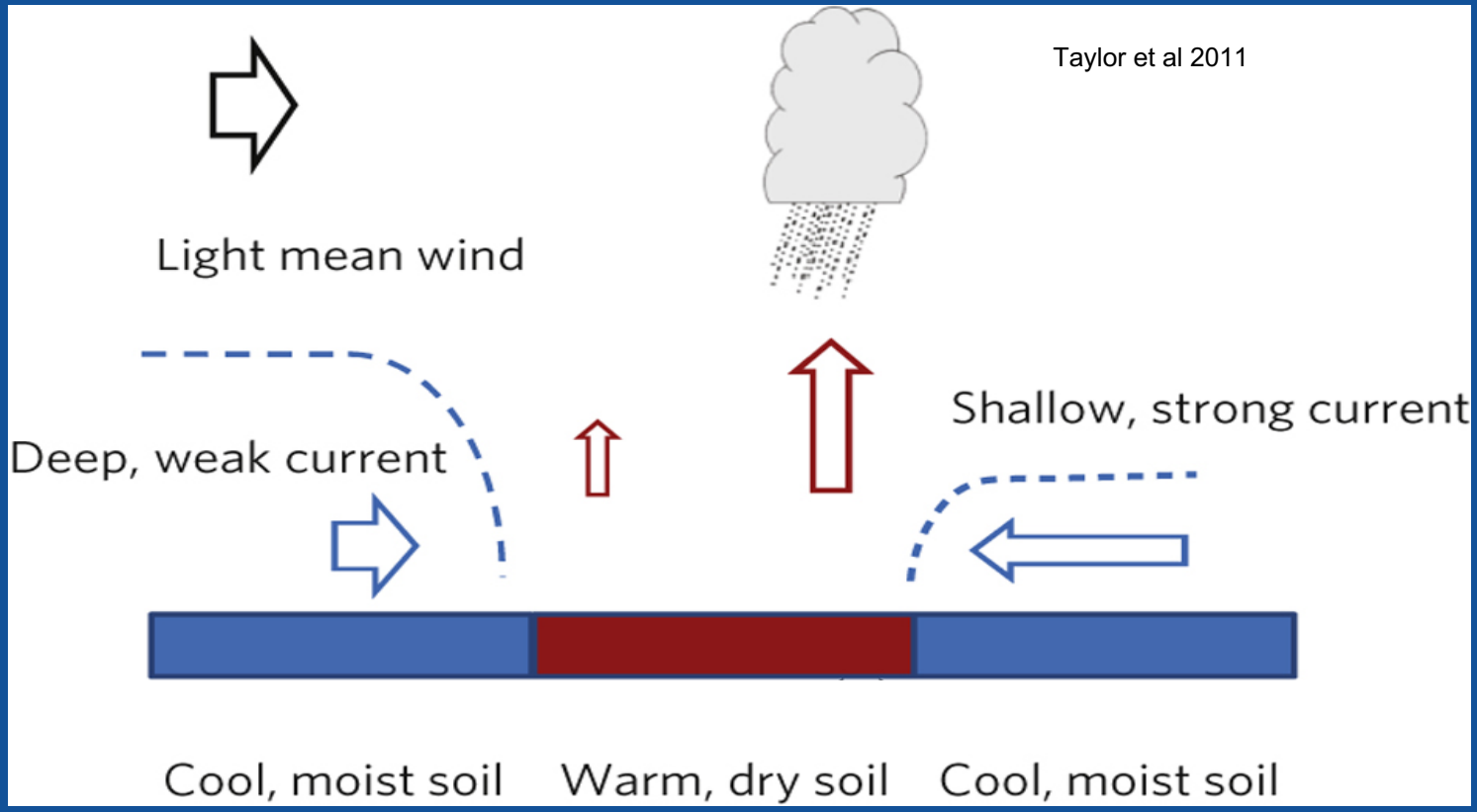

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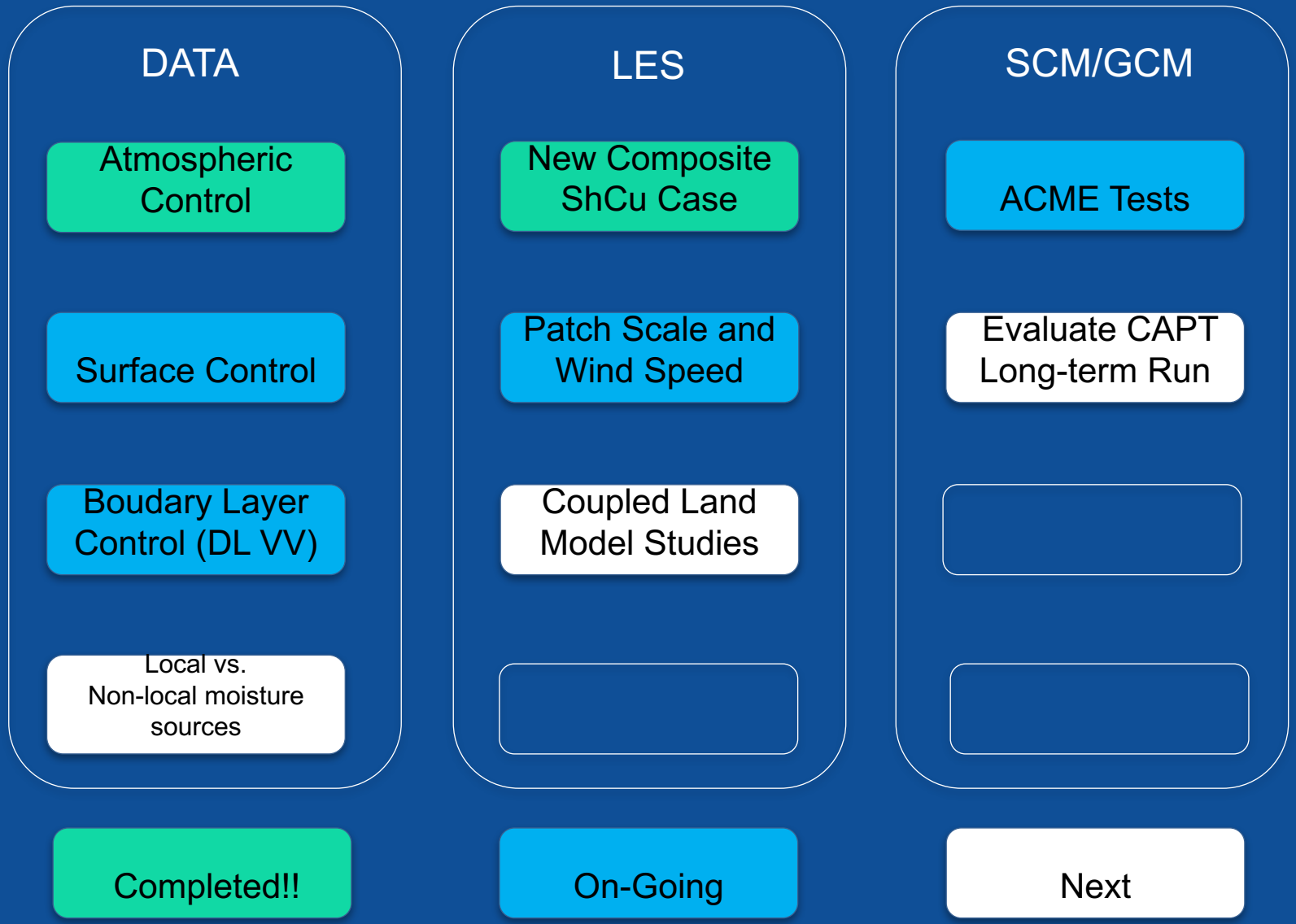
Lee et al (2017)

Where are we and our next steps?



Thank you!