# Exploring the Mechanisms of Land-Atmosphere Interactions during HI-SCALE

Jingyi Chen[1], Samson Hagos[1], Heng Xiao[1], Robert Houze[1, 2], Jerome Fast[1], Zhe Feng[1]

[1] Pacific Northwest National Laboratory, Richland, WA, USA [2] Department of Atmospheric Sciences, University of Washington, Seattle, WA, USA

Pacific Northwest NATIONAL LABORATORY

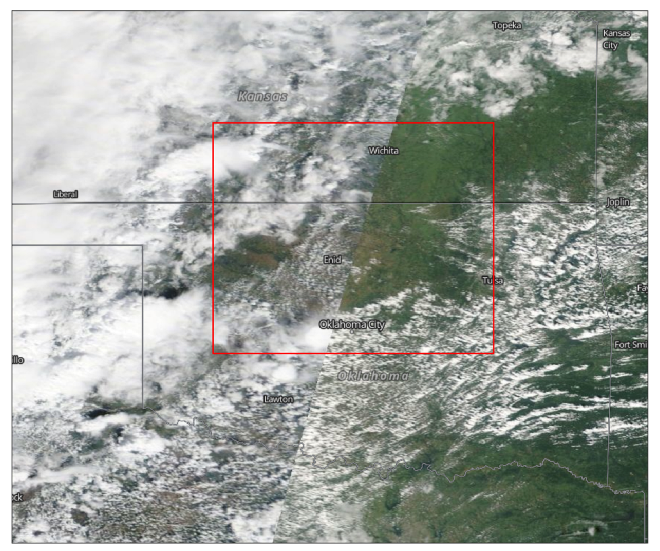
## Introduction

Land-atmosphere interactions play important roles in the initiation of shallow convection and the subsequent potential transitions to deep convection. This study explores how the land properties are related to the convection and cloud populations during daytime over Southern Great Plain (SGP) based on an LES-version of WRF Simulations. Isentropic and cluster analysis of **Equivalent potential temperature ($\theta_e$)** are used to assess how land surface conditions lead to the simulated cloud populations.

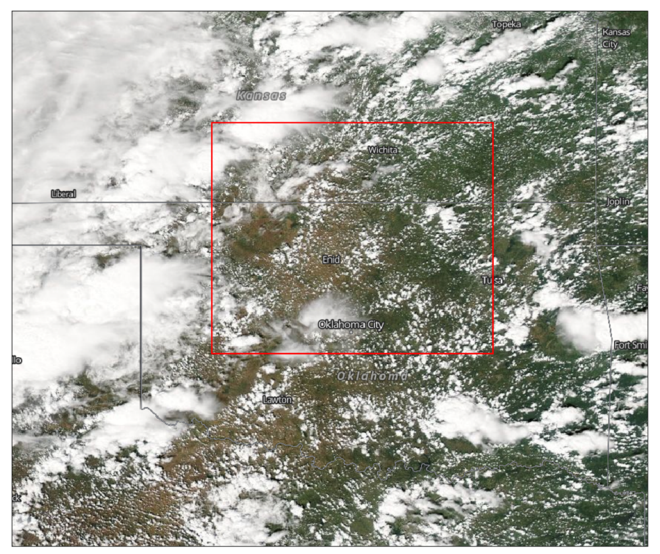
## Case Overview

- **Time and Location:** August 30th, 2016, Southern Great Plain
- A "Golden Day" with transitions from shallow to deep convection

**MODIS Terra ~1630 UTC (~1030 CST)**



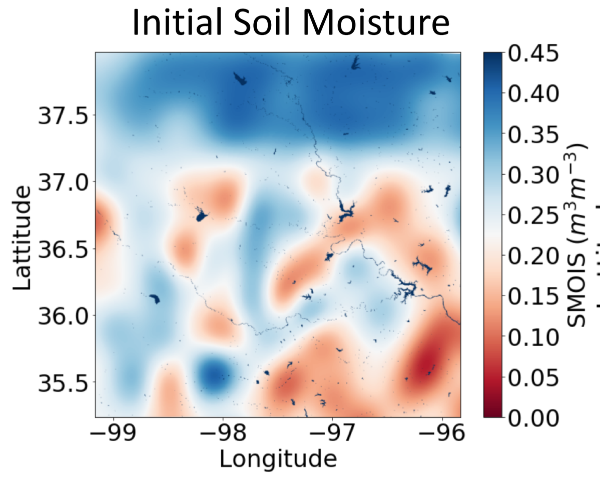
**MODIS Aqua ~1950 UTC (~1350 CST)**



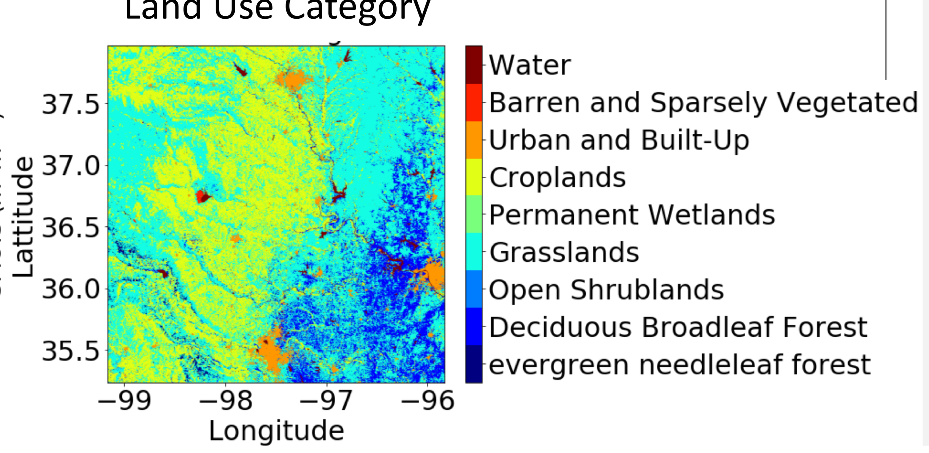
## WRF-LES Simulations

- From 08/30 12:00 UTC to 08/31 00:00 UTC
- Spatial Resolution: 300m
- Output time step: 15 min
- More details are in Jerome Fast's talk (A41D03) on Thursday.

Initial Soil Moisture




Land Use Category




## Isentropic Analysis

**Isentropic analysis helps to**

- reduce the 4D dataset into 3D (horizontal 2D -> $\theta_e$),
- separate the air between the ascent, warm, moist air and subsiding, cold, dry air, and
- isolate the irreversible convection overturning by filtering out reversible motions.

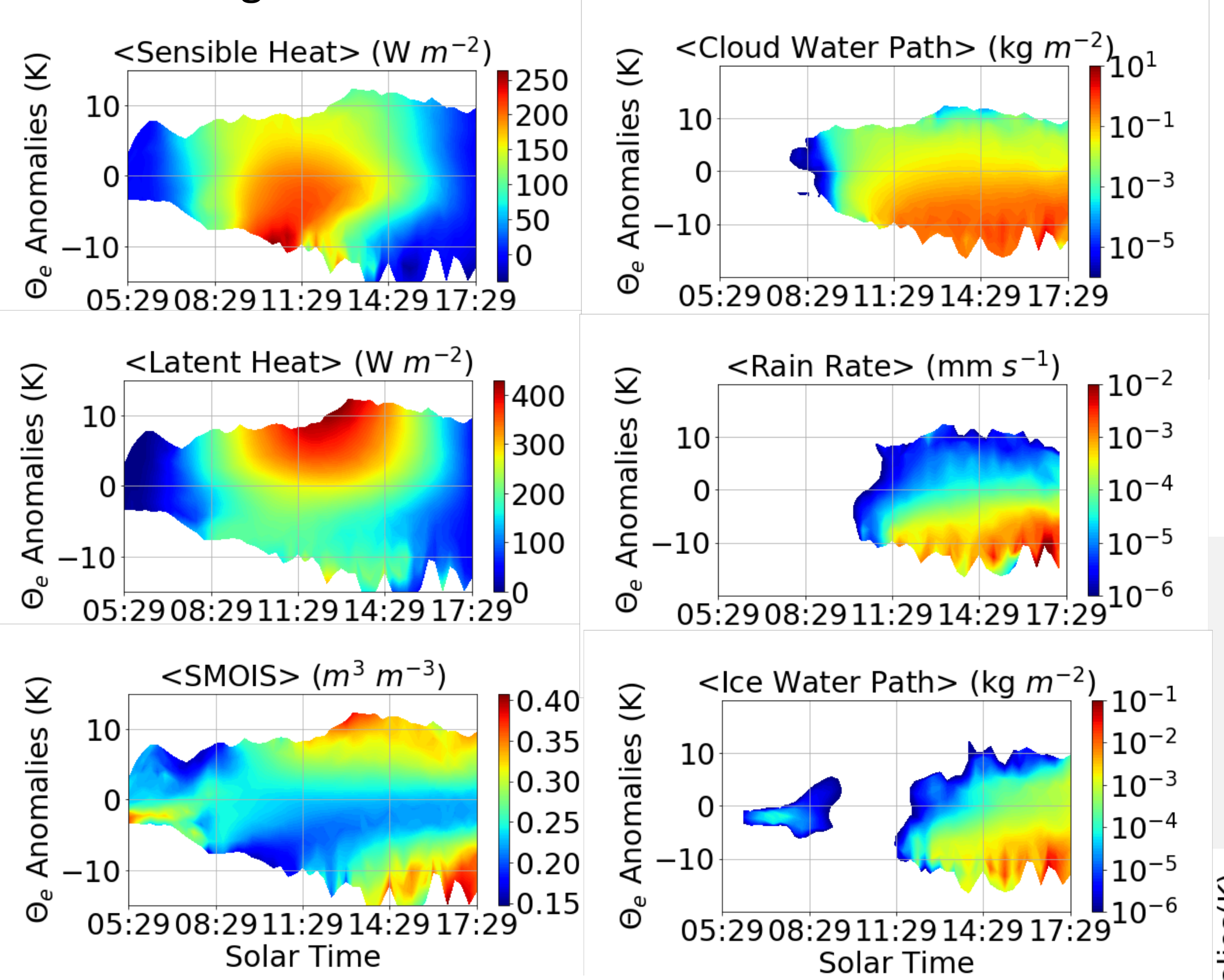



**Figure 2.** Isentropic distribution of surface properties.

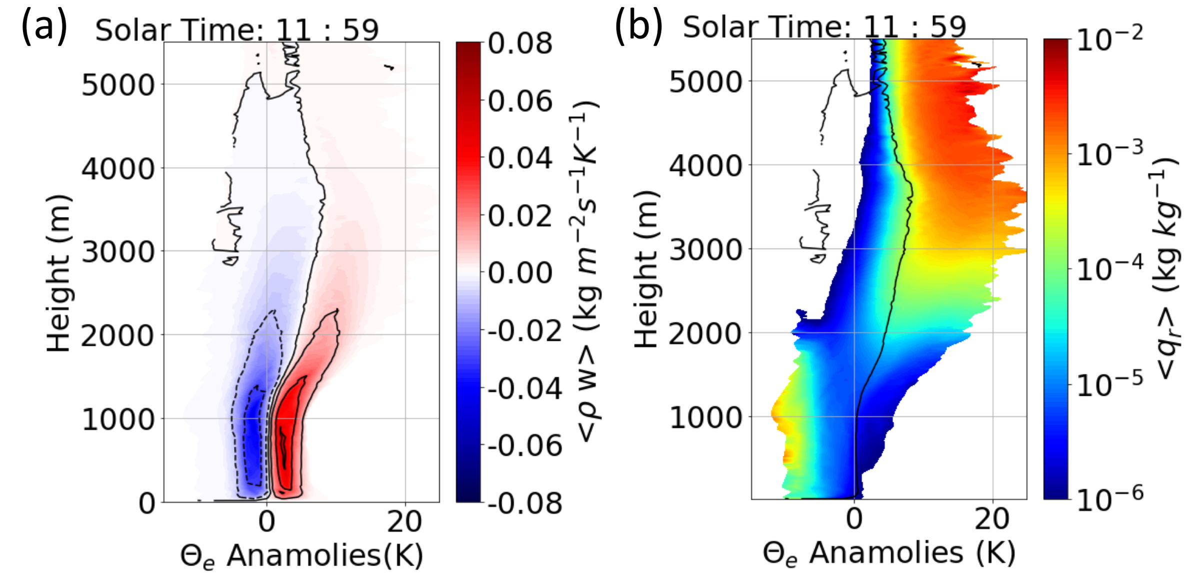



**Figure 1.** Isentropic distribution of (a) mass flux and (b) rain water mixing ratio.

$$< \rho x > (z, \theta_{e0}) = \frac{1}{L_x L_y} \iint_{0\,0}^{L_x L_y} [\rho x \, \delta(\theta_e - \theta_{e0})] \, dx \, dy \quad \text{(Eq.1)}$$

$$< x > = < \rho x > / < \rho > \quad \text{(Eq.2)}$$

**In lower troposphere (Figure 1):**

- Upward mass flux is associated with positive $\theta_e$ anomalies ($\theta_e'$), and vice versa.
- Rainwater starts to appear over the region with positive $\theta_e'$, and falls on the region with negative $\theta_e'$.

**Over surface (Figure 2):** lowest level $\theta_e'$ ($\theta_{es}'$)

- High $\theta_{es}'$ are associated with high latent heat (LH) and low sensible heat (HFX).
- Soil moisture (SMOIS):
  a. High initial SMOIS causes high LH, so the $\theta_{es}'$ of those region increase.
  b. Raining events cause another high SMOIS region with low $\theta_{es}'$.
- Regions with large cloud water path are over low $\theta_{es}'$.

**Land use type (Figure 3):**

- Grassland and broadleaf forest are associated with high values of $\theta_{es}'$, while cropland, urban and water are associated with low values of $\theta_{es}'$.

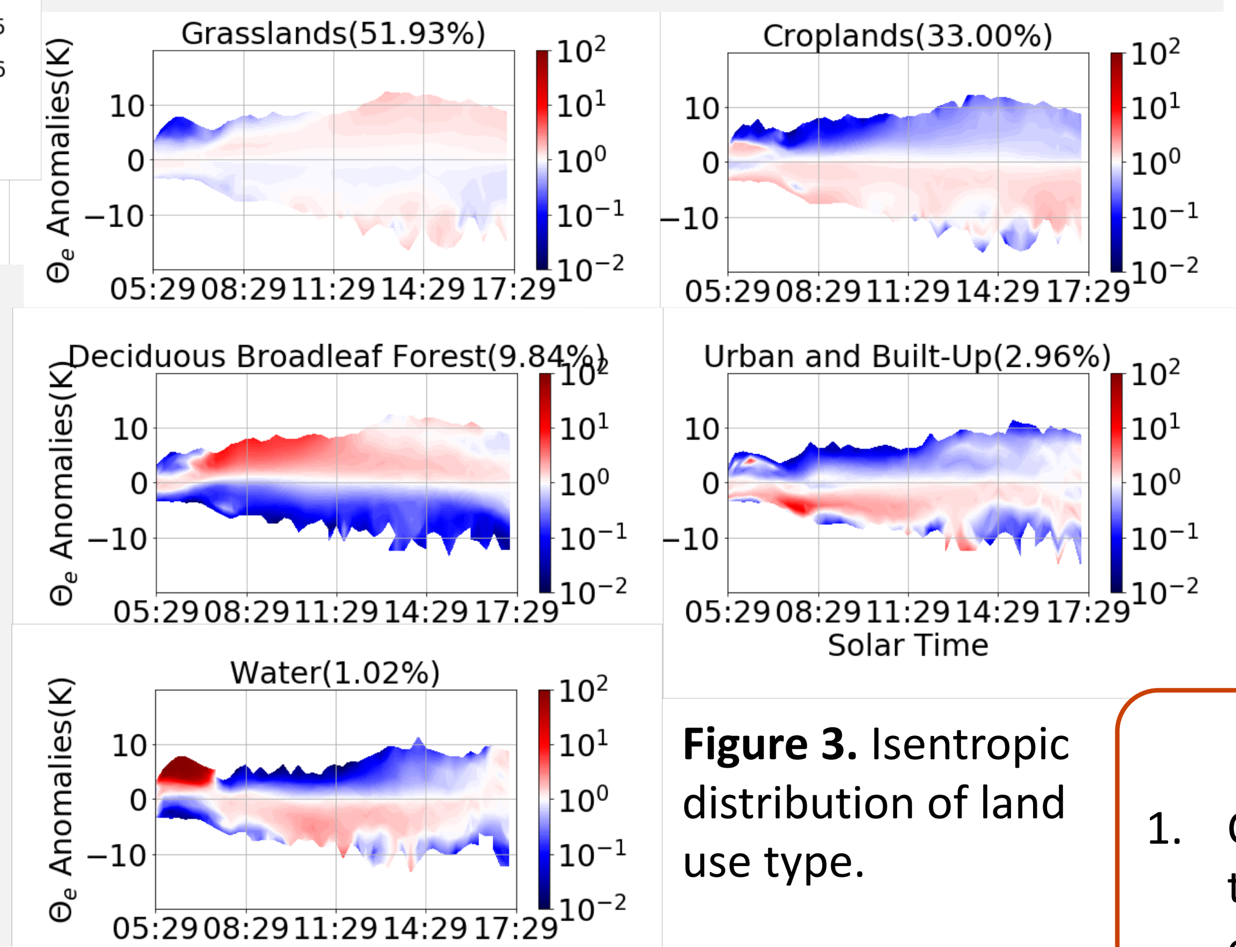



**Figure 3.** Isentropic distribution of land use type.

$$\frac{< LU_i > (z, \theta_{e0})}{f_i} = \frac{\frac{\iint \delta(LU, LU_i)\delta(\theta_e, \theta_{e0}) dx\, dy}{\iint \delta(\theta_e, \theta_{e0}) dx\, dy}}{\frac{1}{L_x L_y} \iint \delta(LU, LU_i)\, dx dy} \quad \text{(Eq. 3)}$$

## Cluster Analysis

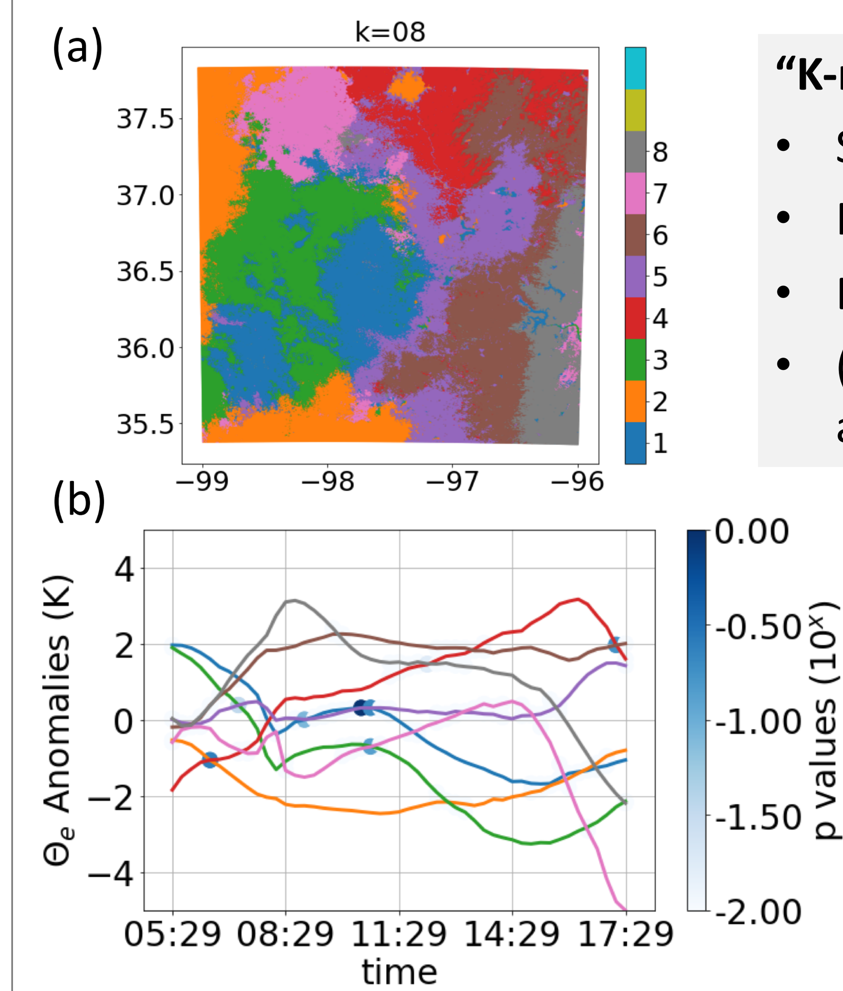



**Figure 4.** (a) Cluster analysis of $\theta_{es}'$. (b) $\theta_{es}'$ time series of each cluster.

**"K-means" unsupervised learning (Figure 4)**

- Samples: $\theta_{es}'$ over all the grids (990×990)
- Features: 49 time steps
- Eight clusters
- (Figure 4b) The trends of $\theta_{es}'$ time series among clusters are dramatically different.

**Budgets of $\theta_e$ (Figure 5):**

$ln\theta_e = ln(\theta) + c_1 q_v$ ($c_1$ is constant)

$\rightarrow d\, ln\theta_e/dt = d\, ln\theta/dt + c_1 dq_v/dt$

- Contributions from $dln\theta/dt$ to $d\, ln\theta_e/dt$ are more than those from $c_1 dq_v/dt$.
- Most of the variations among clusters are explained by $c_1 dq_v/dt$.

- Period 1 (5:29-8:29):
  High LH causes high $c_1 dq_v/dt$, hence high $dln\theta_e/dt$ and increasing $\theta_{es}'$.
- Period 2 (8:29-11:29):
  Negative $c_1 dq_v/dt$ and positive $dln\theta/dt$ are balanced.
- Period 3 (11:29-14:29):
  Rain processes compensate the water vapor depletion.
- Period 4 (14:29-17:29):
  Similar with P3 except for more rain.

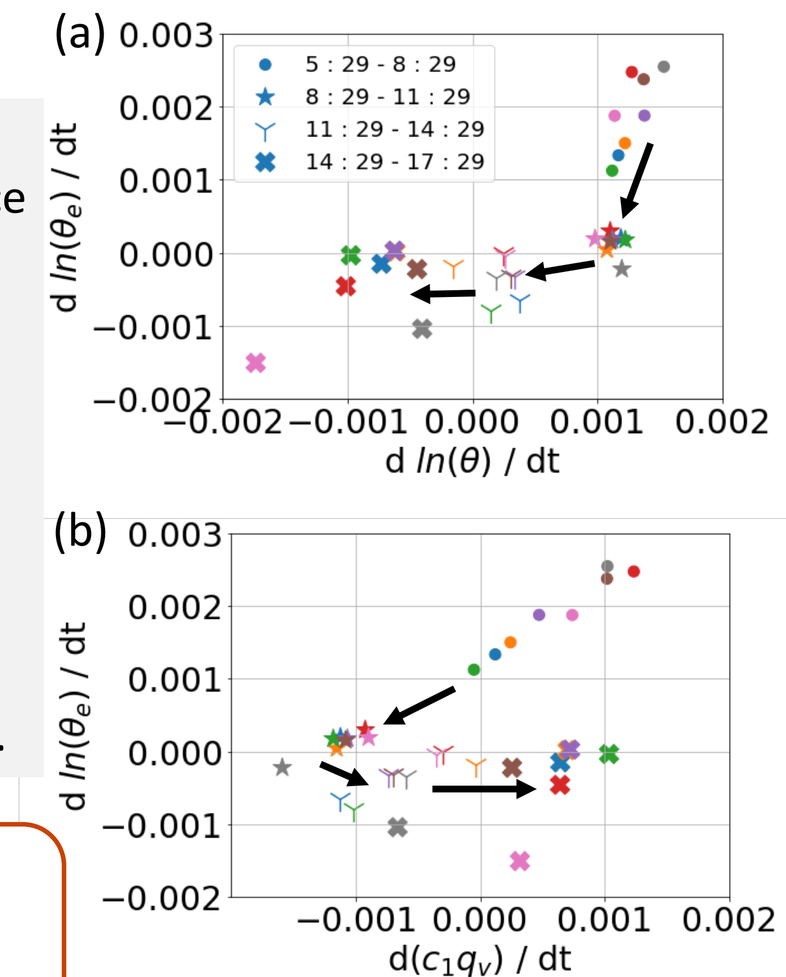



**Figure 5.** Contributions from (a) $dln\theta/dt$ and (b) $c_1 dq_v/dt$ to $dln\theta_e/dt$ for the 8 clusters from Figure 4.

## Summary

1. Convection points start with high $\theta_e$, which is transported upward. As rain is formed, rain falls over the low $\theta_e$ environment.
2. Convection prefers to occur over grassland and forest, rather cropland, urban and water.
3. The spatial variations of $q_v$ tendency are larger than those of $\theta$ tendency, and hence contribute more to the different trends of $\theta_e$ time series.

**Notations:**

$\theta_e$: equivalent potential temperature
$\theta_e'$: $\theta_e$ spatial anomalies
$\theta_{es}'$: lowest level $\theta_e'$ (about 10m)
$\theta$: potential temperature
$q_v$: water vapor mixing ratio
$\rho$: air density (in Eq.1)
$L_x$ or $L_y$: domain size (in Eq.1 and Eq.3)
LU: index of the land use type (in Eq.3)
z: the height above the ground (in Eq.3)
$\theta_{e0}$: the $\theta_e$ of each isentropic contour (In Eq. 1 and Eq.3)
$\delta()$: Dirac's delta function (in Eq.1 and Eq.3)
$f_i$ : fraction of the i[th] land use type over domain (in Eq.3)

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**For more information, contact jingyi.chen@pnnl.gov**