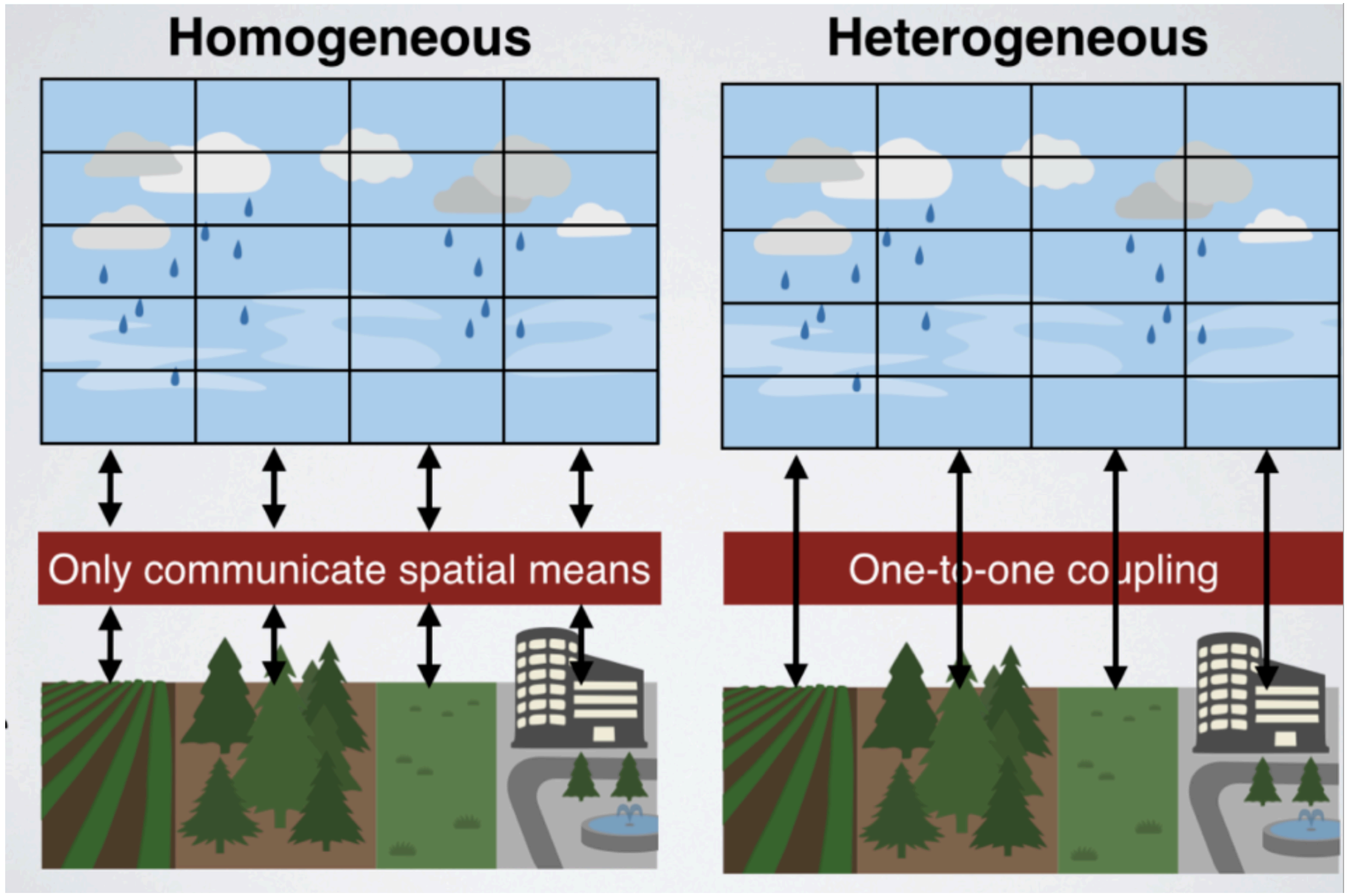
Pacific Northwest
NATIONAL LABORATORY

Understanding the land-atmosphere interactions at grid and subgrid scales in E3SM

Meng Huang, Po-Lun Ma, Ruby Leung
PNNL

Nathaniel Chaney
Duke University

Coupling of Land and Atmospheric Subgrid Parameterizations (CLASP)



- Land-surface heterogeneity can affect the atmosphere (e.g., turbulence, clouds, and the surface climate).
- Current E3SM has subgrid treatments for land and atmosphere, but they interact at grid scale.
- Our goal is to improve the representation of land-atmosphere coupling that accounts for land heterogeneity

Pacific Northwest NATIONAL LABORATORY

How do we account for land heterogeneity?

CLUBB vs. CLASP surface boundary conditions

- Surface moments needed to describe land-atmosphere interactions
  - Vertical fluxes: $\overline{u'w'}$, $\overline{v'w'}$, $\overline{w'\theta'}$, $\overline{w'q'}$
  - Second-order: $\overline{w'^2}$, $\boldsymbol{\overline{\theta'^2}}$, $\overline{q'^2}$, $\overline{\theta'q'}$
  - Third-order: $\overline{w'^3}$, $\overline{w'^2\theta'}$, $\overline{w'^2q'}$, $\overline{w'\theta'^2}$, $\overline{w'q'^2}$, $\overline{w'\theta'q'}$

$$\overline{\theta'^2} = \begin{cases} Q_0^2/u_*^2\left(4(1-8.3\zeta)^{-2/3}\right), \zeta < 0 \\ Q_0^2/u_*^2(4), \zeta > 0 \end{cases}$$

Q_0: sensible heat flux
u^*: friction velocity
ζ: stability parameter
(Andre et al., 1978)

- **Default E3SM (CLUBB)**

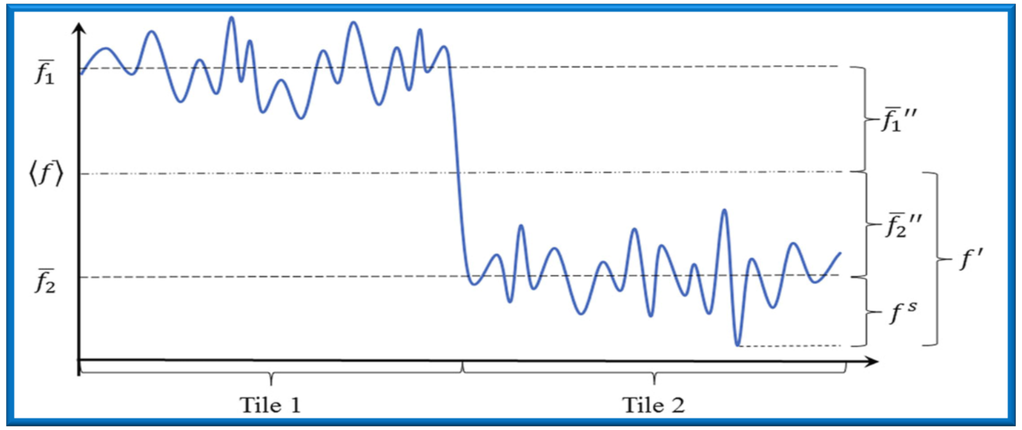
1. aggregate the predictors from individual tiles (<Q_0>, <u_*>, <ζ>)
2. calculate the temperature variance

Since MOST is applied at tile level, the aggregated ζ may not be truly representative.

- **New CLASP approach**

1. calculate the temperature variance at the tile level ($\overline{\theta'^2}_i$)
2. calculate the tile-aggregated temperature variance:

$$\overline{\theta'^2} = \langle \overline{\theta'^2}_i \rangle + \langle \overline{\theta_i}''^2 \rangle$$



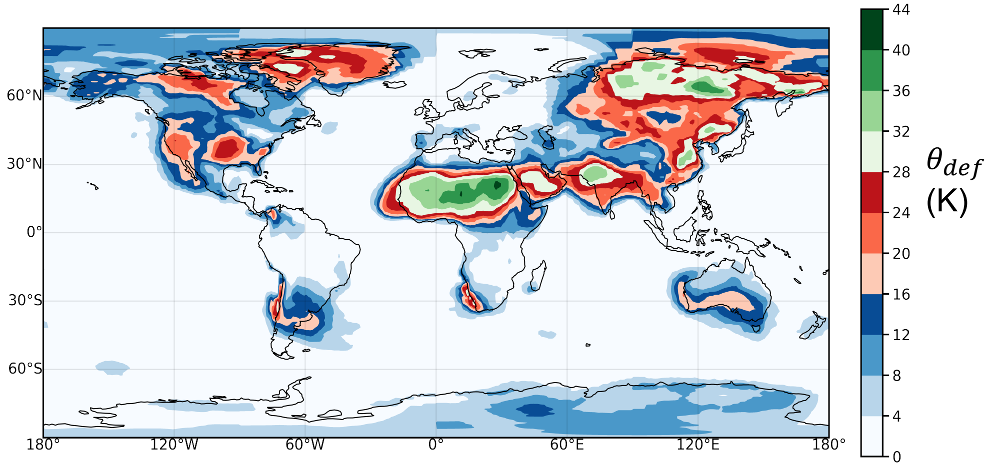
E3SM Single Column Model (SCM)

- **Experiments**
  - CTL (Control Experiment)**:** Default configuration with **CLUBB** surface boundary conditions
  - HET (Heterogeneity Experiment)**:** Prescribed **CLASP** surface boundary conditions from HydroBlocks

- Continuous hourly large-scale forcing from ARM SGP, 6/1/2015-6/30/2015, every 30-min output

- Hindcast approach
  - SCM is initiated every day at 00 UTC, run for 2 days, and only 24-48 h simulations are combined as a continuous timeseries for analysis

LoCo Coupling Metrics Toolkit – Heated Condensation Framework



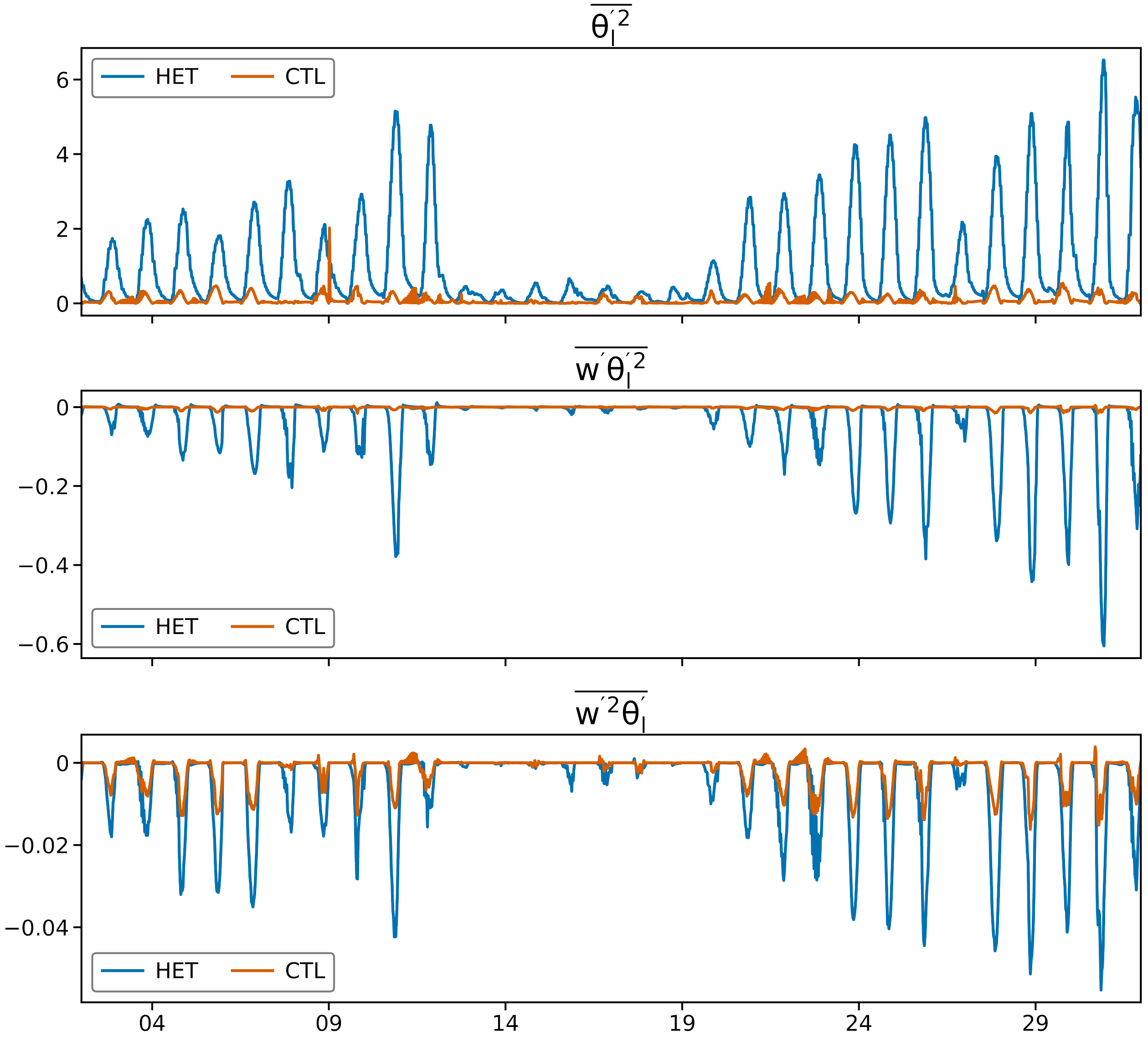
Average θ_{def} from E3SM simulation in January 2013

Comparing HET surface moments with CTL

Temperature variance

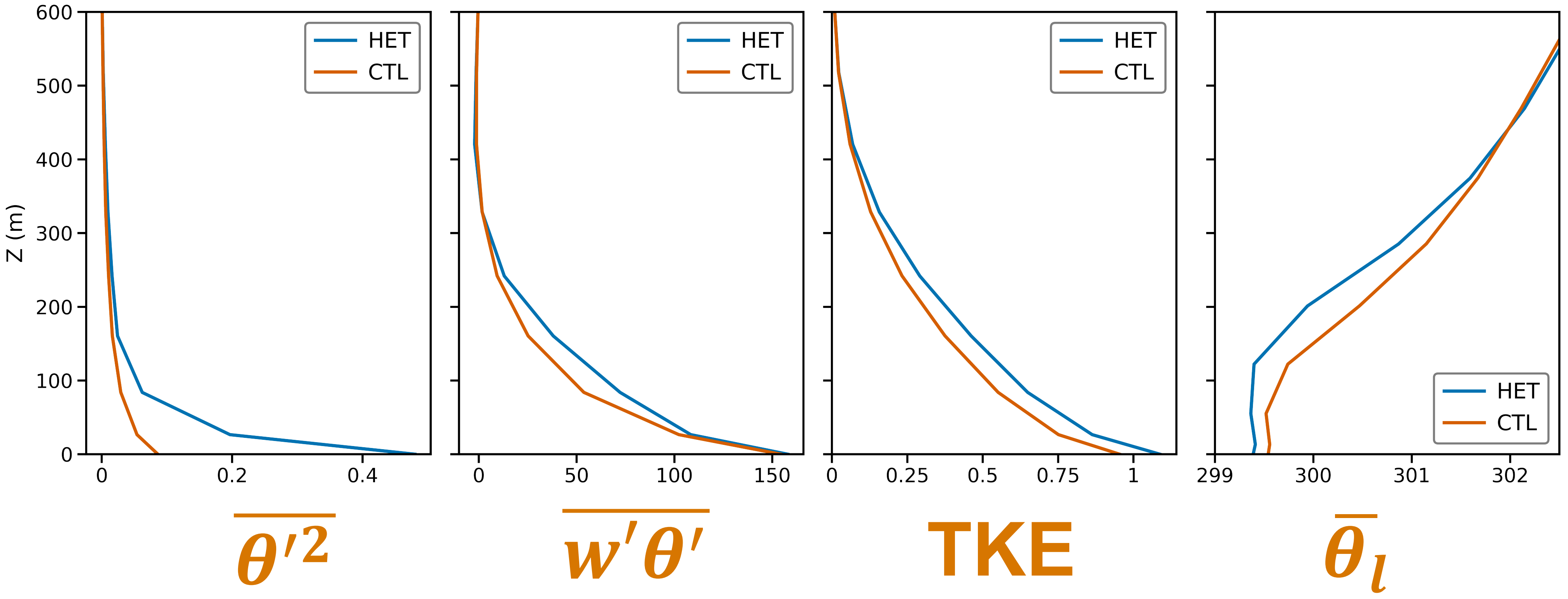
Flux of variance

Flux of flux



- Accounting for surface heterogeneity greatly enlarges surface moments
- More variability over heterogeneous surface than over homogeneous surface

Vertical profiles of HET and CTL



Profiles averaged over 14-16 UTC (08-10 CT) 4 June 2015

- **Enlarged HET surface temperature variance** could impact up to ~200 m high
- Corresponding buoyancy term (temperature variance times buoyancy parameter) generates the positive temperature flux
- Resulting in an increased TKE
- Leading to the **enhanced vertical mixing** and more developed PBL

Significant monthly mean* and relative difference, even in SCM when the atmospheric profile is constrained

* Averaged over 2 (30 min) * 24 h (/day) * 30 days = 1440 times

	CTL	HET	(HET-CTL)/CTL*100 (%)
Precipitation (mm day-1)	3.16	3.29	+4.1
Total Cloud Fraction (%)	56	57	+1.8
Low Cloud Fraction (%)	9.5	8.5	-9.6
Mid-level Cloud Fraction (%)	17.0	16.6	-2.8
High Cloud Fraction (%)	52.3	53.4	+2.2
Liquid Water Path (g m-2)	19.8	17.2	-13.0
Ice Water Path (g m-2)	16.1	17.2	+6.6
Shortwave CRE (W m-2)	-48.5	-47.0	+3.1
Longwave CRE (W m-2)	30.0	30.8	+2.6
Net CRE (W m-2)	-18.5	-16.2	+12.4

- Increased precipitation and total cloud fraction
- Enhanced turbulent mixing transport more moisture upward, resulting in decreased low cloud fraction and LWP and increased high cloud fraction and IWP
- Increased SW CRE and LW CRE, resulting in a decrease in net CRE (implication on radiation balance and climate)
- Heterogeneous boundary conditions greatly impact the PBL turbulence and convection

Pacific Northwest NATIONAL LABORATORY

Summary

- Accounting for surface heterogeneity
  - enhances turbulent mixing
  - results in deeper PBL
  - transports moisture to higher level, forming more (less) ice (liquid) clouds
  - increases precipitation

- Next Steps
  - implement the CLASP approach in ELM
  - better understand the coupling between ELM and EAM
  - perform SCM and global simulations to assess impacts of land-surface heterogeneity

Thank you