Towards explicitly capturing the impacts of land surface heterogeneity on convective updrafts in CESM

2023 CESM Workshop

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Land-atmosphere communication in CESM2

- Currently: CAM and CLM communicate only grid-cell mean values
- But relatively small-scale land surface heterogeneity can impact the overlying atmosphere
  - Boundary layer clouds & precipitation *(Berg and Stull,* 2005, *Pielke Sr.,* 2001)
  - Generation of mesoscale circulations *(Doran et al*., 1995; *Avissar and Schmidt*, 1998; *Bou-Zeid et al*. 2005)
  - LWP and TKE (*Simon et al.* 2021)

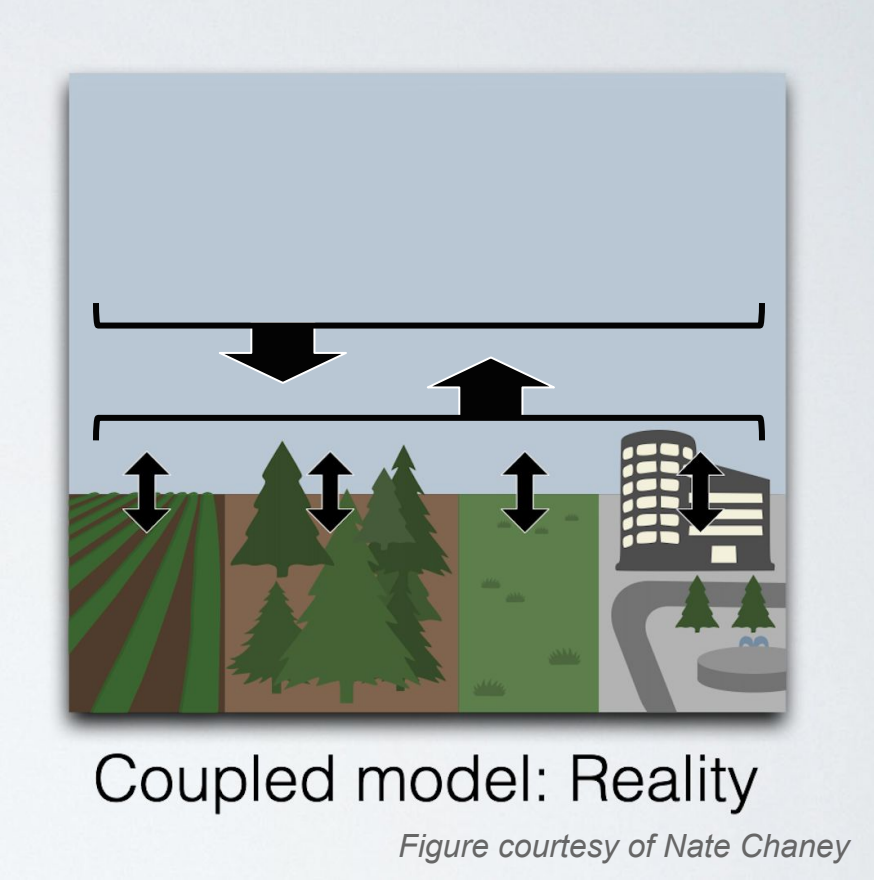

Figure courtesy of Nate Chaney

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  - LWP and TKE (*Simon et al.* 2021)
- CLASP CPT aims to address this

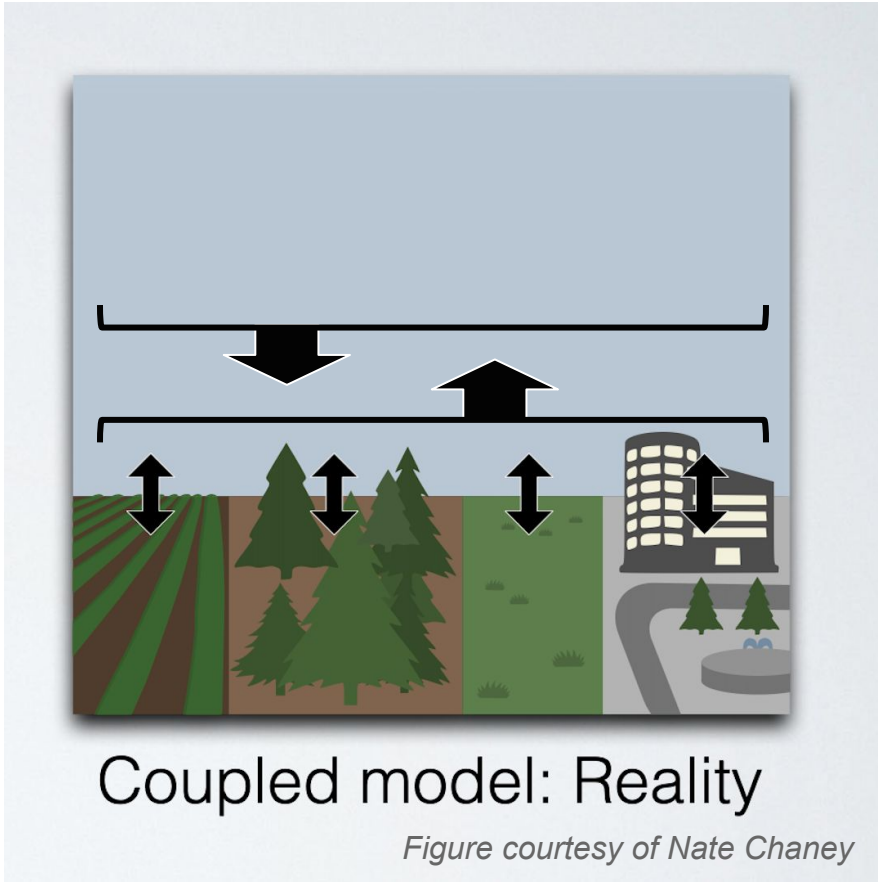

Figure courtesy of Nate Chaney

A new strategy: link existing representations of subgrid heterogeneity across land and atmosphere

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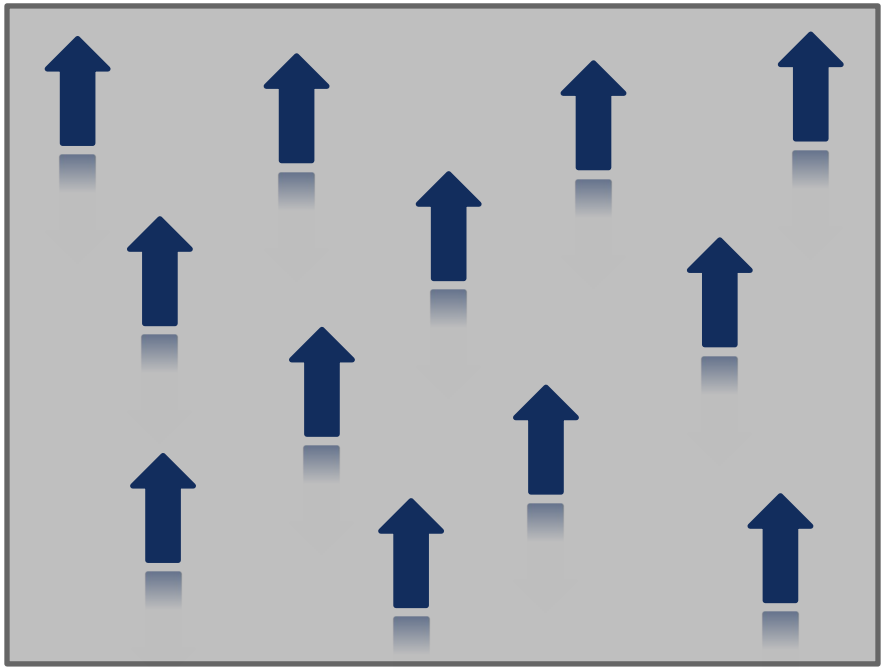

- Multiple updraft plumes initialized when grid-mean surface buoyancy >0
- Plumes undergo stochastic entrainment until eventually the buoyancy flux hits zero

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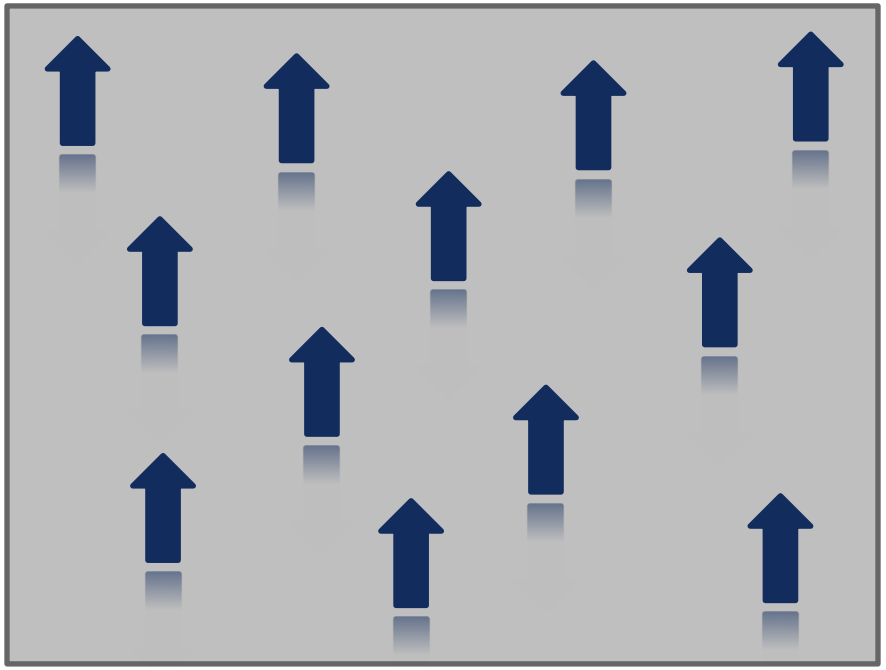

- Multiple updraft plumes initialized when grid-mean surface buoyancy >0
- Plumes undergo stochastic entrainment until eventually the buoyancy flux hits zero
- Turbulent fluxes of moisture and temperature are split between CLUBB and a new term based on I updrafts:

$$\overline{w'\varphi'} = \overline{w'\varphi'}_{\text{CLUBB}} + \sum_{i=1}^{I} a_i(w_i - \overline{w})(\varphi_i - \overline{\varphi}),$$

Witte et al. (2022) Eq. 16

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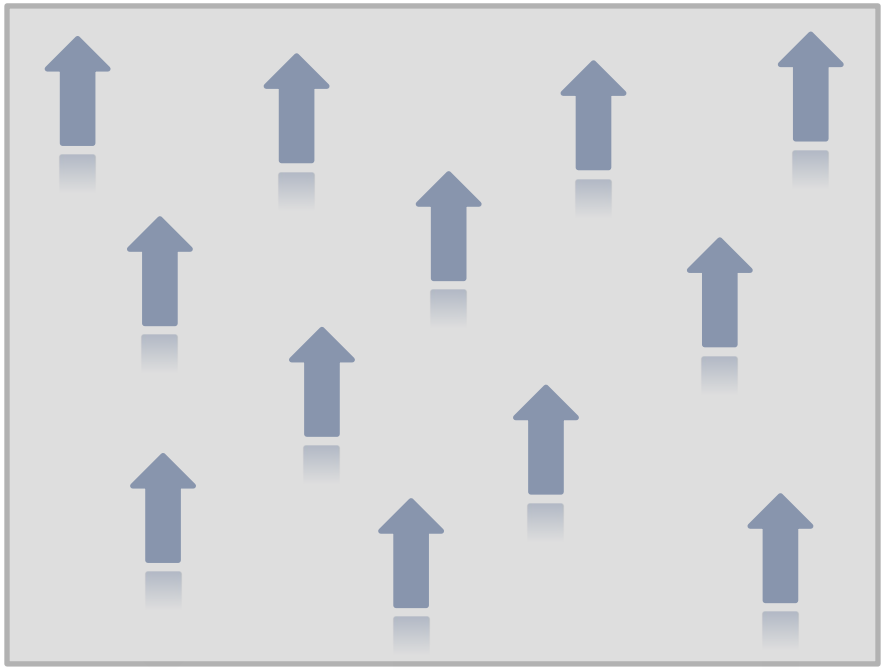
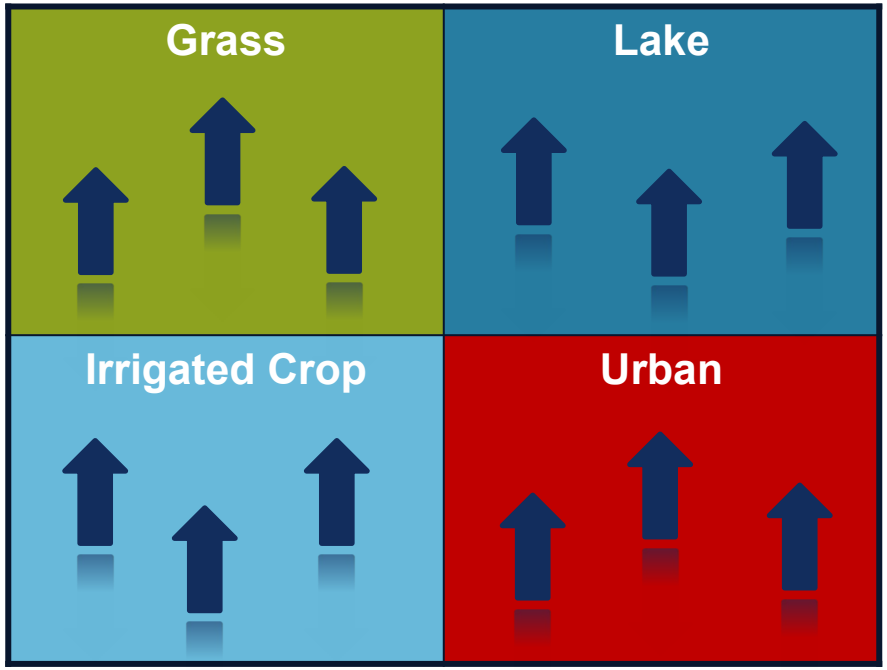
+ Land surface heterogeneity





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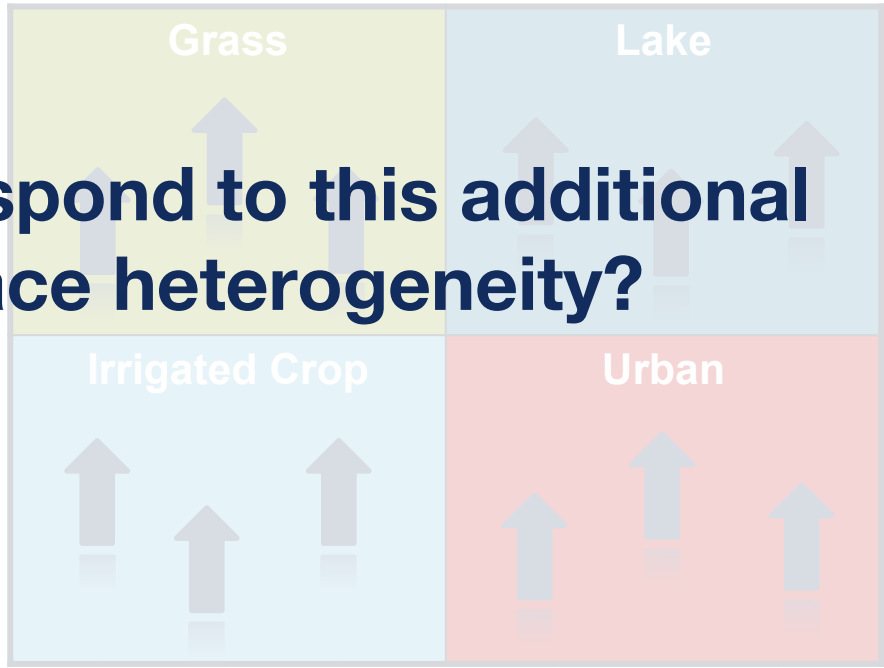
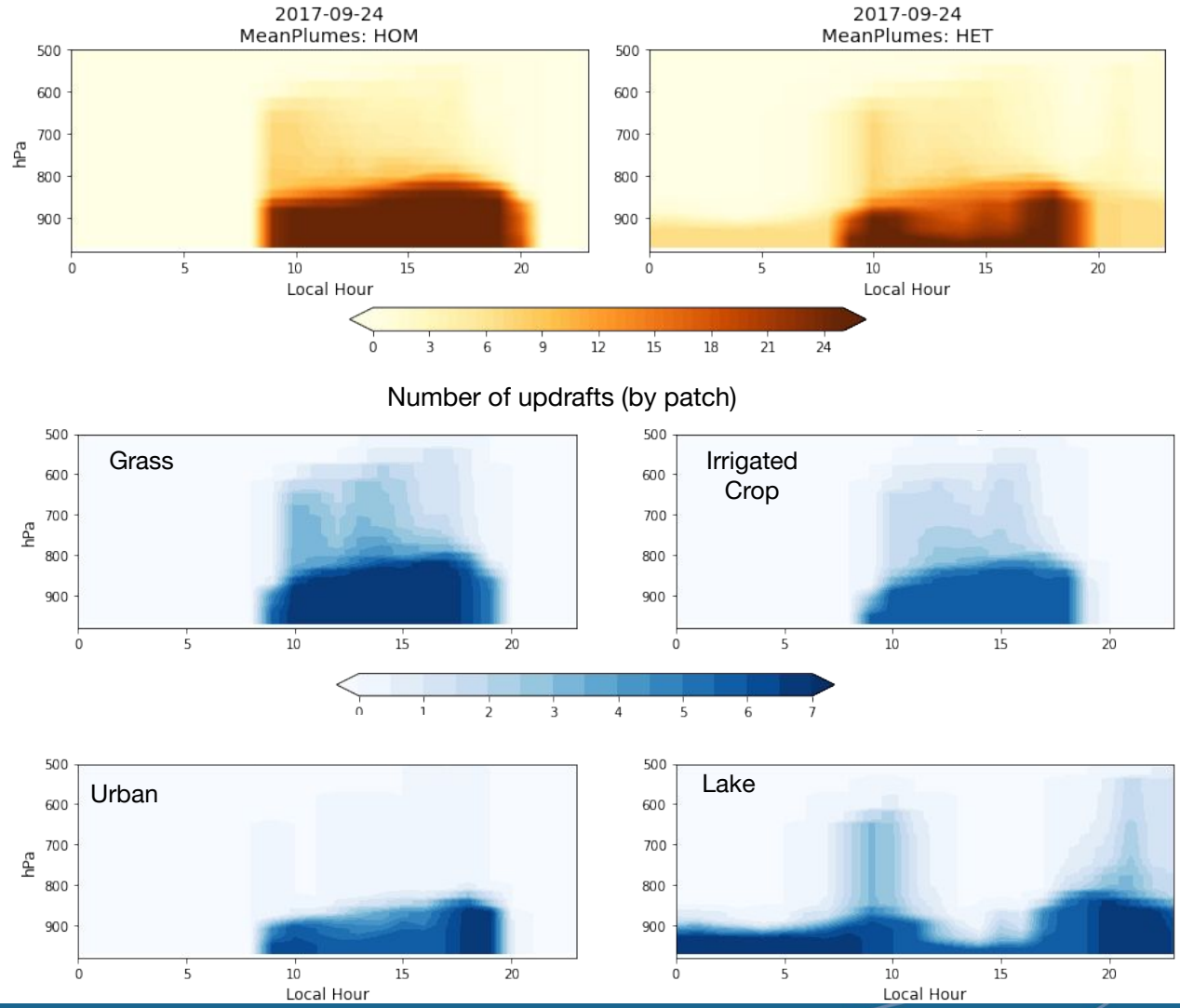


Does the atmosphere respond to this additional information on surface heterogeneity?

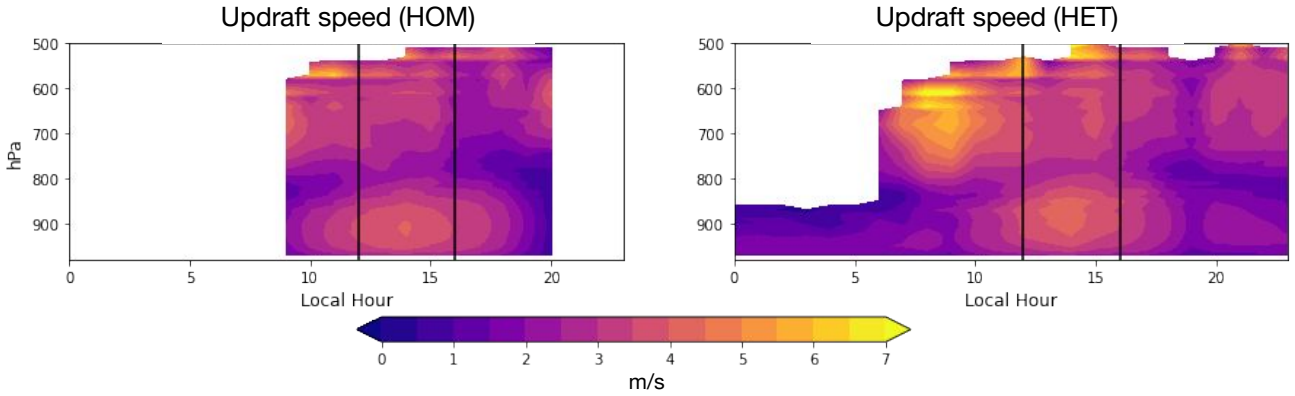
A case study: Aug 24, 2017

- Single-column (SCAM) experiments:
  - DOE ARM Southern Great Plains site with LASSO-VARANAL forcing
  - 2-day “hindcast” targeting warm-season shallow convection days
- New “highly heterogeneous” surface used with same atmospheric forcing
  - Even split between urban, lake, grass, and irrigated cropland
- CLUBB-MF set to use 25 updraft plumes
  - Even division across surfaces = 6 plumes/patch
  - “Extra” plume allocated to warmest patch (based on SHFLX) at each timestep
  - Using a constant entrainment length (i.e., entrainment does not vary in time)

Diurnal cycle of patch-level fluxes is clear in number of plumes present



Characteristics of updrafts also change with the addition of surface type information



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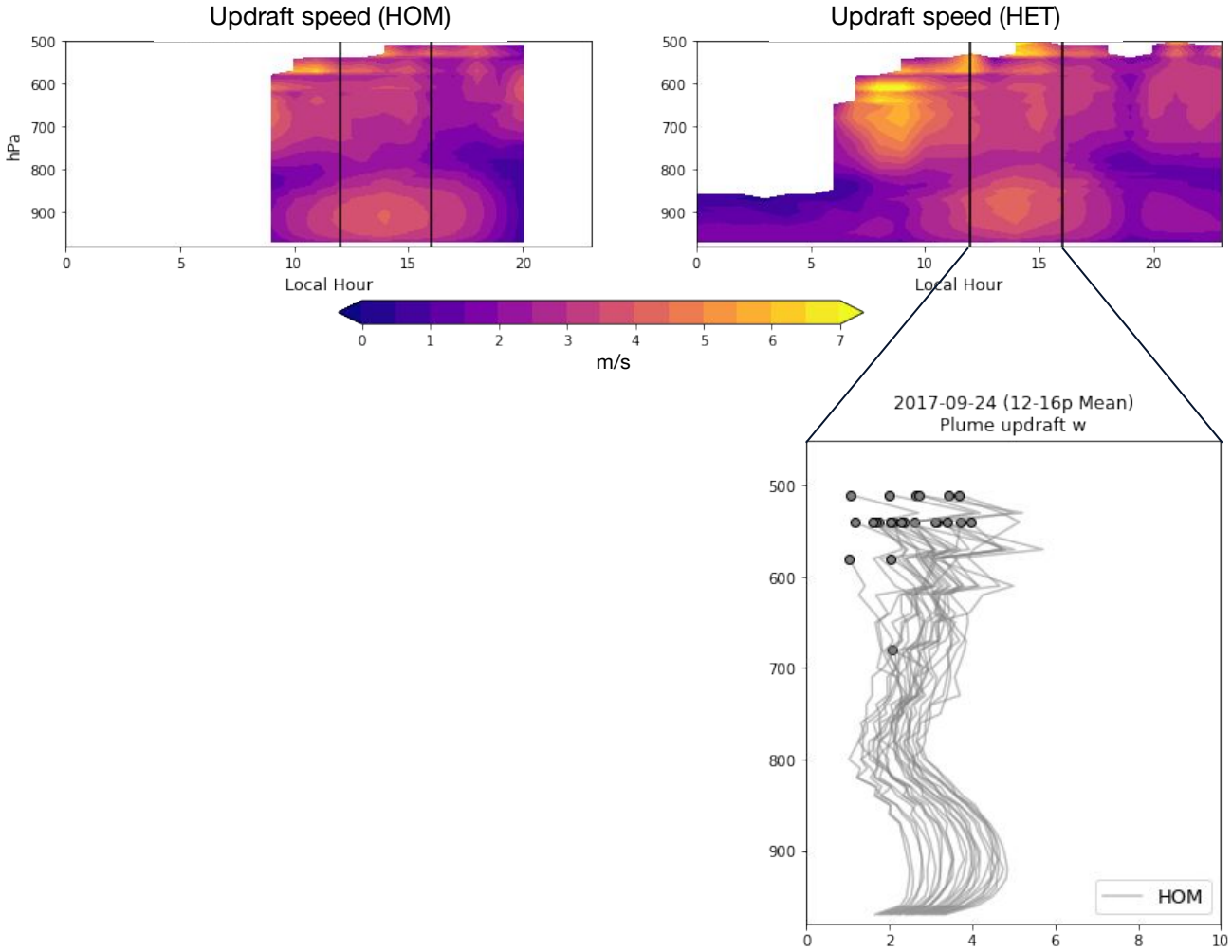

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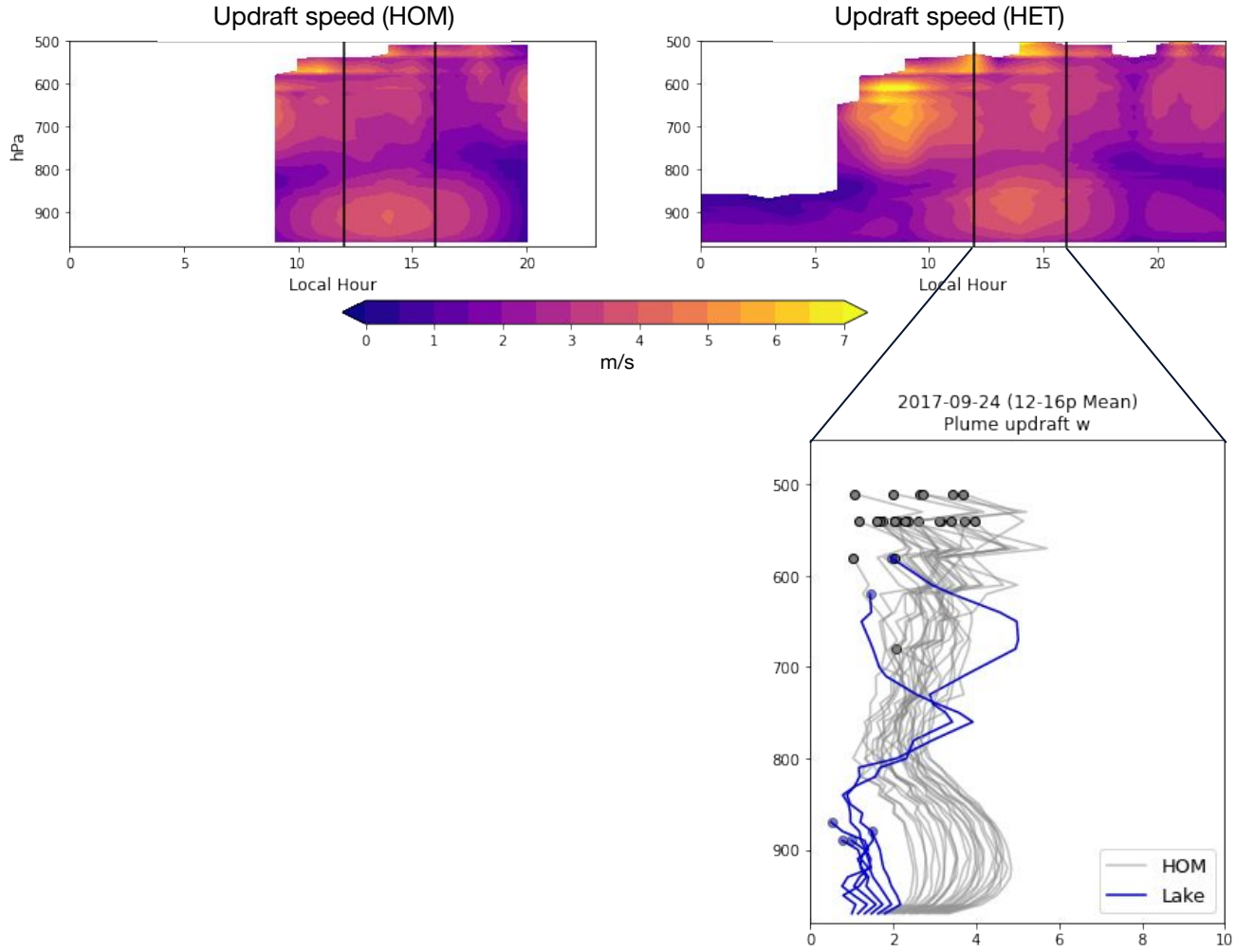

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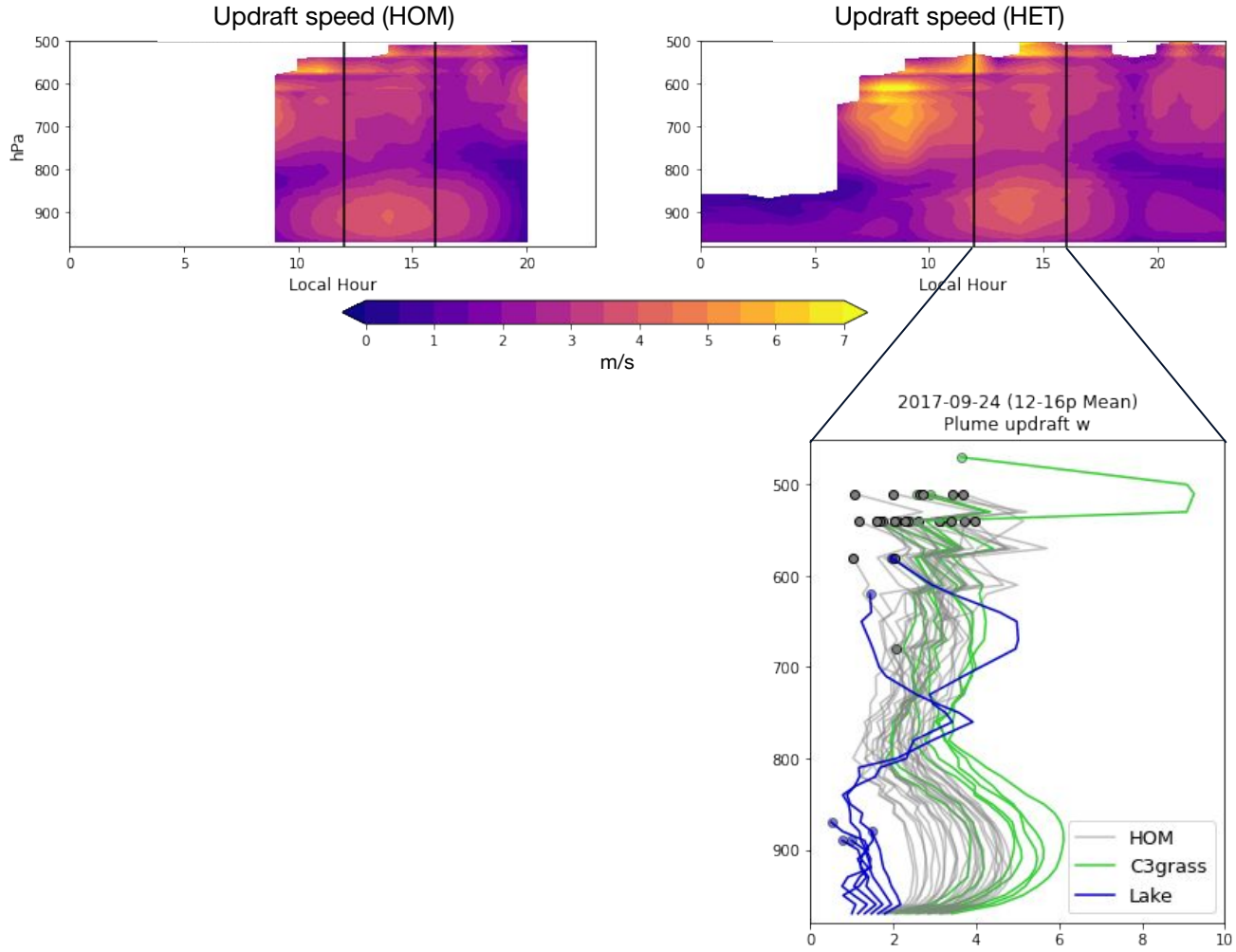

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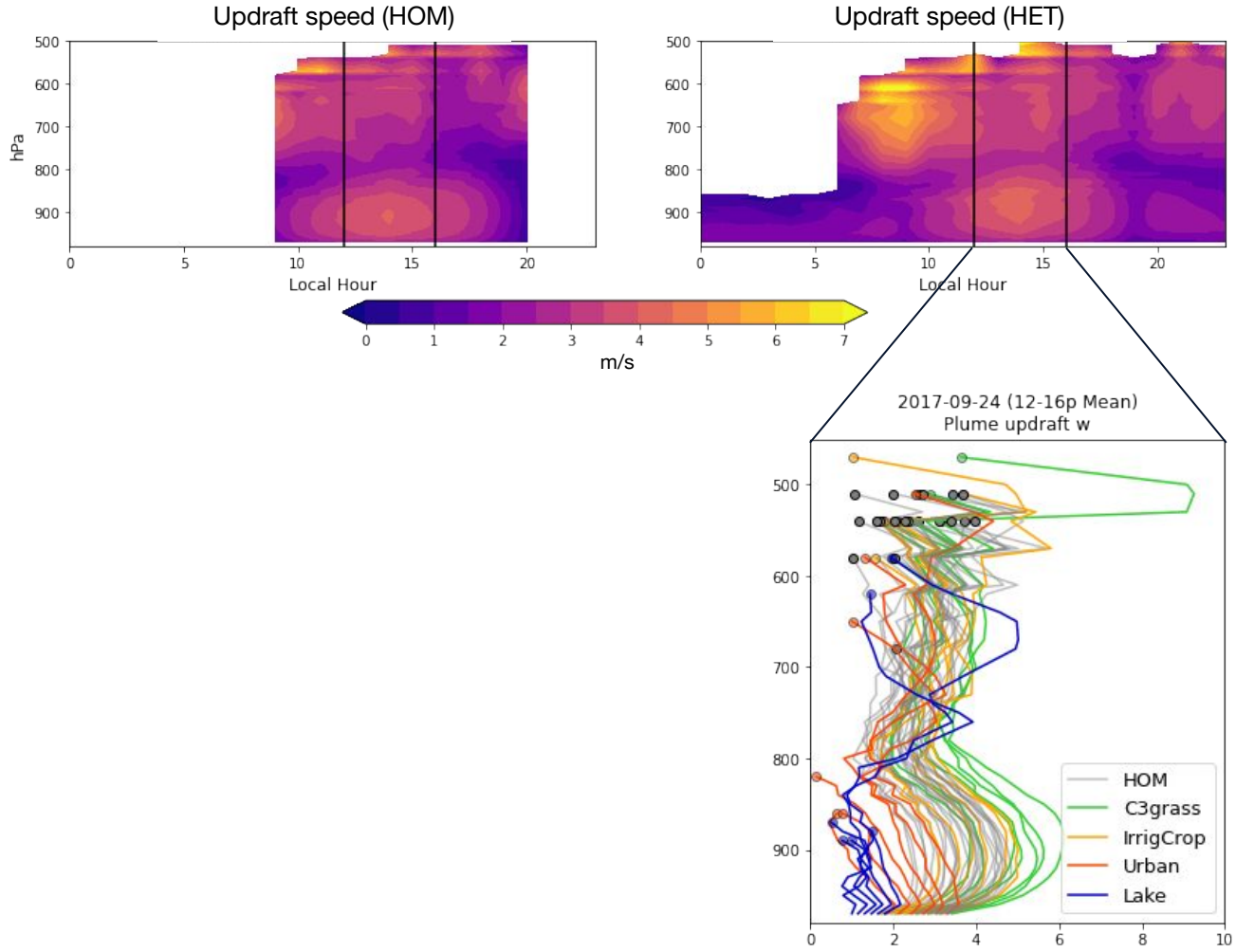
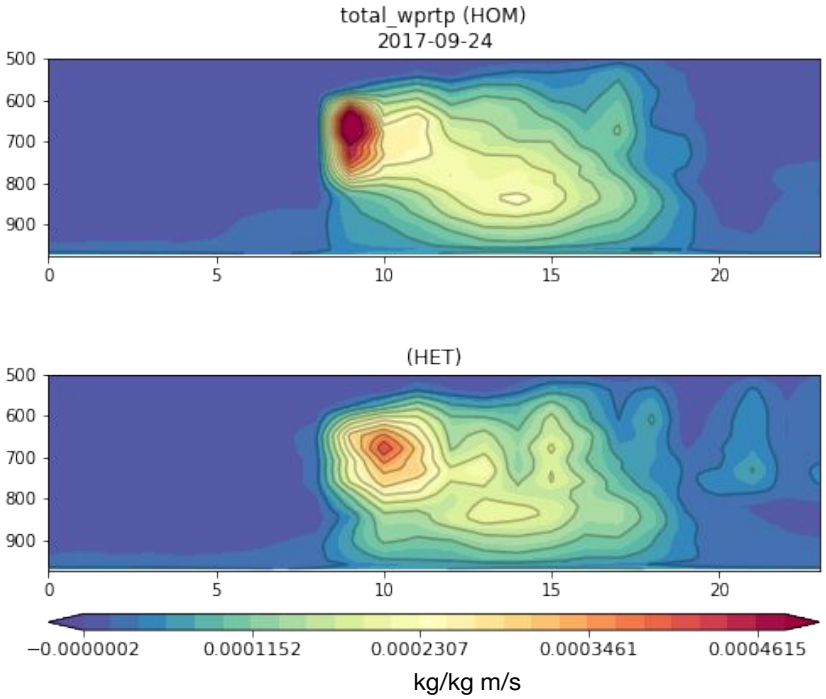
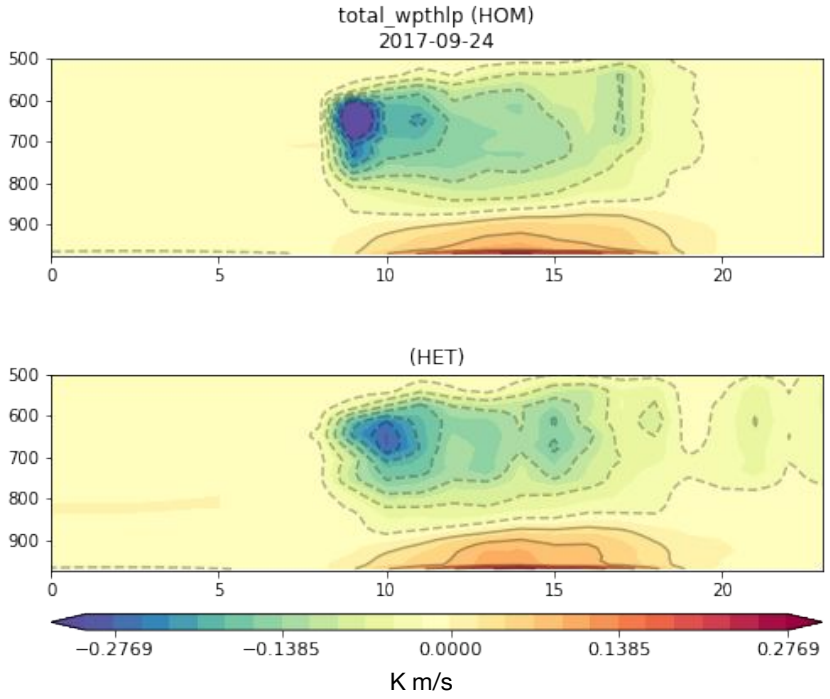


Those changes drive a response in the turbulent fluxes of moisture and temperature





Conclusions

- CLUBB-MF paired with surface tile fluxes/states can effectively communicate the impacts of surface heterogeneity into the vertical
  - Depth and speed of updraft plumes vary according to surface type
  - Those changes in plumes drive shifts in larger-scale atmospheric variables

- This approach opens up new possibilities and opportunities:
  - More explicitly representing mesoscale secondary circulations
  - Communicating sub-grid atmospheric information back to the land

Thank you!

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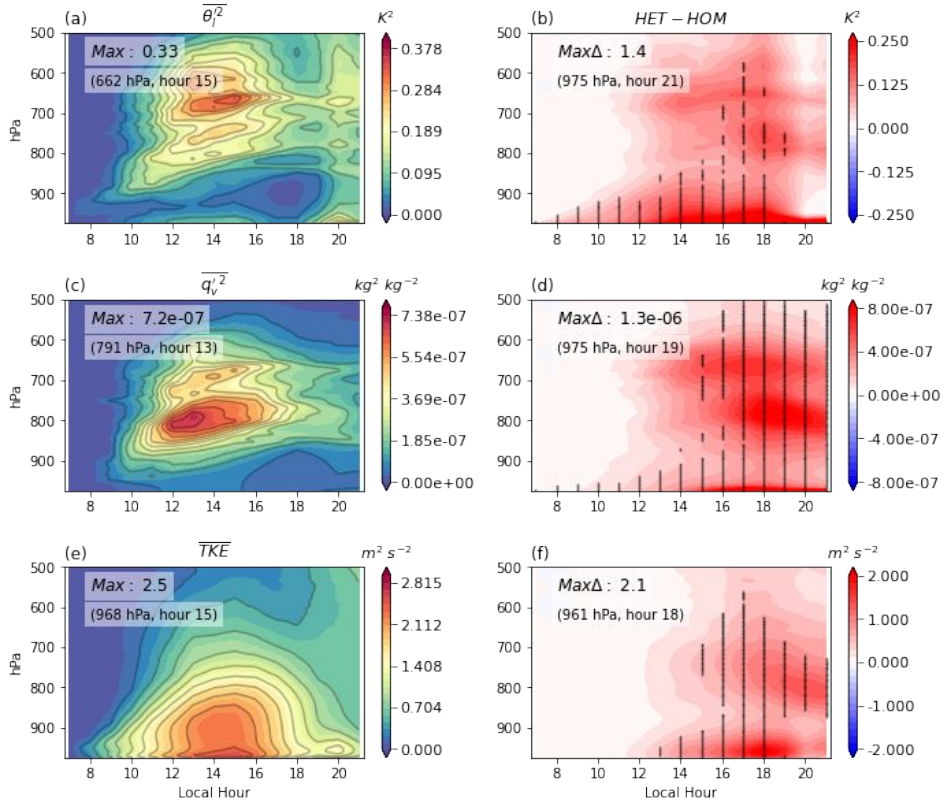
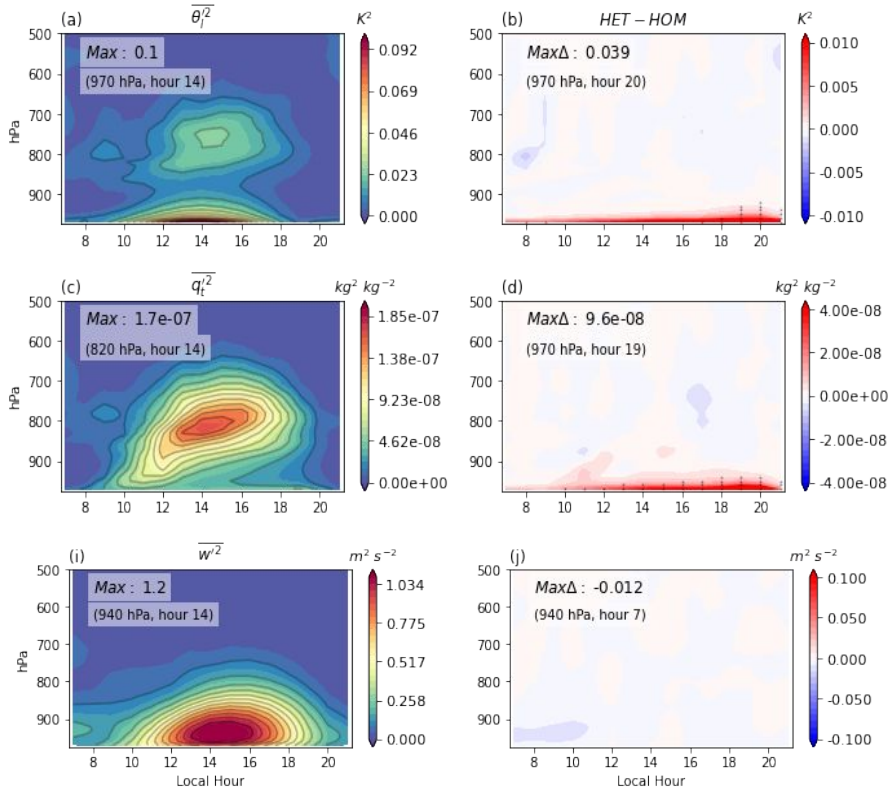
Extra Slides

Adding heterogeneity using only CLUBB

WRF-LES

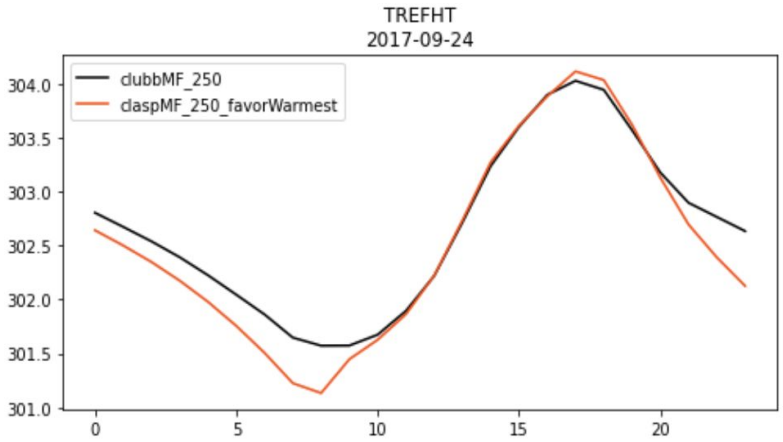


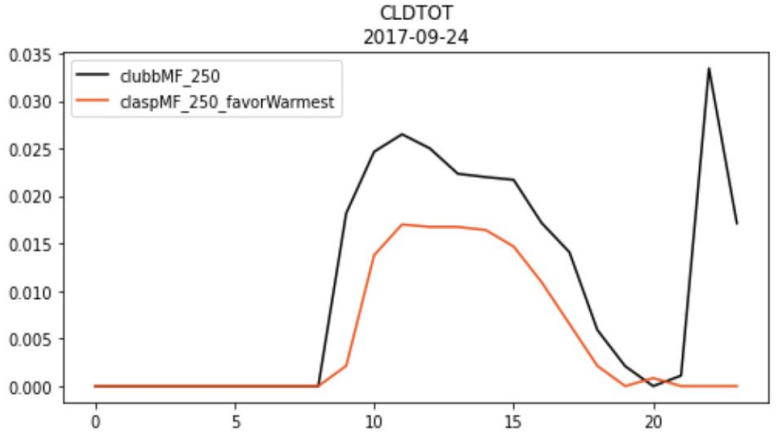
SCAM

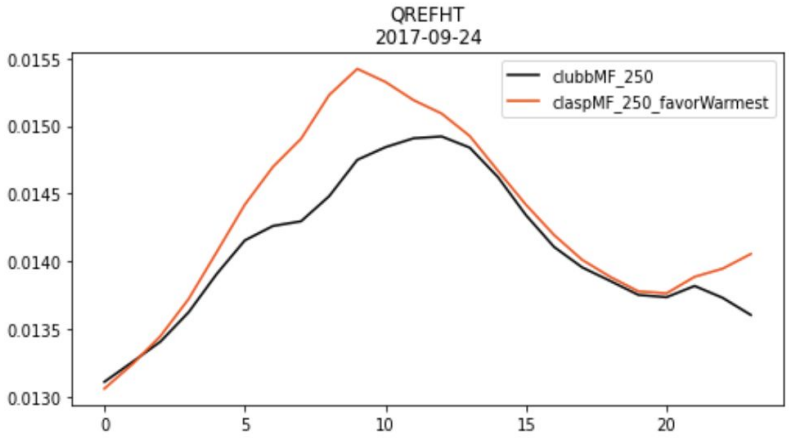


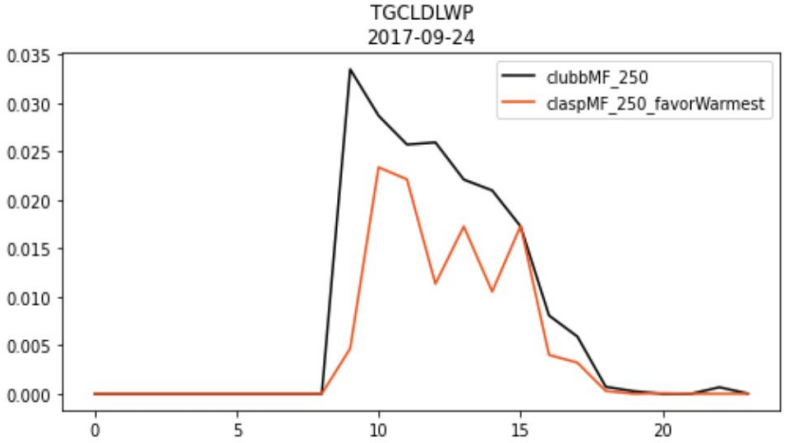
Time-height plots of (left) *HOM* and (right) *HET-HOM*, averaged over all 60 days; and (right) Stippling indicates significant differences at the 95% confidence level.

More on atmospheric response on 9/24









Sensitivity to entrainment length scale

L_ε = 50 m

L_ε = 250 m

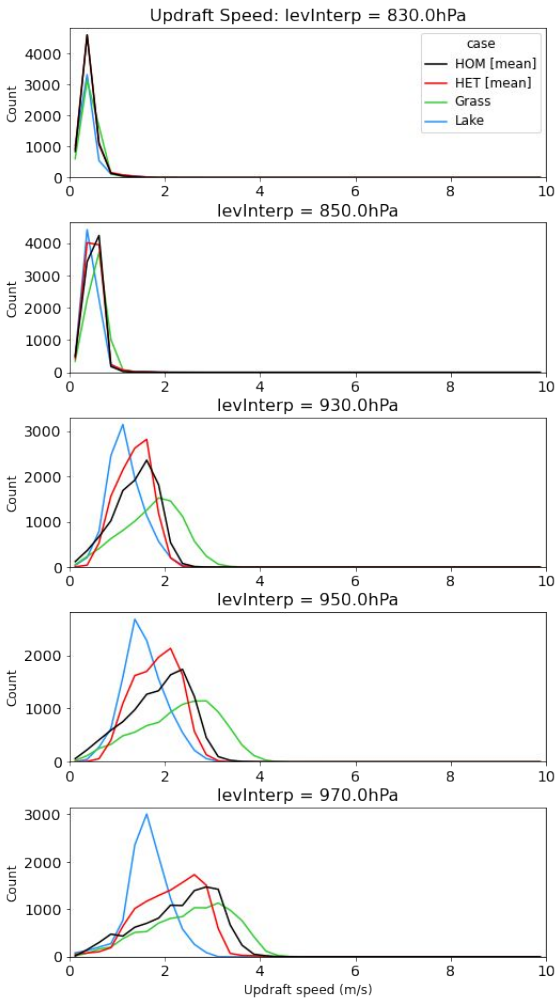
830 hPa

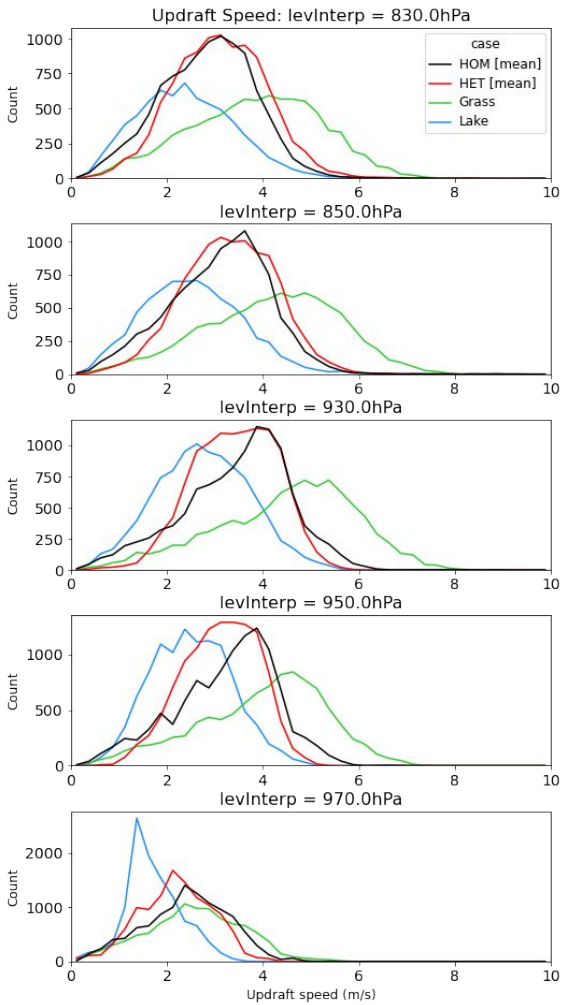
850 hPa

930 hPa

950 hPa

970 hPa





Histograms of updraft speeds from 7a-7p local time over all 74 days simulated.

Entrainment rate sensitivity:
Not only updraft speed, but also moments

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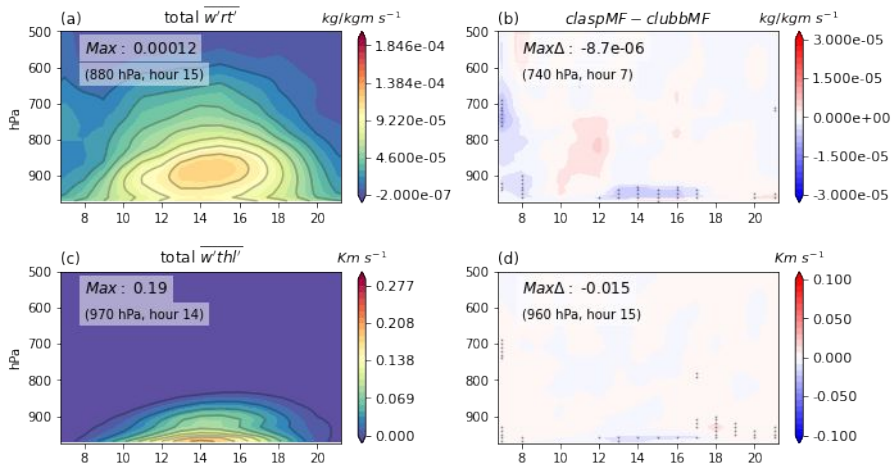

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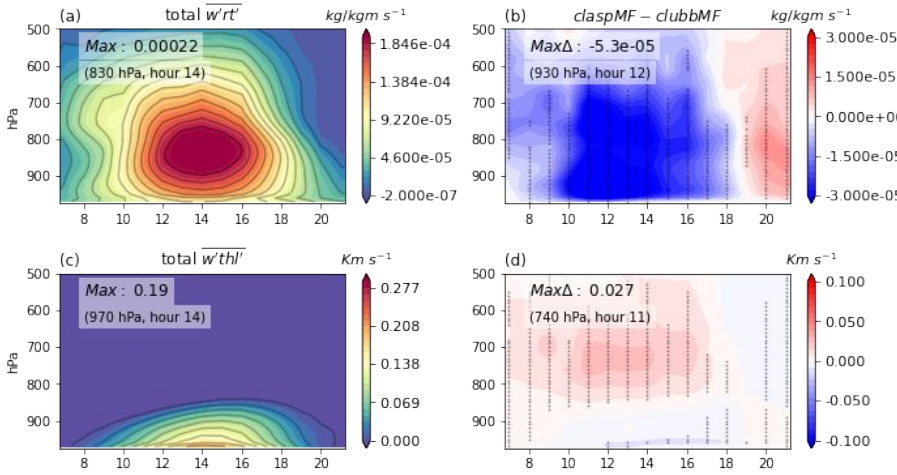
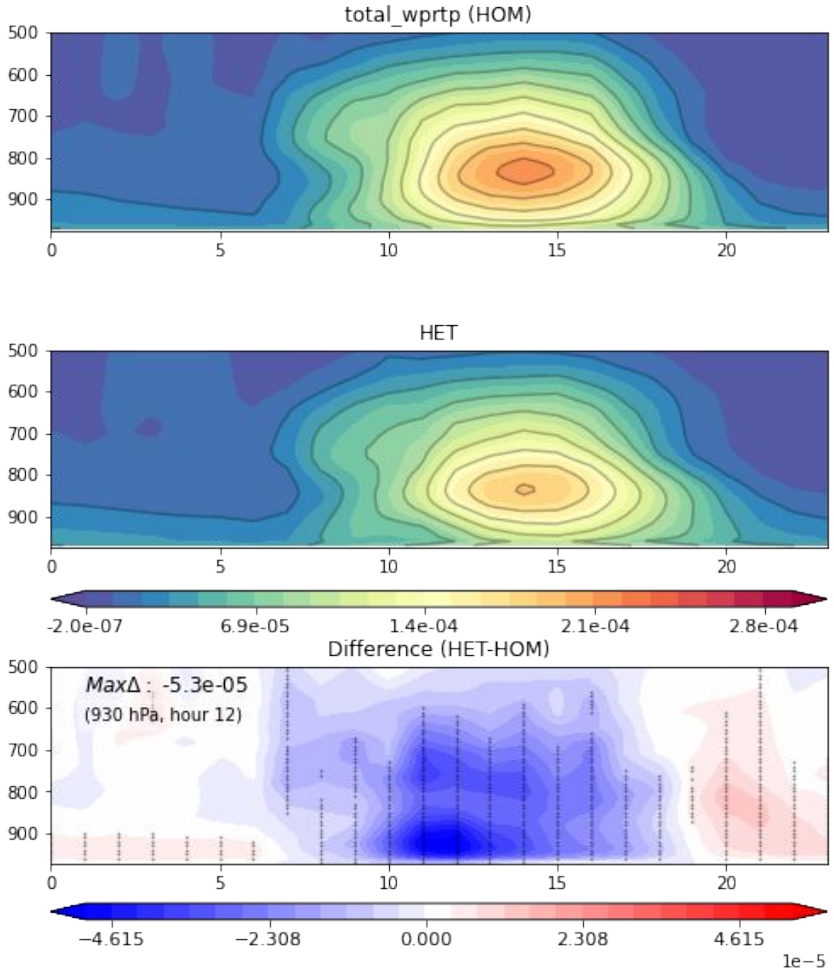
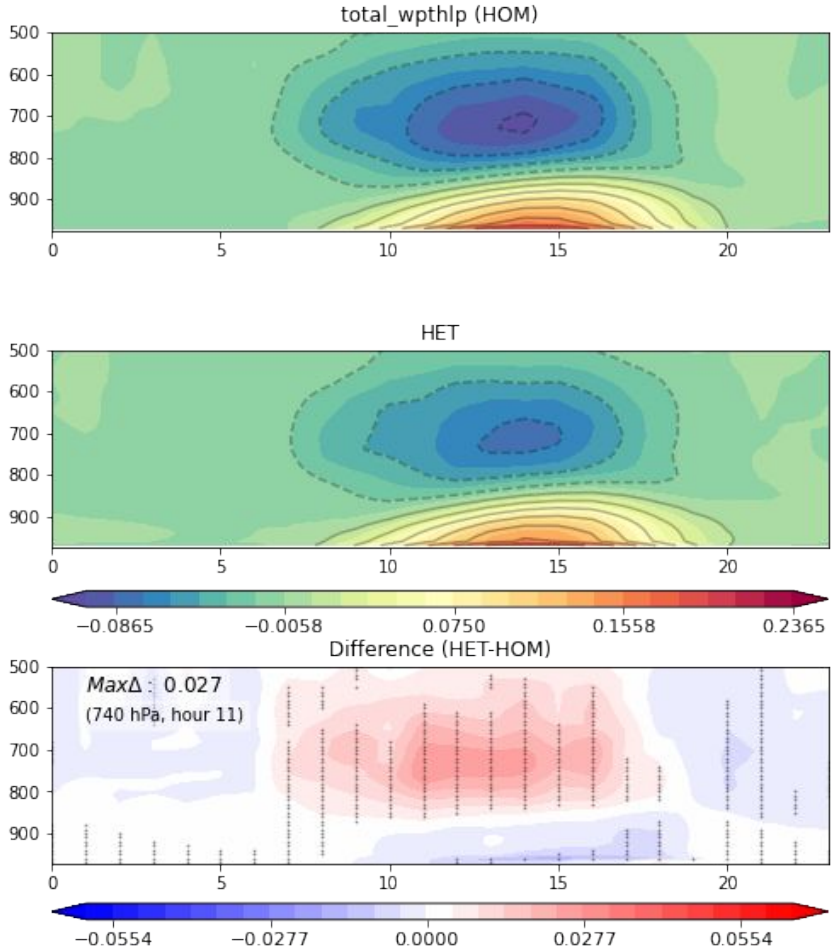
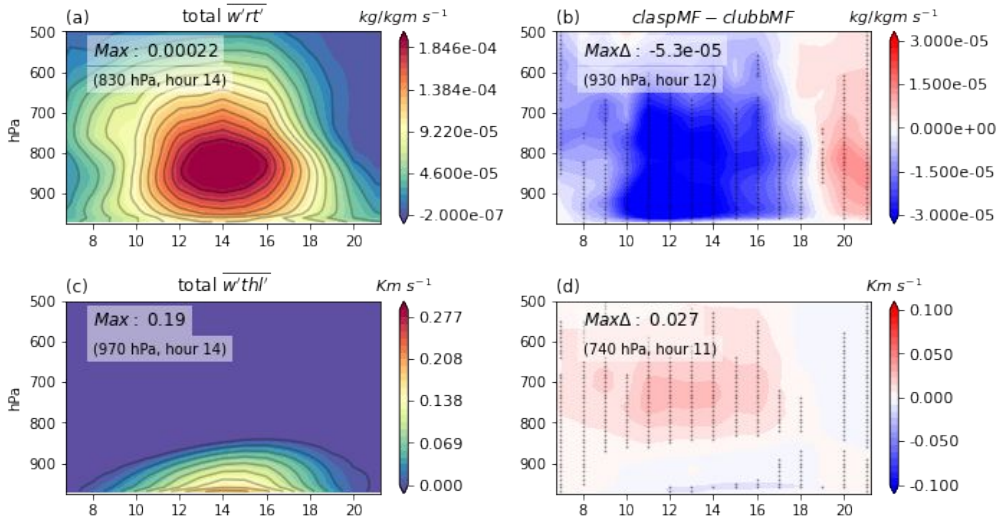


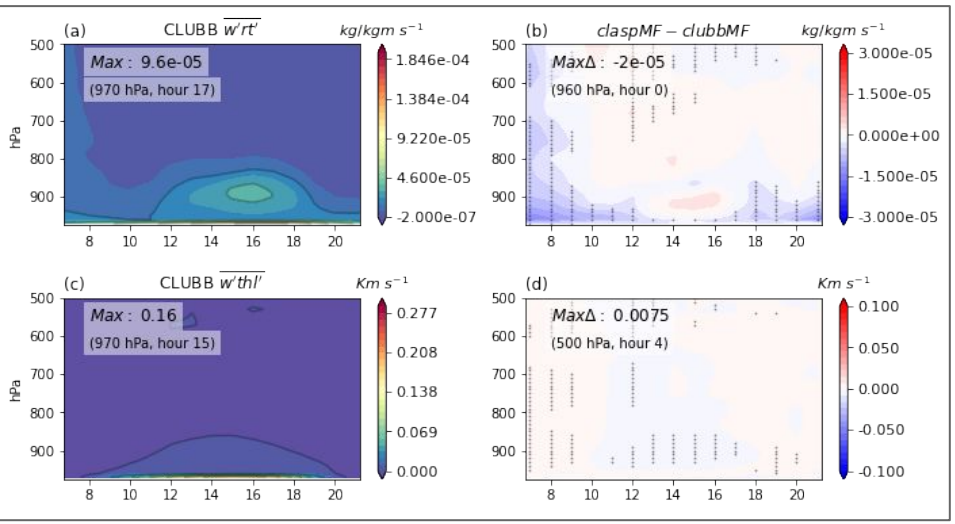
Roughly similar signals over all 74 days

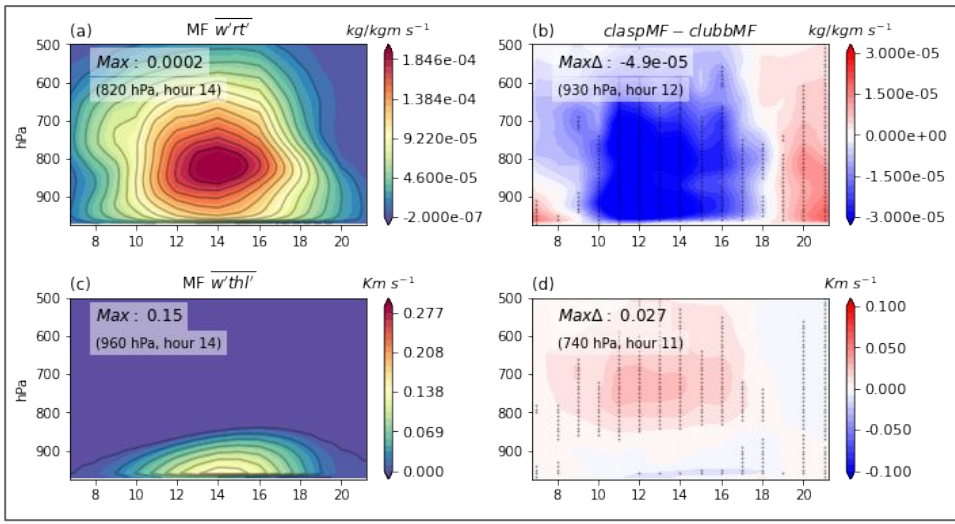




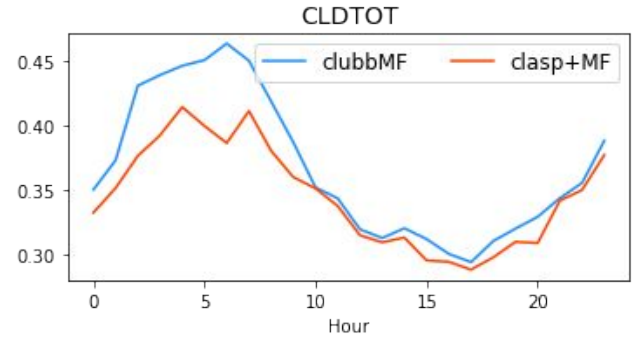
Most changes in turbulent moments/variances stem from the MF component, not CLUBB

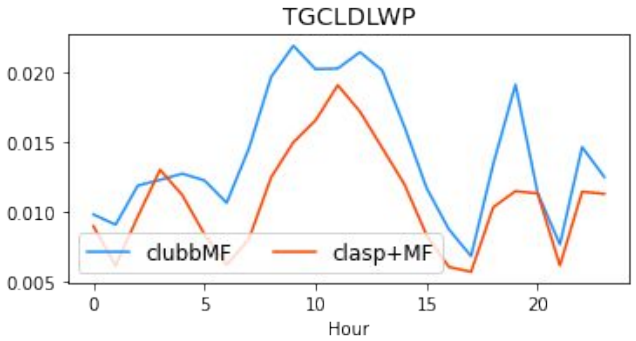


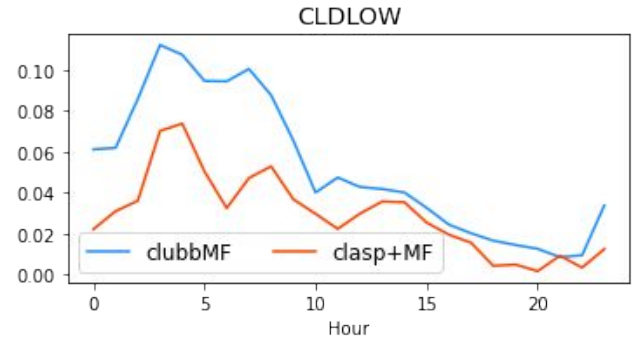


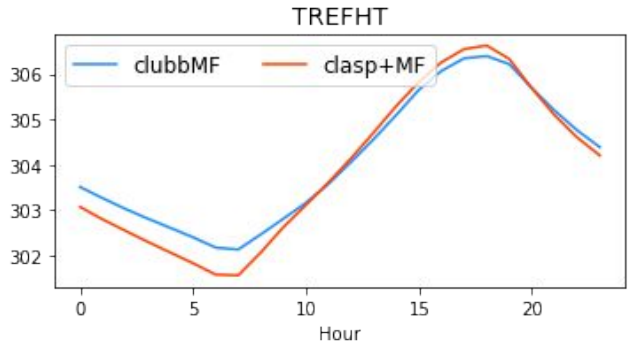


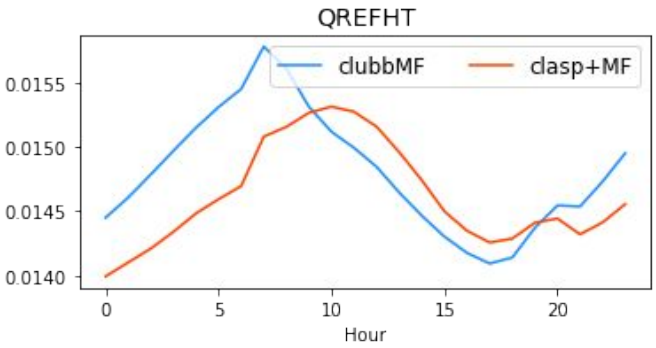
Average atmospheric response:
Reduced cloud frac and a shift in diurnal cycles



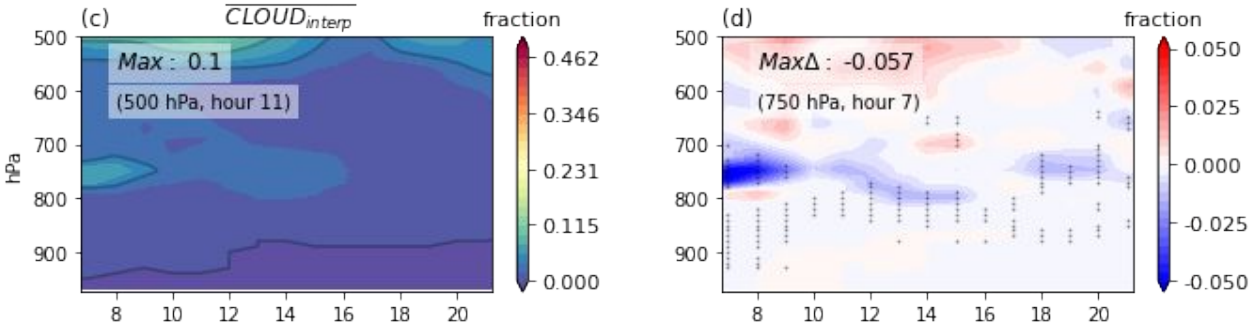


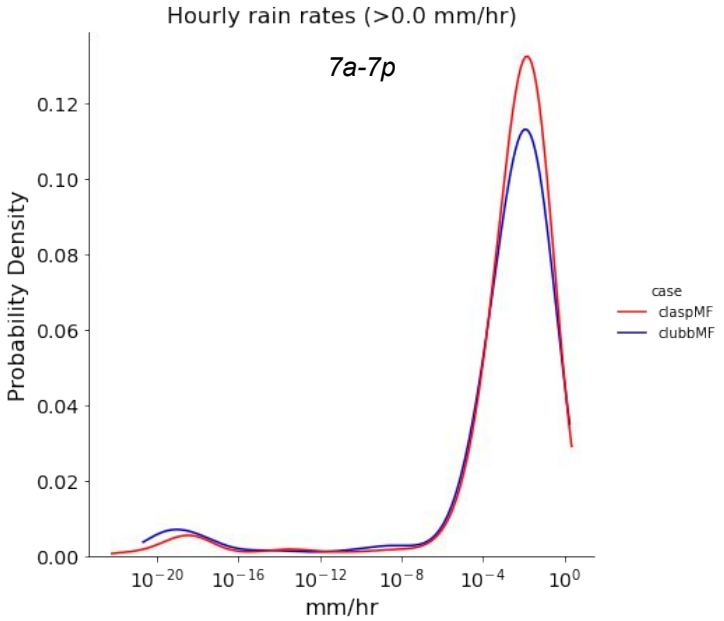






Average atmospheric response:
Cloud fraction and rainfall response to HET





Average atmospheric response:
Reduction of in-plume condensation