Assessing the Sensitivity of Atmospheric Convective Updrafts to Subgrid Land Surface Heterogeneity in CESM2

AMS Annual Meeting 2024

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Land-atmosphere interactions

- Relatively small-scale land surface heterogeneity can impact the overlying atmosphere
  - Boundary layer cumulus (*Berg and Stull,* 2005)
  - 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)

- Land-atmosphere coupling in most global climate models relies only on grid-cell mean values (i.e., fluxes)

- Climate Process Team: CLASP

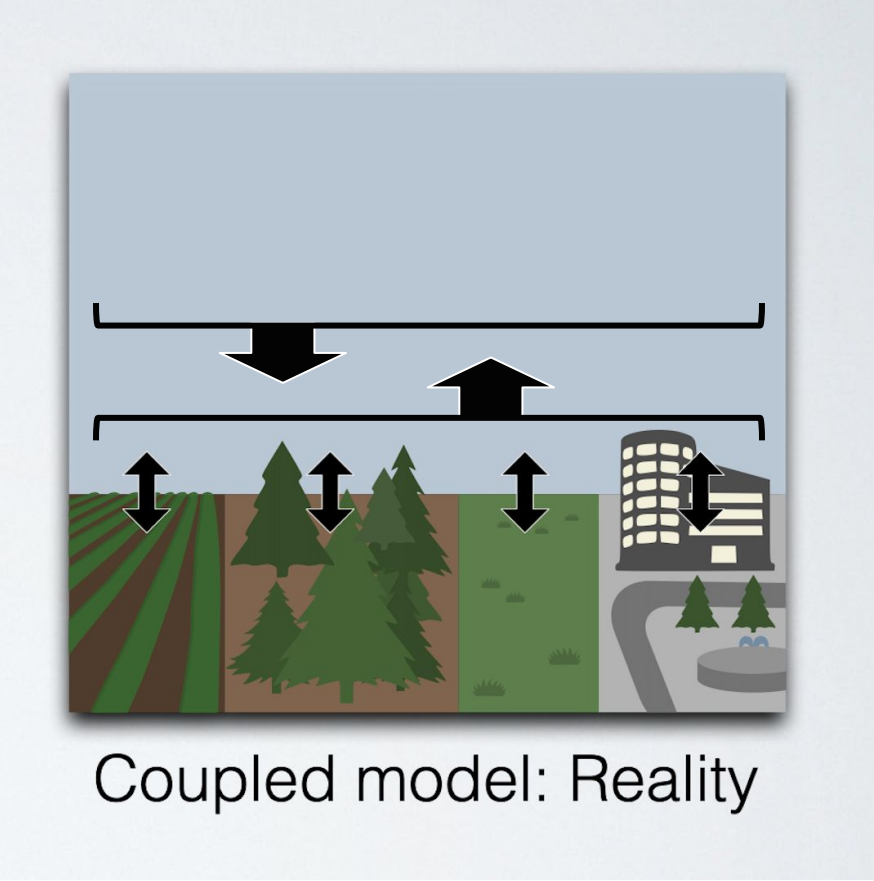

Figure courtesy of Nate Chaney

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

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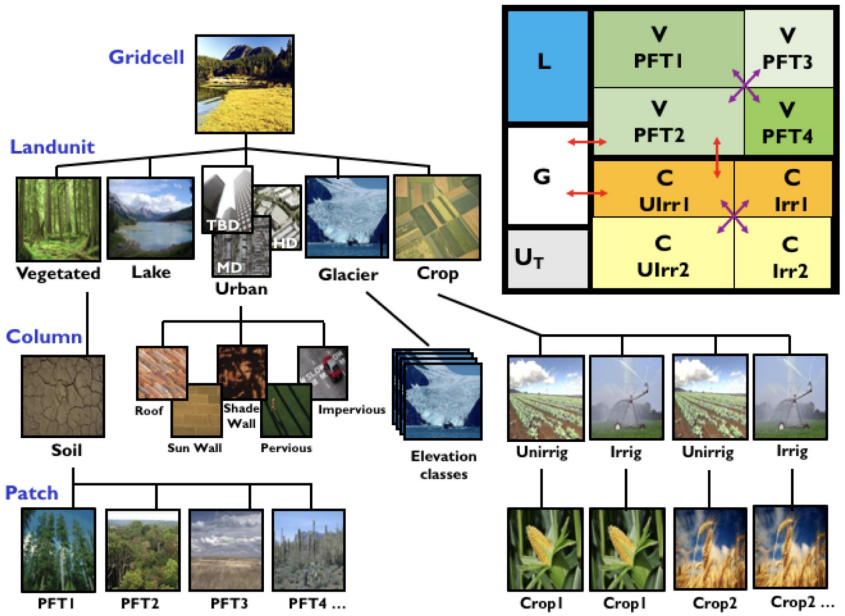
CLM5:



Lawrence et al., 2019

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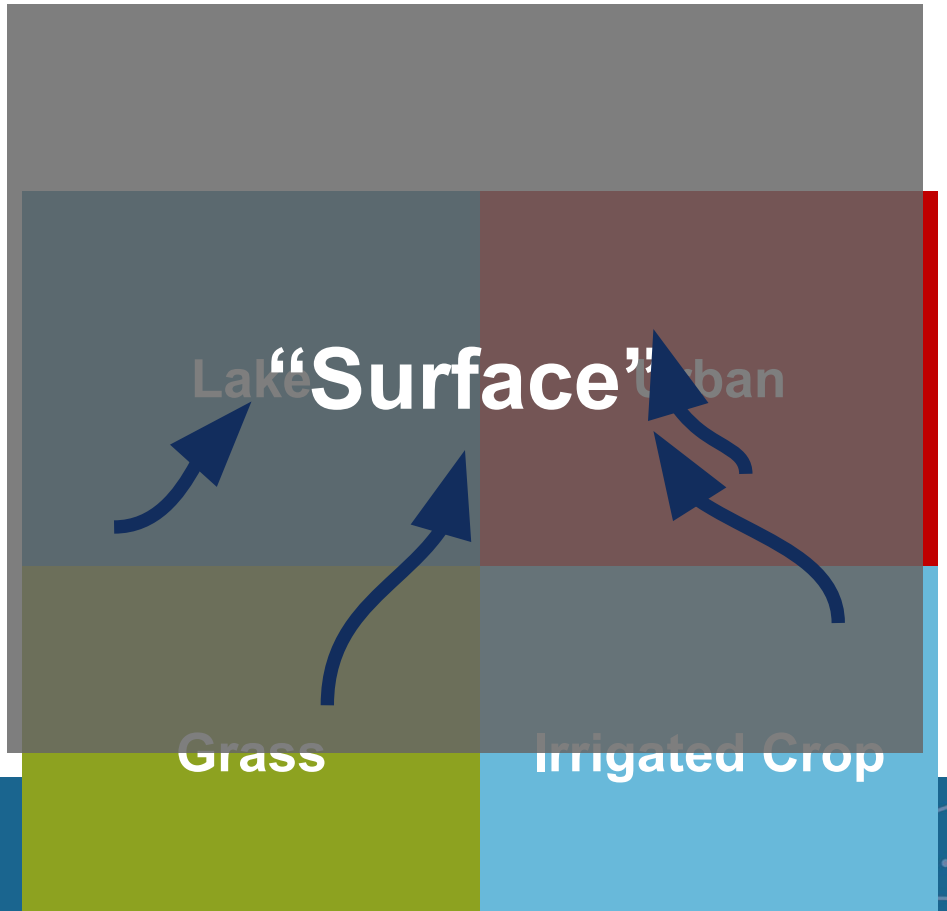
Surface types represented statistically in the Community Land model (CLM)

Lawrence et al., 2019

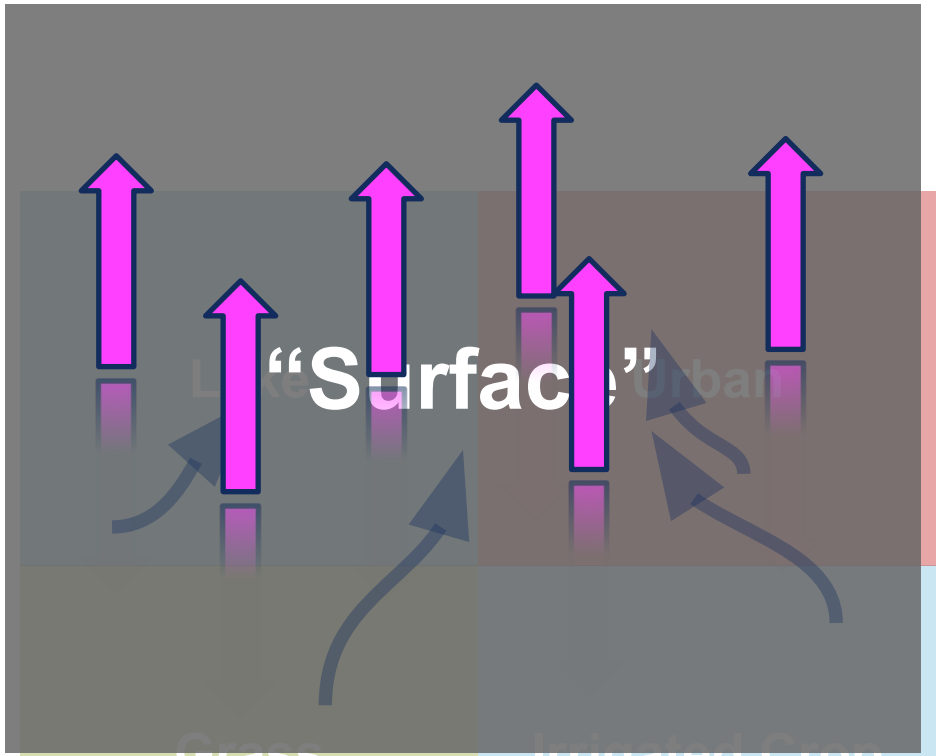
A new strategy: link existing representations of subgrid heterogeneity across land and atmosphere



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

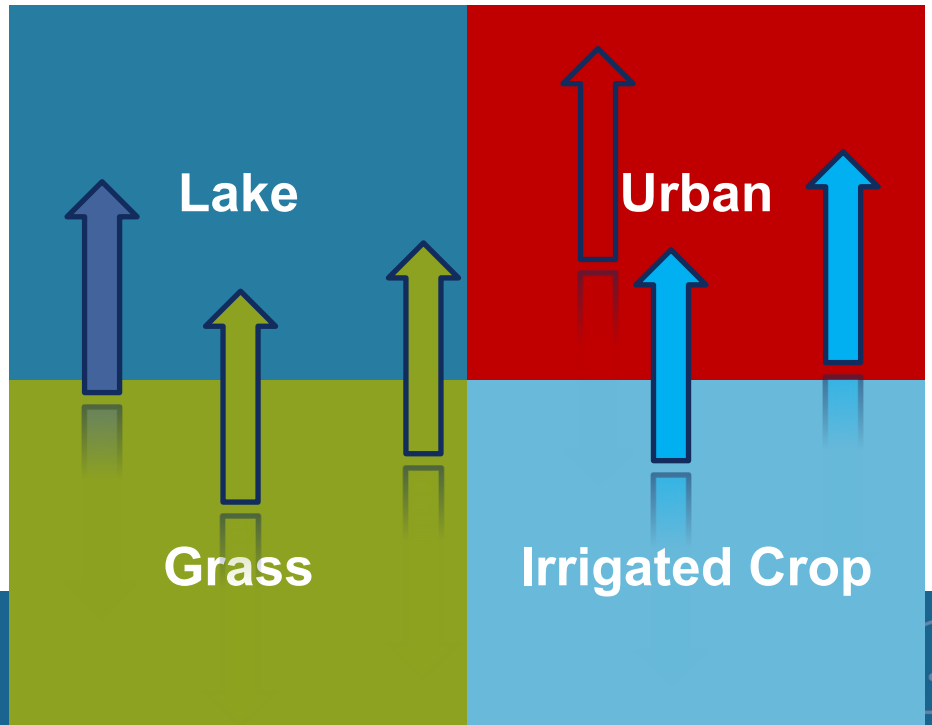
Atmospheric heterogeneity: ***CLUBB-MF*** *See* Witte et al. *(2022) for model details*

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



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

What if we remove the intermediate step?



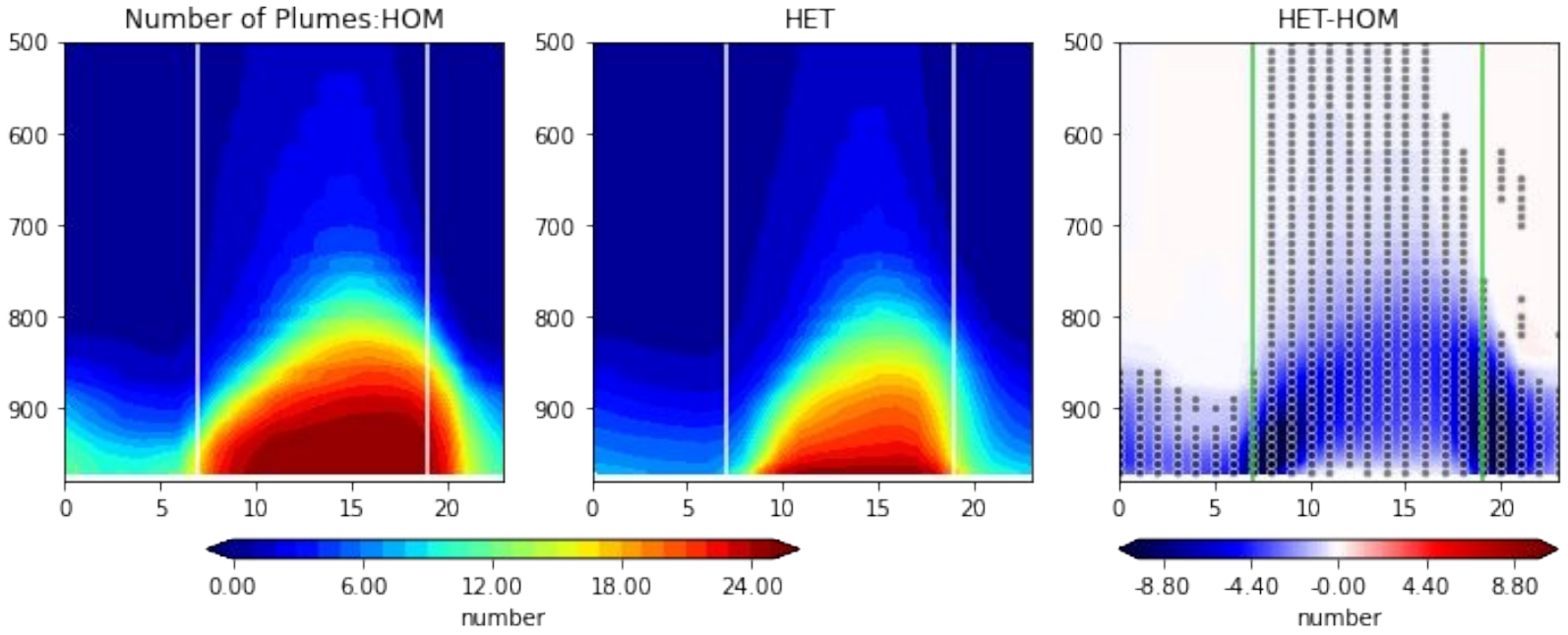
Modeling experiments

- Single-column (SCAM) experiments:
  - DOE ARM Southern Great Plains site with LASSO-VARANAL forcing
  - 2-day “hindcasts” from 2015-2016 JJA
  - HOM vs. HET cases

- New “highly heterogeneous” surface used with same atmospheric forcing
  - Even split between urban, lake, grass, and irrigated cropland

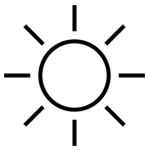
- CLUBB-MF set to use 25 updraft plumes
  - Roughly even division across surfaces (~6 plumes/patch)
  - Using a constant entrainment length (i.e., entrainment does not vary in time)

The impact of initializing *all* plumes at once vs. over each surface individually is apparent



Number of plumes per hour present at each vertical level, averaged over all *JJA days.*

But averaging over *all* days could mask days with more or less sensitivity to HET…



Clear days (87 days)

Precip < 75th percentile
Low-level (>600 mb) cloud liquid < 50th percentile

Cloudy days (38 days)

Precip < 75th percentile
Low-level (>600 mb) cloud liquid >= 50th percentile

Rainy days (43 days)

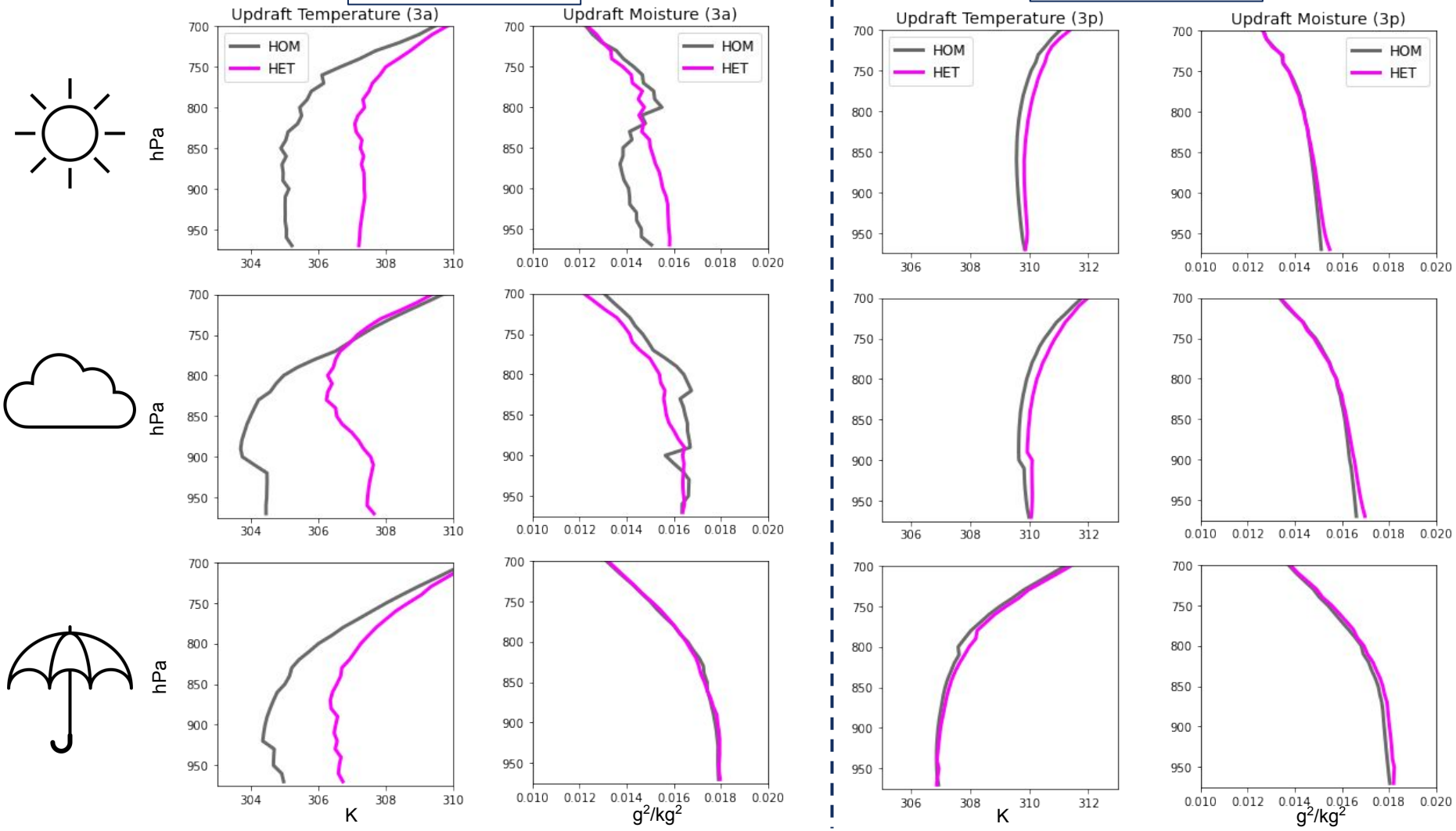
Precip >= 75th percentile

All based on daytime (6a-6p) averages

Does sensitivity to HET vary across days?

3 AM (local)

3 PM (local)



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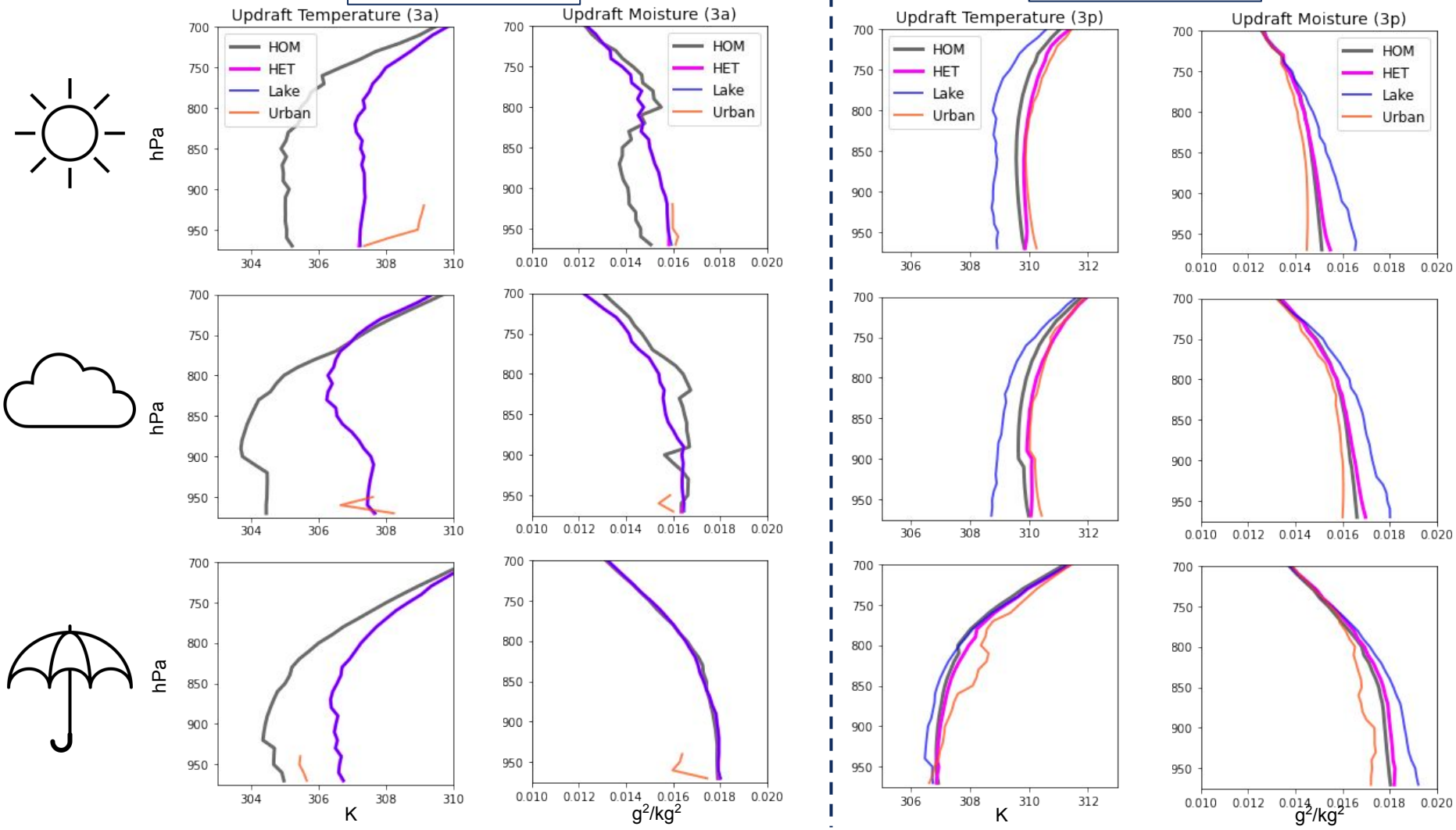

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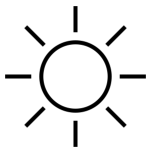

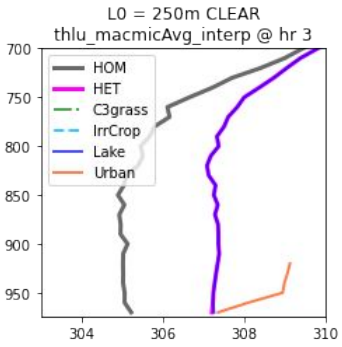

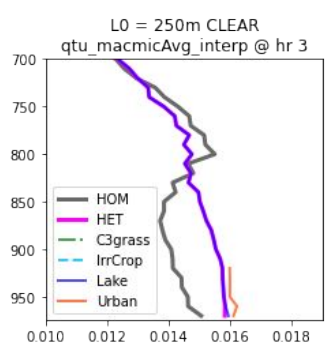

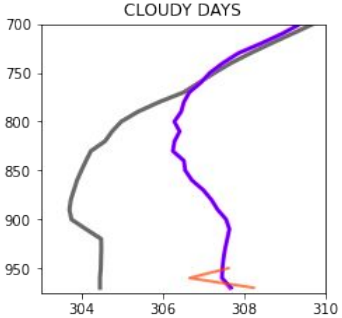

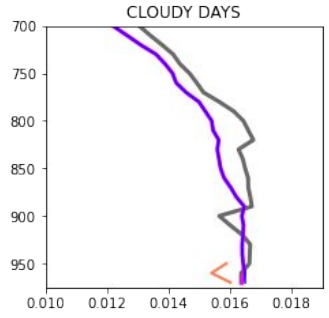

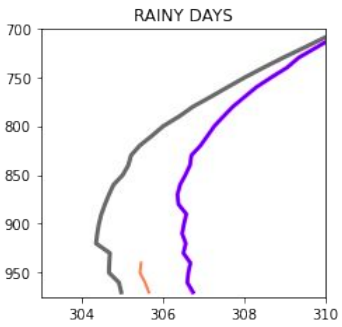

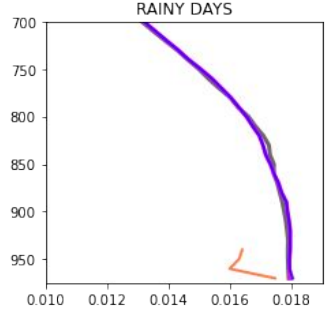

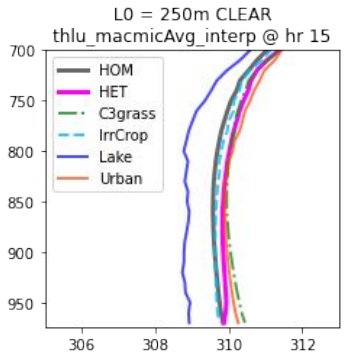

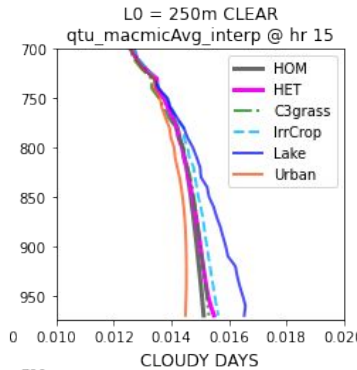

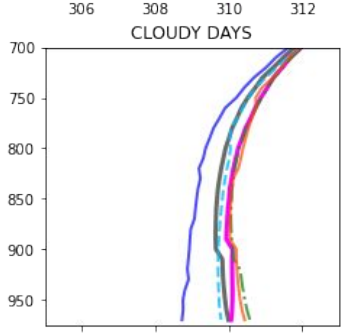

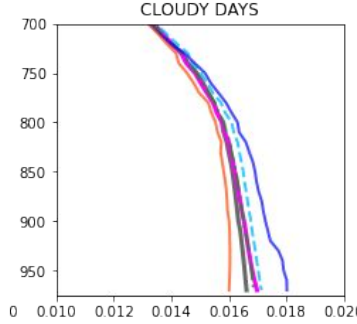

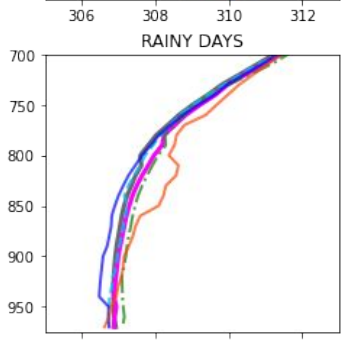

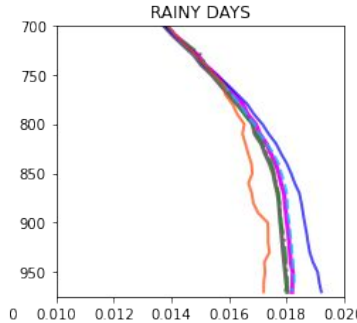

Does sensitivity to HET vary across days?

Yes

- Overnight, HET leads to enhanced updraft T regardless of day type
  - Primarily due to lake initiated plumes
  - Updraft moisture more sensitive to day type; primarily enhanced on clear days
- Daytime updrafts are typically warmer/wetter, though strongest signals are on  and  days

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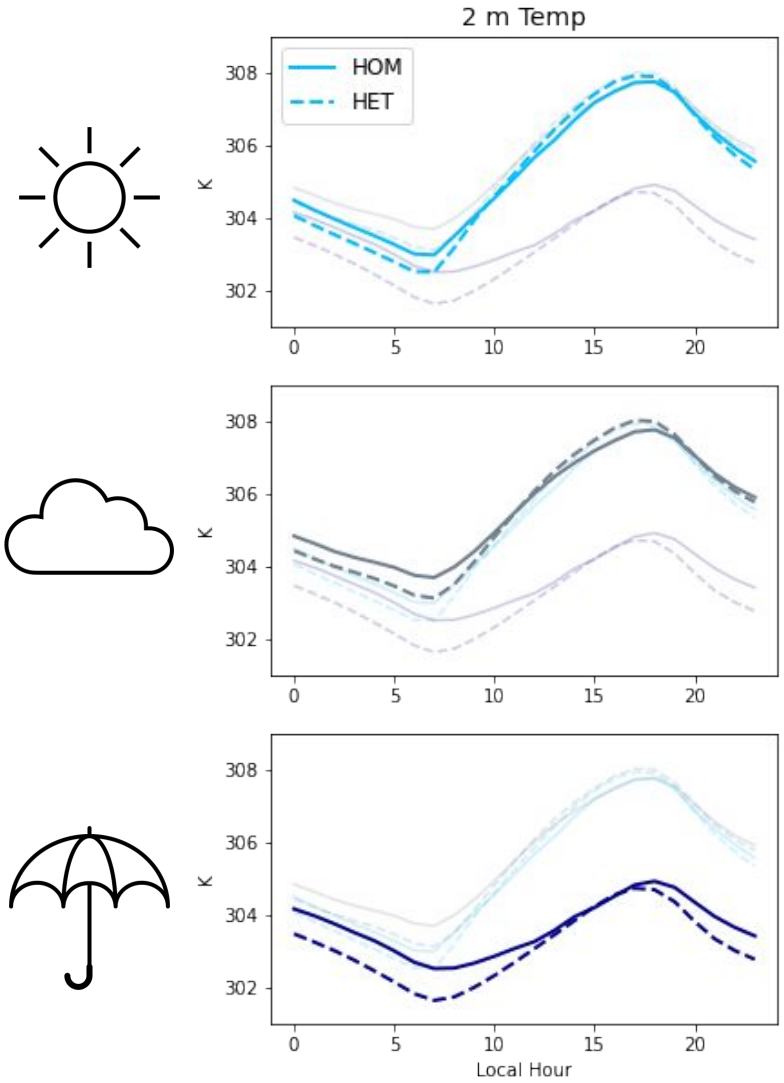
But what do differences in updrafts mean for other parts of the atmosphere?

What do these differences really mean?



- Diurnal temperature range enhanced in HET (most pronounced on cloudy days)

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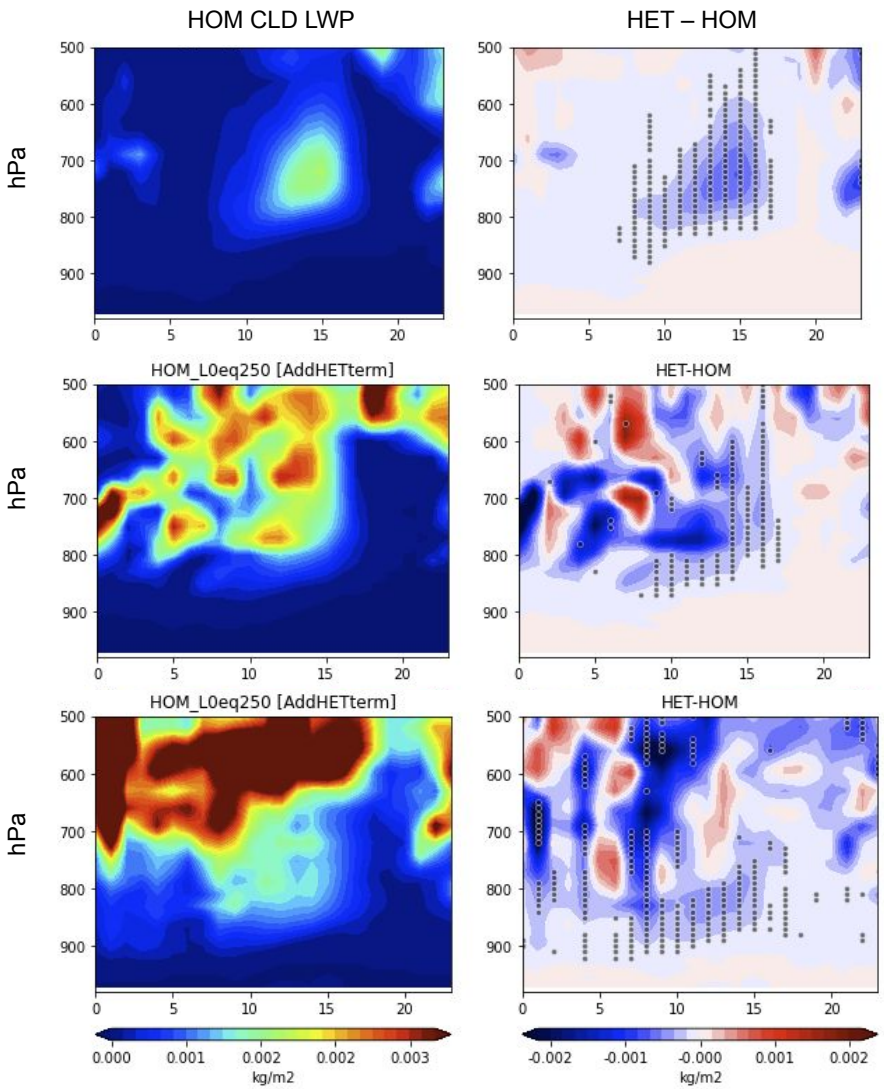

- Diurnal temperature range enhanced in HET (most pronounced on cloudy days)

- On all days, low-level cloud liquid water path (and fraction) is **reduced** in HET during daytime
- Signs of reductions overnight as well for days with clouds/rain

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But what do differences in updrafts mean for other parts of the atmosphere?

- All days exhibit nocturnal cooling near the surface (but  strongest)
-  days show a larger daily maximum temperature as well
  - Perhaps tied to reductions in cloud thickness/fraction, which slightly increases net incoming surface radiation

Key Takeaways

- Existing subgrid parameterizations can be linked to better capture interactions that occur below typical grid resolutions of O(100) km
- Mass flux (MF) plumes carry the signal of heterogeneous surfaces vertically into the atmosphere
  - Can ultimately alter near-surface temperature, moisture (not shown), and cloud properties
- The new scheme remains to be validated, but the framework is a first step towards capturing mesoscale secondary circulations induced by surface heterogeneity

Thank you!

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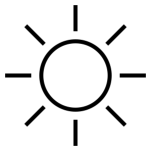
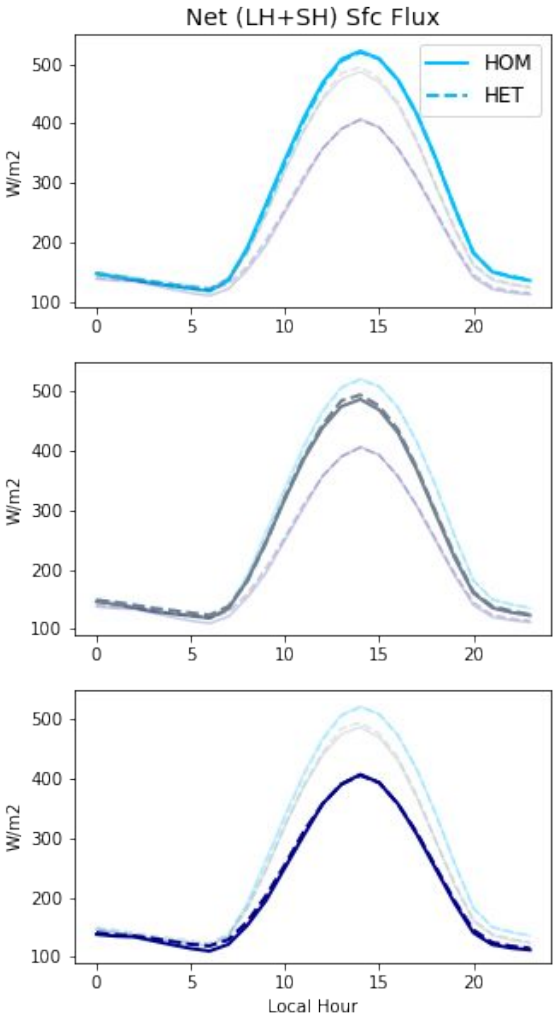
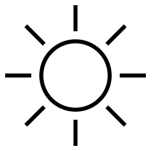
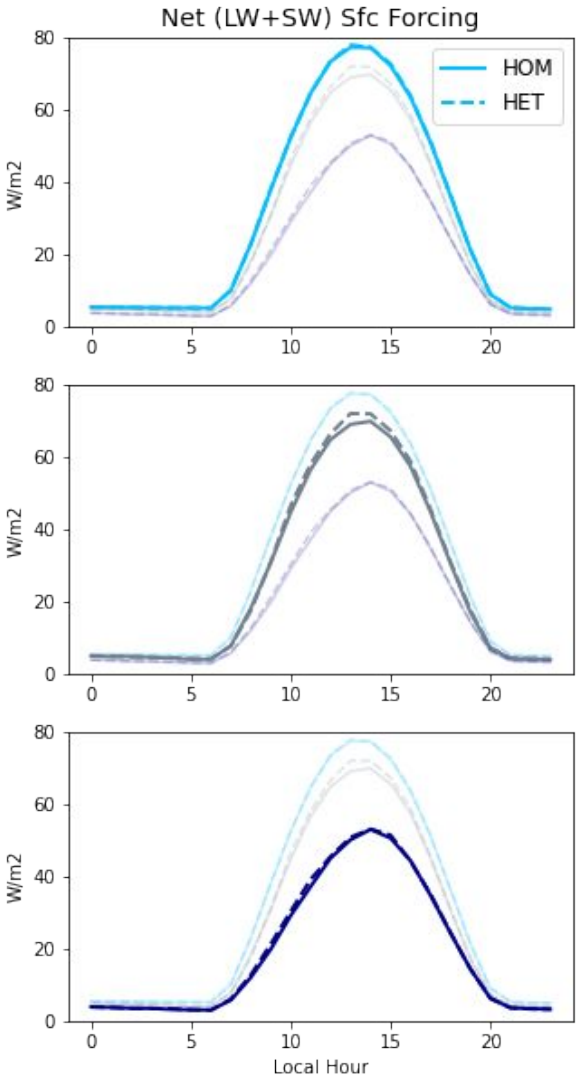




```
Clear days:
Max increase @ hr 4 = 2.679413
Max decrease @ hr 9 = -5.201202
Cloudy days:
Max increase @ hr 13 = 9.726624
Max decrease @ hr 9 = -1.577927
Rainy days:
Max increase @ hr 6 = 8.756500
Max decrease @ hr 14 = -1.674103
```

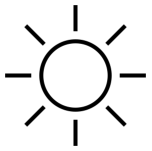
What do these differences really mean?

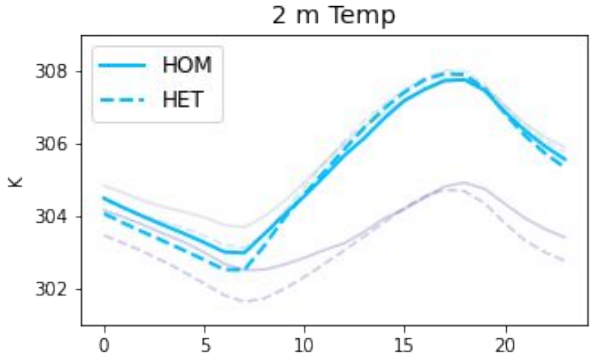


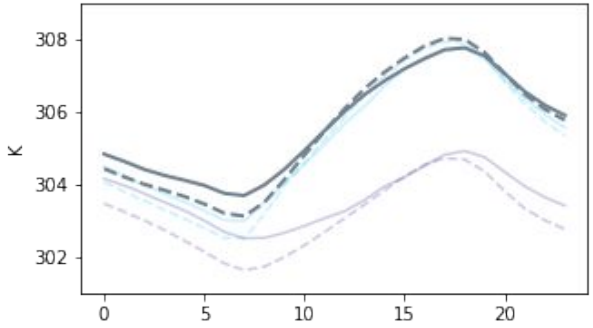


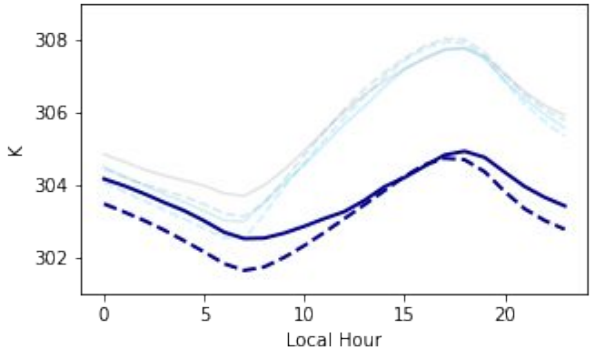

```
Clear days:
Max increase @ hr 13 = 0.642082
Max decrease @ hr 6 = -0.037941
Cloudy days:
Max increase @ hr 13 = 2.994003
Max decrease @ hr 8 = -0.708820
Rainy days:
Max increase @ hr 11 = 1.975224
Max decrease @ hr 16 = -0.116795
```

What do these differences really mean?



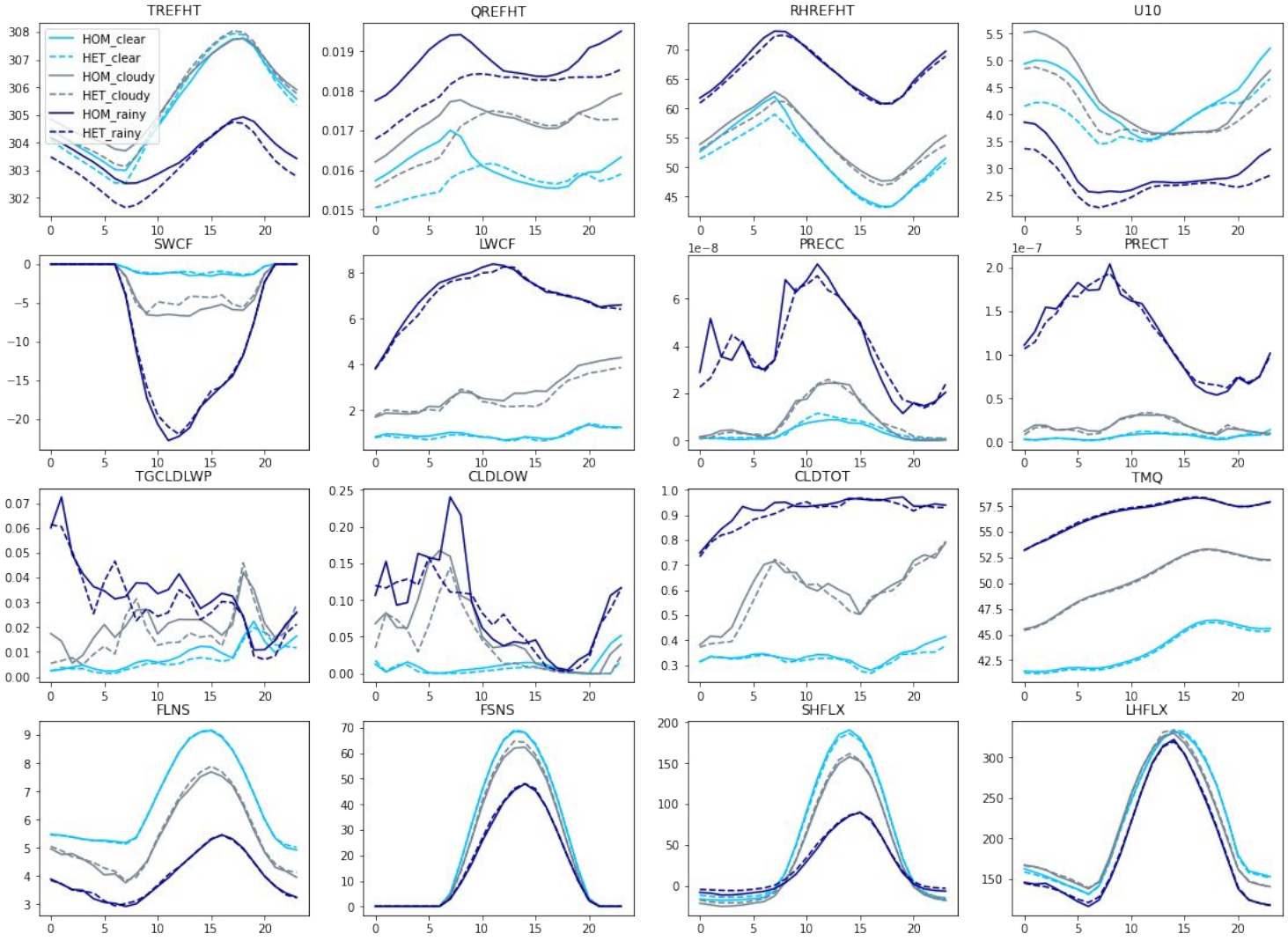







```
Clear days:
Max increase @ hr 13 = 0.285400
Max decrease @ hr 6 = -0.487885
Cloudy days:
Max increase @ hr 16 = 0.348328
Max decrease @ hr 7 = -0.567749
Rainy days:
Max increase @ hr 16 = 0.036560
Max decrease @ hr 7 = -0.877136
```

What do these differences really mean?



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