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Thermodynamic constraints on the sensitivity of boundary layer clouds to land surface flux partitioning

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CLASP

- **Coupling of Land-Atmosphere Subgrid Parameterizations**
- Currently, atmospheric models ignore all but the sub-grid spatial mean over land.
- Goals:
  - Assess impact of subgrid land surface variability on model grid scale states and fluxes.
  - Develop a means to communicate subgrid information to relevant atmospheric model parameterizations (e.g., shallow convection) to improve simulation of L-A interactions and climate.
- Expectation: thermally-driven secondary circulations are the missing link – can their effects be parameterized satisfactorily?

Approach

A Hierarchy of models have been employed:

- WRF-**LES** at 250m resolution over ARM SGP region (*Simon et al.*)
- **SCM** (CESM-SCAM) at same location (*Hay-Chapman et al.* J7B.5)
- 2 linked SCMs (*Waterman et al.*)
- CESM-2 (*Fowler et al.*, J8B.6)

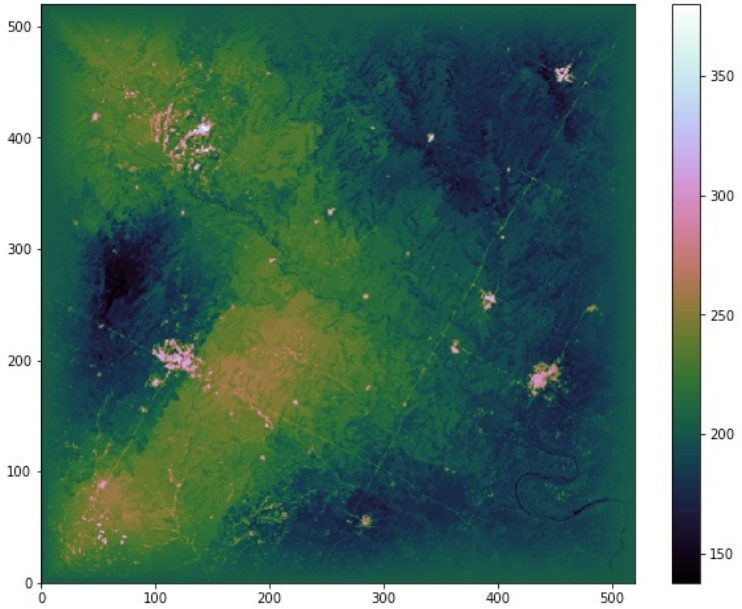
LES is 3D, convection-resolving, surface heterogeneity resolving

SCM is 1D, parameterized convection (CLUBB)

- SCM samples heterogeneity via an ensemble of simulations with a range of evaporative fraction (EF) applied to same available energy.

Domain and Simulations

- LES domain: 130x130km (520x520), 92 cases spanning Apr-Sep 2015-2019, ICs @ 06LT, run through evening.
  - Forcing from VARANAL data.
  - Homogeneous prescribed surface (HOM)
  - Heterogeneous prescribed surface forcing (HET; example right) from HydroBlocks offline runs
  - Most HET arises from soil moisture (wet/cool vs hot/dry patches)
- SCM is run for the same cases.
  - A base case with forcing matching HOM above.
  - Ensemble of 20 cases with same SH+LH, but EF=0,0.05,0.1,… 0.95.



Sensible heat flux [W/m^2]

Expectations

- The atmospheric response to surface heterogeneity is scale dependent, magnitude dependent, synoptic-situation dependent.
- Differences between LES & SCM simulations may help elucidate the role of secondary circulations (3D vs 1D) although there are many model differences too (vertical resolution, parameterized convection, cloud microphysics, turbulent transfer, etc.)

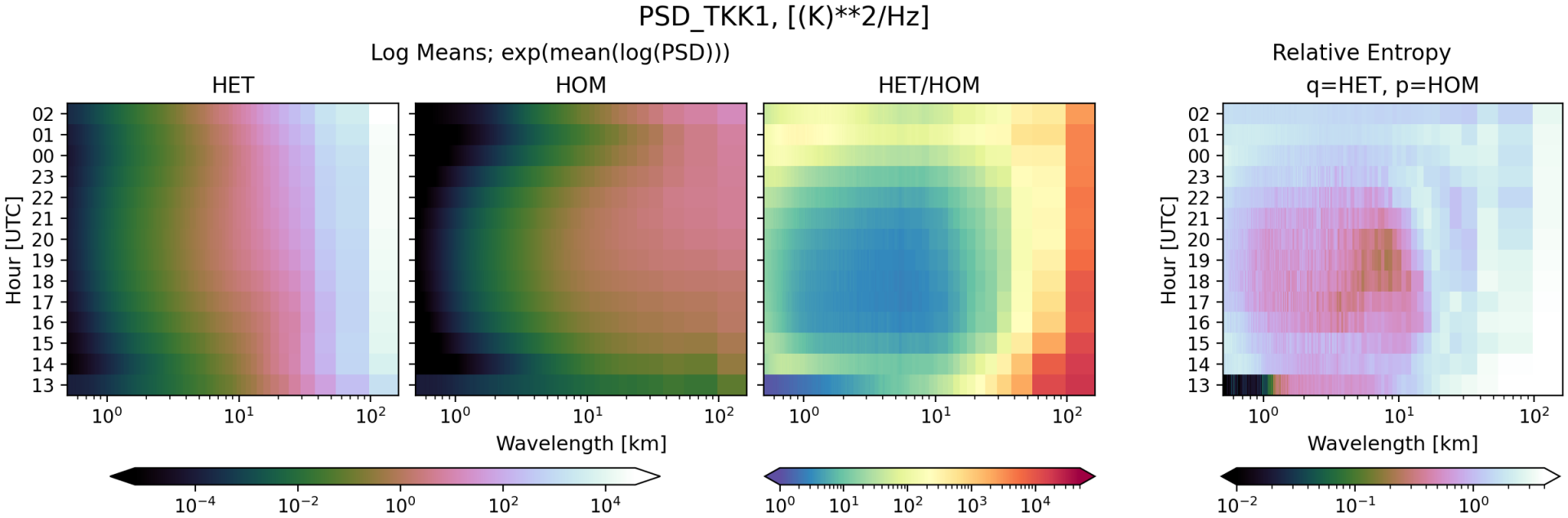
LES statistics: HET vs HOM

- Focus on the spatial power spectral density (PSD) of key fields.
- 2D horizontal fields processed into a single 1D horizontal spectrum
- Range of scales resolved: 500m to 130km.
- Statistics:
  - Log means across 92 cases exp(mean(log(PSD))) as a function of wavelength, hour, and for 3D fields: height.
  - Relative entropy (HET vs HOM) between the distributions across 92 cases (8 bins, each spanning an order of magnitude of power)

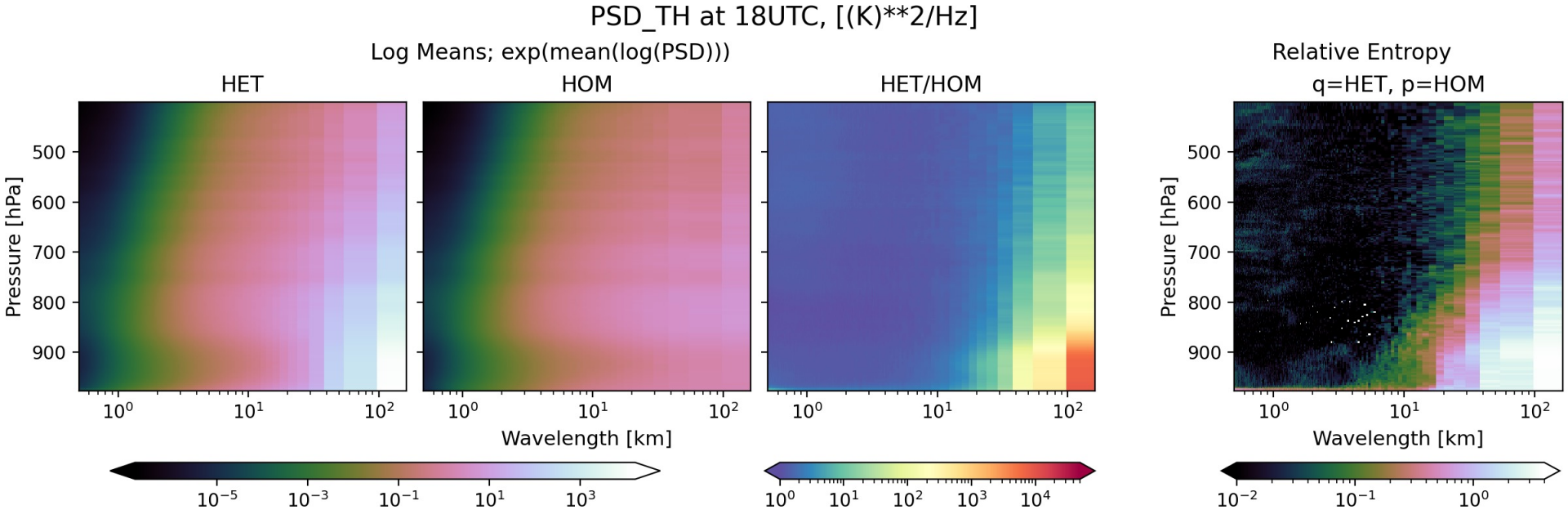
Three views HET vs HOM in LES

- 2D field comparisons in *wavelength vs hour-of-day* space
  - Layer 1 temperature, humidity, moist enthalpy, LCL height
- 3D comparisons in *wavelength vs height* space at local noon
  - Temperature, humidity, density, potential temperature, MSE
- 3D comparisons in *hour vs height* space at three wavelengths:1km, 10km, 130km
  - Temperature, humidity, density, potential temperature, MSE

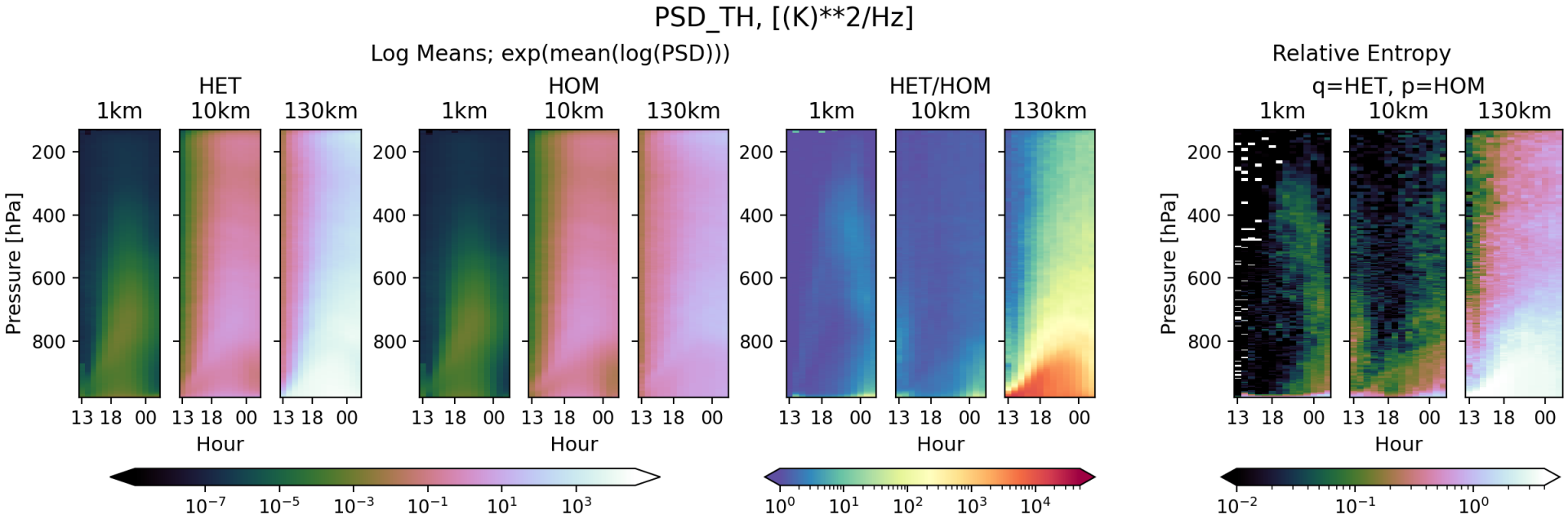
All variables exhibit quite similar characteristics – only temperature will be shown here.



- Generally, more power at longer scales, midday & after sunset.
- 1-15km "hole" where daytime energy doesn't care about the surface.
- Surface HET strongly felt at scales >20km, weakly all scales sunrise/set.
- Very similar picture for other variables – humidity changes are a bit more sluggish than temperature



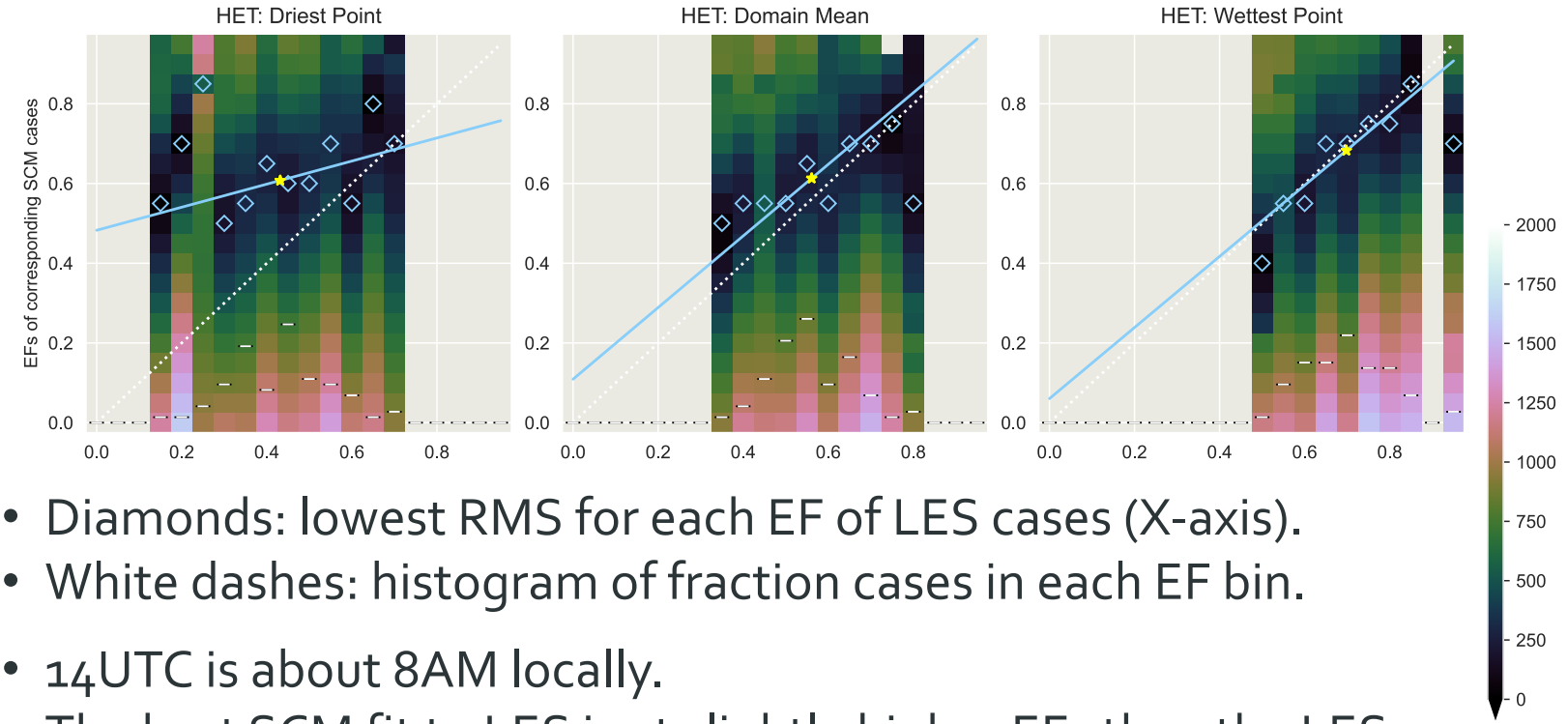
- More energy at longer scales and in lower troposphere.
- Surface HET effects penetrate more deeply at longer wavelengths.
- Relative entropy shows this linkage between horizontal and vertical scales very clearly



- At 1km, thermals extend deeper as morning goes to afternoon.
- Surface HET effects penetrate more deeply at longer wavelengths.
- At 10km, hardly any difference between HET and HOM above 800hPa.
- At 130km (domain-scale: wavenumber 1), HET has a lot more power.

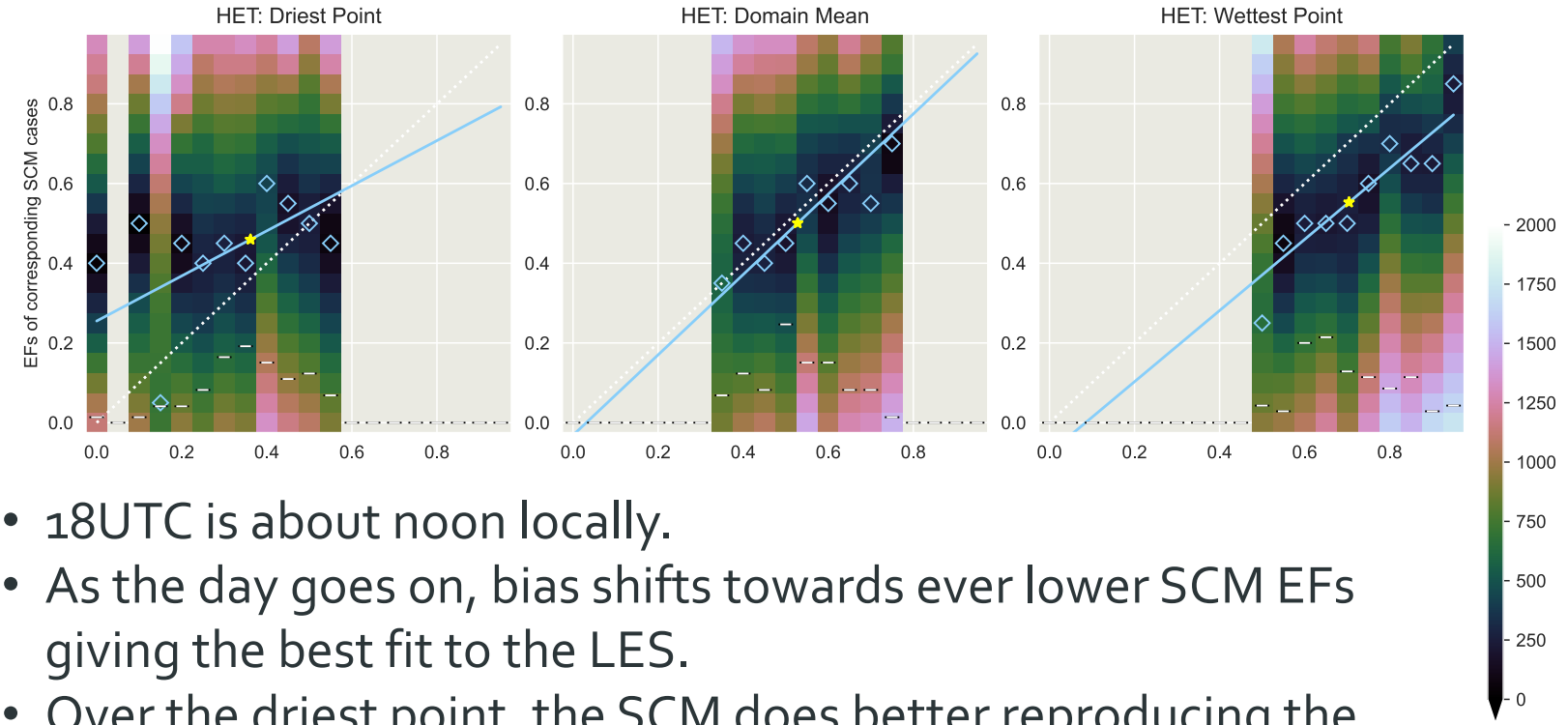
Comparing SCM to LES

- Variables examined: LCL height, PBL depth, cloud base – as before, results are similar, so only LCL height is shown here.
- We expect that SCM and LES should agree best in terms of afternoon PBL and convection-related metrics when EFs agree, less when they are highly divergent.
- Across 92 cases, the LES does not fill the entire phase-space of EFs, but by design the SCM does.
- To fill out the phase space, we look at domain mean LES results, and also results over the wettest (highest EF) and driest (lowest EF) grid cells of each LES simulation.

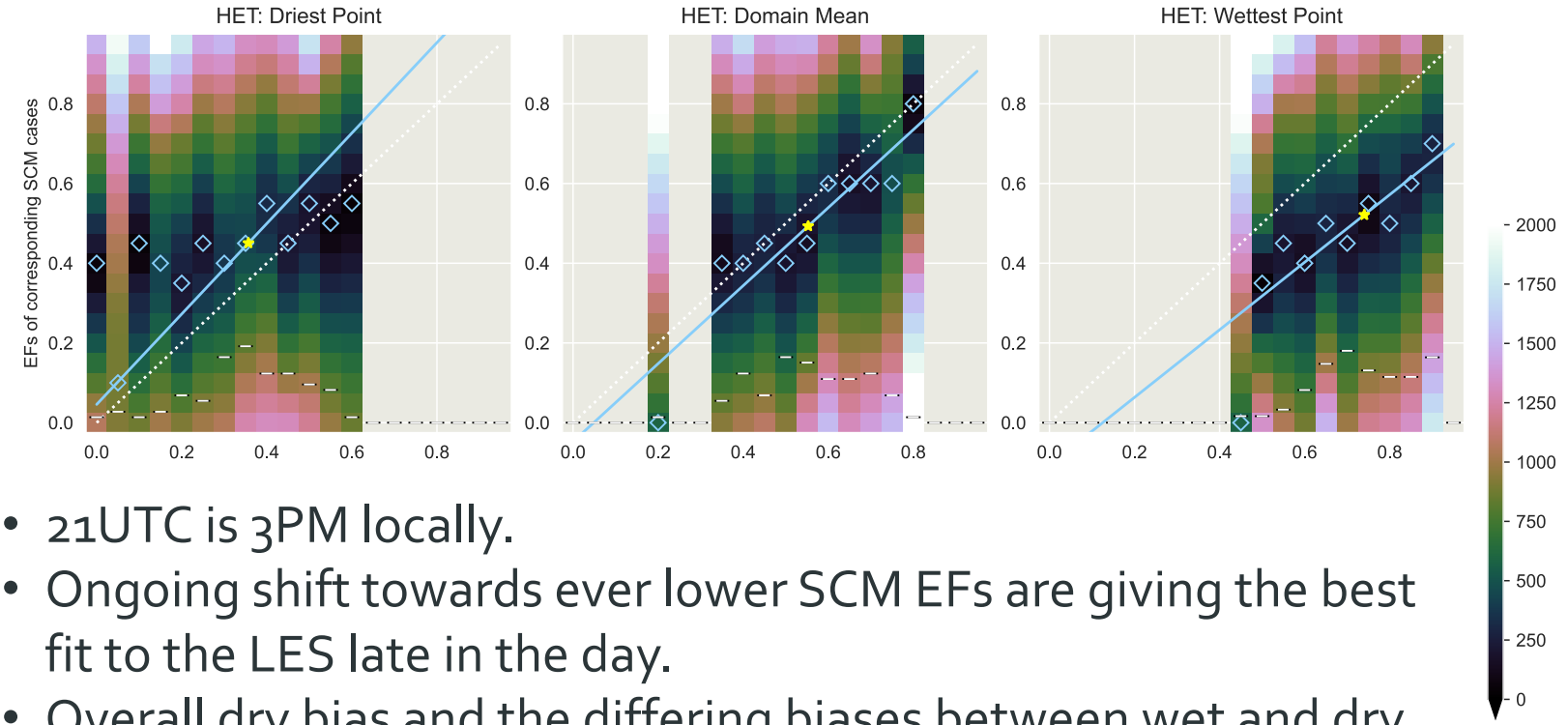


- Diamonds: lowest RMS for each EF of LES cases (X-axis).
- White dashes: histogram of fraction cases in each EF bin.

- 14UTC is about 8AM locally.
- The best SCM fit to LES is at slightly higher EFs than the LES.
- Similarly, over the driest spot in the domain, the SCM does better reproducing the LES when its EF is biased high.



- 18UTC is about noon locally.
- As the day goes on, bias shifts towards ever lower SCM EFs giving the best fit to the LES.
- Over the driest point, the SCM does better reproducing the LES when its EF is biased high.
- Vice versa over the wettest point.



- 21UTC is 3PM locally.
- Ongoing shift towards ever lower SCM EFs are giving the best fit to the LES late in the day.
- Overall dry bias and the differing biases between wet and dry areas bears out the hypothesis that the EF biases are compensating for the lack of mixing from secondary circulations in the SCM.