Global Energy and Water Cycle Exchanges Project

# Improved Initialization of the L-A System? A Need to Revisit the Modeling of Surface States and Fluxes

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With materials from the GLASS Panel Project Leaders



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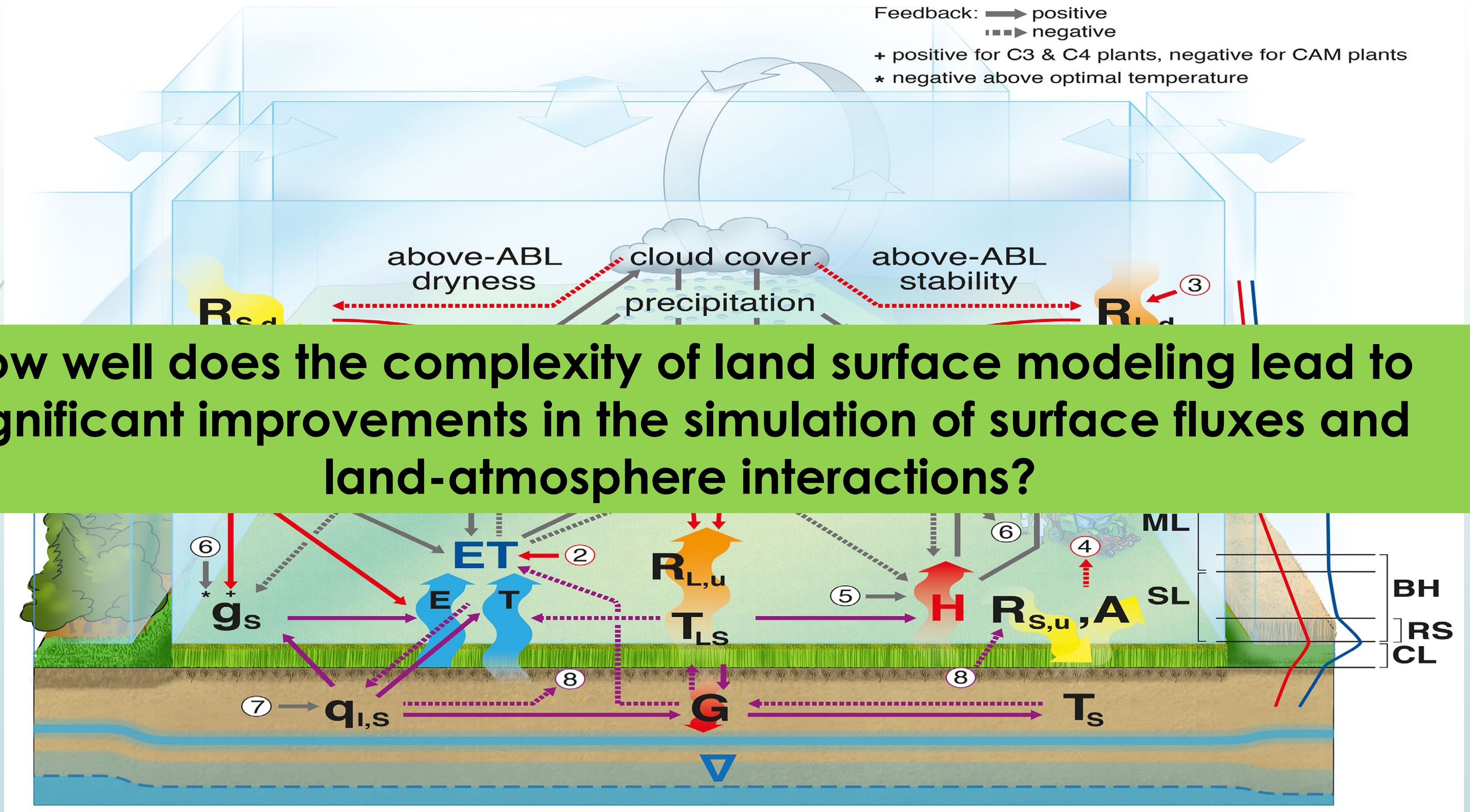
# The Land-Atmosphere System




**How well does the complexity of land surface modeling lead to significant improvements in the simulation of surface fluxes and land-atmosphere interactions?**

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# Implications for Increased Land Surface Model Complexity (and Coupled Model Demand)

1. More process representation: Do we see improved modeling of surface states and fluxes?
2. Large increase in the number of model parameters: Is this a good thing?
3. Moving towards high-resolutions (km-scale): Growing challenges in how to initialize these models (spin-up time and data availability/readiness)
4. …

**There is a long list of questions of how the complexity of land surface models enhances the initialization. But let's take a step back and ask, are these increases in complexity actually improving the modeling of surface fluxes and L-A interactions?**

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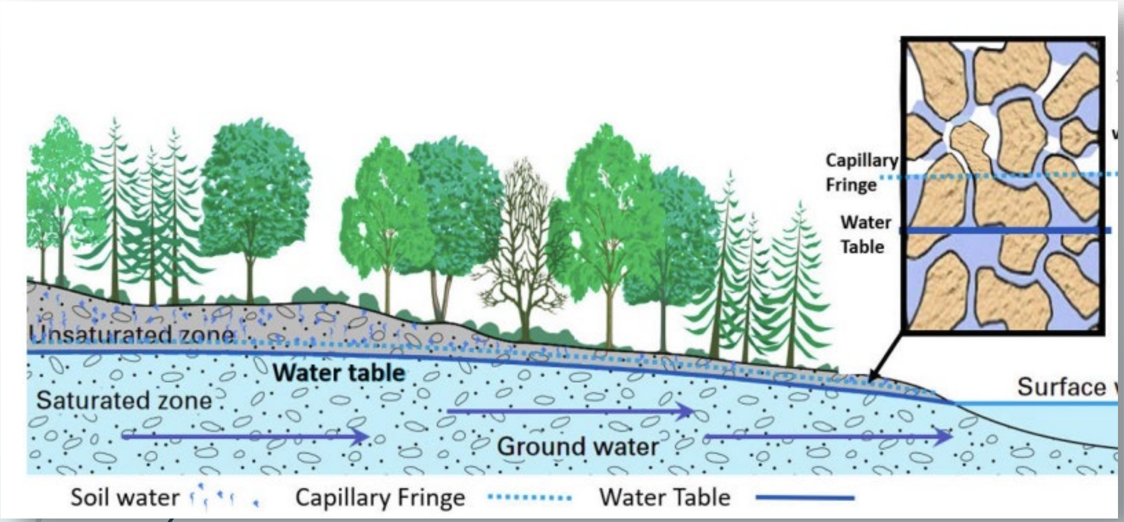
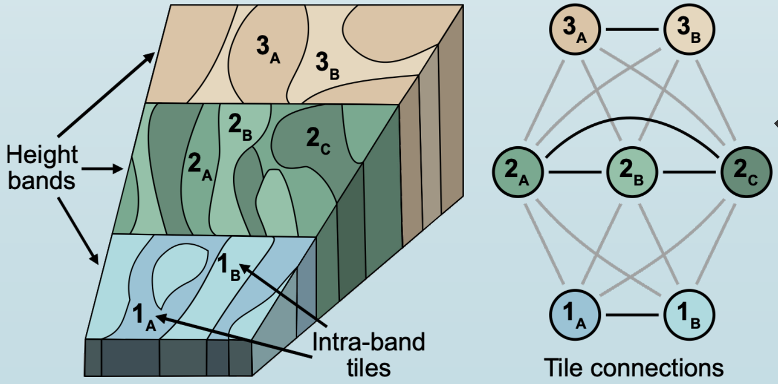
# Role of Subsurface Flow on Surface States and Fluxes



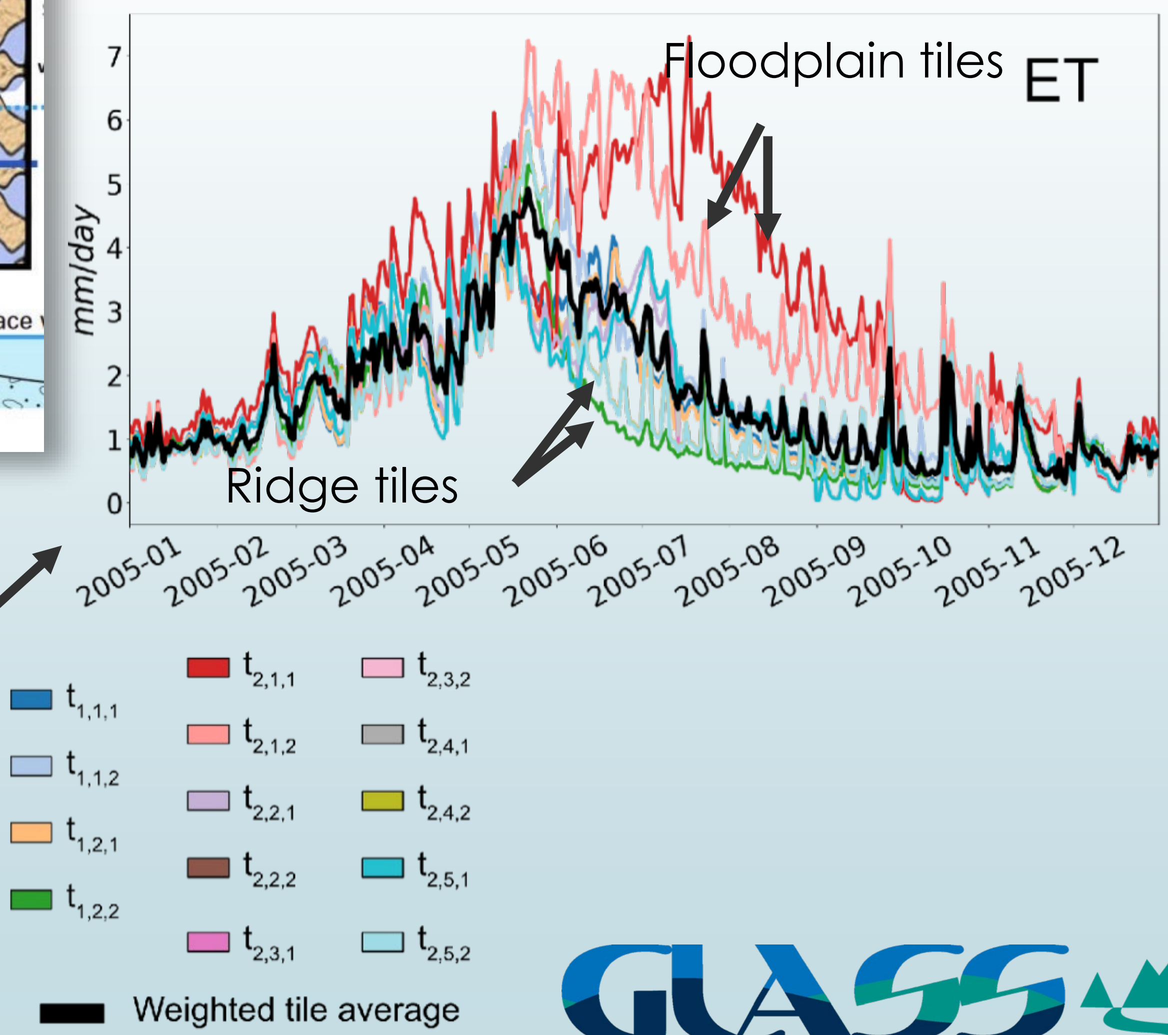

Credit: Stefan Kollet and Laura Condon

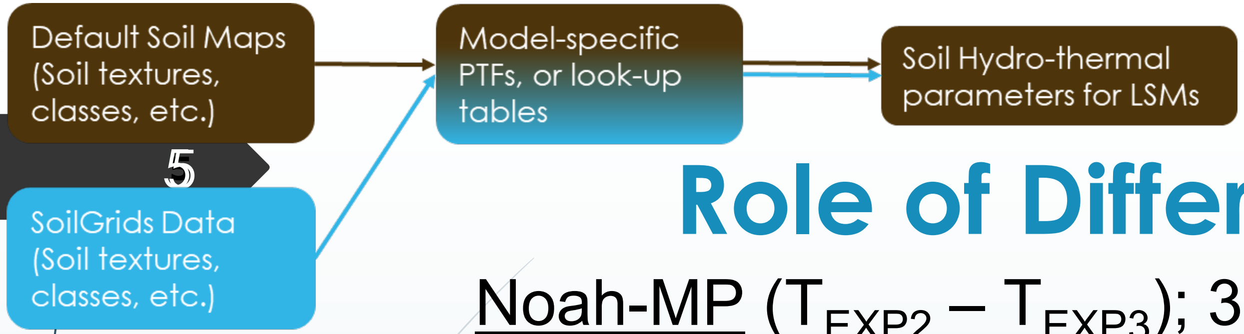
Characteristic hillslope




Chaney et al., 2018

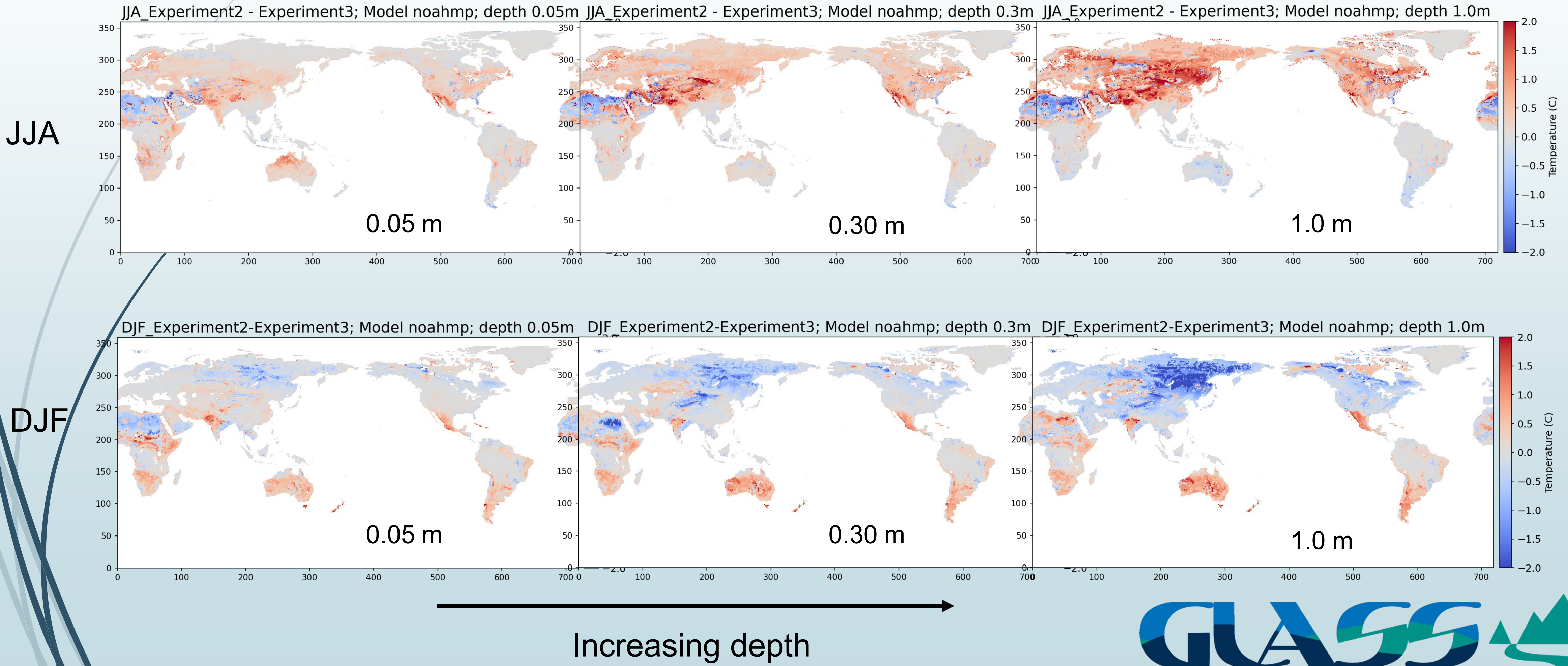
Output from land model tiles of a 0.25 degree grid






# Role of Different Soil Maps

Noah-MP ($T_{EXP2} – T_{EXP3}$); 30-year daily average *difference*

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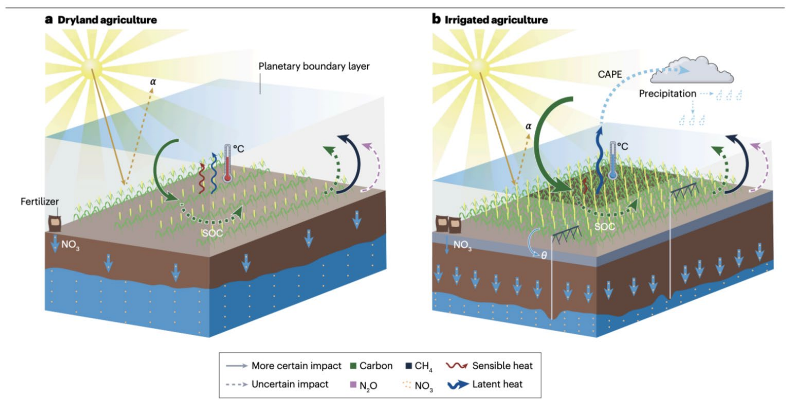
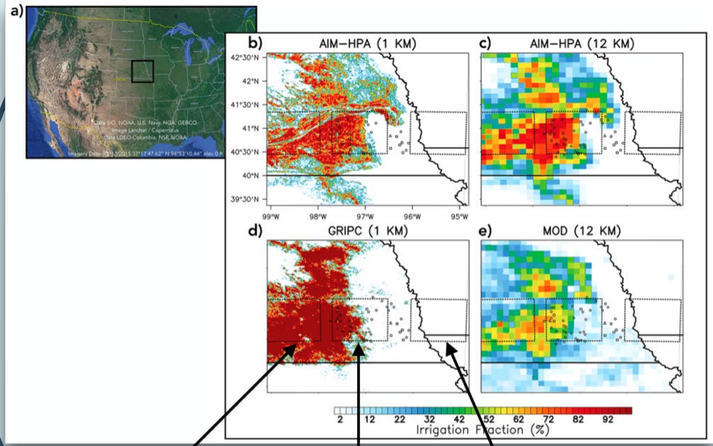
# Importance of Modeling Irrigation in Land-Atmosphere Interactions

## Role of irrigation in surface energy balance

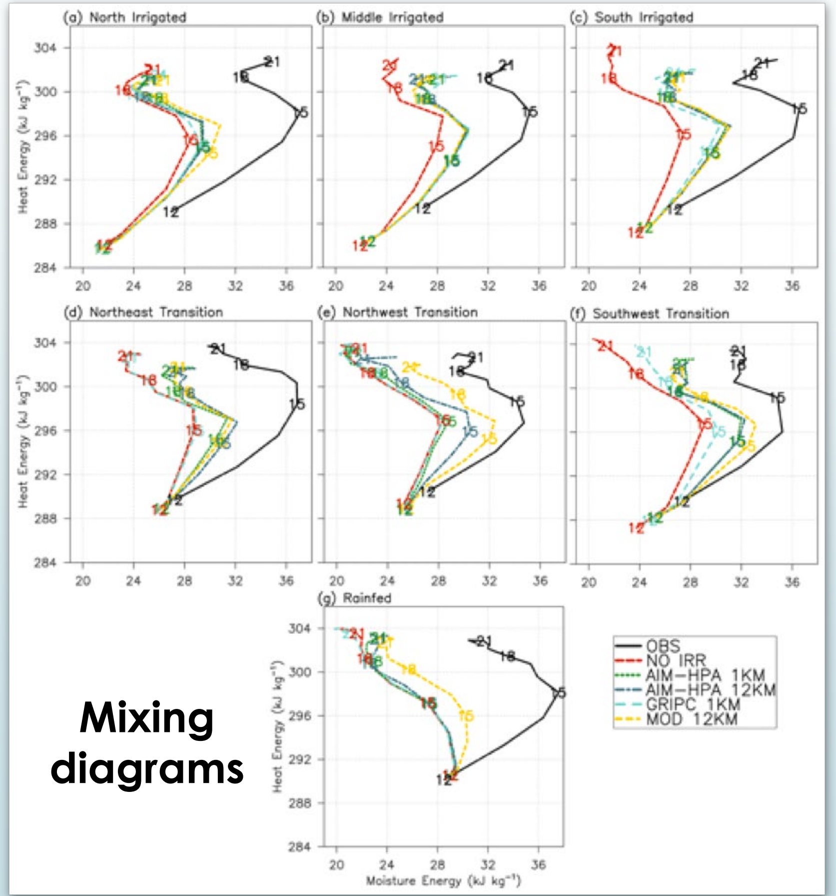



## Case-study Noah-MP forced with different irrigation datasets




Irrigated Transition Rained

## Sensitivity of macroscale response of atmosphere to different irrigation parameterizations/datasets




Credit: Tricia Lawston Parker

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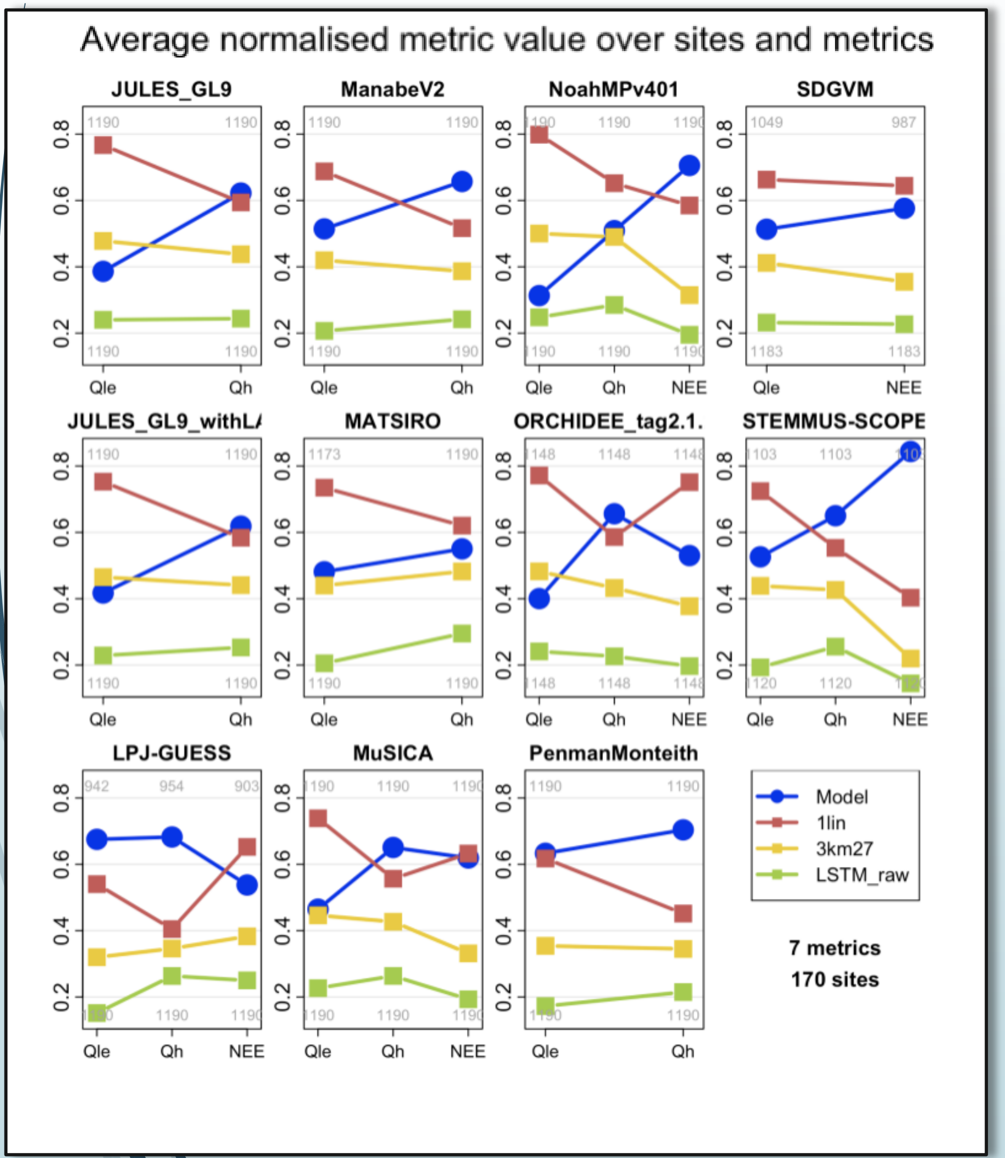
# PLUMBER2: Benchmarking Surface Fluxes in Land Surface Models




- Land surface models are run at 170 eddy covariance towers and the simulated fluxes are then compared to the observations.
- Qe = Evaporation; Qh = Sensible heat flux; NEE = Net ecosystem exchange
- Empirical approach (long-short term memory neural network; LSTM) provides the current "best case model" (i.e., benchmark). Uses same input data as land surface models.
- **Take home message**: Out-of-sample empirical approaches still appreciably outperform state-of-the-art land surface models

Credit: Gab Abramowitz

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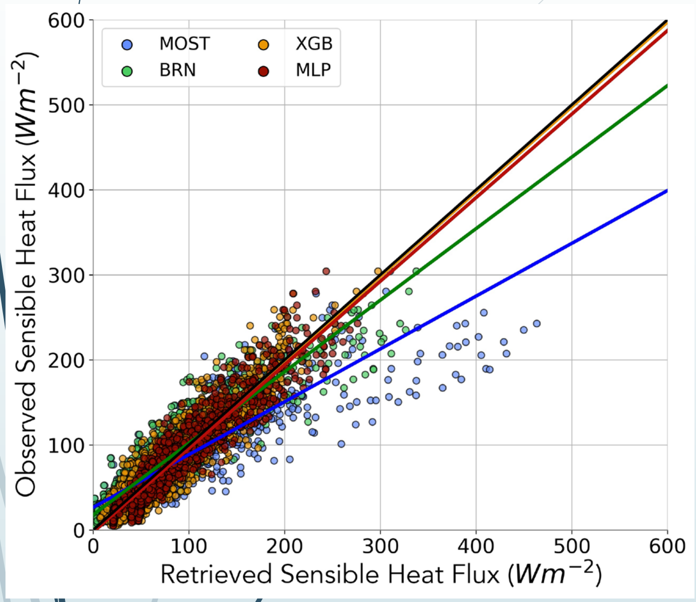
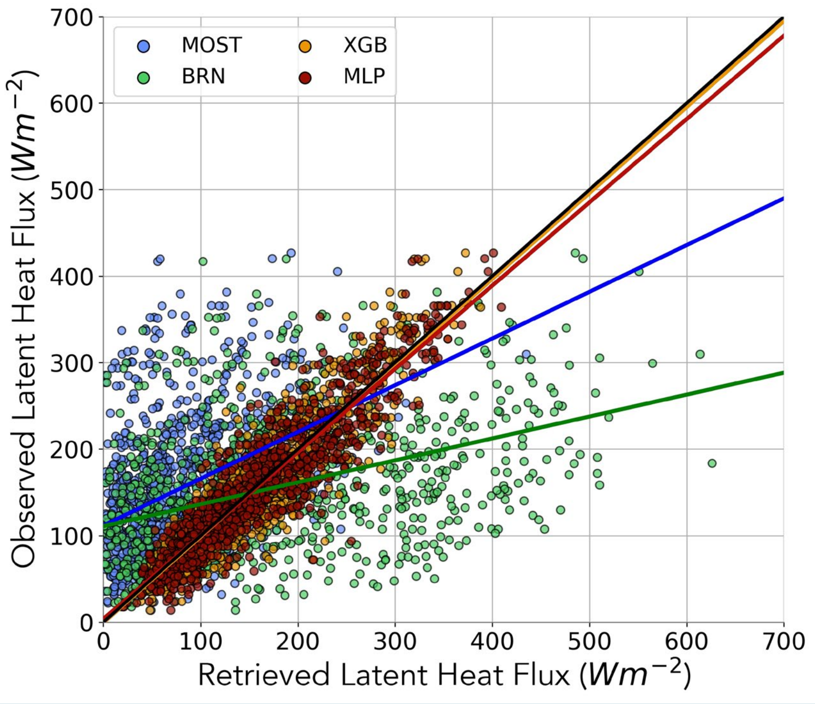
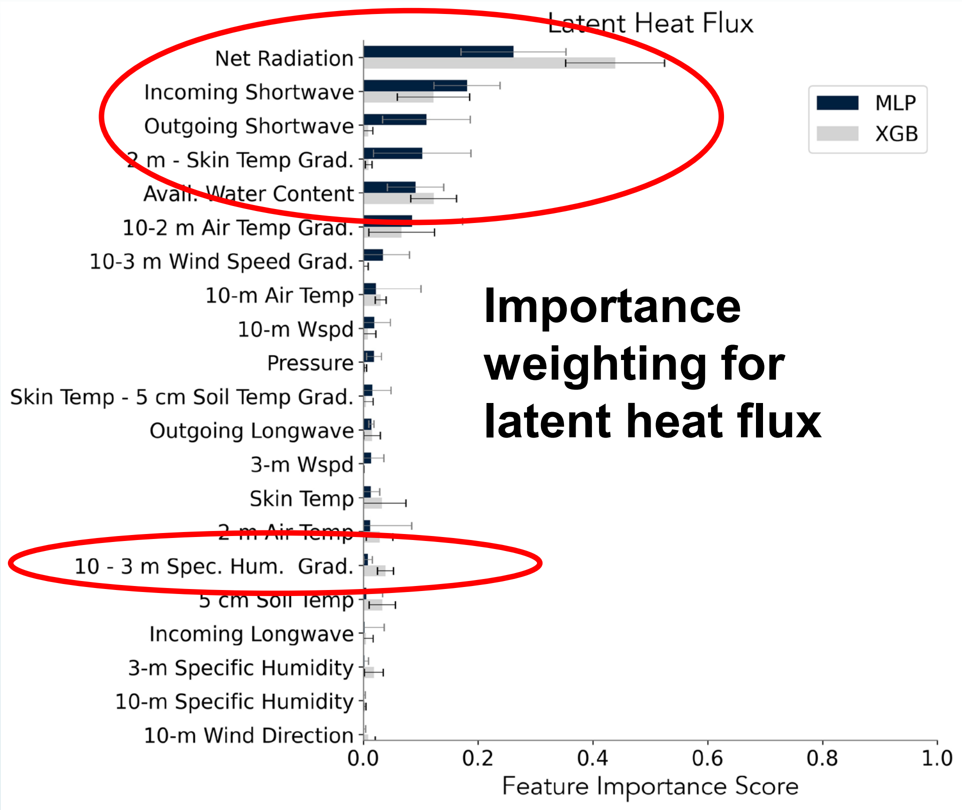
# The Role of Monin-Obukhov Similarity Theory (MOST)



**MOST** is fundamental for the coupling of land surface and atmospheric model components. **It is applied in almost all coupled model systems from LES to global.**




**Importance weighting for latent heat flux**

$$\frac{\partial \overline{u}}{\partial z} = \frac{u^*}{\kappa z}\phi_M\left(\frac{z}{L}\right)$$

$$\frac{\partial \overline{\theta}}{\partial z} = \frac{H_0}{u^*\kappa z}\phi_H\left(\frac{z}{L}\right)$$

$$\frac{\partial \overline{q}}{\partial z} = \frac{Q_0}{u^*\kappa z}\phi_L\left(\frac{z}{L}\right)$$

**ML outperforms MOST and BRN. ML has great potential to improve surface layer flux relationships. Current partitioning of fluxes is huge error source** ***(Lee and Buban JAMC 2020, Lee et al. MWR 2021, Lee and Meyers 2023, Wulfmeyer et al. BLM 2023).***

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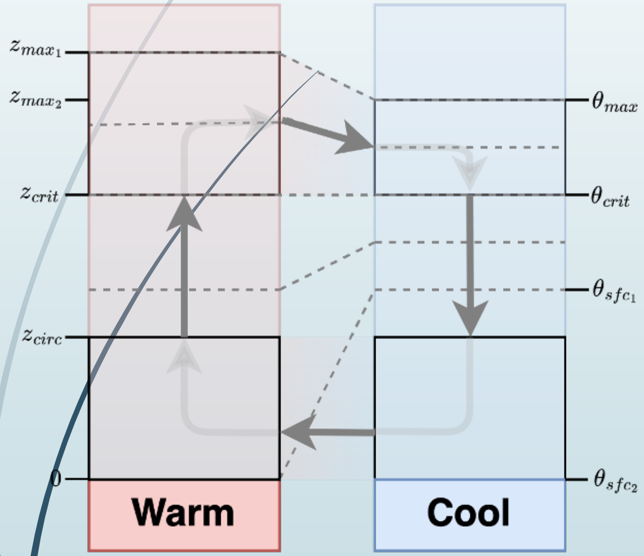
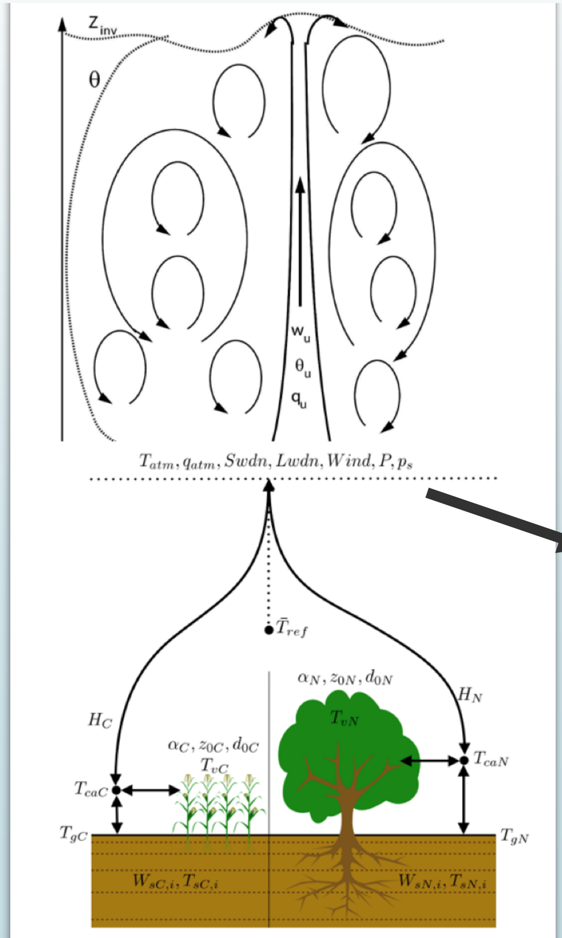
# Parameterizing Atmospheric Turbulence (Aerodynamic Resistances)

Parameterizing sub-grid secondary circulations




Courtesy: Tyler Waterman

Surface heterogeneity-informed buoyant plumes

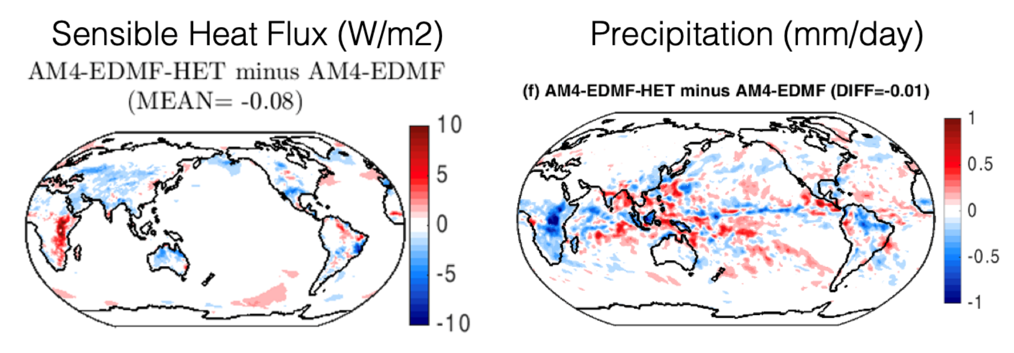



Courtesy: Khaled Ghanam

- Strong assumptions in surface turbulence parameterizations (e.g., planar homogeneity in MOST) that substantially limit their applicability.

- The **CLASP project** is exploring how surface coupling can be improved by accounting for parameterized heterogeneous-surface driven microscale to mesoscale circulations.

**Global Climatology Differences (CLASP vs. Baseline)**

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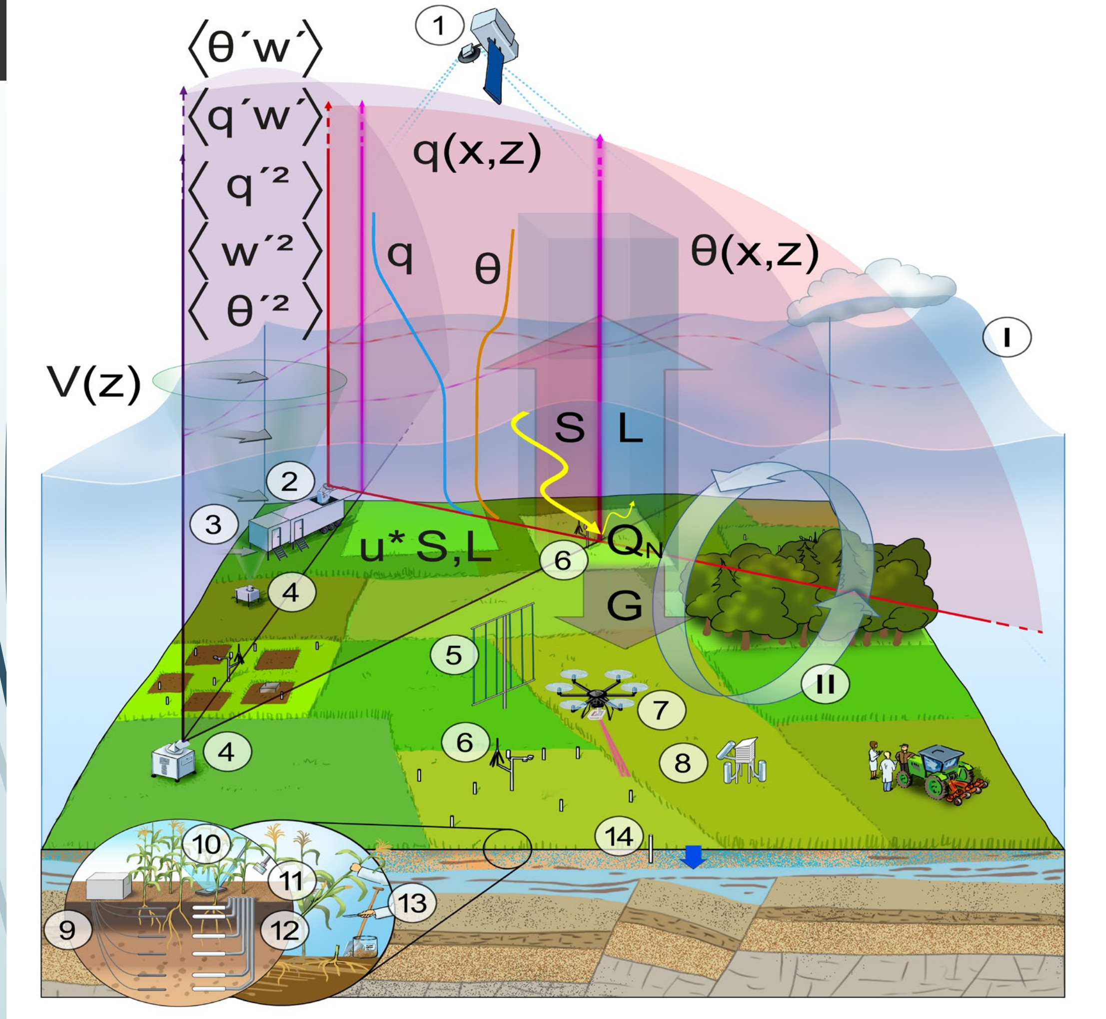
# GEWEX LAFO (GLAFO) Design




Proposed sensor synergy:
I: PBL top, II: mesoscale vortex
1: Satellite remote sensing
2: Vertically staring Doppler, water vapor, temperature, and $CO_2$ lidar systems, infrared spectrometer (IRS), microwave radiometer (MWR), cloud radar
3: Scanning Doppler, water vapor, temperature, and $CO_2$ lidar systems
4: Scanning Doppler lidar systems
5: Fiber-based distributed sensors
6: Energy balance and eddy covariance stations
7: Unmanned aerial vehicle (UAV)
8: Water vapor and $CO_2$ isotope sensor
9: Time-domain reflectometers (TDRs)
10: Leaf area index (LAI) measurement
11: Gas exchange system for photosynthesis and transpiration rates
12: Tensiometers
13: In-situ canopy measurements such as biomass and canopy height
14: Soil moisture and temperature network

***Wulfmeyer et al. GEWEX Newsletter 2020, GLAFO White Paper 2021 (see [https://www.gewex.org/panels/global-landatmosphere-system-study-panel/glass-projects](https://www.gewex.org/panels/global-landatmosphere-system-study-panel/glass-projects))***

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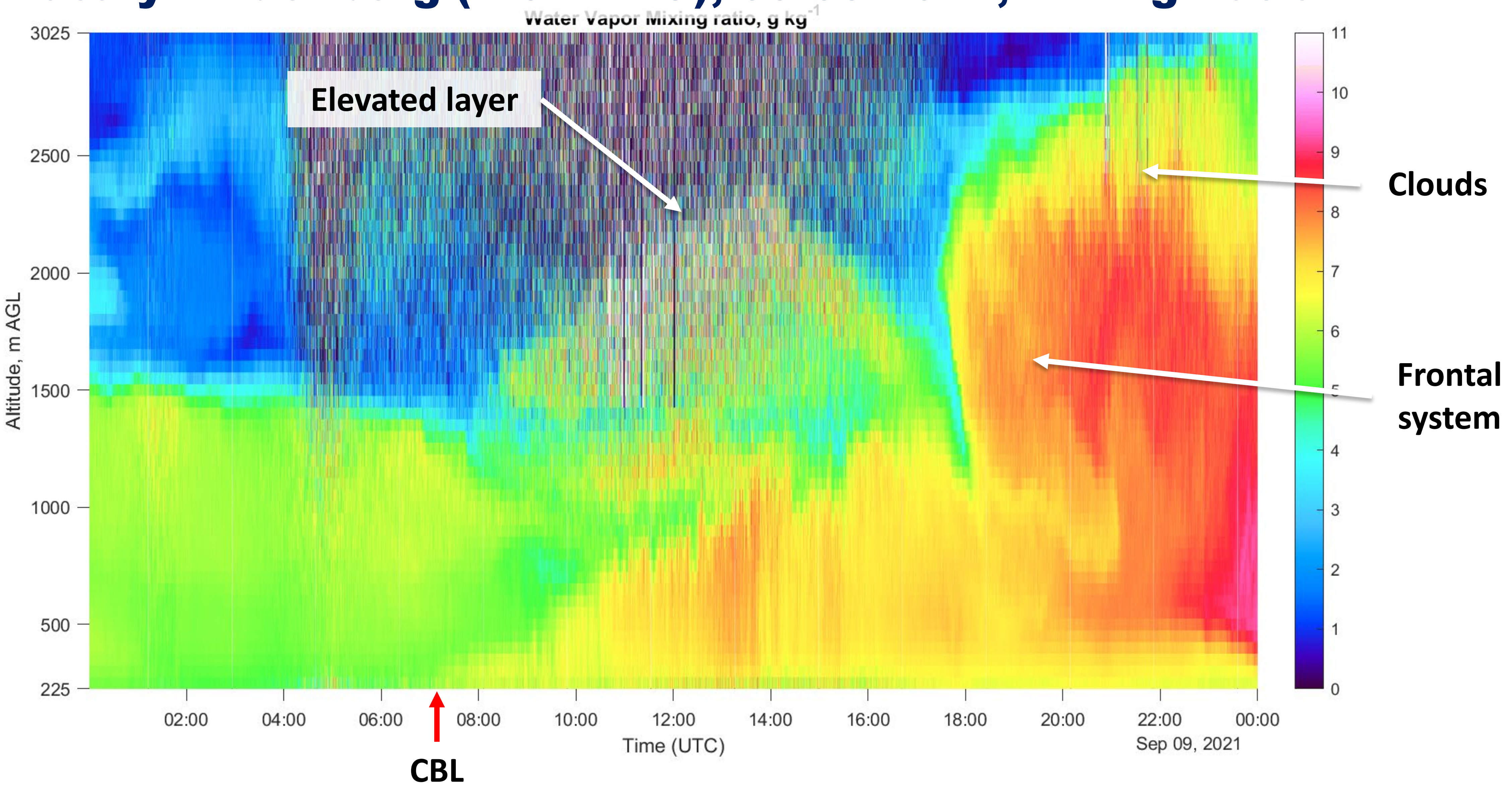
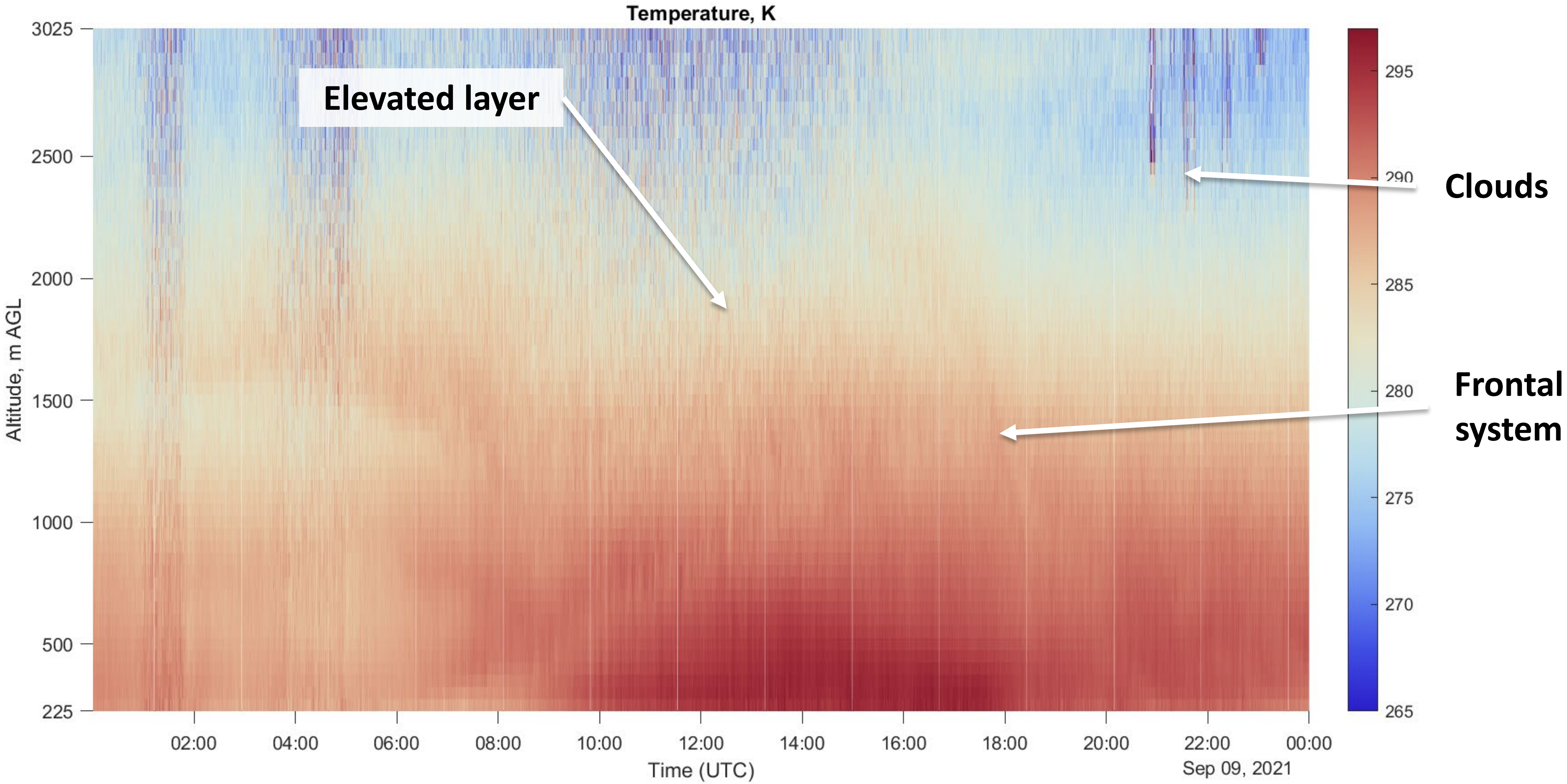
# German Weather Service (DWD) Meteorological Observatory Lindenberg (MOL-RAO), 09.09.2021, Mixing Ratio

10 s, 50 m



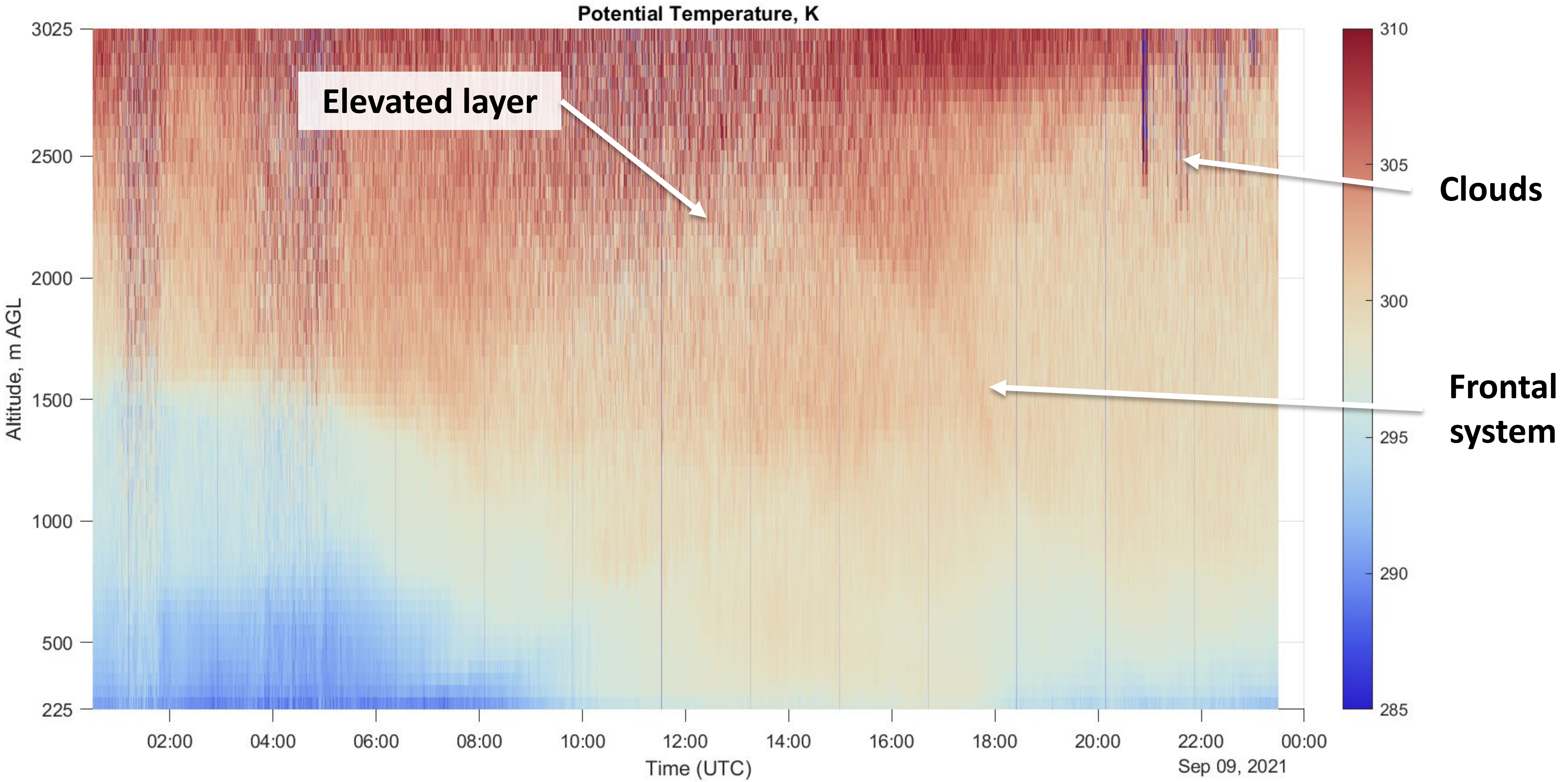
# Temperature

**10 s, 50 m**



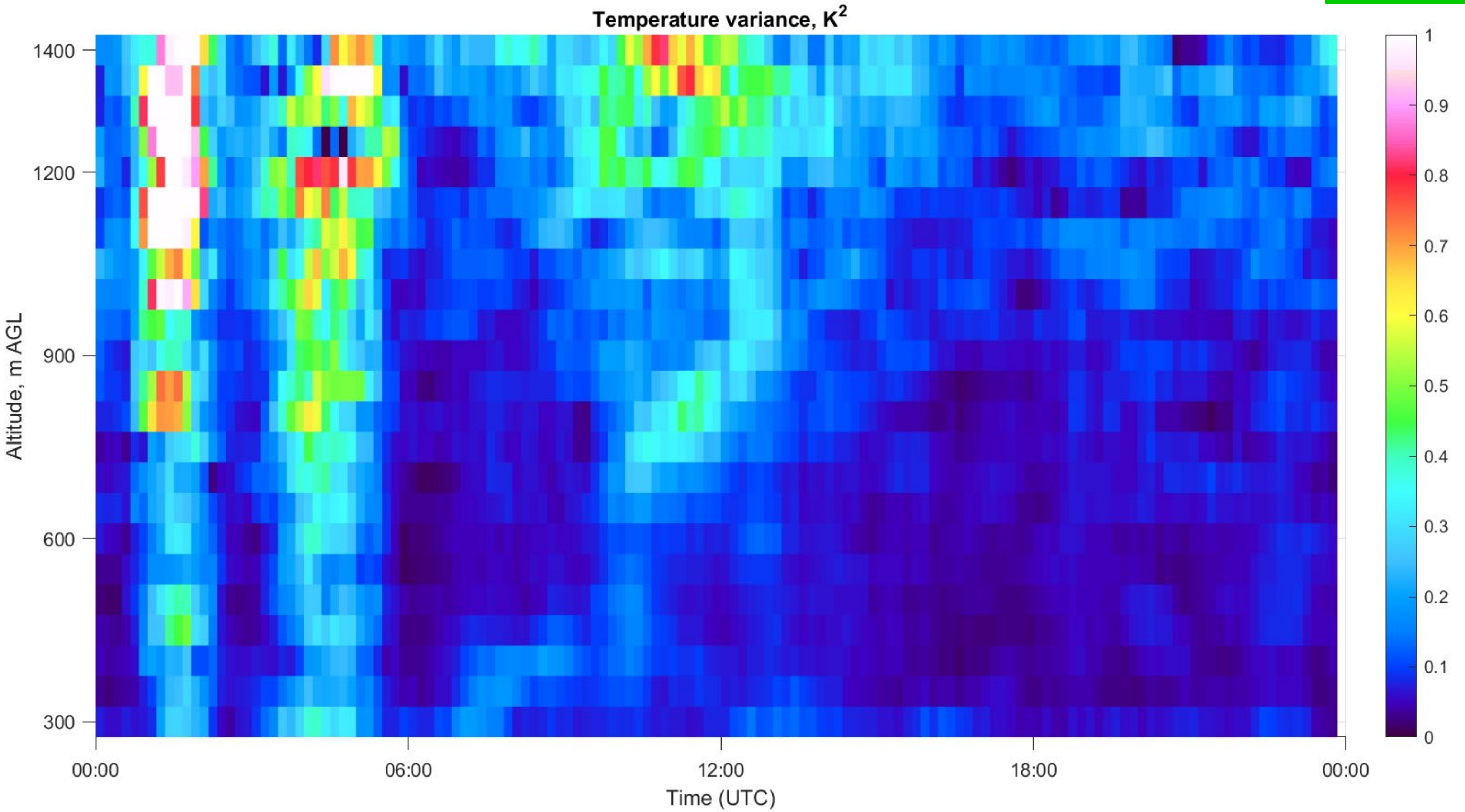
# Potential Temperature

10 s, 50 m



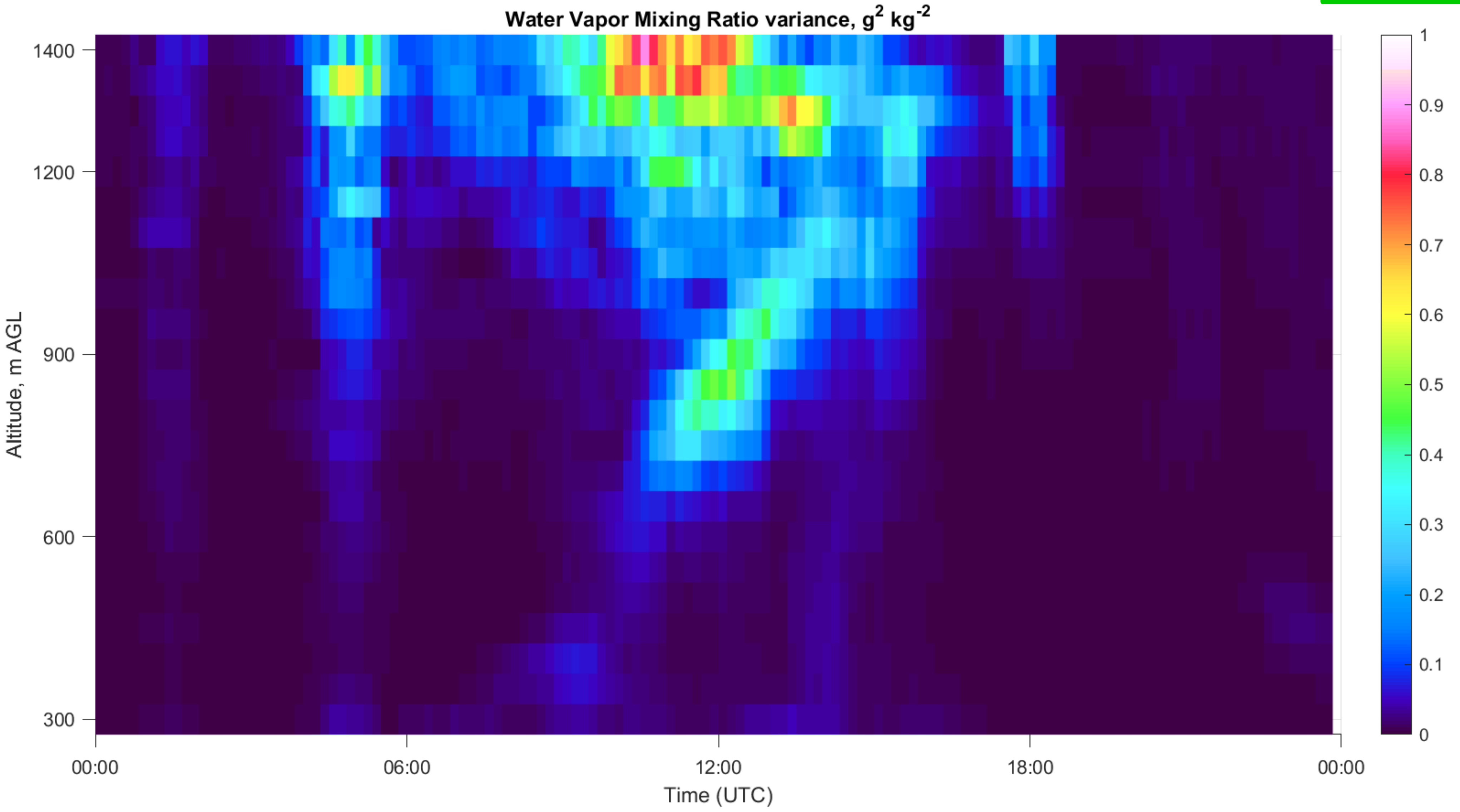
# Temperature Variance

1 h (averaged every 600s), 50 m



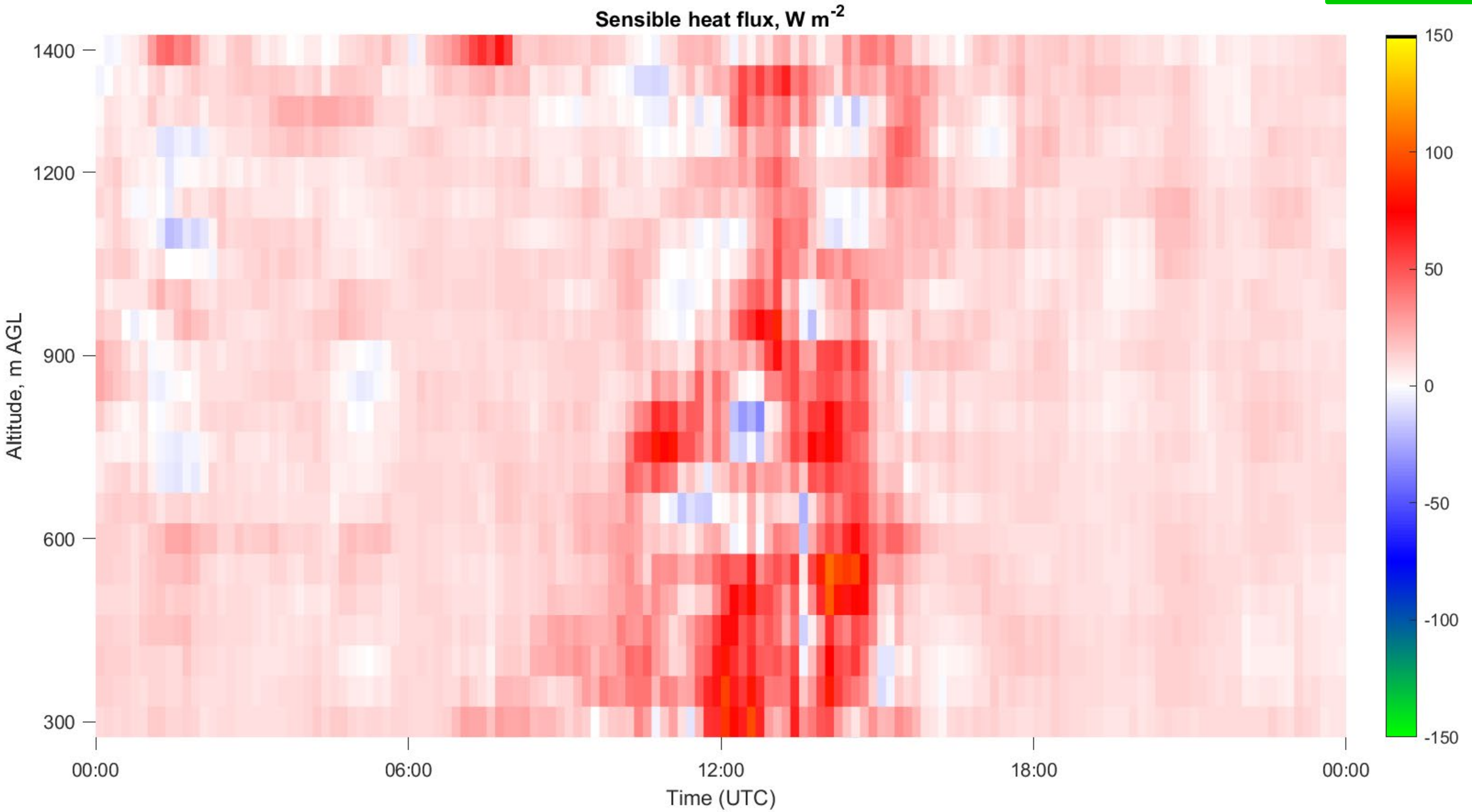
# Mixing Ratio Variance

1 h (averaged every 600s), 50 m



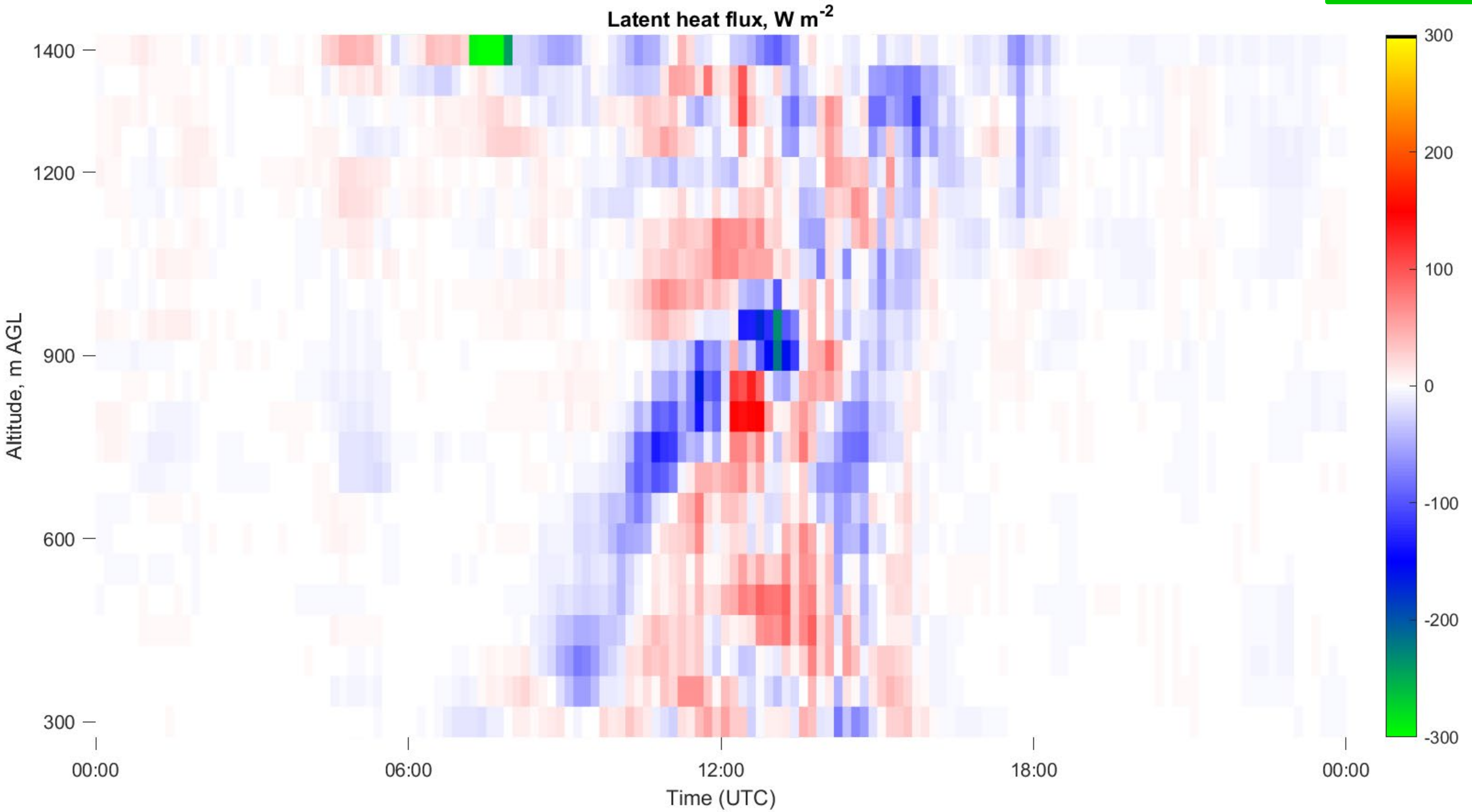
# Sensible Heat Flux

1 h (averaged every 600s), 50 m



# Latent Heat Flux

1 h (averaged every 600s), 50 m

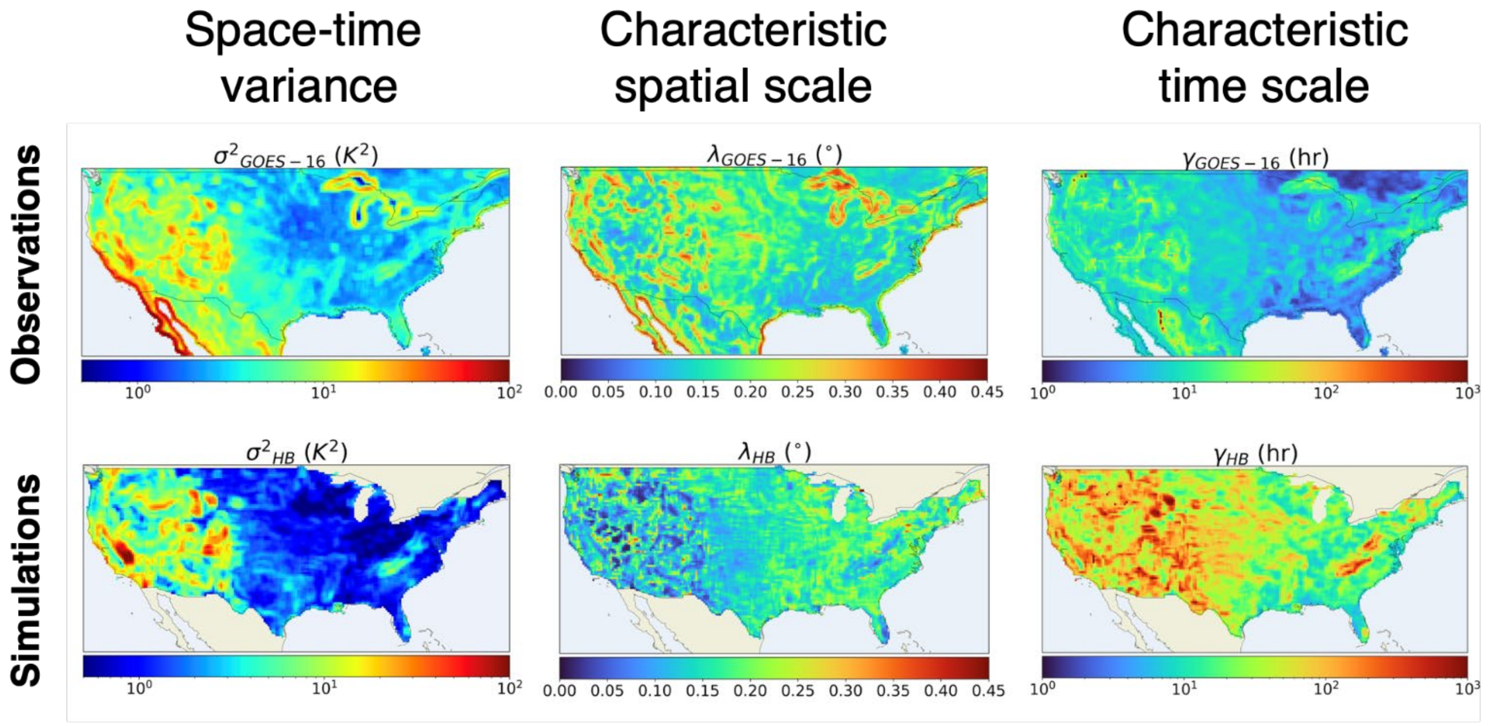


# Need to Move to Evaluate Space-Time Patterns of Land Surface Models

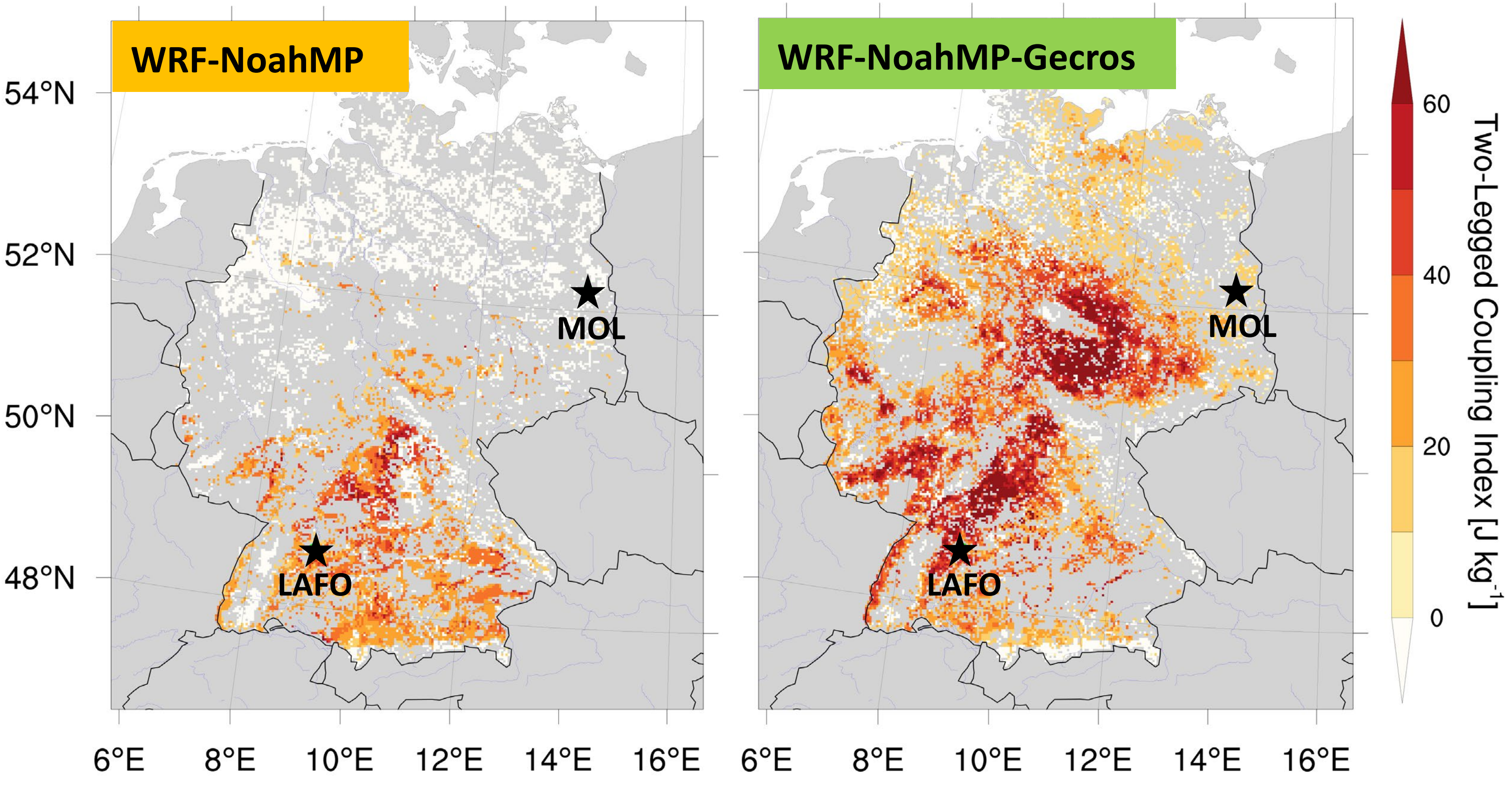
- Land surface models produce "movies" of states and fluxes. These movies should be evaluated as such, instead of only in space or time

- **CLASP** is exploring how space-time covariance on 10 min – hourly remotely sensed global Land Surface temperature (LST) data can be used to explore the realism of simulated space-time patterns of evaporation.

$$C(h,\tau) = \sigma^2 e^{-\left(\frac{\tau}{\gamma}\right)^a - \left(\frac{h}{\lambda}\right)^a}$$



# How do State-of-the-Art Models Represent Land-Atmosphere (L-A) Feedback?




*April-August 2005, grid increment 3 km (Warrach-Sagi et al. JGR 2022)*

$$TLCI = \sigma(q_{l,s}) \frac{d\,ET}{dq_{l,s}} \frac{d\,CAPE}{dET}$$

$TLCI$: Two legged-coupling index
$\sigma$: Standard deviation
$q_{l,s}$: Soil moisture content
$ET$: Evapotranspiration
$CAPE$ : Convective available potential energy

**White:** No two-legged coupling
**Grey:** Not analyzed due to lack of observations outside Germanys or no significance

- **Current L-A system models seem to underestimate the sensitivity of cloud formation to land-surface properties.**
- **This requires an understanding of land-atmosphere (L-A) feedback on the km-scale.**

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# Summary and Outlook

- Accurate representation of **L-A feedback** crucial for model initialization.
- Model systems should be verified with respect to **surface fluxes** and various **feedback metrics**.
- **Correct soil maps** critical for accurate simulations of soil temperatures.
- **Irrigation** needs to be considered and simulated in respective regions.
- **Increase of complexity of LSM does not improve the simulation of fluxes.** The best approach is a simple ML effort.
- **MOST introduces large errors in the simulation of surface latent heat fluxes**, which translates to incorrect flux partitioning. **The simulation of surface fluxes must be replaced.**
- **Dynamics of vegetation must be considered for simulations on the seasonal scales.**
- **CLASP** developed **new parameterization of turbulence** over complex terrain.
- **GLAFOs** provide **turbulence and flux profiles** for process studies and model verification.

# Thank you

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