An investigation into the influence of high-resolution land-surface heterogeneity on atmospheric dynamics

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Work done at Duke University as part of the CLASP-LES working group

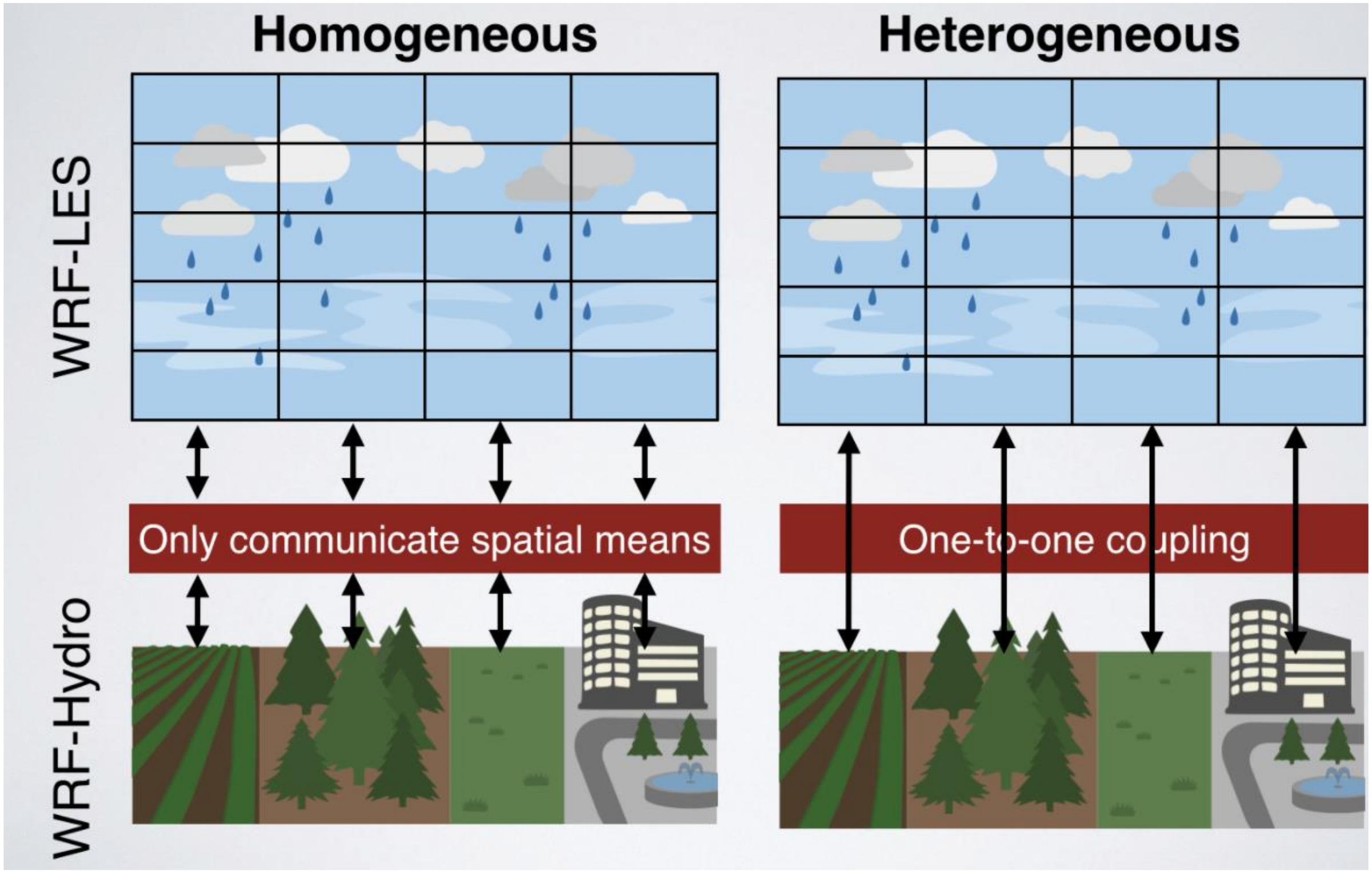
CLASP Climate Process Team

Coupling of **L**and and **A**tmospheric **S**ubgrid **P**arameterizations

Outline

- CLASP-LES motivation
- Southern Great Plains (SGP) site
- HydroBlocks
- Results thus far

CLASP-LES


Homogeneous
Heterogeneous
WRF-LES
Only communicate spatial means
One-to-one coupling
WRF-Hydro

CLASP-LES Motivation

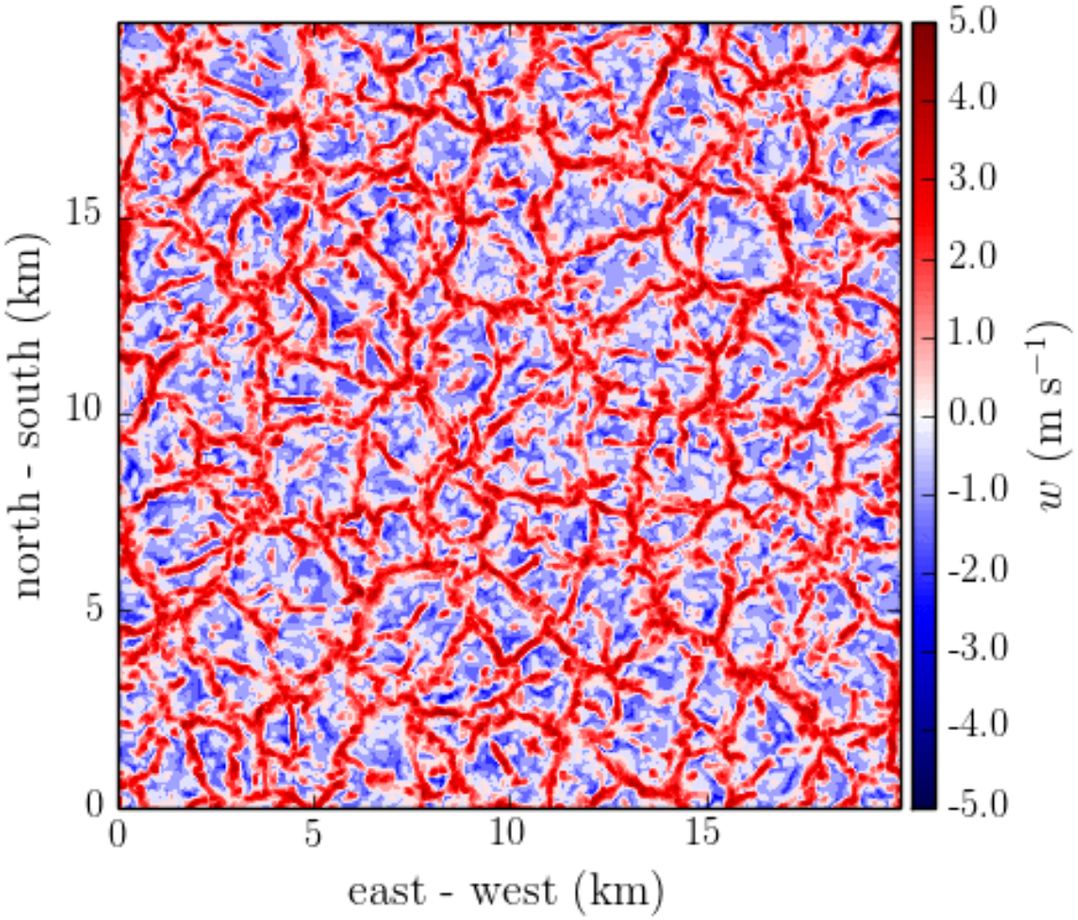
- Use high-resolution large-eddy simulation (LES) to evaluate CLASP hypothesis and inform CLASP-Parameterization
    - CLASP Hypothesis: land-surface heterogeneity impacts atmospheric dynamics
- Large body of literature of the opinion that a mean wind will “blend” surface fluxes
    - Is this true?
    - Some literature indicates otherwise
- Ultimate questions: *when* does surface heterogeneity matter, and *how*?

CLASP-LES Motivation

- Why LES?
    - Simulate atmospheric dynamics/fluxes with reduced parameterization
    - Can represent high-resolution heterogeneity directly as a lower boundary condition to the atmosphere
    - Will use as a tool to inform parameterization efforts

CLASP-LES Motivation

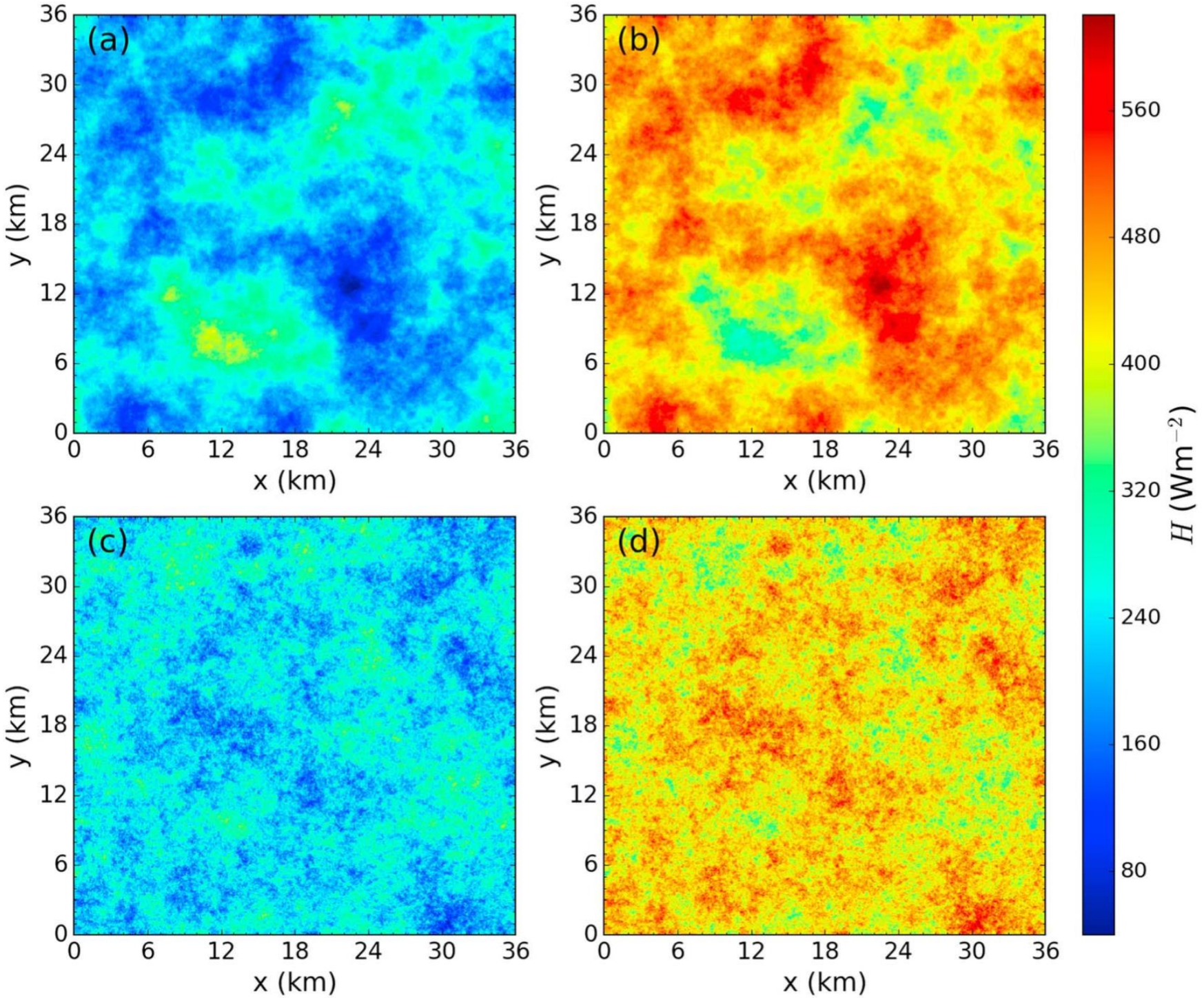
- A visual example of the resolved dynamics of atmospheric using WRF-LES at 25-m resolution



CLASP-LES Motivation

- Kang 2016 showed different scales of heterogeneity can create large atmospheric differences
    - Used synthetic surface-flux fields
    - Found larger scales of heterogeneity triggered deep convection
    - Relevant and encouraging to CLASP project

Kang 2016, JGR: Atmospheres



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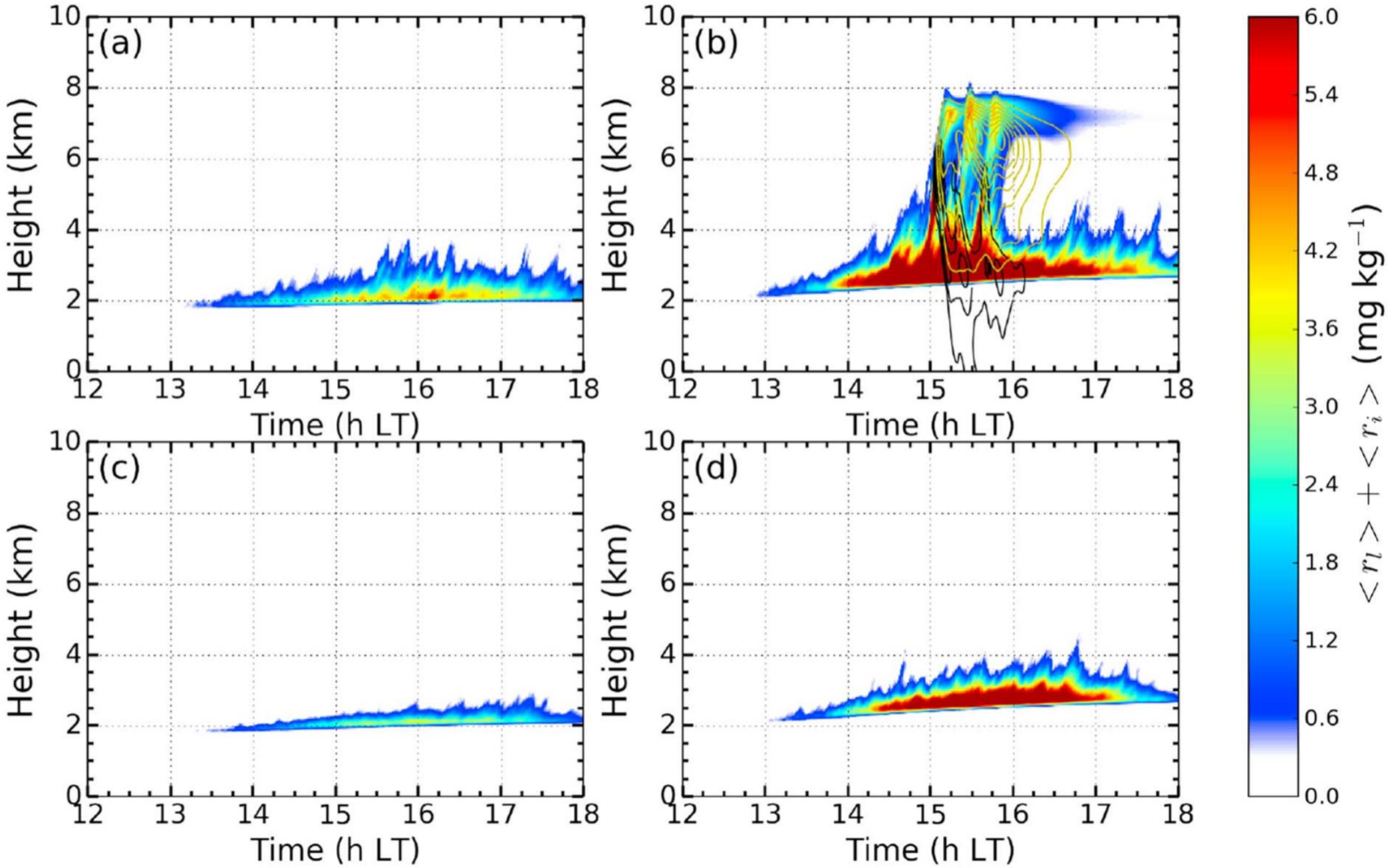


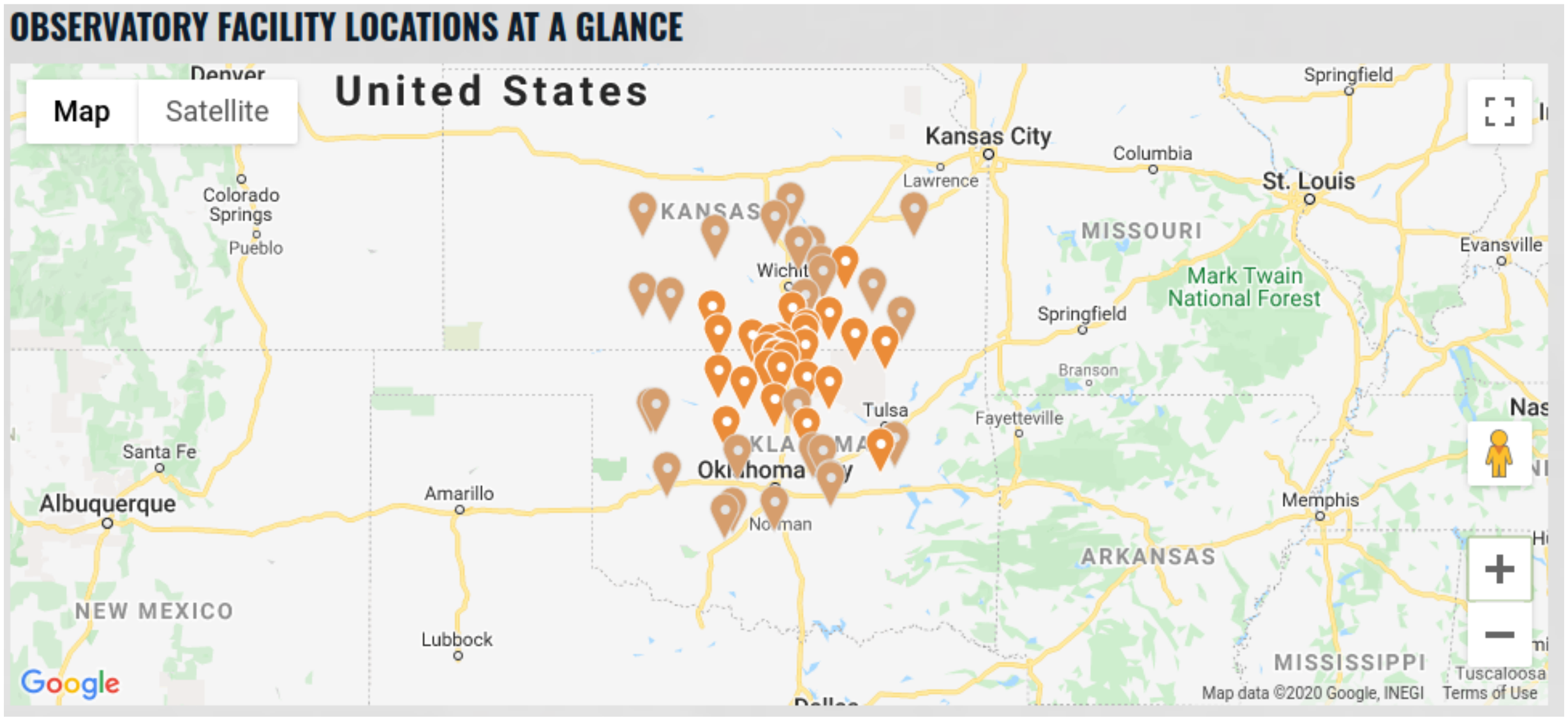
CLASP-LES Motivation

- Extend idea of Kang 2016 to real(istic) surface fluxes
  - Using HydroBlocks + WRF-LES
  - Aim to both motivate CLASP project and inform CLASP-Parameterization efforts

Current Experiment

- LES over Southern Great Plains (SGP) site as starting place
    - Well-documented site
    - Relatively flat terrain, wealth of observational and simulation data available
        - Namely LASSO

SGP Site



from arm.gov

LASSO

- LES ARM Symbiotic Simulation and Observation
- Collection of statistical LES simulations over SGP ARM site
    - Using Weather Research and Forecasting (WRF) model
        - Model setup and forcing data available for multiple days/events
            - VARANAL forcing: NOAA Rapid Refresh + energy conservation via observational surface flux data

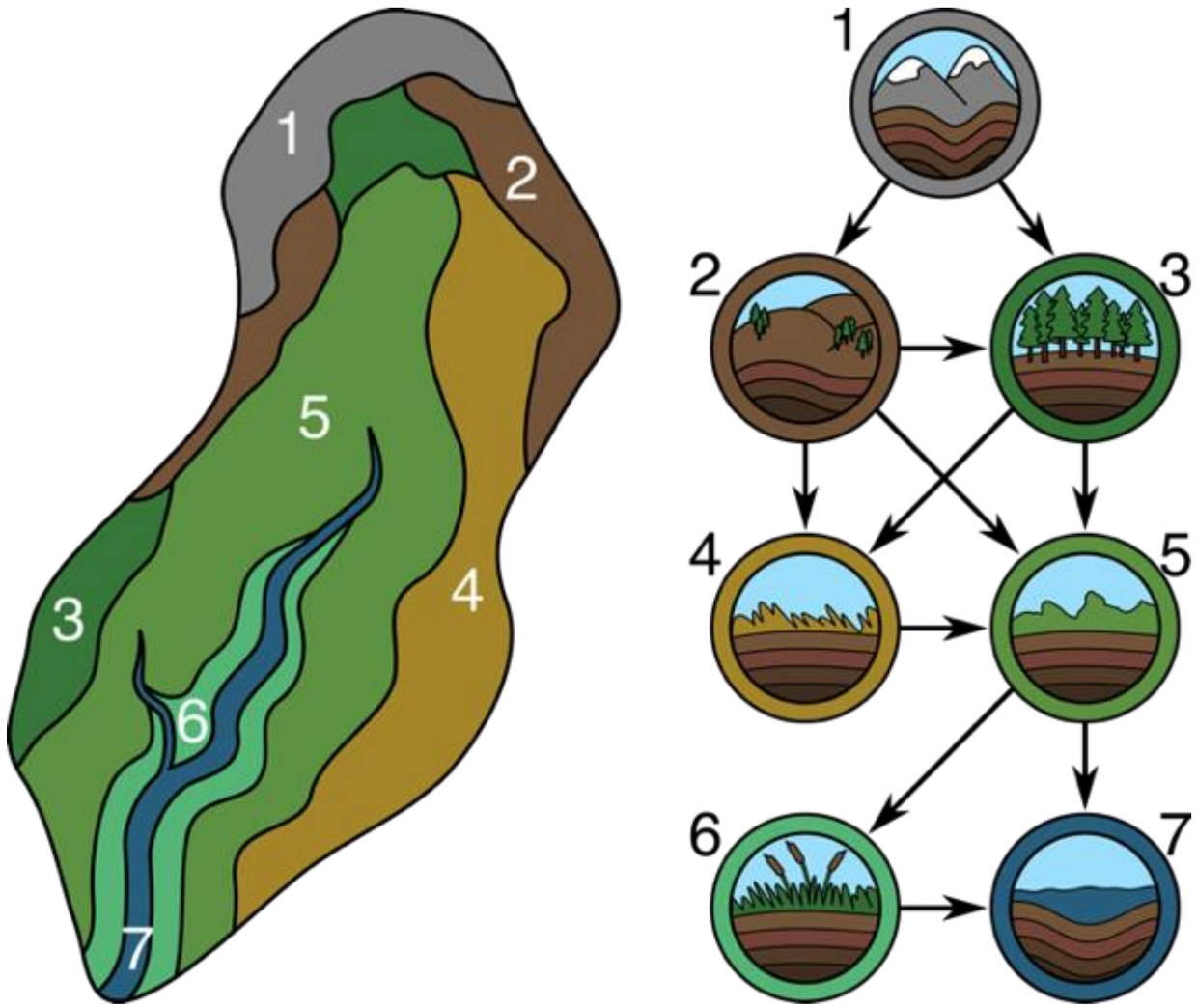
LASSO

- Unique LES philosophy (for NWP)
- Consider LES to be purely statistical
- Every column forced with same large-scale tendencies
  - i.e. ***not*** nested LES with prescribed lateral BCs
  - Akin to super-parameterization; great for our needs
  - Mimics current subgrid parameterization in climate models
- Time-evolving scalar surface flux and skin temperature values

Initial LES Setup

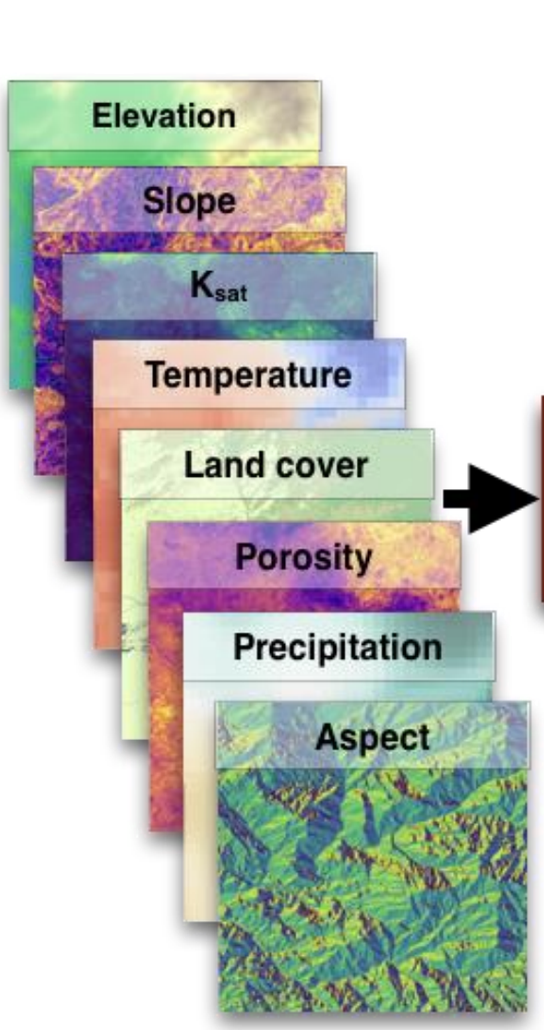
- Weather Research and Forecasting (WRF) model
  - Model setup and lateral forcing from LASSO
- Surface sensible heat flux, latent heat flux and skin temperature prescribed using HydroBlocks
  - One-way coupling (for now)
  - High-resolution soil data used to create heterogeneous surface conditions

HydroBlocks



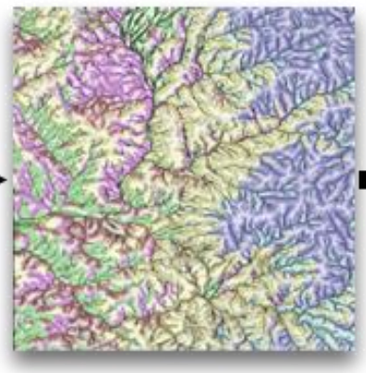
- The core of HydroBlocks is the Noah-MP land surface model
- Lateral connectivity between clusters/tiles along hillslopes
- The novelty of HydroBlocks is the way in which the sub-grid tiles/clusters are assembled (and the number)

HydroBlocks: Clustering



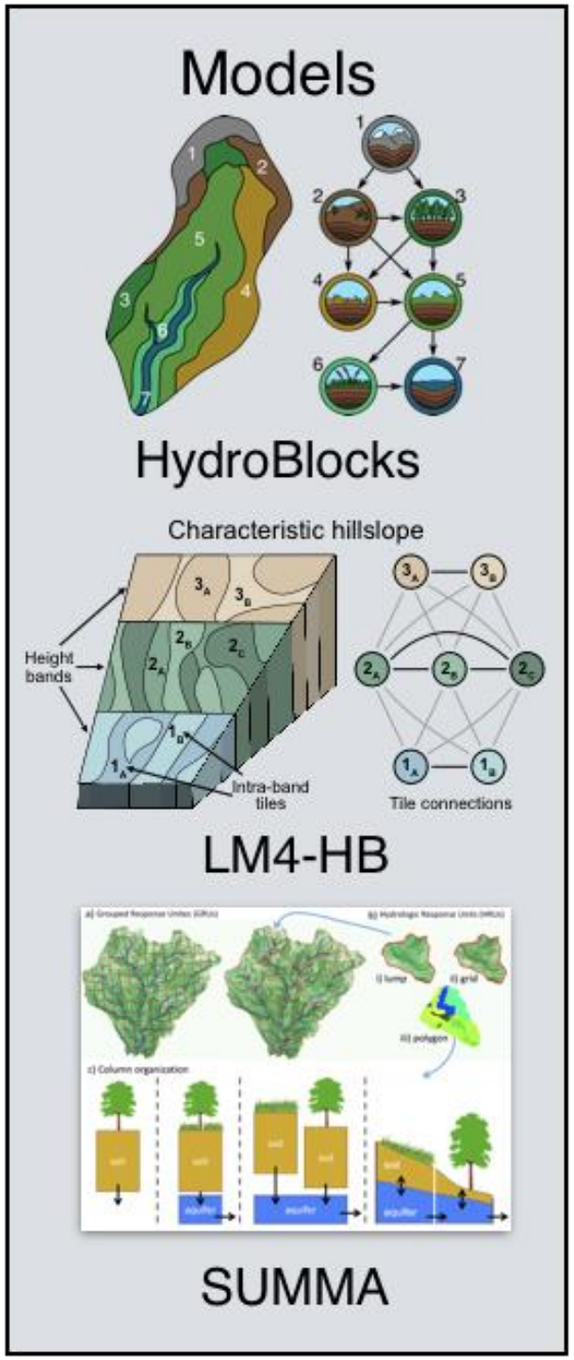
Proxies of heterogeneity

Hierarchical Multivariate Clustering



HRUs

Note: LSM only "sees" statistical distribution of HRUs with associated properties, meteorology, and interconnections



Chaney, N., et al. (2018), Harnessing big data to rethink land heterogeneity in Earth system models, Hydrology and Earth System Sciences

SGP domain: HydroBlocks tiles (i.e., clusters)

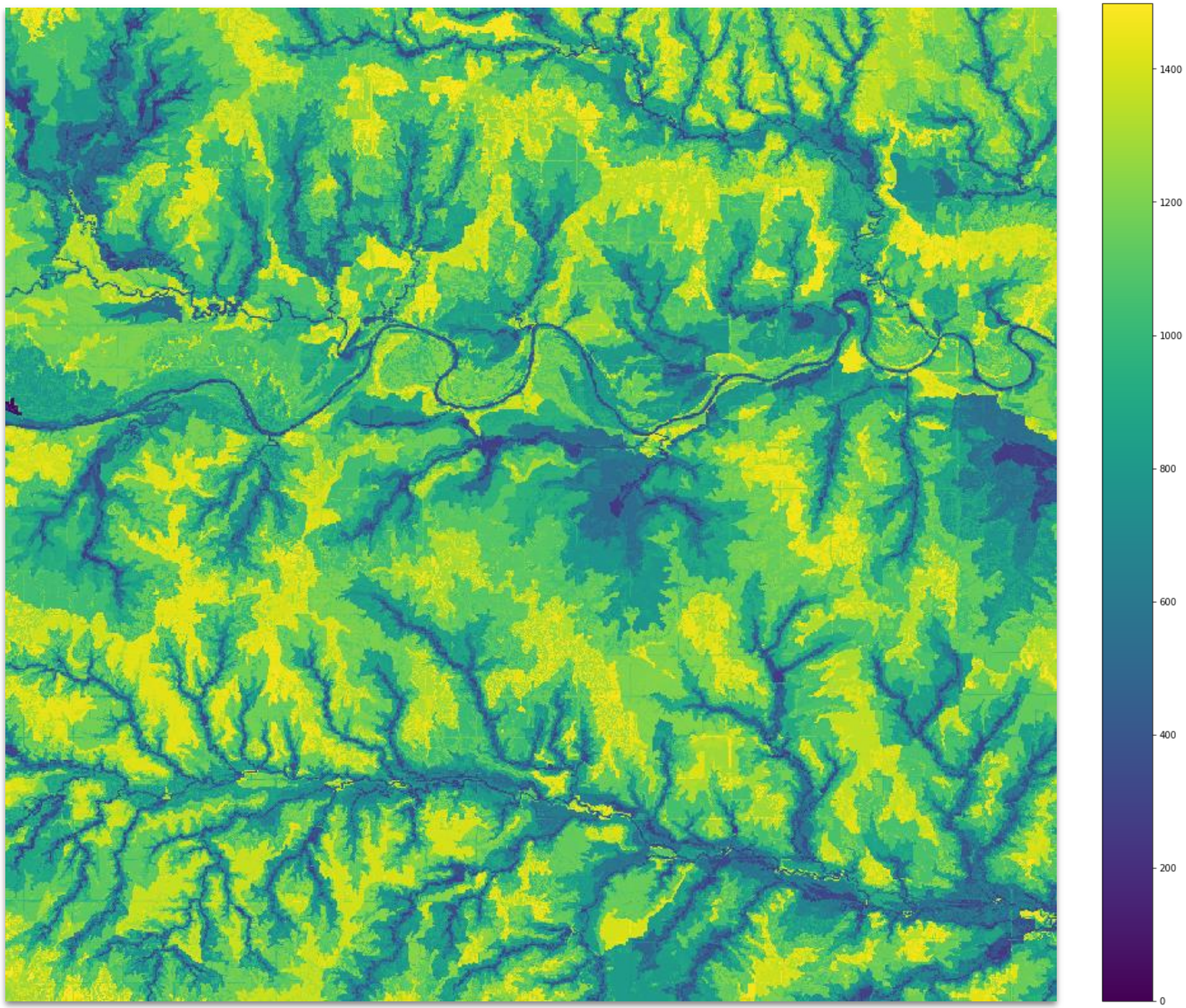
-Clusters are derived from:

- Land cover: NLCD
- Elevation: NED DEM
- Soil: POLARIS

-Each 30 meter grid cell is assigned a cluster/tile

-Reduced down to ~1500 tiles/clusters (think effective number of grid cells)

- Why so many? The purpose here is to produce a very high resolution time varying maps of surface fluxes for the LES

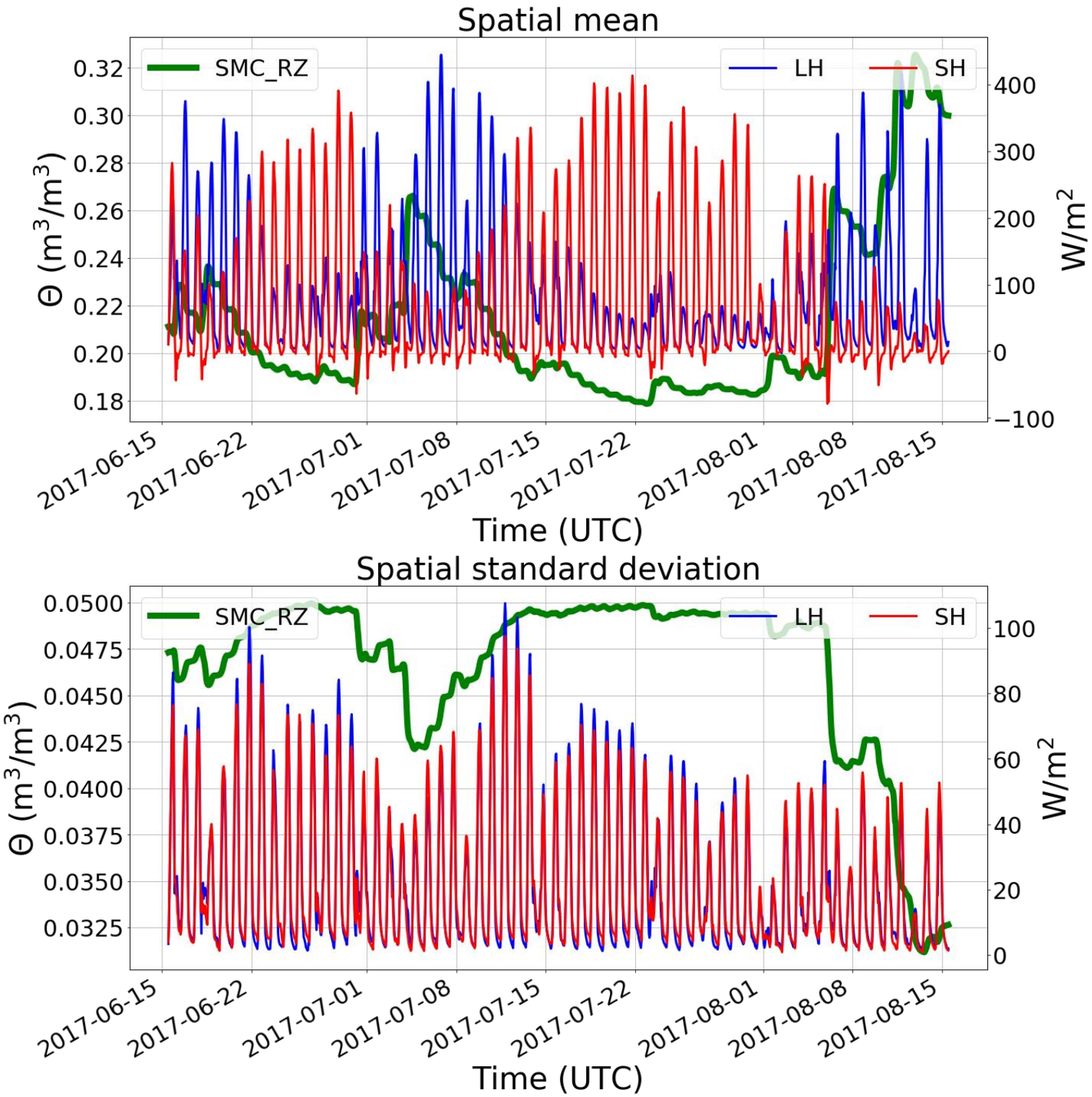


HydroBlocks over SGP site

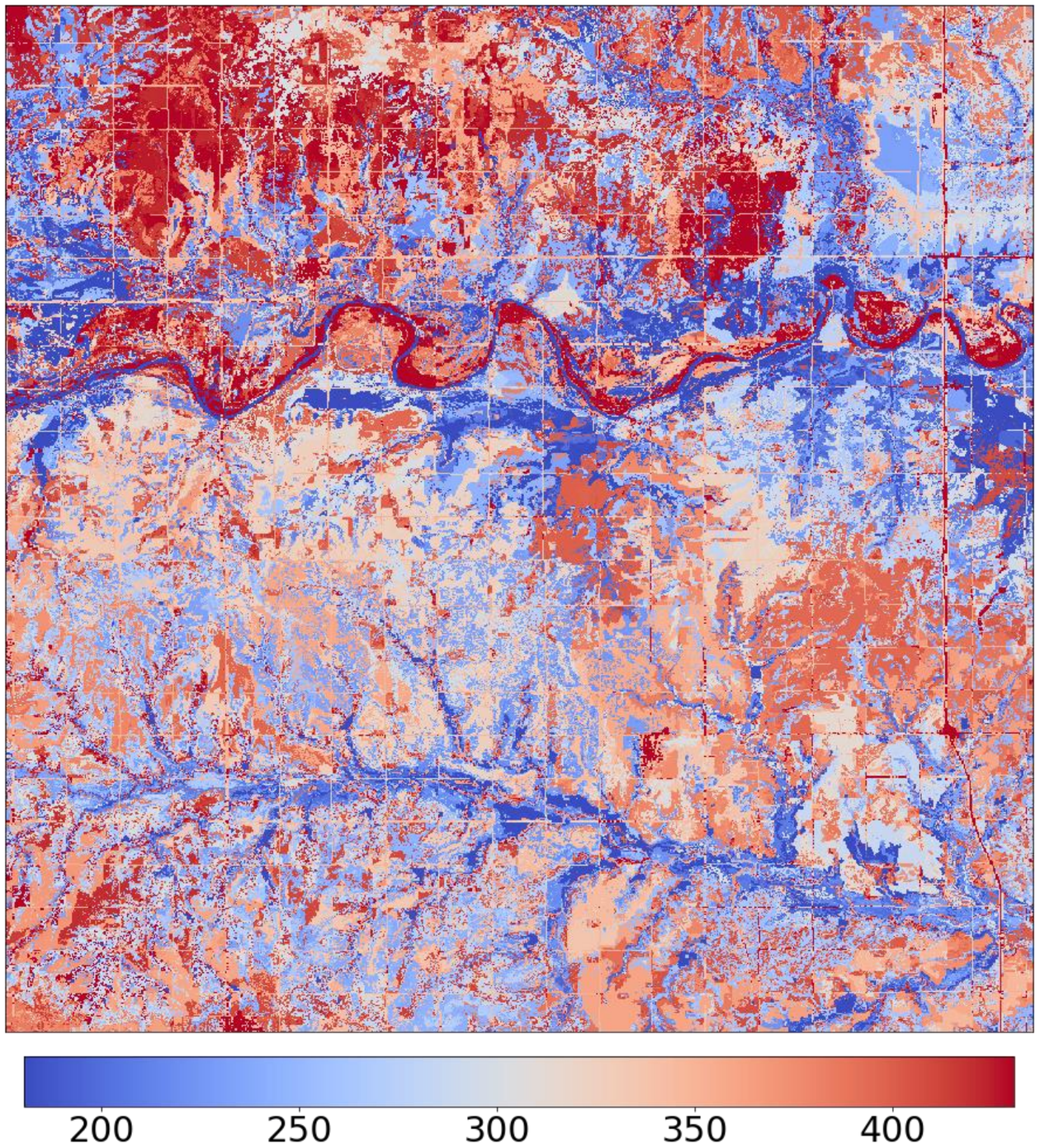
- Forced using 4 km downscaled NLDAS-2 with Stage-IV radar rainfall (Ming Pan at Princeton developed this dataset a few years back)

- Spatial mean of each meteorological variable corrected at each hourly time step using the VARANAL data from the SGP site

- Takes about 2 hours to run on a single core for 2015-2017 at an hourly time step.



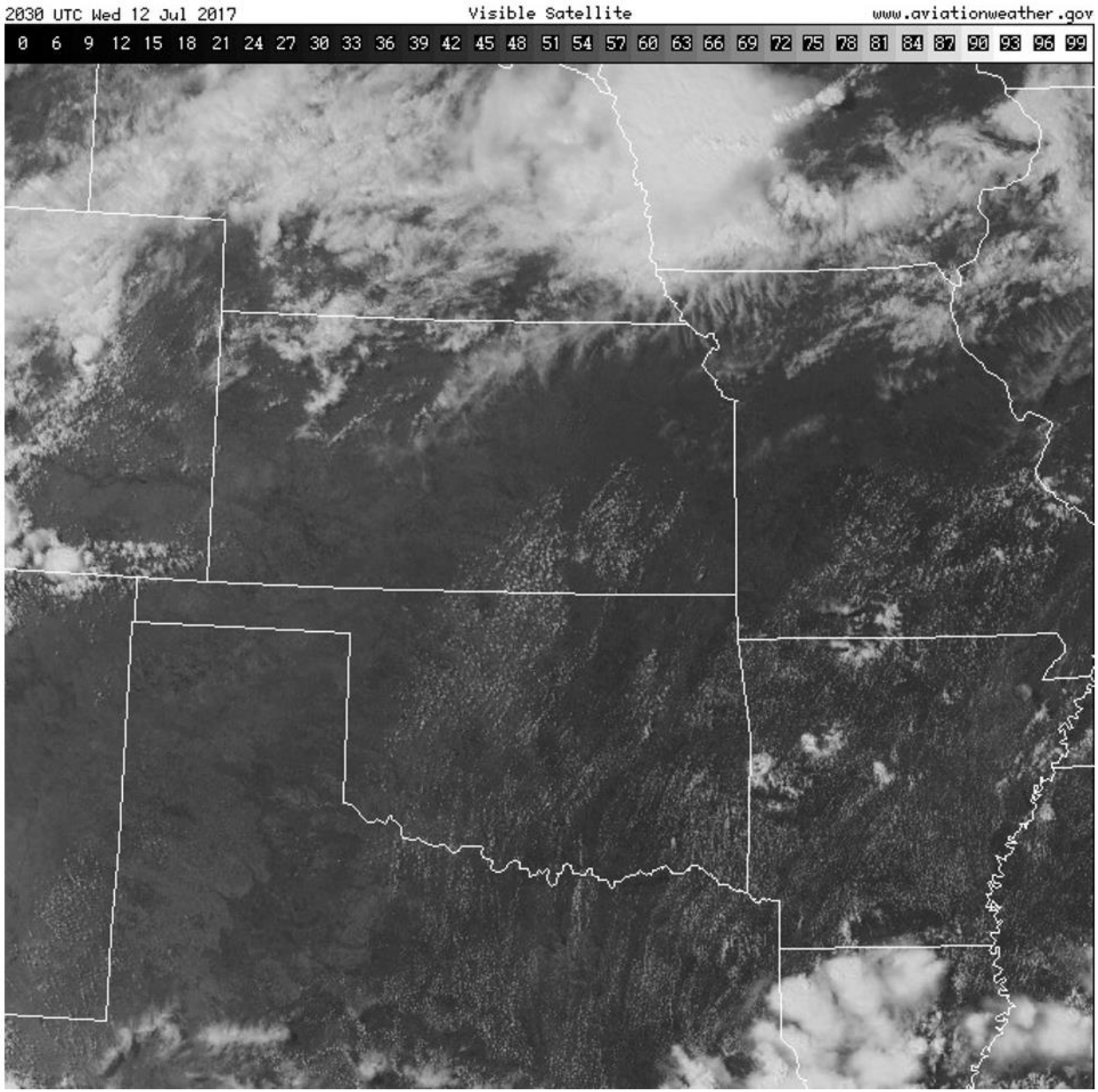
Simulated sensible heat flux (07/12 1:00 pm)



WRF-LES Setup

- Modeling July 12, 2017
- dx = 100 m
- dz ~ 30 m near surface
- nx, ny = 251
- Thompson graupel scheme (microphysics)
- RRTMG long- and short-wave radiation schemes
- Monin-Obukhov (basic) surface layer scheme
- Prescribed surface physics from HydroBlocks
    - Considering heterogeneous and homogeneous cases with identical mean surface values over domain
- PBL and cumulus schemes turned off
- TKE-1.5 (Deardorff) turbulence closure

- Satellite image of July 12, 2017



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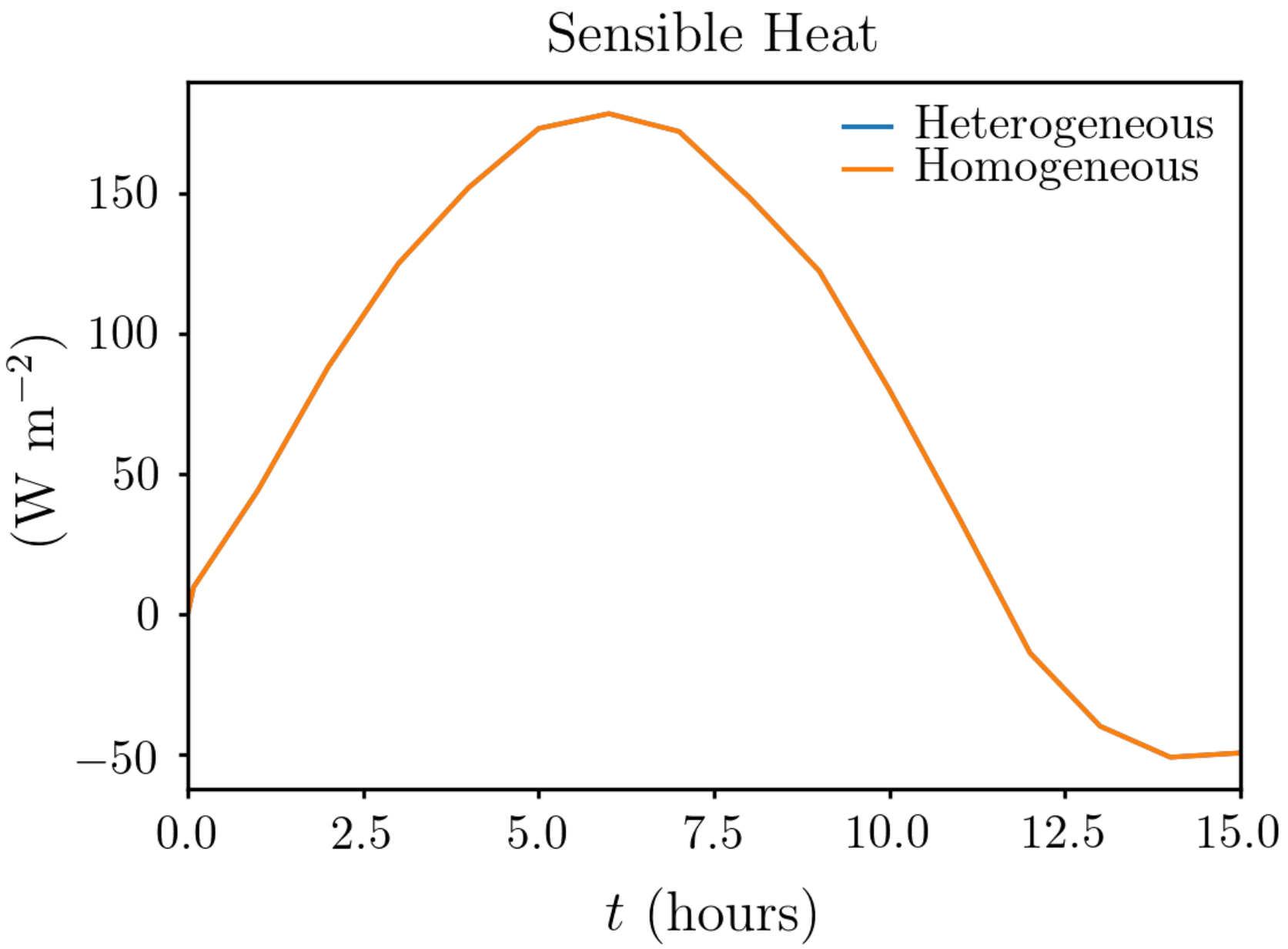

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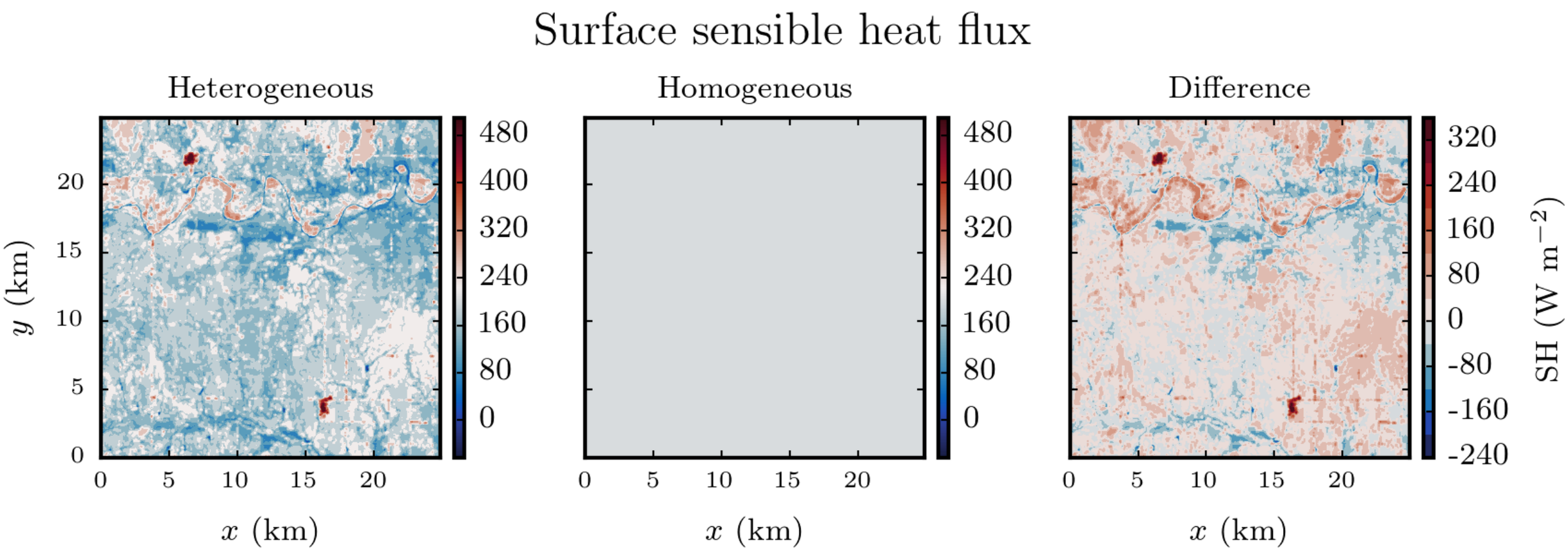
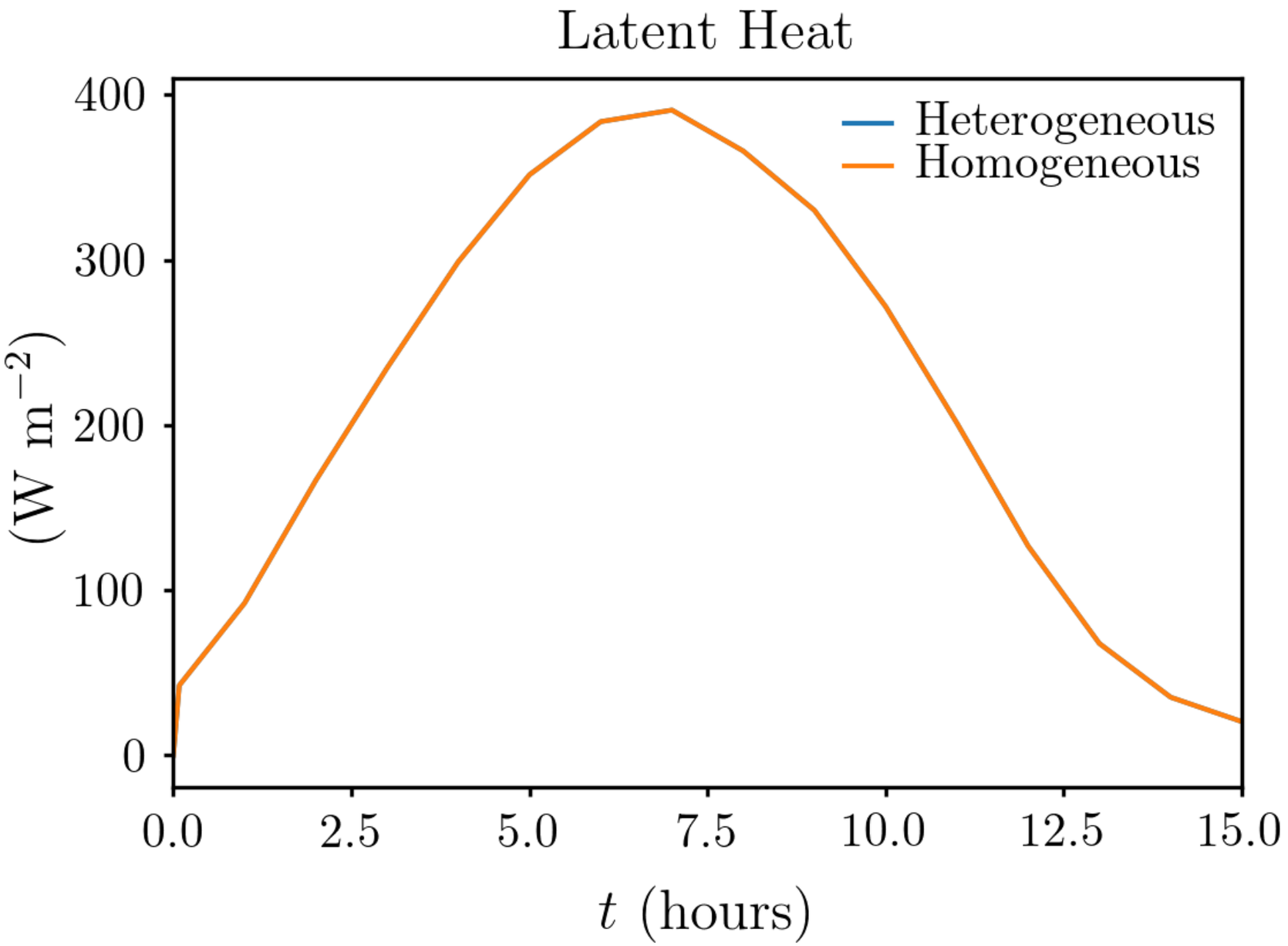


at 1100 local time

WRF-LES Setup



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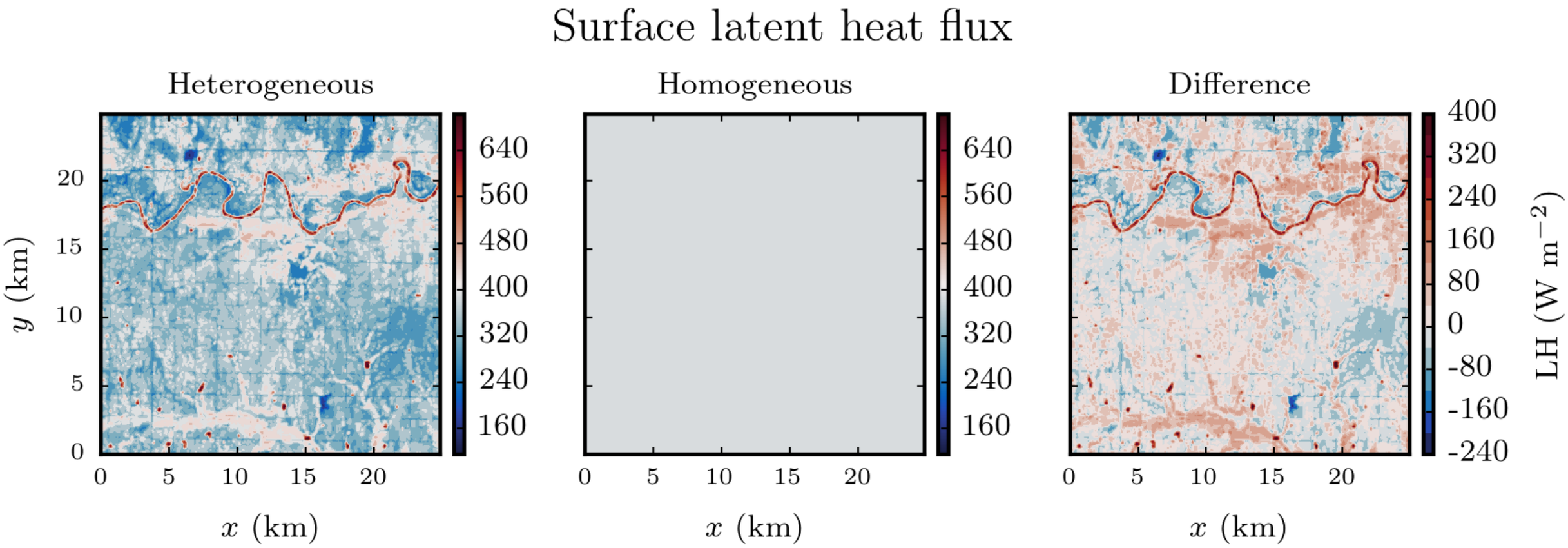
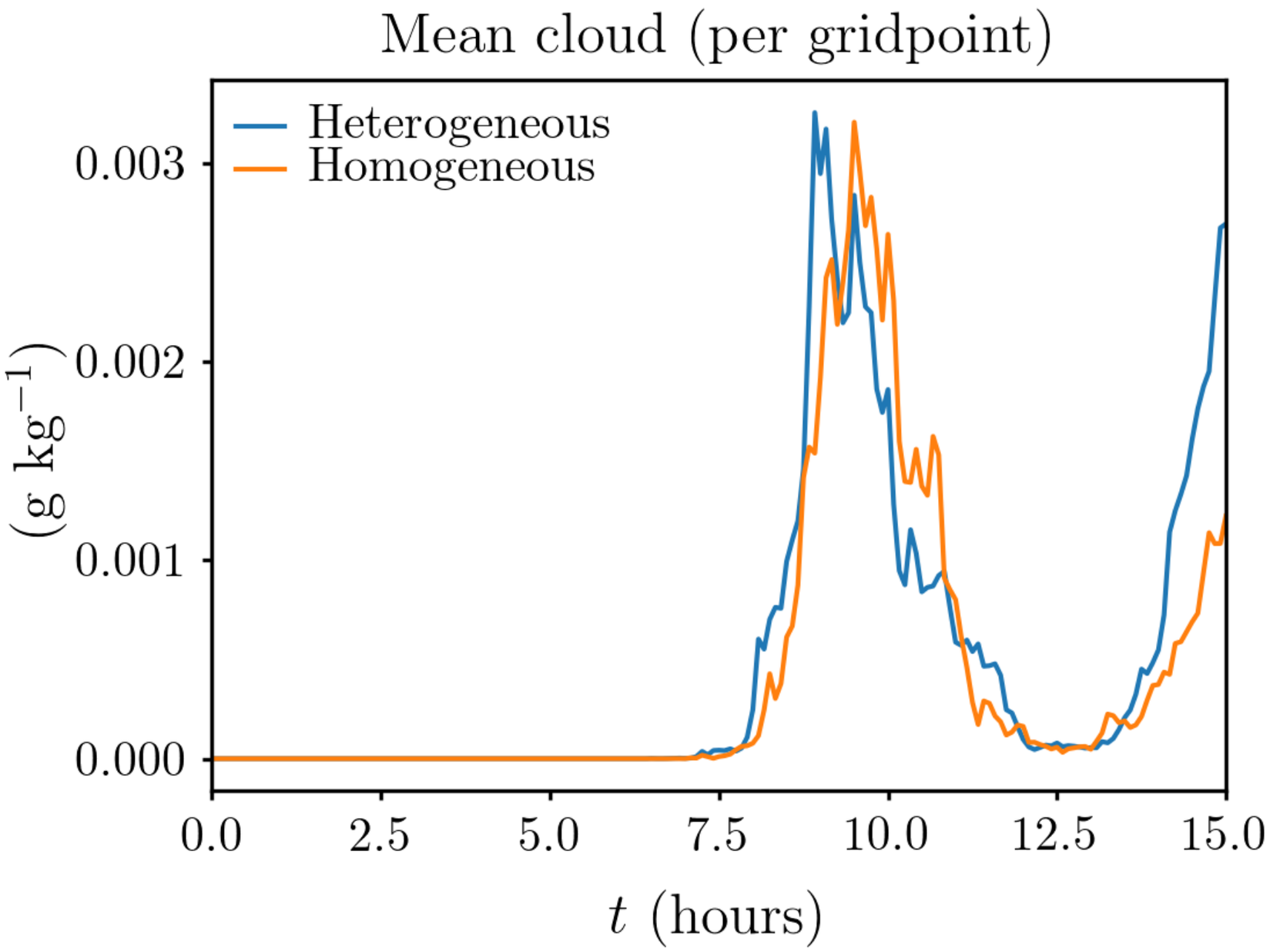


1100 local time

Initial Results



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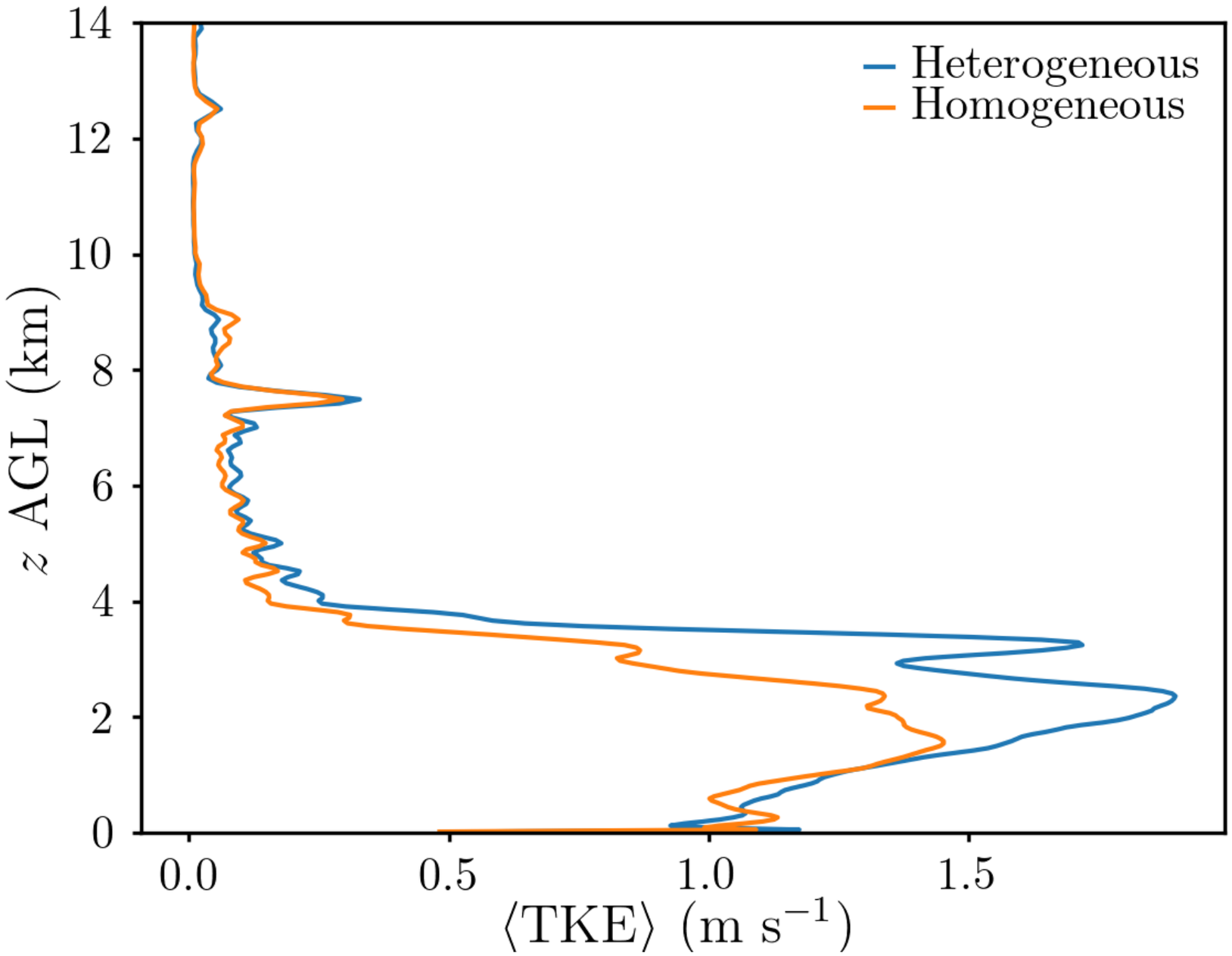
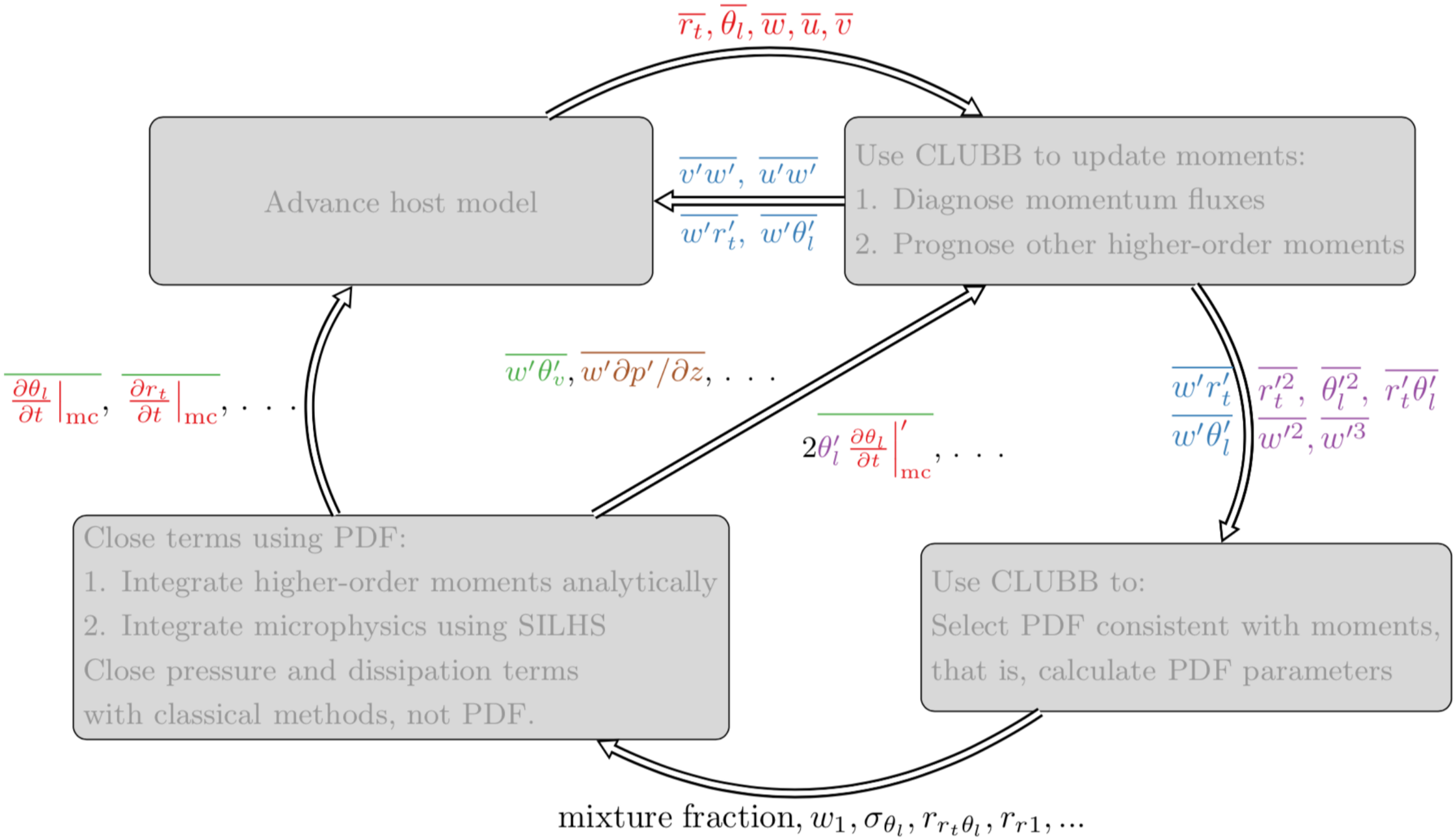


at t=15 h

Potential Path Forward: CLUBB

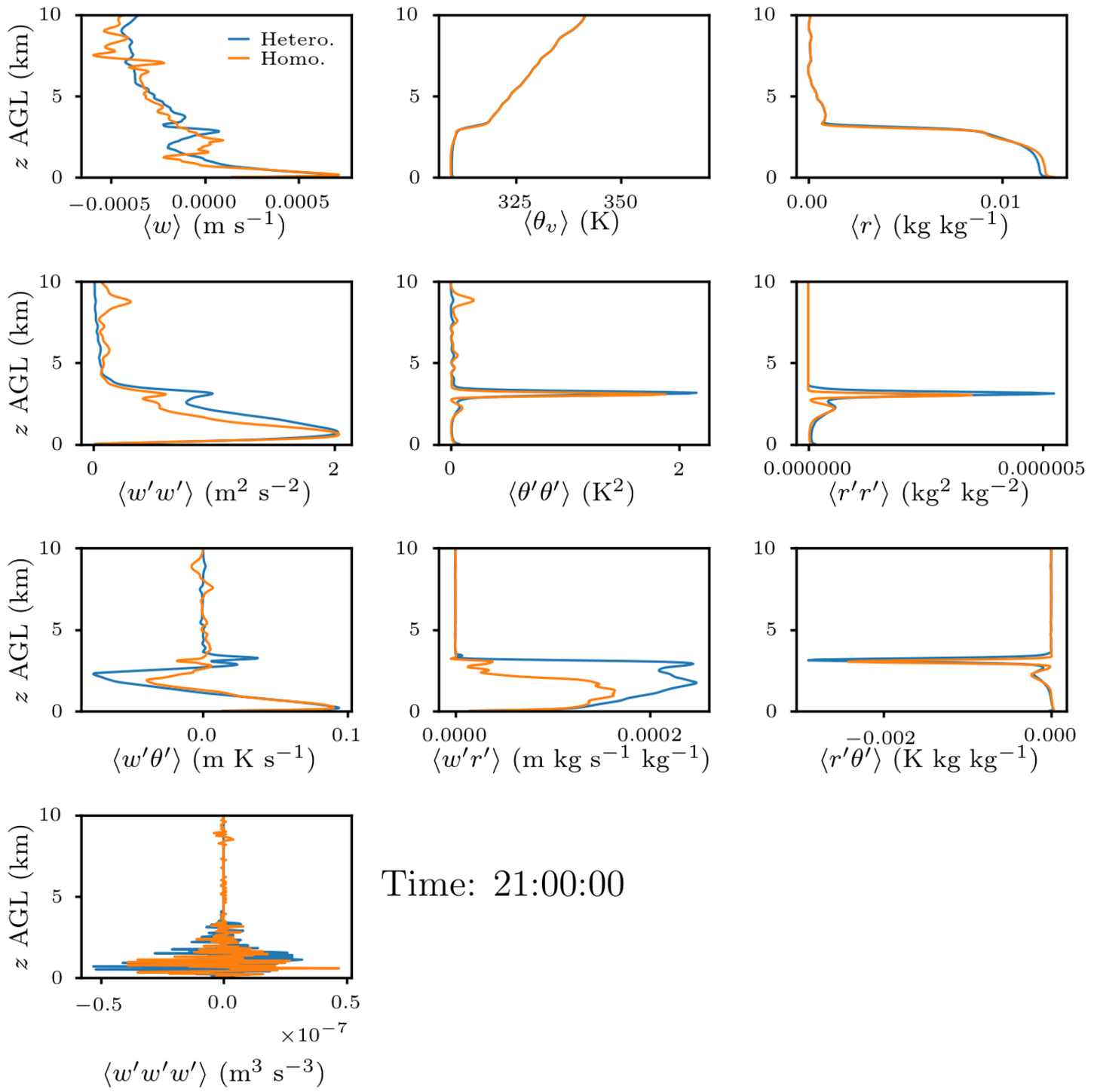
- Cloud Layers Unified By Binormals (CLUBB)
  - "[A] parameterization of sub-grid scale variability in atmospheric models."
  - An "LES emulator" which parameterizes domain-averaged moments
  - Can be run alone or as a parameterization in a coarse-scale (dx > 2 km) weather/climate model

A CLUBB-SILHS time step,
illustrating the main calculations and flow of information



from Larson 2019

CLUBB Moments from WRF-LES



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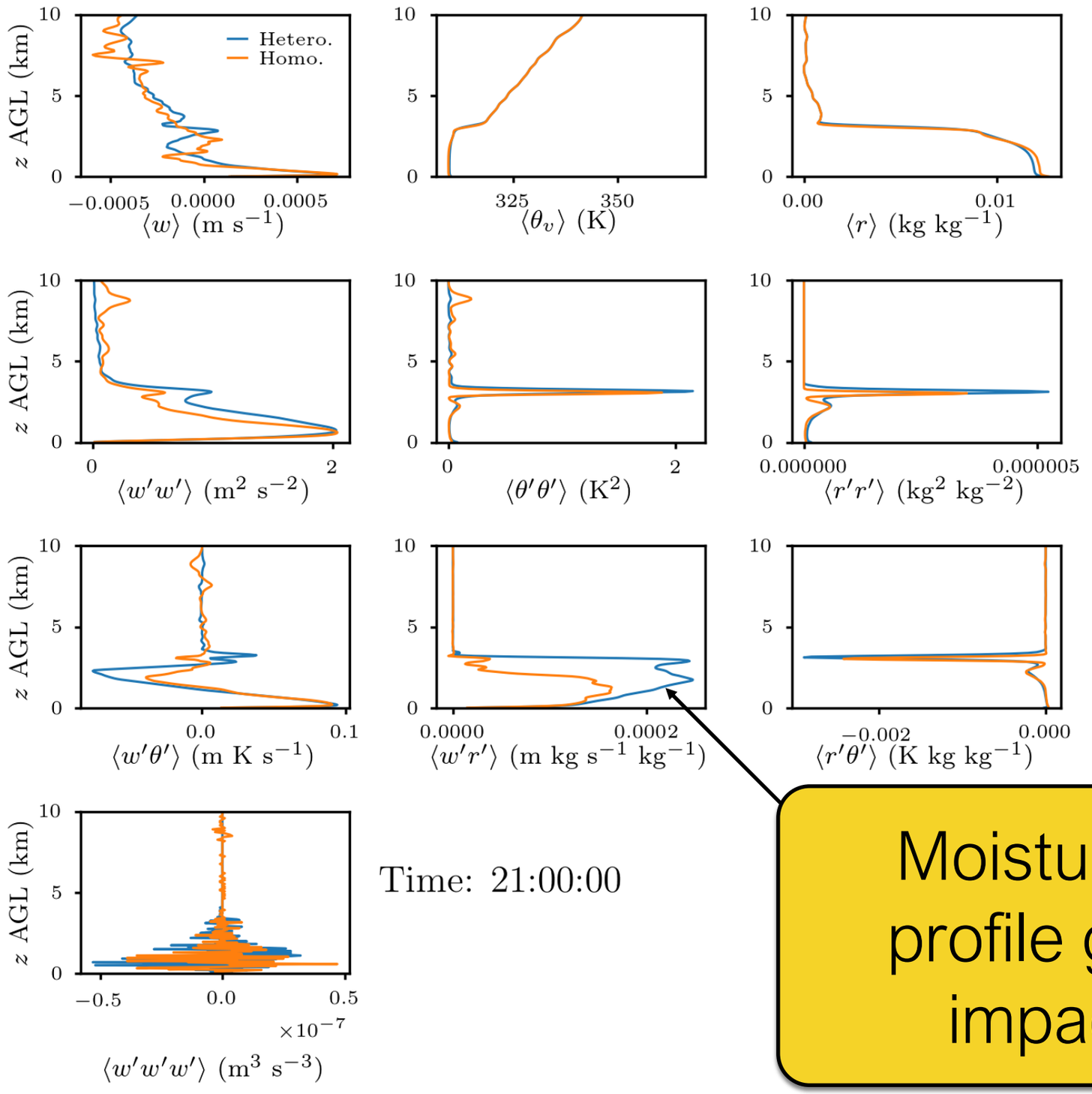

Moisture-flux profile greatly impacted

Final Thoughts

- Initial WRF-LES cases forced with HydroBlocks show a signal of surface heterogeneity at relevant scales
    - For cloud development, and also for moments parameterized by CLUBB
    - Even for a relatively simple test case at SGP site
- Next steps include:
    - More complex events at SGP site and more complex sites (e.g. CHEESEHEAD)
    - More thorough land/atmosphere coupling, e.g. surface roughness
- Interested in extending CLUBB philosophy to include surface heterogeneity in subgrid parameterizations