Representing land surface heterogeneity in E3SM Land Model

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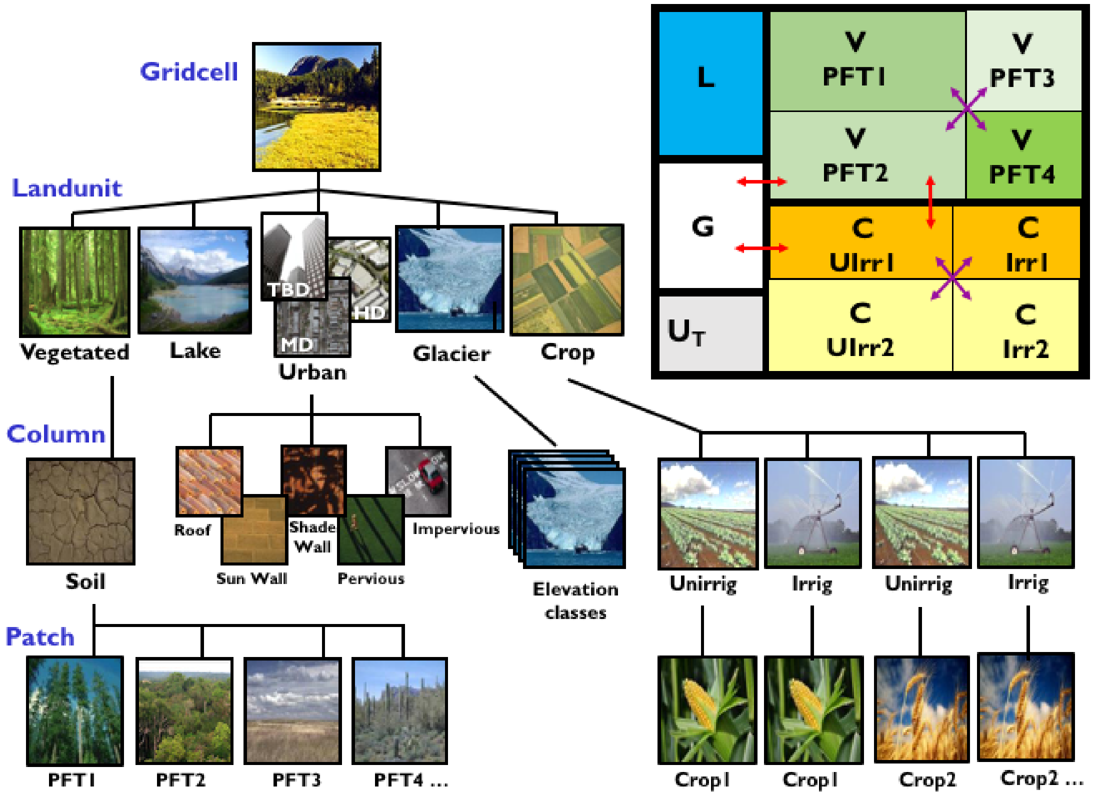
Land surface heterogeneity

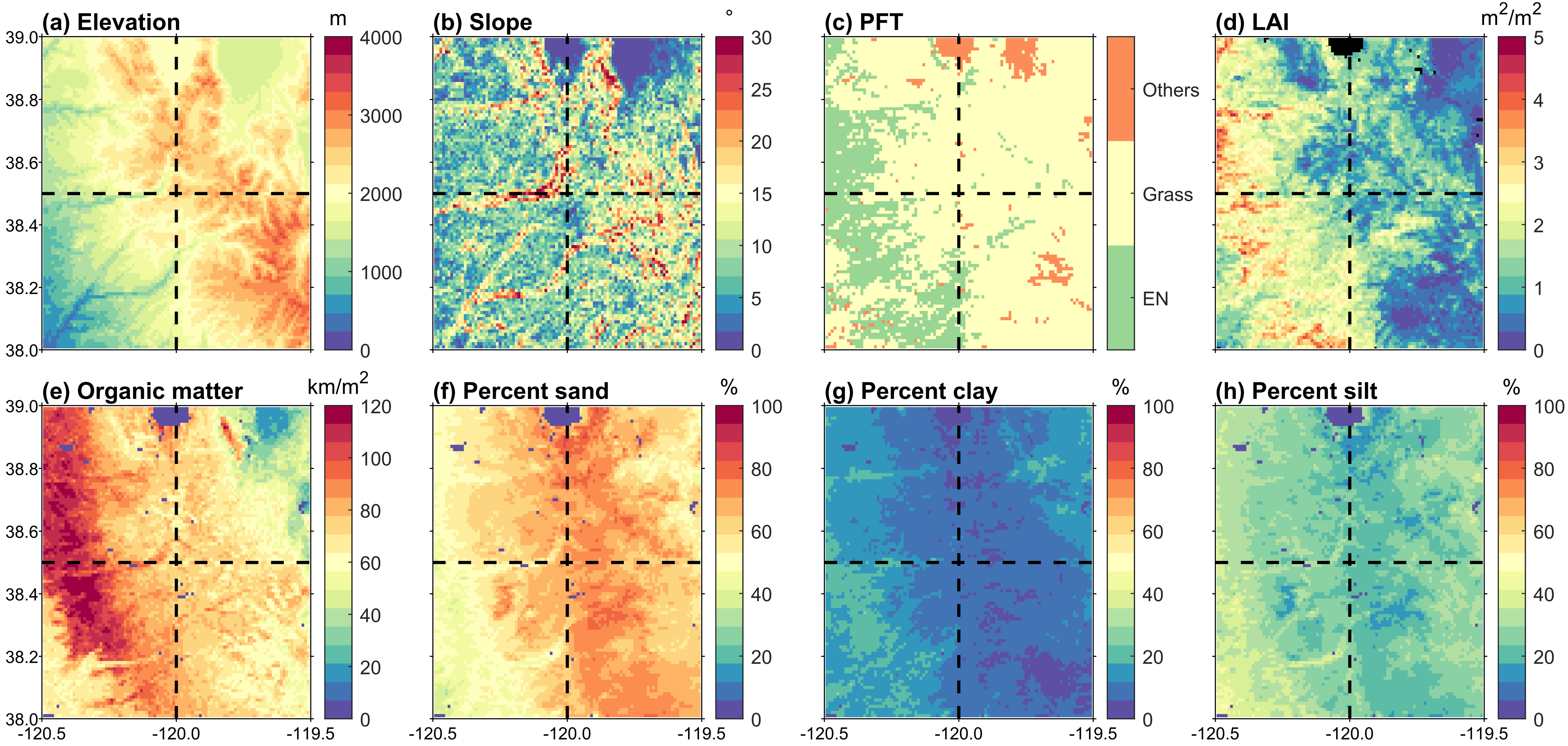
- Land surface heterogeneity (LSH) is ubiquitous.
  - Land use and land cover types (LULC)
  - Vegetation and soil characteristics
  - Topography



Configuration of the CLM/ELMv1 subgrid hierarchy

Topographic distribution (Fan et al., 2019)

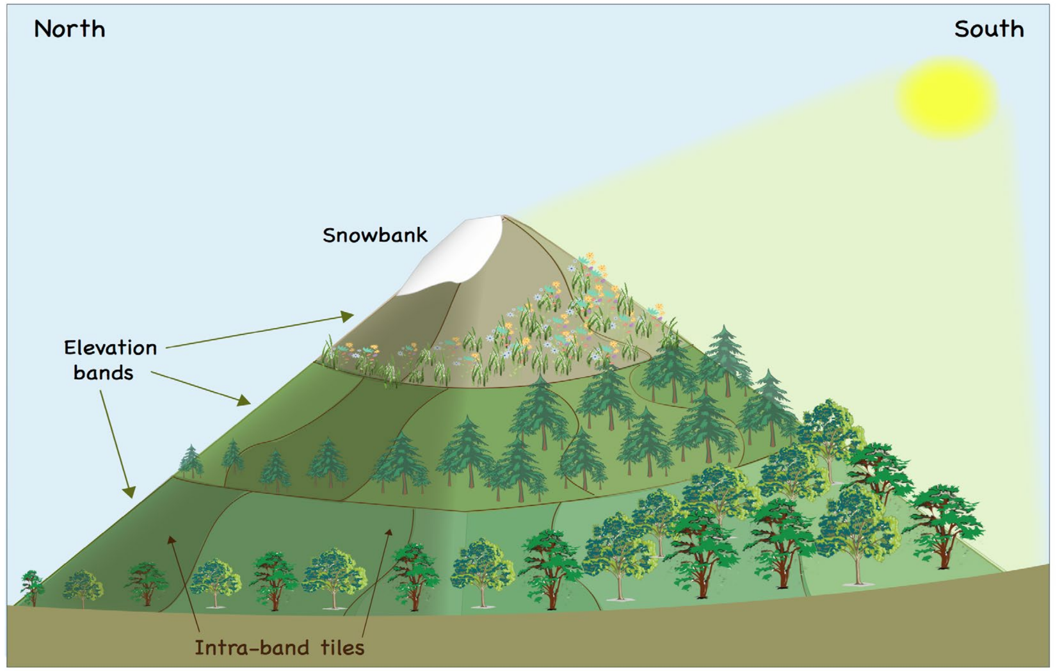
High-resolution (1km) land surface datasets for ELM

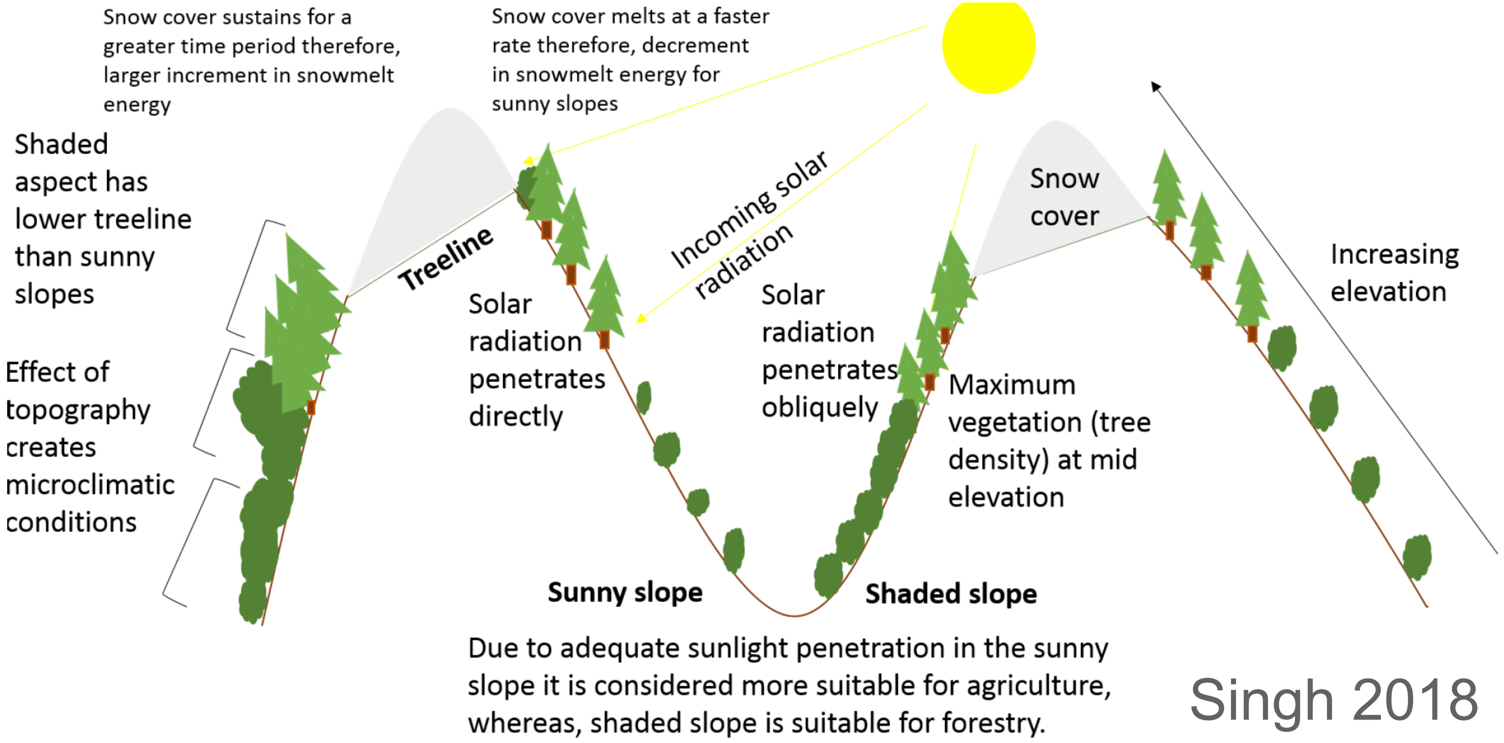


Li et al. (2024)

Topographic heterogeneity affects land surface processes

- Topography can modify **downwelling solar radiation** at the land surface and **laterally transporting water** from ridges to valleys
- Topography can affect the vegetation, soil and snow distributions.

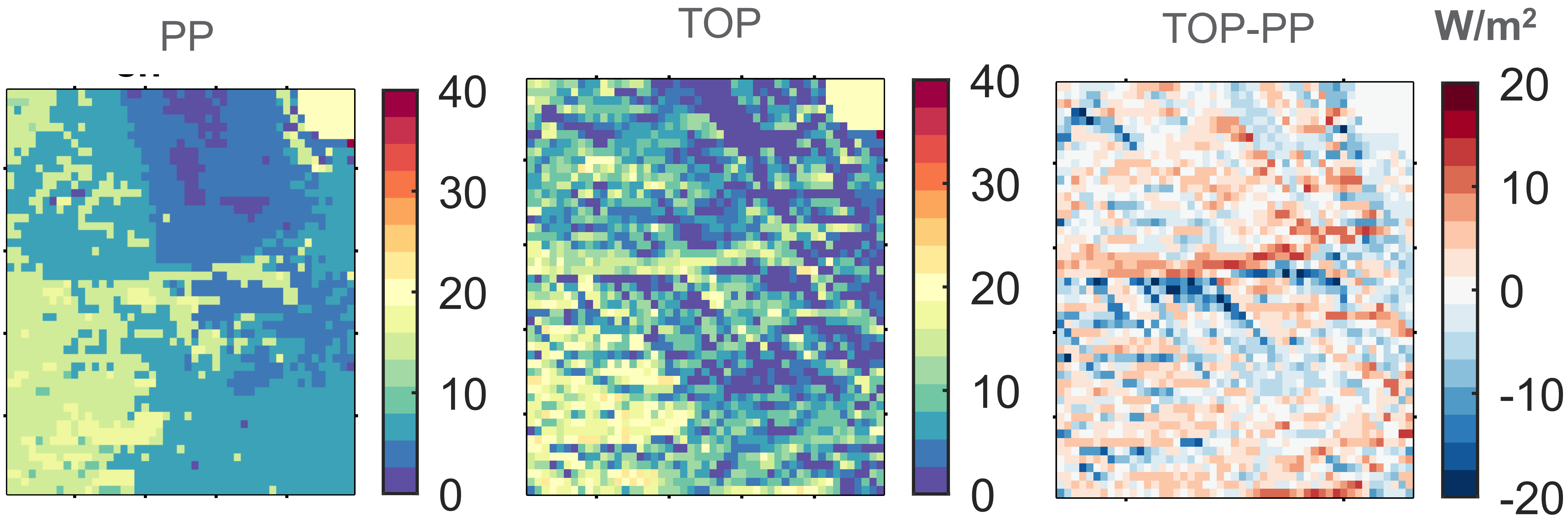




Singh 2018

- However, nearly all CMIP6 ESMs do not account for the effects of surface topography.

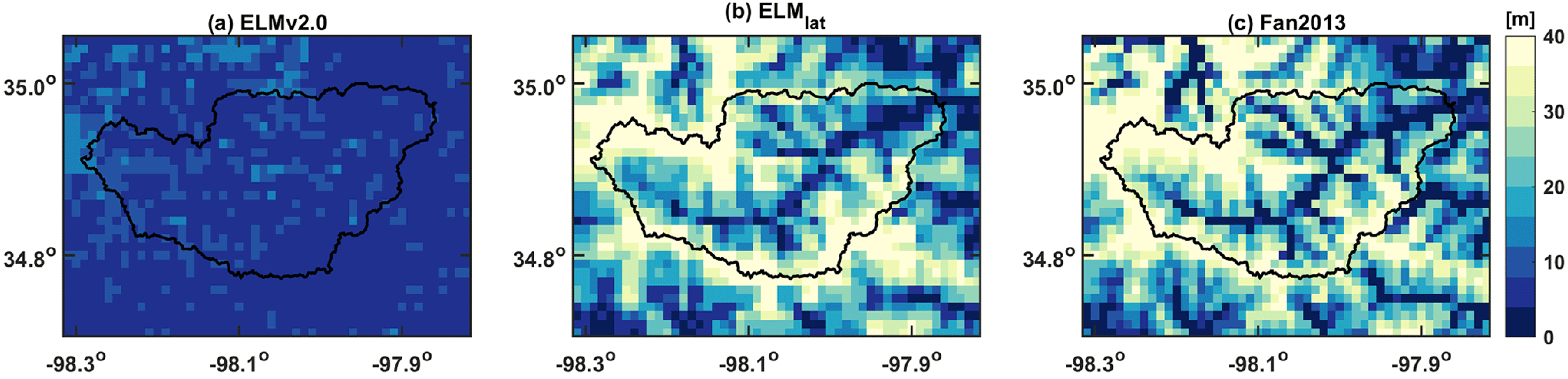
Topography distorts the spatial distribution of surface energy balance components



1km sensible heat flux

Hao et al. (2021,2022)

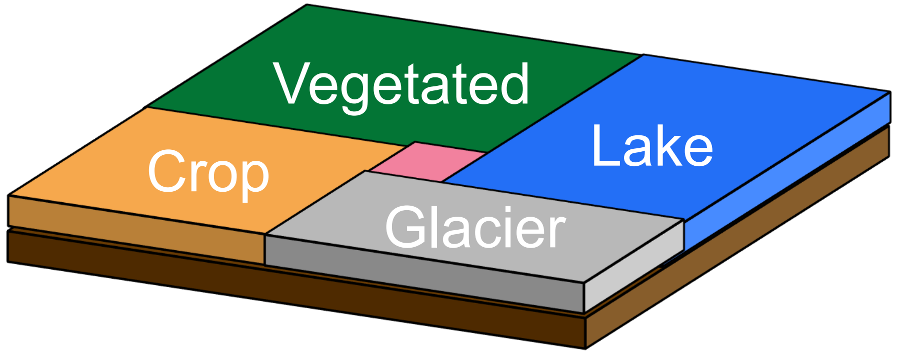
Representing inter-grid-cell lateral subsurface flow in ELM



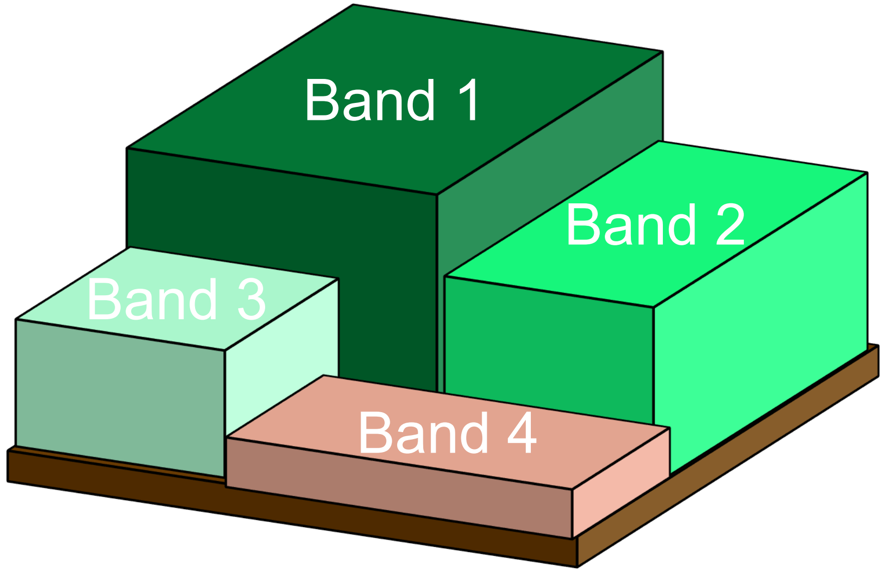
1km groundwater table depth

Qiu et al. (2024)

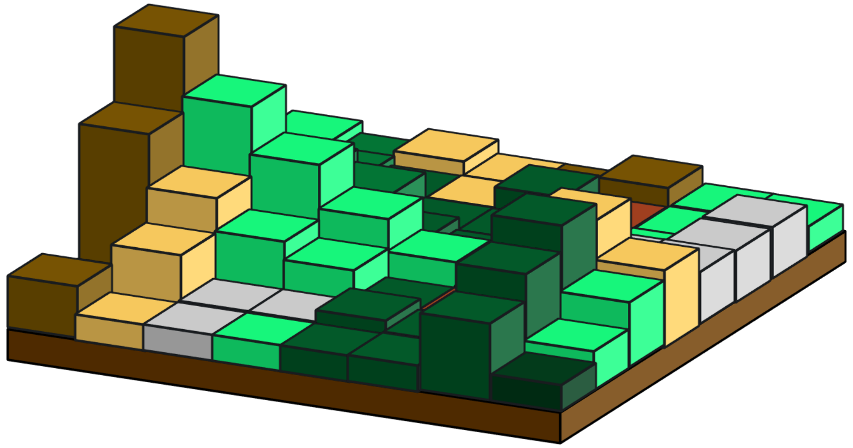
Different sub-grid schemes in ELM



Default (D)



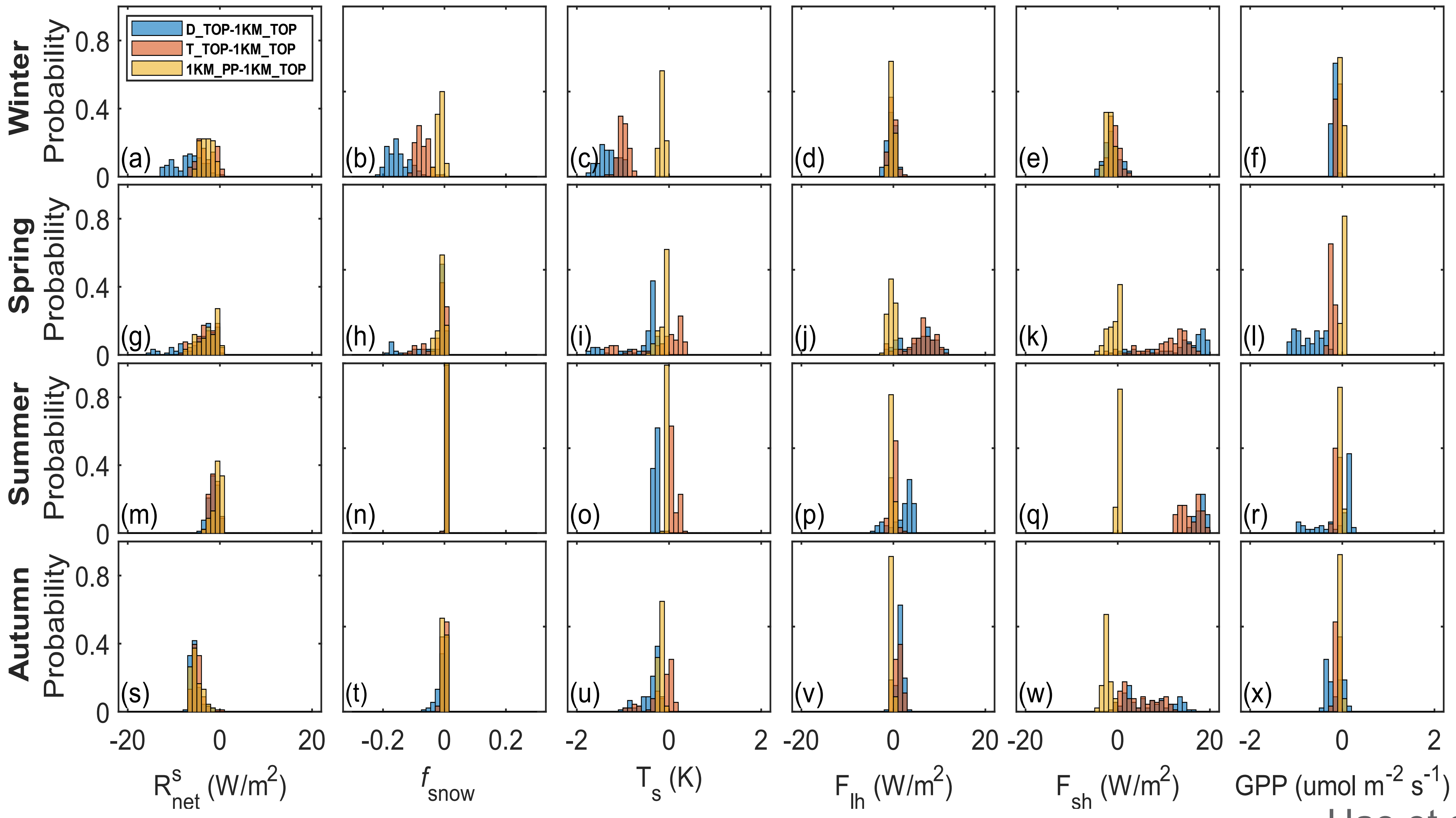
Topunit (T)



High-resolution (1km)

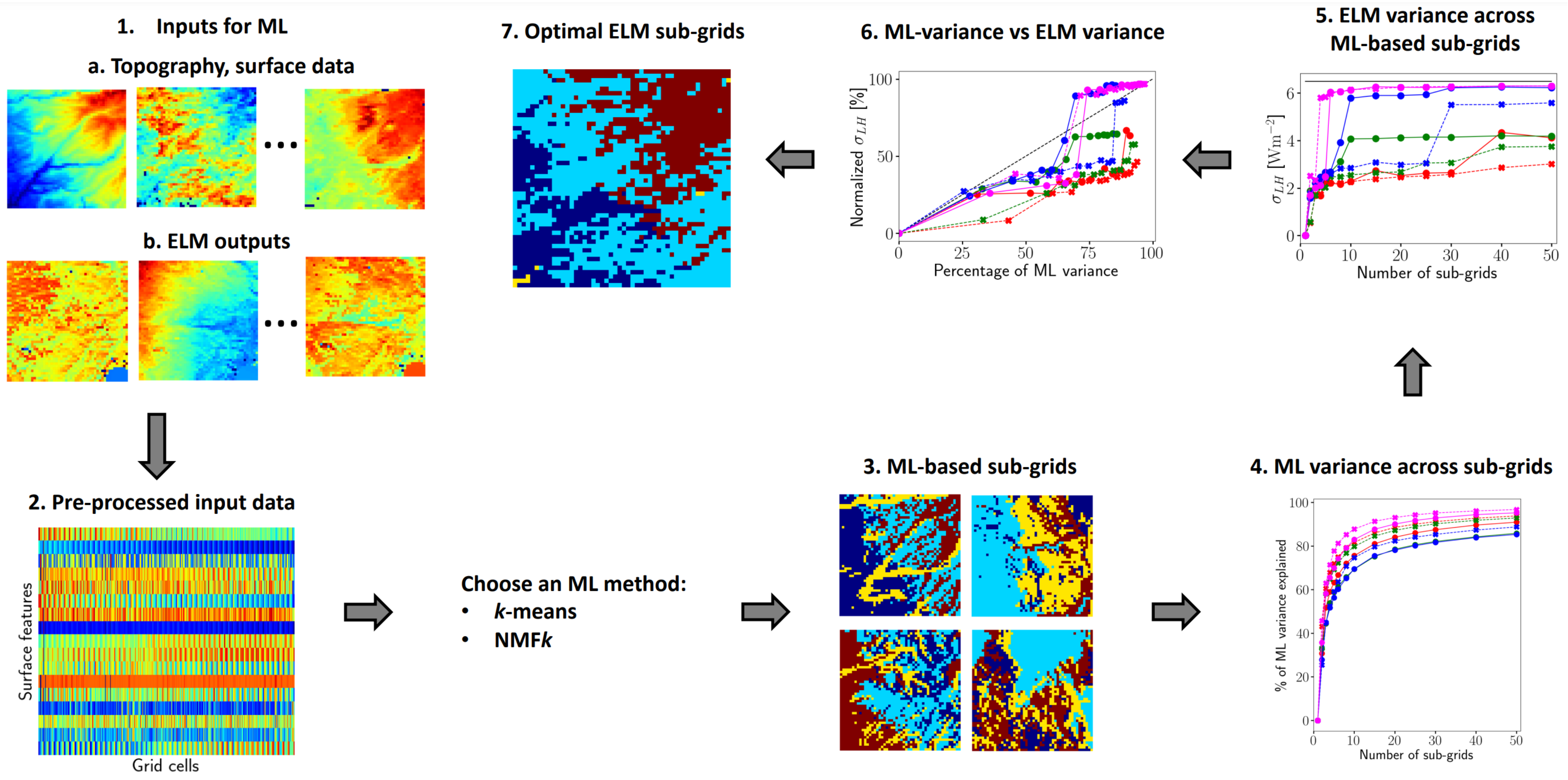
Hao et al. (2022)

Topounit provides better performance than the default sub-grid structure



Hao et al. (2022)

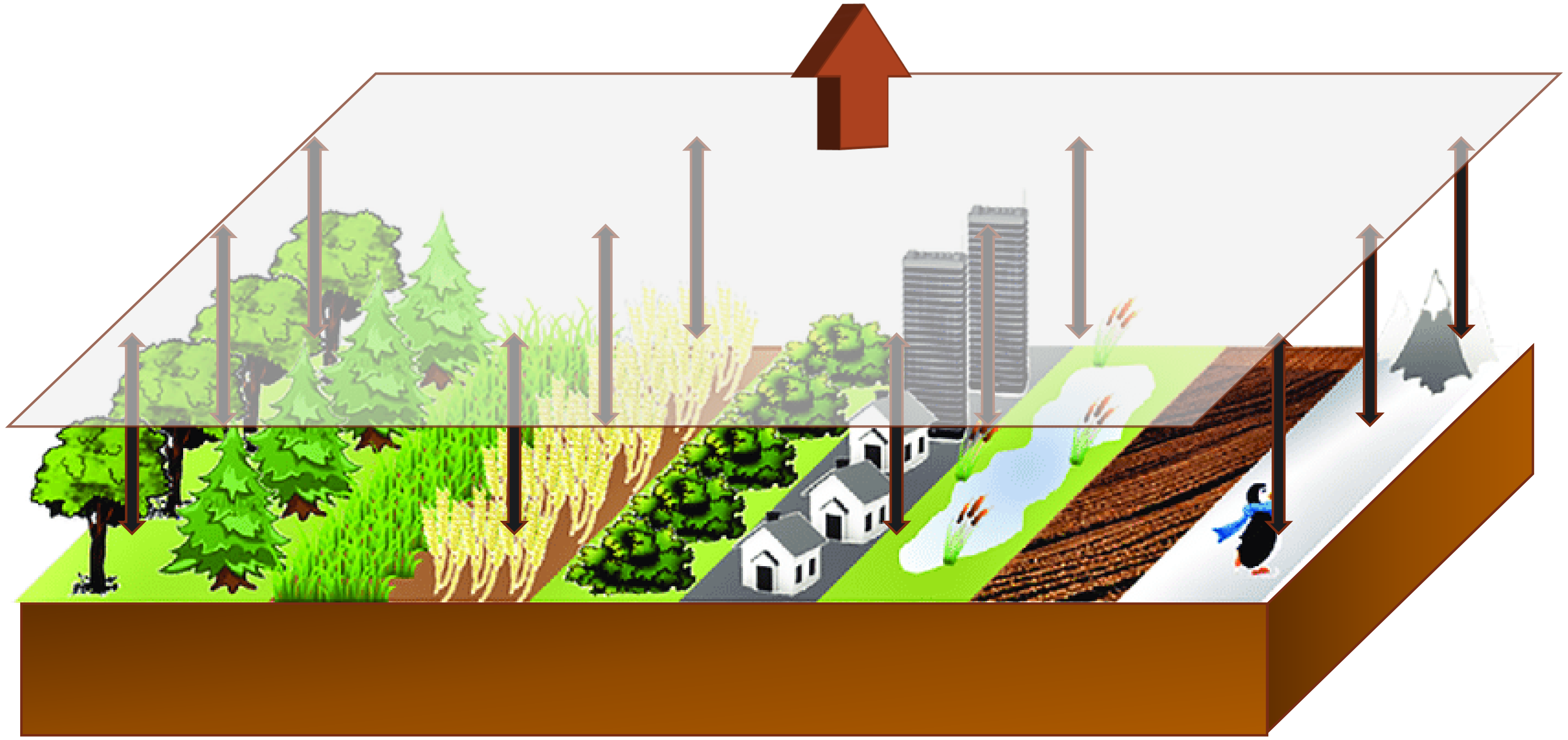
Physics-informed machine learning to identify optimal sub-grid structure



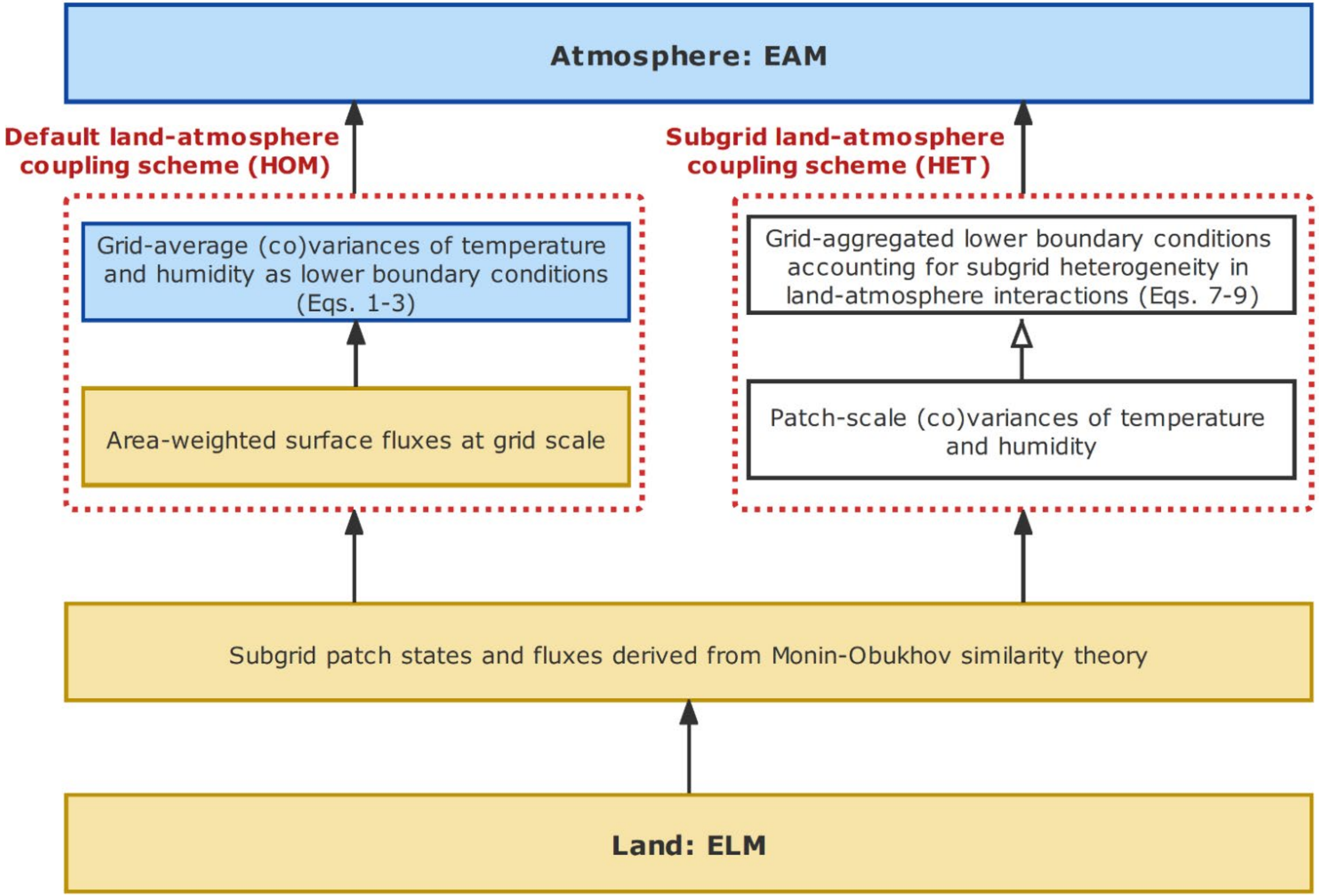
Sub-grid heterogeneity can modify the structure of the atmospheric boundary layer

- Most of the existing ESMs couple the land and atmosphere using grid-scale mean fluxes and state variables, thus ignoring the LSH effects (represented by scalar variance, e.g., temperature variance).
- LSH can modify the vertical structure of the planetary boundary layer (PBL).

Grid mean + scalar variance

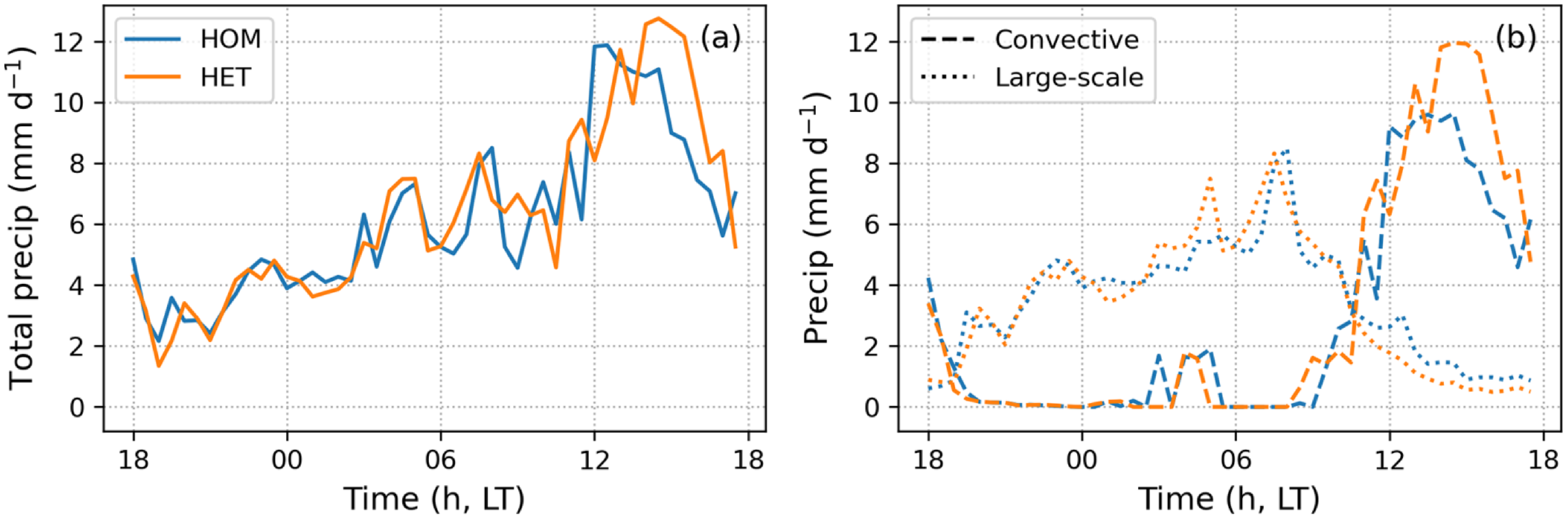


New sub-grid land-atmosphere coupling scheme



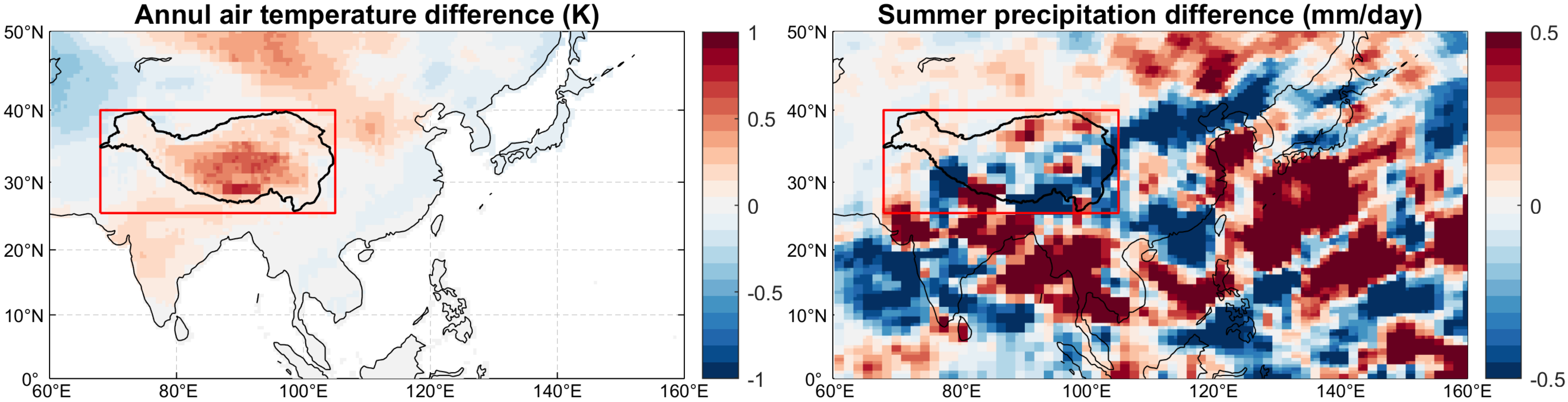
Huang et al. (2023)

Sub-grid heterogeneity affects the atmospheric and cloud dynamics



Huang et al. (2023)

Regional and remote impacts of topographic heterogeneity



Hao et al. (2023)

Take-home Message

- ❑ Implemented a new sub-grid topographic parameterization in ELM to account for the effects of sub-grid topography on solar radiation flux (Working on kilometer-scale parameterization) as well as a lateral subsurface flow model.
- ❑ Quantified the impacts of representing sub-grid heterogeneity with different complexities on surface energy balance and surface boundary conditions.
- ❑ Used advanced machine learning (ML) methods to develop a novel/optimal sub-grid structure in ELM.
- ❑ Develop a new land-atmosphere coupling scheme in E3SM via accounting for the impacts of sub-grid heterogeneity on the lower boundary condition for the atmosphere model.
- ❑ Topography-radiation interaction over mountains shows regional and remote impacts.

References

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Thank you

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