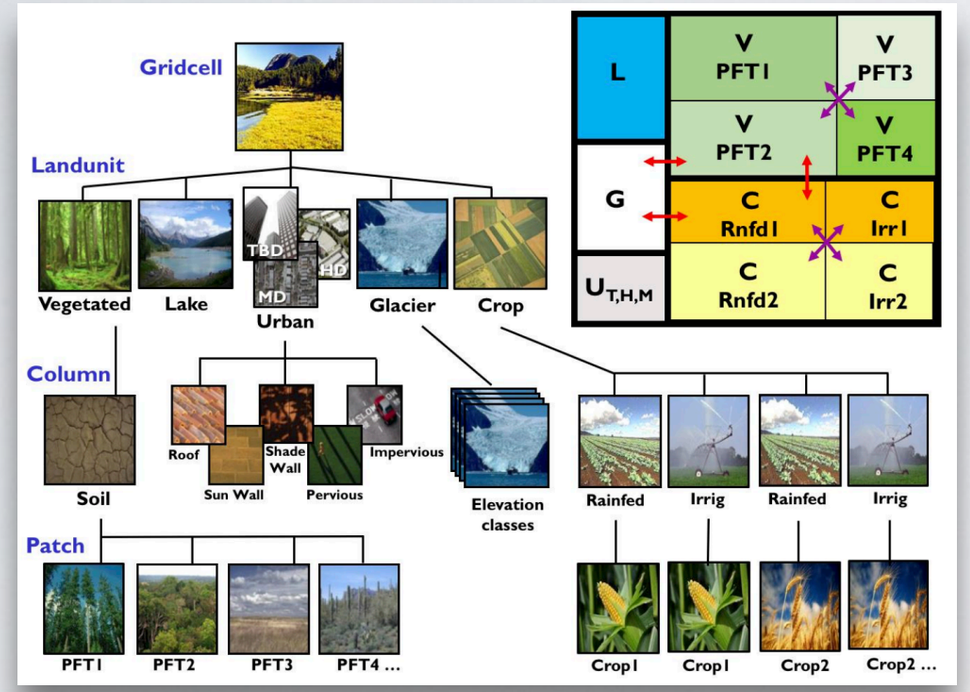
Sub-grid heterogeneity: Where do we go from here?

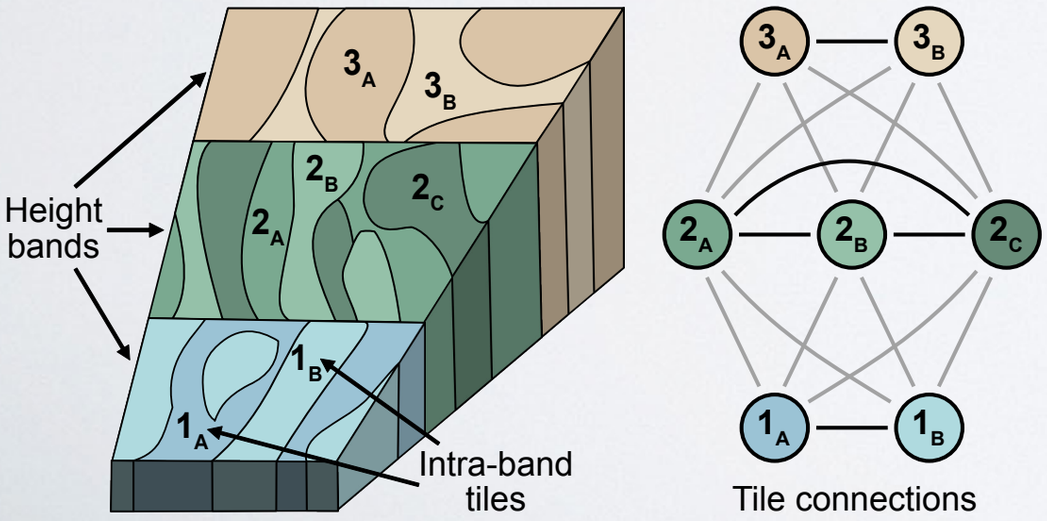
Nathaniel Chaney, Laura Torres-Rojas, Enrico Zorzetto, and Noemi Vergopolan

Where are we? Focus on sub-grid "tiling" schemes



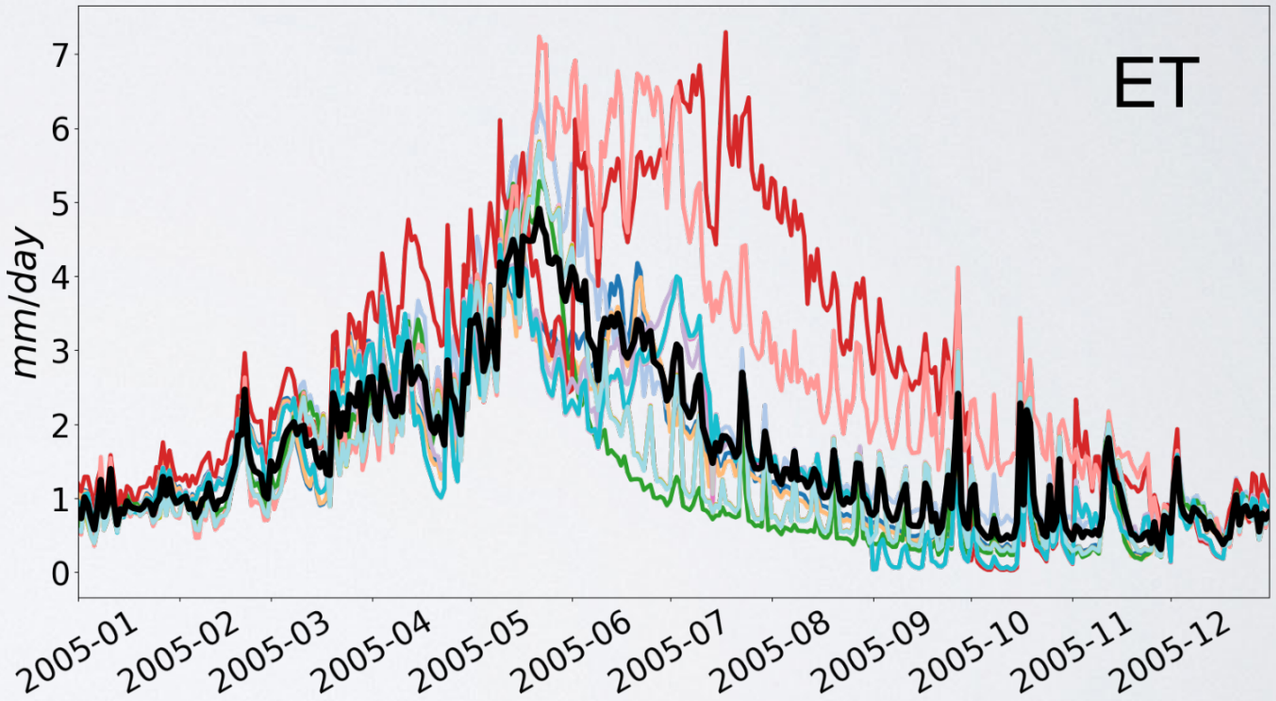
Lawrence et al., 2019

Characteristic hillslope



Chaney et al., 2018

Example output from land model tiles of a 0.25 degree grid cell



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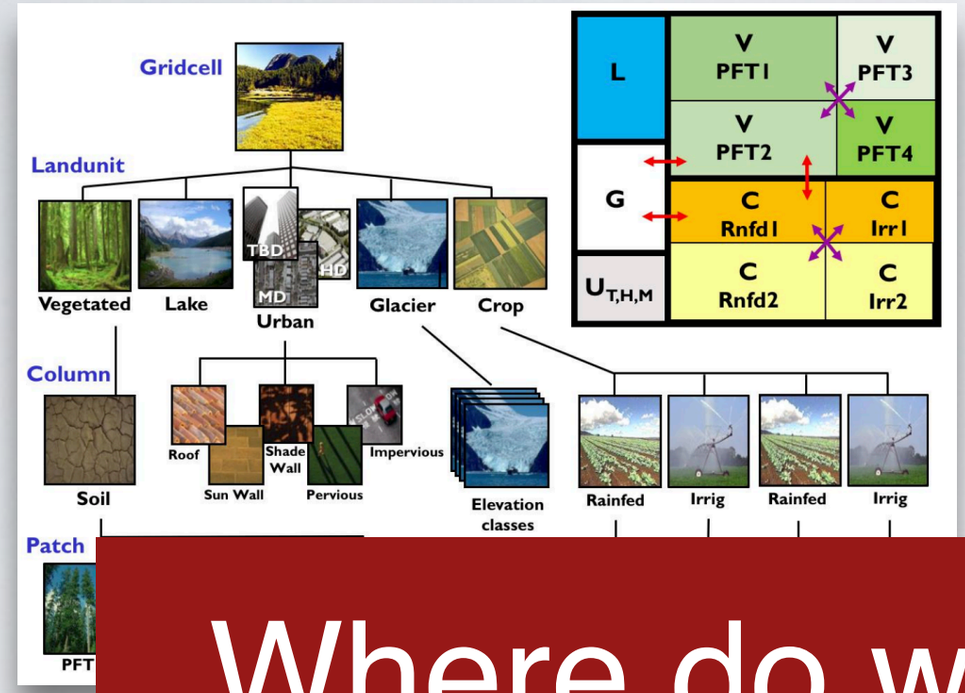

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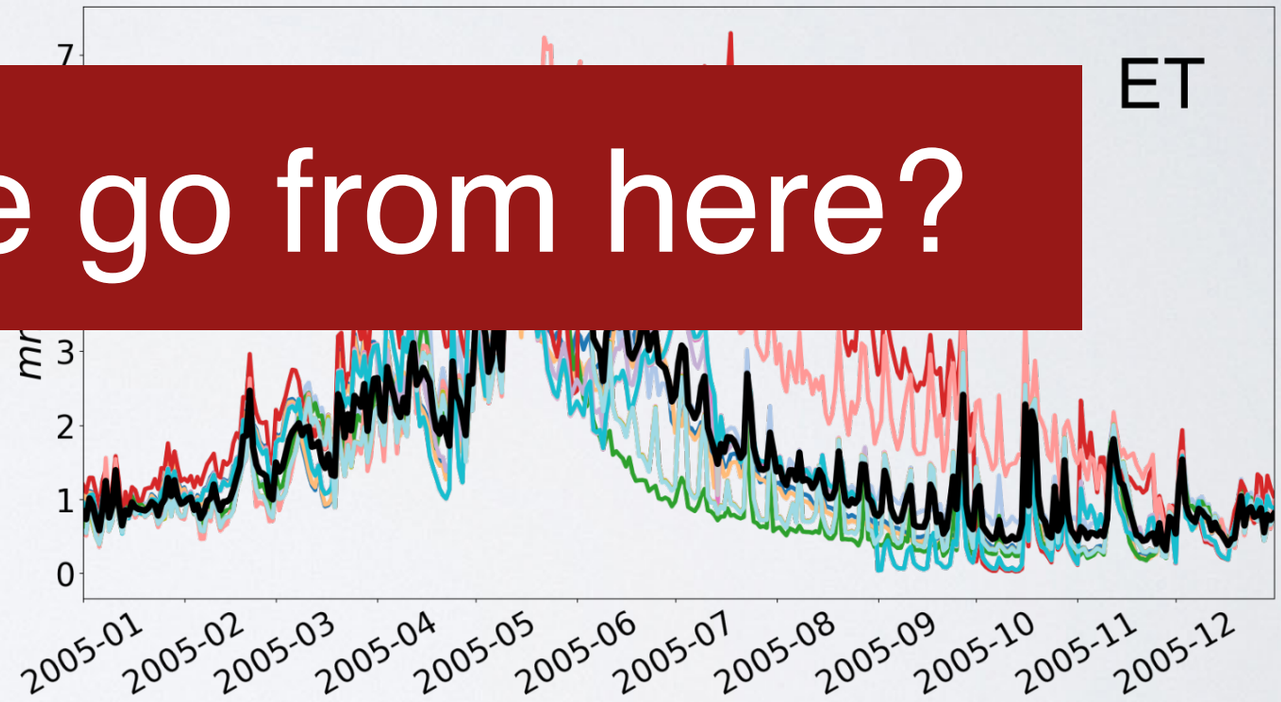
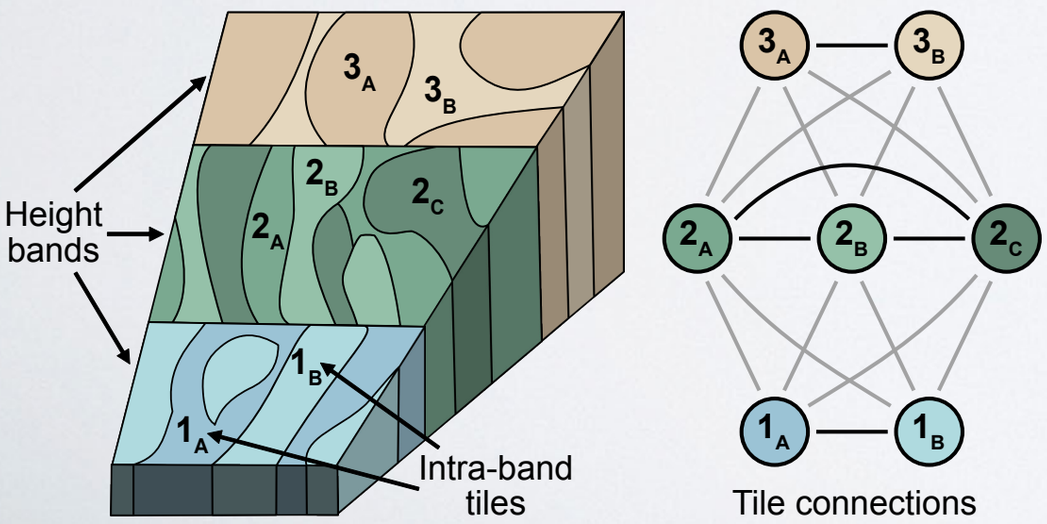


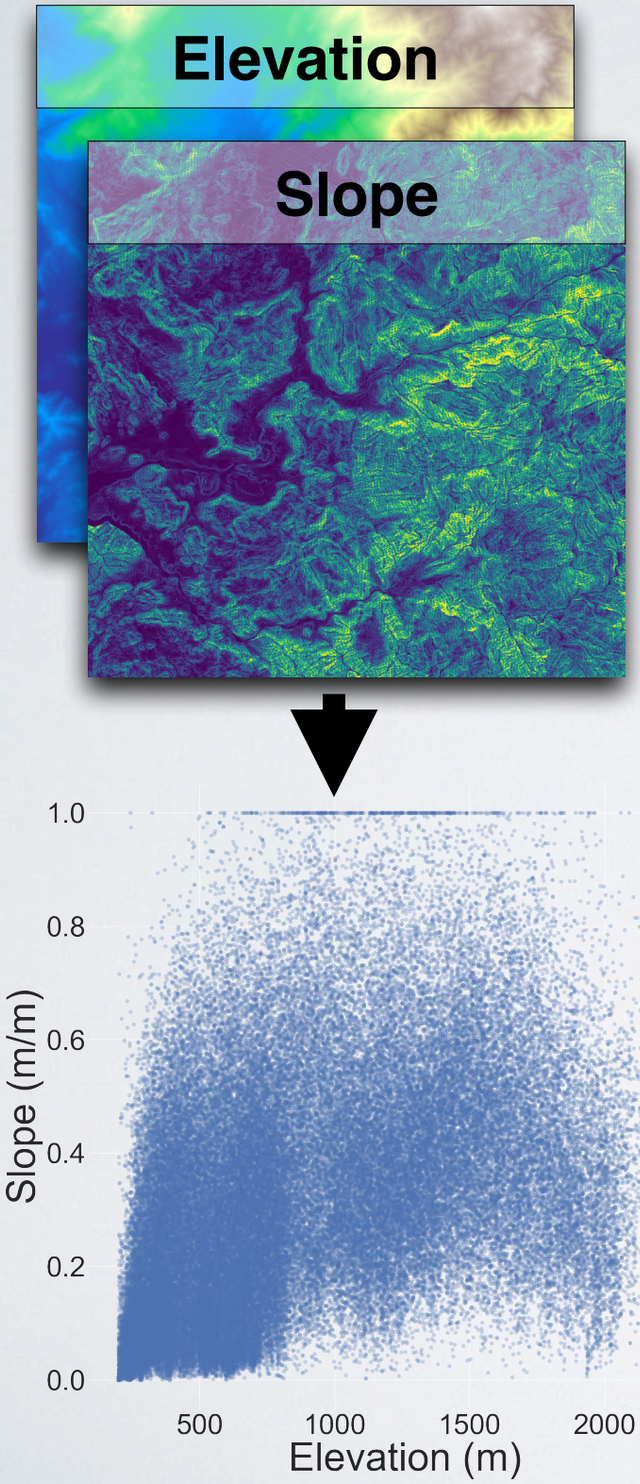
Where do we go from here?

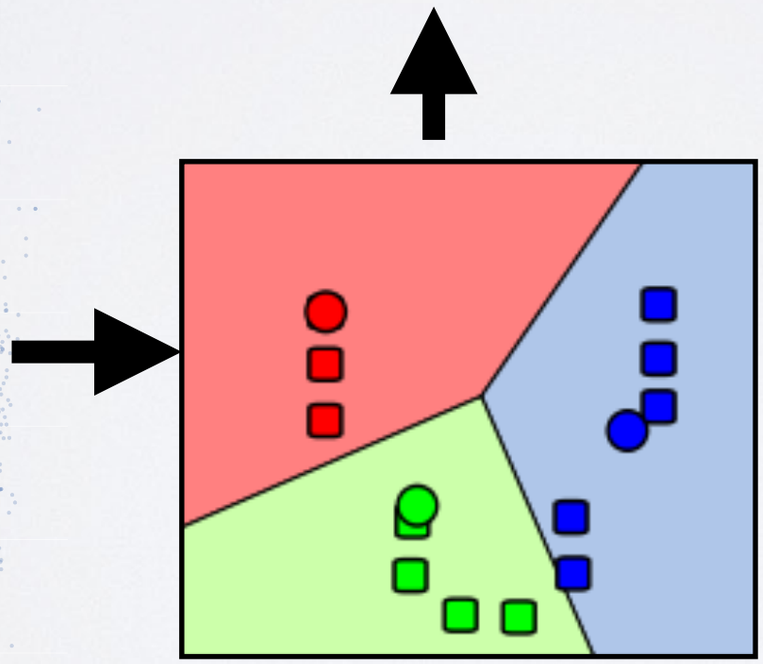
Characteristic hillslope



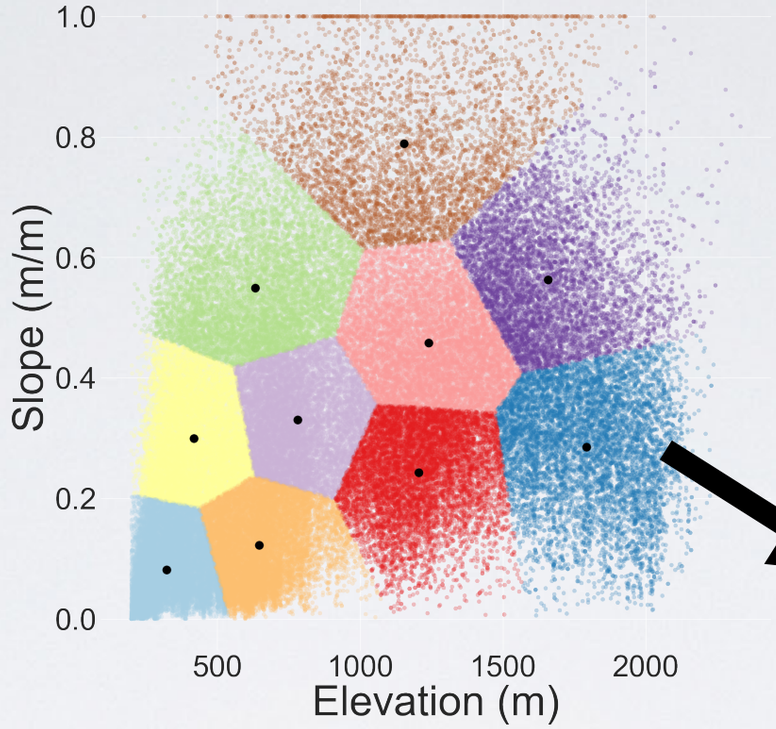
Chaney et al., 2018

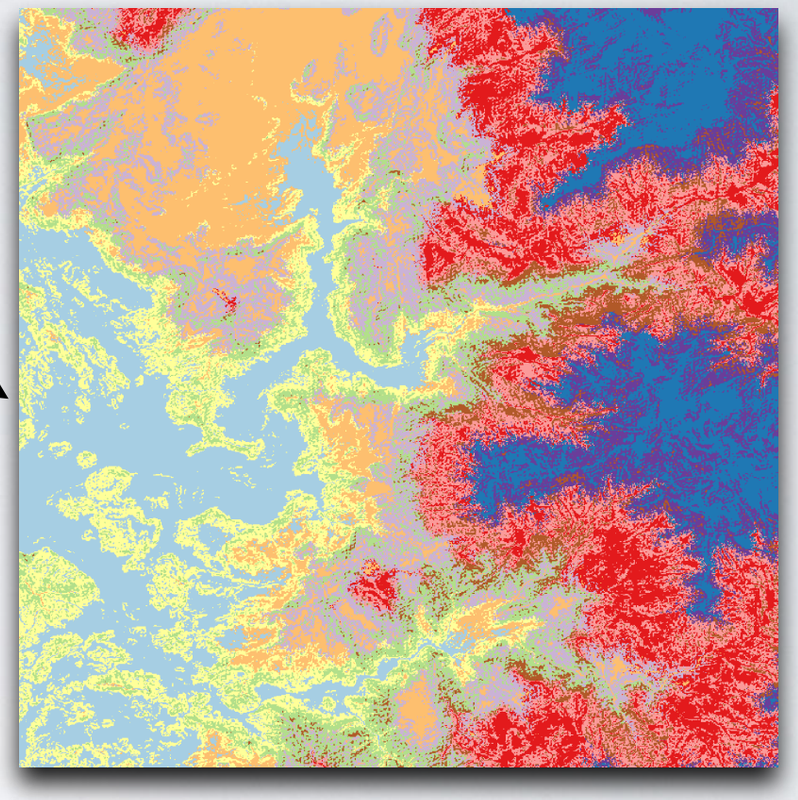
1) Recast "tiling" as a clustering exercise





K-means clustering
(e.g., n=10)



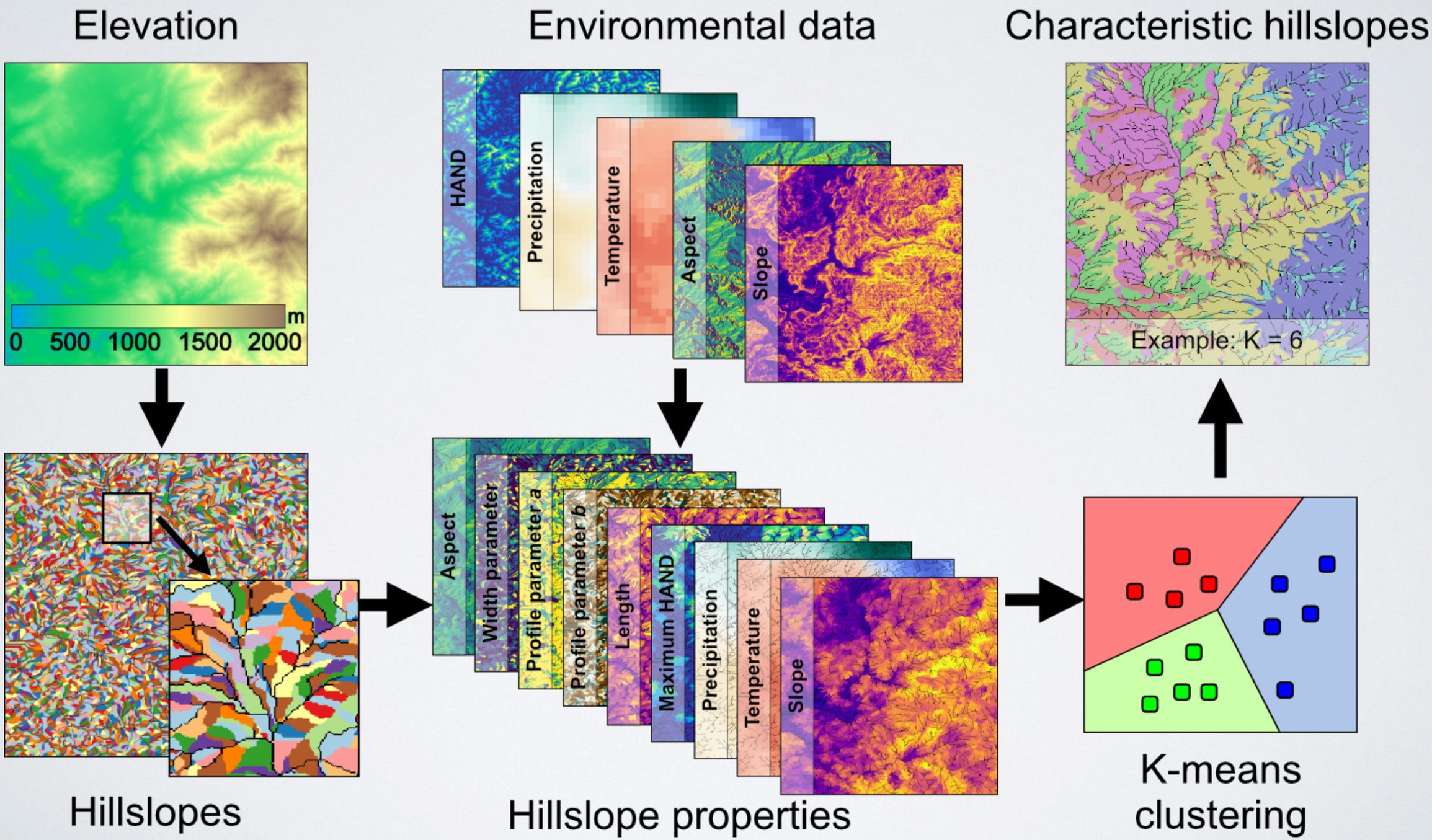


Clusters/Tiles

Model only "sees" statistical distribution of tiles with associated properties, meteorology, and interconnections

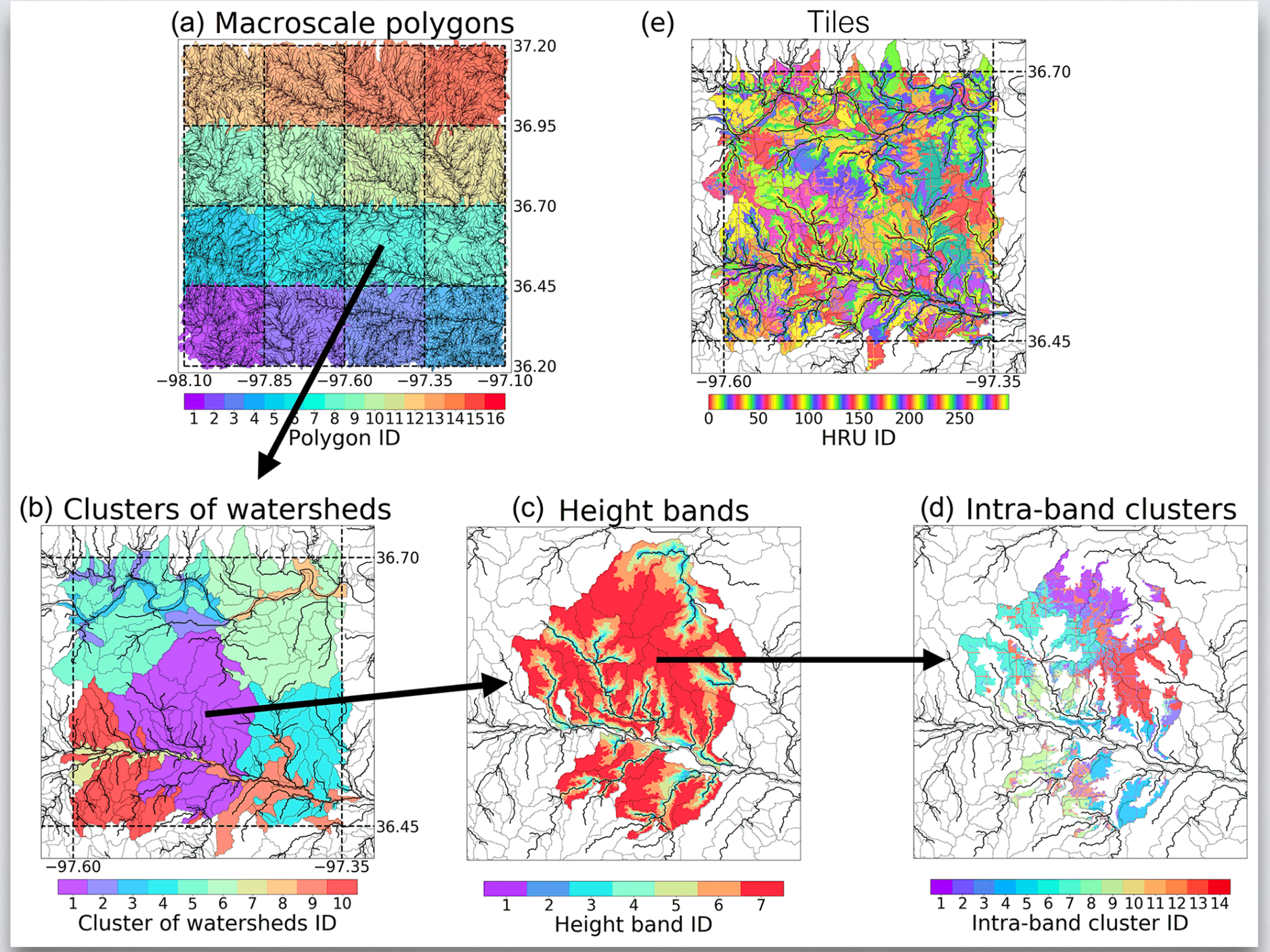
Bring in geomorphological units

Define K characteristic/representative hillslopes



Chaney et al., 2018

Create "generalizable" approaches to assemble tile configurations



Chaney et al., 2021

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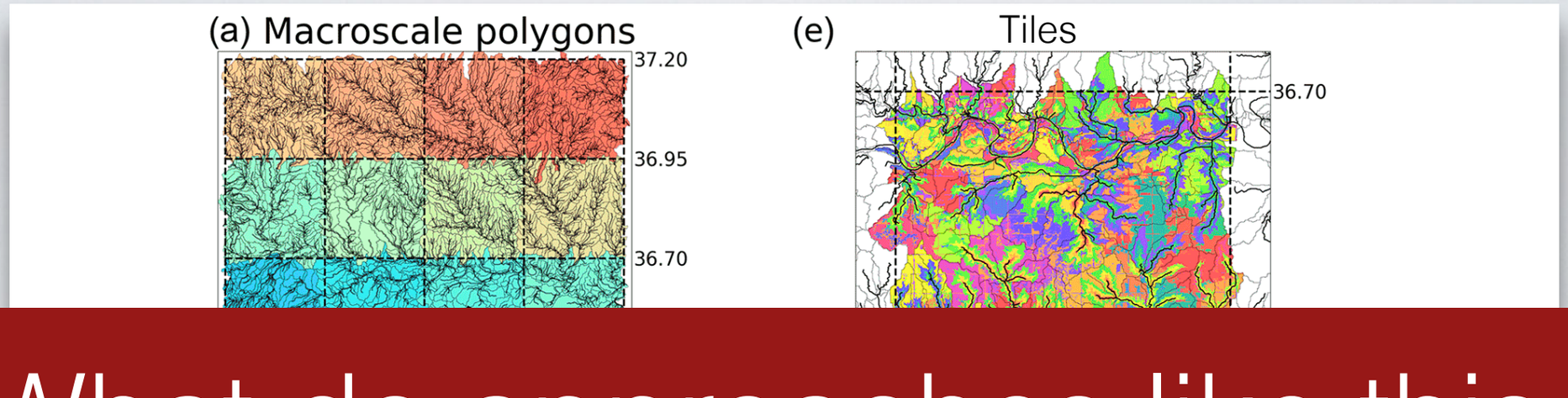
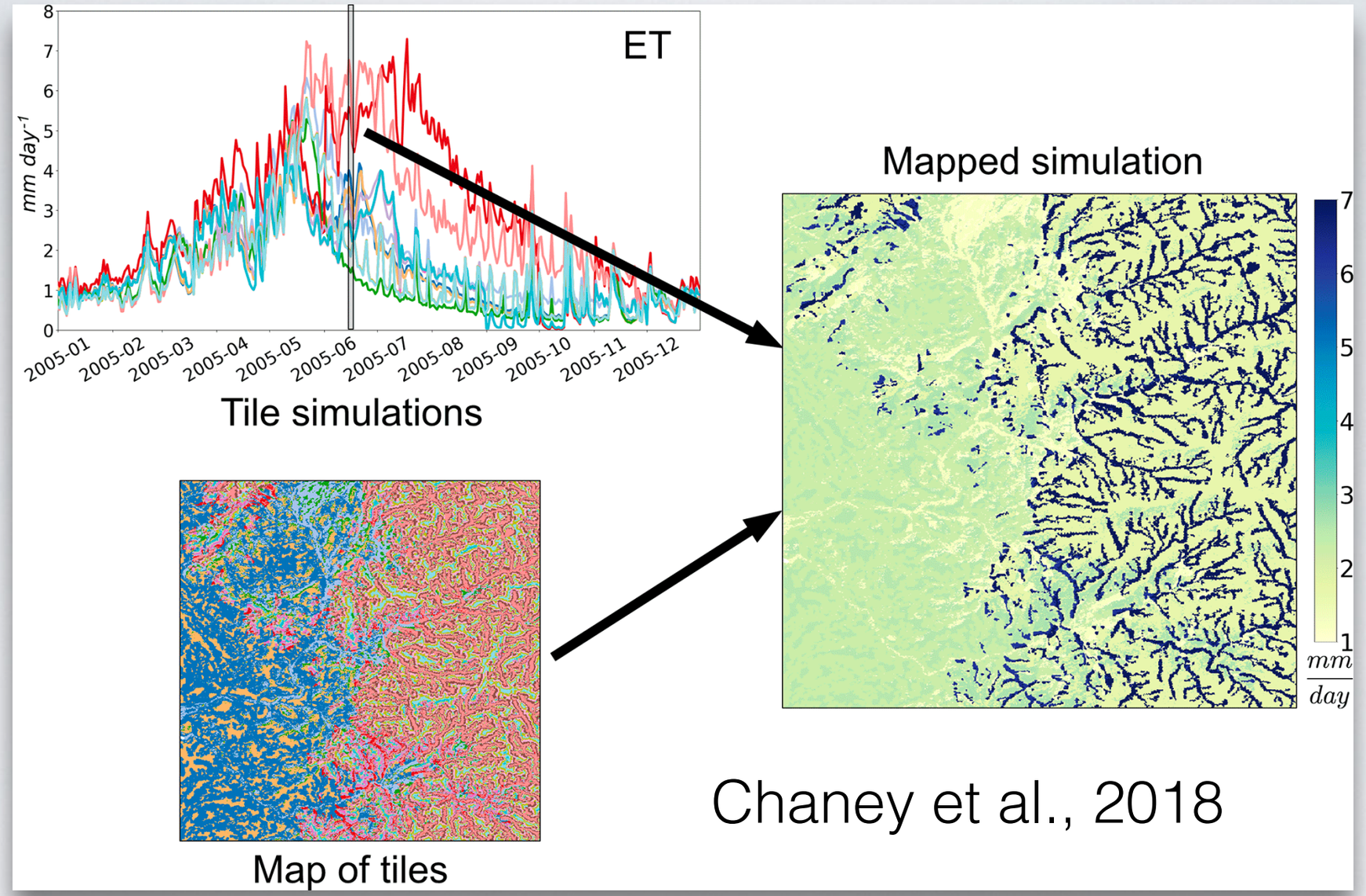


What do approaches like this enable us to do?

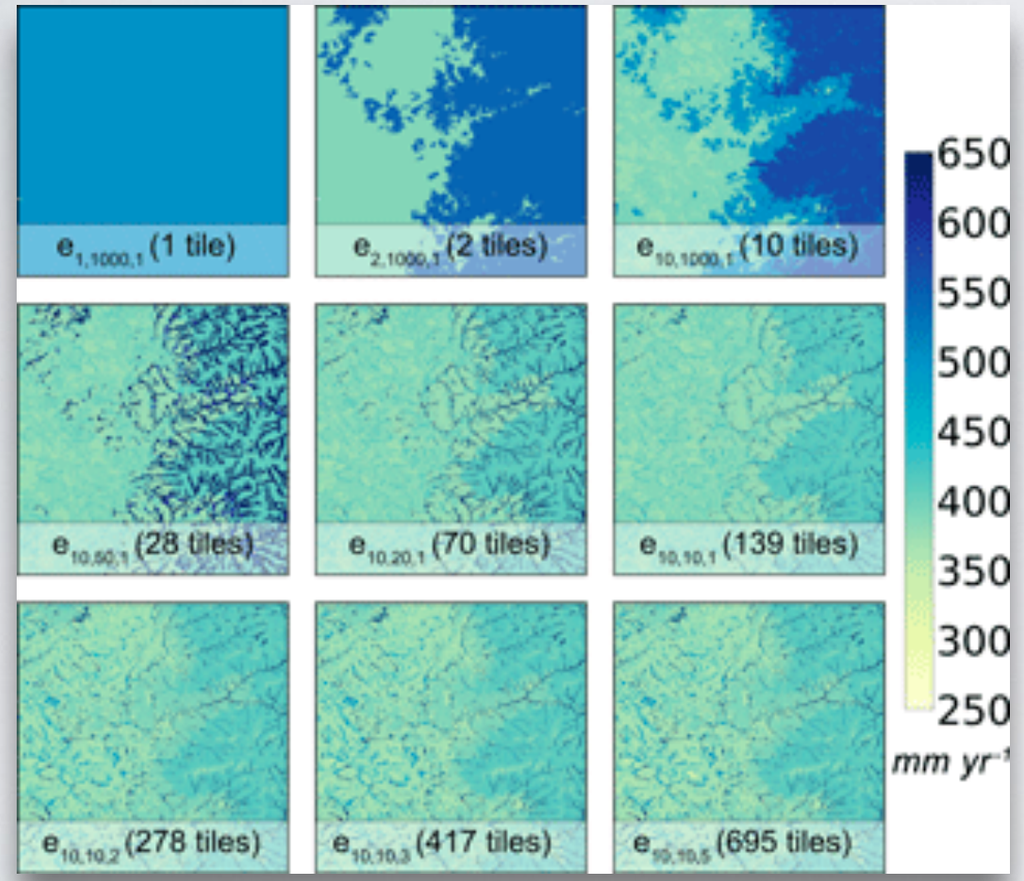
Chaney et al., 2021

2) Leverage clustering approaches to "map" the tile results for applications/evaluation

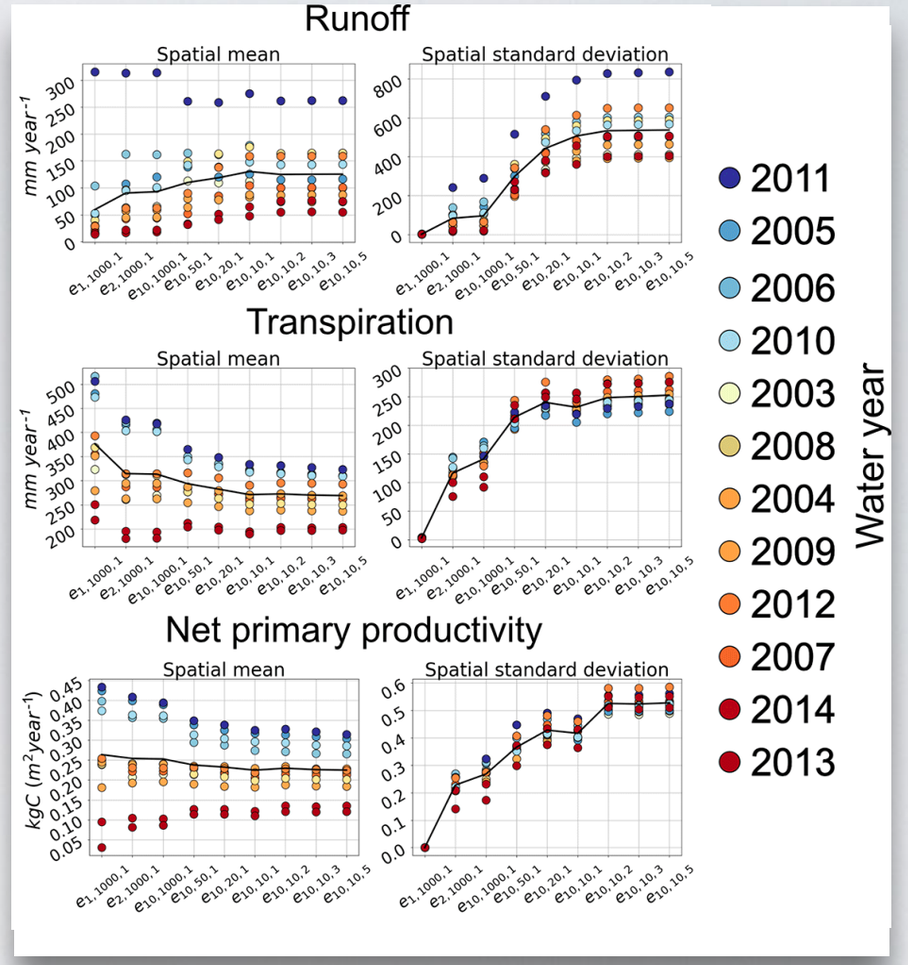


- Leverage one-to-many mapping to produce field-scale estimates
- Remove the modeler excuse of "scale mismatch" when comparing to observations (at least at field scales)
- Assess the level of simulated heterogeneity that is being represented

3) Optimal tile configurations per LSM cell



Chaney et al., 2018



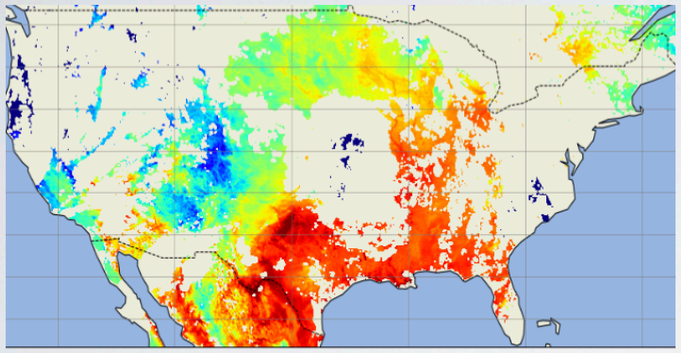
- Converge on fully distributed field-scale (10-100 m) simulations with anywhere from ~10-1000 tiles. It depends on the timescale and acceptable “threshold”
- Approach to effectively get all the fully distributed model output for a fraction of the cost (1/100-1/10,000)
- Caution: “Optimal” grid cell configurations will require careful load-balancing

4) Evaluate simulated sub-grid heterogeneity

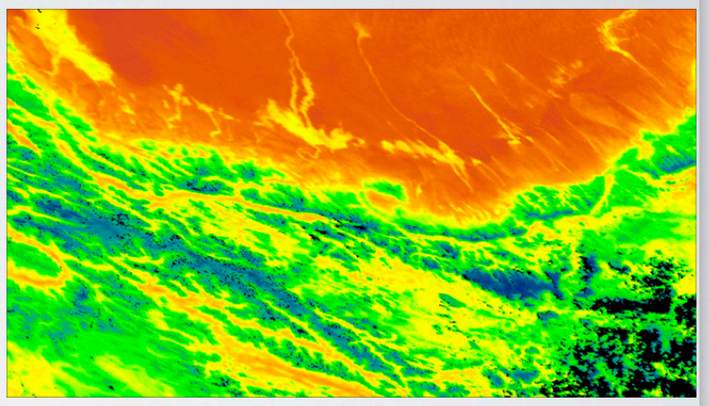
- We keep adding complexity to our tiling schemes but are we actually evaluating the simulated sub-grid heterogeneity?
- Evaluating how the scheme additions impacts the spatial mean of states and fluxes is oversimplistic (right answer for wrong reason)
- Need data this sufficiently high spatial (and preferably temporal resolution) to evaluate time varying sub-grid statistics (e.g., Land surface temperature; LST)

Remote sensing of LST

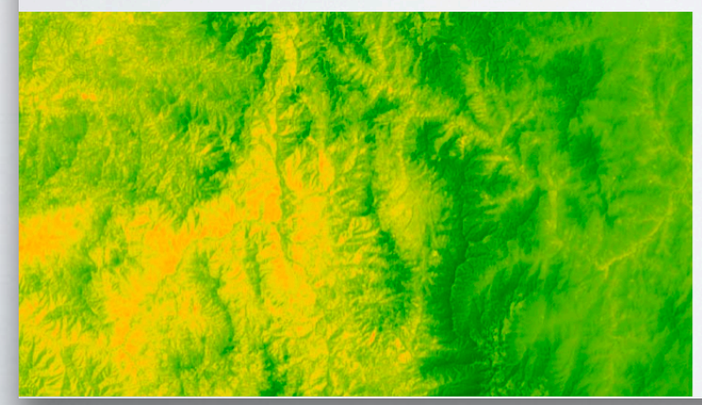
GOES 16/17(~2 km, hourly)



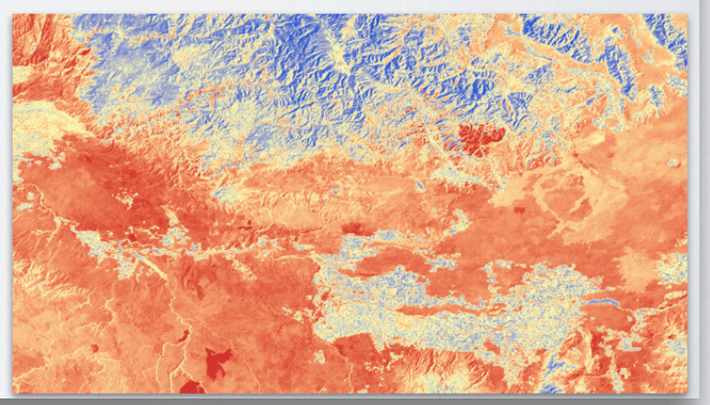
MODIS (~1 km, daily)



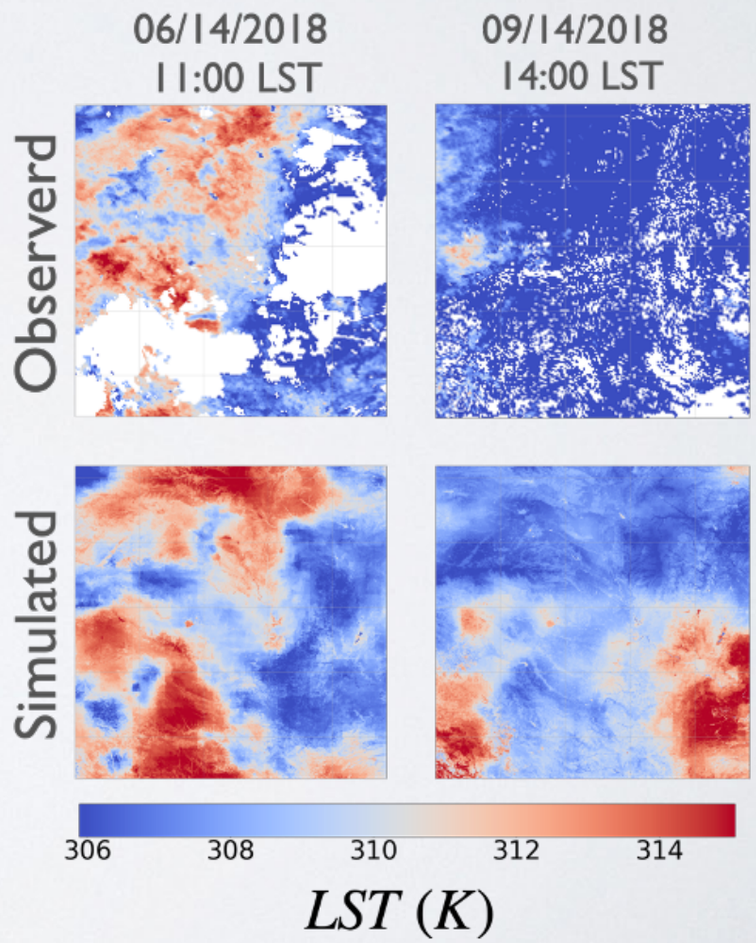
Landsat 8/9 (~100 m, 8 days)



ECOSTRESS (~70 m, ~4 days)

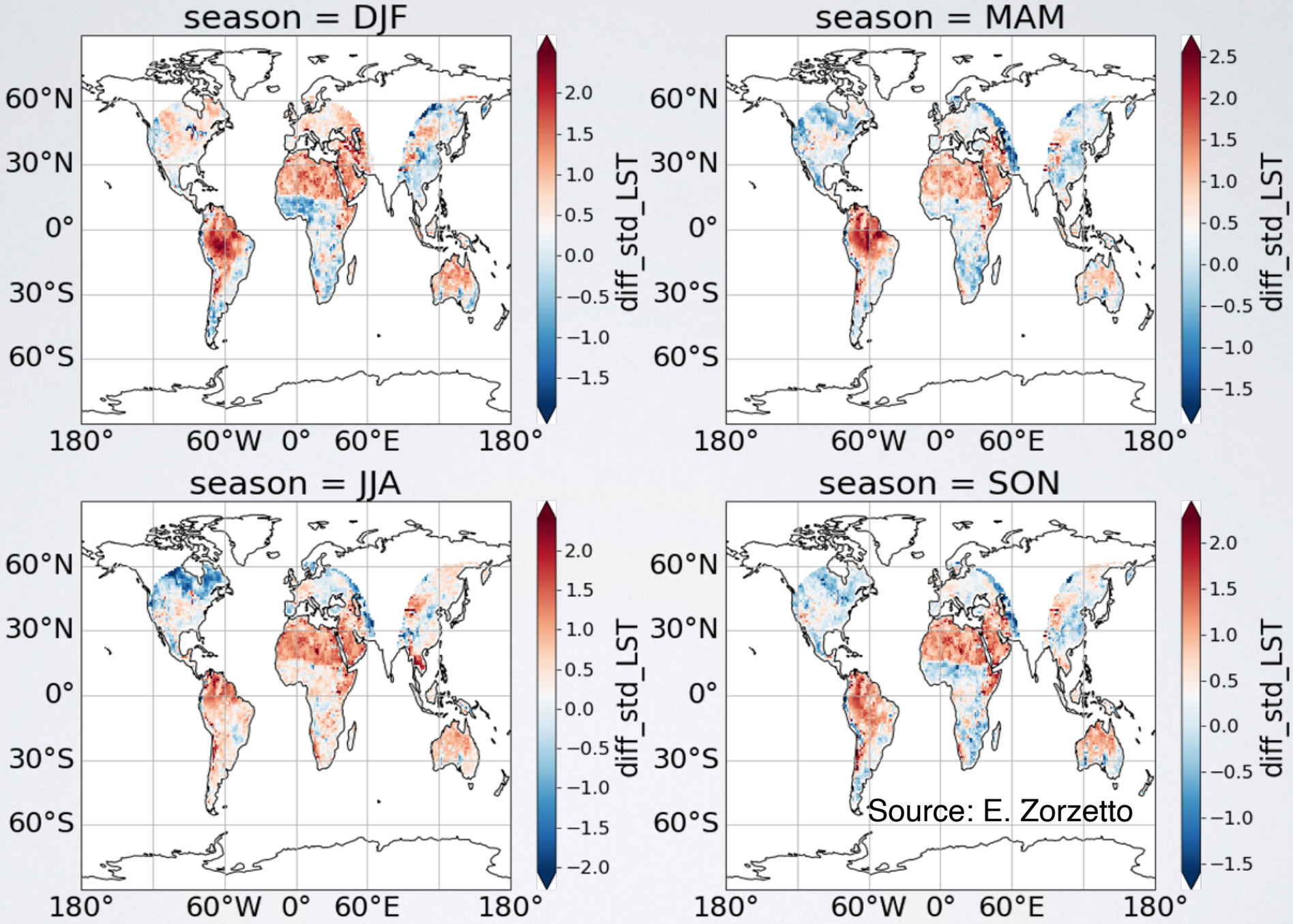


GOES-R vs HydroBlocks LST



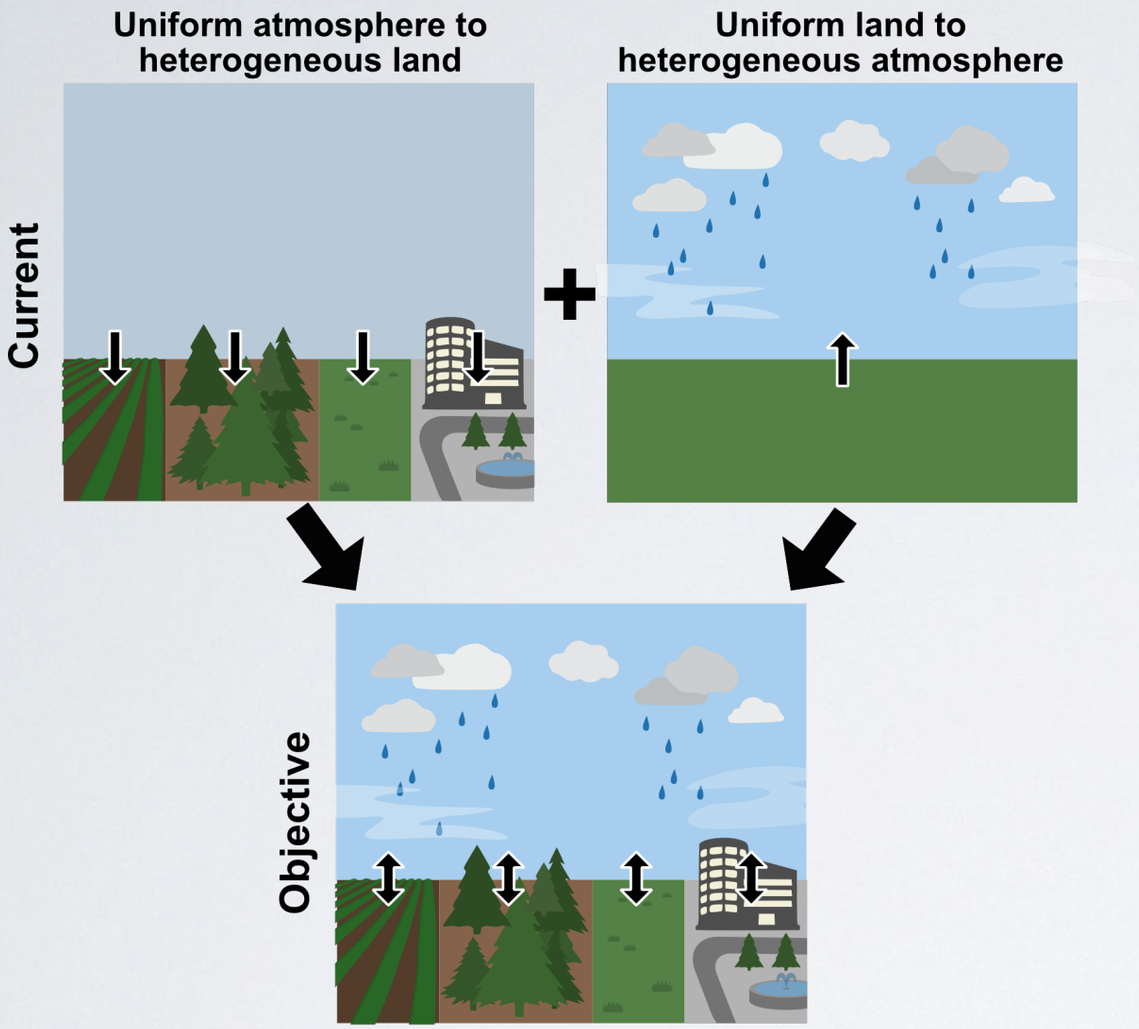
Evaluate simulated sub-grid heterogeneity II

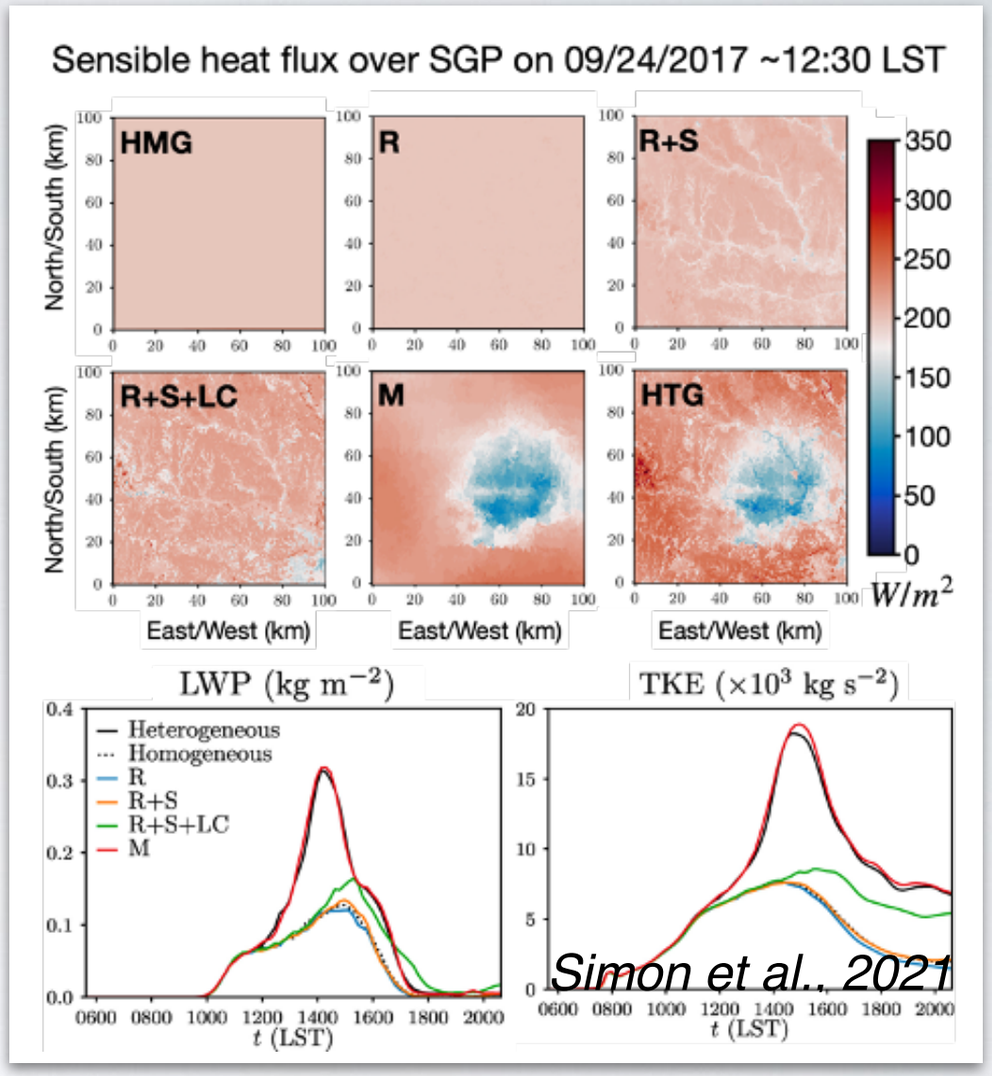
Copernicus LST - GFDL AM4 (LST spatial variance)



We need to evaluate our simulated sub-grid states (and fluxes)

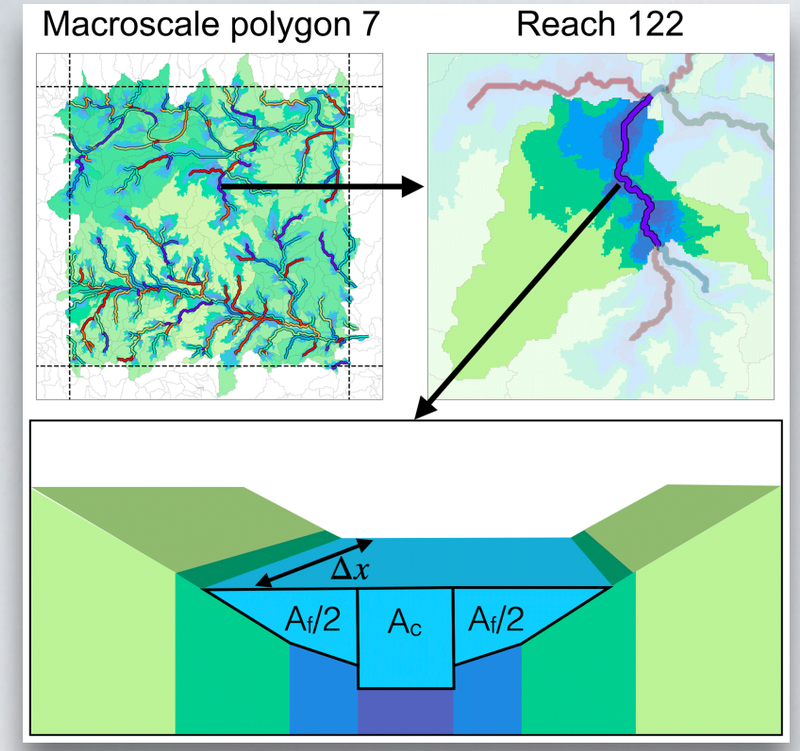
5) Improve connection of land tiles and atmosphere

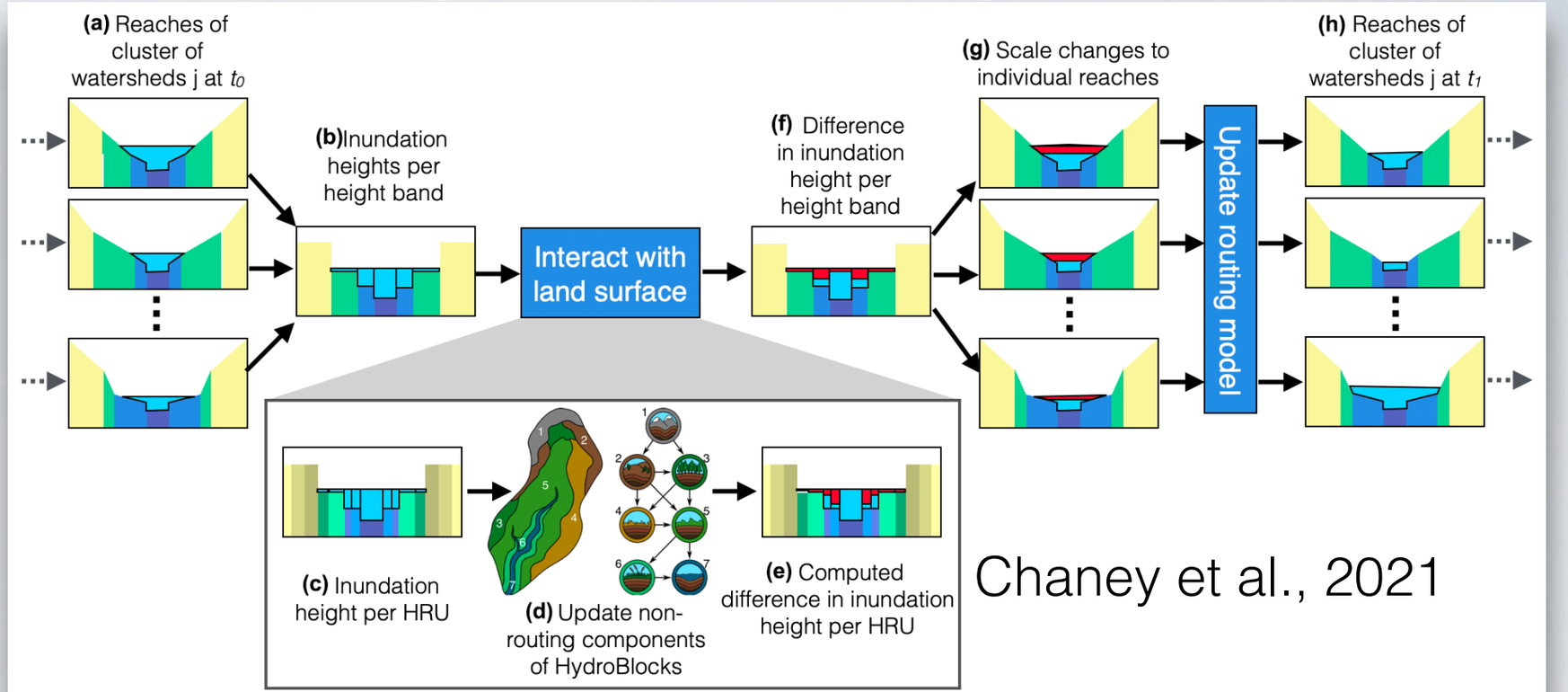




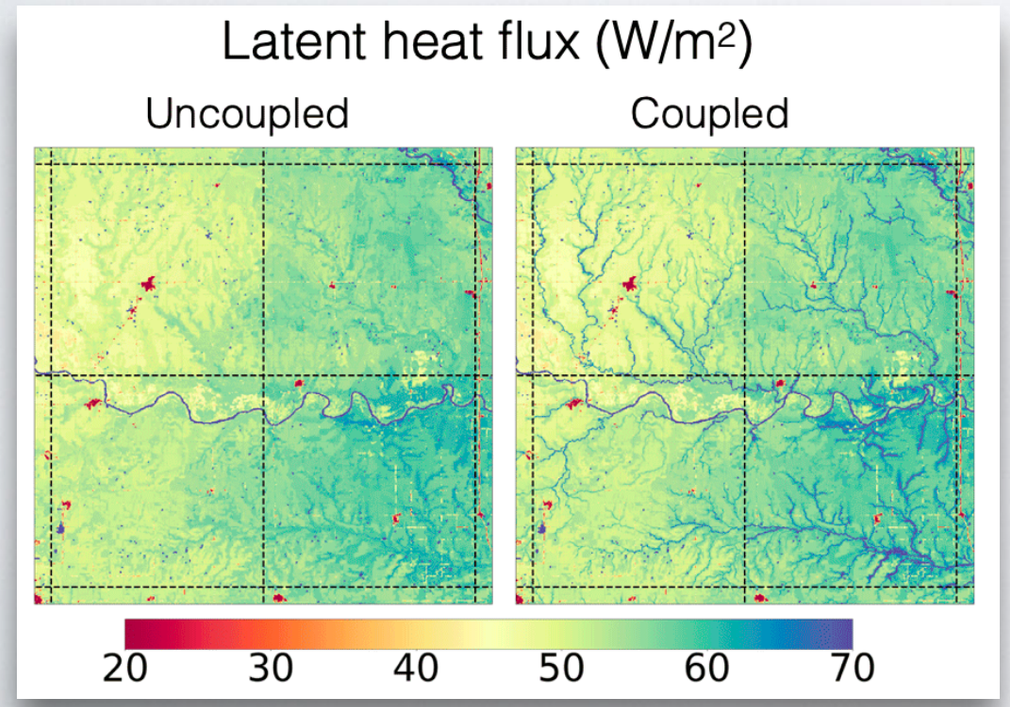
- The sub-grid land vs atmosphere model development silos has led to a large disconnect between their respective advances
- Atmosphere does not “feel” sub-grid land surface heterogeneity (e.g., impact of sub-grid heterogeneity on convection mostly non-existent).
- This will matter for many sub-grid land setups including urban/rural, coastal, mountain/valley, antecedent scattered thunderstorms, lake/land, etc…

6) Intertwine routing and tiling schemes



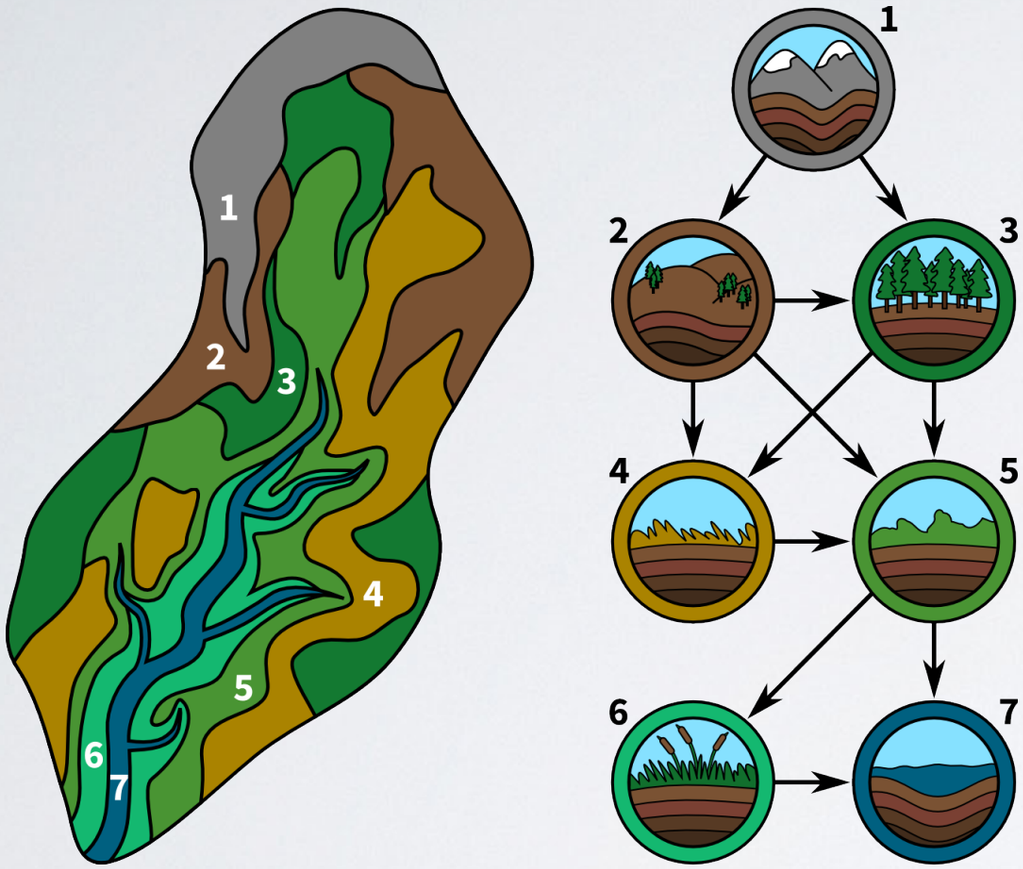


Chaney et al., 2021



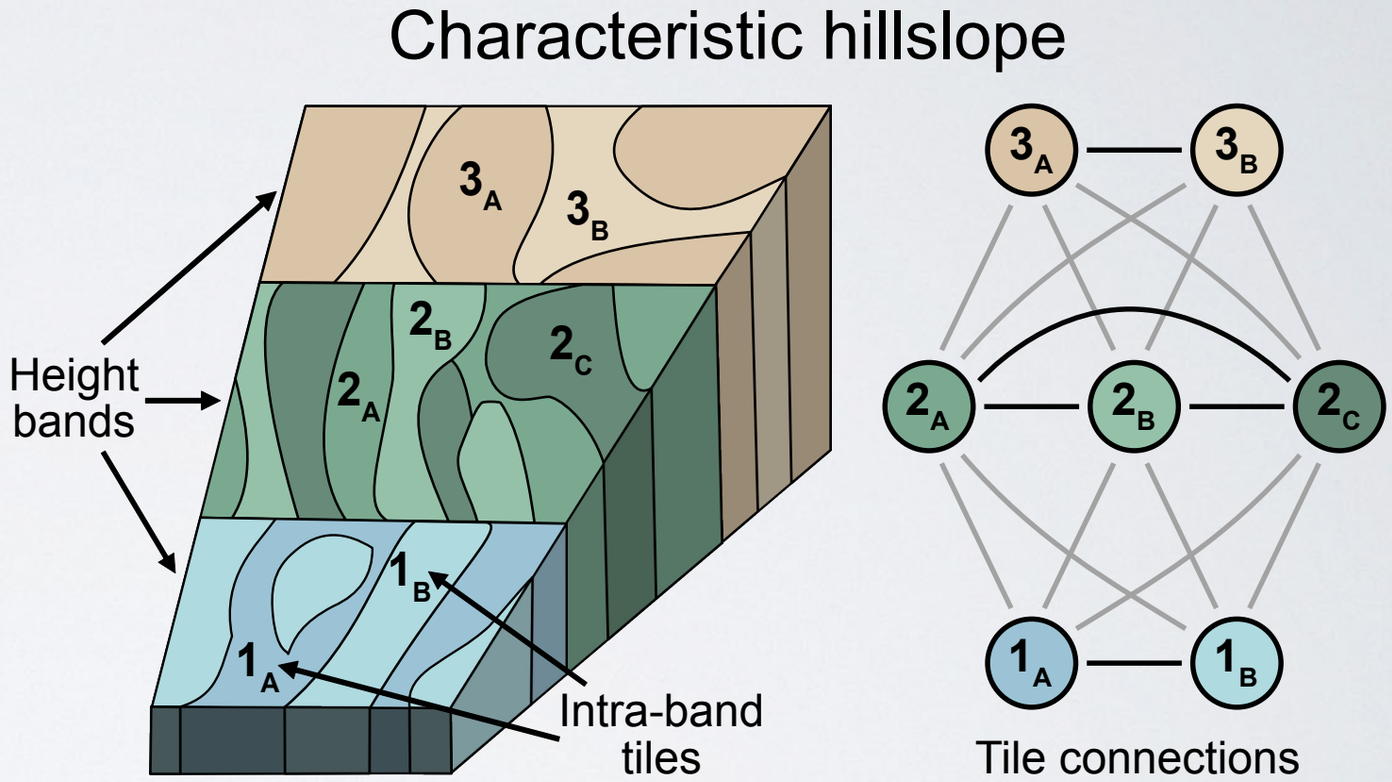
- Hillslope/stream interactions (e.g., ephemeral)
- Move away from predefined “lake tile” designation; move to flooding tiles (and merging/splitting)
- Implications for water management (e.g., surface water abstraction)
- Challenge: Need to reduce number of reaches. Avoid “removing” lower order streams and instead abstract (e.g., cluster)

7) Intra-cell sub-grid tile connections I



HydroBlocks

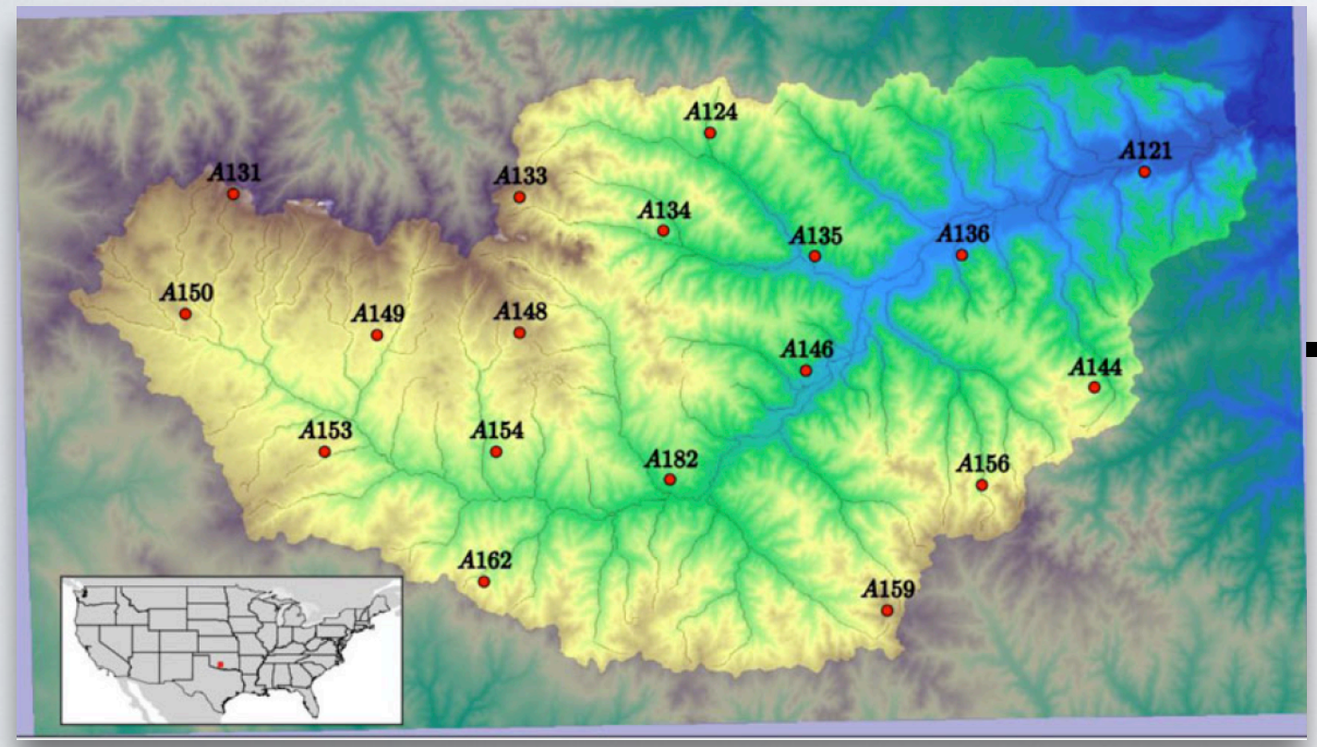
Chaney et al., 2016

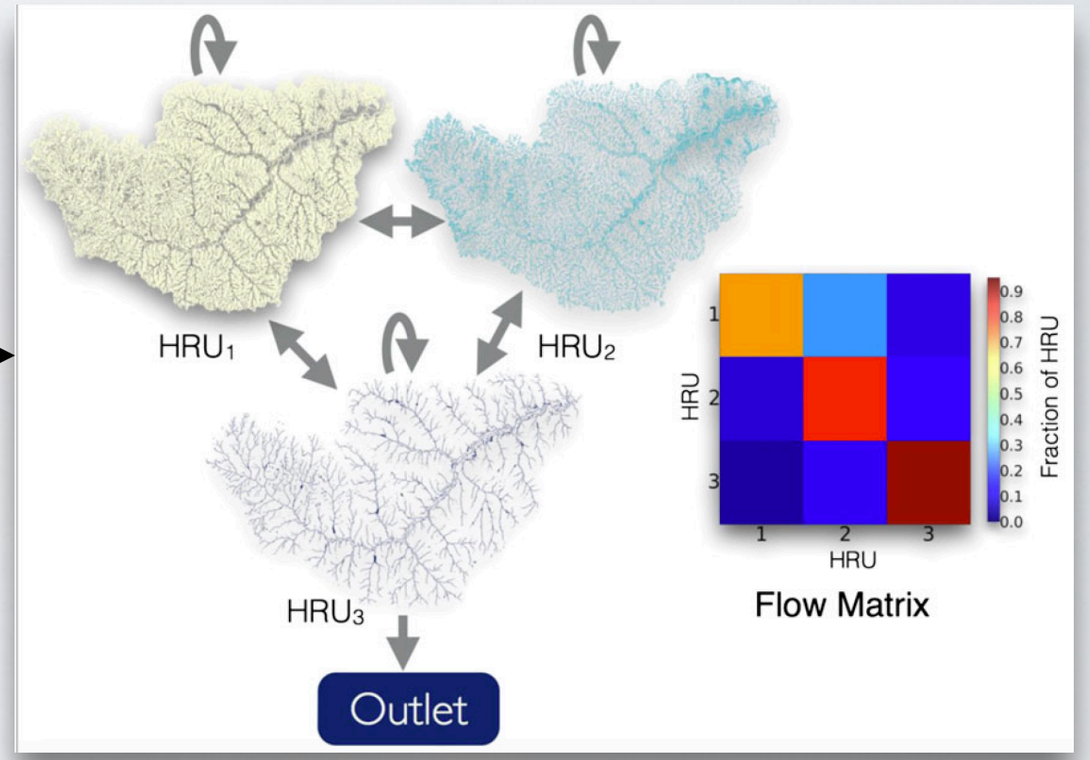


GFDL LM4.2

Chaney et al., 2018

7) Intra-cell sub-grid tile connections II





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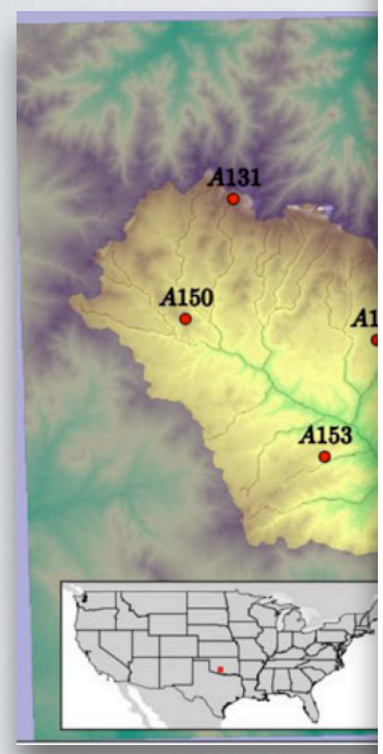

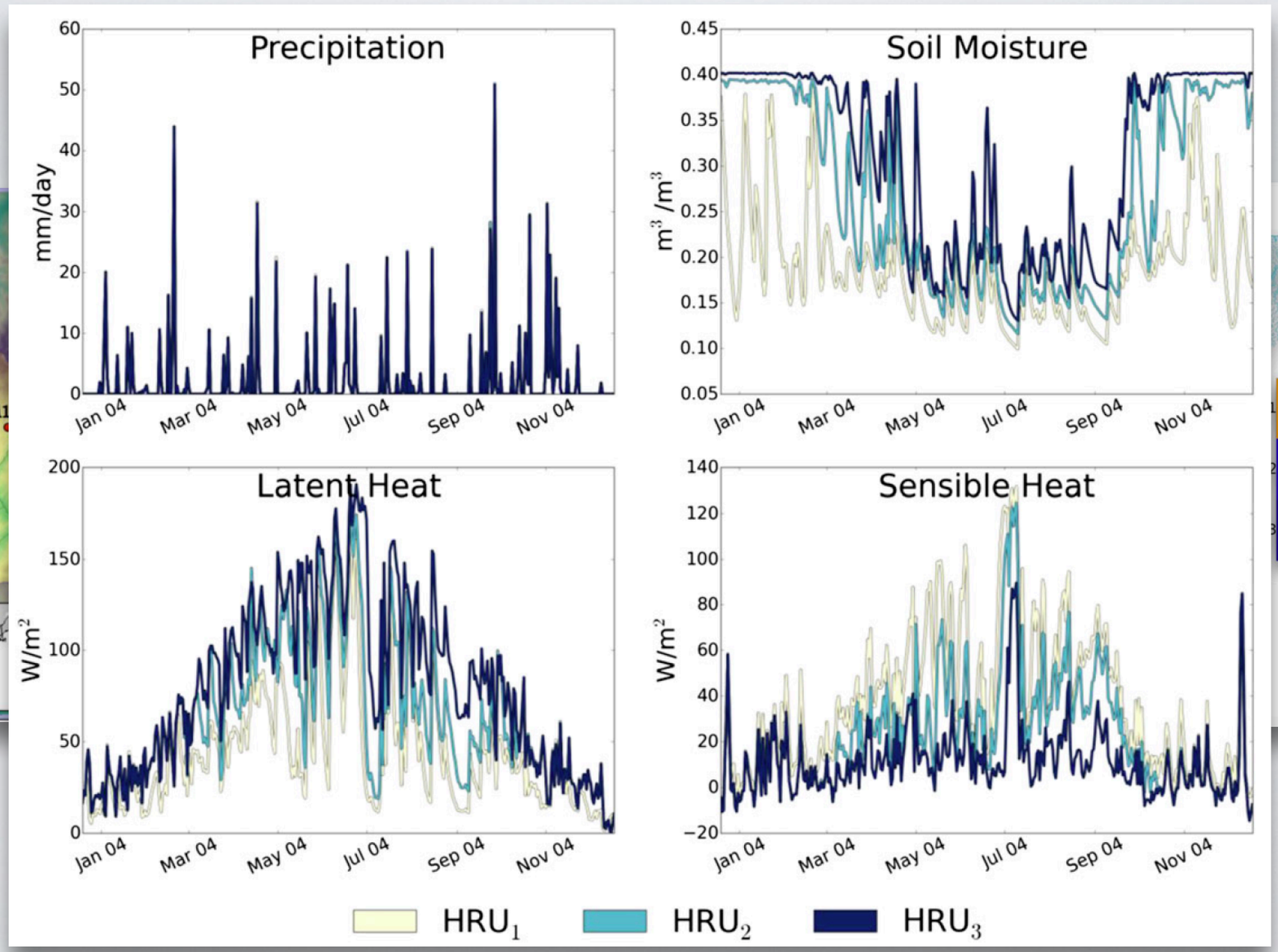

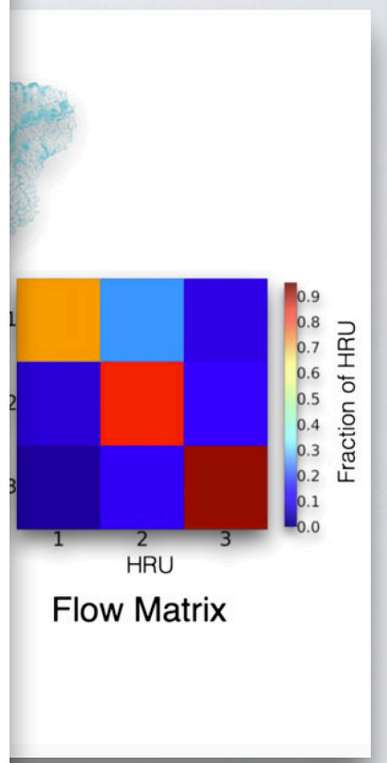

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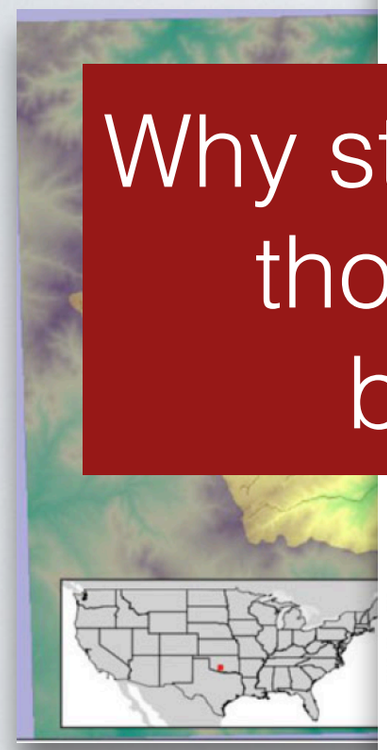
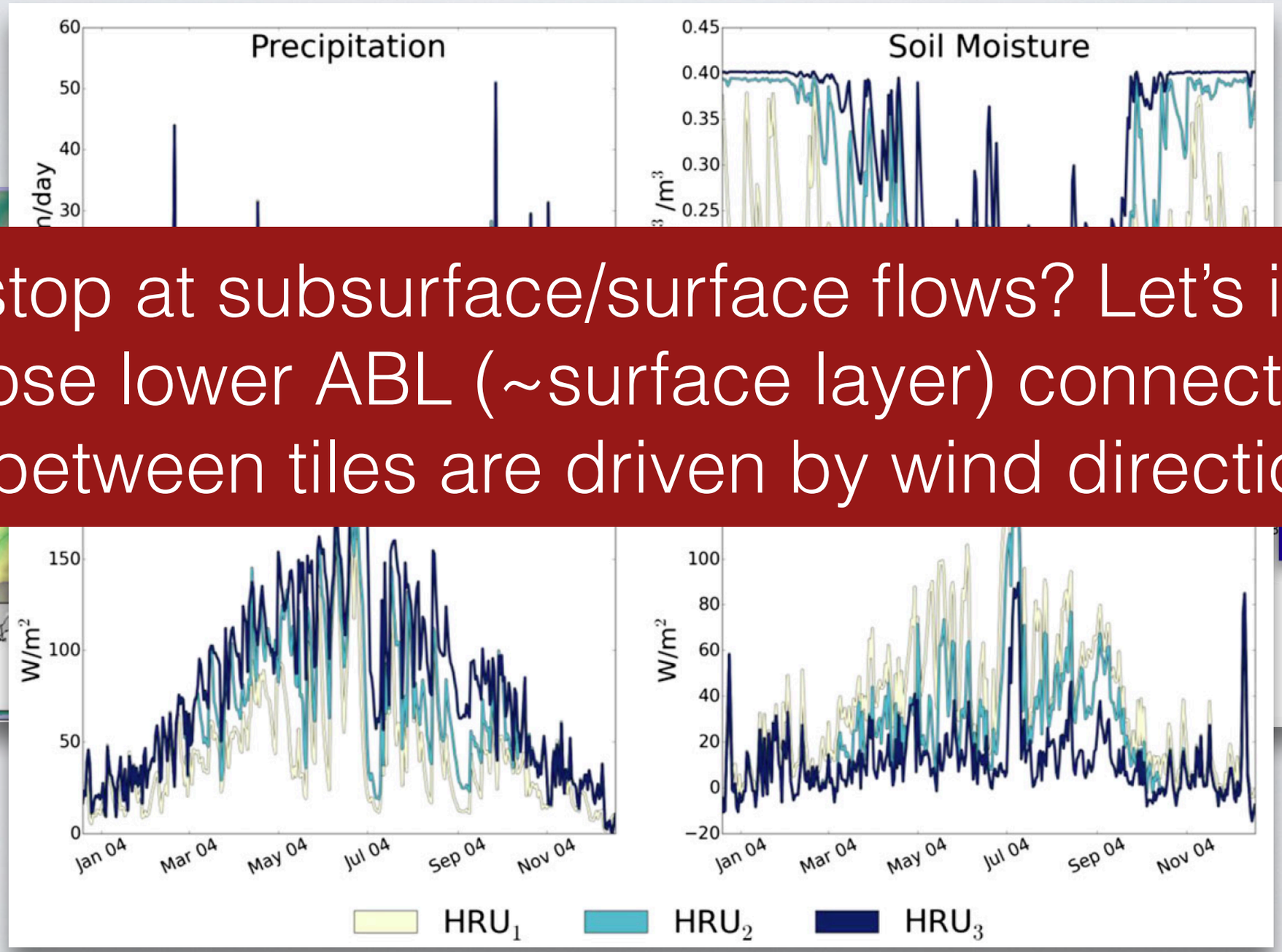
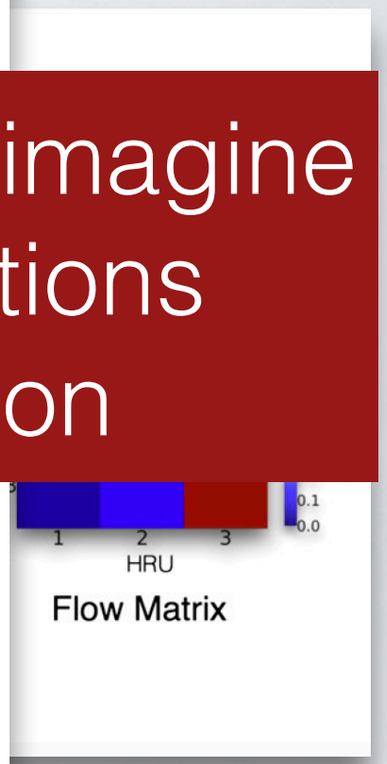
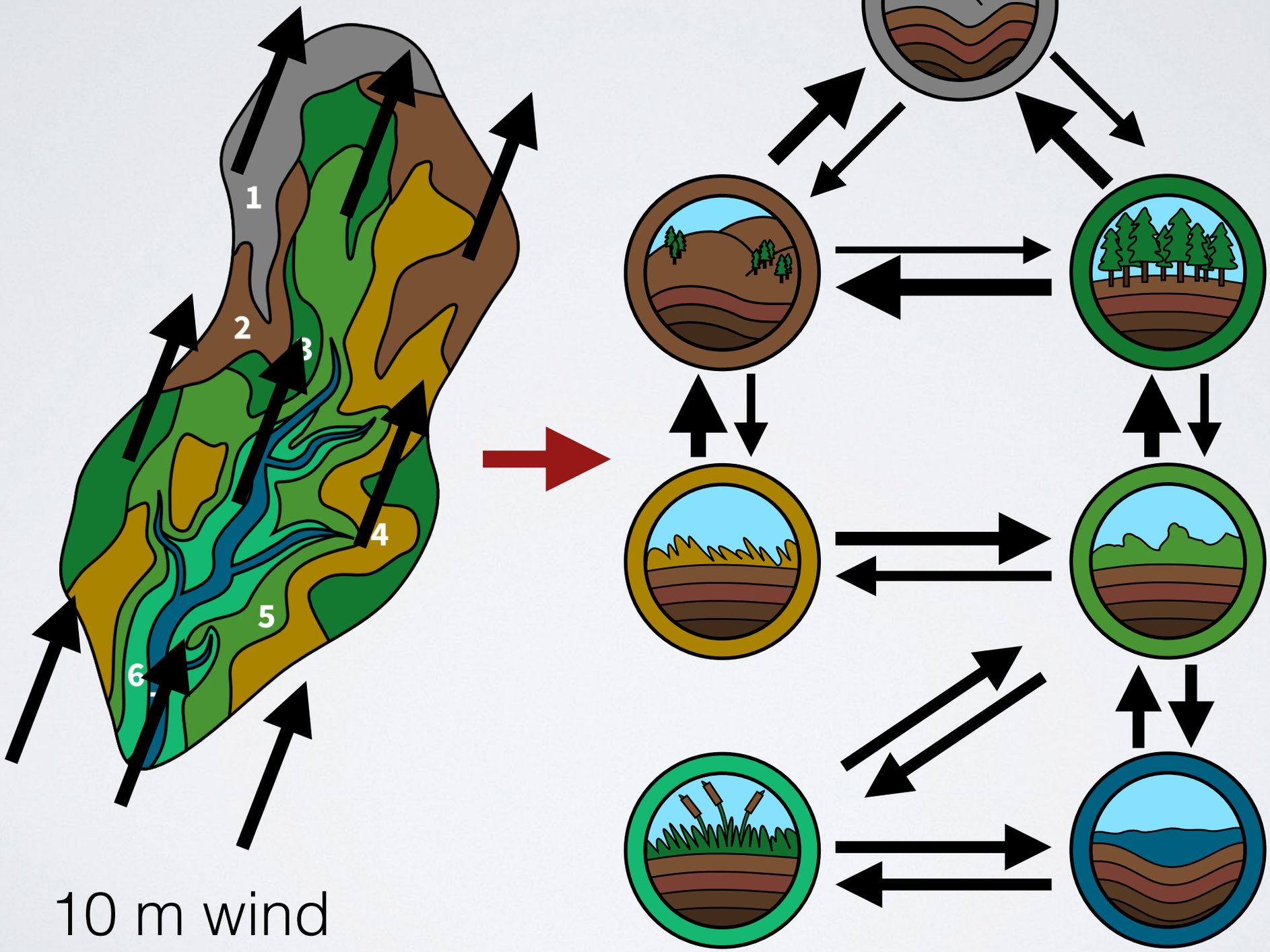






Why stop at subsurface/surface flows? Let's imagine those lower ABL (~surface layer) connections between tiles are driven by wind direction

7) Intra-cell sub-grid tile connections III



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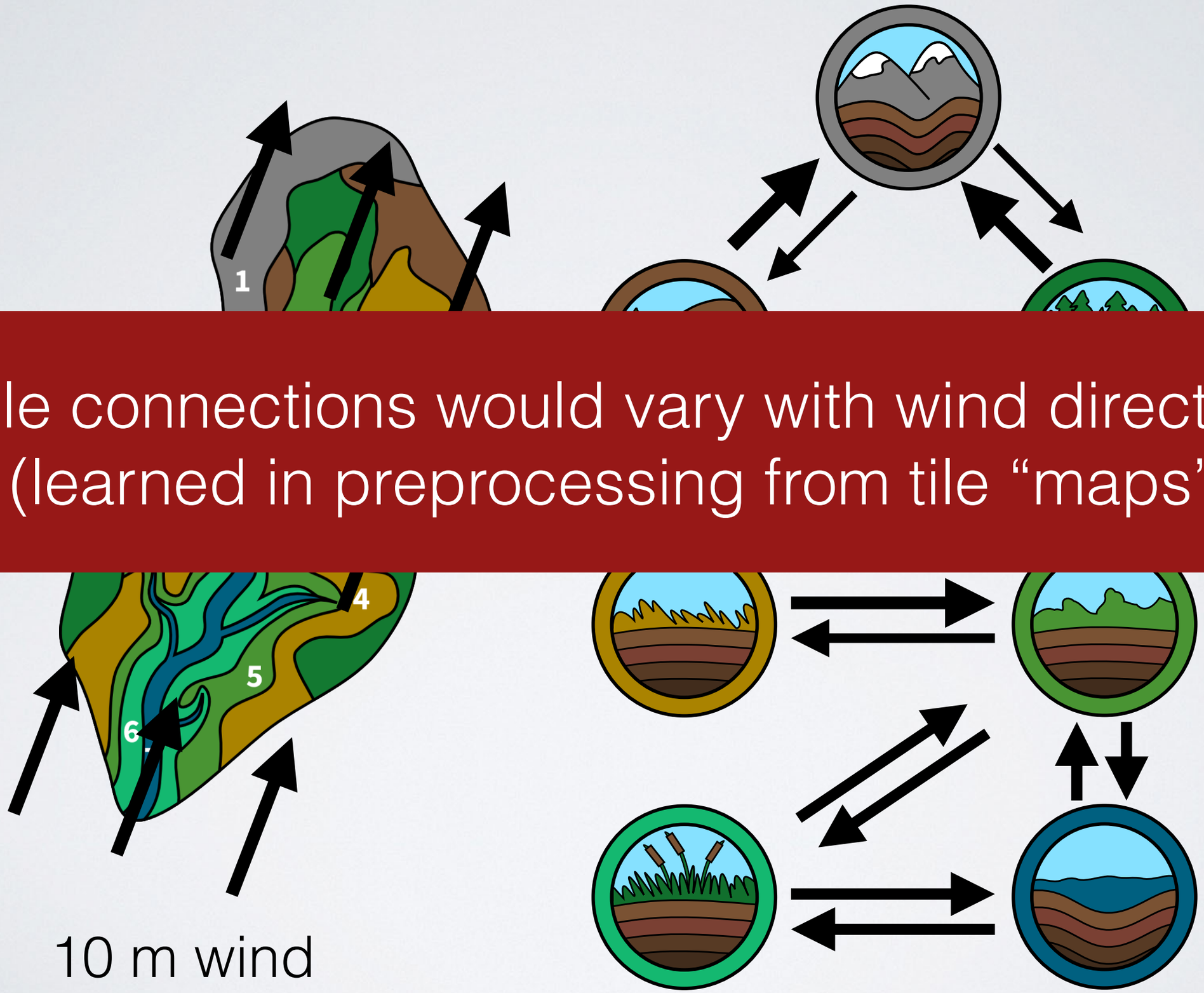
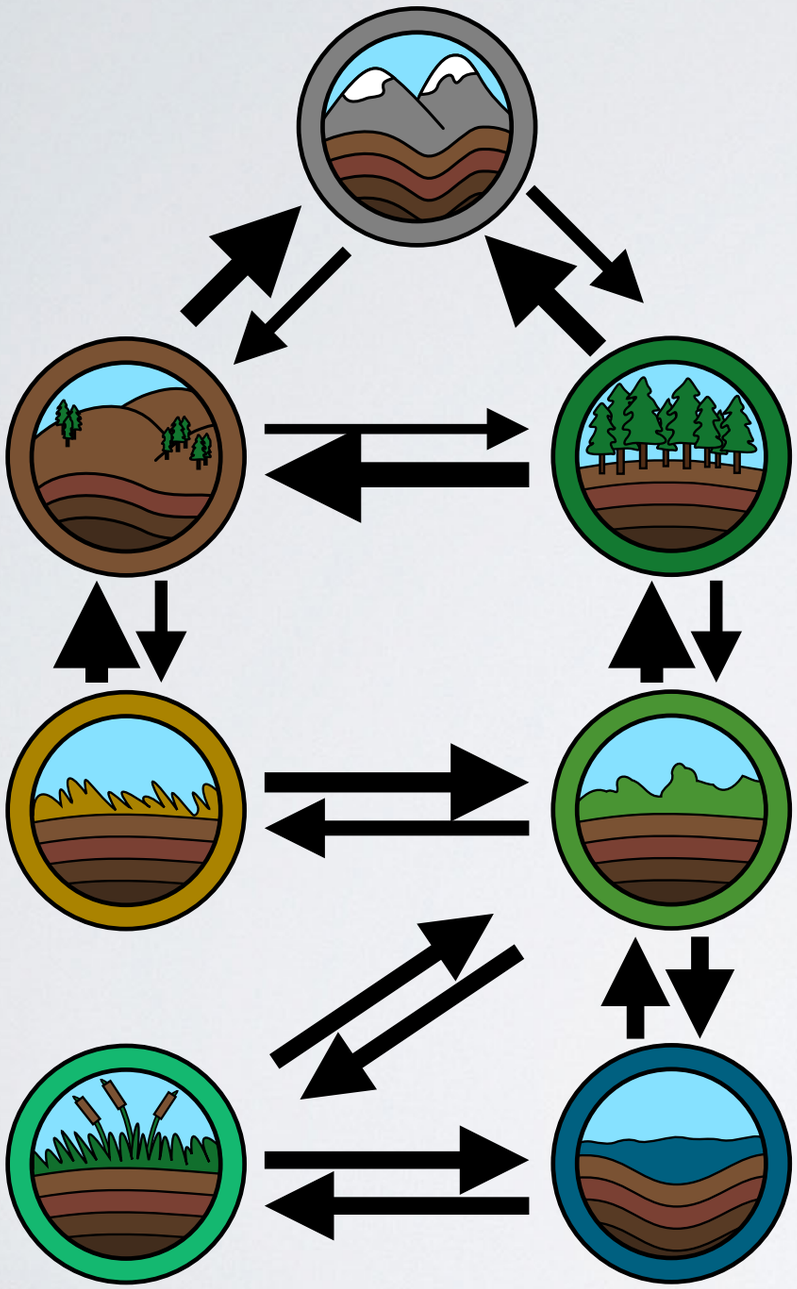


Tile connections would vary with wind direction (learned in preprocessing from tile “maps”)

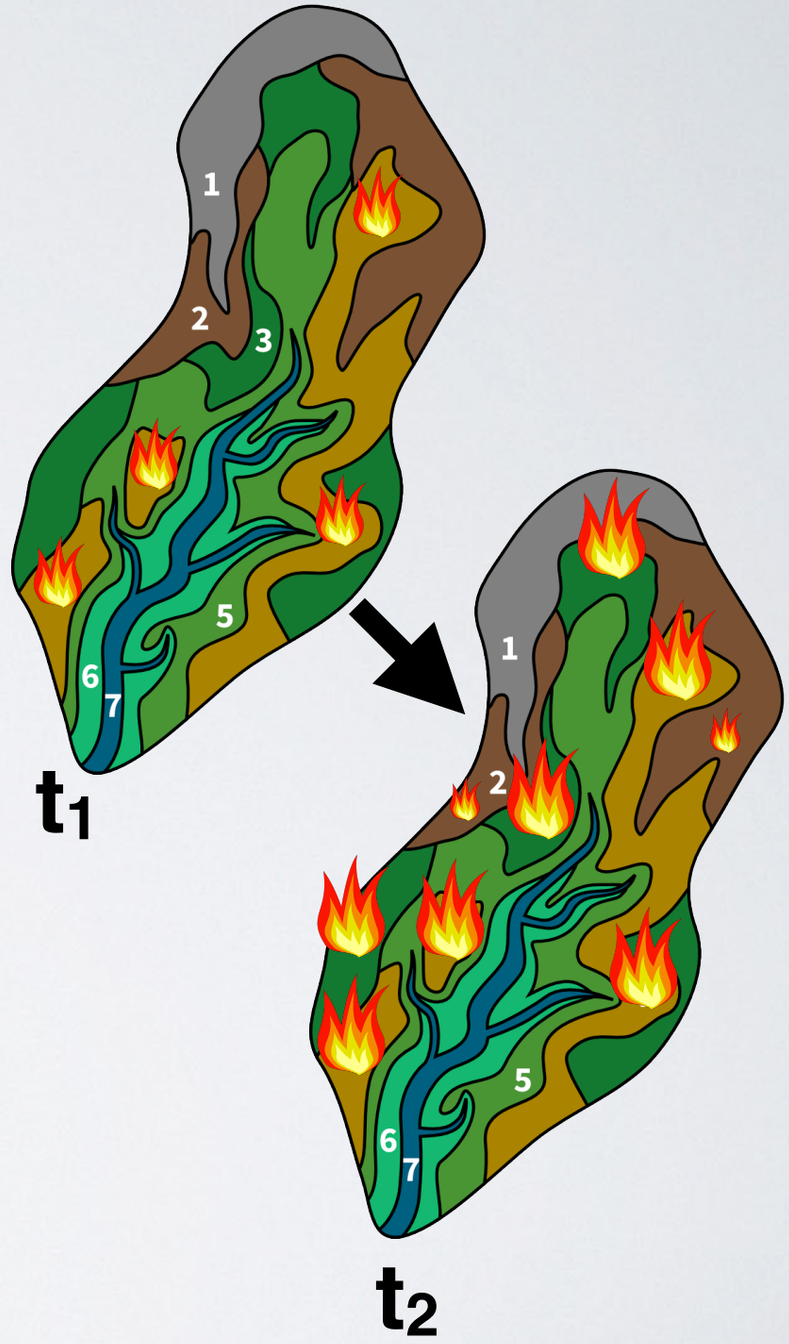
10 m wind

7) Intra-cell sub-grid tile connections IV



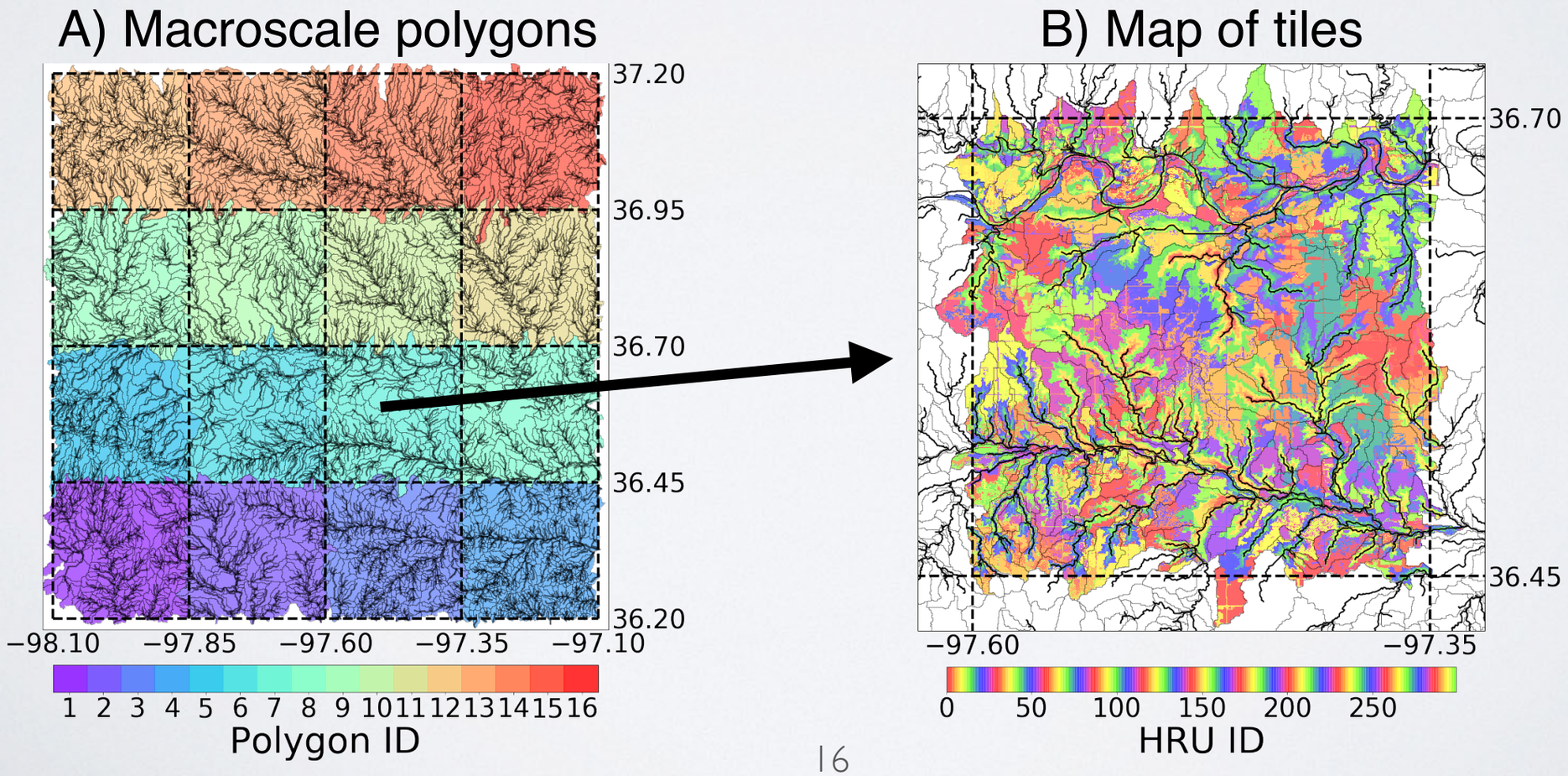
<u>Potential applications?</u>

- Fire
- Blowing snow
- Dust emission/ deposition
- Nutrient transport
- Advection of heat and moisture
- …



8) Inter-cell sub-grid tile connections

- The scale separation of grid/sub-grid breaks is not as clean as we would like
- This becomes more of an issue at higher resolutions (e.g., 10 km grid)
- This will matter for routing, land-atmosphere interactions, groundwater…
- Similar to sub-grid, the connections of tiles across grid cells can be learned in preprocessing (assuming we save the maps of clusters/tiles).
- Caution: The computational complexity that this would add (e.g., MPI message complexity) is doable but certainly not trivial



Ideas for next-generation tiling

1. Recast tiling as a clustering exercise
2. Leverage clustering approaches to “map” the tile results for applications/evaluation
3. Derive optimal tile configurations per LSM grid cell
4. Evaluate (more objectively) simulated sub-grid heterogeneity
5. Improve interactions between sub-grid land and atmosphere
6. Intertwine routing and tiling schemes
7. Intra-cell sub-grid tile connections
8. Inter-cell sub-grid tile connections