A Proposed Model Development Strategy to Incorporate 3-D Subsurface Hydrologic and Thermal Processes within the Community Land Model

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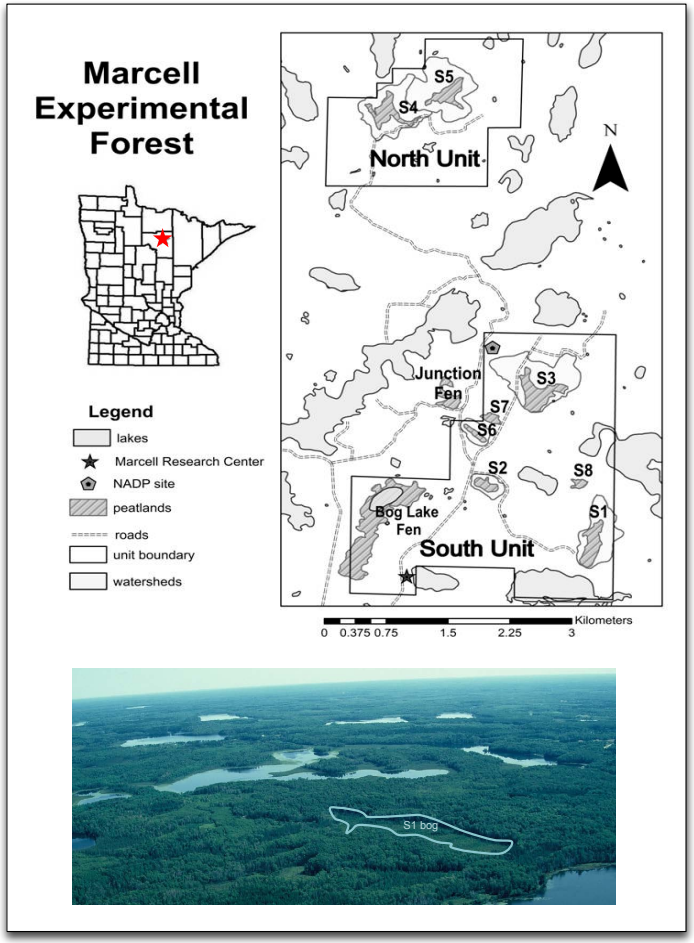
CCSM Land Model Working Group
29, February, 2012

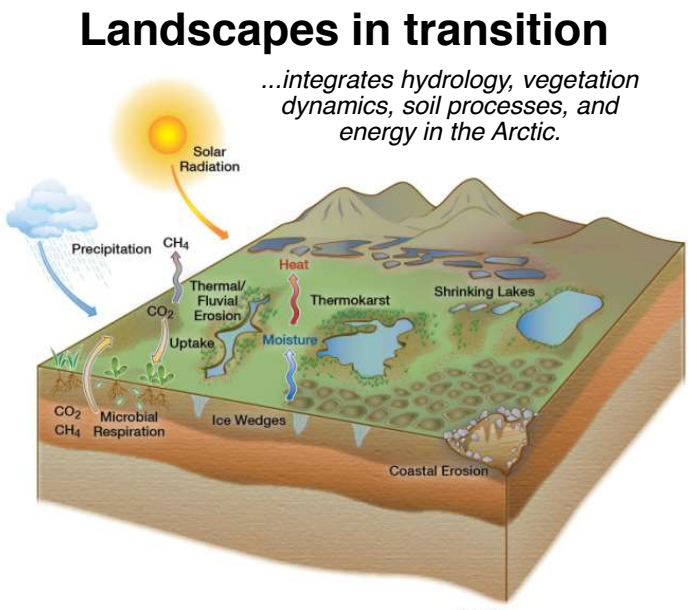
Motivation

- Assess the response of northern peatland ecosystems to increases in temperature and exposures to elevated CO_2 concentrations (SPRUCE project).



Credit: Sebestyen et. al, 8th Annual Forestry, Wildlife and Natural Resource Research Review, 2011

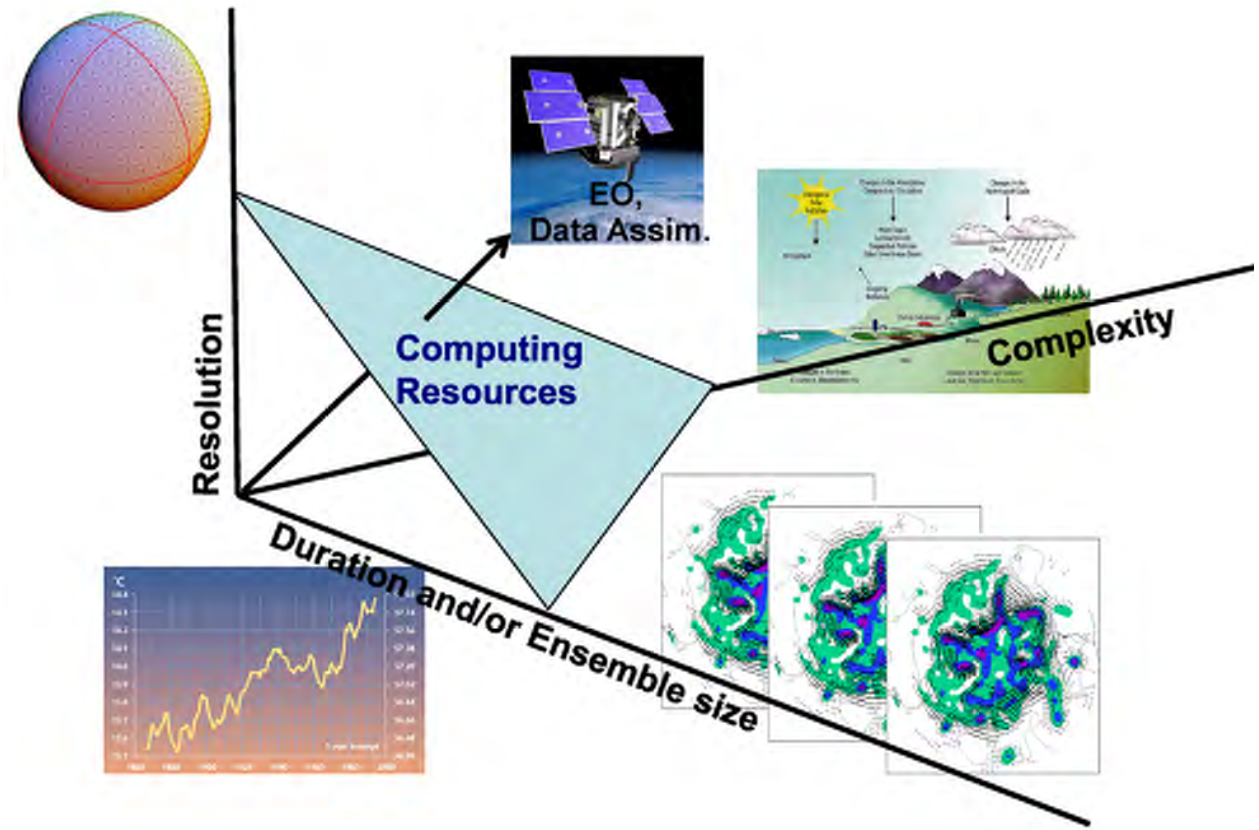
Motivation



Source: http://ngee.ornl.gov

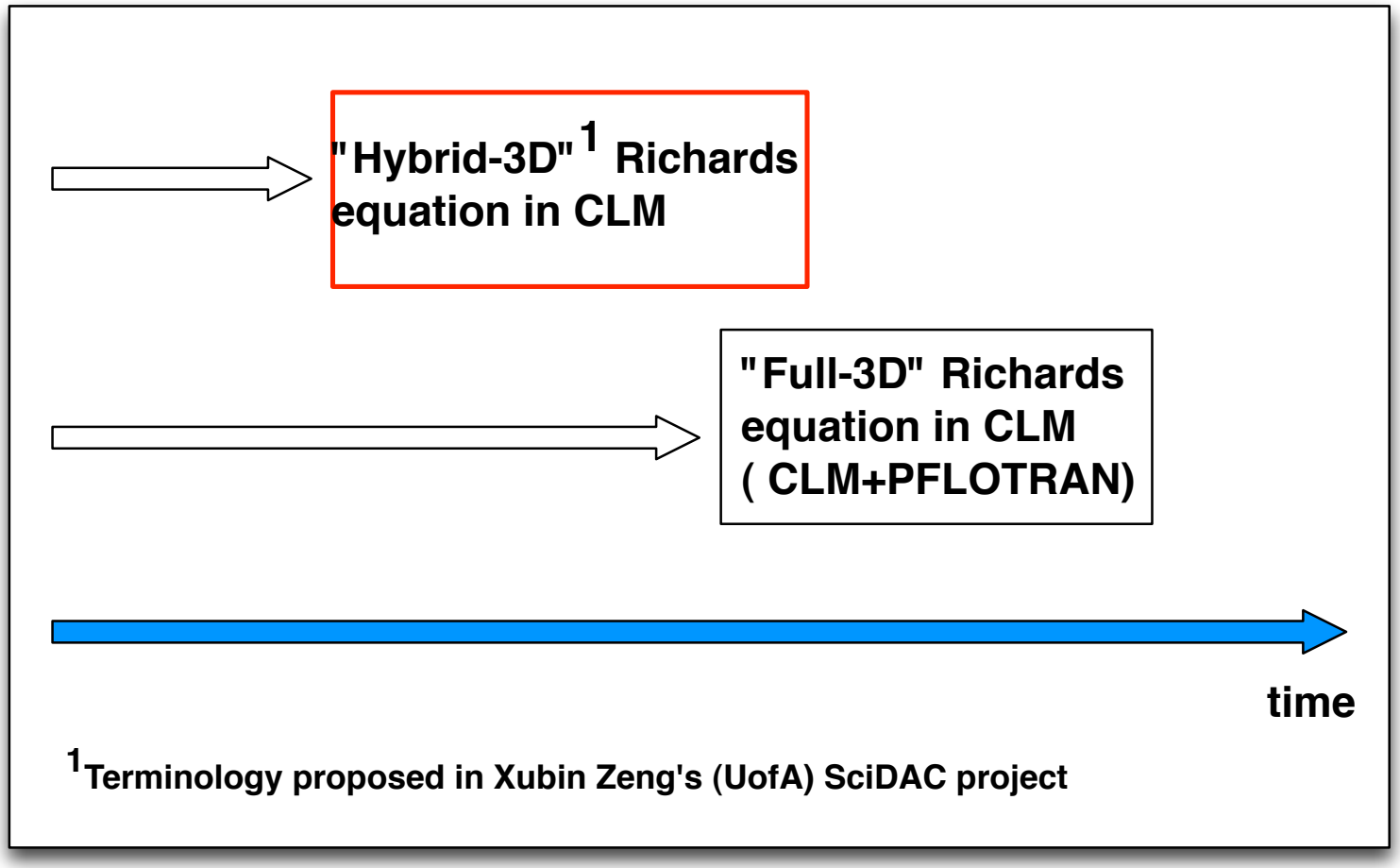
- "How does permafrost degradation, and the associated changes in landscape evolution, hydrology, soil biogeochemical processes, and plant community succession, affect feedbacks to the climate system" (Next- Generation Ecosystem Experiments: NGEE Arctic)

Motivation



Credit: DOE ASCR report - Challenges in Climate Change Science and the Role of Computing at the Extreme Scale, 2008.

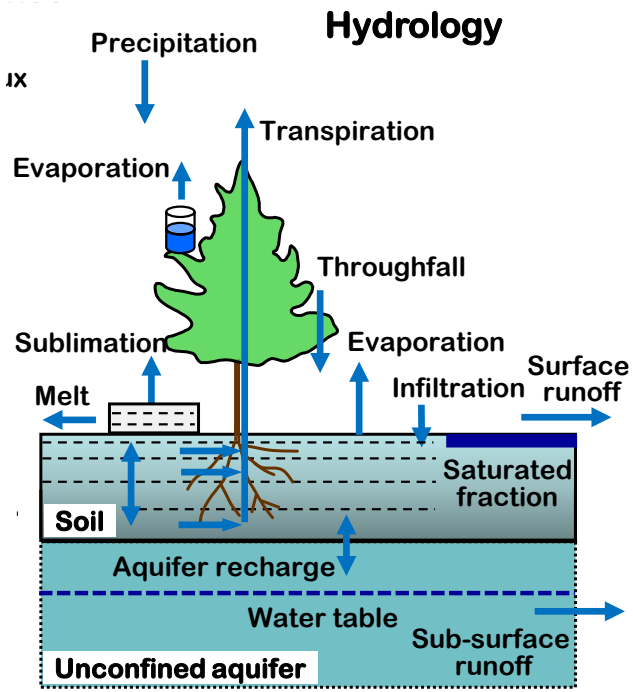
Model development pathways



Model development pathways: Lateral flows within CLM

- Richards equation in CLM-4.0

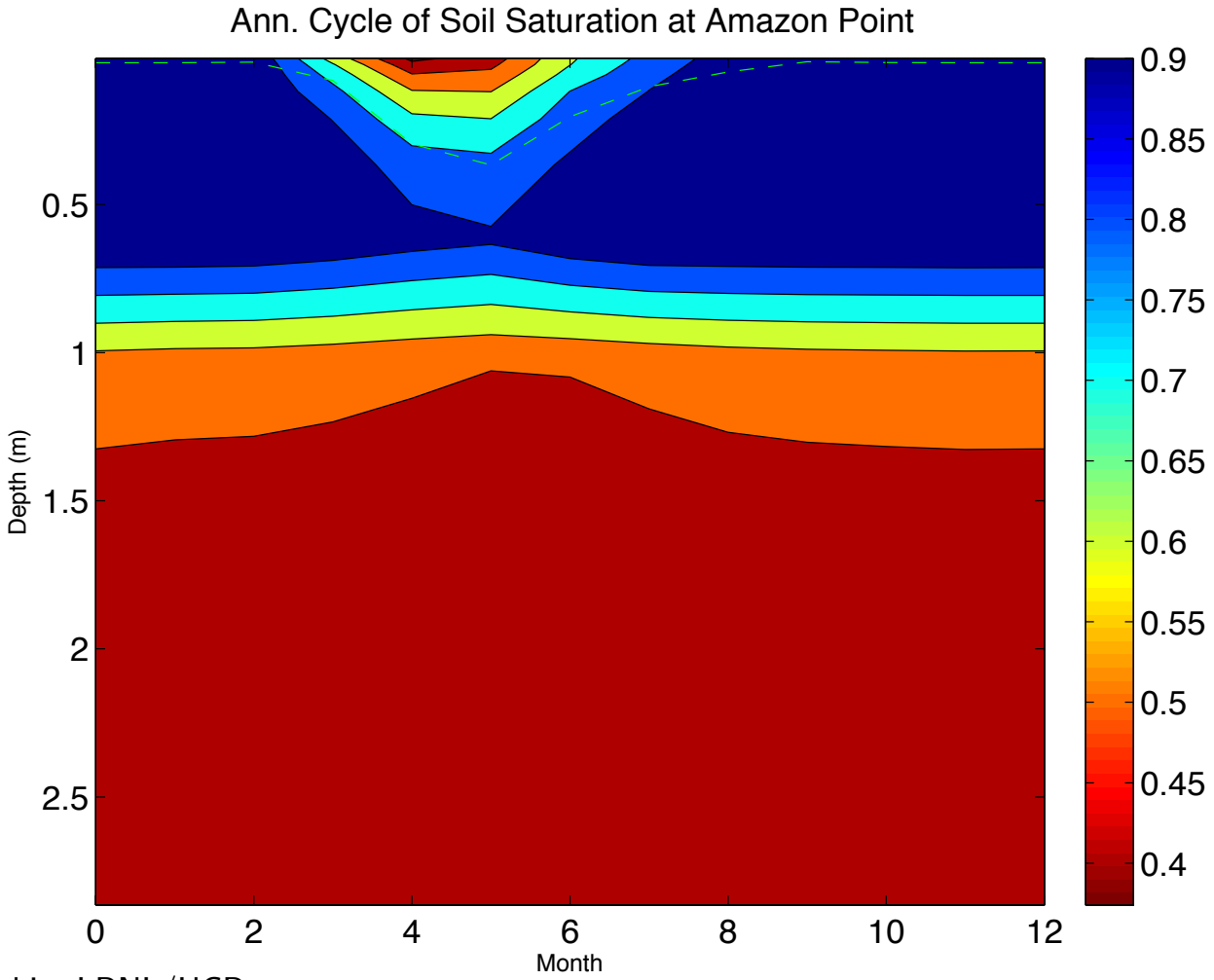
$$\frac{\partial \theta}{\partial t} = -\frac{\partial q_z}{\partial z} - Q \quad (1)$$



- Richards equation: With lateral flows

$$\frac{\partial \theta}{\partial t} = -\frac{\partial q_z}{\partial z} - Q - \frac{\partial q_x}{\partial x} - \frac{\partial q_y}{\partial y} \quad (2)$$

Shortcoming of unsaturated-saturated zone interaction in CLM4.0



Credit: Zack Subin, LBNL/UCB.

Model development pathways: Lateral flows within CLM

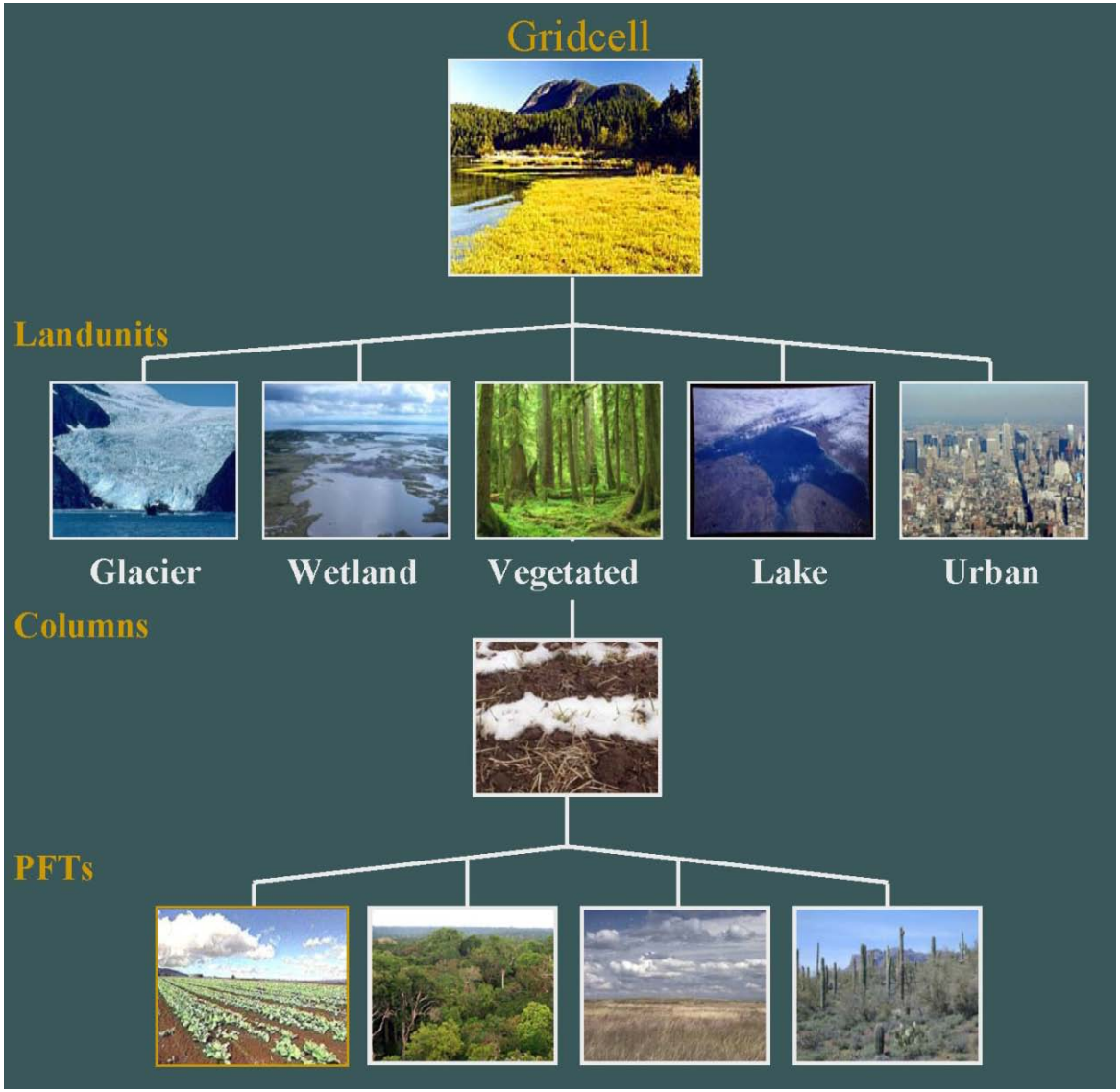
- Proposed variably saturated flow equation with lateral flow

$$\left(\frac{\theta S_y}{\eta} + C(h)\right)\frac{\partial h}{\partial t} = -\frac{\partial q}{\partial z} - Q - \frac{\partial q_x}{\partial x} - \frac{\partial q_y}{\partial y} \qquad (3)$$

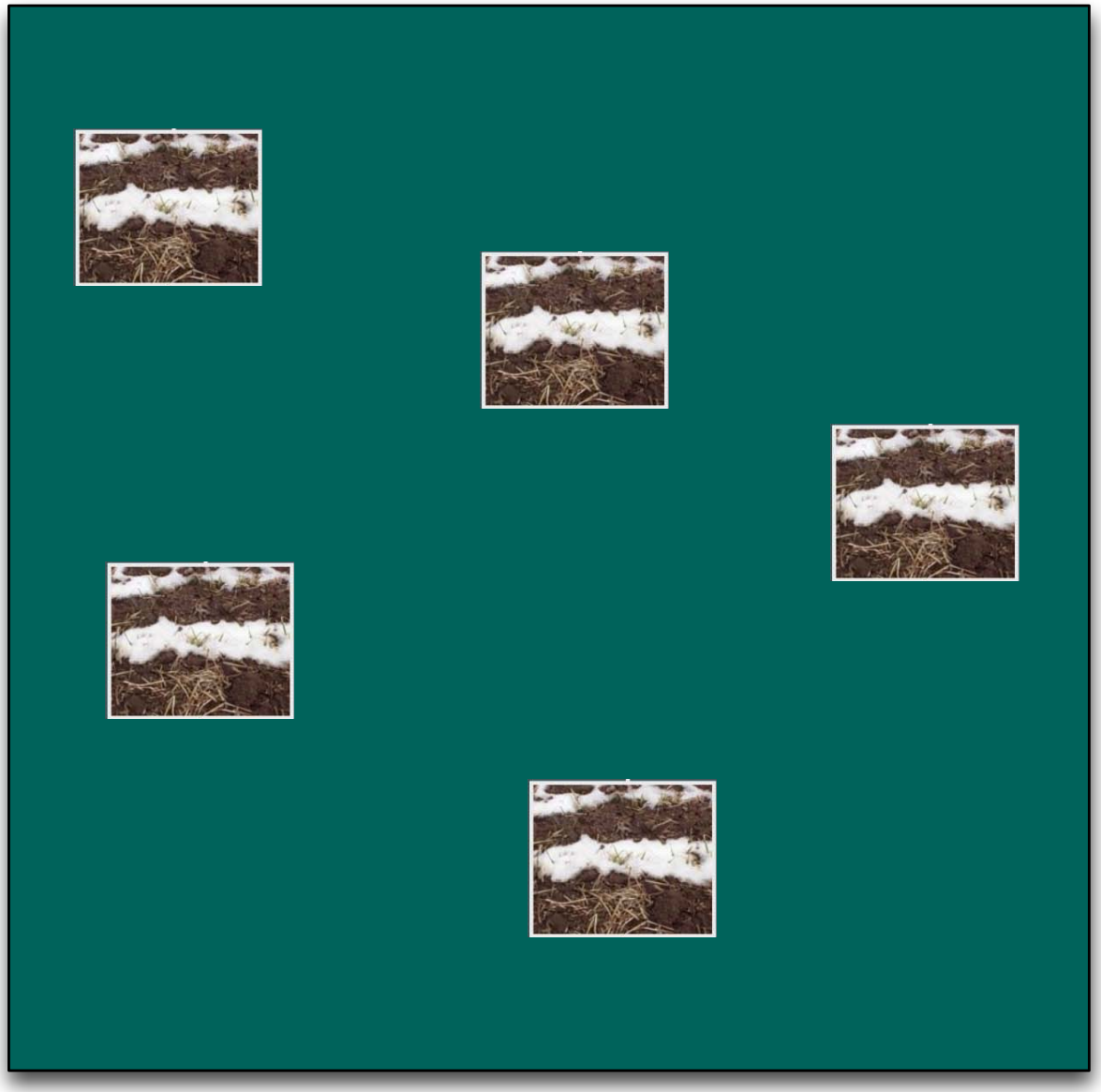
  where $C(h) = \frac{d\theta}{dh}$.

- "Hybrid-3D" equation: Lateral fluxes (q_x, q_y) will be computed from state values (h,θ) of previous time-step.

CLM subgrid representation



CLM subgrid representation: Soil columns



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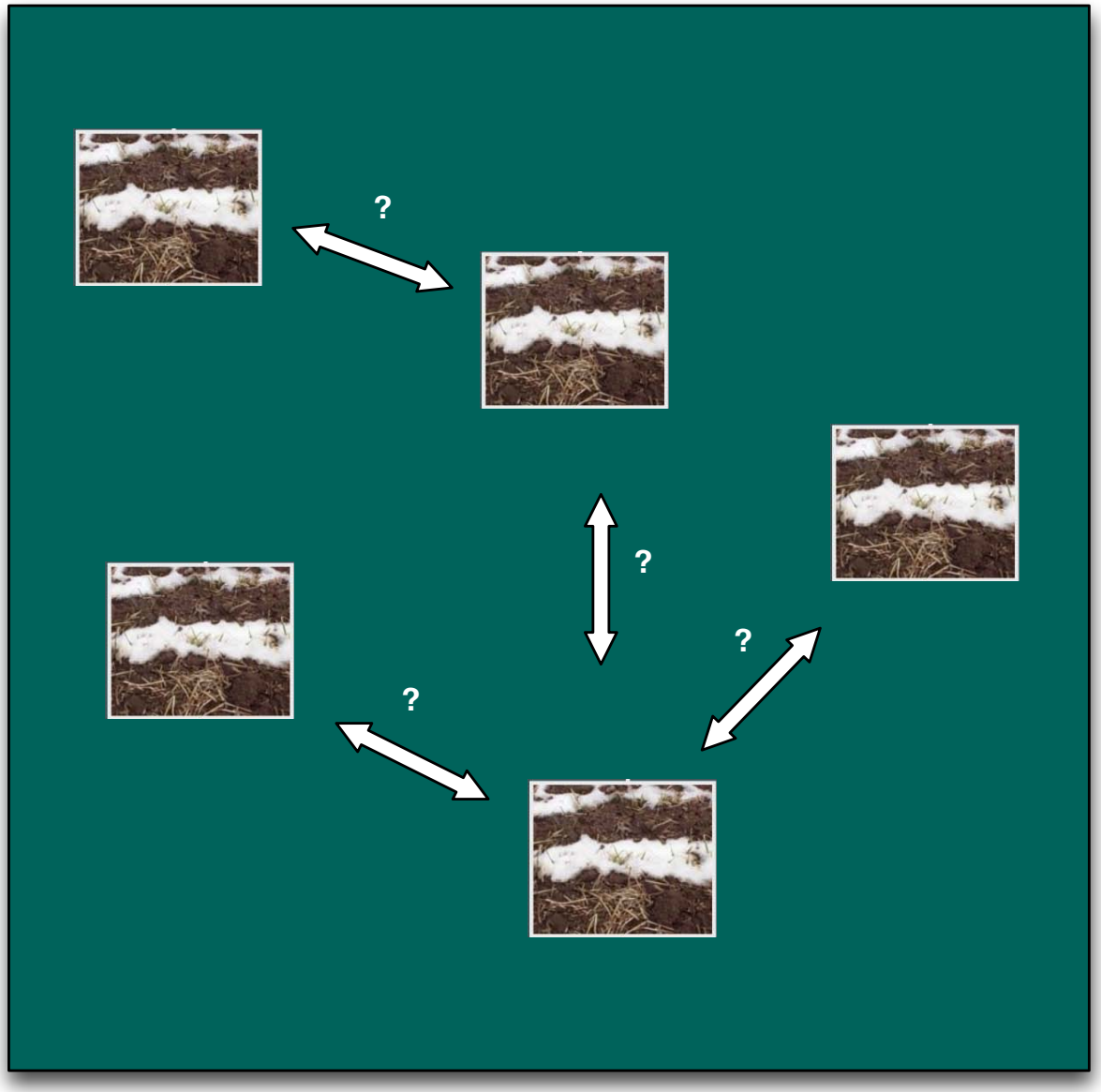

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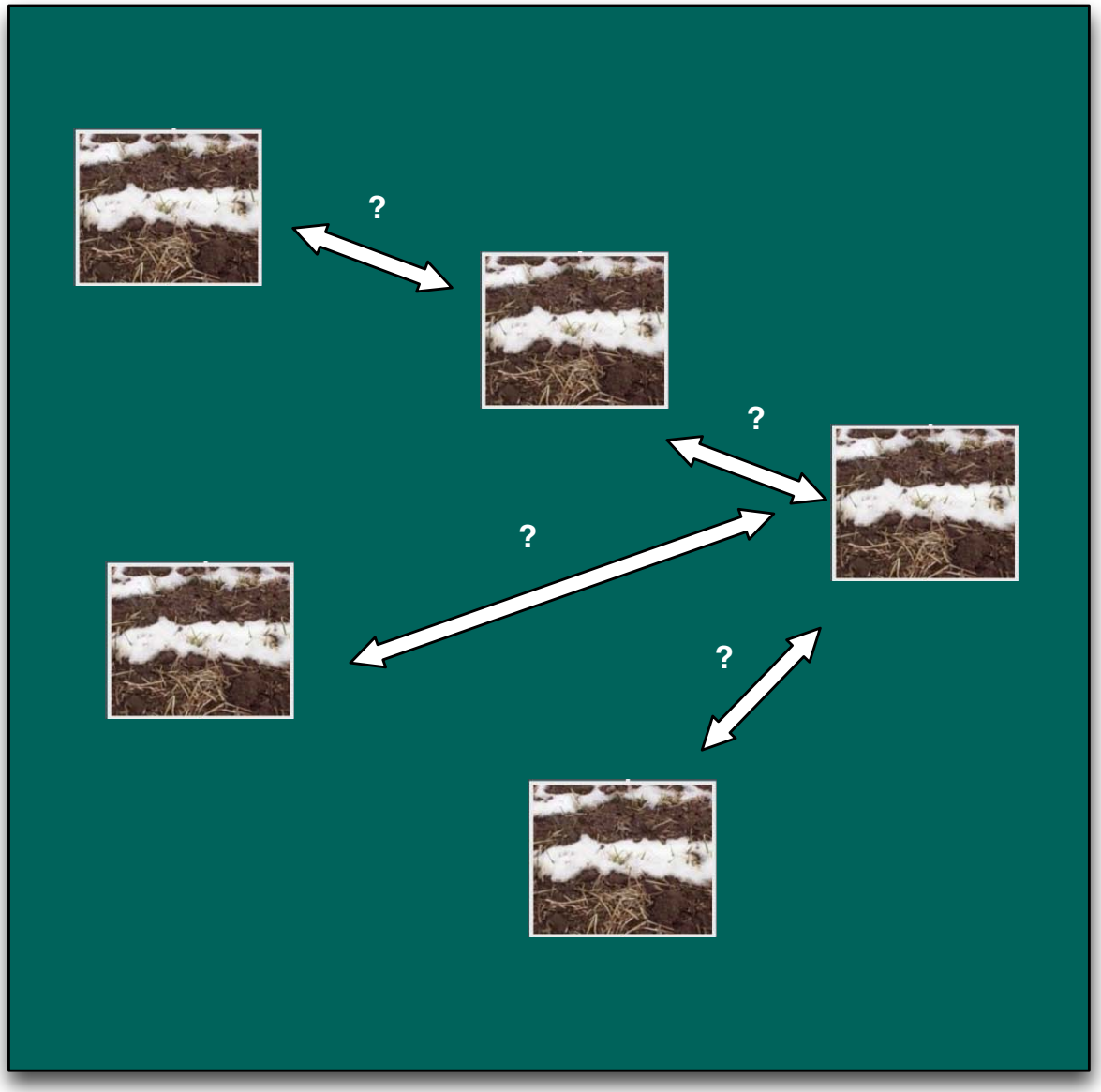

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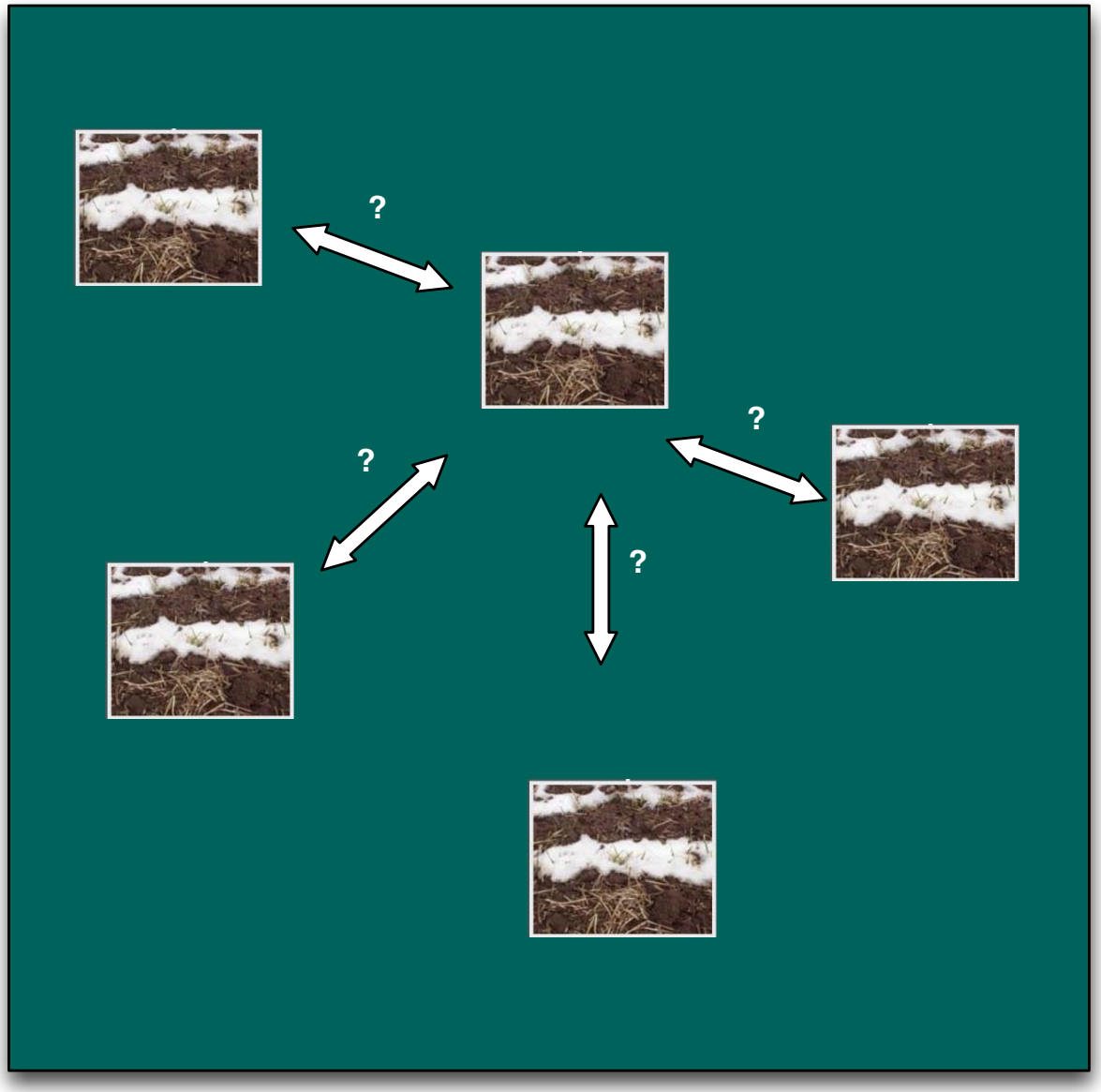
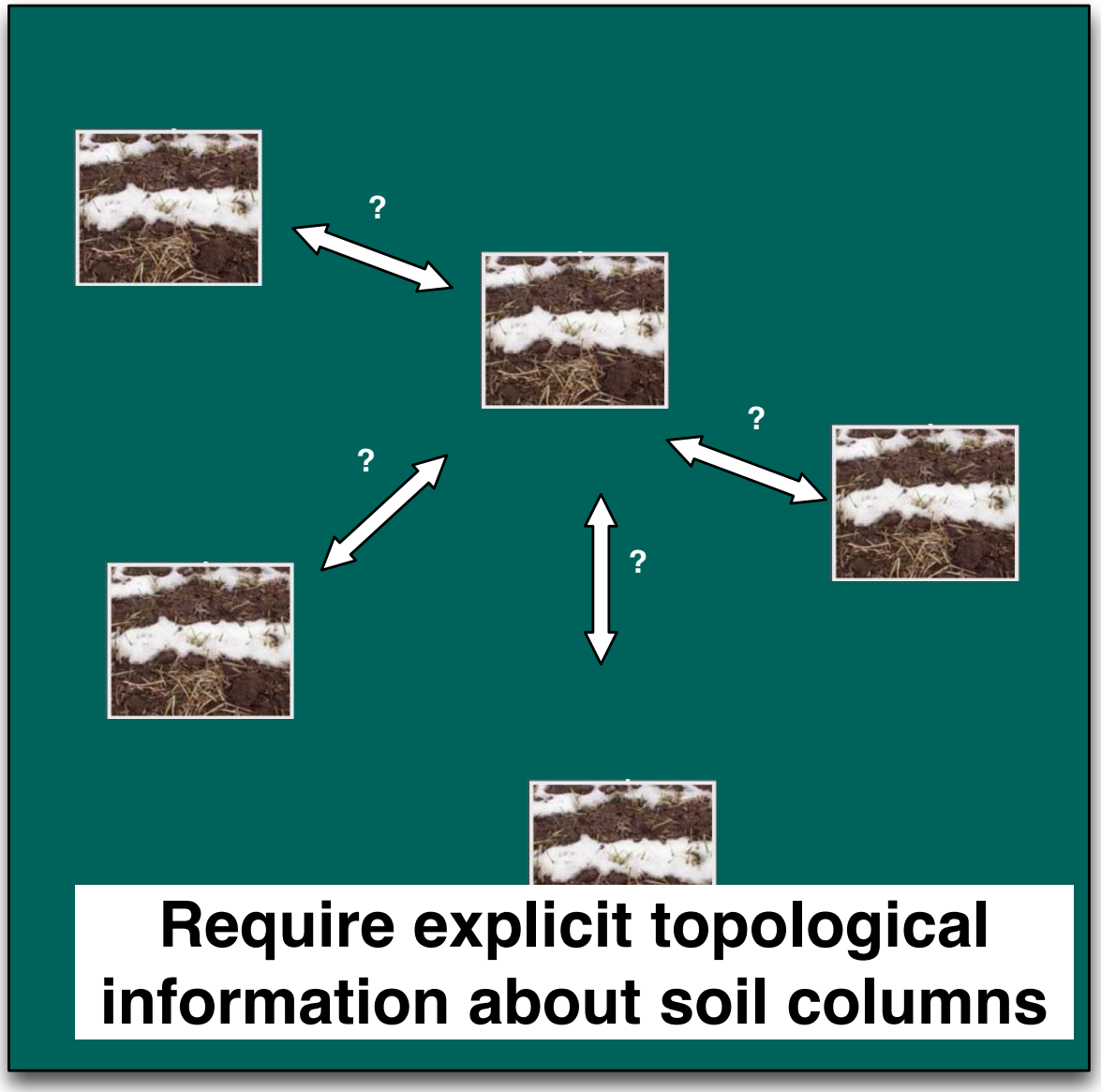
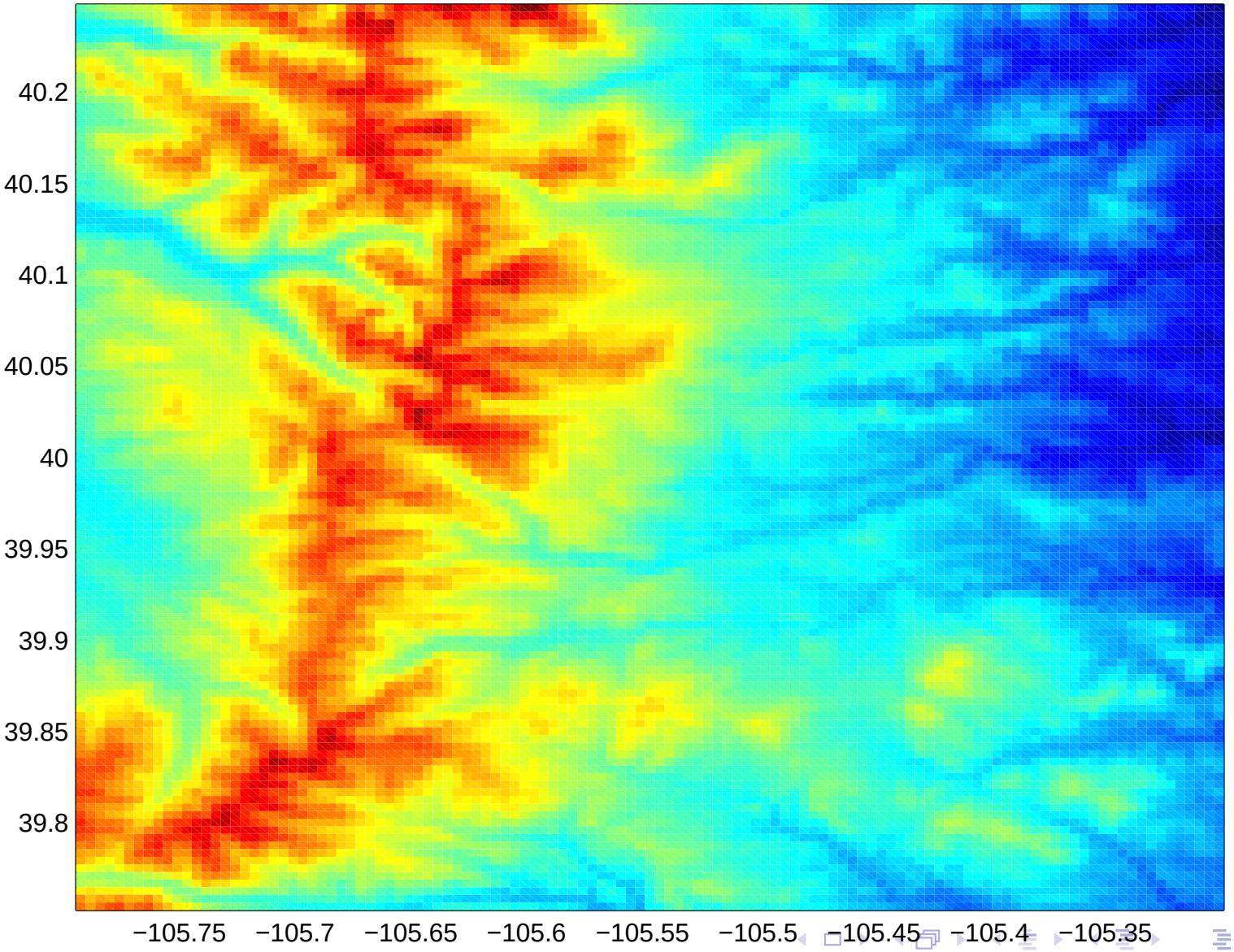


CLM subgrid representation: Soil columns



An example within 0.5° CLM grid



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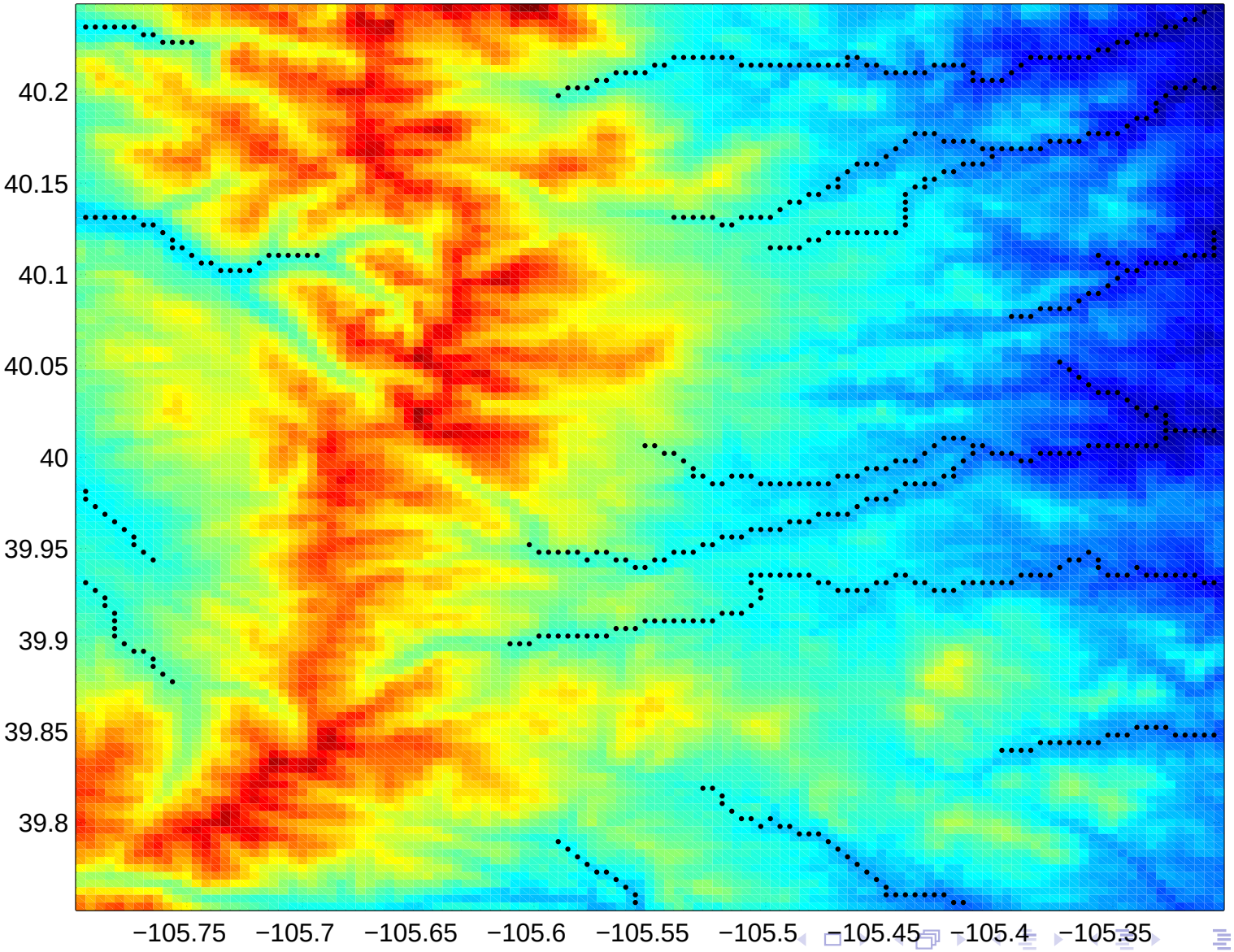

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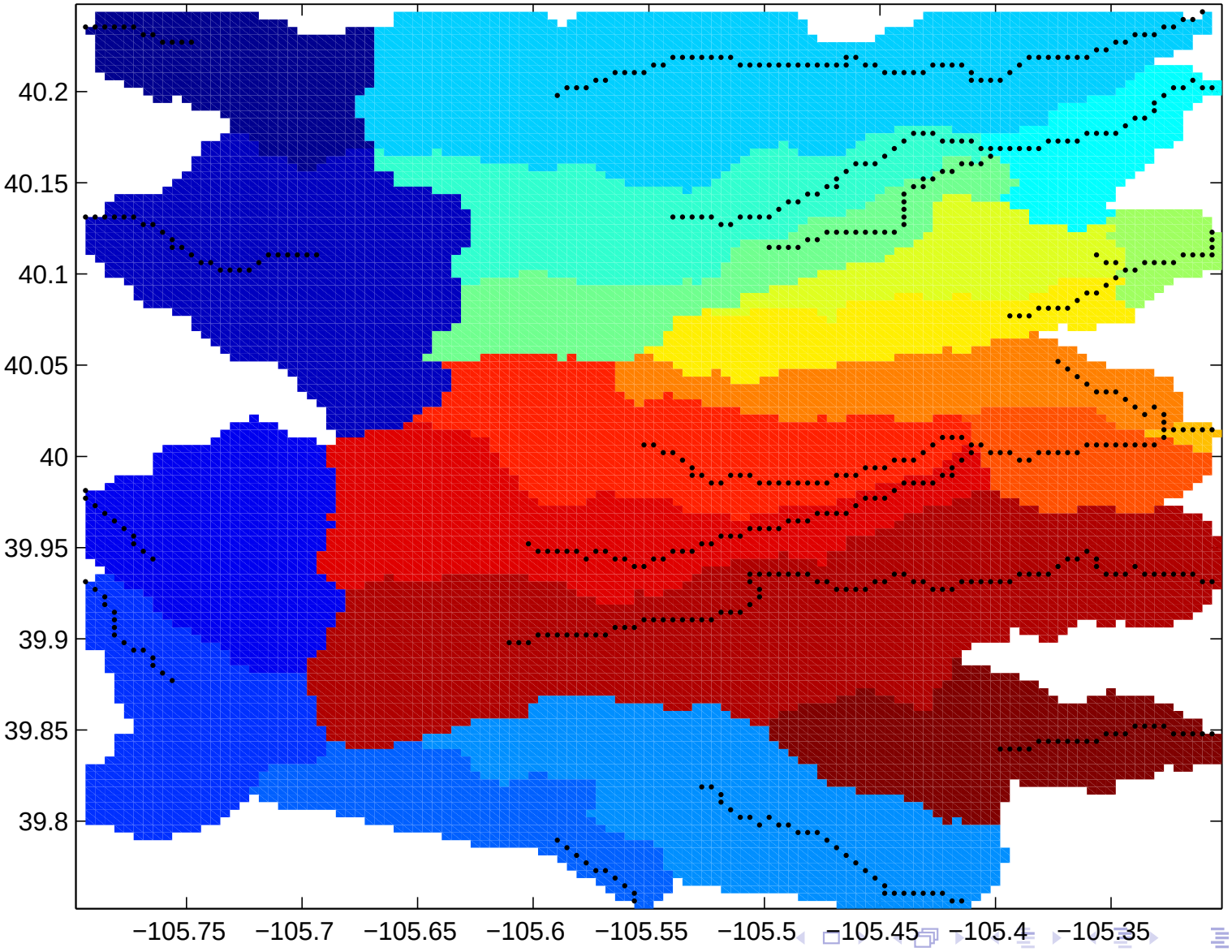

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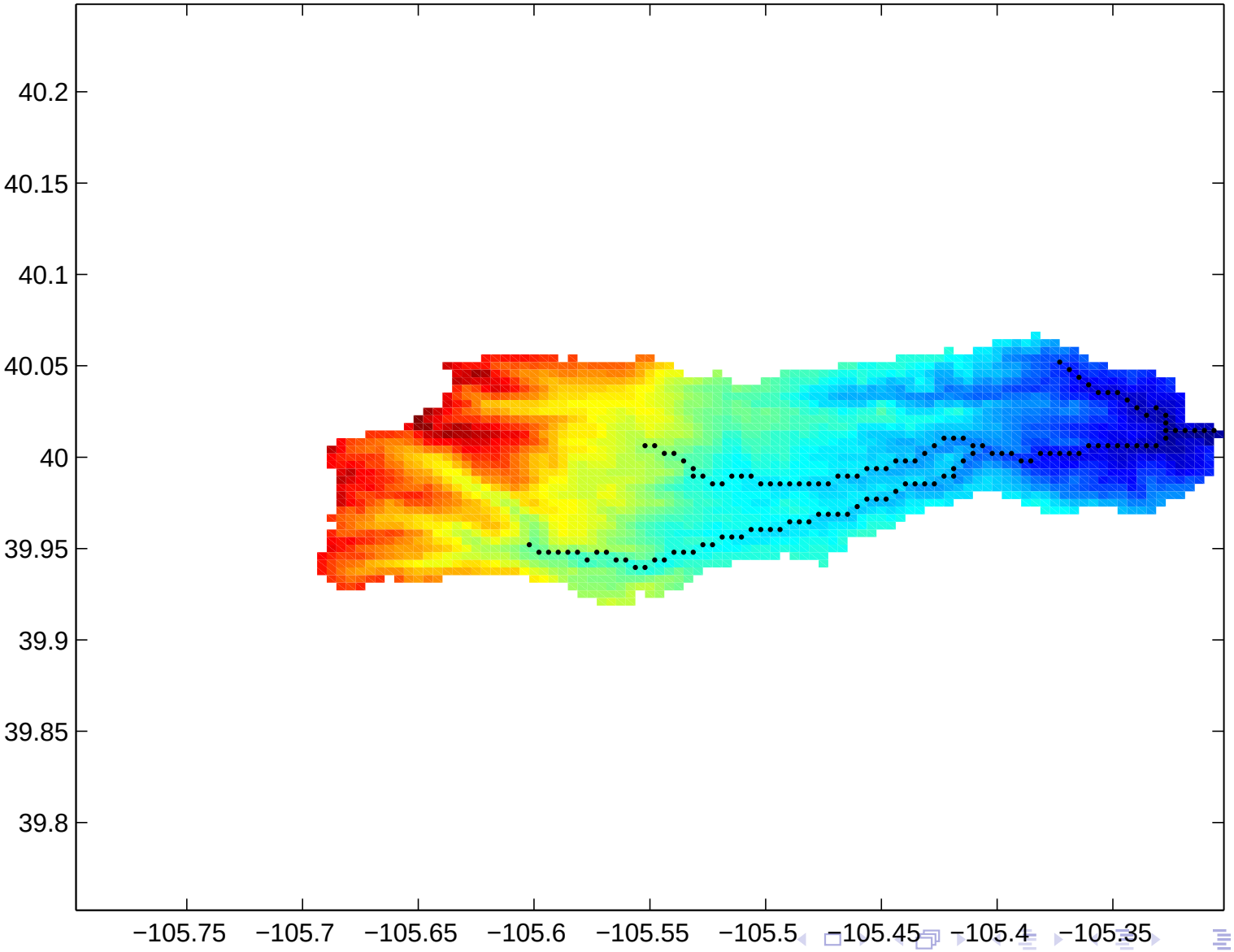

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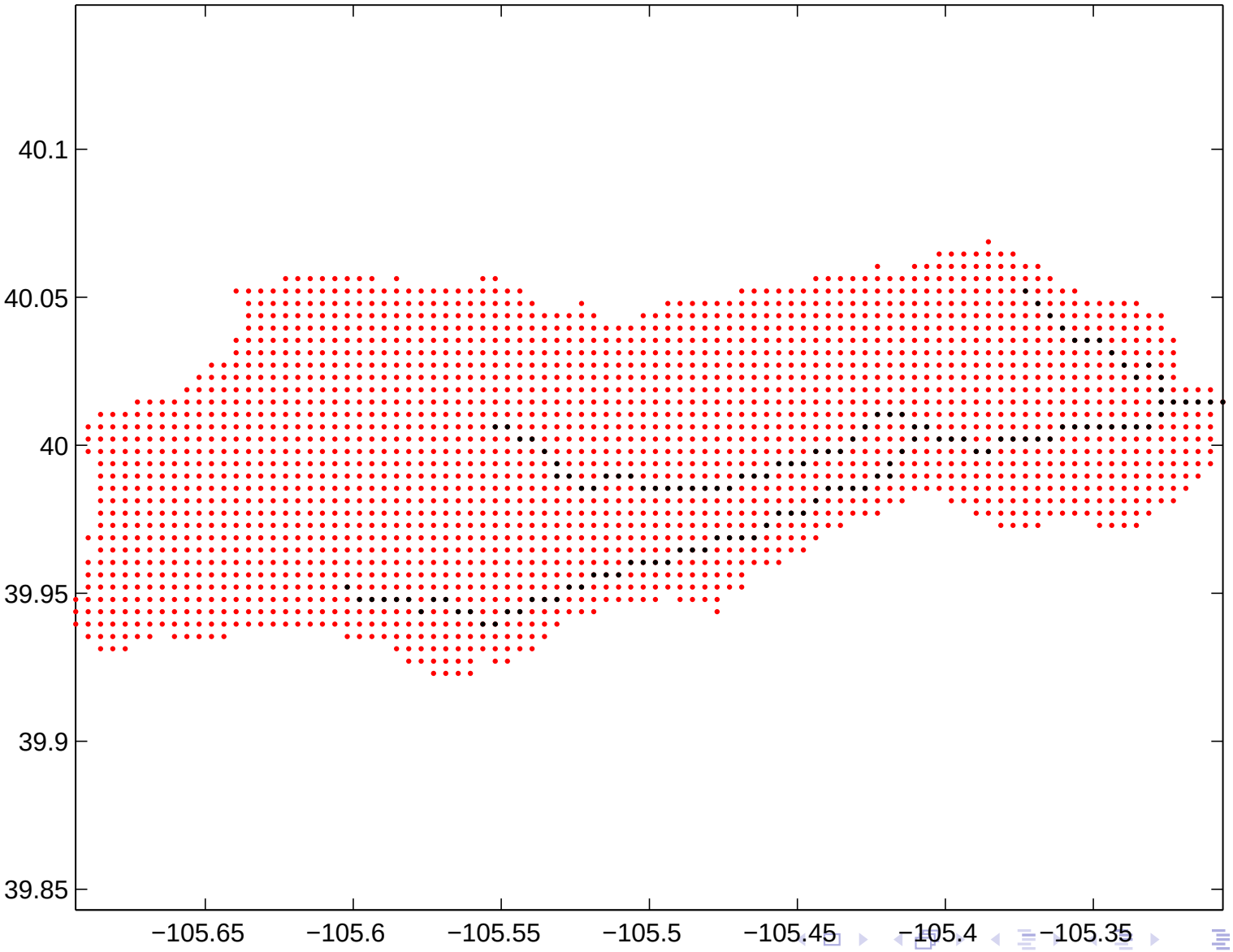

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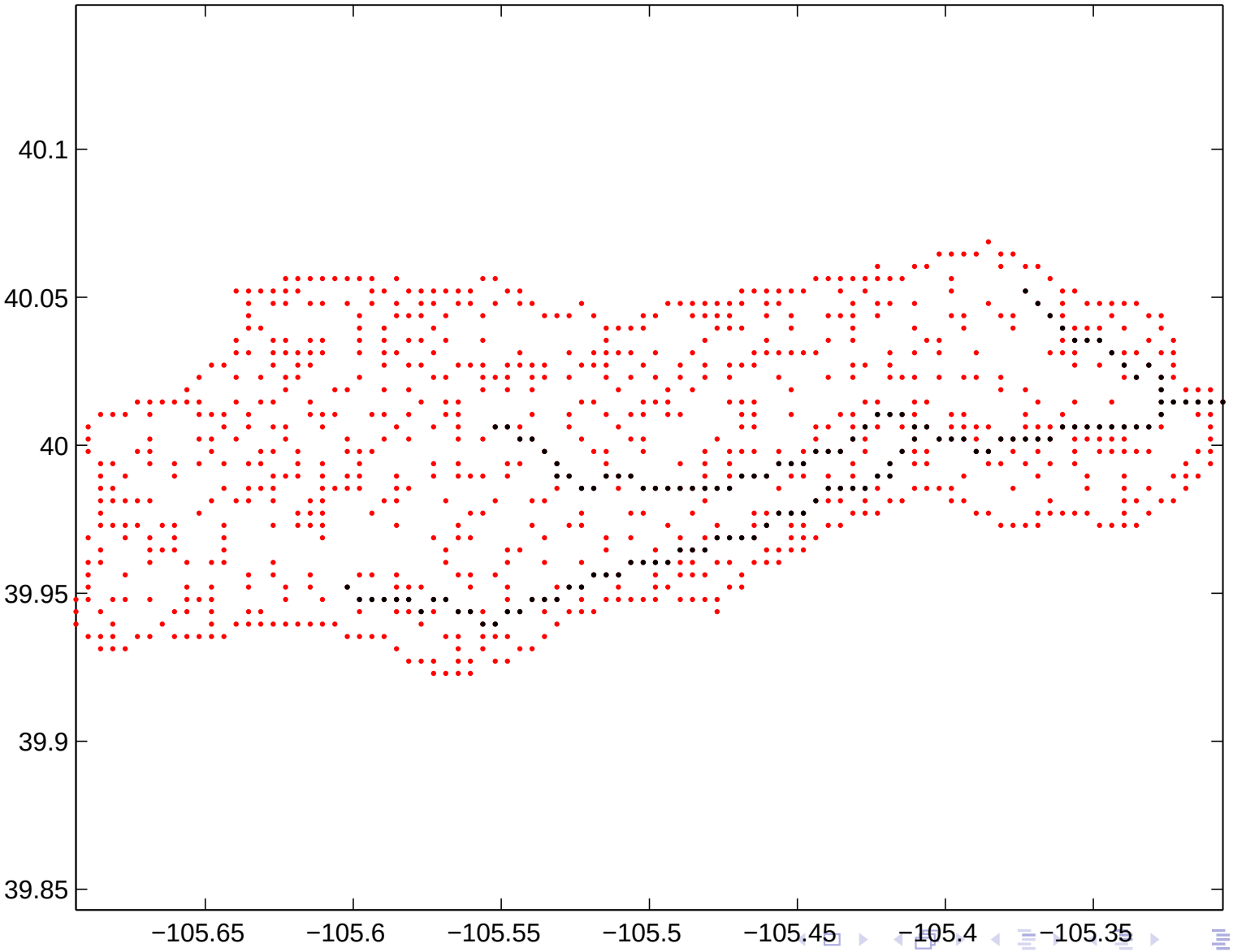

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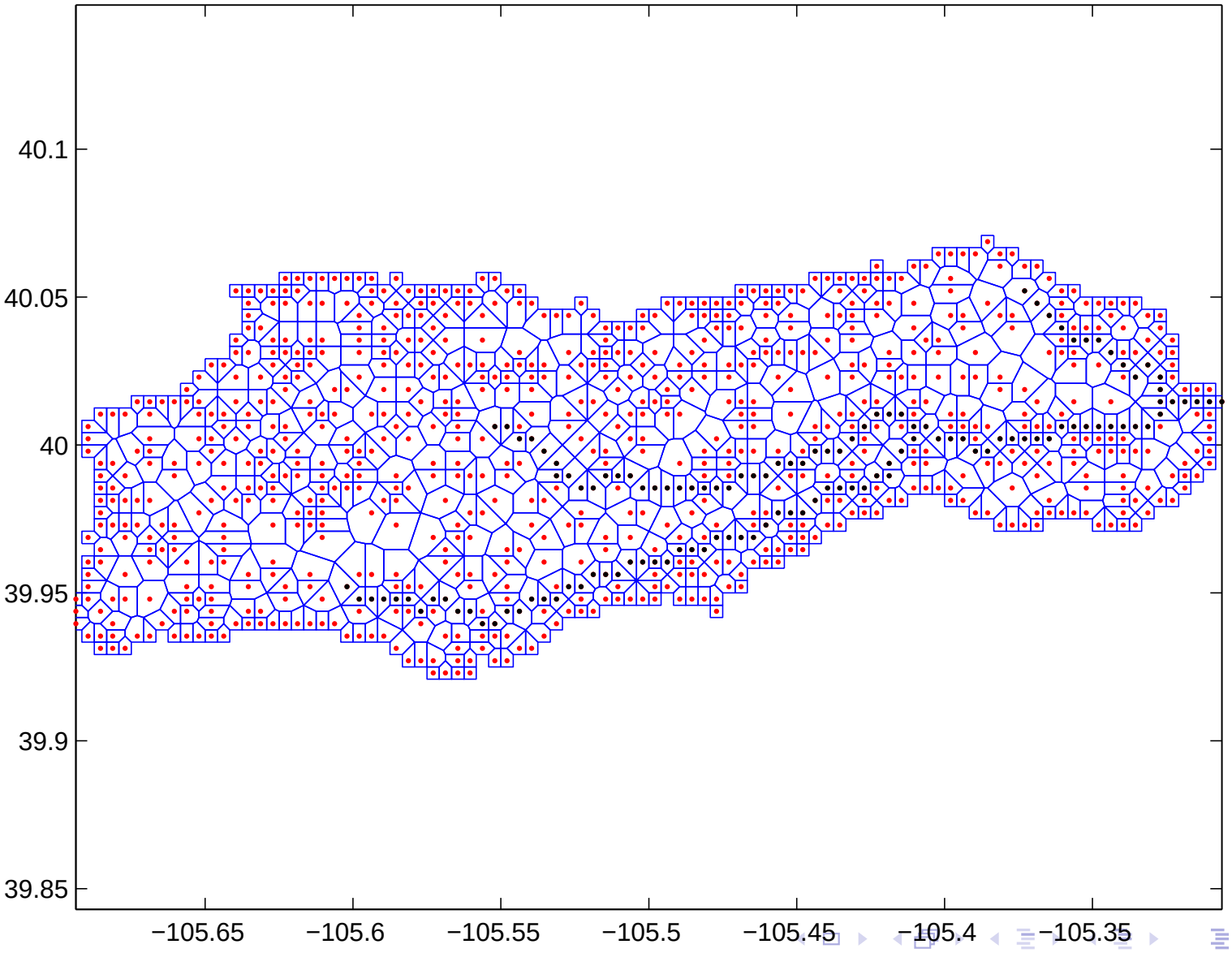
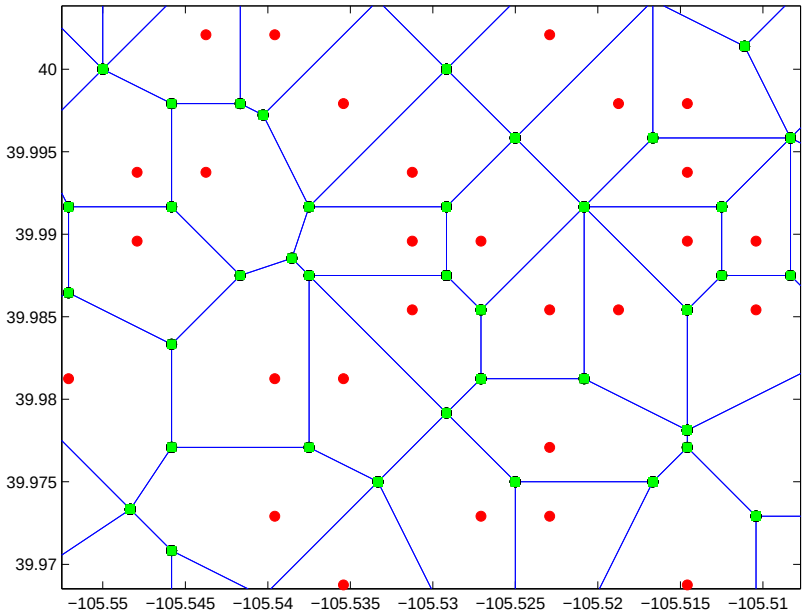
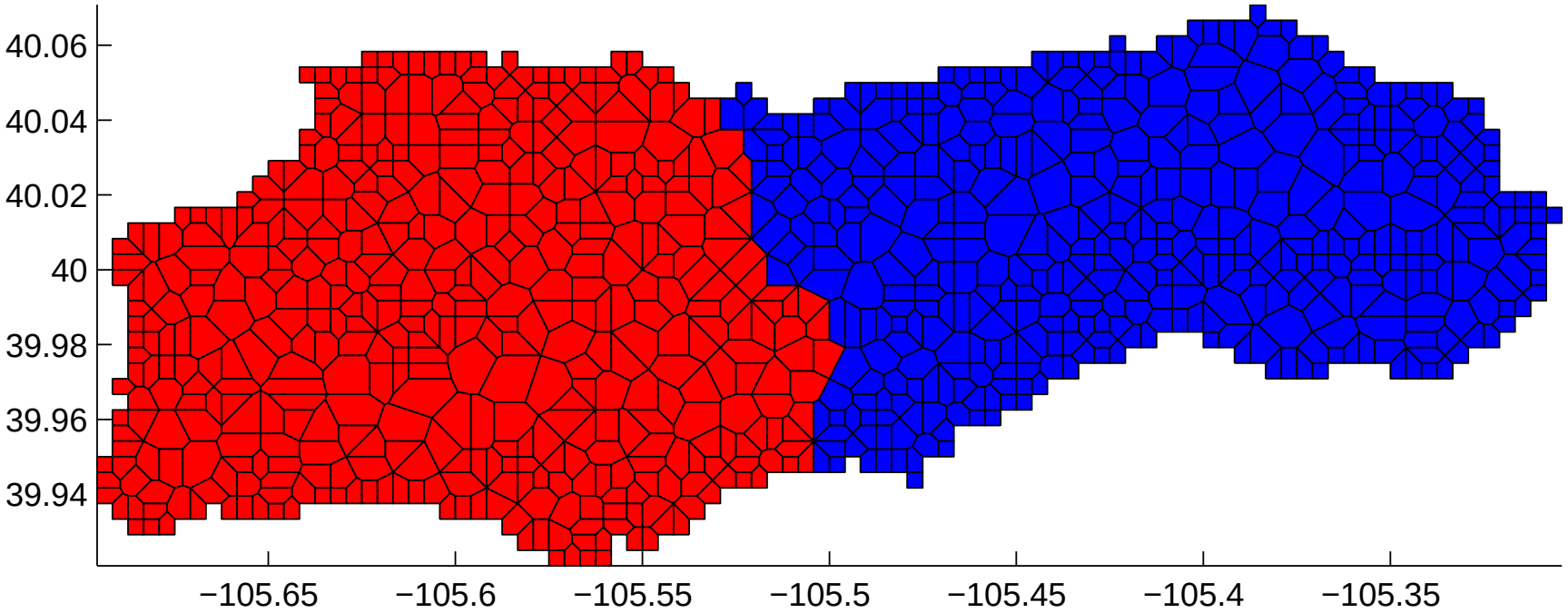


Unstructured mesh file format

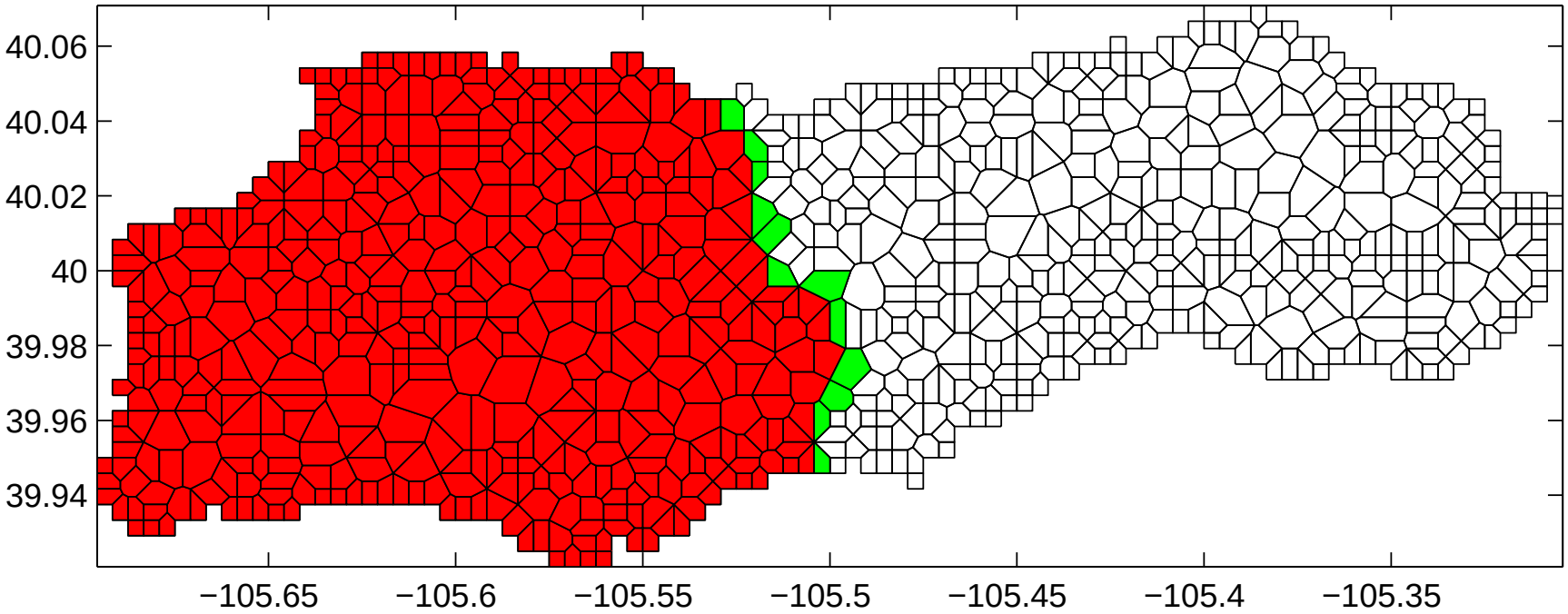


- Latitude/Longitude of cell center
- Latitude/Longitude of cell vertex
- Ids of vertices forming a cell
- Currently supporting arbitrary n-th vertex 2D cell (Would like to advocate for triangular mesh i.e. $n = 3$)

Domain decomposition: ParMETIS-based partitioning



Domain decomposition: Halo cells



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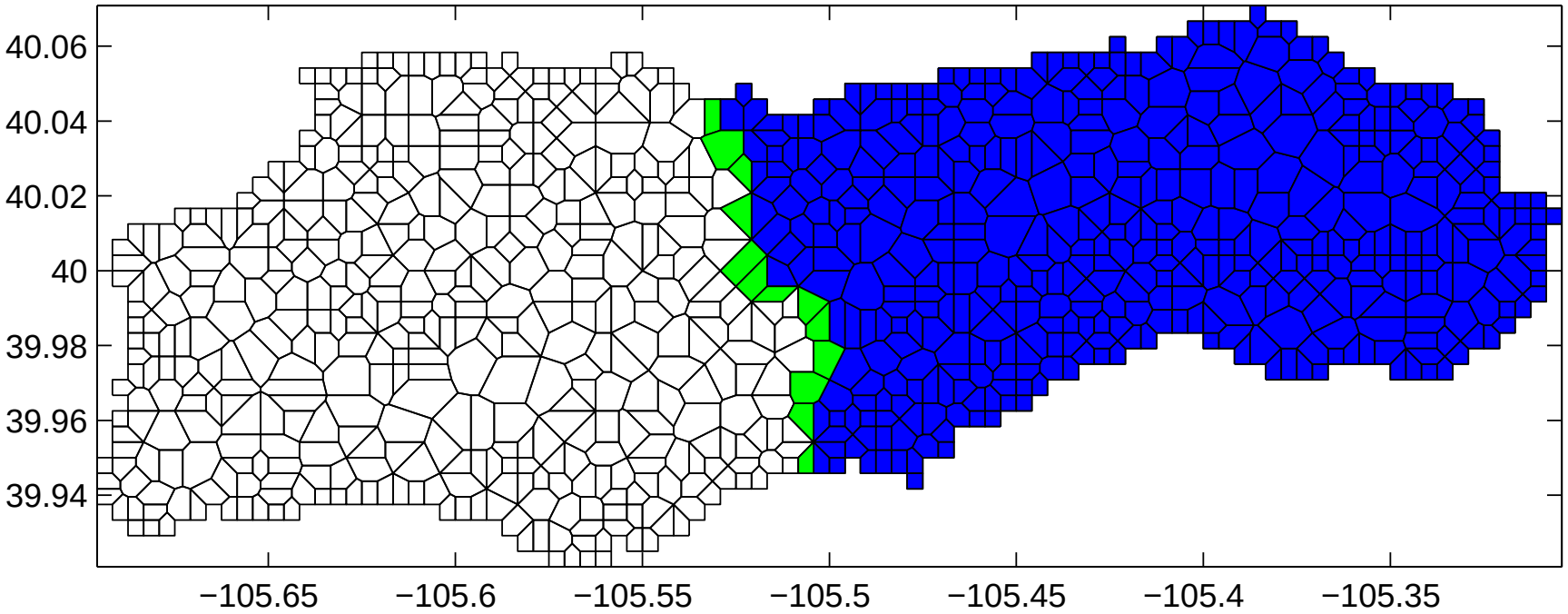
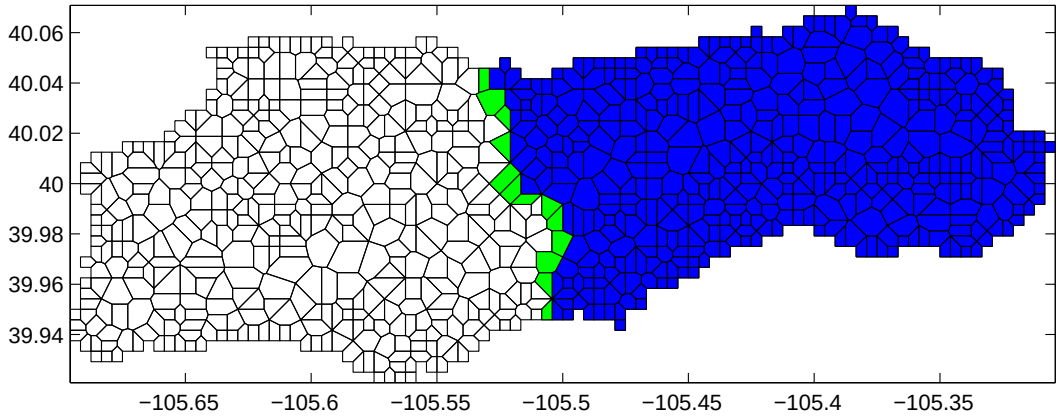


Domain decomposition: New data structure



$\text{Cell}_1\ \text{Cell}_2\ \ldots\ \text{Cell}_{nActive}\ \ \text{Cell}_{nActive+1}\ \text{Cell}_{nActive+2}\ \ldots\ \text{Cell}_n$

where

nActive: Number of active cells

n : Total cells (active + halo cells)

Summary

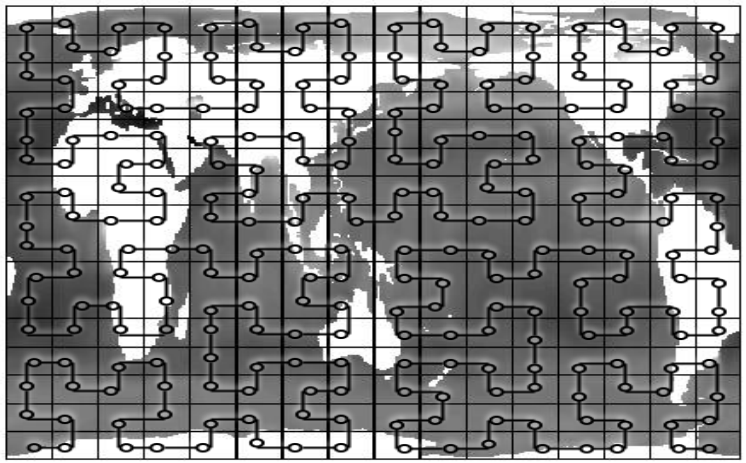
Proposed CLM development:

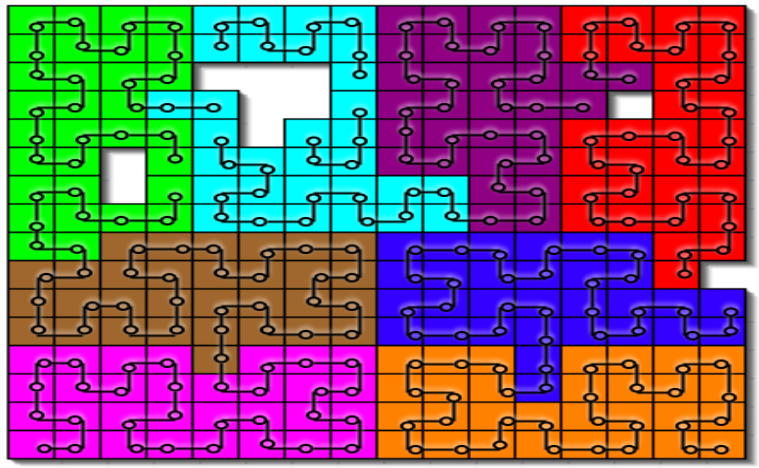
- Variably saturated subsurface flow formulation
- Explicit representation of soil columns within a grid cell and input file format
- Domain decomposition

- Data structures to accomodate halo cells
- Across processor communication to update halo cells
- Use higher-resolution surface dataset to generate meshes at varying resolution

Learning from other model components: Space filling curves

Parallel Ocean Program Model





Credit: John M. Dennis, June 22, 2006
Software Engineering Working Group Meeting

Acknowledgements

- DOE Advance Scientific Computing Rresearch
- DOE Biological and Environmental Research: Climate Science for a Sustainable Energy Future

Questions?

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