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Representing Topography in ESMs with Porous Barriers

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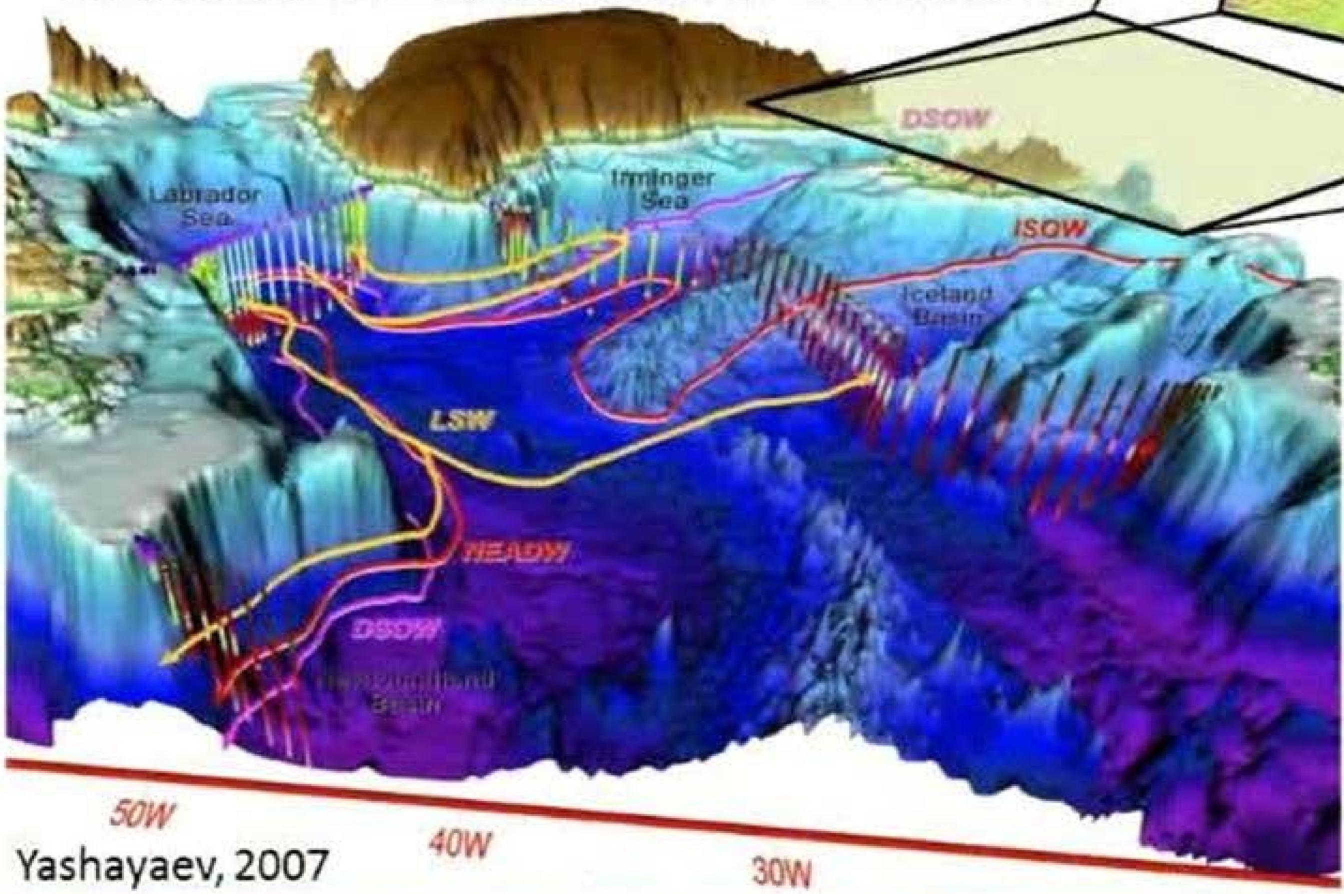
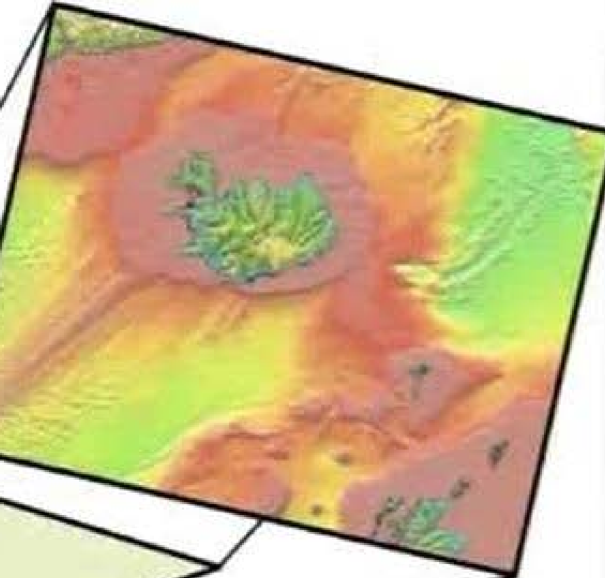
Context & motivation

- Topography shapes ocean circulation and water masses



Yashayaev, 2007

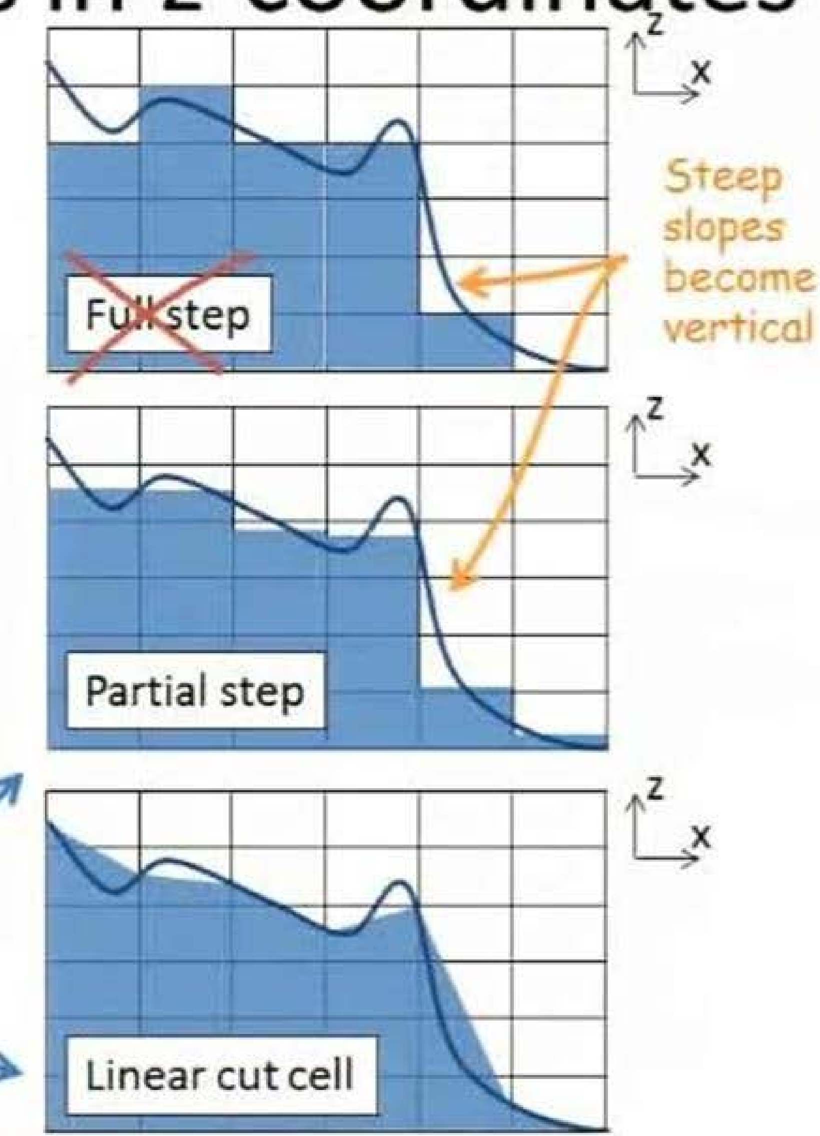


Smith & Sandwell, 1997

- Contemporary finite resolution models are challenged to represent all important topographic features

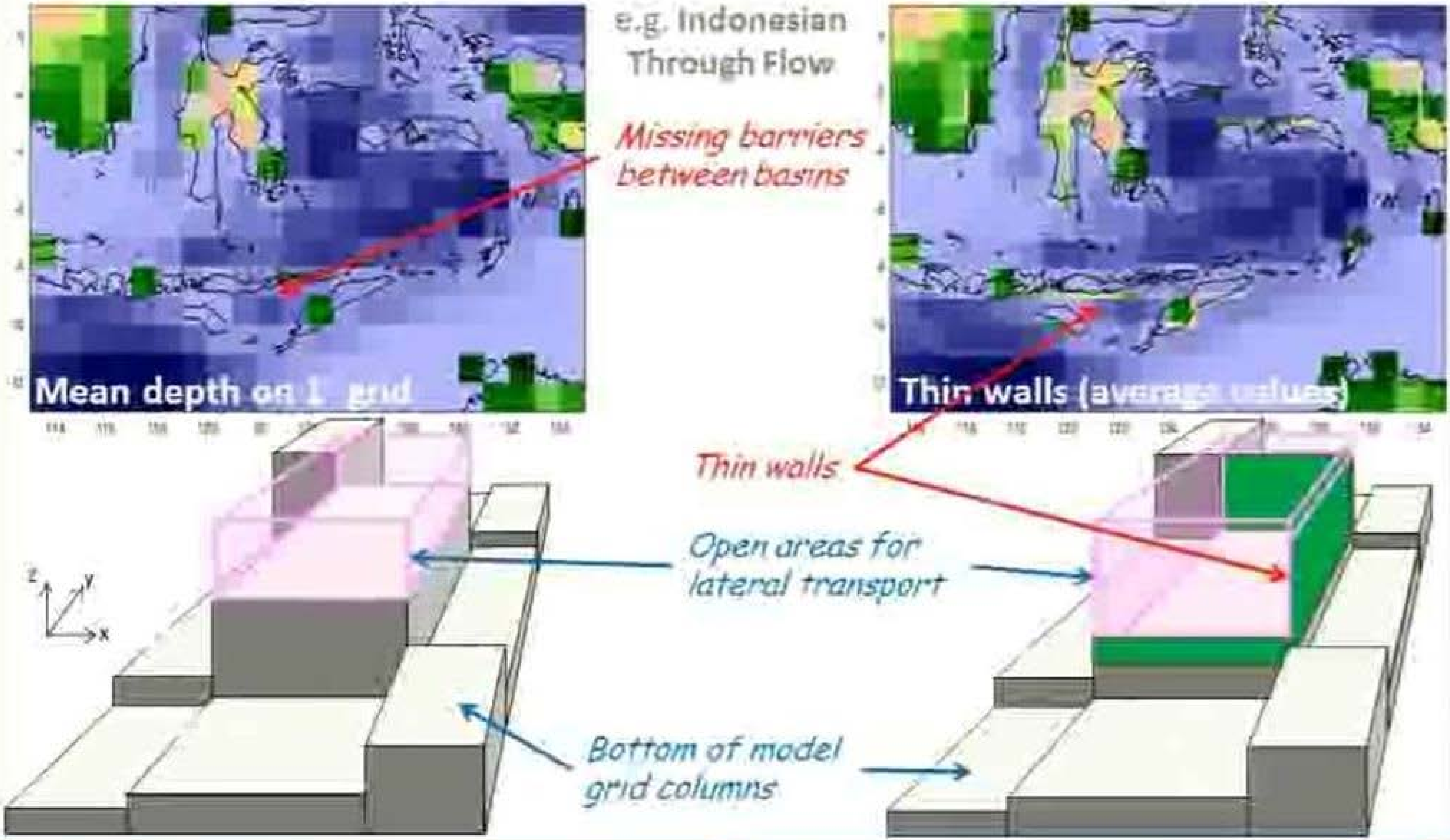
Common approaches in z-coordinates

- Models use a filtered topography
  - **typically use column mean elevation**
- Creation of gridded topography requires **subjective** intervention!
  - Procedure involves interpolation/sub-sampling/smoothing **+ editing!**
  - Without editing results are clearly wrong
  - Reproducibility (lack of documentation)
- Most climate OGCMs use finite volume formulation
  - for **z-coordinates**, z*, p, p*, ...
- "Full step" method fit topography to the grid
  - ~~No longer used~~ **Rarely used**
- General method is "cut cells"
  - partial steps or "shaved" cells



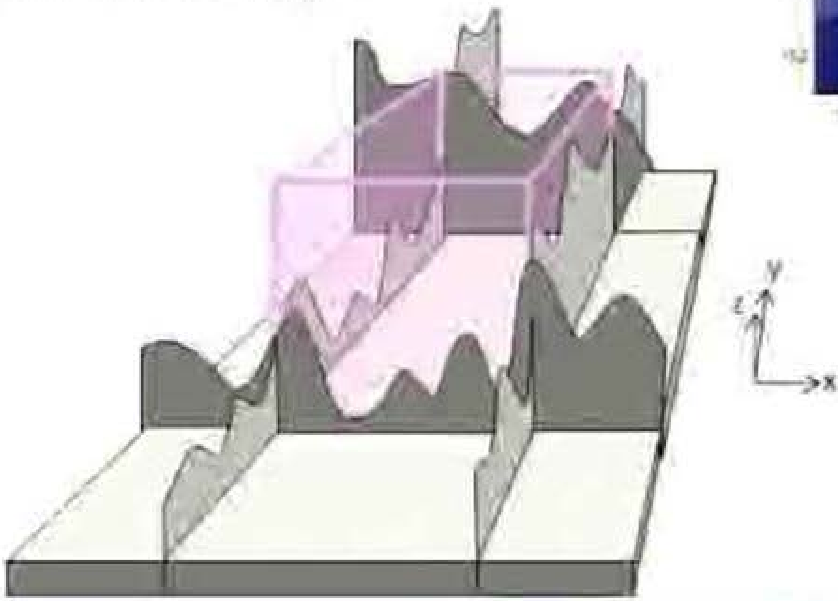
Maier-Reimer & Mikolajewicz, '92

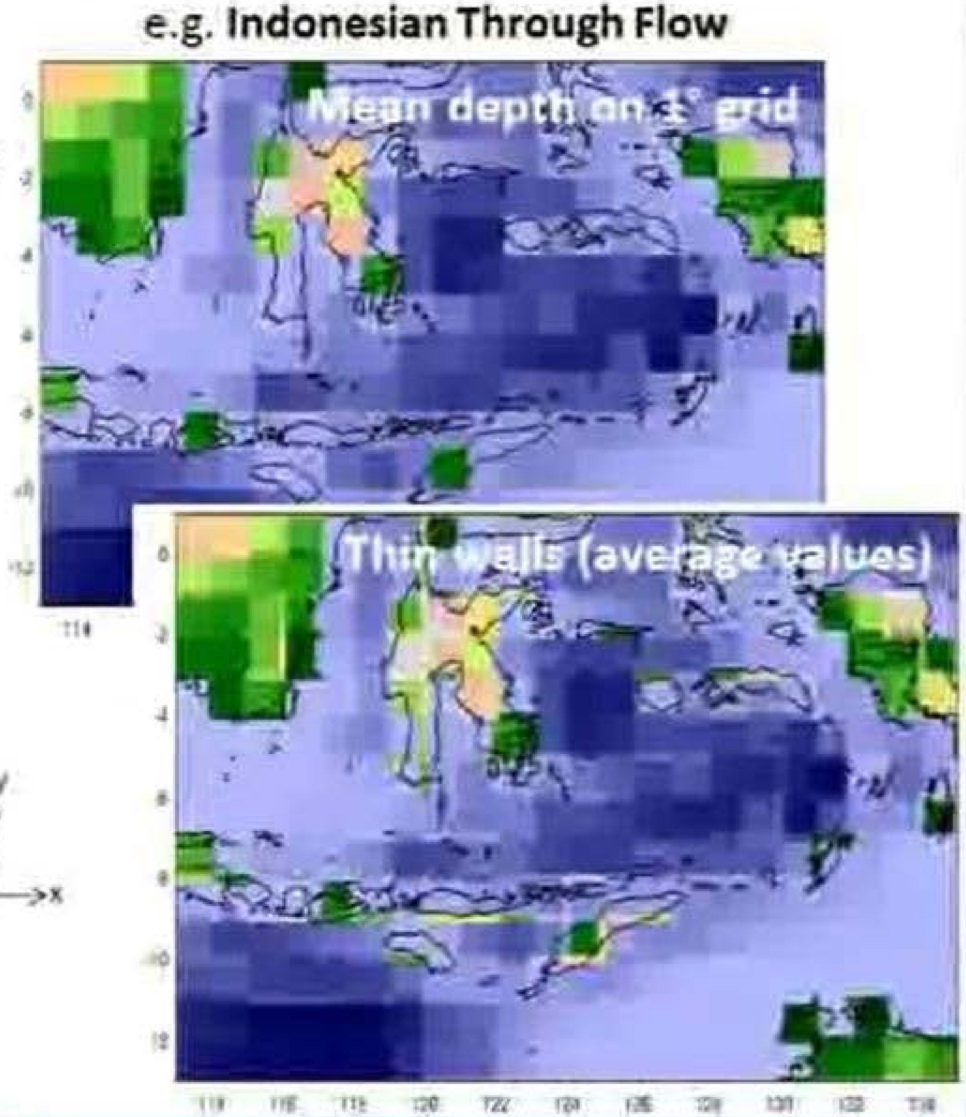
Thin walls (not quite cut cells)



Porous barrier representation (intro)

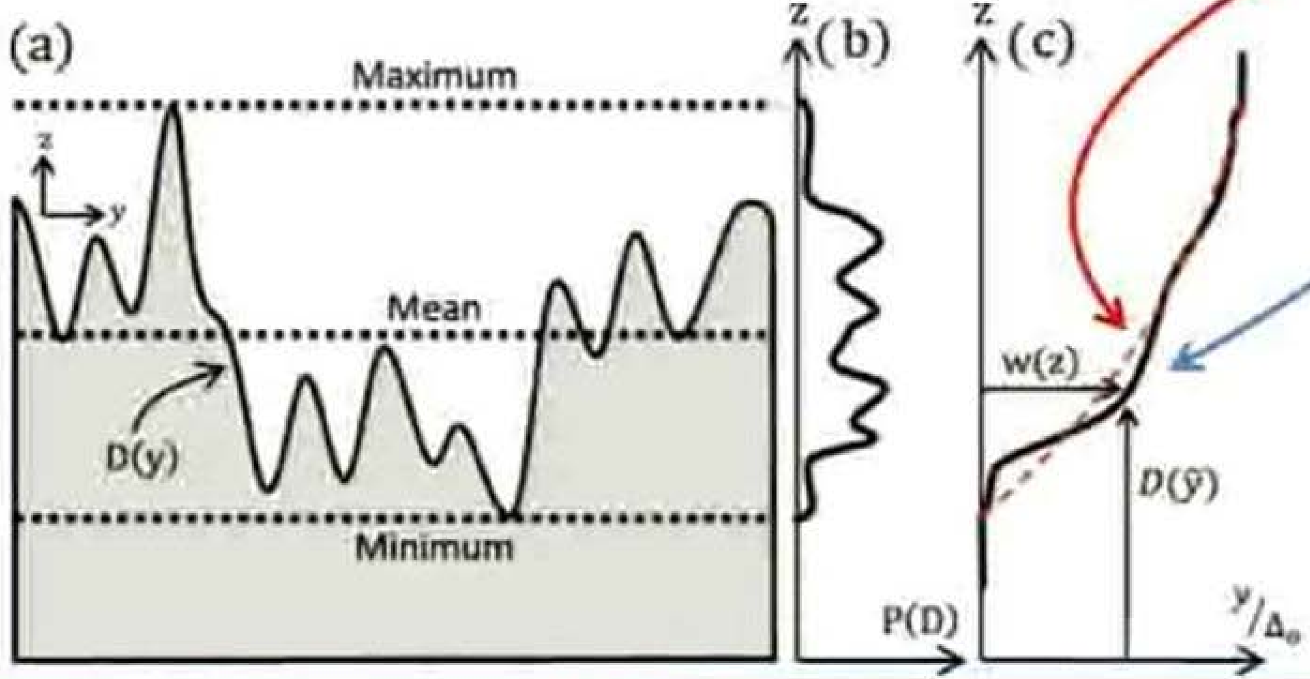
- Why not just use real-world "actual" values of areas/volumes in FVM (without added DOFs in model)?
- As opposed of modeling a resolvable shape





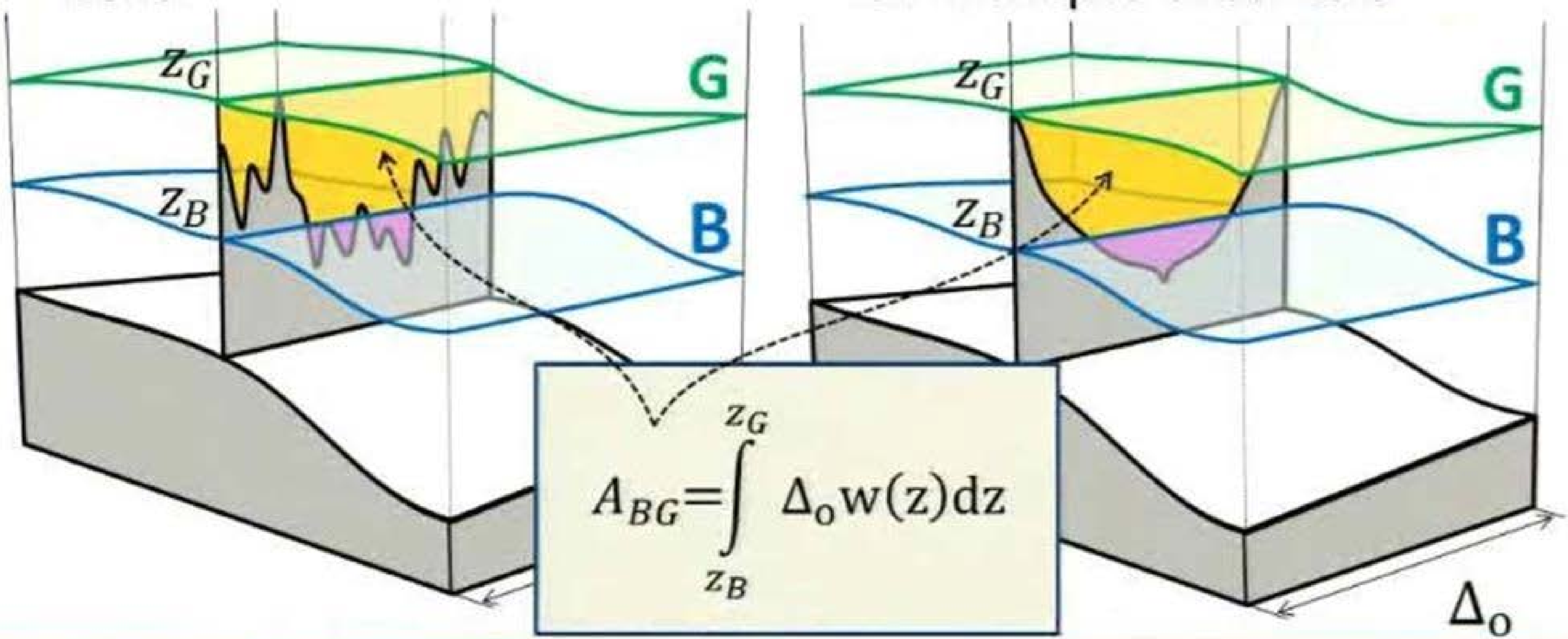
Describing topography to a model (1)

- Water below the minimum is completely blocked
- Water above the maximum is unimpeded
- The cumulative PDF is an ***effective open width***
- Can use actual cPDF or parameterize by curve fit



Describing topography to a model (2)

- Given w(z) we can calculate the actual area for exchange between cells
- A budget for a single DOF in a cell cannot distinguish between a single channels or multiple channels



$$A_{BG} = \int_{z_B}^{z_G} \Delta_o w(z) dz$$

Available volume within cell

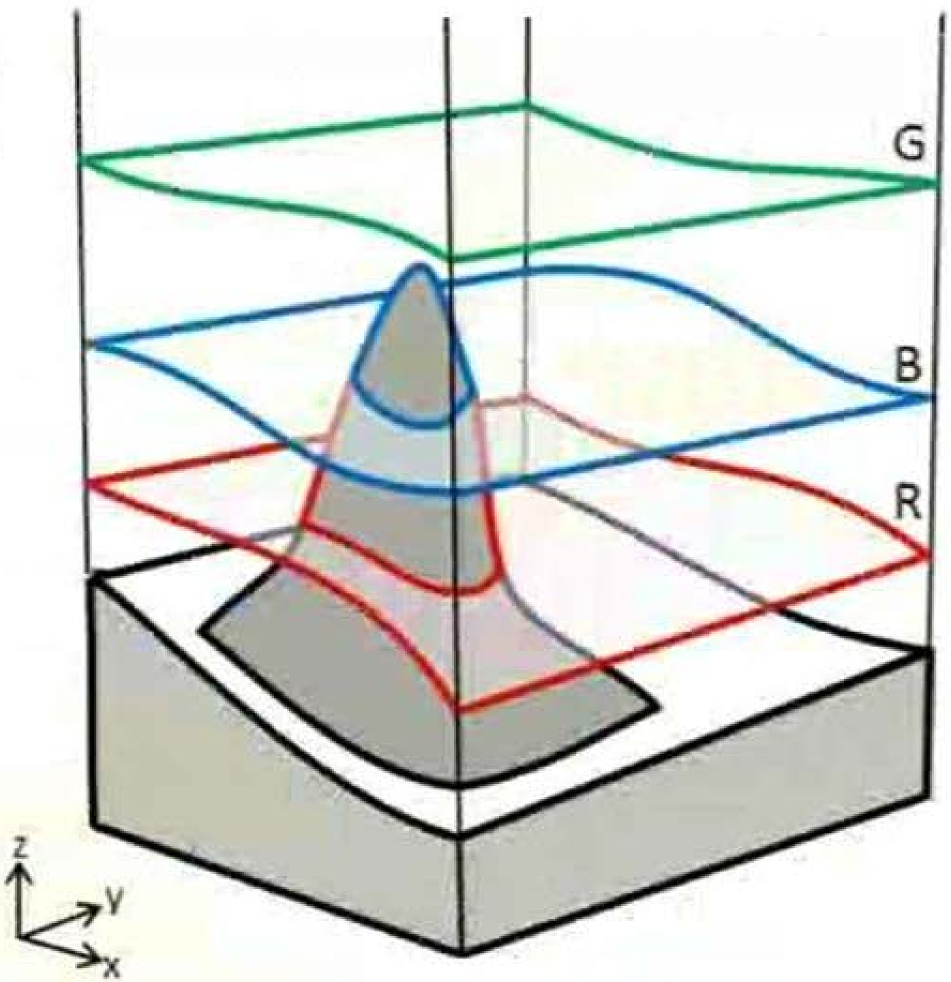
- Sub-grid topography within a column displaces fluid, reducing capacity as a function of depth
- Open volume of FV cell:

$$V = C(z_1) - C(z_2)$$

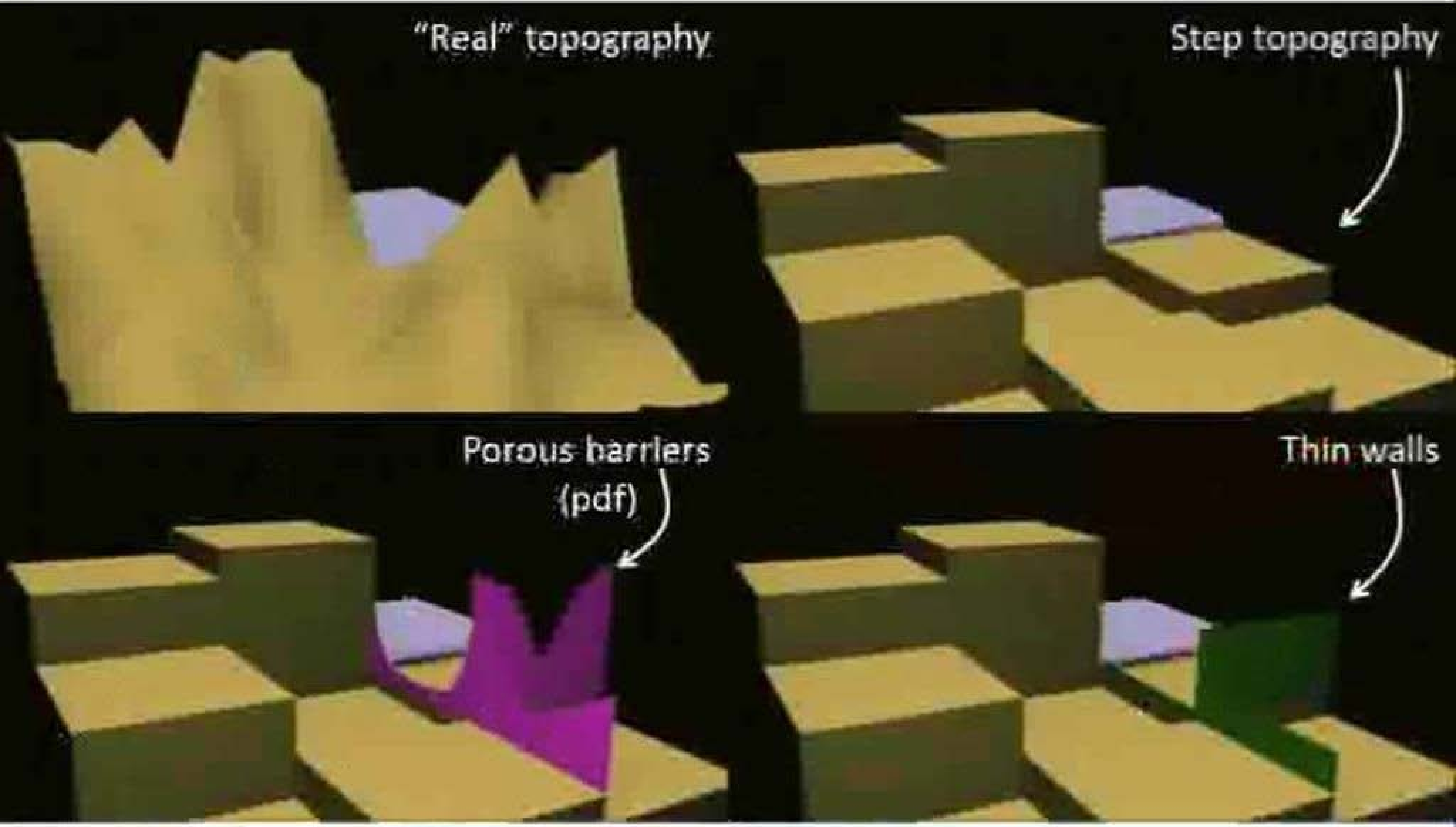
where $C(z)$ is all volume below depth z:

$$C(z) = \int_{-\infty}^{z} \mathrm{A}(z)dz$$

$$= \int_{-\infty}^{z} A_o w(z)dz$$



Cartoon of topographic representations

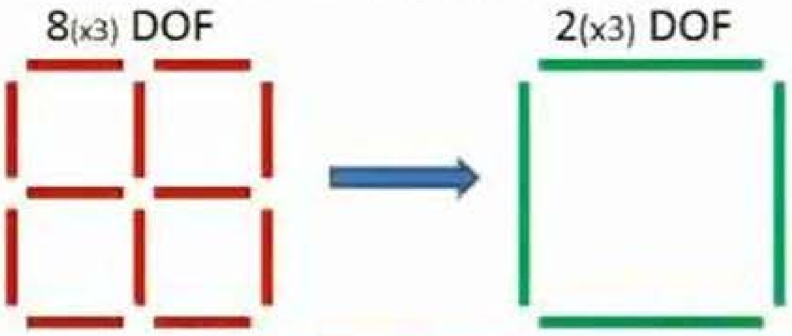


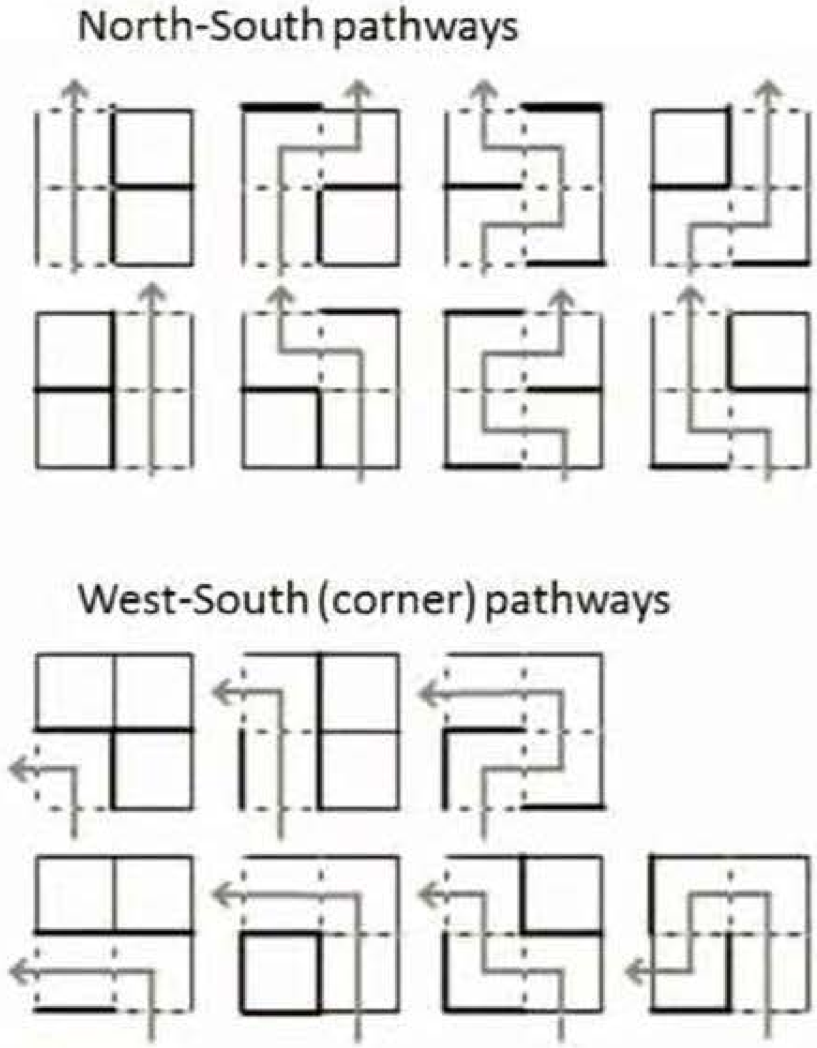
Generating porous barrier data

- Use a notion of "**deepest connectivity**"
- Start with ultra-fine resolution topo.
- Take a recursive approach
  - Use repeated coarsening

At each fine level (before coarsening):

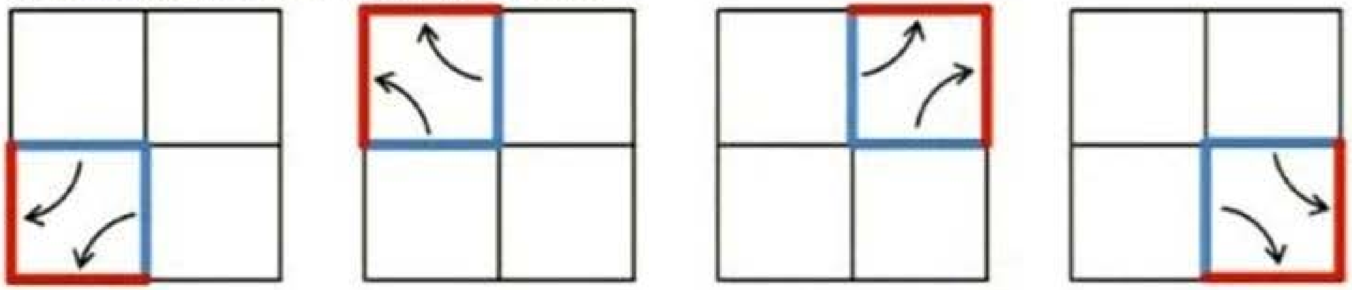
1. Diagnose "true" connectivity
2. "Optimally" re-arrange inner walls
3. Coarsen subject that "deepest connectivity" **cannot deepen**
   - Carry min, max and mean



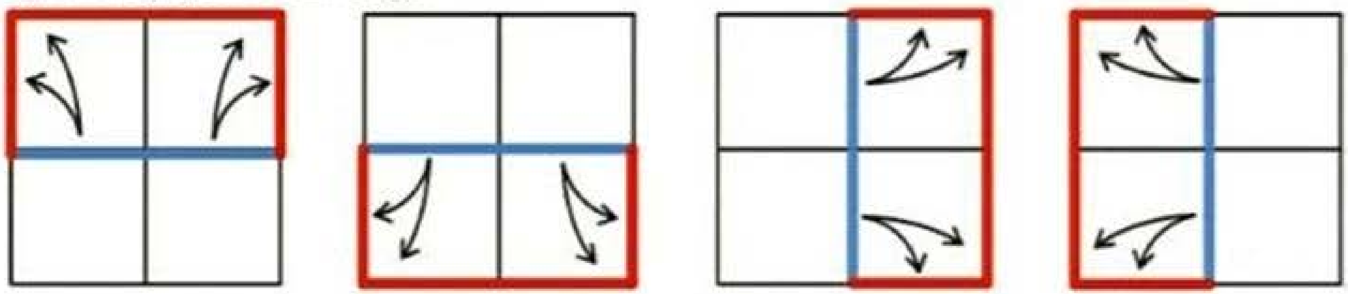


Re-arranging fine-grid walls

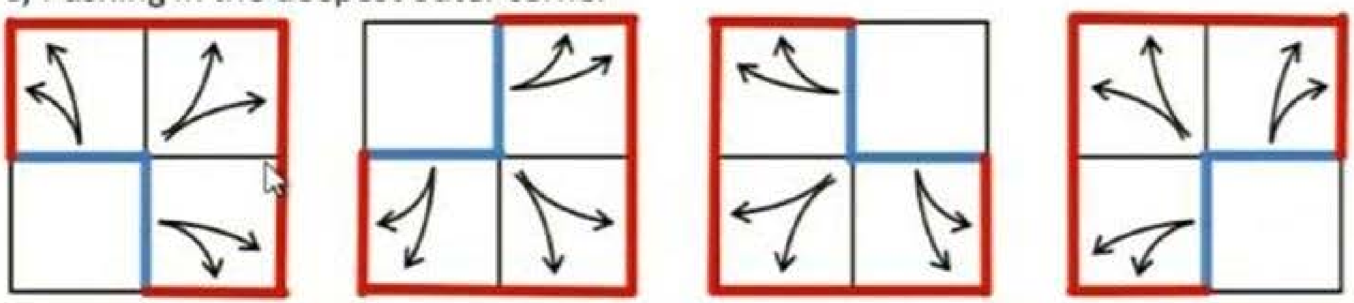
a) Pushing out the tallest inner corner



b) Folding open a tall ridge

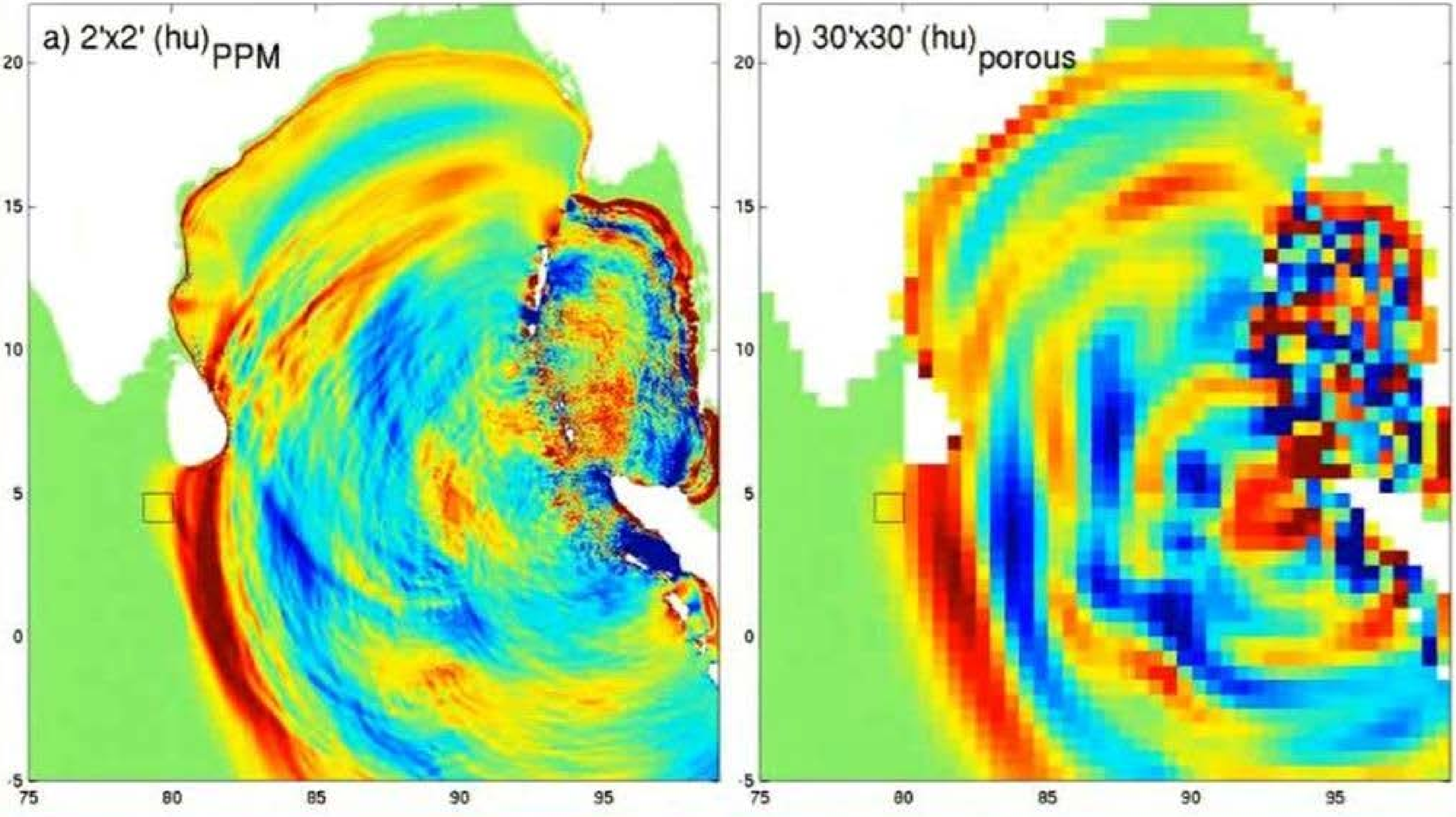


c) Pushing in the deepest outer corner



Test: shallow water wave travel time

Sea surface elevation (same color scale)

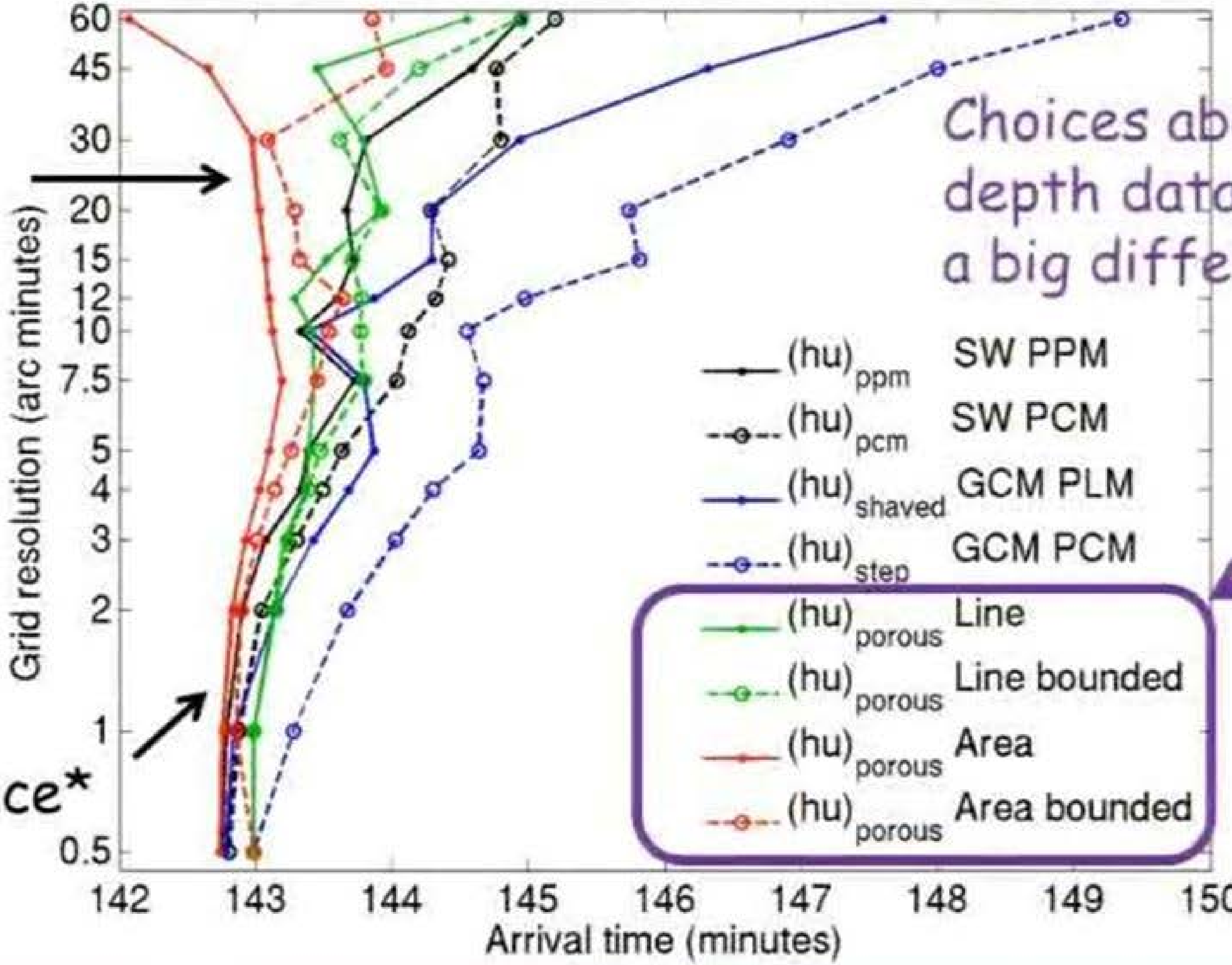


Tsunami arrival times

(depends on inverse of barotropic wave speeds)

Porous barriers are more accurate

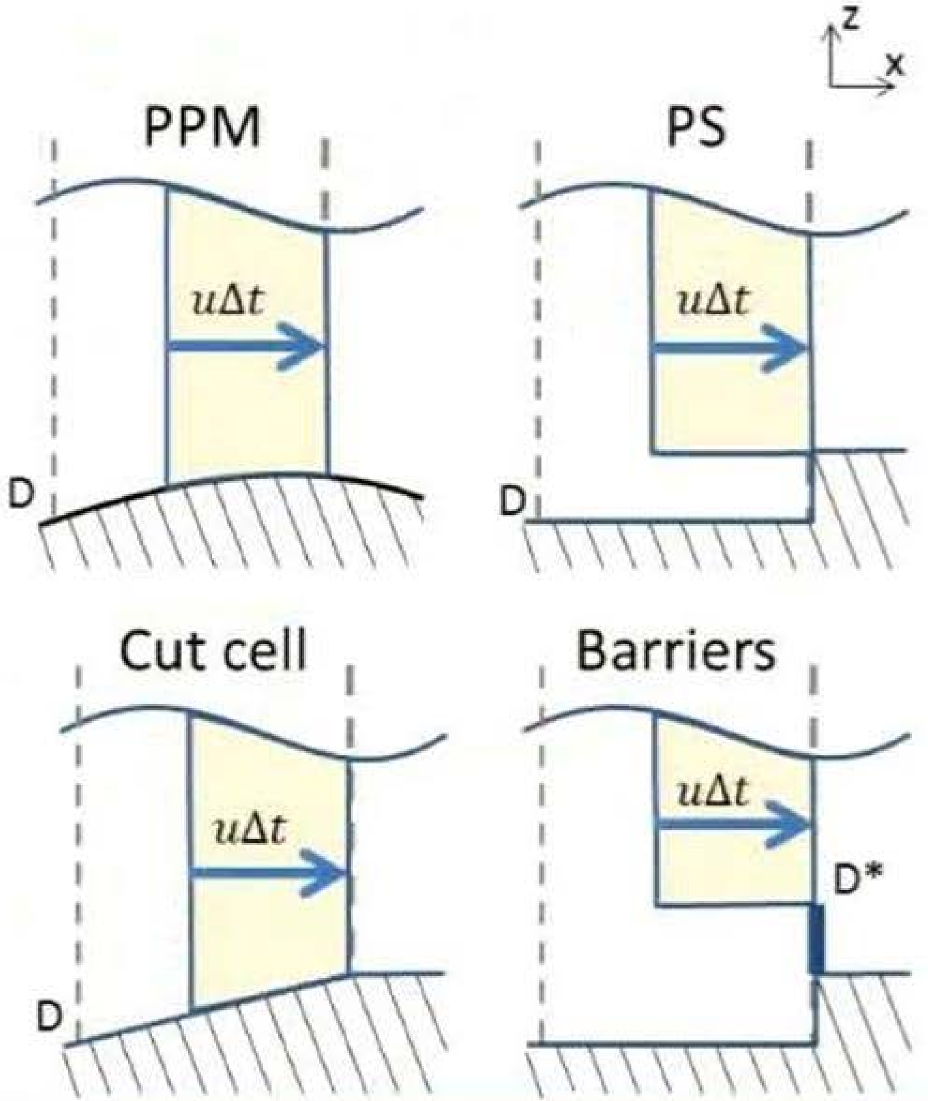
General convergence*



Choices about depth data make a big difference

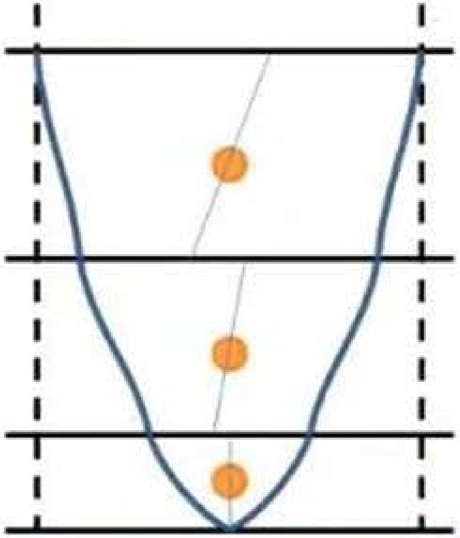
SWE upstream mass flux

- PPM/PCM reconstruct total column thickness
- Cut cell prescribes shape of lower surface
- Similarly, porous barriers dictate an "overflow" depth
  - assumed constant upstream
- Using spatial average depth for D* gives most accurate wave speed

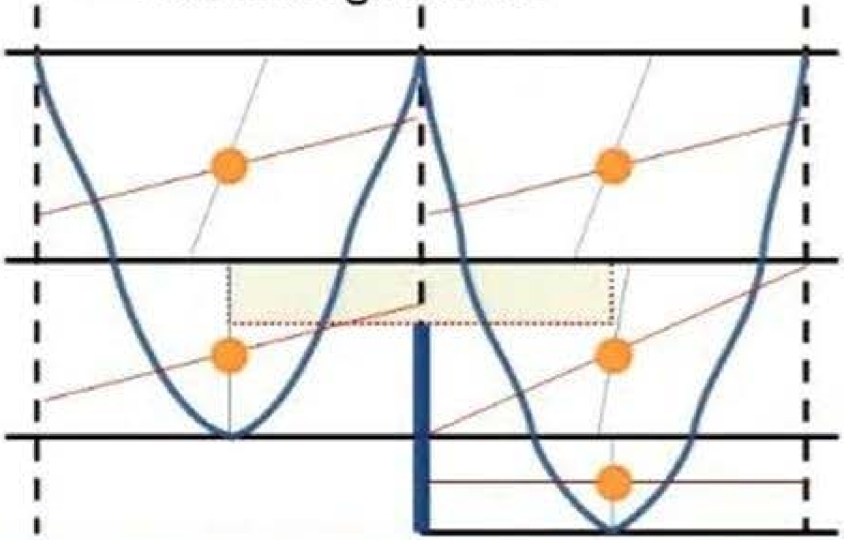


Reconstruction in the vertical/horizontal

- Reconstructions in the vertical are unaware of w(z)
  - (except w(z)=0 defines lower mesh position – self-evident?)
  - can apply usual 1D approaches
- Vertical transport: ALE
  - No CFL / small cell problems



- Information for reconstructions can pass through porous barriers, not below a solid wall
- **Reconstruct** only for open region?
  - Horizontal transport
  - Pressure gradients



Summary of Porous Barriers

- A precise application of the finite volume method to discretizing the equations of motions
  - Uses the "actual" areas and volumes (or very close) for control volumes
    - Much more accurate, especially at low resolution (relative to fine scales of topography)
    - Easily adopted in most finite volume ocean models
      - e.g. MITgcm
  - A connectivity-preserving interpolation for thin wall and porous barrier data
    - "Ad-hoc" algorithm but objective relative to past practices!
    - Needs to be solved properly as an optimization problem.