Adcroft, Ocean Modelling, 2013
10.1016/j.ocemod.2013.03.002

Representing Topography in ESMs with Porous Barriers

Alistair Adcroft

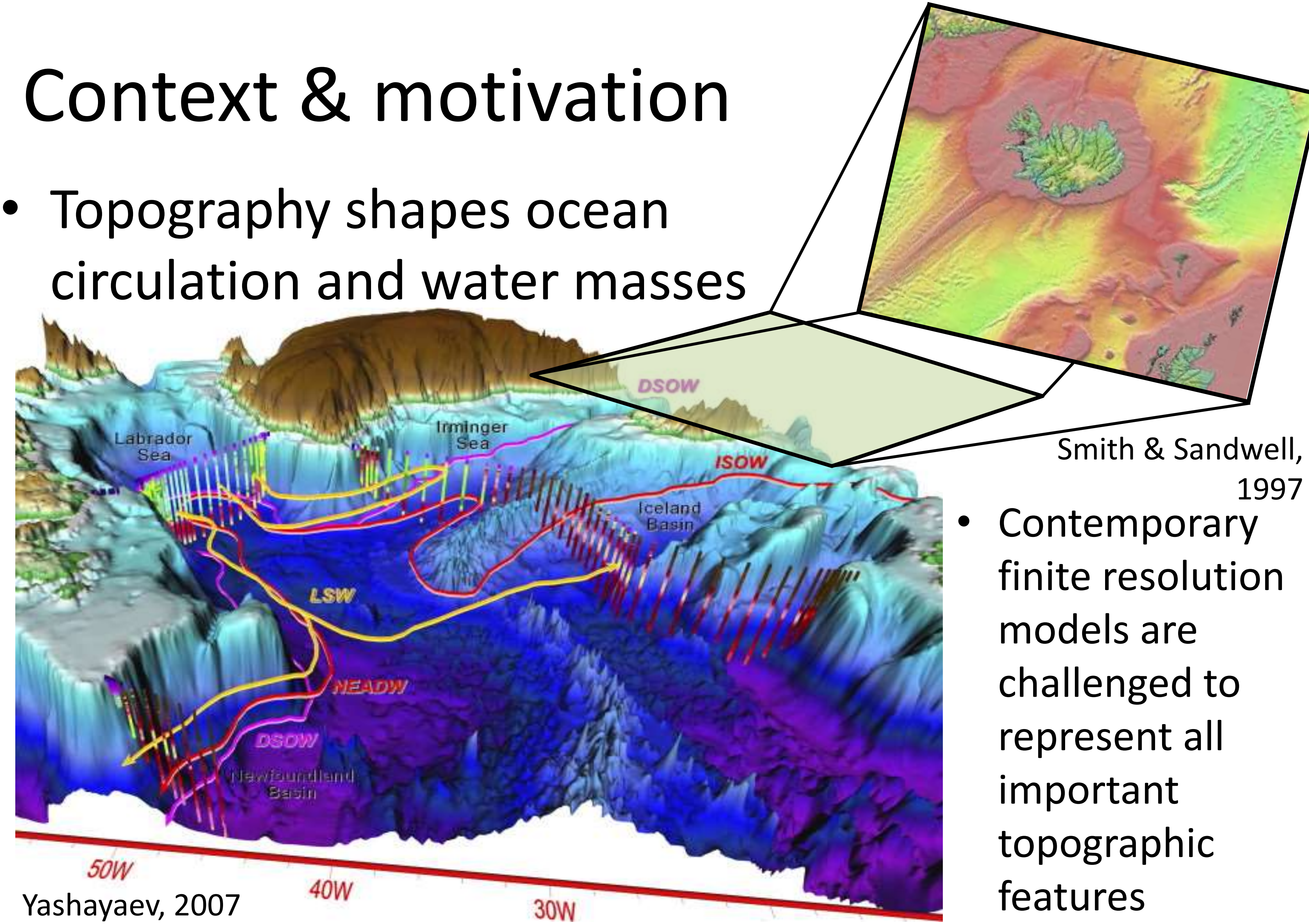
PRINCETON UNIVERSITY

NOAA GFDL

Thanks to: C.N. Hill, J.-M. Campin, E. Kestenare, M. Losch, A. Biastoch, R.W. Hallberg & M. Harrison

Context & motivation

- Topography shapes ocean circulation and water masses



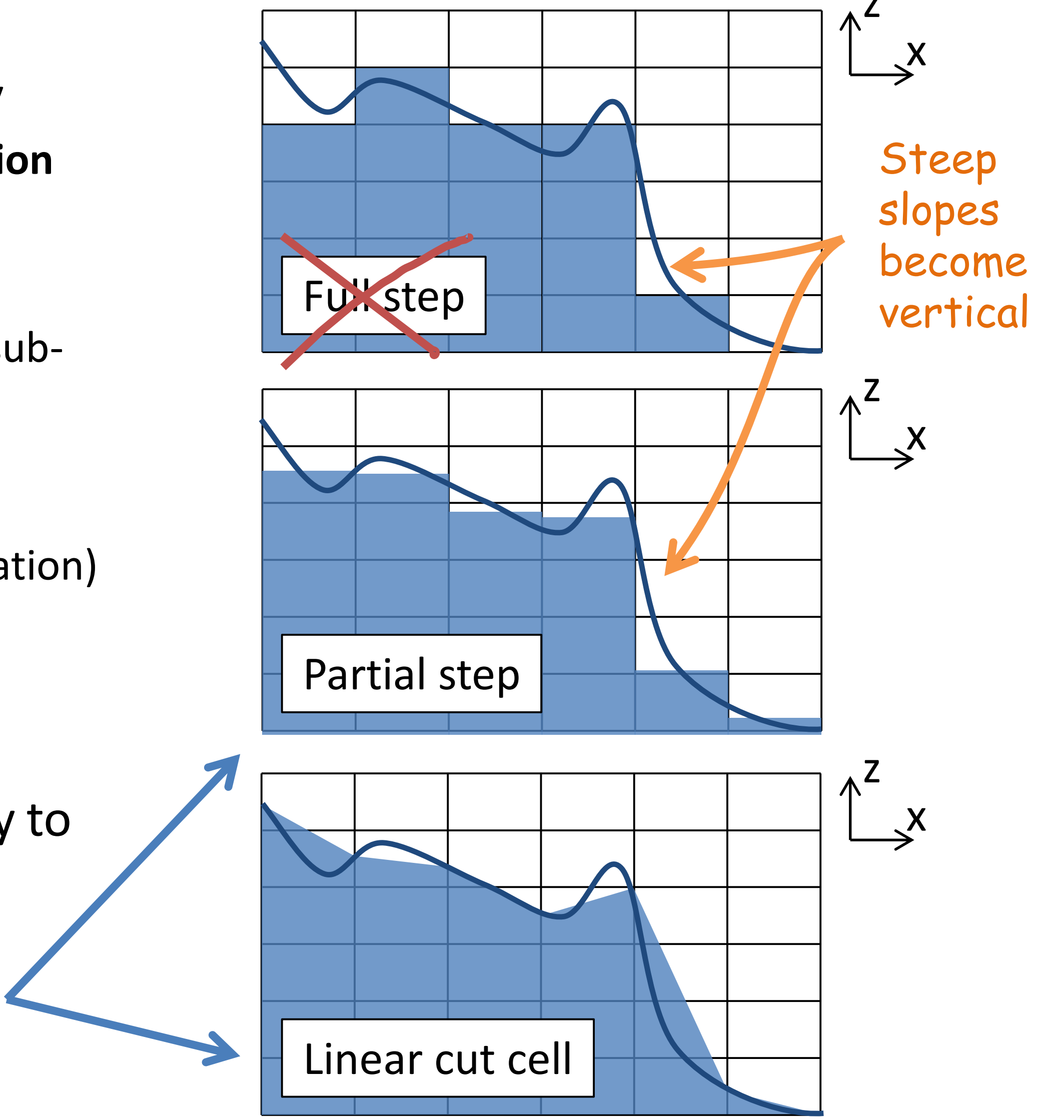
Smith & Sandwell, 1997

Yashayaev, 2007

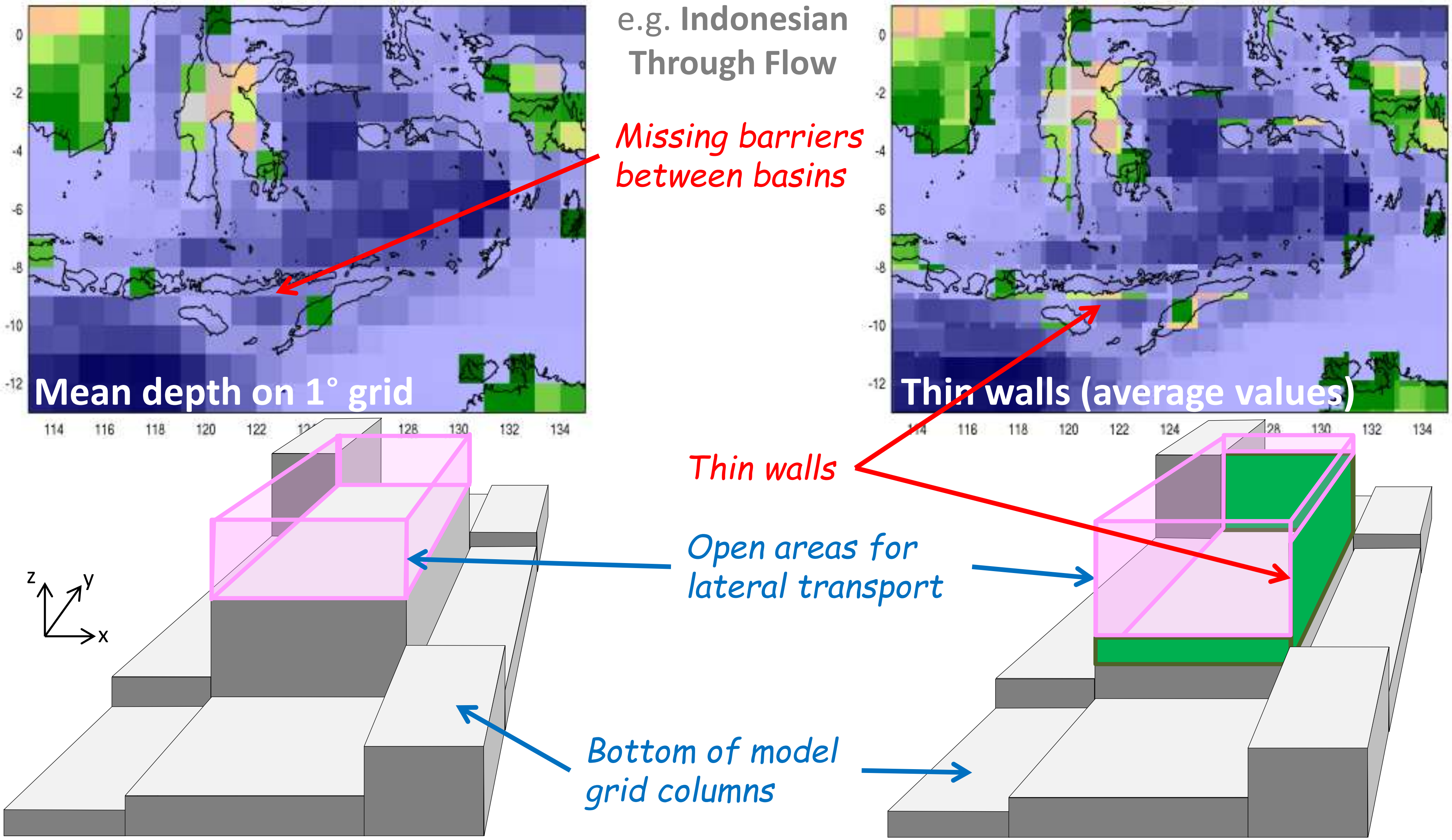
- Contemporary finite resolution models are challenged to represent all important topographic features

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

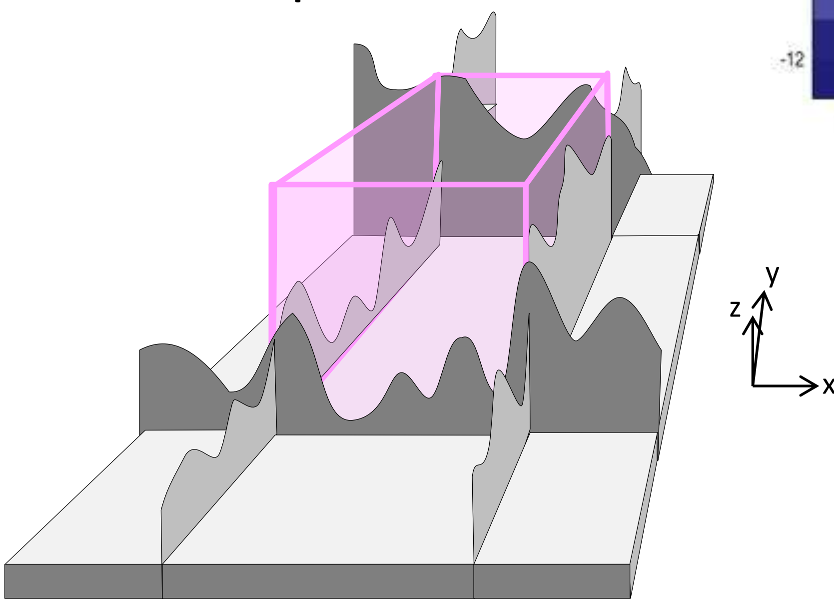


Thin walls (not quite cut cells)

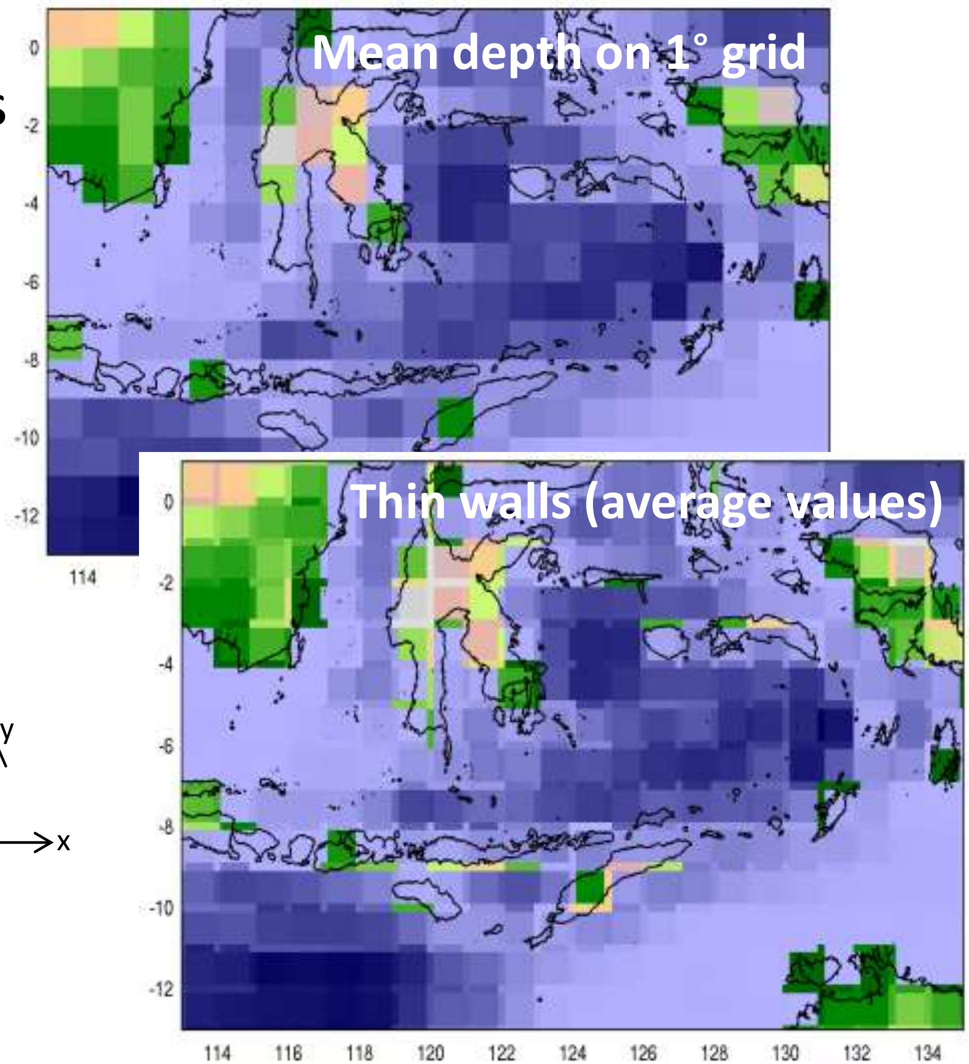


Porous barrier representation (intro)

- 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

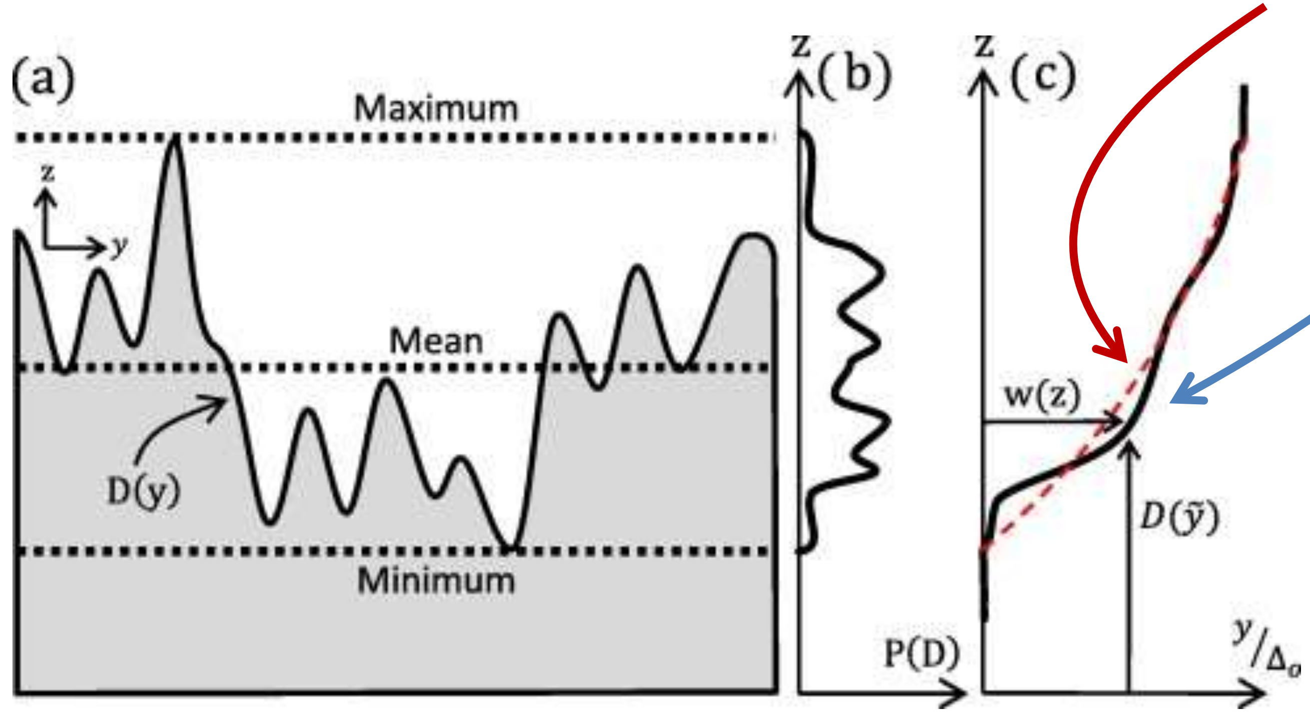


e.g. **Indonesian Through Flow**



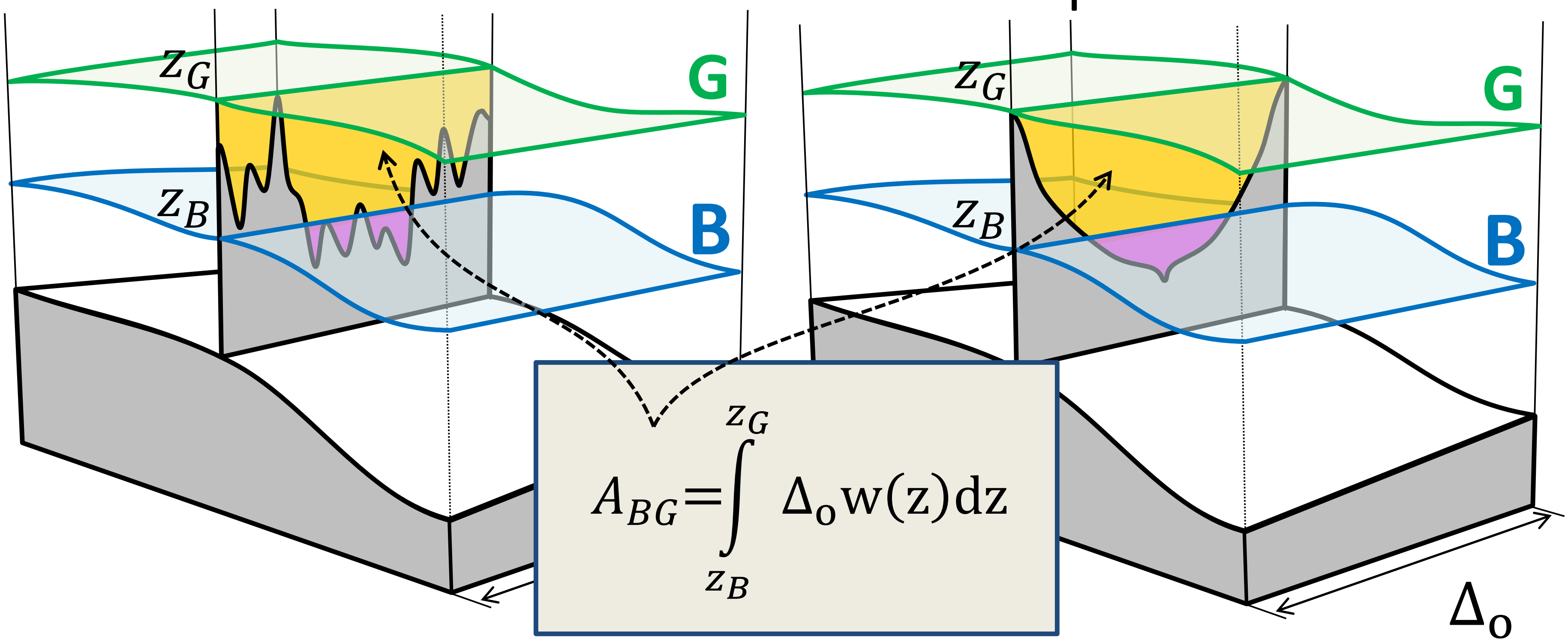
Describing topography to a model (1)

- 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



Available volume within cell

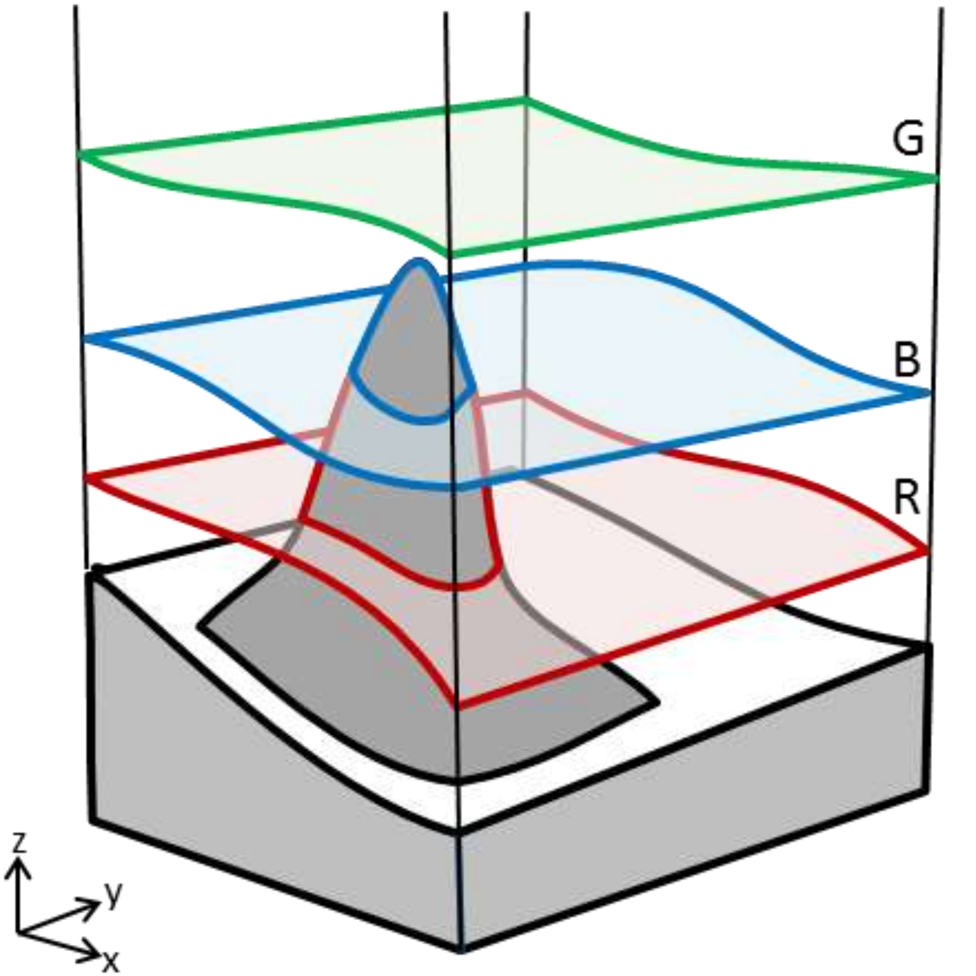
- Sub-grid topography within a column displaces fluid, reducing capacity as a function of depth
- Open volume of FV cell:

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

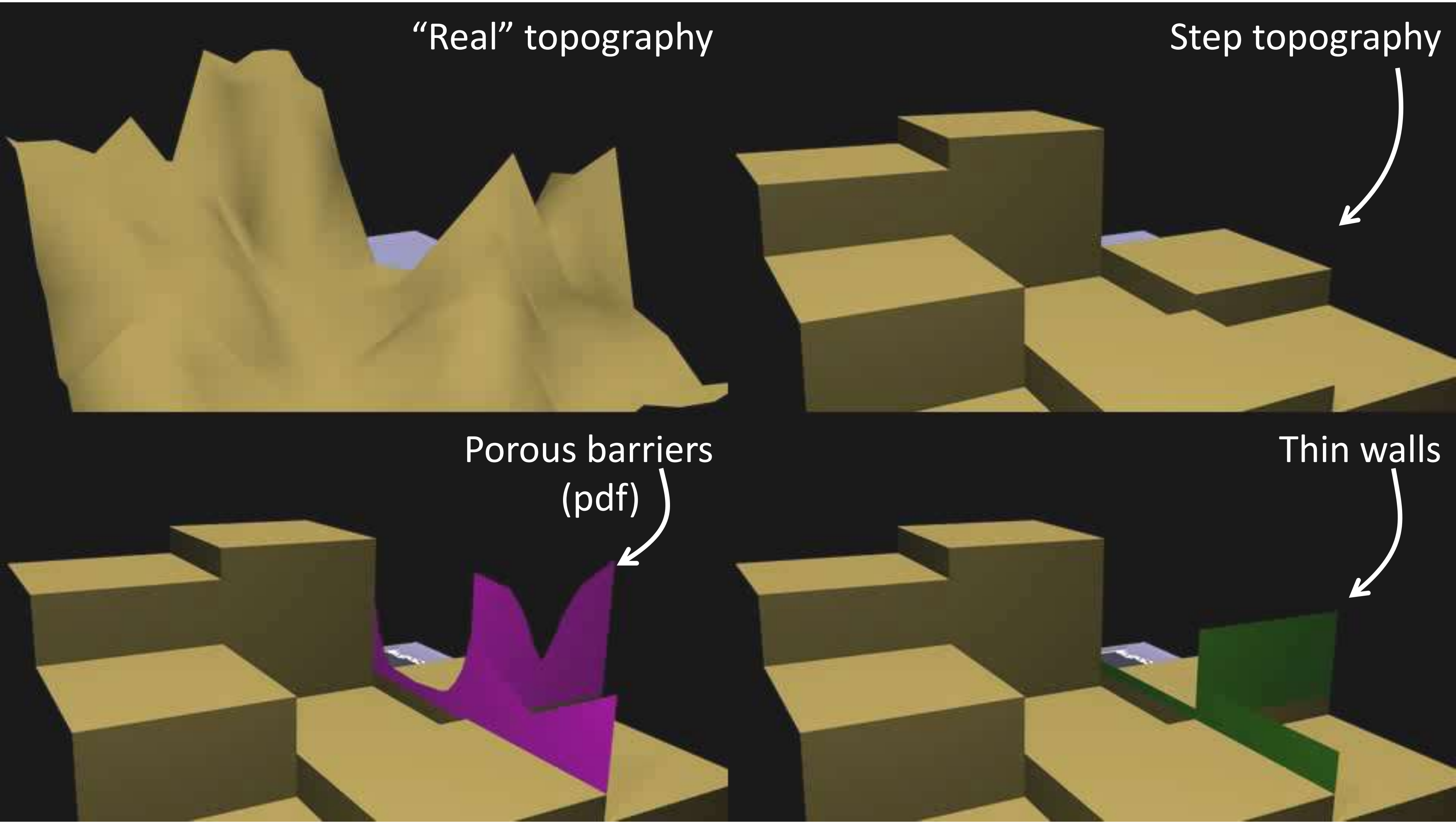
where $C(z)$ is all volume below depth z:

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

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



Cartoon of topographic representations



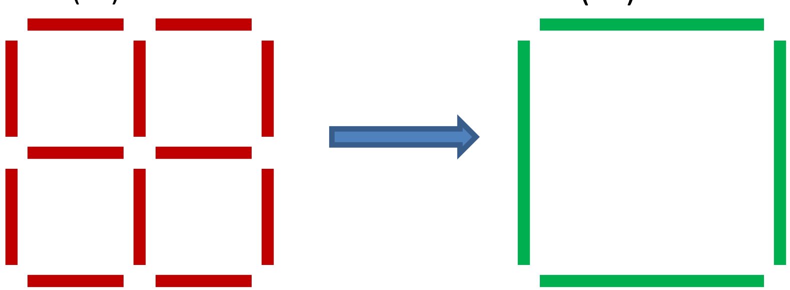
Generating porous barrier data

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

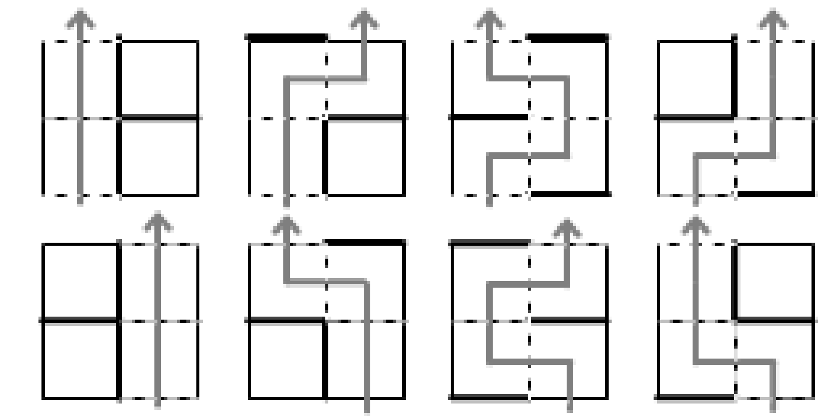
At each fine level (before coarsening):

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

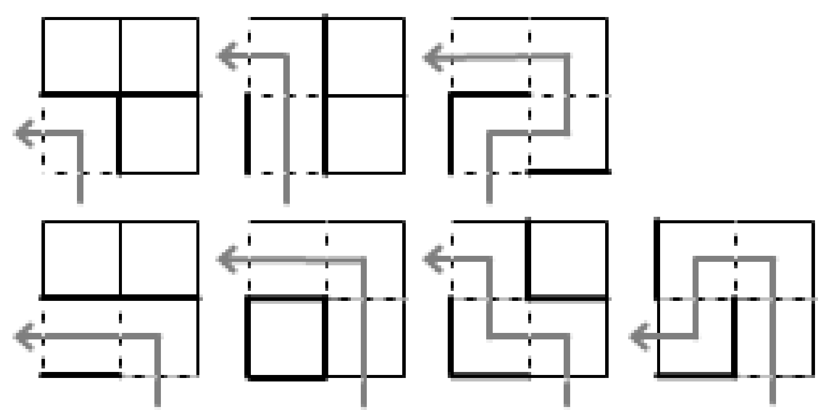
8(x3) DOF 2(x3) DOF



North-South pathways

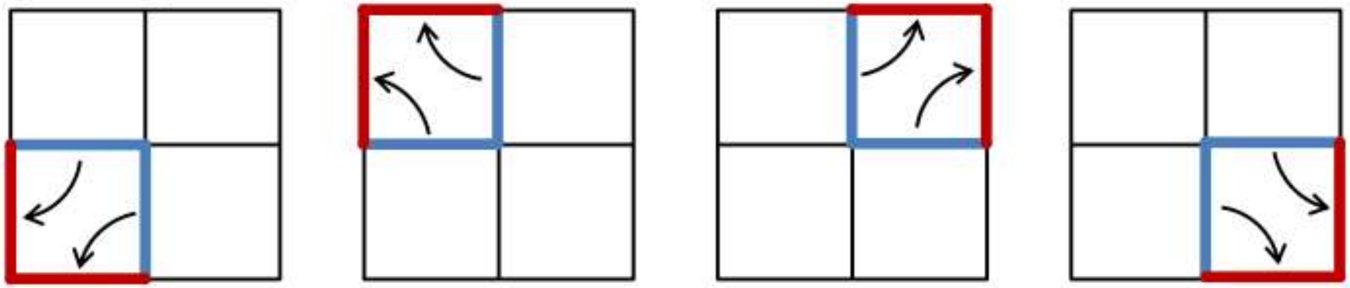


West-South (corner) pathways

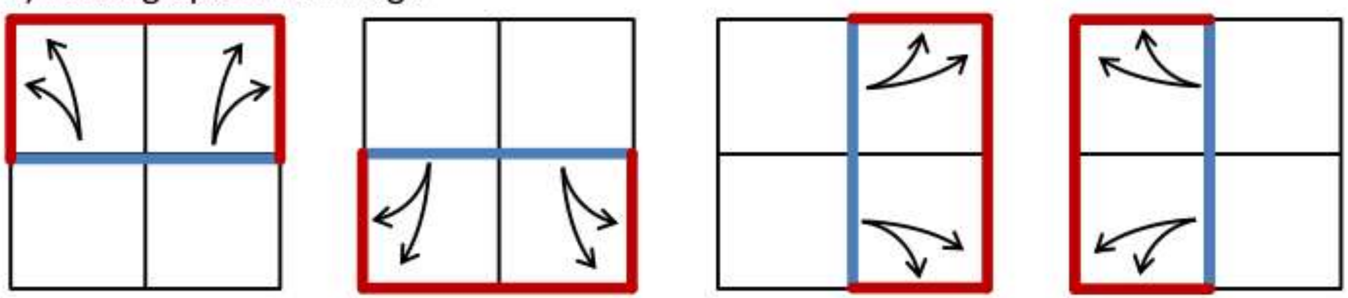


Re-arranging fine-grid walls

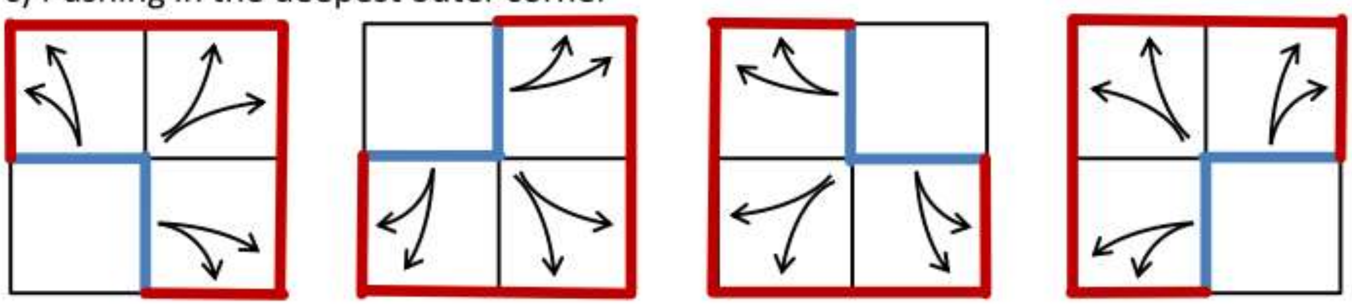
a) Pushing out the tallest inner corner



b) Folding open a tall ridge

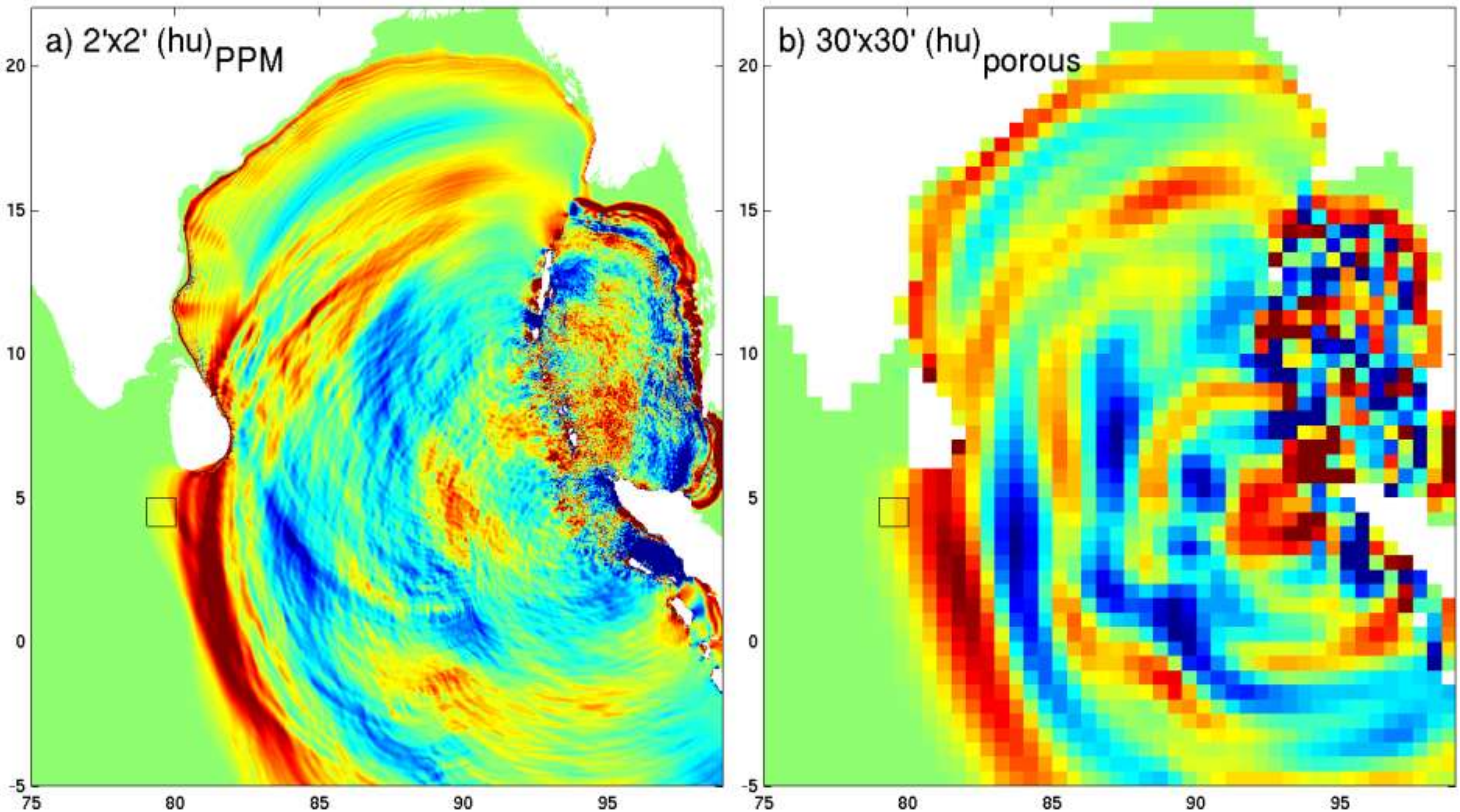


c) Pushing in the deepest outer corner



Test: shallow water wave travel time

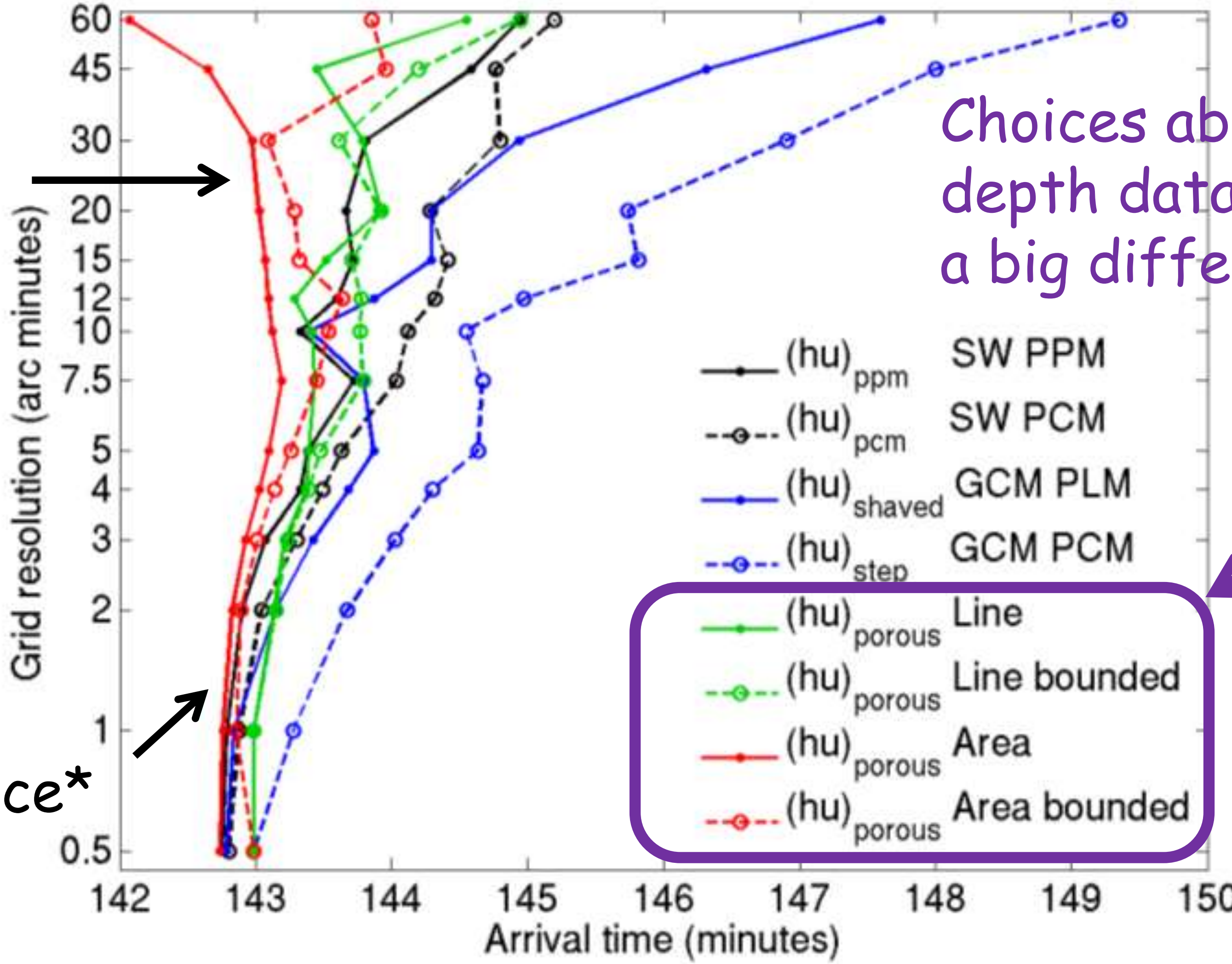
Sea surface elevation (same color scale)



Tsunami arrival times

(depends on inverse of barotropic wave speeds)

Porous barriers are more accurate

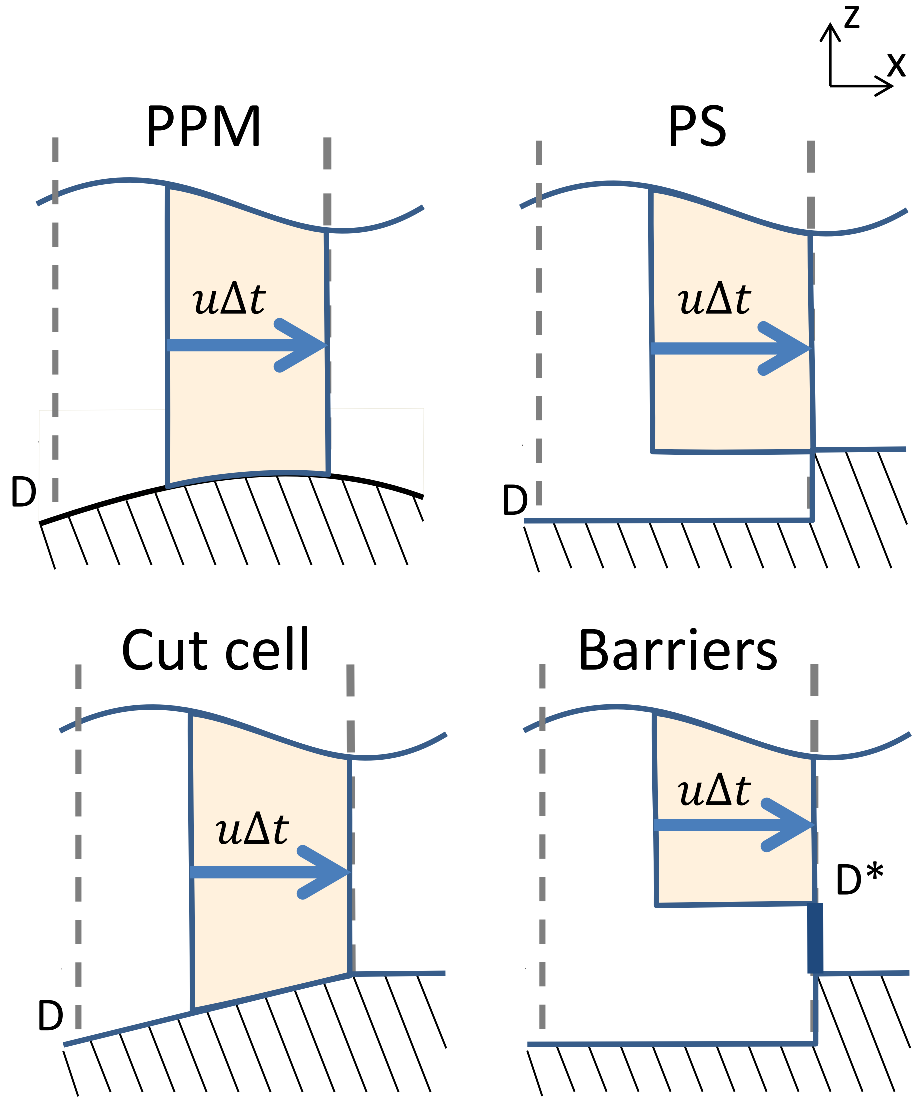


Choices about depth data make a big difference

General convergence*

SWE upstream mass flux

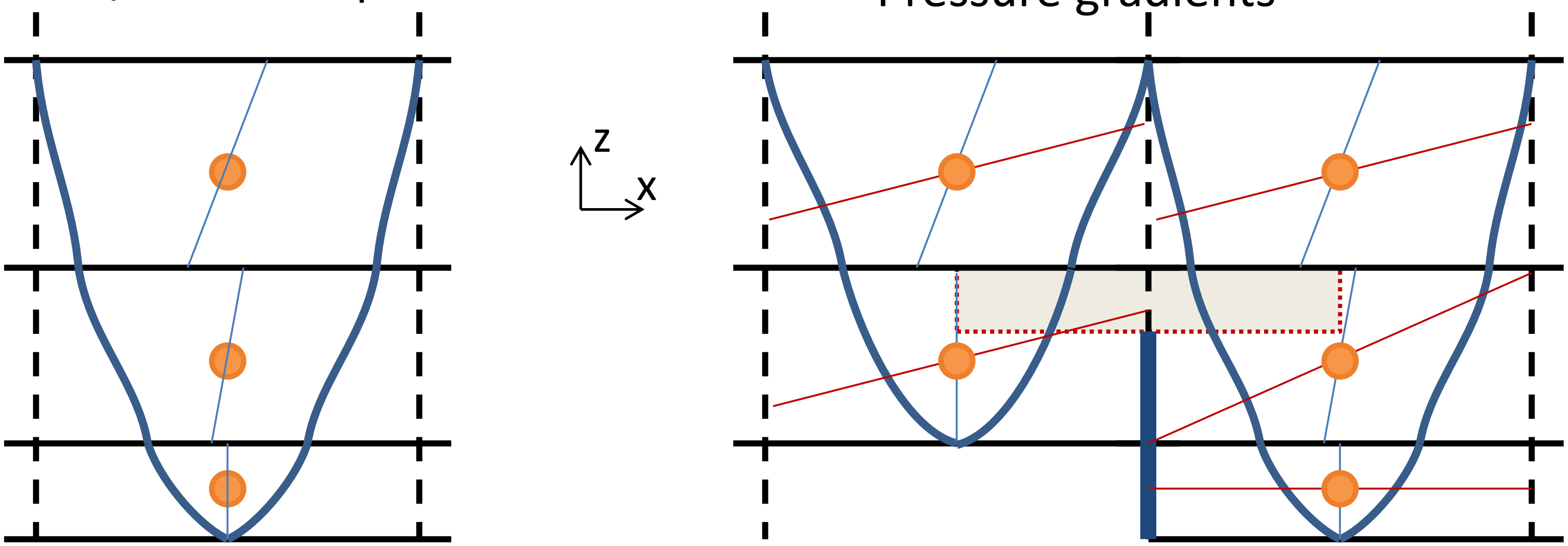
- PPM/PCM reconstruct total column thickness
- Cut cell prescribes shape of lower surface
- Similarly, porous barriers dictate an “overflow” depth
  - assumed constant upstream
- Using spatial average depth for D* gives most accurate wave speed



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, <u>not</u> 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.