An Update on Modeling Land-Ice/ Ocean Interactions in CESM

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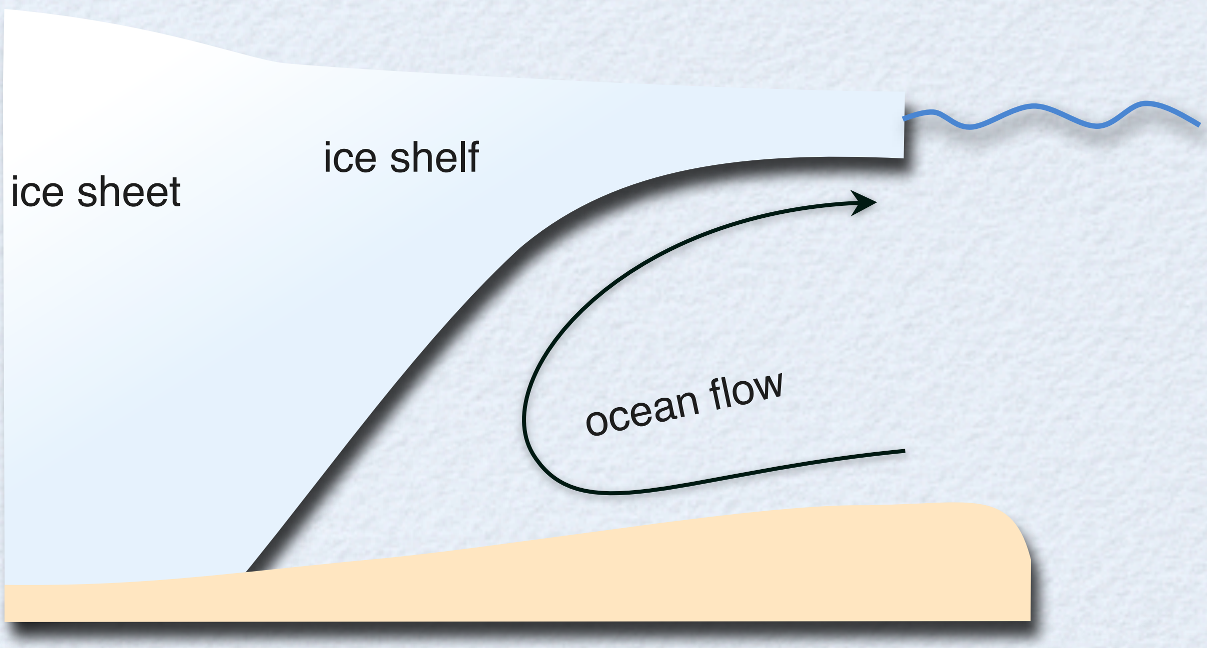
OUTLINE

- Ice-shelf/Ocean Coupling
- Boundary Conditions
- Challenges with the Immersed Boundary Method
- A New Partial Cells Approach



ICE-SHELF/OCEAN COUPLING

Challenging Physics:

- Many length scales
-
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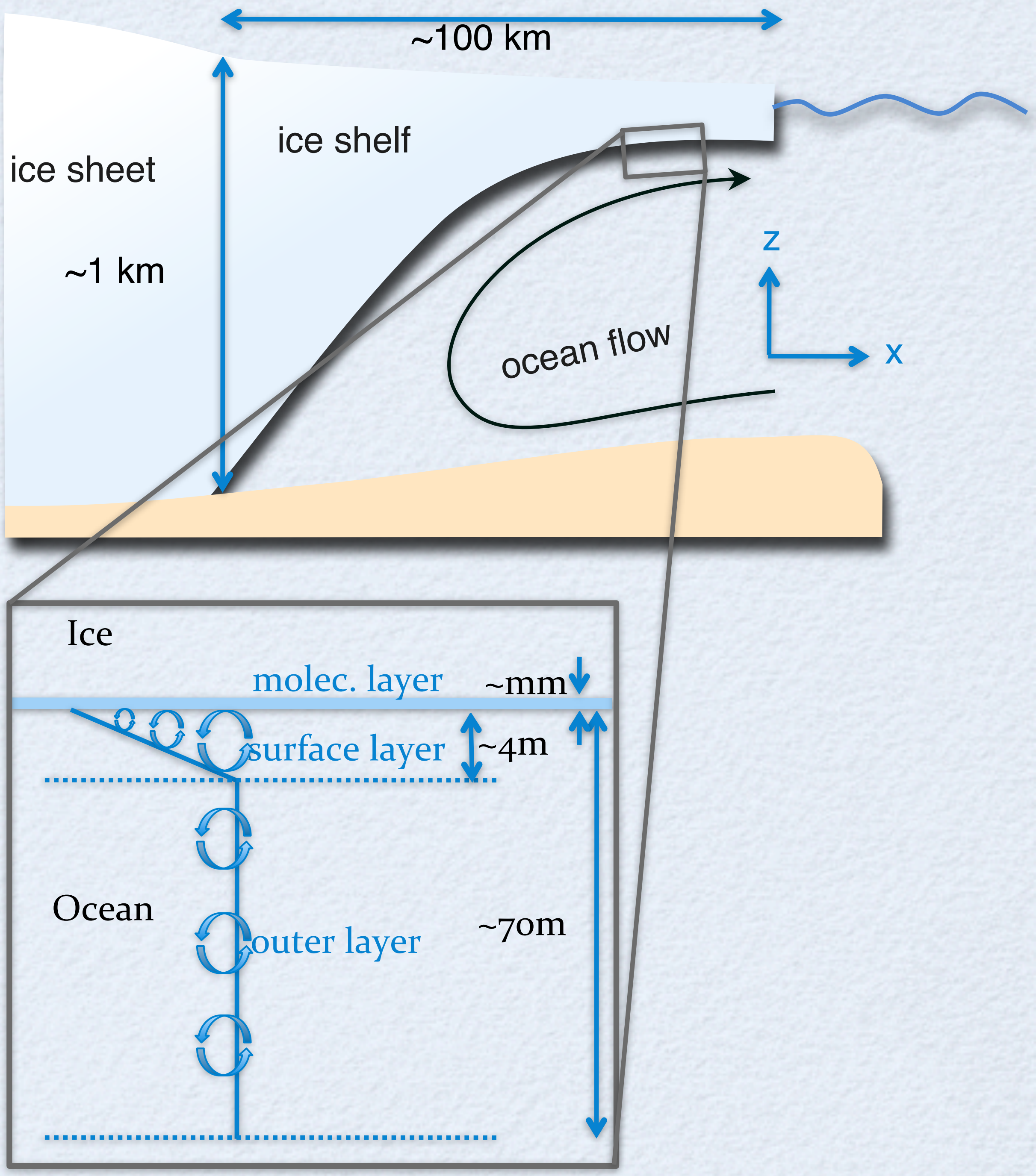
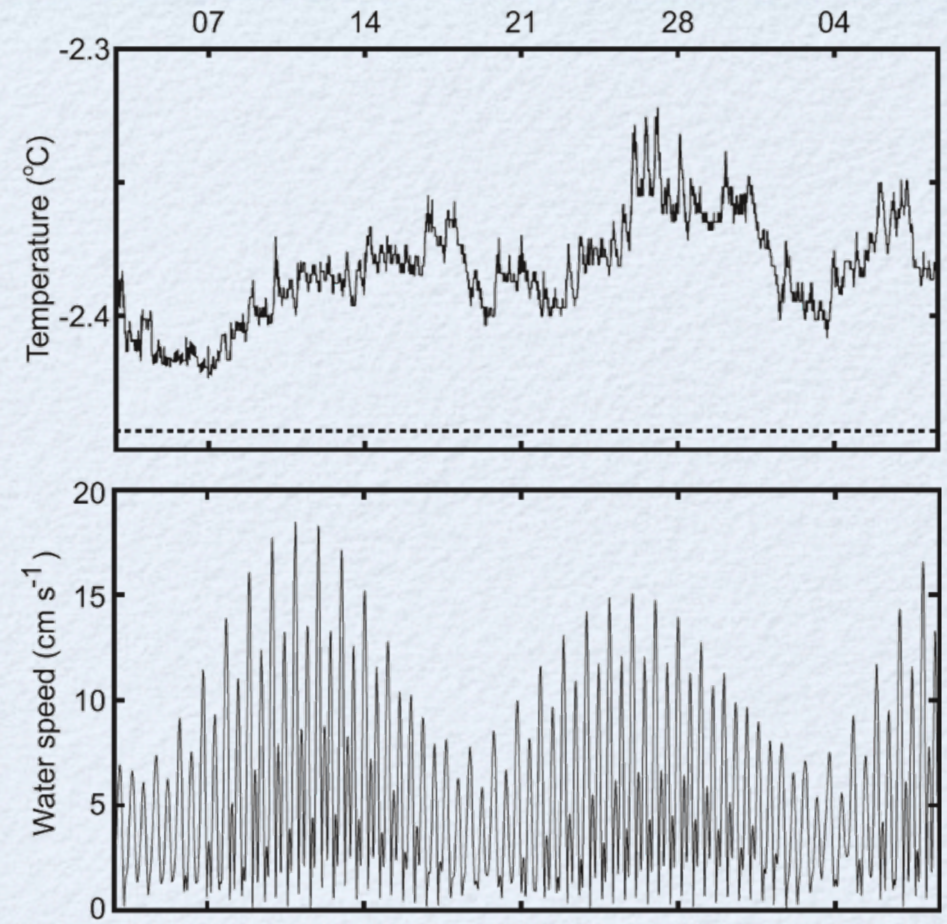


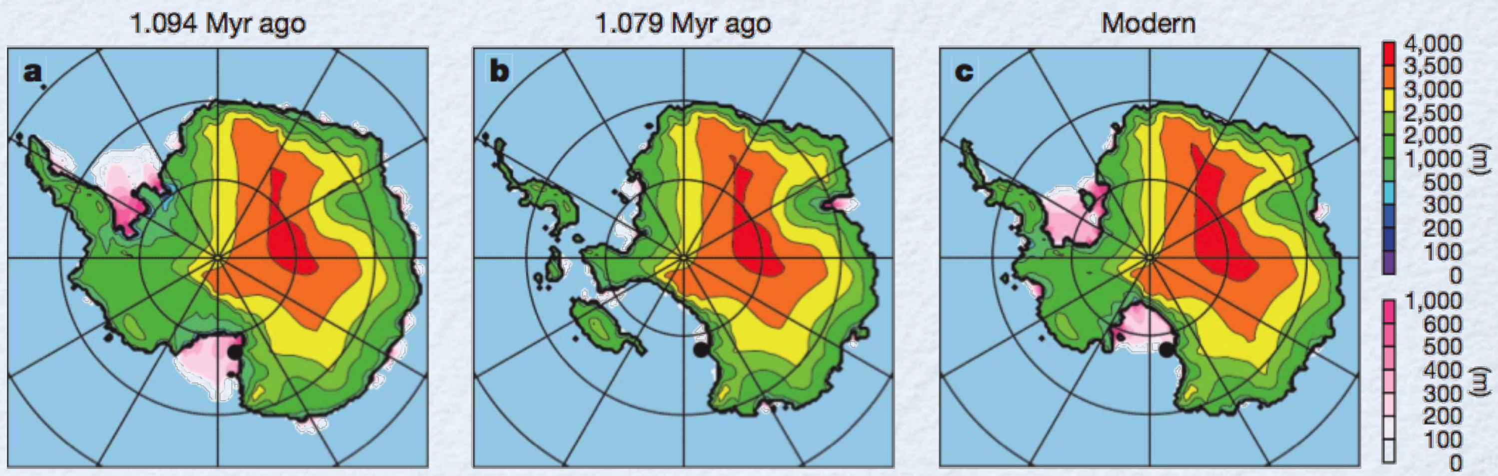
Ice -Shelf/Ocean Coupling



Jenkins et al. 2010

Challenging Physics:

- Many length scales
- Many time scales
-

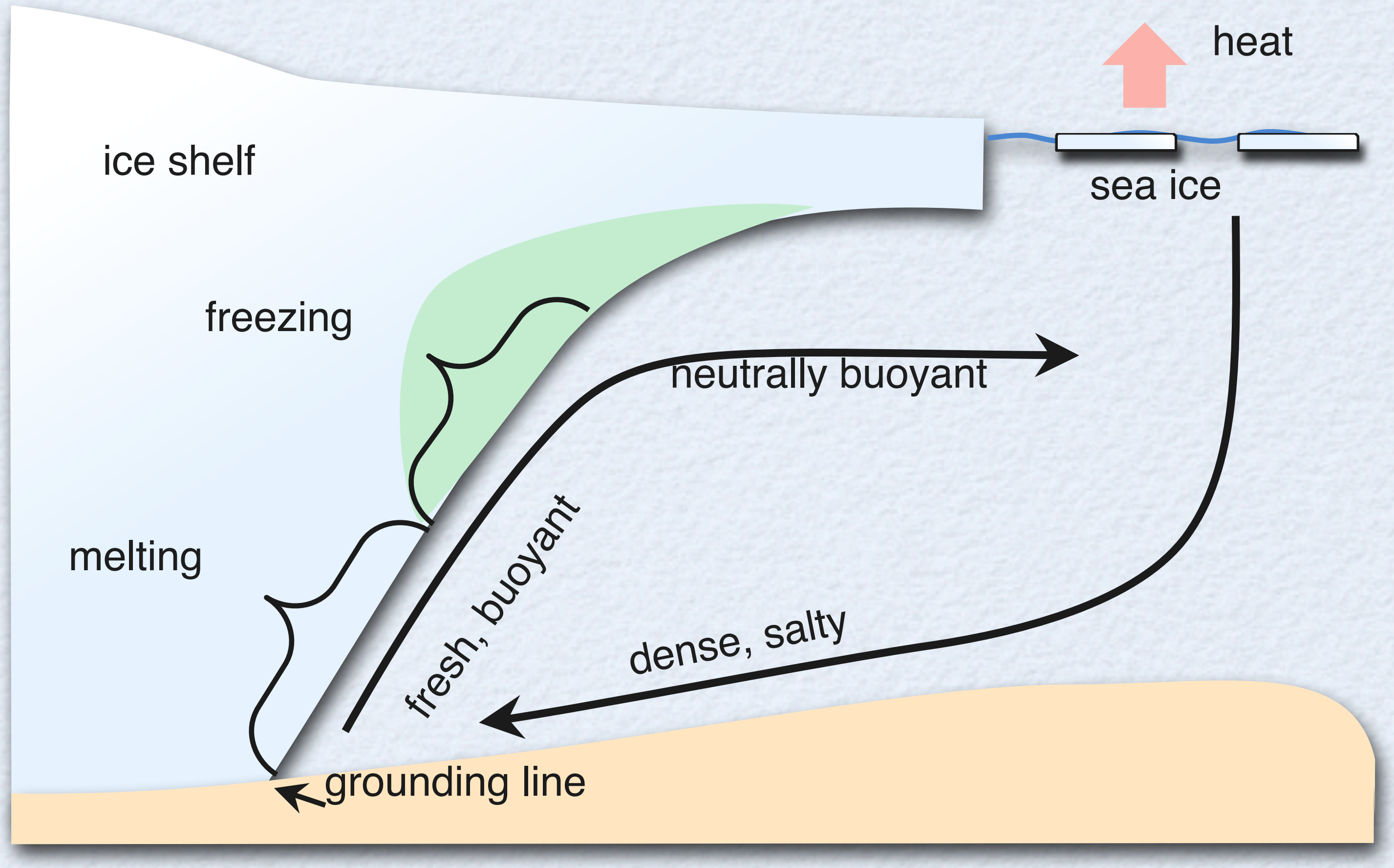


Pollard and DeConto 2009

ICE/OCEAN COUPLING

Challenging Physics:

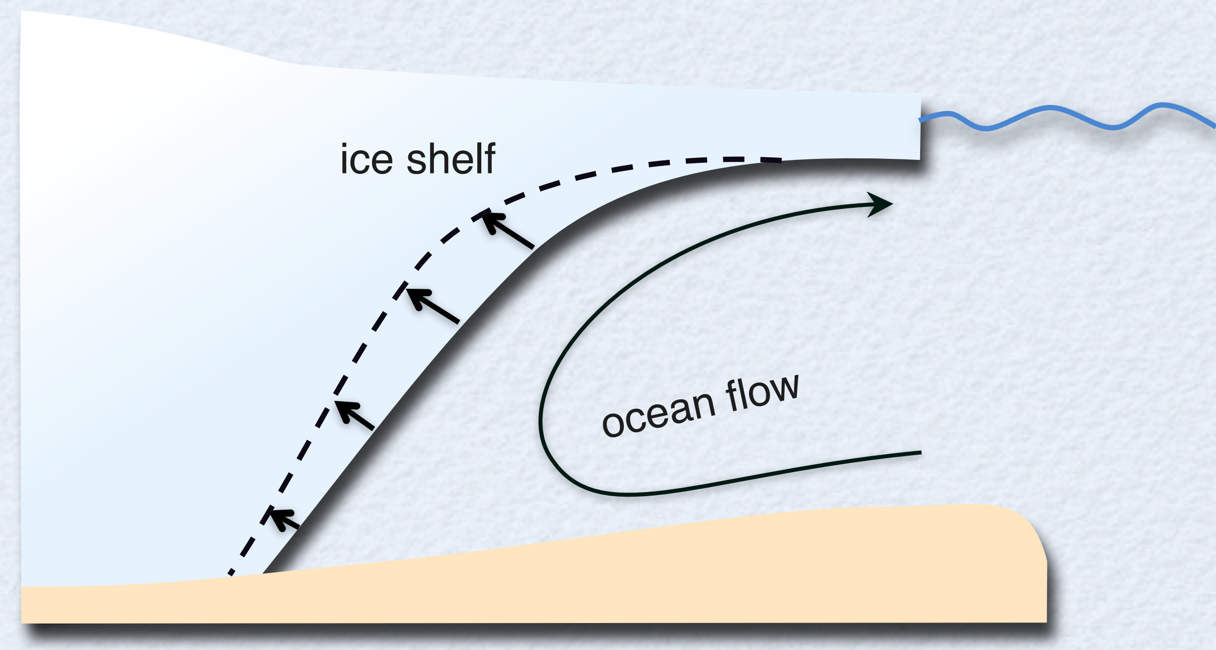
- Many length scales
- Many time scales
- Many processes

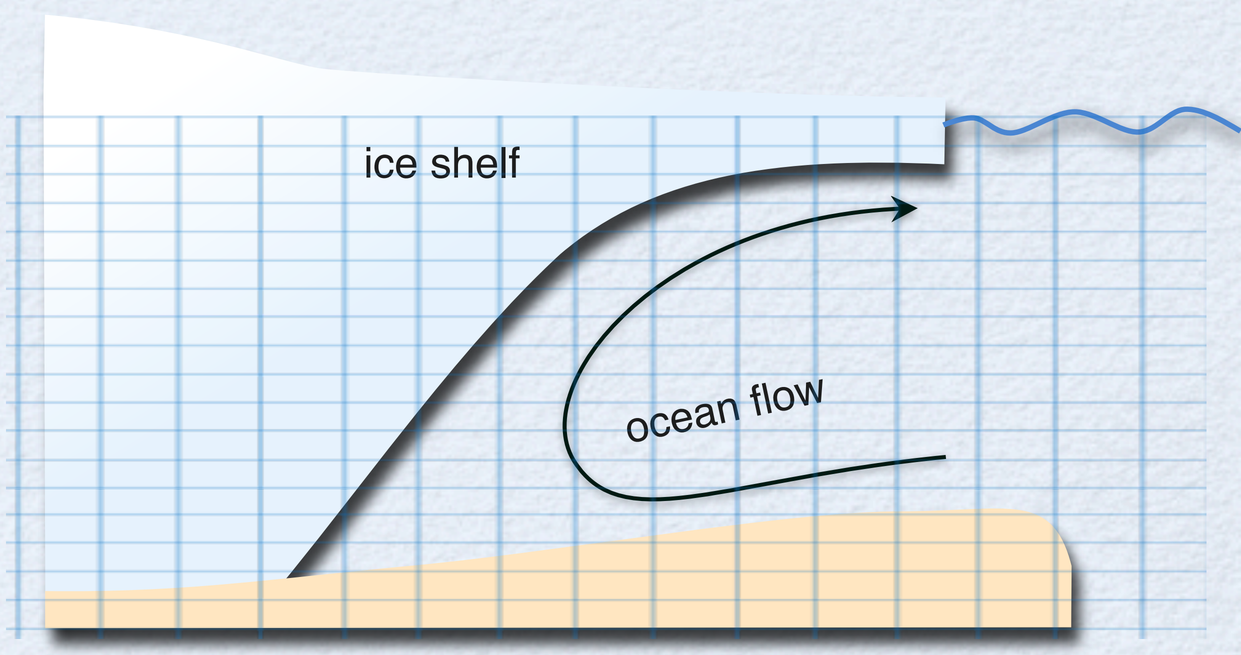


ICE/OCEAN COUPLING

Challenging Numerics:

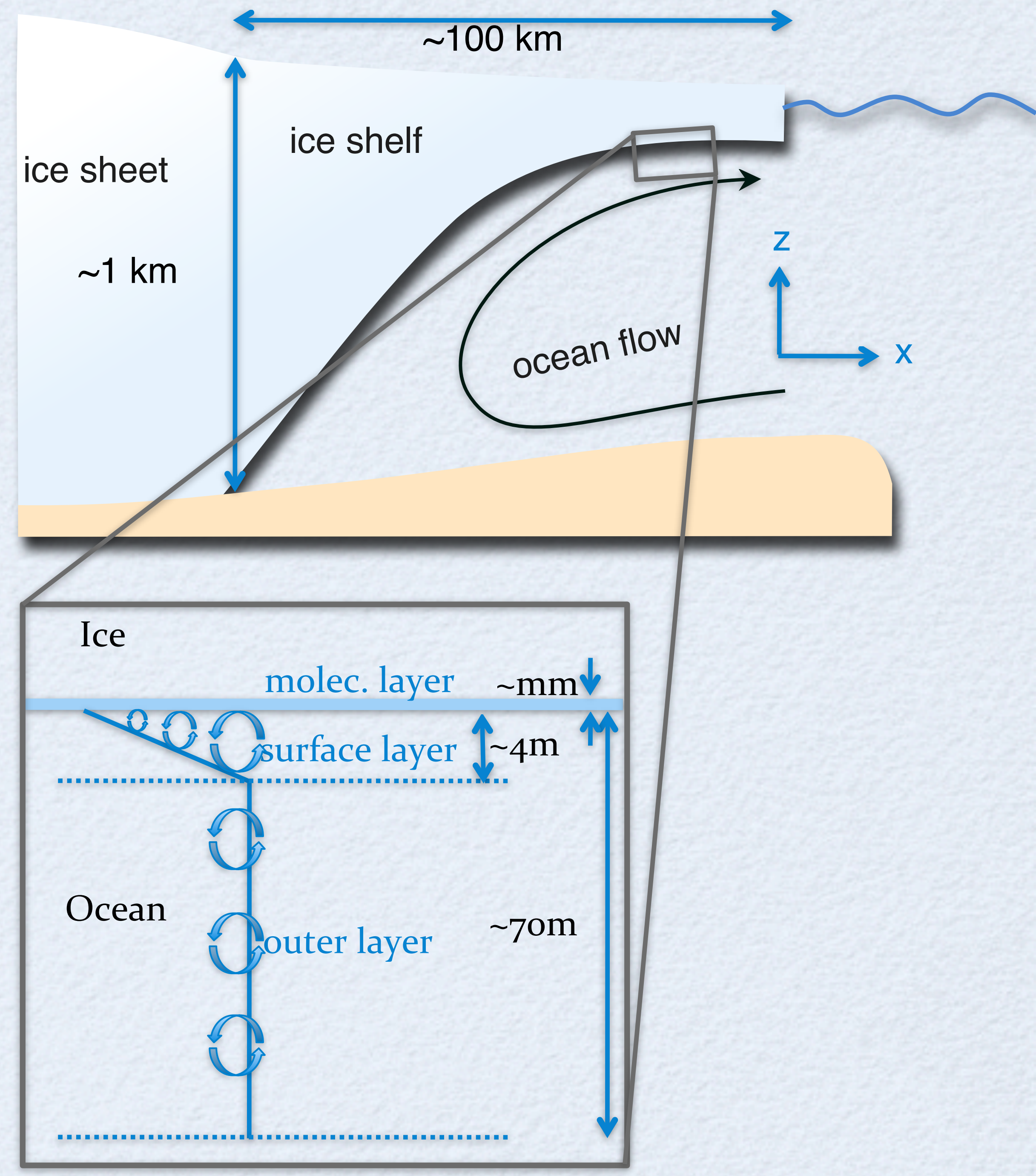
- Moving boundaries
- Anisotropic grids $(\Delta x \gg \Delta z)$
- Under-resolved physics





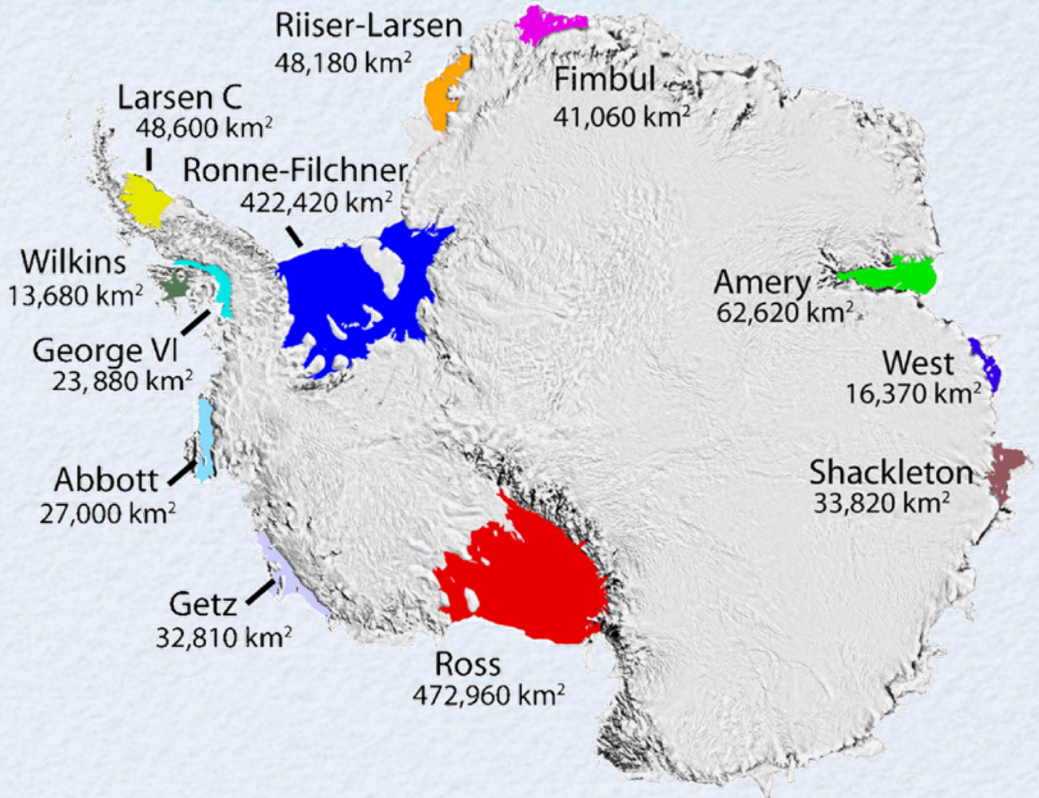
Boundary Layer Physics

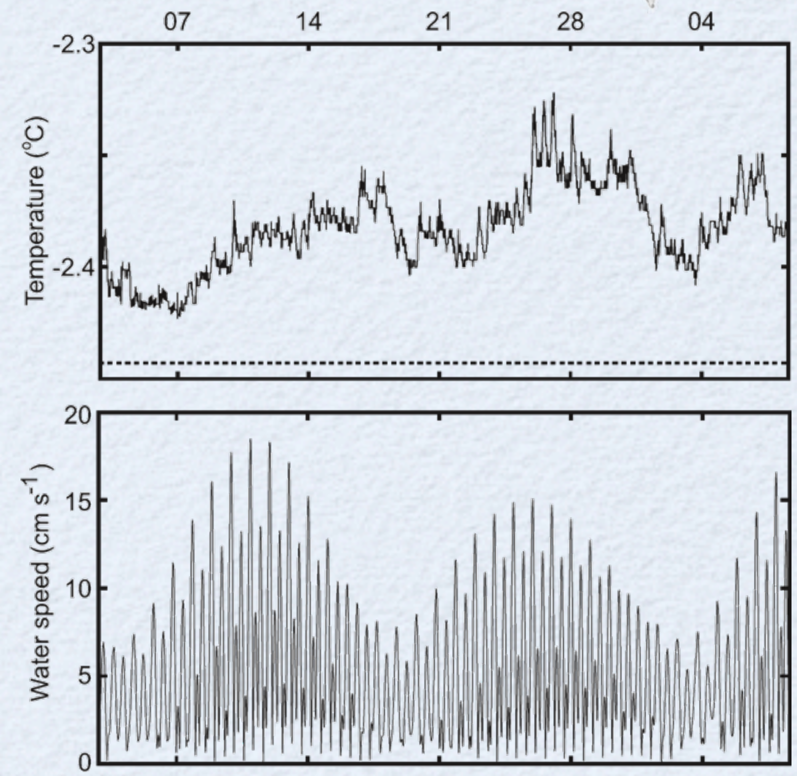
- Simplified version of McPhee 2008 boundary layer model for sea ice
- Gives **heat, salt, momentum** and **mass fluxes** at the interface
- Includes **stratification**, very important for rapid melting



Boundary Layer Physics

- Unknown coefficients are calibrated based on measurements under Ronne Ice Shelf (Jenkins et al. 2010)
- More calibration data expected in coming years (Fimbul, Larsen C and George VI Ice Shelves)

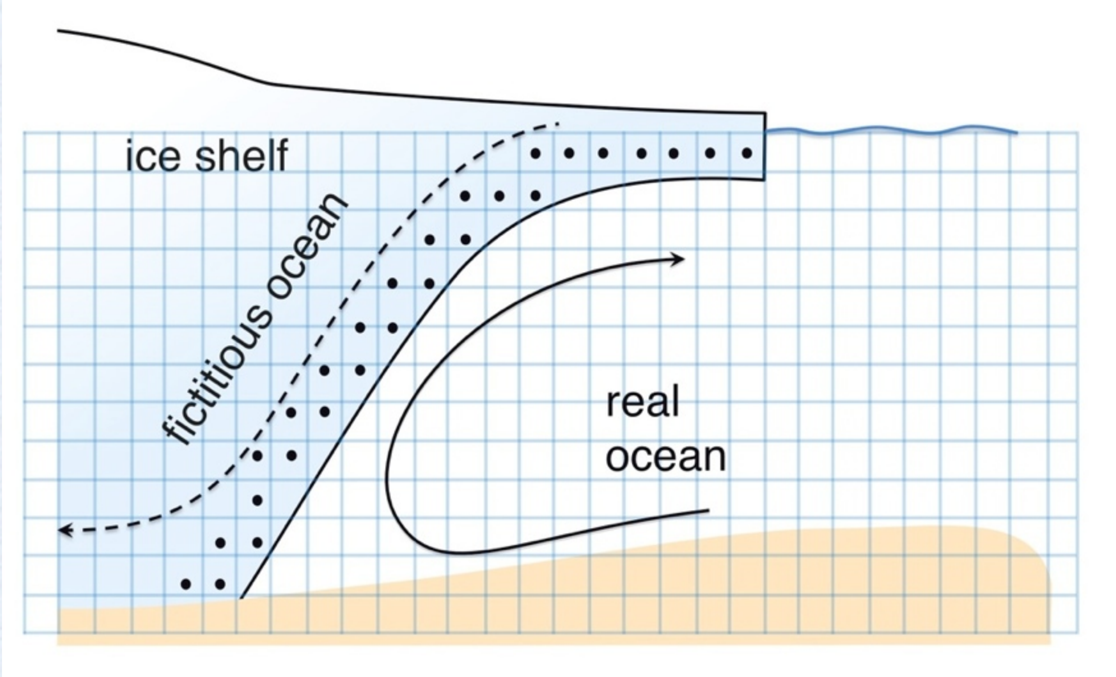


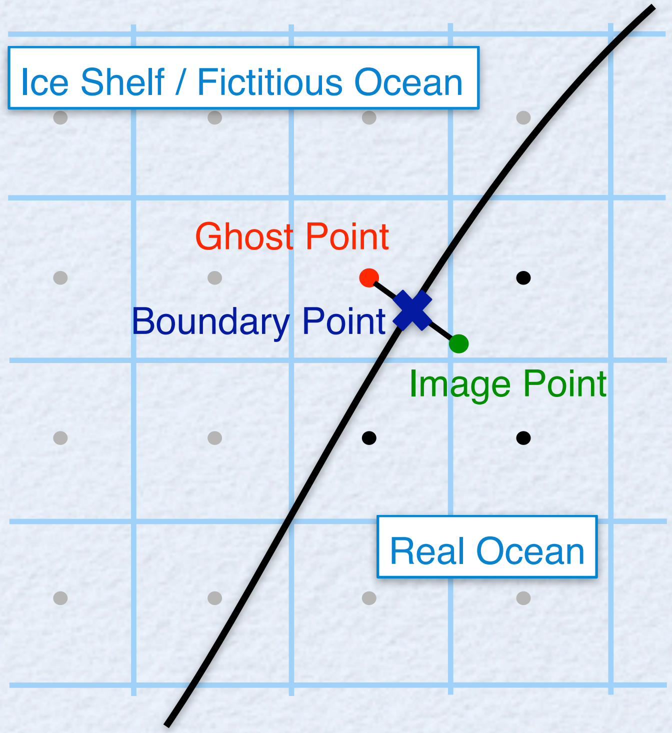


Jenkins et al. 2010

Immersed Boundary Method

- Handle complex, moving boundaries on constant grids (including calving front)
- Boundary conditions by forcing a fictitious flow
- Extrapolate fluid values from image points to ghost points using boundary conditions (mass, heat and salt fluxes)

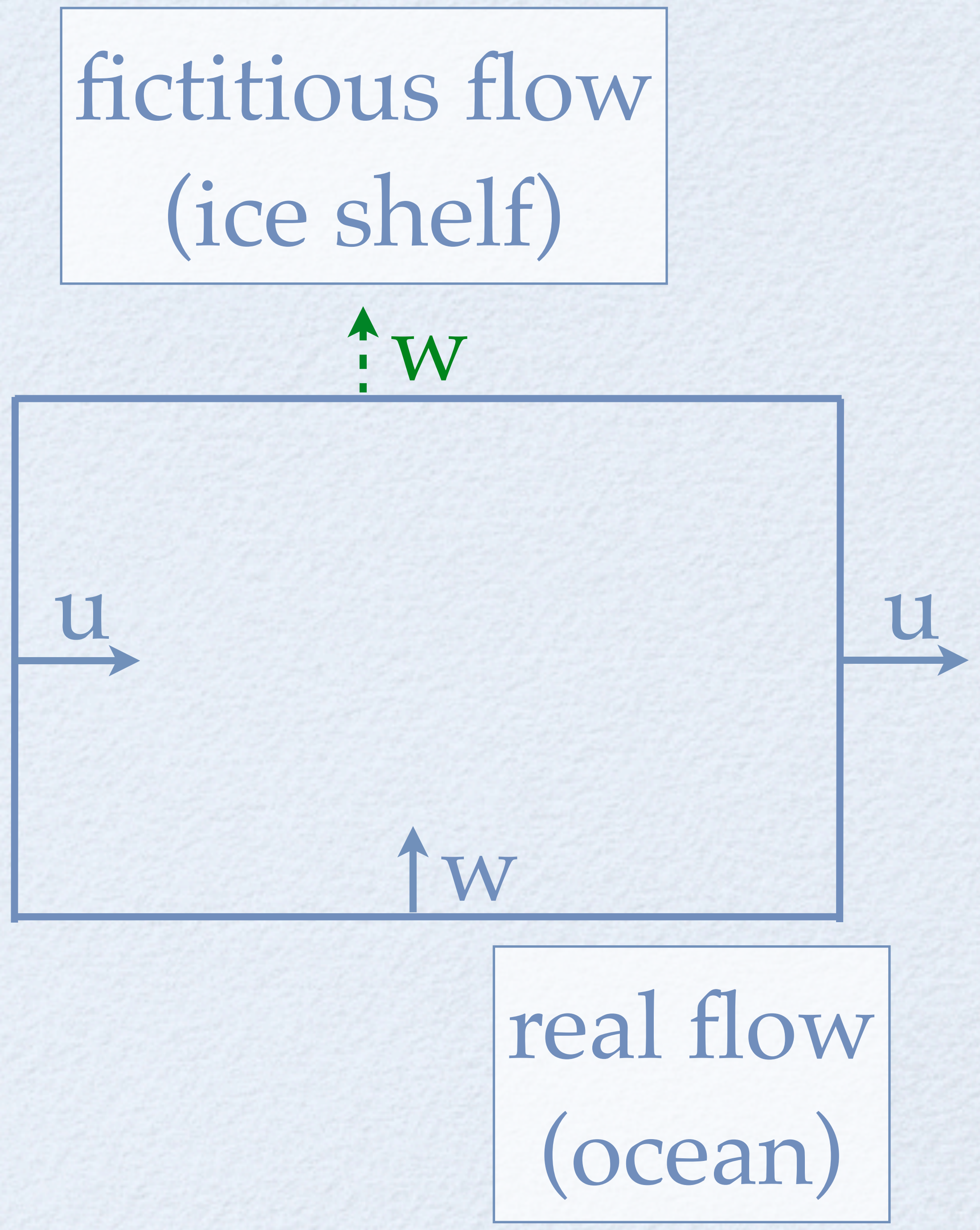




Challenges

Continuity:

- w at the top of the cell found by continuity (sum of fluxes is zero)



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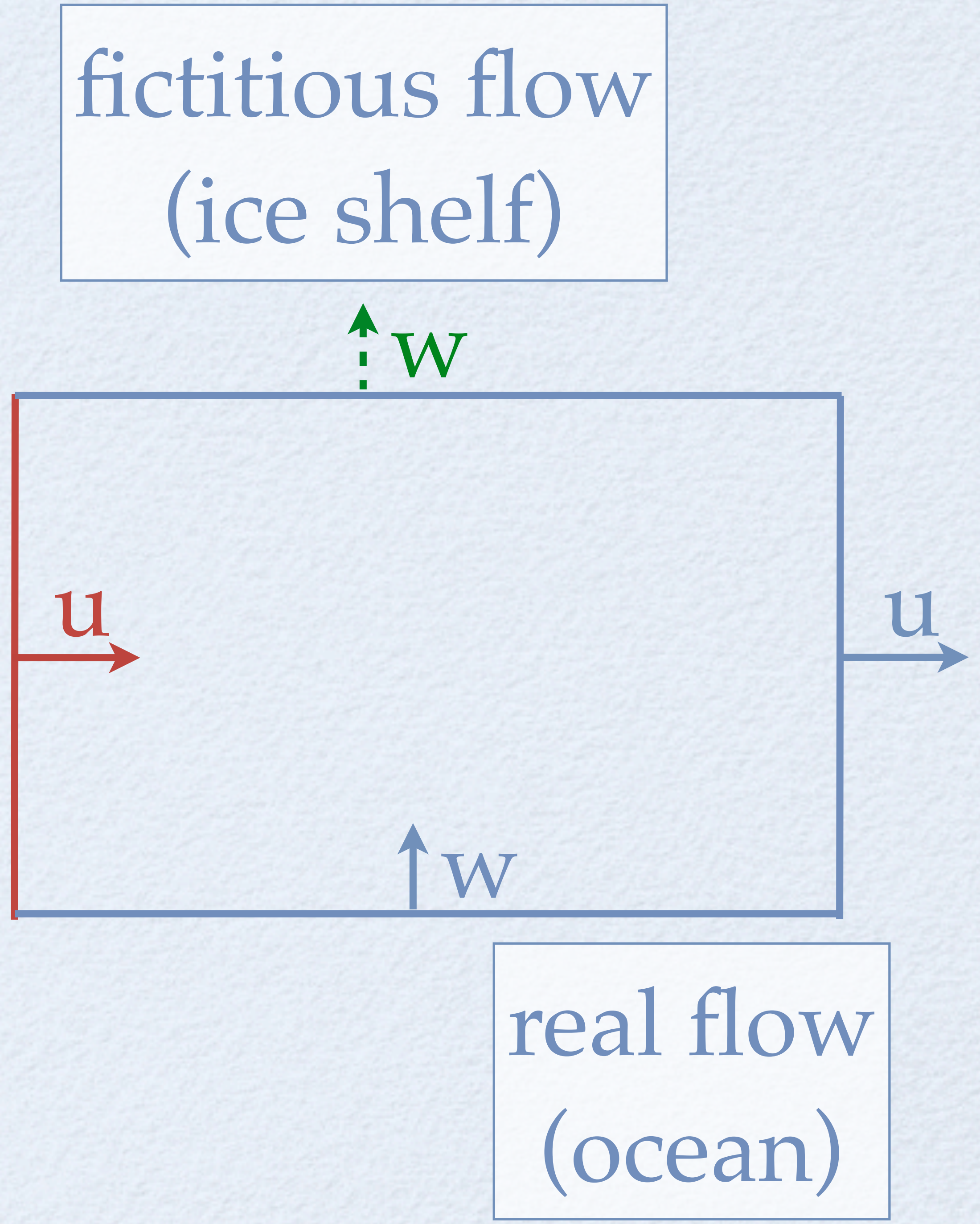

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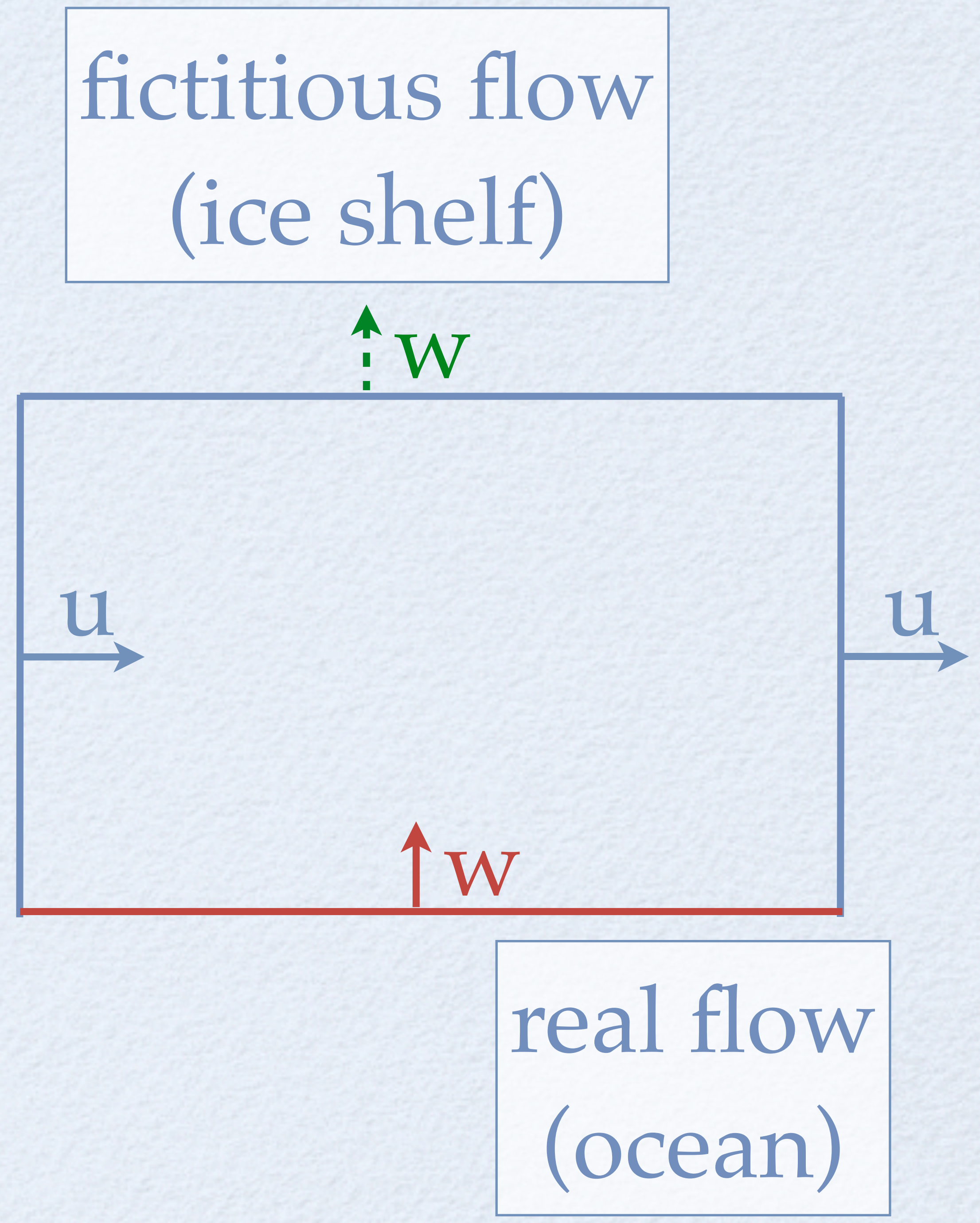

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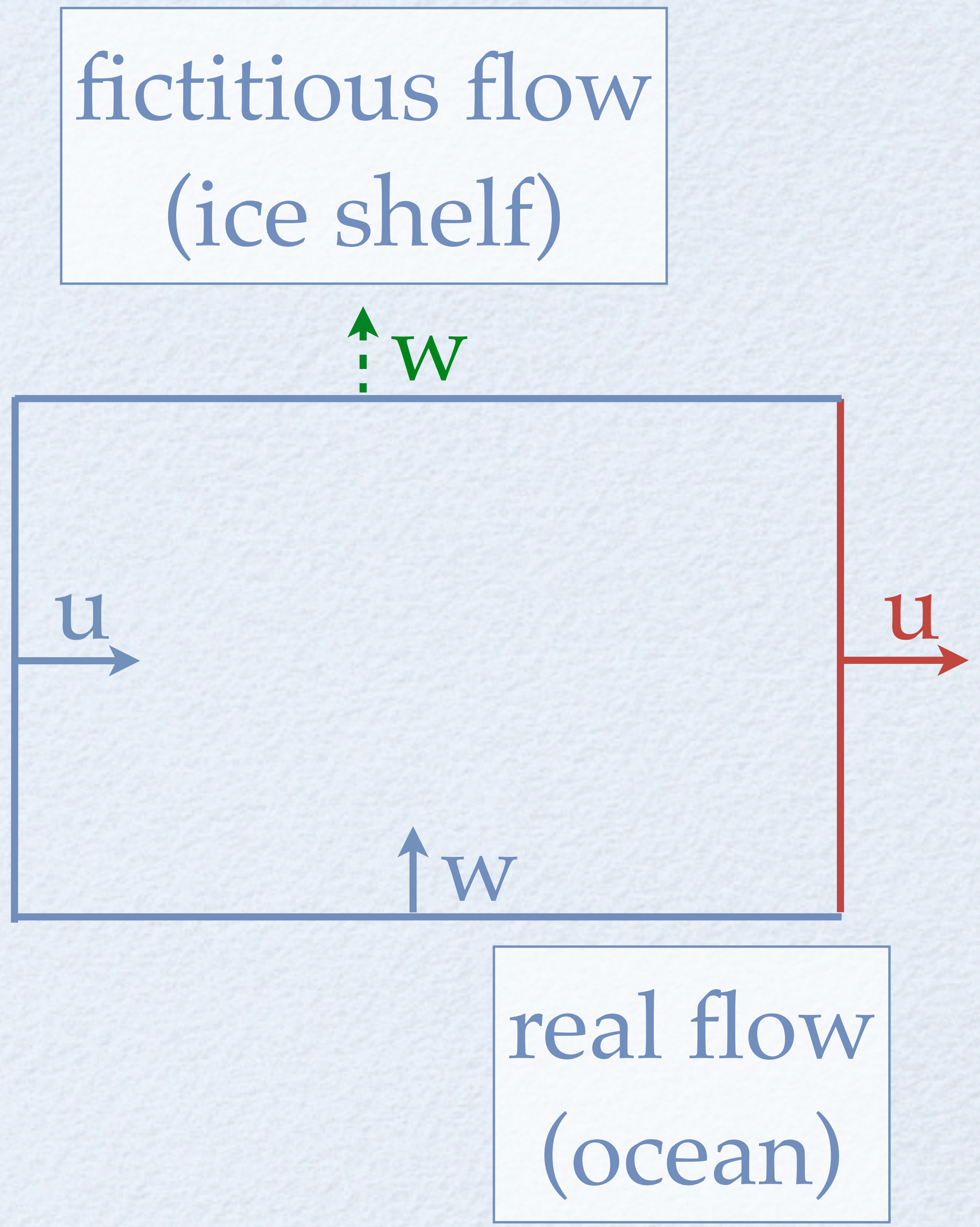

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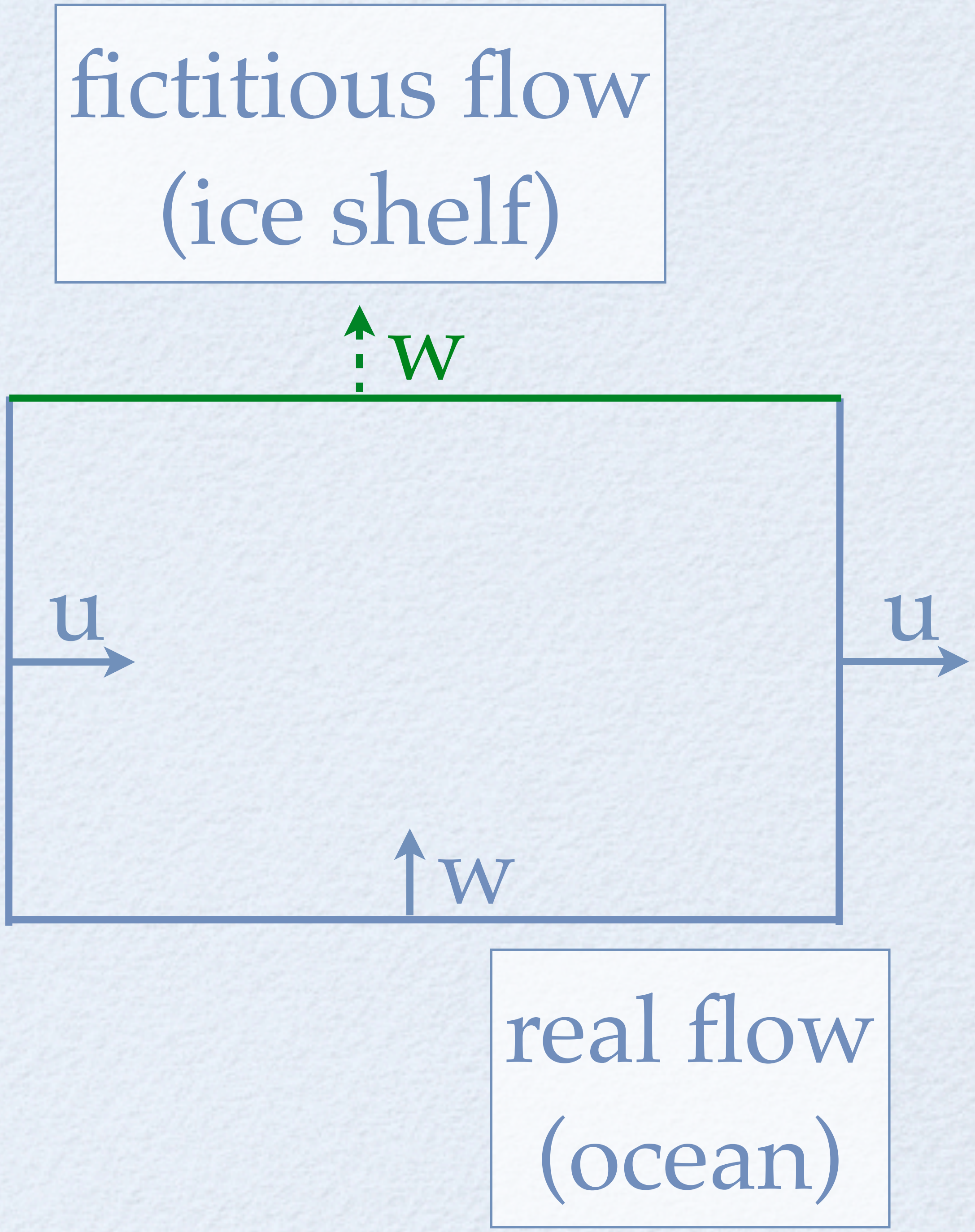
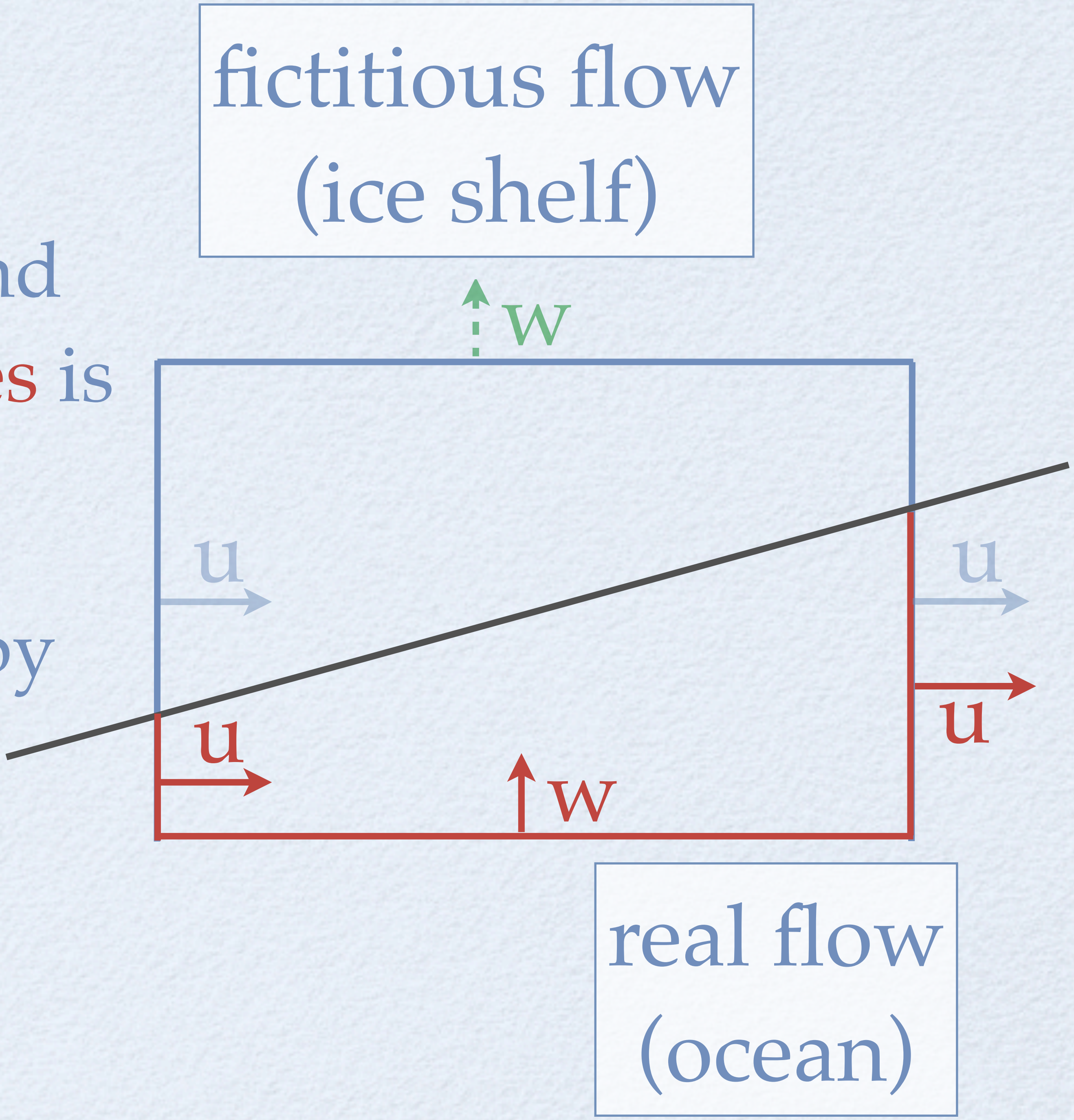


Challenges

Continuity:

- w at the top of the cell found by continuity (sum of fluxes is zero)
- Normal velocity u_n found by fluxes in real flow only



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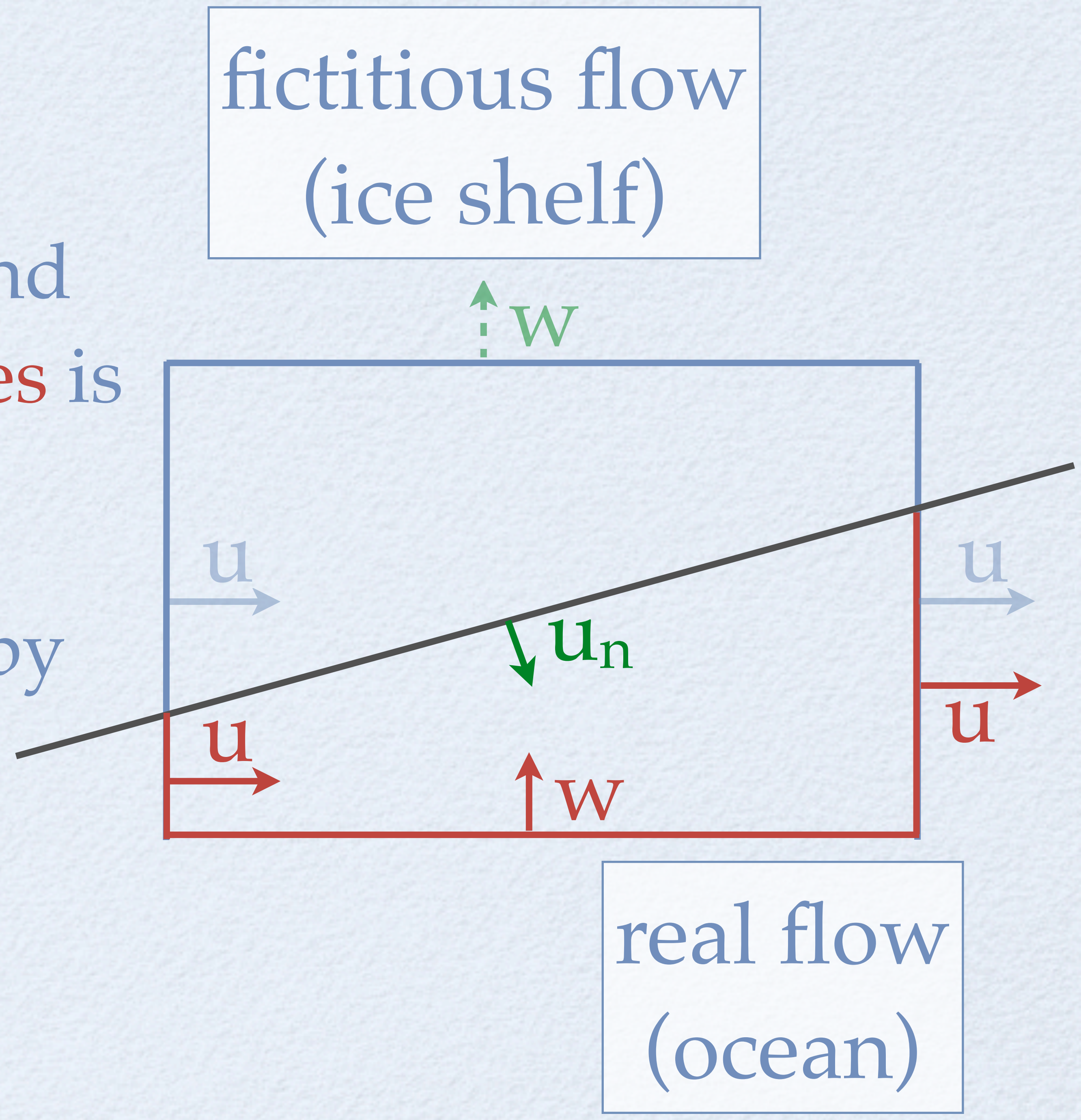
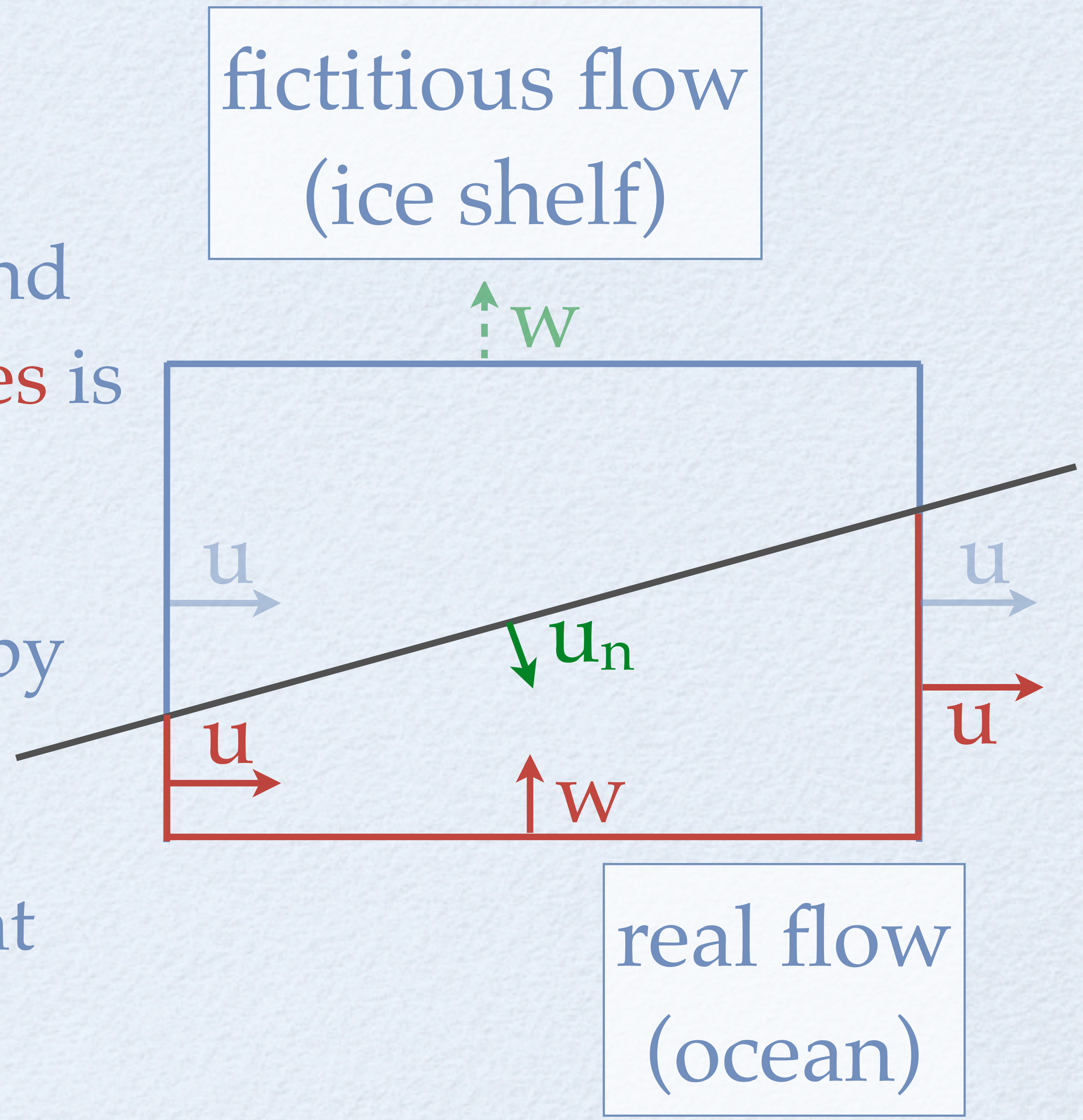


Challenges

Continuity:

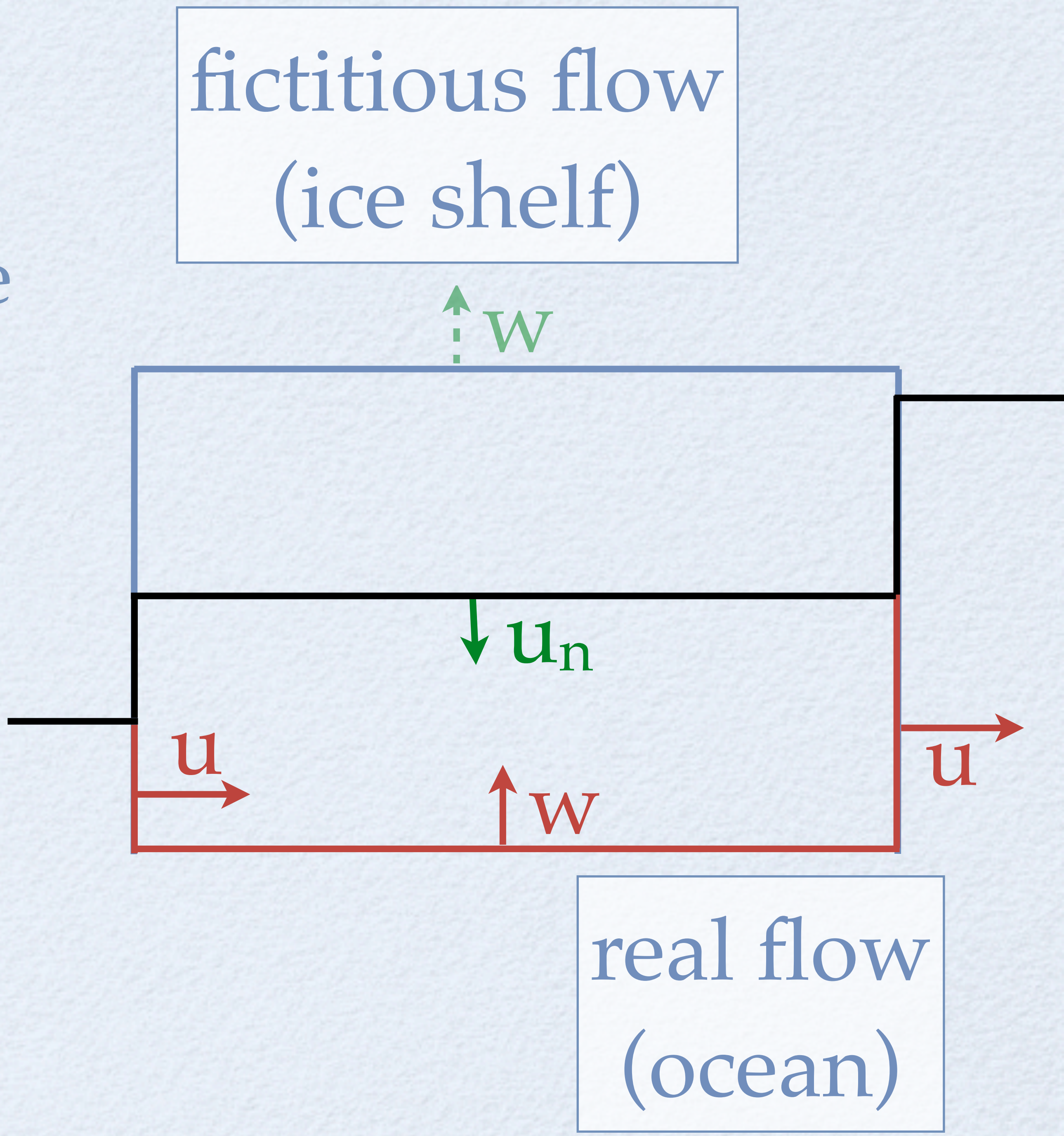
- w at the top of the cell found by continuity (sum of fluxes is zero)
- Normal velocity u_n found by fluxes in real flow only
- Different flux areas on right and left
- u_n **not** an interpolation of w



Challenges

Continuity:

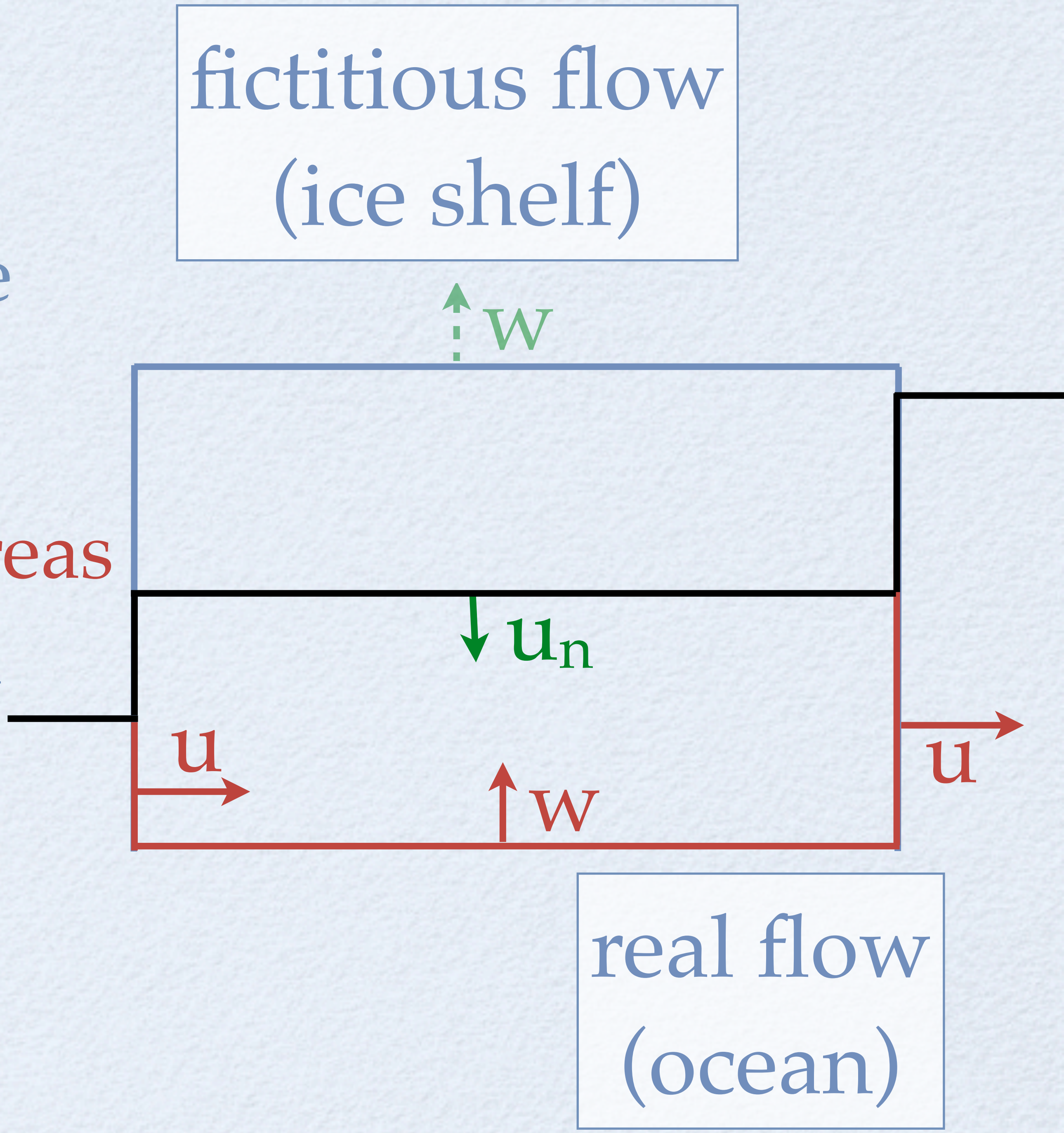
- Partial cells do not solve the problem



Challenges

Continuity:

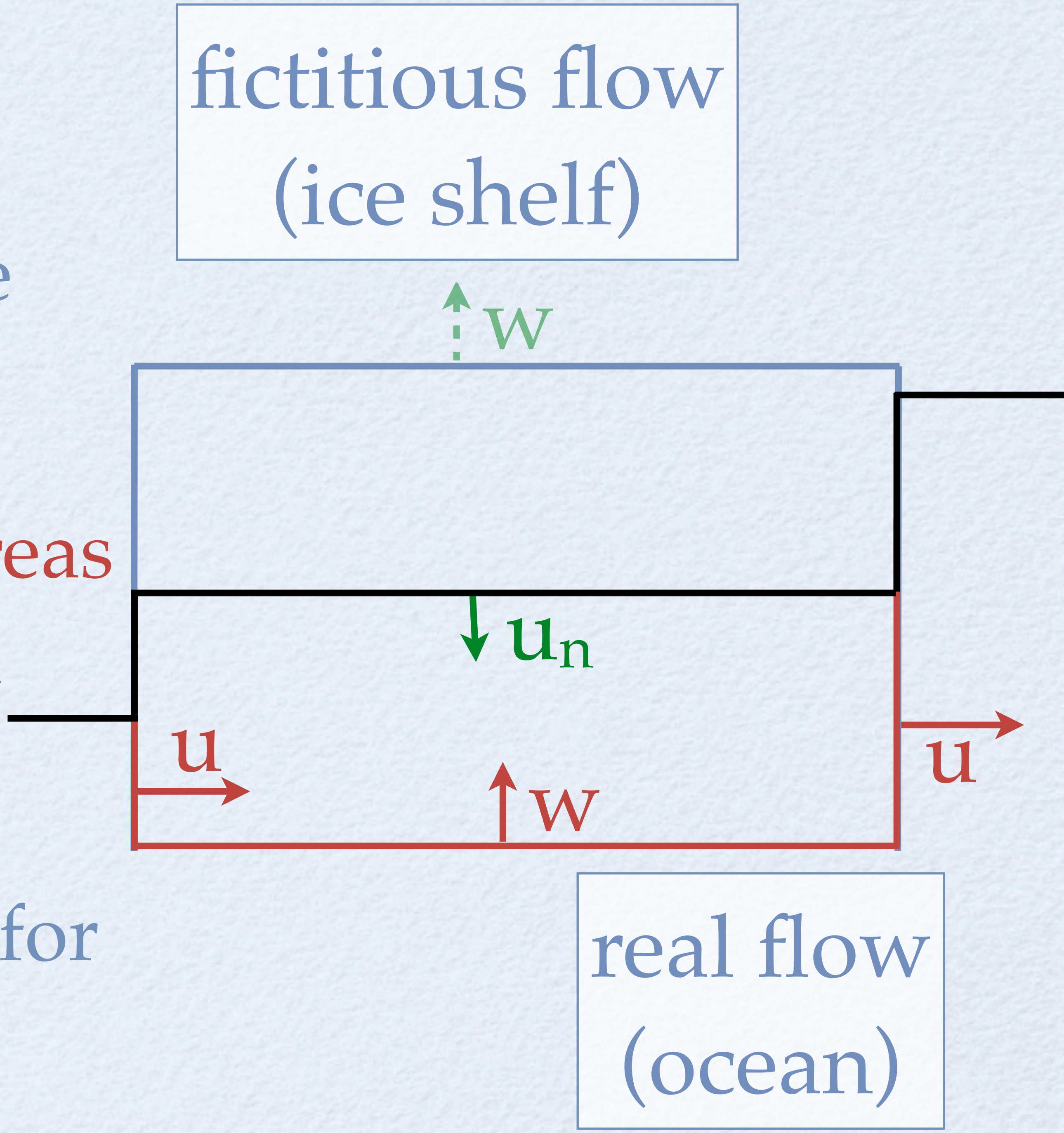
- Partial cells do not solve the problem
- Interface is flat but fluxes areas are still different on left and right



Challenges

Continuity:

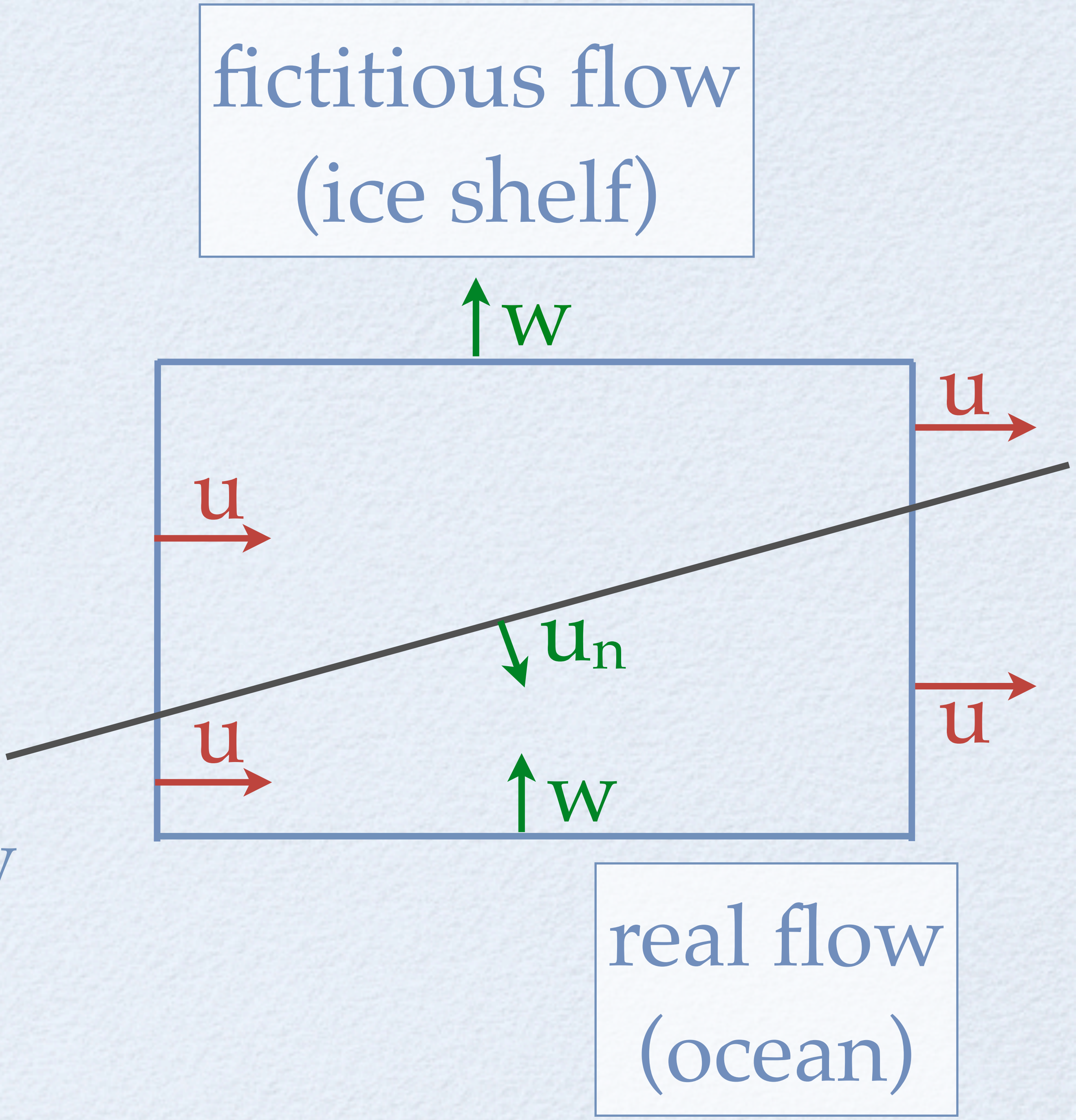
- Partial cells do not solve the problem
- Interface is flat but fluxes areas are still different on left and right
- The flux areas are the same for the full box: u_n is not an interpolation of w and w



Challenges

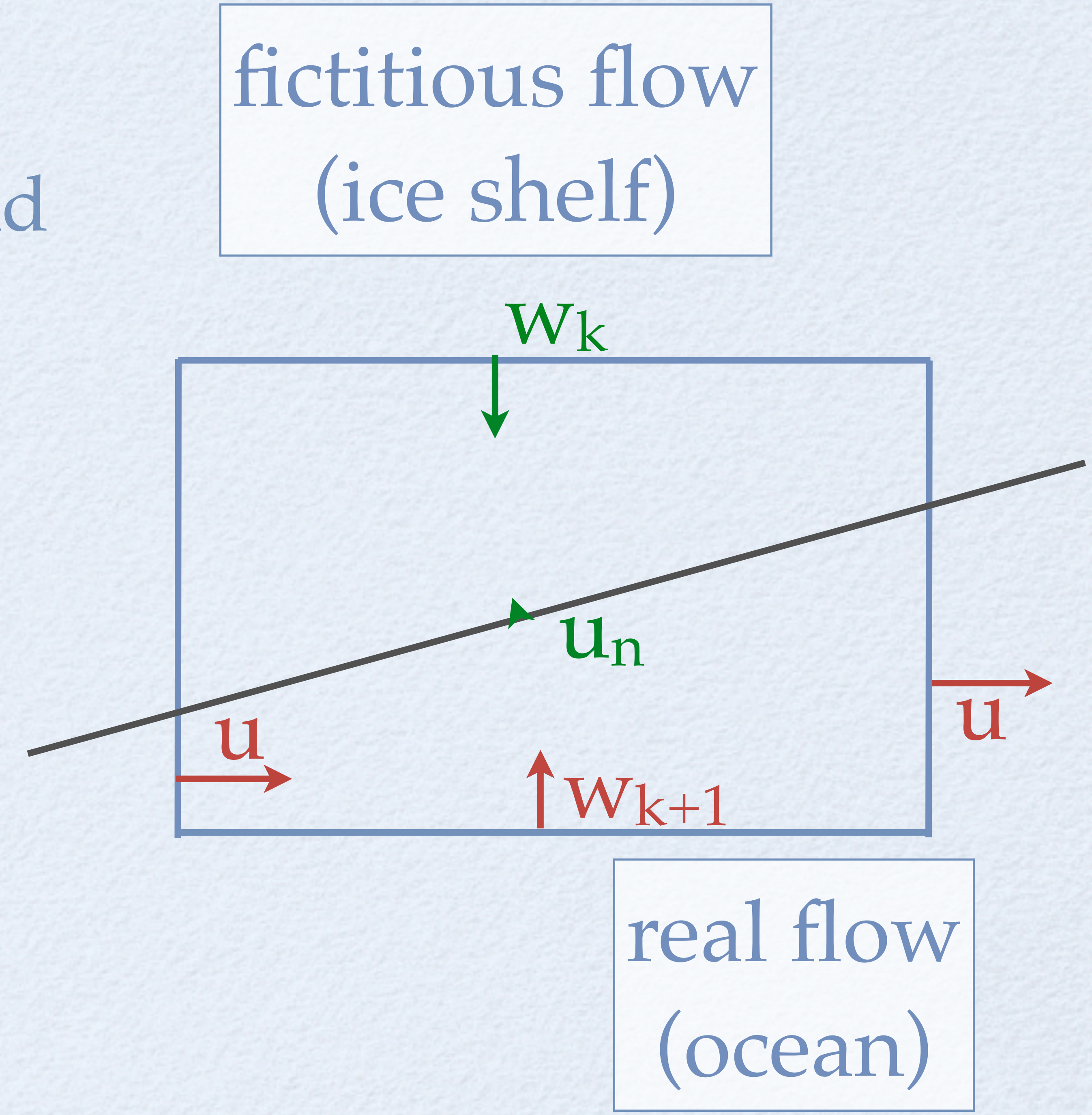
Continuity:

- Separate u's for real and fictitious parts of cut cells would solve *this* problem
- But this would require a **complete redesign** of POP to handle the fictitious flow



Challenges

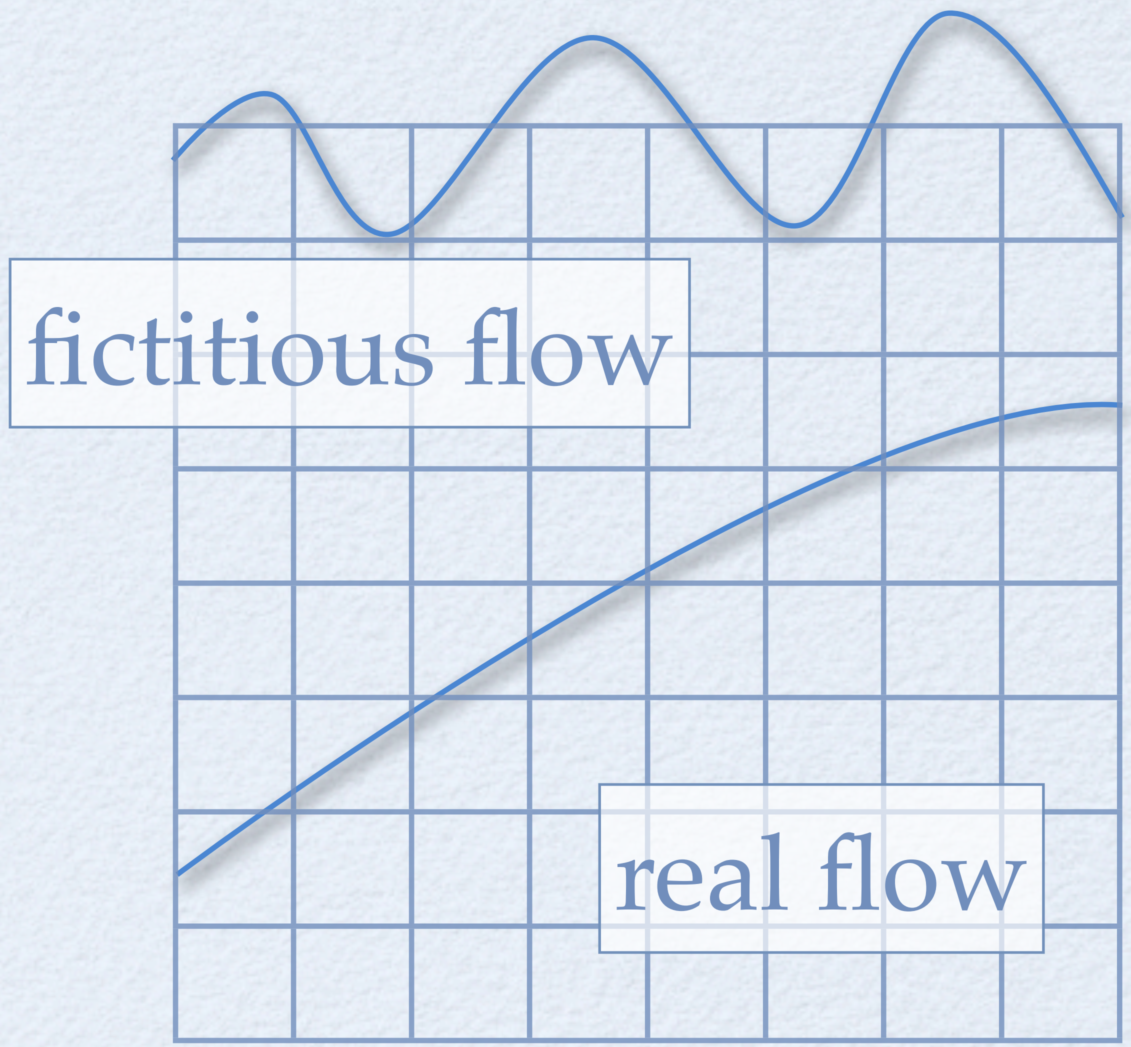
- w_k could be computed so that interpolation of w_k and w_{k+1} gives $u_n \approx 0$
- Allow divergence (ignore continuity) in fictitious flow
- But leads to *very* noisy w
- Wildly unphysical tracer advection in fictitious flow



Challenges

Fictitious surface height:

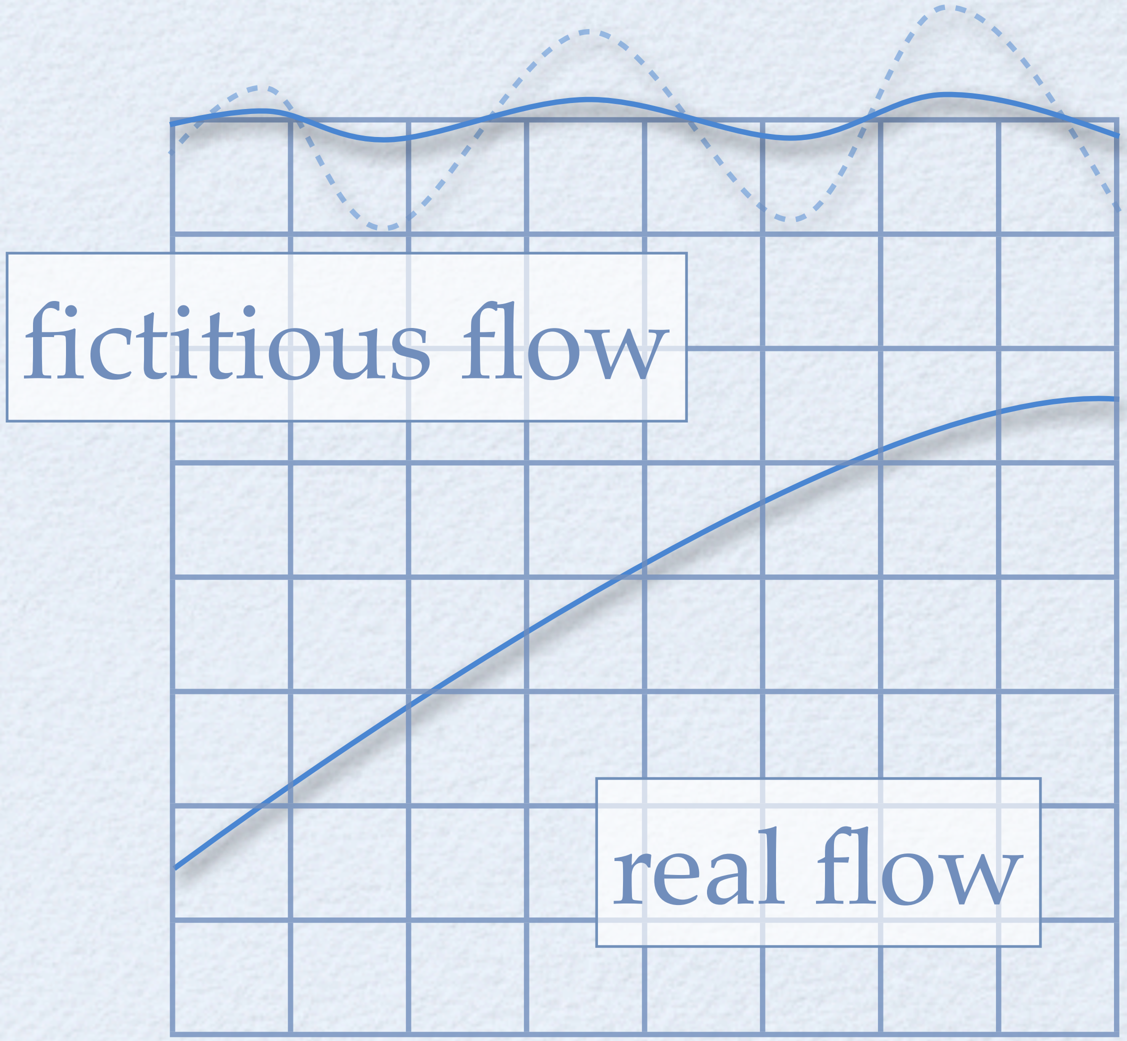
- **not** constrained by barotropic solver



Challenges

Fictitious surface height:

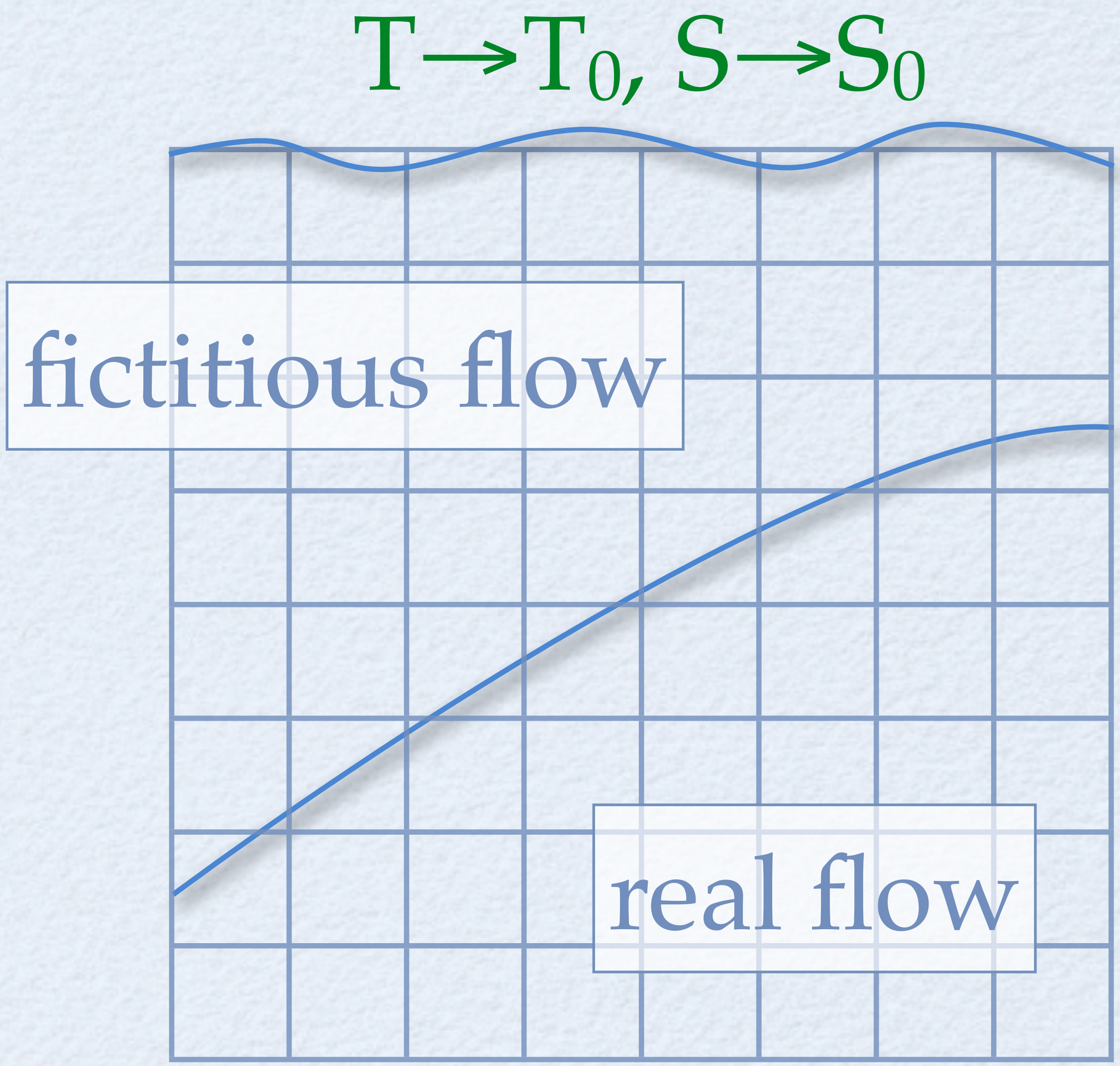
- **not** constrained by barotropic solver
- can be constrained by modifying fictitious horizontal velocities



Challenges

Fictitious surface height:

- **not** constrained by barotropic solver
- can be constrained by modifying fictitious horizontal velocities
- Instability unless T/S are restored at the surface

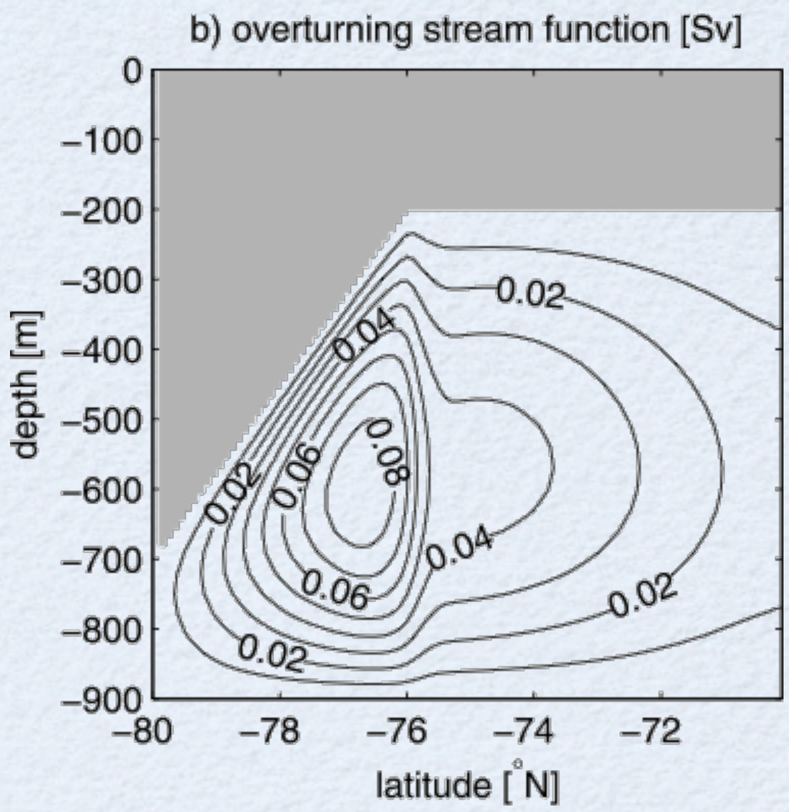


Challenges

It seems that the fictitious flow isn't worth the trouble!

A New Approach

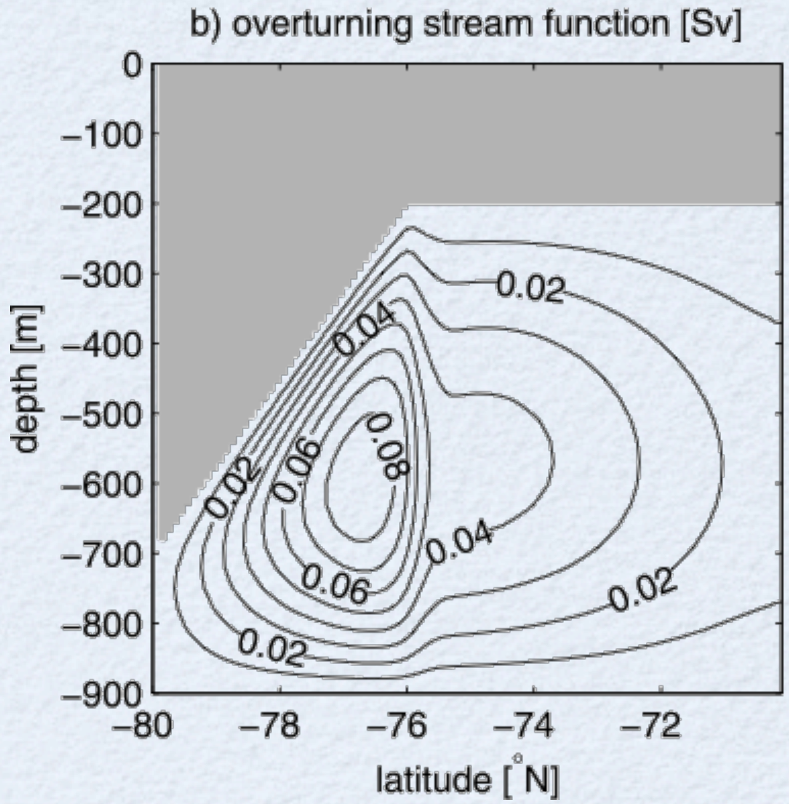
- Interface by partial cells
- No fictitious flow
- Based on Losch 2008: static ice shelves in MITgcm



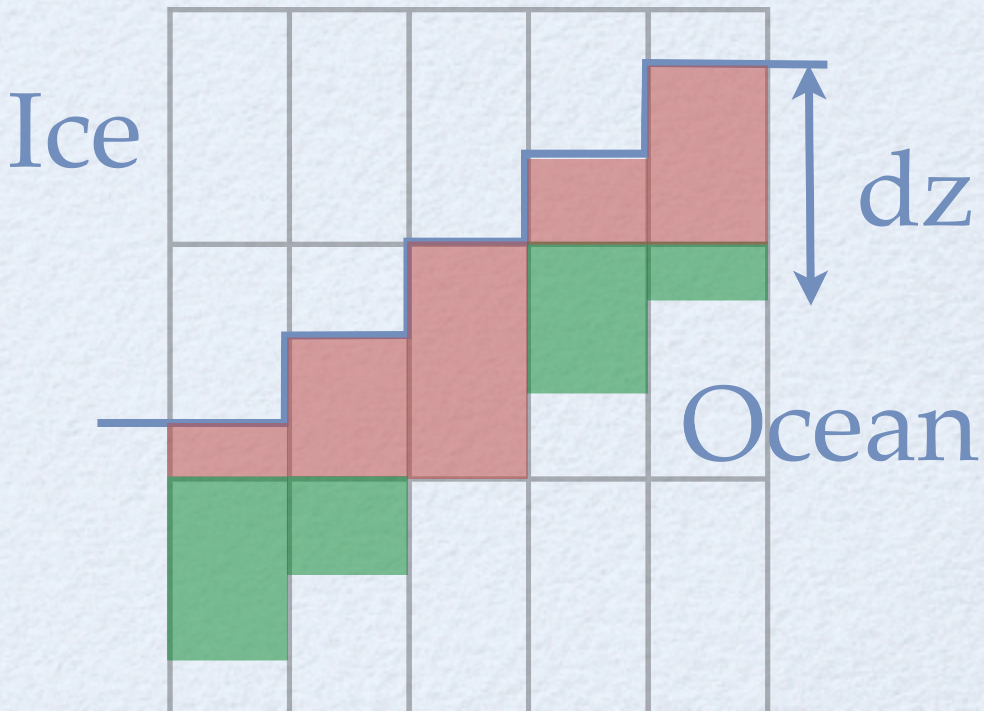
Losch 2008

A NEW APPROACH

- Interface by partial cells
- No fictitious flow
- Based on Losch 2008: static ice shelves in MITgcm
- Salt/heat from melting/freezing mixes into both partial cell and next cell below (reduces noise)

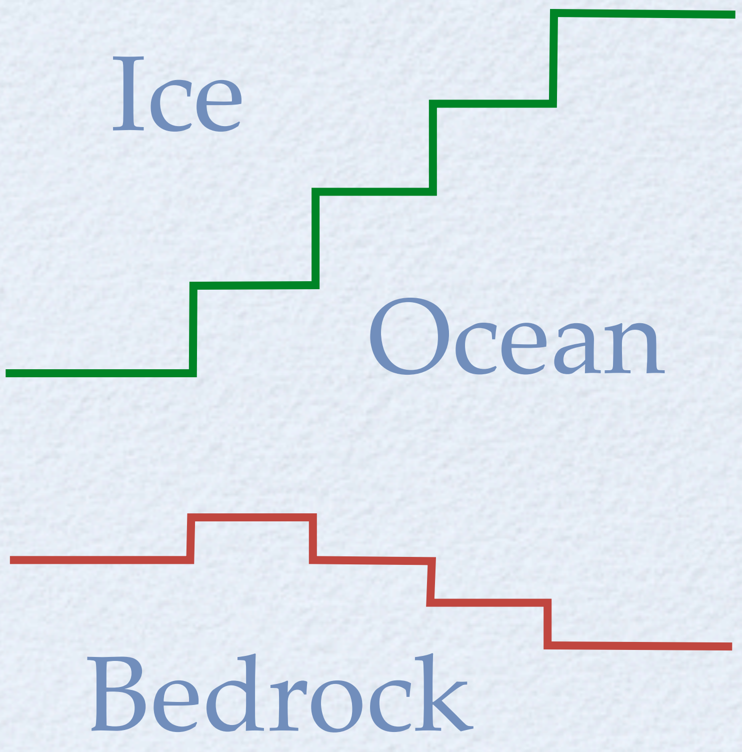


Losch 2008



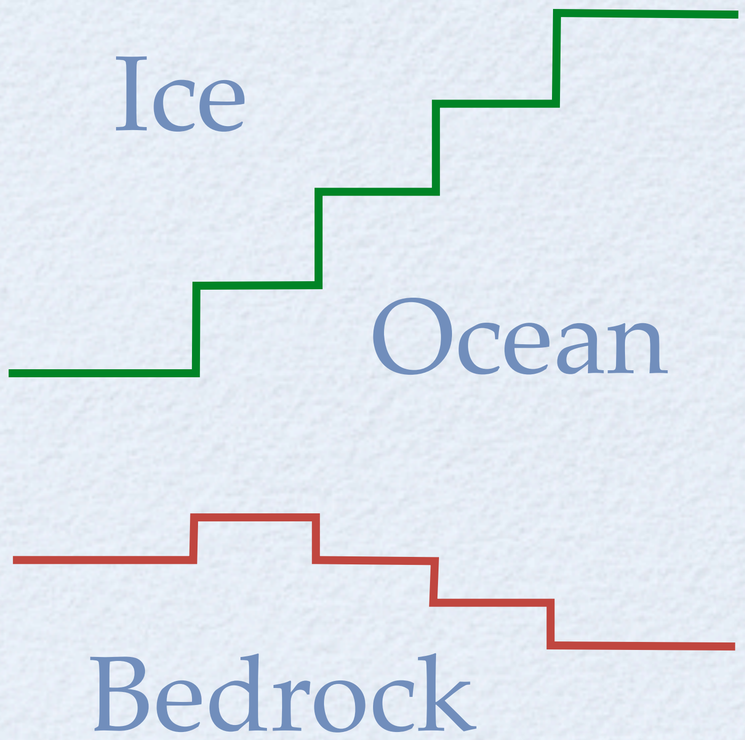
A New Approach

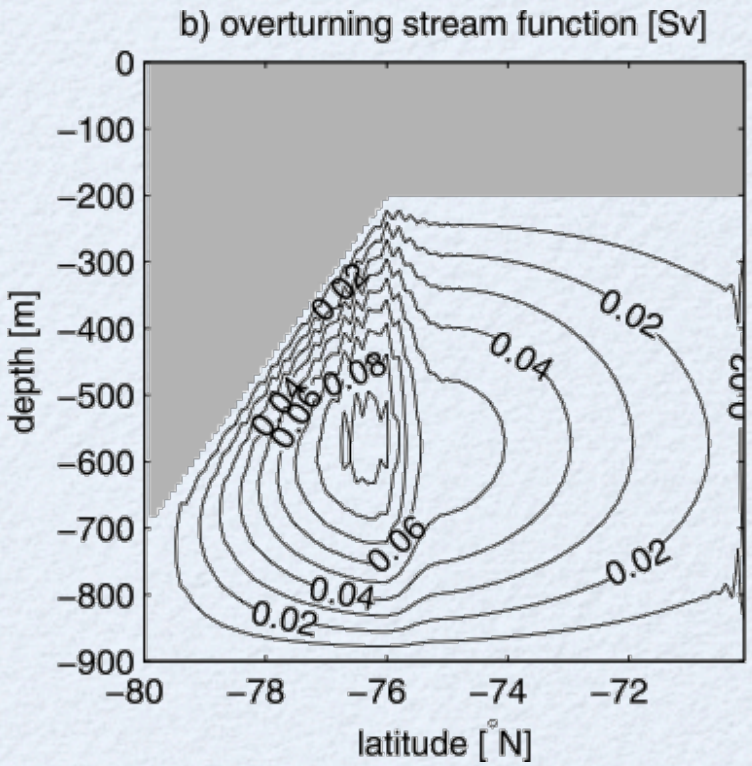
- Pros:
  - Static interface tested with other ocean models
  - Similar to bathymetry
  - Same boundary conditions as IBM



A New Approach

- Pros:
  - Static interface tested with other ocean models
  - Similar to bathymetry
  - Same boundary conditions as IBM
- Cons:
  - Tested only for static ice shelves
  - Stair-step geometry can lead to noisy fields
  - Pervasive modifications

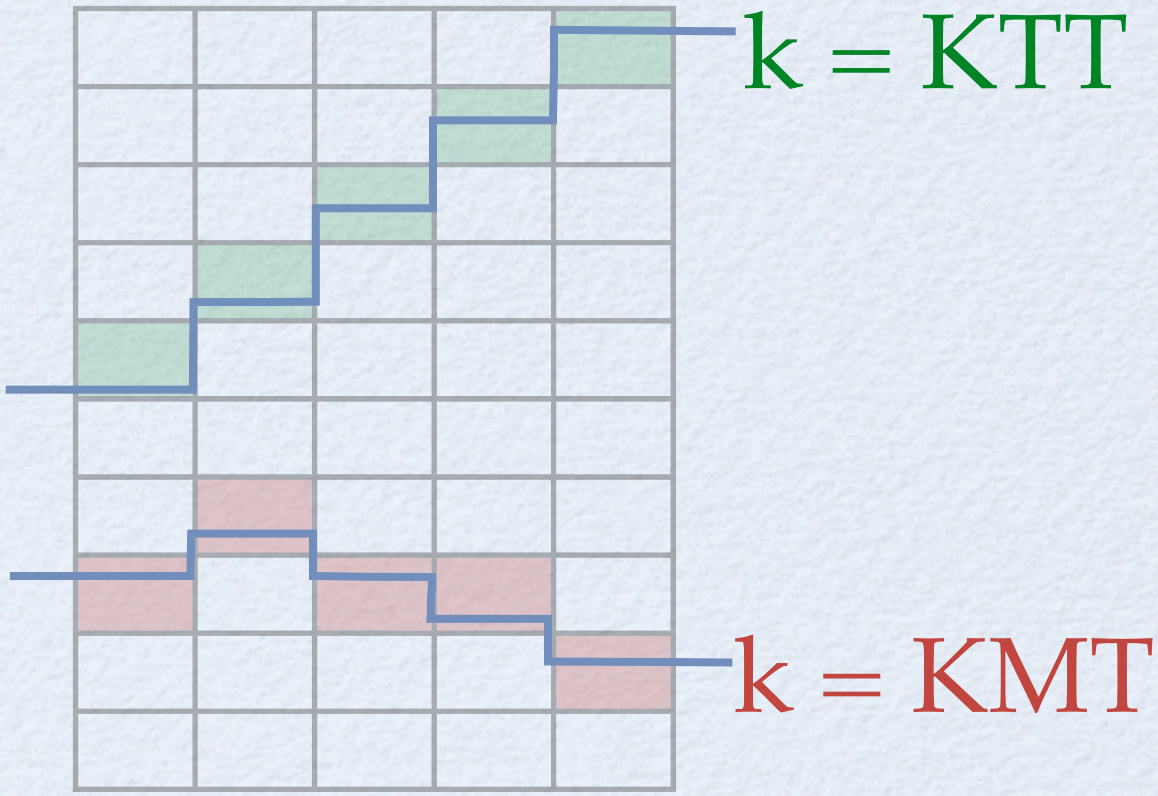




Losch 2008

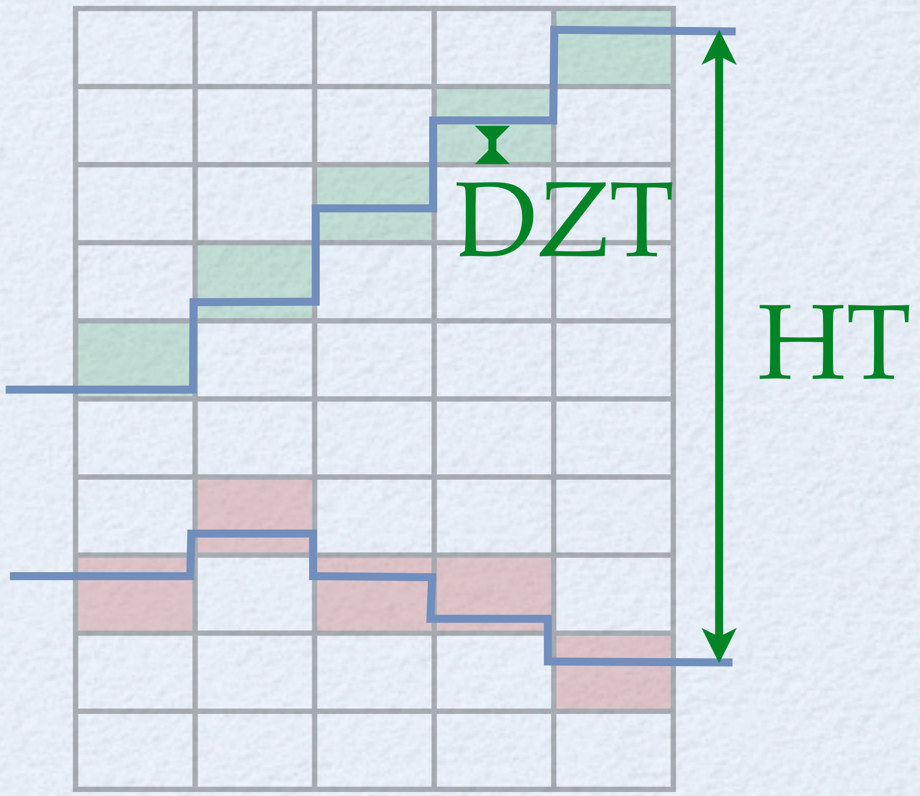
New Approach: Implementation

- Vertical indexing in POP from KTT to KMT (rather than 1 to KMT) on T grid, similar on U grid



New Approach: Implementation

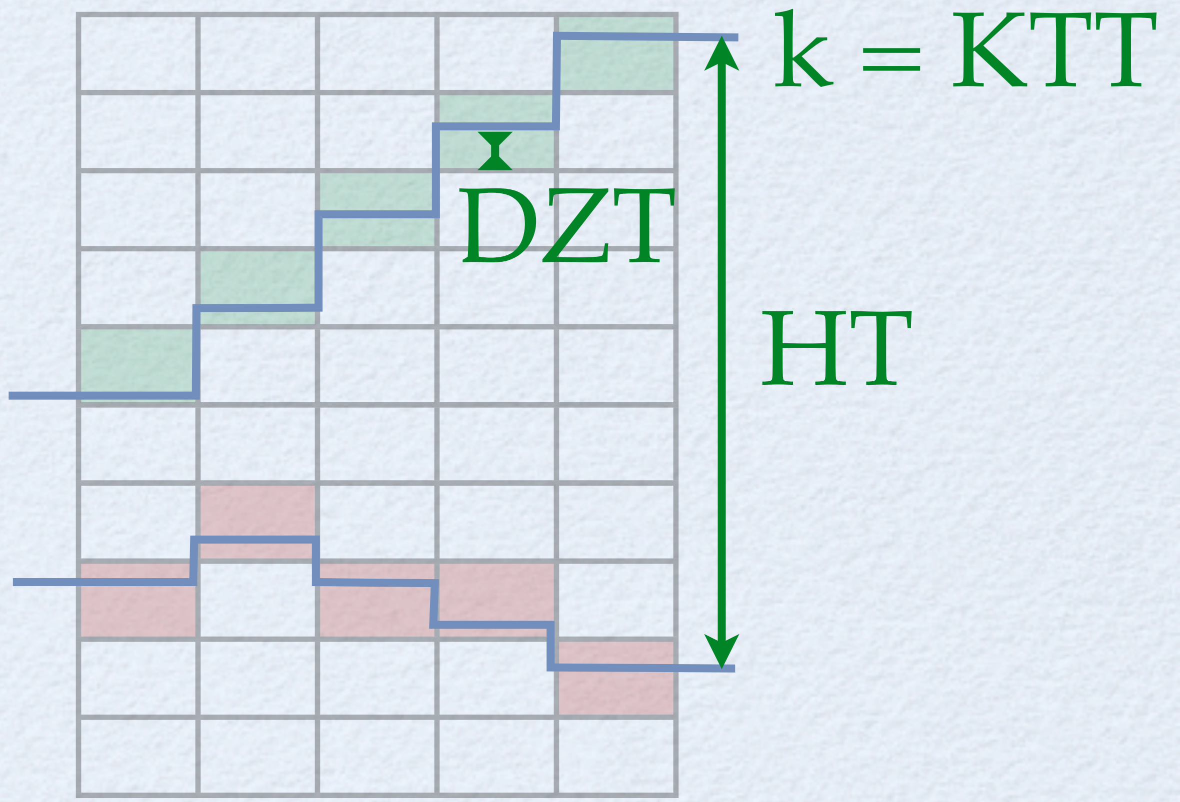
- Vertical indexing in POP from KTT to KMT (rather than 1 to KMT) on T grid, similar on U grid
- Modifications to grid cell thickness DZT/DZU and total thickness HT/HU



New Approach: Implementation

As interface moves:

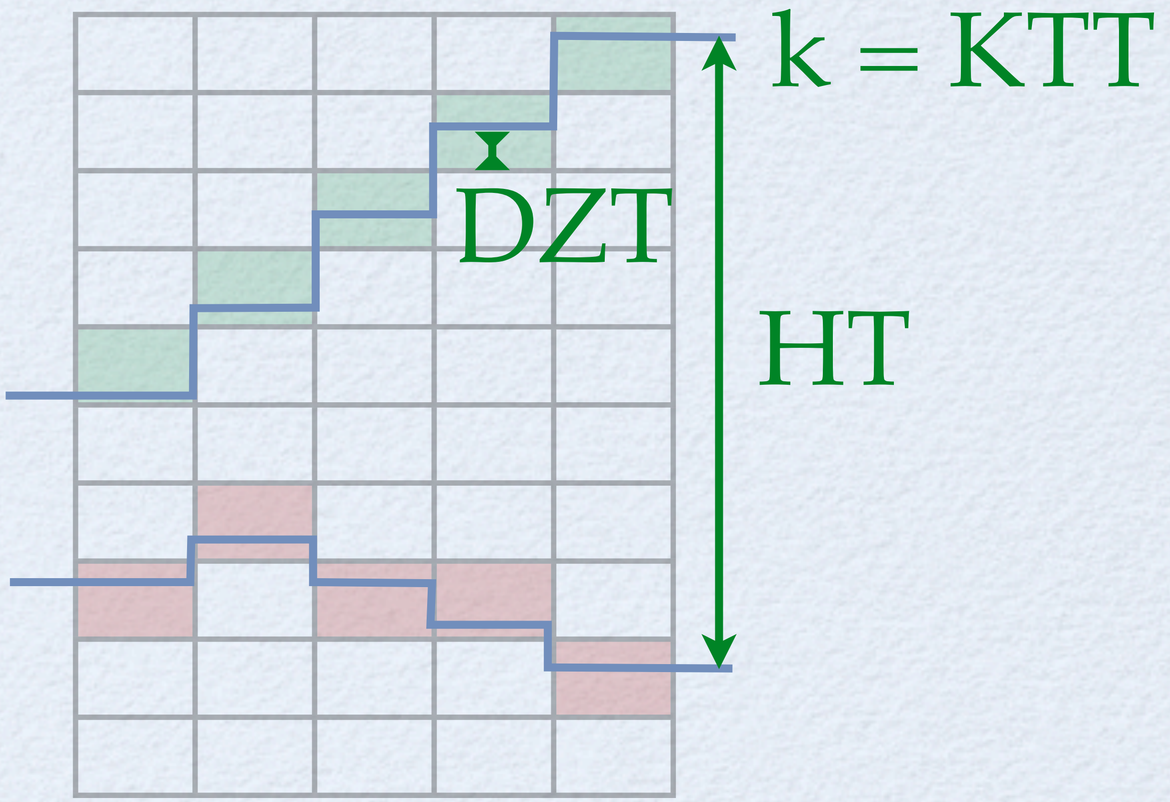
- Recompute KTT/KTU, DZT/DZU and HT/HU



New Approach: Implementation

As interface moves:

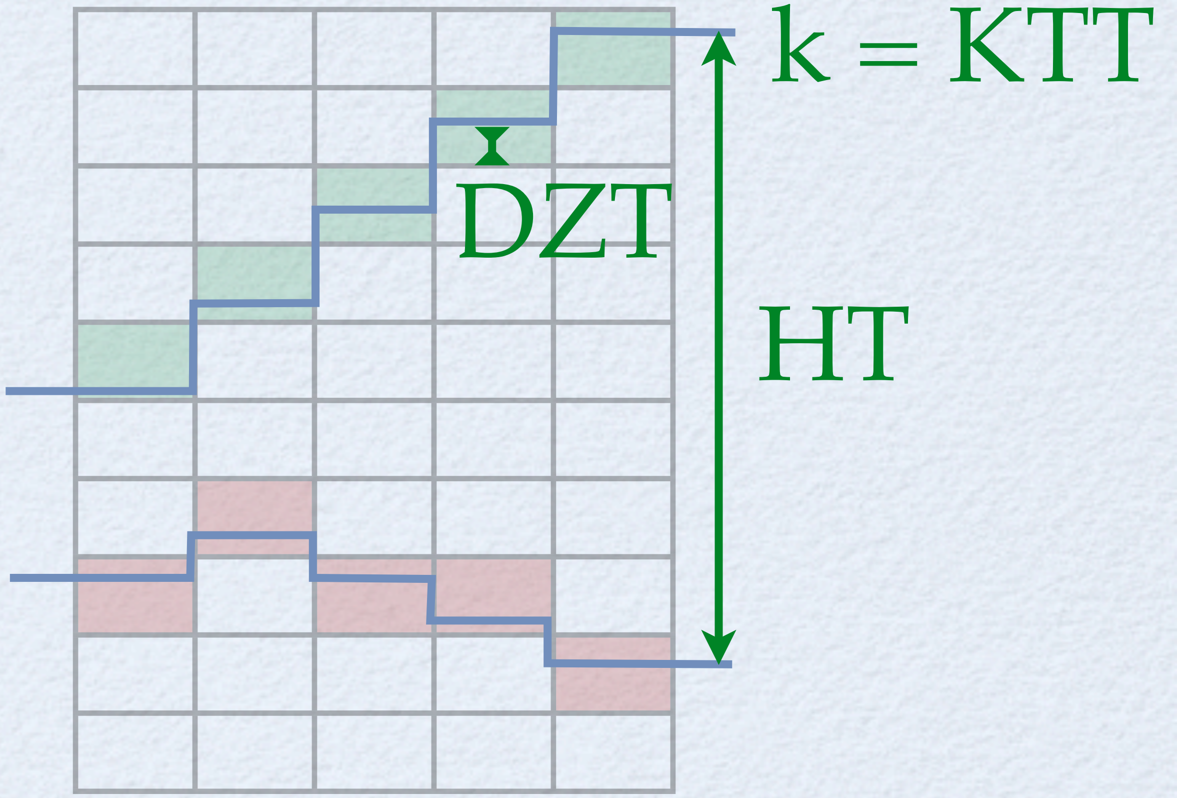
- Recompute KTT/KTU, DZT/DZU and HT/HU
- Reinitialize barotropic solver, flux-limiting advection coefficients



New Approach: Implementation

As interface moves:

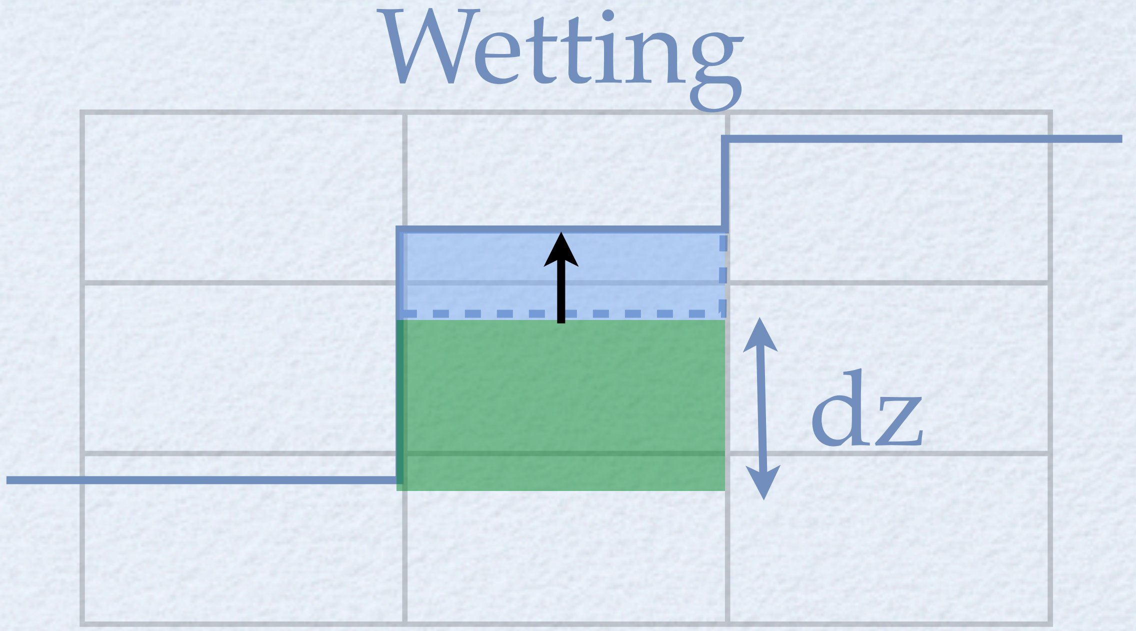
- Recompute KTT/KTU, DZT/DZU and HT/HU
- Reinitialize barotropic solver, flux-limiting advection coefficients
- Account for mass fluxes



New approach: implementation

“Wetting” and “drying” of cells:

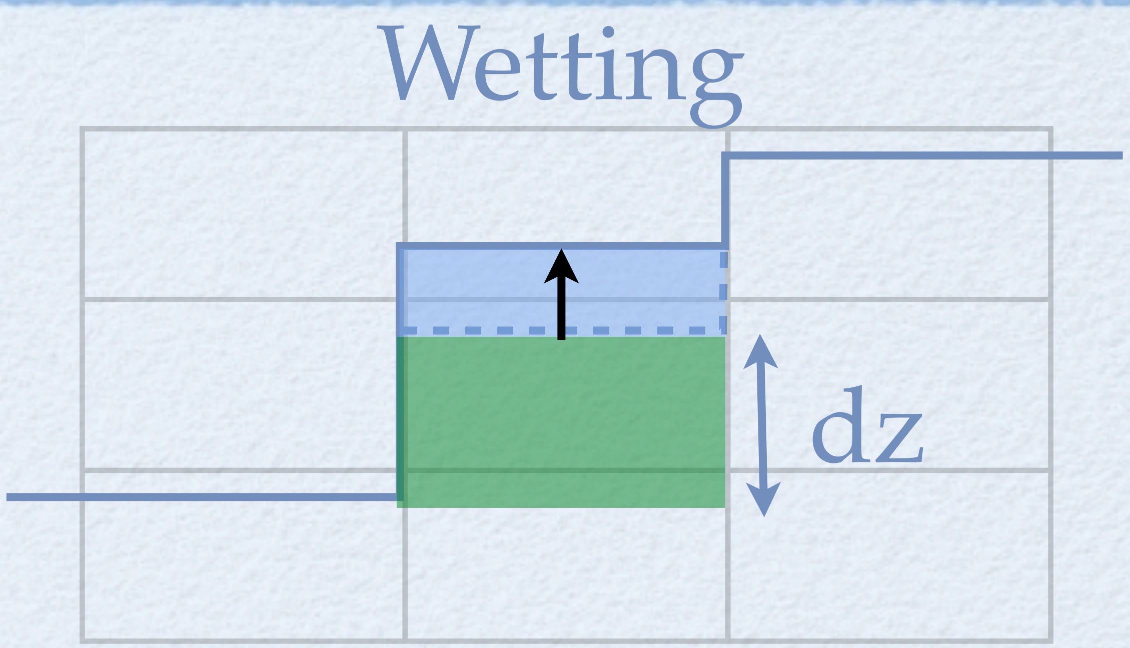
- Tracers in new “wetted” cells conservatively distributed *from* neighboring cell(s)

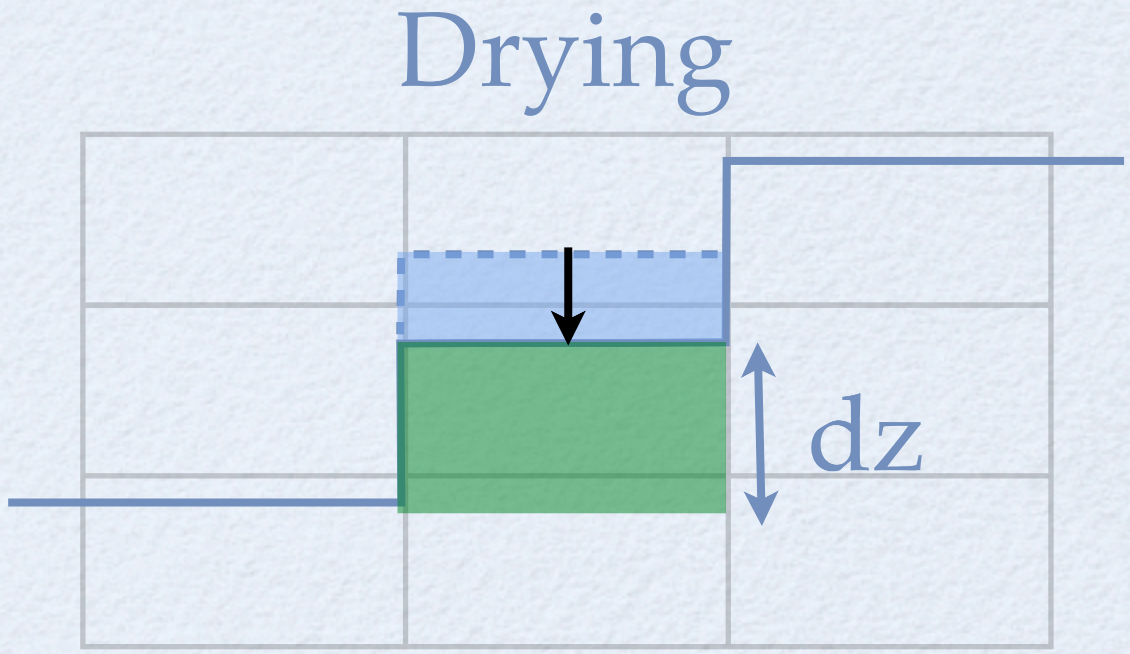


New Approach: Implementation

"Wetting" and "drying" of cells:

- Tracers in new "wetted" cells conservatively distributed *from* neighboring cell(s)
- Tracers in old "dried" cells conservatively distributed *to* neighbor(s)





Summary

- Unsolved problems with Immersed Boundary Method in POP (and probably ocean models generally)
- New approach to land-ice/ocean interface similar to partial bottom cells (no fictitious flow)
- Requires substantial changes to indexing in POP
- New methods required to handle “wetting” and “drying” of grid cells as boundary moves