The Pressure Gradient Force at the Front of Ice Shelves in Sigma-Coordinate Ocean Models

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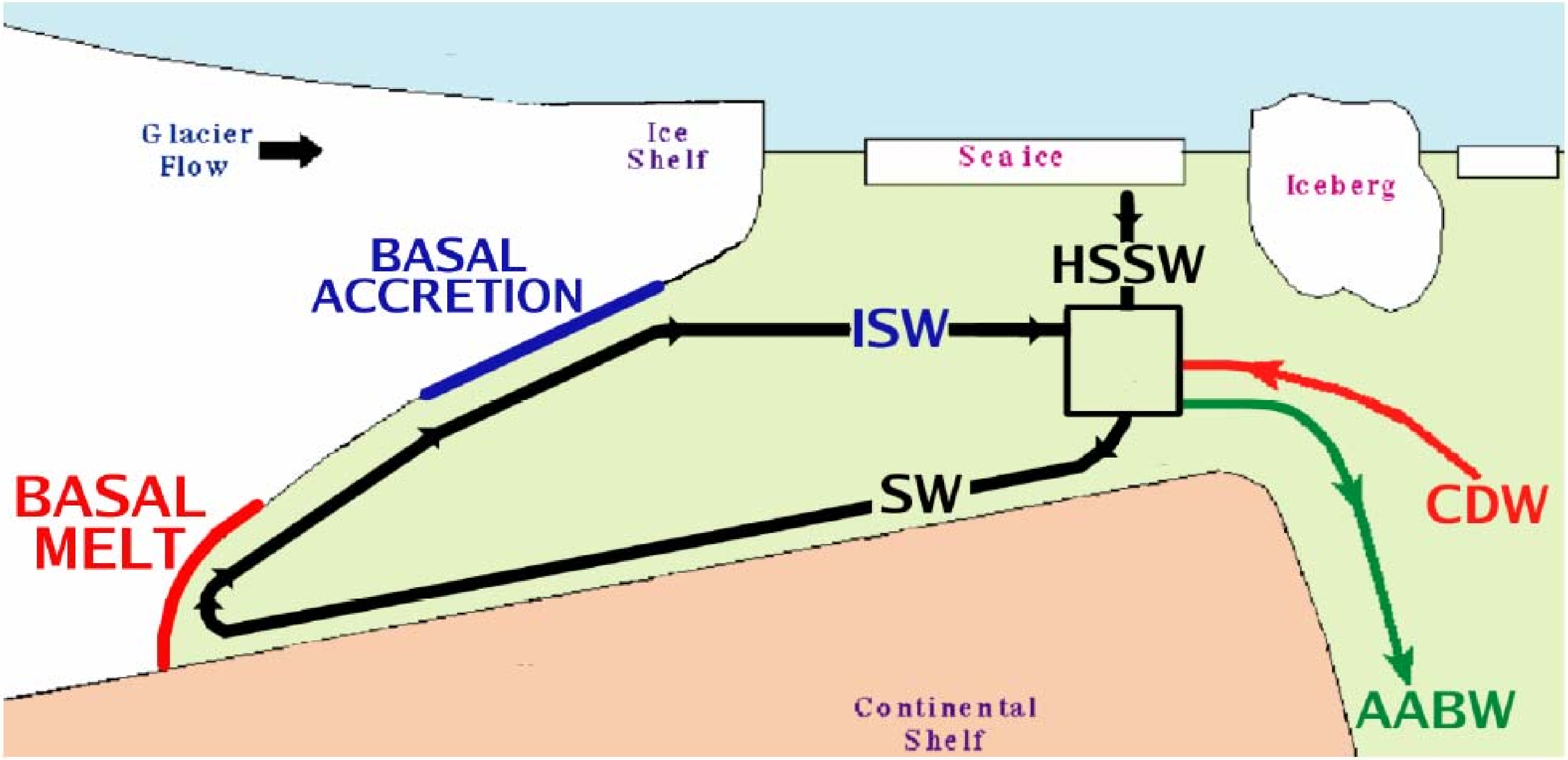
Outline of Presentation

- Introduction and ocean/ice shelf modeling
- ISOMIP experiments and "problem"
- Pressure gradient force algorithm experiments
- Conclusions

Introduction

- Ice streams flowing from Antarctica cross the grounding line and begin to float as ice shelves
- 40% of the shelf ocean in Antarctica is covered by ice shelves which modify the water below => changes in water mass characteristics
- Conversely, water can melt or freeze ice shelf base => ice shelf mass balance changes
- Ice shelf mass balance also a function of iceberg calving, snow fall and flow from ice sheets => dynamics of upstream ice influenced by ice shelves? (relevant to global sea level)



HSSW = High Salinity Shelf Water (≥ 34.6 psu,~-1.9°C)

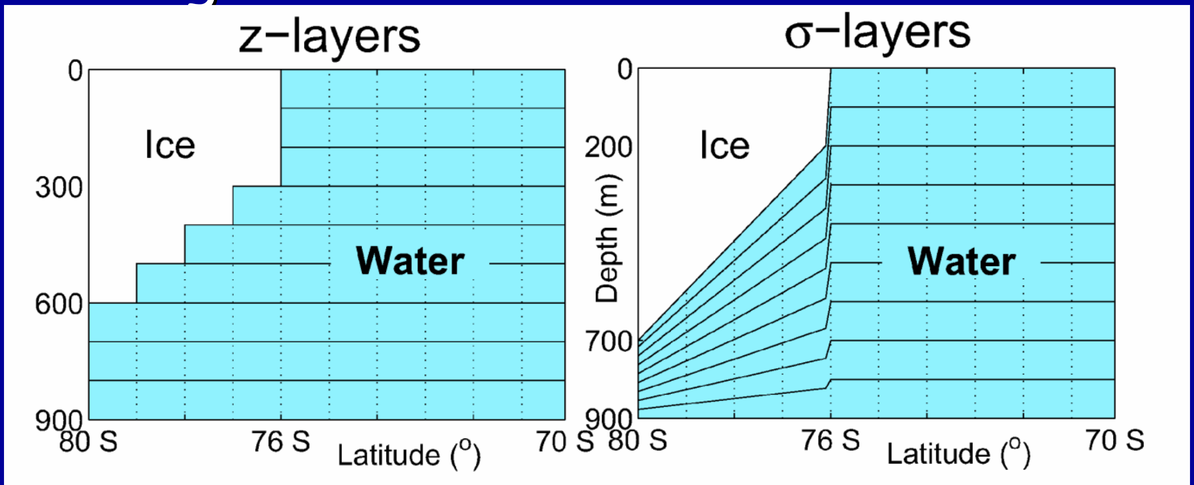
SW = Shelf Water (~-1.9°C) – Low Salinity (< 34.6psu) or High Salinity

ISW = Ice Shelf Water (~-2°C)

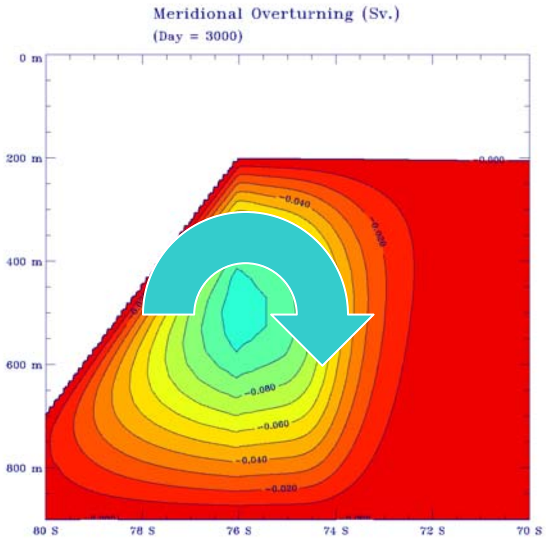
CDW = Circumpolar Deep Water, AABW = Antarctic Bottom Water

Ice Shelf/Ocean Modeling

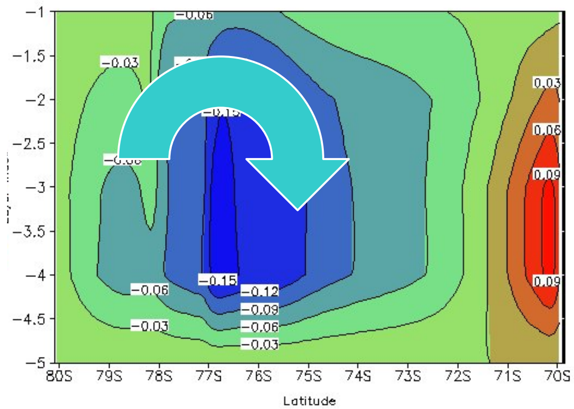
- Pressure gradient force calculation assumes ice shelf has no flexural rigidity and pressure at the base comes from the floating ice
- Thermodynamic interactions
- Sigma-coordinate modeling
  - Advantages: ice shelf base/ocean layer well represented (e.g. buoyant ice shelf water plumes)
  - Disadvantages: PGF at ice shelf front



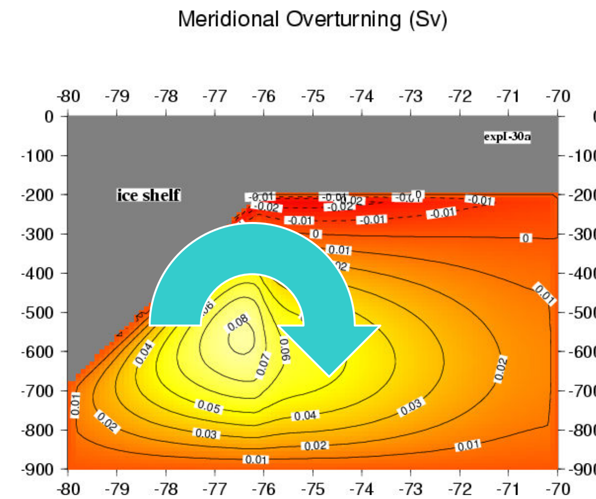
Idealized Test Cases (ISOMIP)



ROMS



MICOM – D. Holland

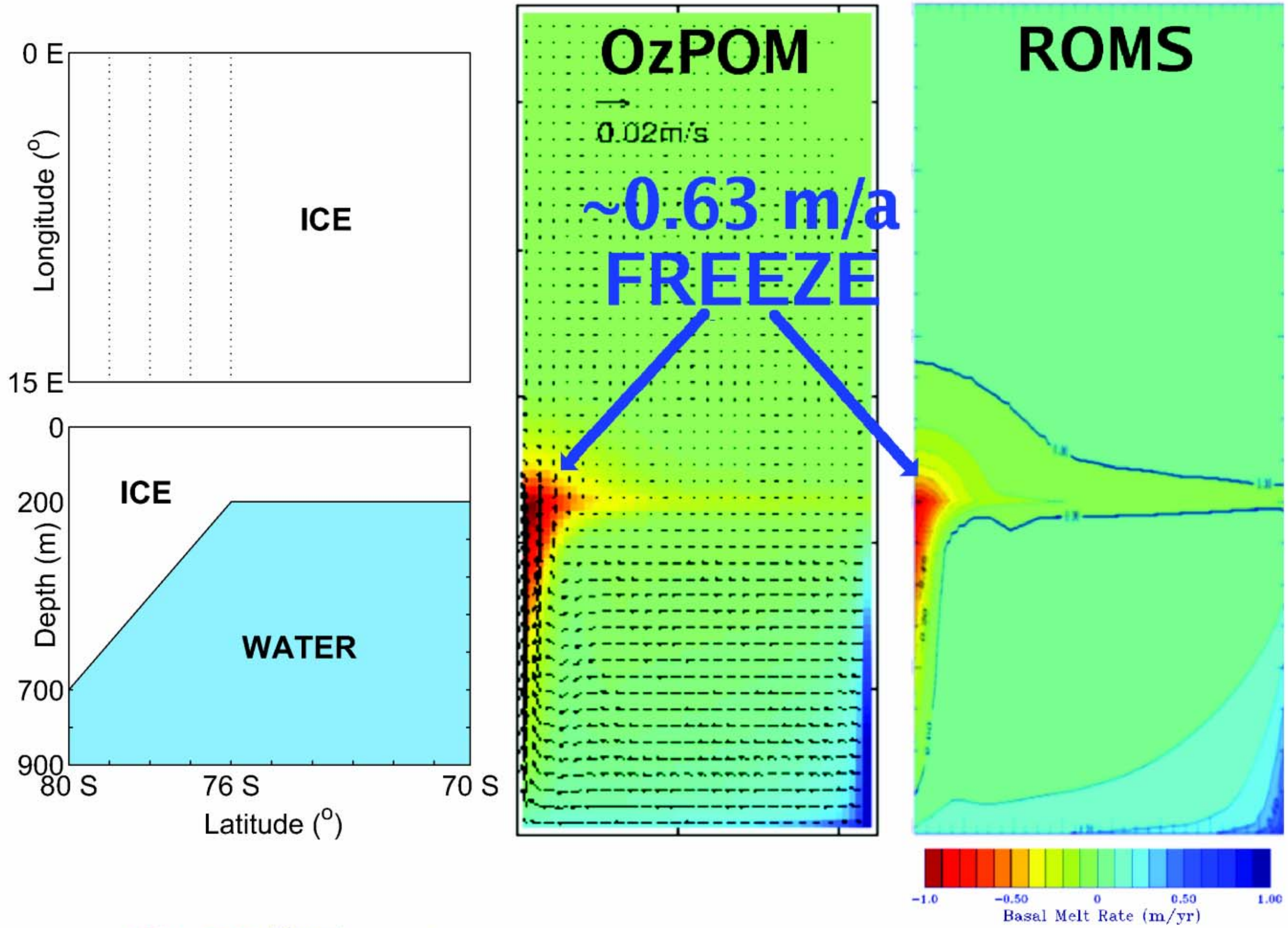


MOM2 – K. Grosfeld

Idealized Test Case: Start w/ uniform water at -1.9 C, 34.4 psu and integrate for 30 yrs.

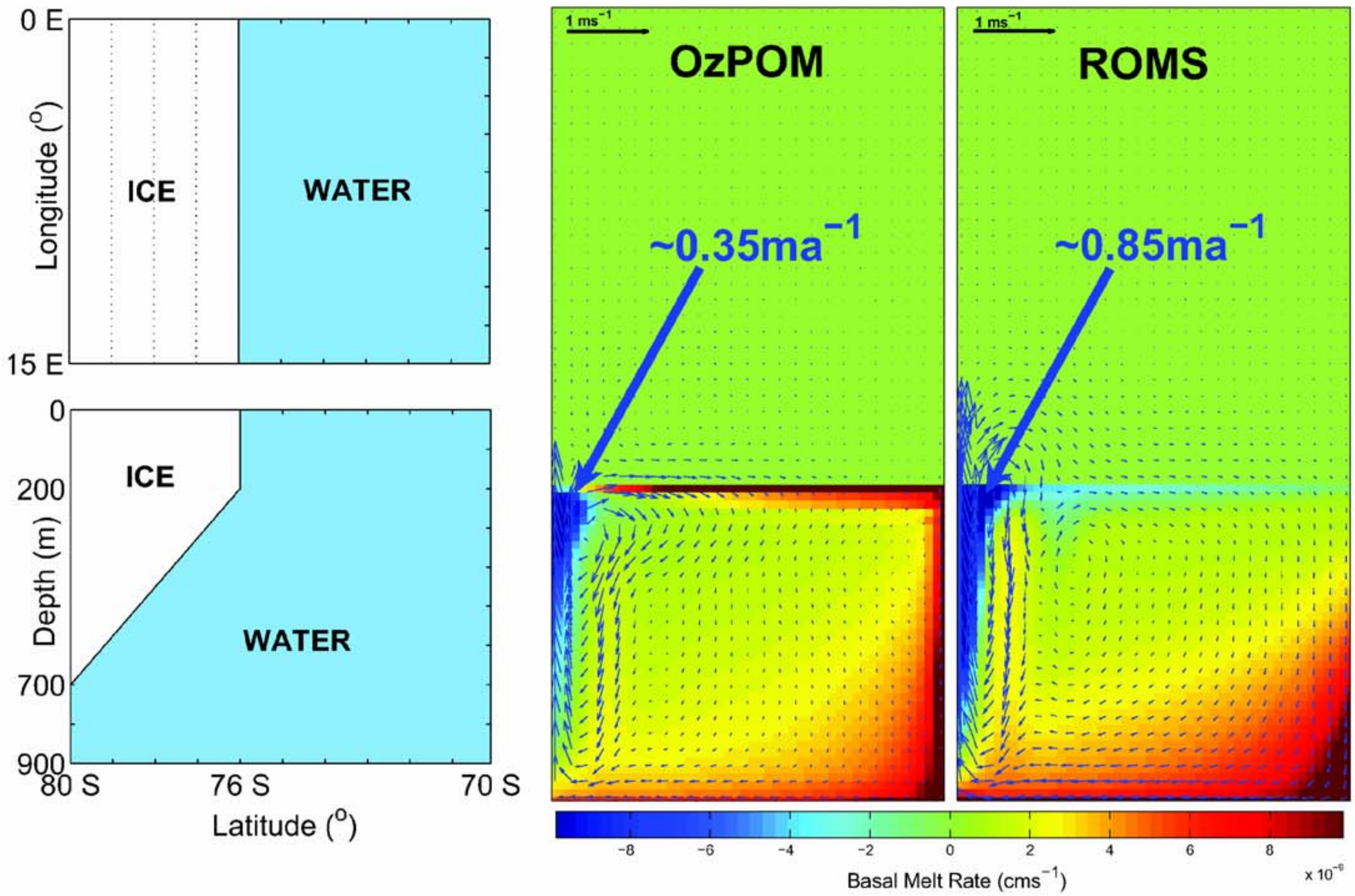
All models have ~ 0.1 Sv. of overturning

Exp 1:'Closed'



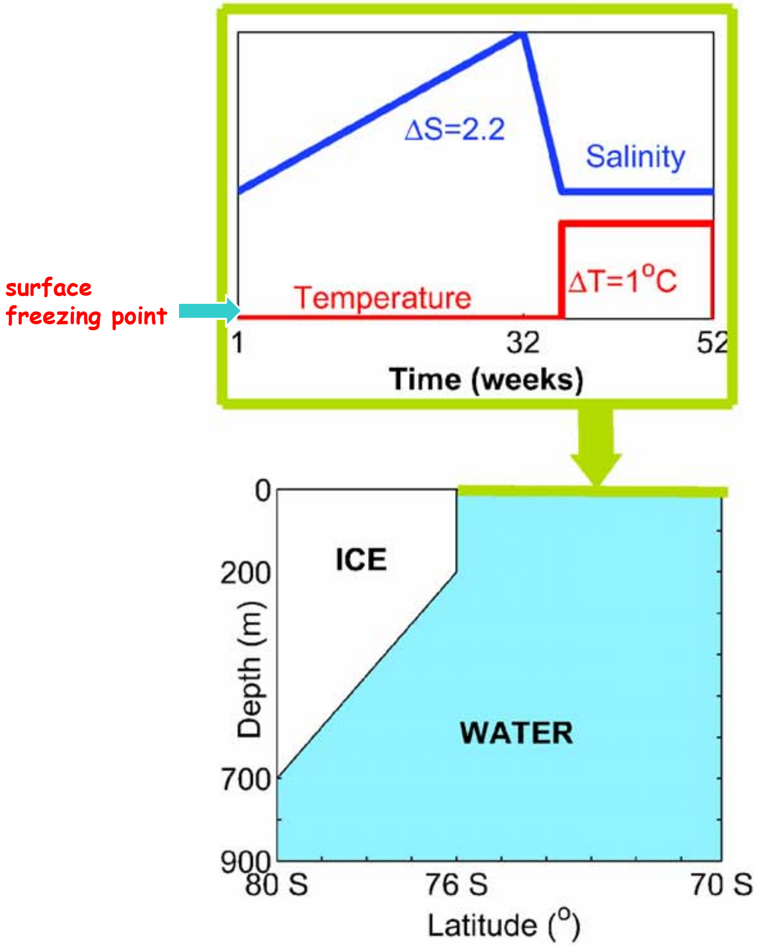
0 E
15 E
Longitude (°)
ICE
0
200
700
900
Depth (m)
ICE
WATER
80 S
76 S
70 S
Latitude (°)
OzPOM
0.02m/s
~0.63 m/a
FREEZE
ROMS
-1.0
-0.50
0
0.50
1.00
Basal Melt Rate (m/yr)

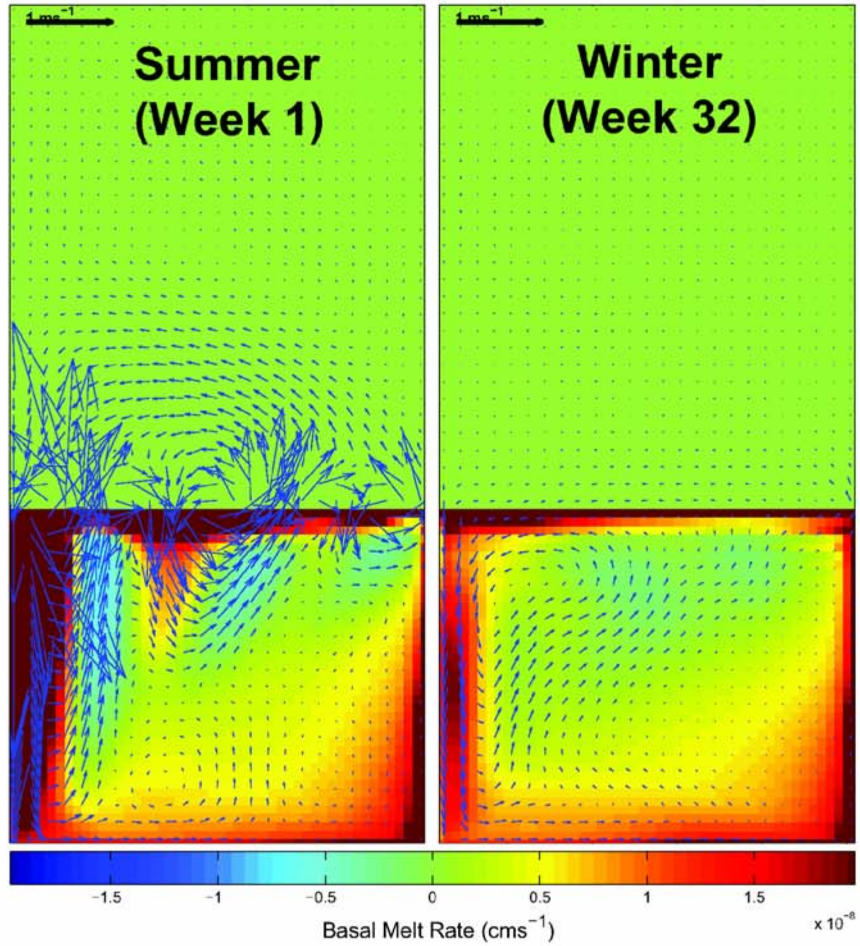
Exp 2: 'Open'



0 E
15 E
Longitude (°)
ICE
WATER
0
200
700
900
Depth (m)
ICE
WATER
80 S
76 S
70 S
Latitude (°)
1 ms⁻¹
OzPOM
~0.35ma⁻¹
1 ms⁻¹
ROMS
~0.85ma⁻¹
-8
-6
-4
-2
0
2
4
6
8
Basal Melt Rate (cms⁻¹)

Exp 3: ‘Open + Seasonal’(OzPOM)

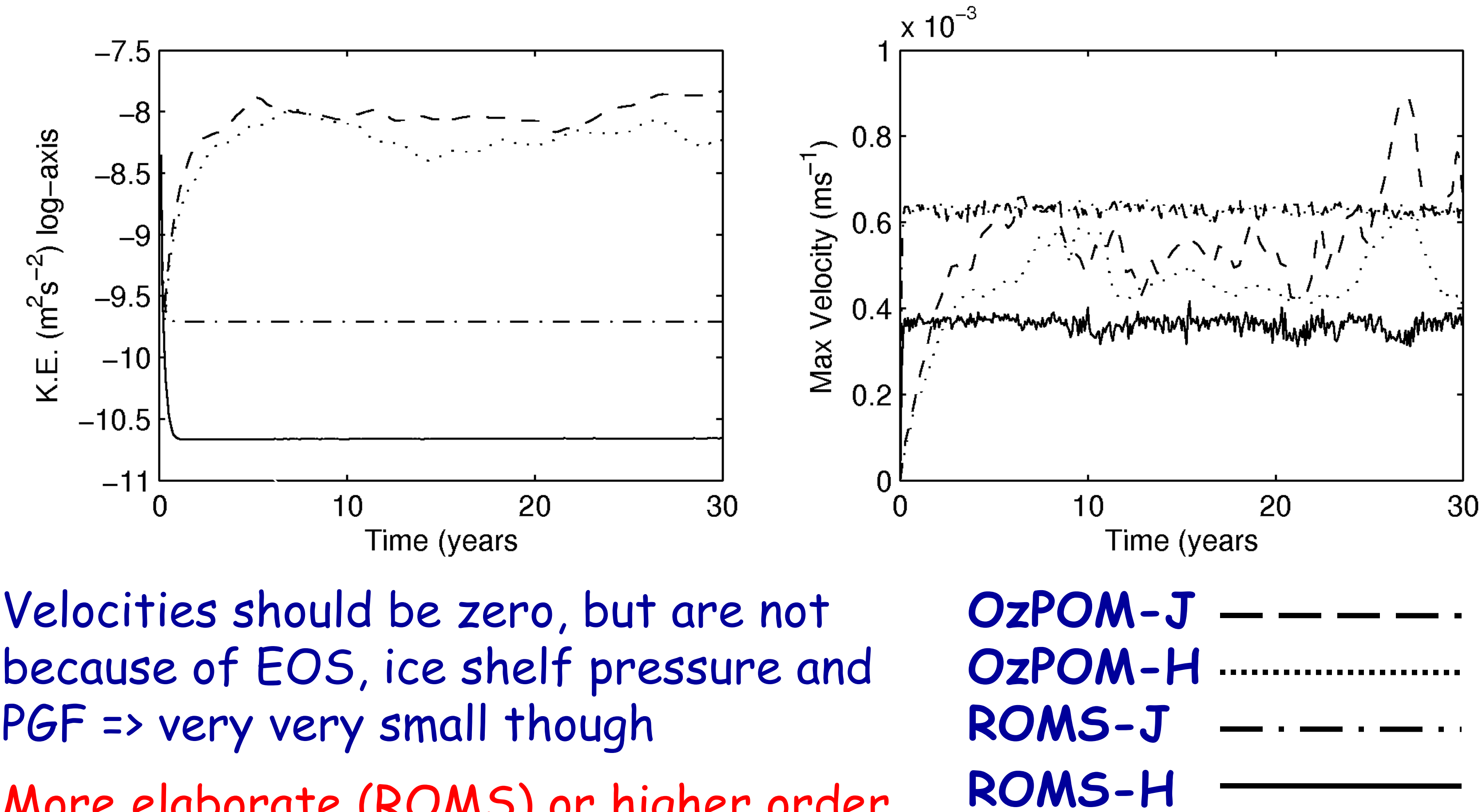




PGF Algorithm Experiments

- Similar to Seamount experiments, but the focus now is on the ice shelf front ('open' domain, s ($\Delta H/2H$) = 0.5 and HC ($\sigma\Delta H/H\Delta\sigma$) = 5.6 at front):
    - OzPOM-J: OzPOM w/ standard density-Jacobian PGF scheme
    - OzPOM-H: OzPOM w/ sixth order combined compact difference scheme
    - ROMS-J: ROMS w/ a standard density-Jacobian scheme
    - ROMS-H: ROMS w/ a density-Jacobian scheme using monotonized cubic polynomial fits
- Base experiment has no forcing (thermodynamic or wind) and uniform T and S
- Other experiments start with uniform T and S, but have ice/water thermodynamics and open water forcing

No forcing, uniform T and S

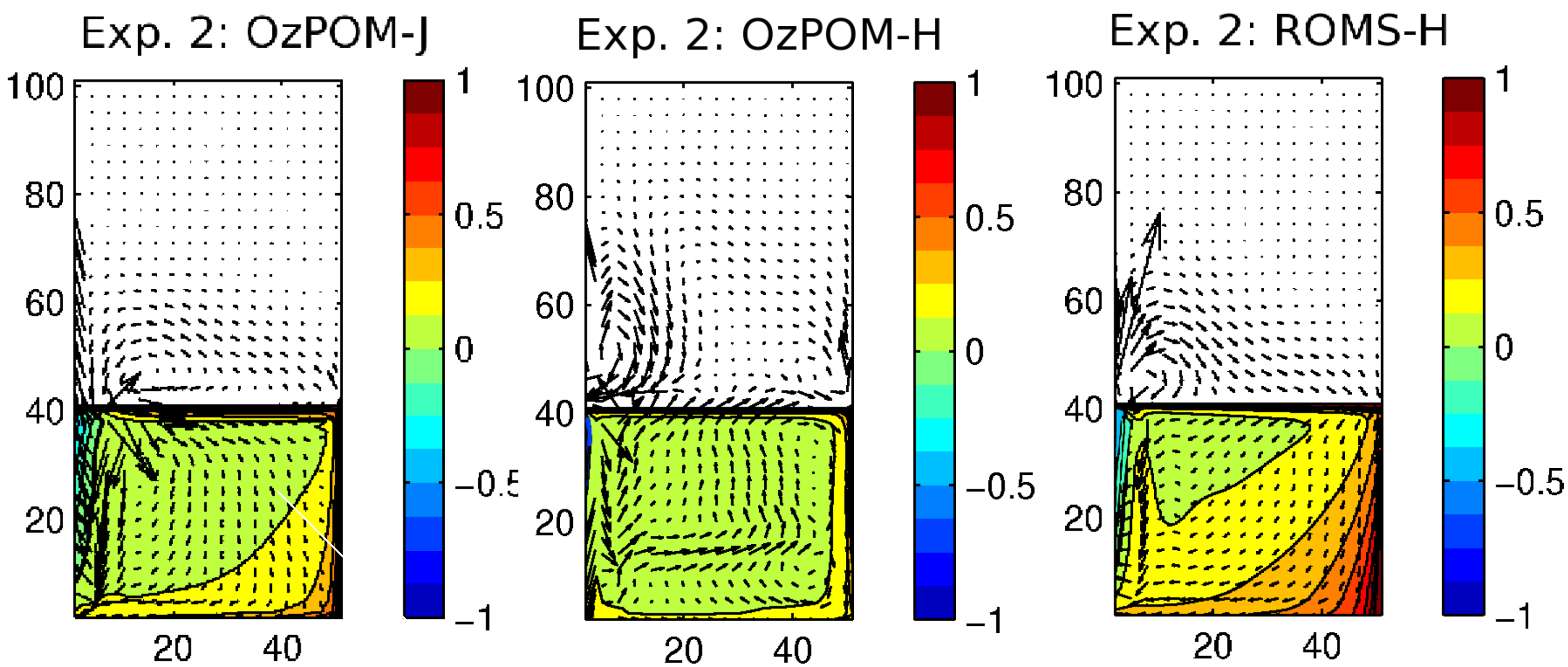


Velocities should be zero, but are not because of EOS, ice shelf pressure and PGF => very very small though

More elaborate (ROMS) or higher order (OzPOM) schemes reduce errors

ROMS-J and OzPOM-J are identical PGF schemes, so other factors besides PGF matter

Ice/water thermodynamics and open water forcing

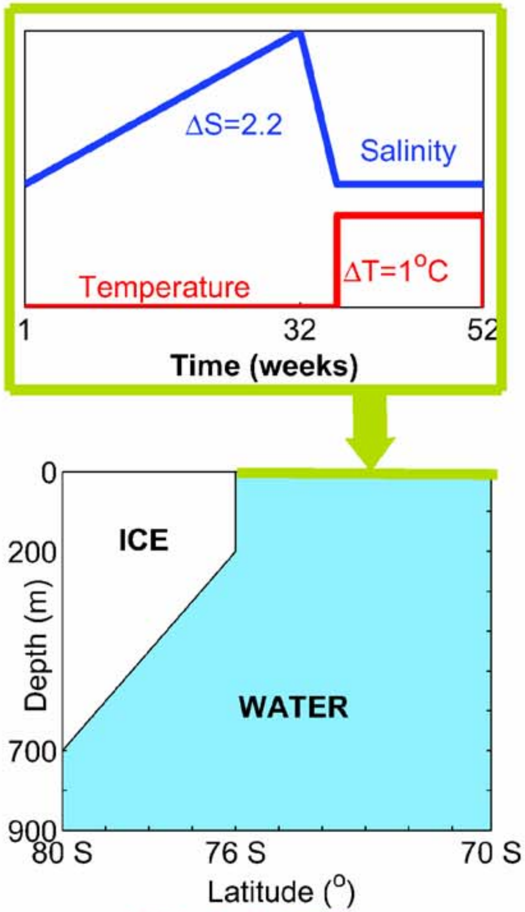


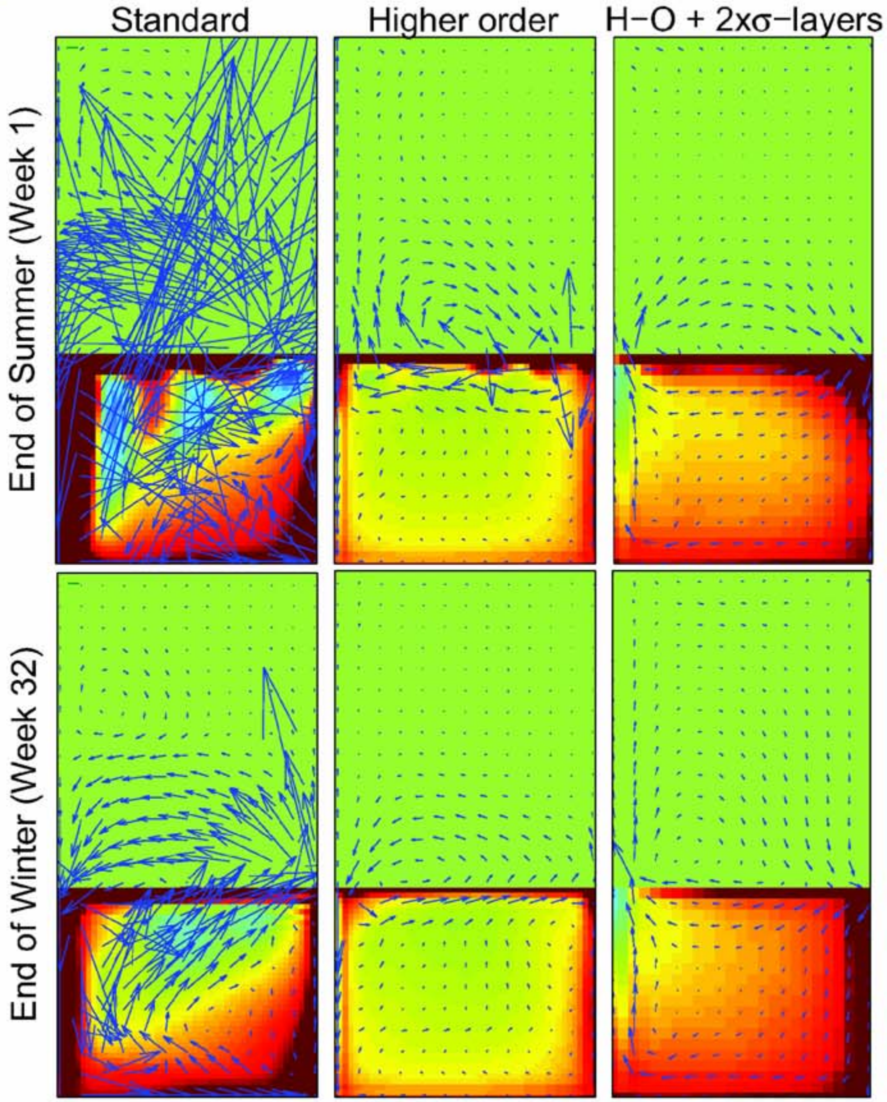
Depth-averaged velocity and ice shelf basal melt

ROMS-H and ROMS-J (not shown) similar, OzPOM-H and OzPOM-J have significant differences

Note clockwise circulation just NW of ice shelf front in OzPOM-H and ROMS-H (vs. OzPOM-J)

Exp 3: Testing Remedies (OzPOM)





Conclusions

- Terrain-following coordinates are well suited to modeling the oceans beneath ice shelves, but the pressure gradient error at the steep ice front can be significant (especially with large density gradients)
- This error can be significantly reduced by use of higher order or more elaborate PGF algorithms
- The differences between ROMS and OzPOM at the ice shelf fronts are not just due to PGF numerics

Acknowledgements

- Some initial OzPOM runs set up by Andreas Klocker
- CPU hours provided by the Tasmanian and Australian Partnerships for Advanced Computing
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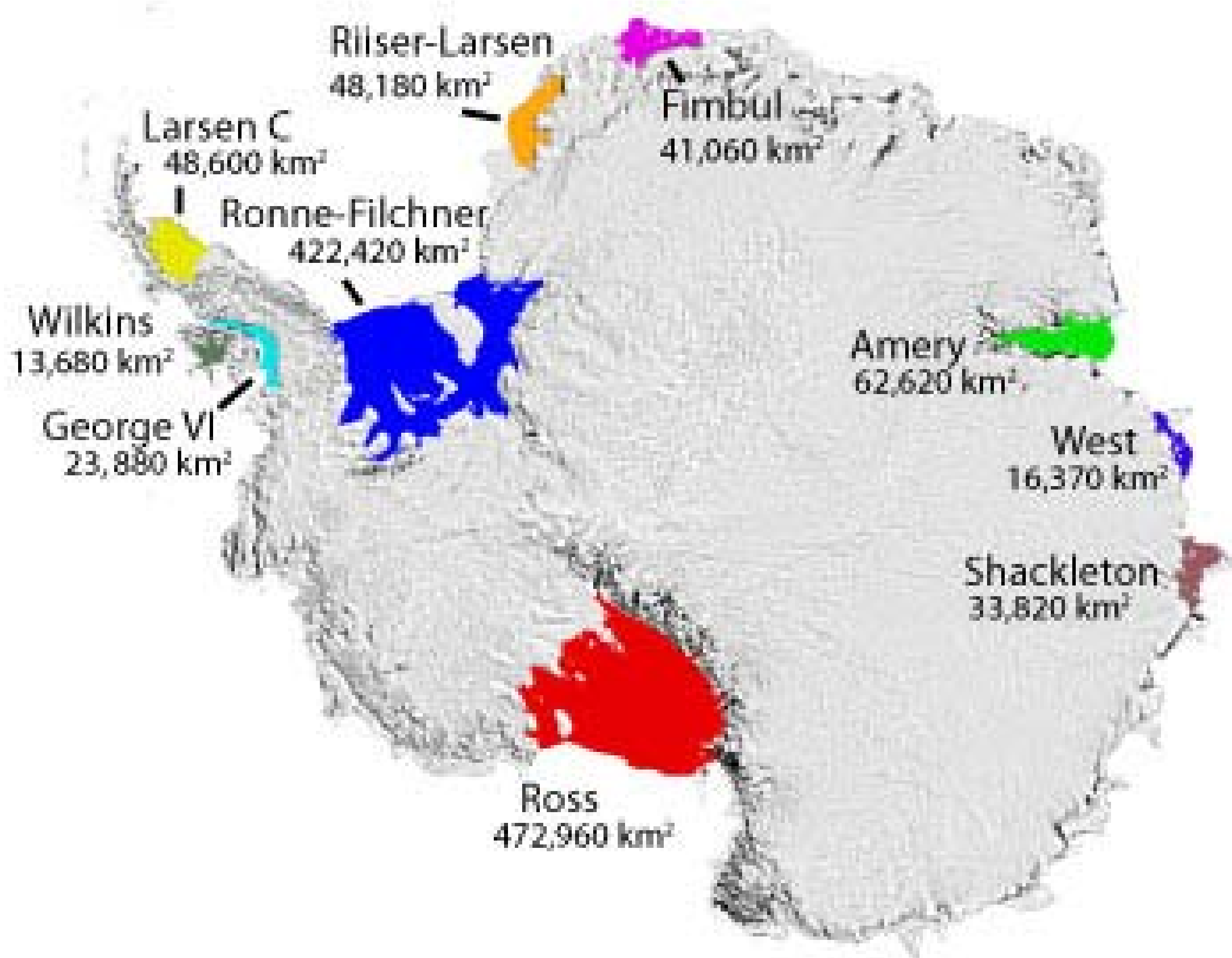
Riiser-Larsen
48,180 km²
Fimbul
41,060 km²
Larsen C
48,600 km²
Ronne-Filchner
422,420 km²
Wilkins
13,680 km²
George VI
23,880 km²
Amery
62,620 km²
West
16,370 km²
Shackleton
33,820 km²
Ross
472,960 km²

From NSIDC

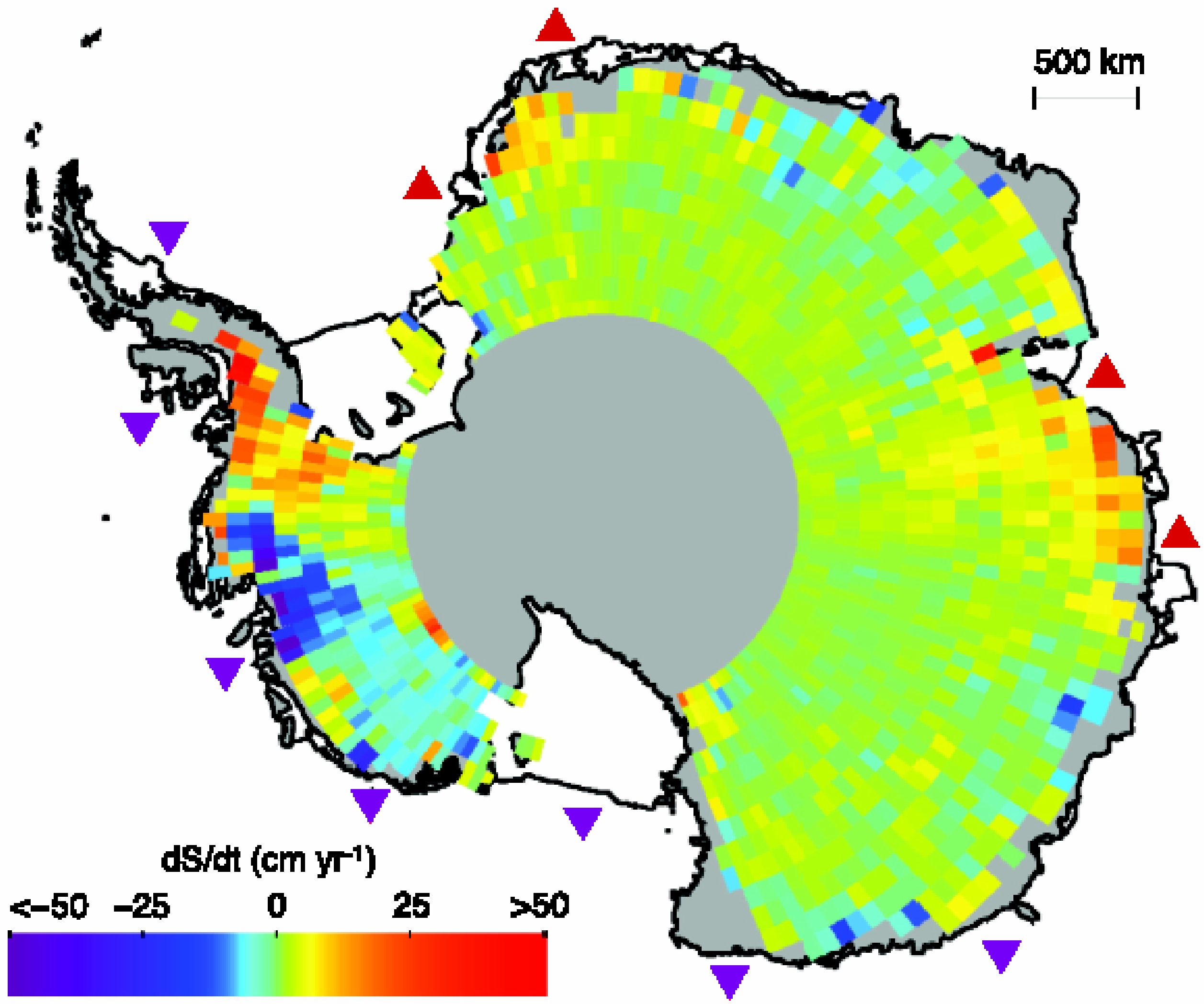

Figure 4.19. *Rates of surface elevation change (dS/dt) derived from ERS radar-altimeter measurements between 1992 and 2003 over the Antarctic Ice Sheet (Davis et al., 2005). Locations of ice shelves estimated to be thickening or thinning by more than 30 cm yr⁻¹ (Zwally et al., 2006) are shown by red triangles (thickening) and purple triangles (thinning).*

From WGI, IPCC Report (Lemke et al., 2007)