Manuscript: Antarctic sub-shelf melt rates via PICO by Reese et al.

Summary:

This manuscript describes the Potsdam Ice-shelf Cavity mOdel (PICO), a new model of Antarctic ice shelf cavity circulation and the heat and freshwater exchange between the ocean and ice shelf. PICO simulates the two-dimensional overturning circulation within Antarctica's ice shelf cavities that is driven by the 'ice-pump mechanism' described by the authors on page 3 lines 7-8 as "melting at the ice shelf base near the grounding line reduces salinity and the ambient ocean water becomes buoyant, rising along the ice shelf base towards the calving front." The model consists of a number of connected boxes. Denser waters from the continental shelf are transported unmodified to the grounding line in a single box, Box 0. The outflow of buoyant waters beneath the ice shelf occurs within a series of adjoining connected boxes (Box 1 through Box n) that span the area between at the grounding line and the ice shelf calving front. T and S properties upper layer outflow boxes become progressively modified following ice melting and refreezing.

The key assumptions in this model are:

1) the inflow volume flux, q, is proportional to the density difference between the relatively denser deeper waters of the shelf outside the ice shelf (Box 0 or B_0) and the relatively lighter waters near the grounding line (Box 1 or B_1).
2) T and S on the outside the cavity do not evolve
3) ice shelf cavity circulation is steady-state
4) no diffusive exchanges of T and S in the vertical and horizontal directions
5) turbulent exchange parameters are constant (no flow rate dependence)
6) salinity at the ice-ocean boundary layer is that of the far-field
7) no conductive heat fluxes from the ocean into the ice shelf
8) no contribution of ice shelf meltwater into the volume flux through the upper layer boxes
9) the ocean equation of state is linearized
10) the prescribed inflow boundary conditions for all boxes of B_k, $k > 0$ is set as the mean of the ice-model grid cell boxes in B_{k-1} that are adjacent to B_k

Each upper layer PICO grid cell maps to many ice shelf model grid cells. In each PICO box the ocean-ice heat and freshwater fluxes are calculated separately.

The two principal unknowns for the model are (1) the constant of proportionality, C, that sets the strength of the density-driven inflow and (2) the turbulent heat flux coefficient, gamma_T*.

The authors use PICO with modern day values of T and S around the continental shelf to determine which set of C and gamma_T* yield the best fit to modern day ice shelf melt rates. Using those parameter values for the entire domain they then calculate the melt rate response to varying ocean temperature variations by +/-2 C for Pine Island, Filchner-Ronne, and all Antarctica ice shelves. Melting in the cold Filchner-Ronne and Antarctica as a whole responds

approximately quadratically with increasing T. In contrast, melting of the warm PIG increases approximately linearly. Both melt rate responses are consistent with earlier modelling results.

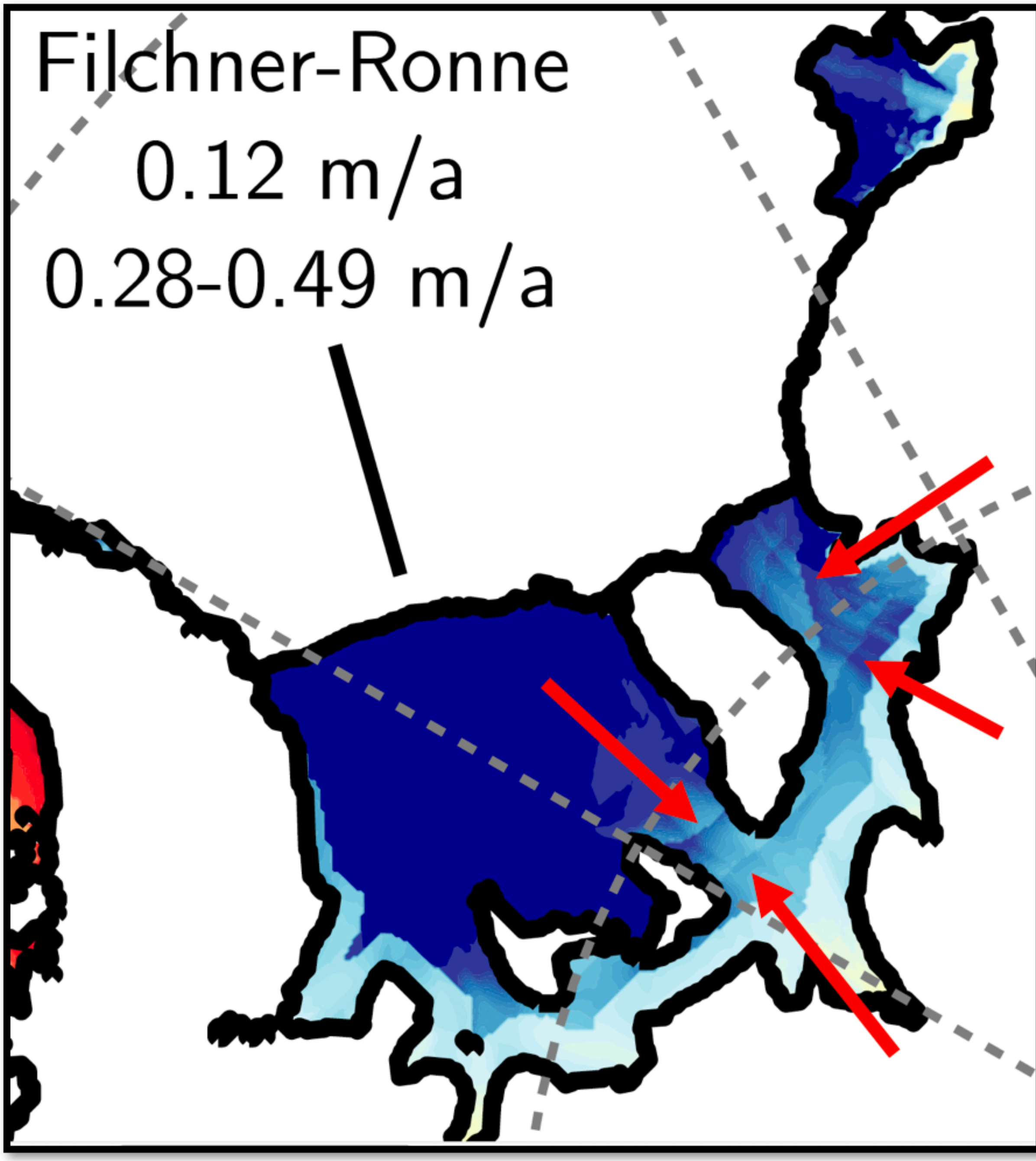
Major Comments:

I found this paper to be clear and well written. While I could not follow the reasoning for several of the model's assumptions I appreciated that the assumptions were articulated.

PICO is a simplified version of the Olbers and Hellmer 2010 model (OH10). If there is any major criticism to be made about this work it is that it was not clear to me why deriving a model that could be "analytically solved" is so important. While there is of course an argument for using the simplest useful model, I found myself wondering whether bits of the physics were being tossed out (e.g., heat conduction into the ice, neglect of contribution of meltwater into the volume transport, use of far-field salinity instead of the boundary-layer salinity one expects from the three-equation model, neglect of velocity dependence on turbulent flux parameter) just to make the system linear.

If PICO's simplifications assumptions were indeed made to yield a linear system of equations that could be directly solved for the purpose of numerical expediency (it is qualitatively described as "very fast" Page 16, Line 13) then it would have been useful for the authors to somehow demonstrate that or at least estimate the computational cost savings enjoyed in comparison to a more complex model such as OH10. At the end of the day, having a nonlinear set of equations that conserves energy and mass but must be solved iteratively might be preferable to one that doesn't conserve either.

Finally, if ruthless simplification is the goal then the authors have could have gone one step further. In its present form the ocean inflow and outflow of PICO has no lateral dependence (no effect of Earth's rotation through the Coriolis effect). Instead of dividing the ice shelves into concentric rings and solving the equations in each ice-model grid cell within each box, the authors could have collapsed each ice shelf into just two dimensions and solved the equations not on the ice model grid but only in the box domain. The melt rates could then be imposed back onto the 3D ice shelf. The reason I mention this is that the concentric ring approach taken by PICO yields very strange patterns in ice melt rates (see annotated red arrows on my excerpt of Fig 5 below). Imposing that pattern of into the ice shelf model would almost certainly lead to an undesirable outcome in the long run.


Filchner-Ronne
0.12 m/a
0.28-0.49 m/a

Minor Comments:

Some comparison of spatial patterns of inferred ice shelf melt rates from observations would be helpful, especially for some of the larger ice shelves, would be helpful. A zoom-in on the spatial pattern of some of the faster melting ice shelves like PIG is also advised.

Given uncertainties in the ice shelf temperatures and the ice shelf melt rates used to fit of the two free model parameters, I'd caution the authors against putting too much emphasis on the nominal values of the parameters.

Page 9, Line 5: "sieve criteria?" This is not a common term.

Page 6, lines 9-15 should be clarified.

Page 12, line 6: I don't find any discussion about the procedure to determine the best-fit parameters. Perhaps you it was included in one point but it seems to be missing now. Page 12, Line 6 refers to the best fit values "found in Sect. 3.1" but 3.1 just describes the criteria and the parameter space.

I think the conclusions section could be rewritten.

Page 16, Line 25: your model also does not "fully reflect the circulation below ice shelves".

Page 16, Line 26: you didn't validate your model to present-day ocean conditions and ice geometries, you found a set of free model parameters that yields best fit to modern day ice shelf melt rates.

Page 16, Line 17: I would not say that PICO "accurately" reproduces the "general" pattern of ice shelf melt with higher melting at the grounding line etc. I'd say that PICO qualitatively reproduces the general pattern of ice shelf melt with higher melting at the grounding line etc.

Page 16, Line 30: I'd back off on the claim that you found two calibrated parameters that are "valid for the whole ice sheet". You found a set of parameters that best fit (using a method that was not described) present-day ice shelf melt rates.