The ocean mixed layer, buoyancy fluxes, and sea ice over the Antarctic continental shelf

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A sea ice-mixed layer model has been used to investigate regional variations in the surface-driven formation of Antarctic shelf sea waters. The model captures well the expected sea ice thickness distribution, and produces deep mixed layers in the Weddell and Ross shelf seas each winter (1985-2011). By deconstructing the surface power input to the mixed layer, we have shown that the salt/fresh water flux from sea ice growth/melt dominates the evolution of the mixed layer in all shelf sea regions, with a smaller contribution from the mixed layer-surface heat flux. An analysis of the sea ice mass balance has demonstrated the contrasting mean ice growth, melt and export in each region. The Weddell and Ross shelf seas expereince the highest annual ice growth, with a large fraction of this ice exported northwards each year, whereas the Bellingshausen shelf sea experiences the highest annual ice melt, despite the low annual ice growth. Current work (not shown) is focussed on atmospheric forcing trends and the resultant trends in the sea ice and mixed layer evolution using both ERA-I hindcast forcing and hadGEM2 future climate projections.

1. Introduction

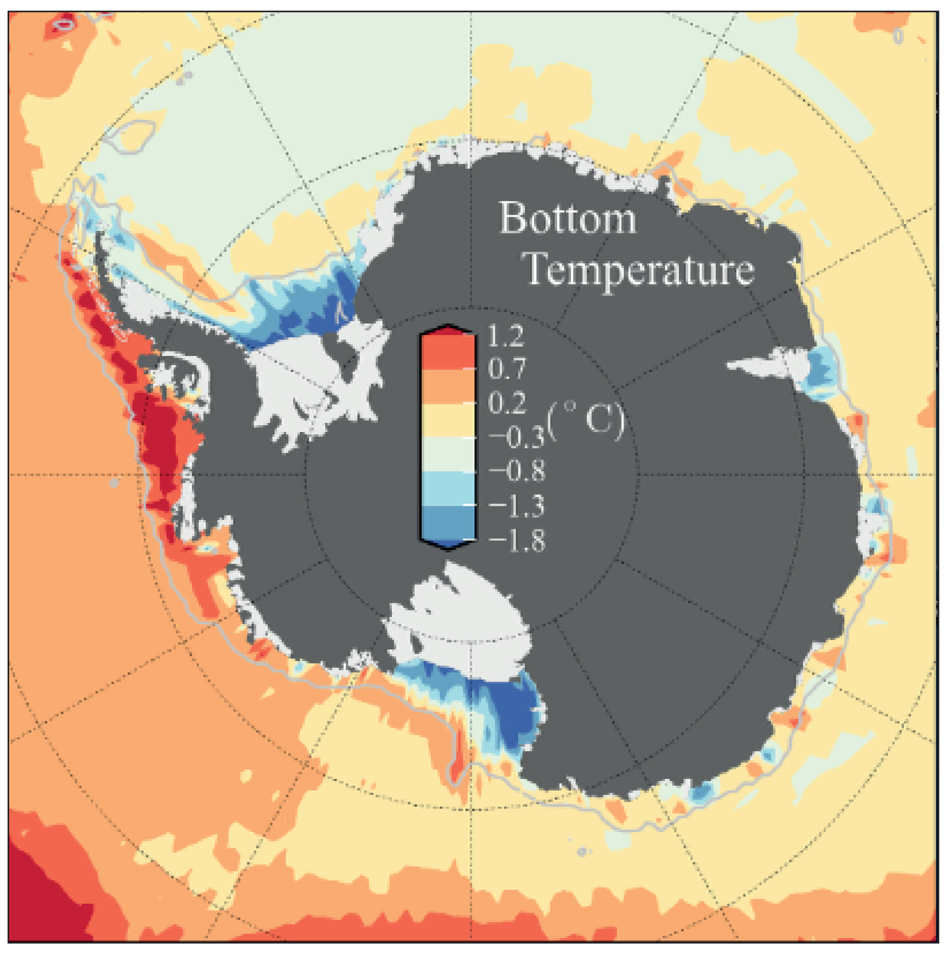

Figure 1: Bottom temperature taken from the World Ocean Atlas 09. The white line is the 1000 m isobath contour. Landmask are taken from the RTOPO dataset.

The continental shelf seas surrounding Antarctica are a crucial component of the Earth's climate system, with the Weddell and Ross (WR) shelf seas cooling and ventilating the deep ocean and feeding the global thermohaline circulation, whereas the warm waters in the Amundsen and Bellingshausen (AB) shelf seas (see Figure 1) are implicit in the recent ocean-driven melting of the Antarctic ice sheet.

The brine rejection from sea growth in the WR shelf seas causes a salinification and deepening of the surface mixed layer, resulting in the formation of High Salinity Shelf Water (HSSW) through the complete destratification of the water column. The AB shelf seas in contrast experience warmer (~-15°C) surface air temperatures in winter (see Figure 2), which, along with several other atmospheric differences was demonstrated by Petty et al. (JPO, 2013) to be sufficient in explaining the lack of shelf water formation in these two regions.

In this study we have coupled an ocean mixed layer model to a sophisticated sea ice model (see Section 3) to understand how regional differences in the atmosphere and the contrasting thermodynamic/dynamic response of the sea ice might control the mixed layer evolution in these four important climatic regions.

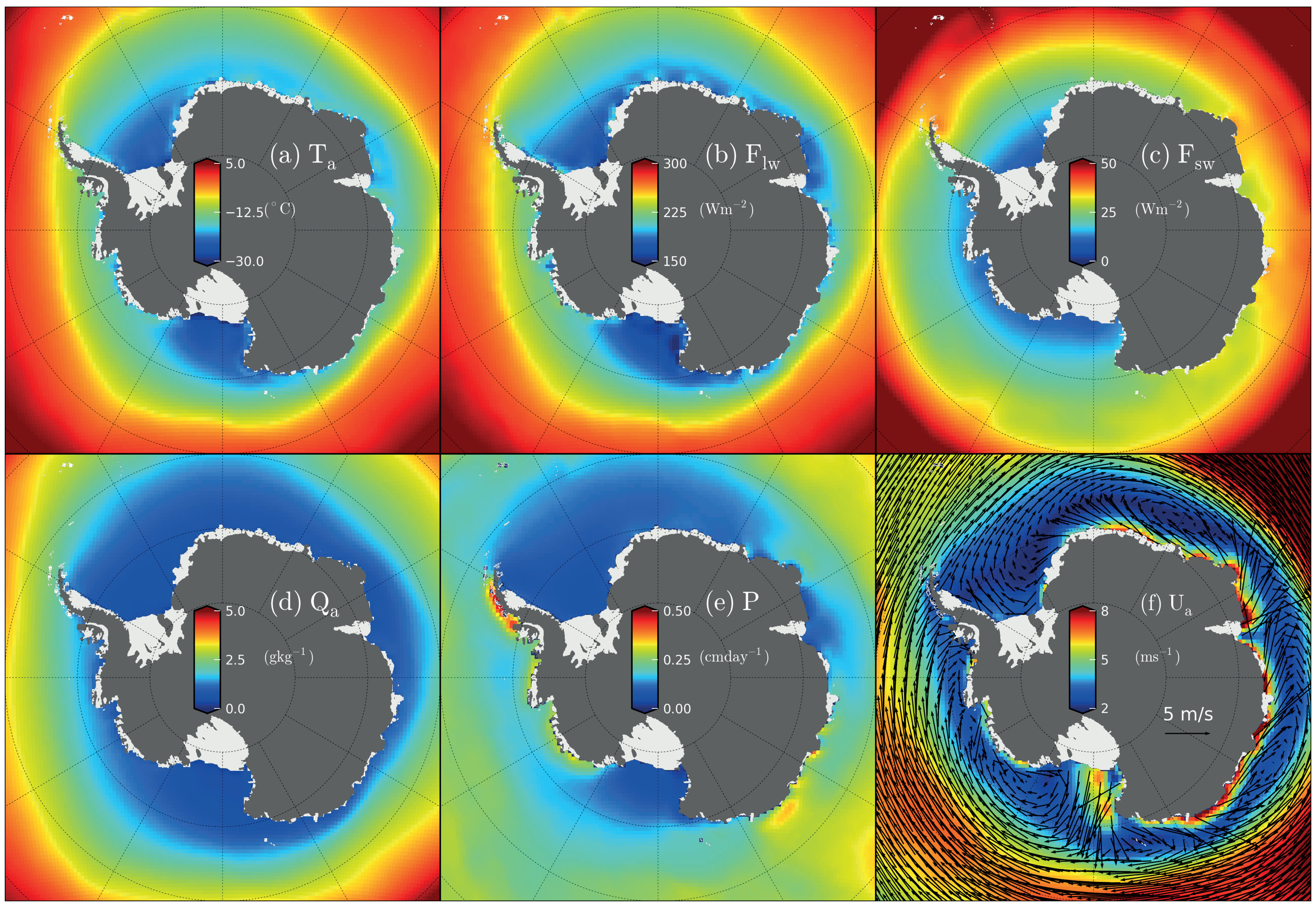

Figure 2: Mean (1980-2011) ERA-I Winter (JAS) atmospheric forcing data: (a) Air Temperature, (b) incoming longwave, (c) incoming shortwave, (d) specific humidity, (e) net precipitation and (f) wind speed.

3. CICE-Mixed Layer Model

We have included a variable mixed layer model into CICE, a sophisticated sea ice climate model component, as shown in Figure 3. The use of a bulk mixed layer model reduces the computational cost, and enables us to have a complete understanding of the impact of surface fluxes on the ocean below, removing the impact of variable ocean dynamics from the model results.

This model is forced by the ERA-I atmospheric data (winter mean shown in Figure 2). A coarse deep ocean T/S grid has also been included into CICE to model the entrainment of shelf waters in winter.

Results of this model are shown in Figures 4-6.

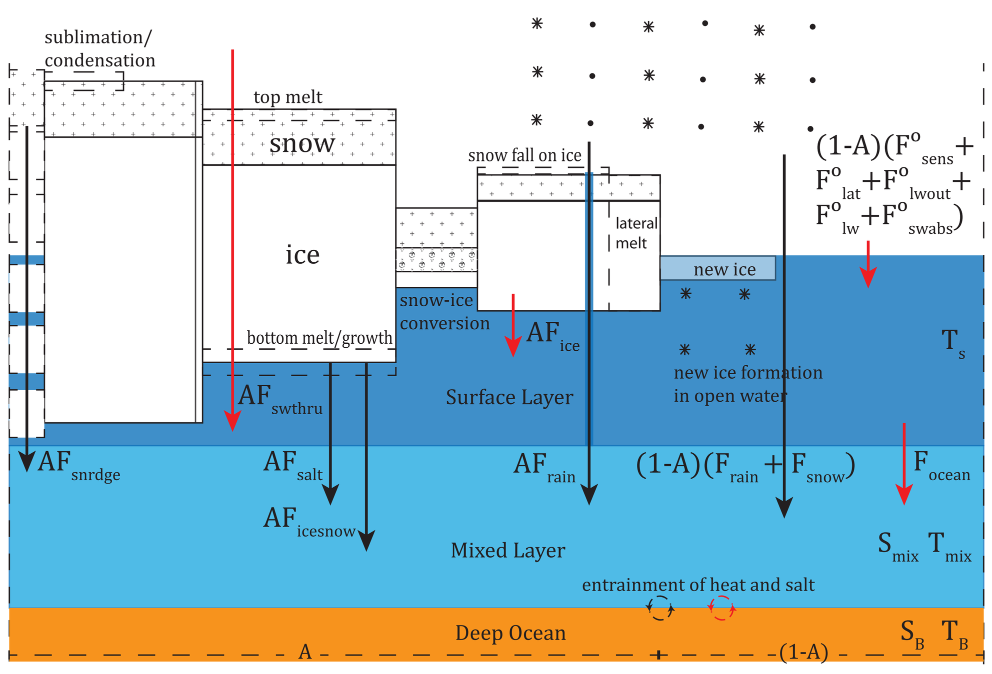

Figure 3: The CICE-mixed layer model schematic.

4. Mixed Layer/ Sea Ice Results

This model captures reasonably well the expected ice concentration and sea ice thickness distribution through comparison to observations and produces deep (>500 m) mixed layers in the Weddell and Ross shelf seas each winter as expected (Figure 4). This results in the complete destratification of the water column in both the southern coastal regions, leading to High Salinity Shelf Water (HSSW) formation, and shallow regions further north (e.g. the Berkner Bank in the central Weddell shelf sea) which do not lead to HSSW formation but do provide an important mechanism through which Modified Warm Deep Water (MWDW) is converted to near HSSW. Shallow mixed layers form in the Amundsen (~200 m) and Bellingshausen (<100 m) shelf seas, with no destratification of the water column, allowing a thick layer of warm water to persist at depth.

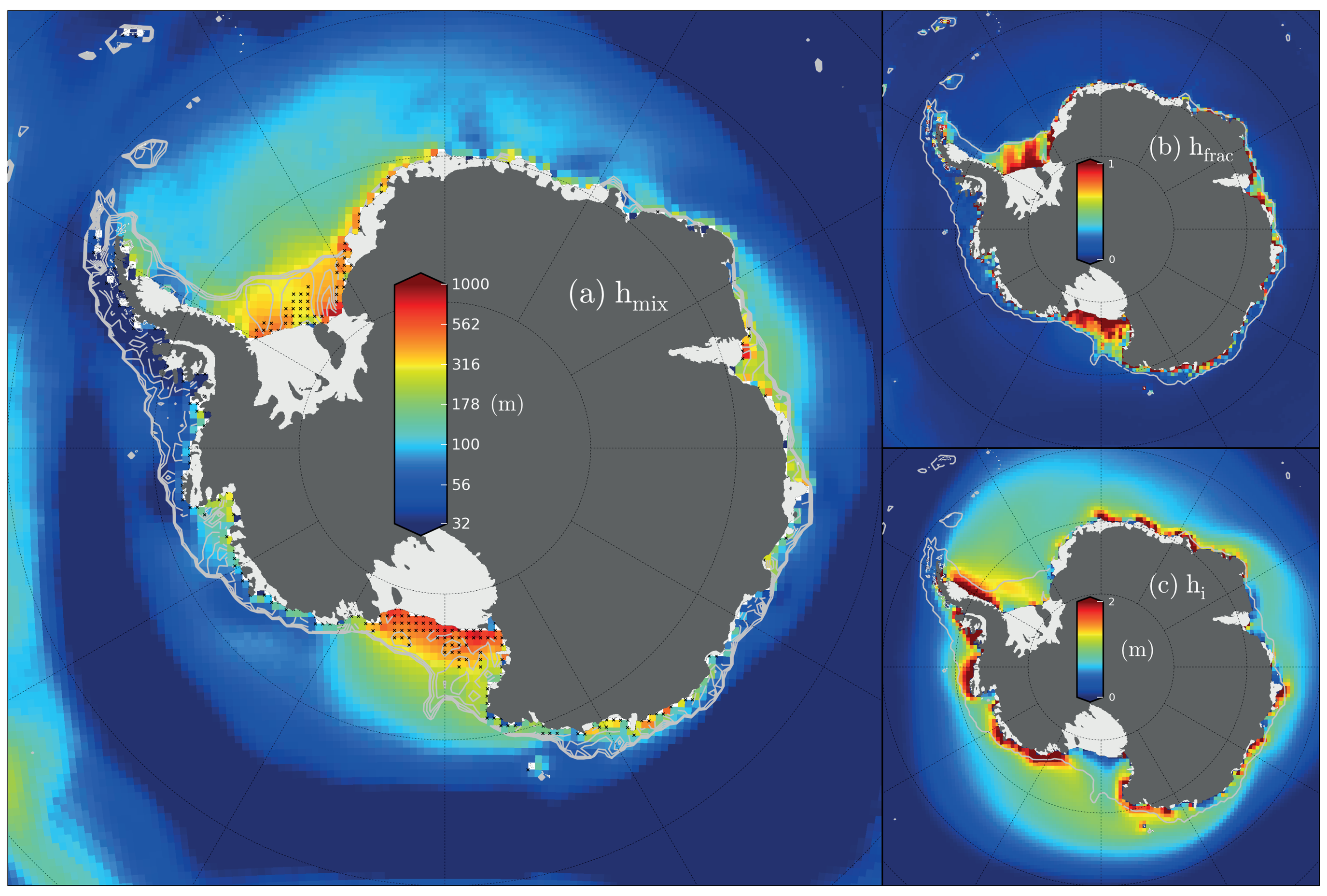

Figure 4: Mean (1985-2011) (a) maximum mixed layer depth, (b) fractional depth of (a) as a function of the water column depth and (c) wintertime (JAS) ice thickness. Note that the colour scale and colour bar in (a) use a logarithmic (base 10) scale. The crosses indicate maximum imxed layer depths greater than 90% of the water column depth

5. Surface Power Input to the Mixed Layer

Figure 5 demonstrates the clear bimodal distribution in the surface power input to the mixed layer in the WR seas compared to the AB seas, adding weight to the hypothesis that regional atmospheric variability controls Antarctic shelf water formation. Figure 5 also highlights the crucial role of sea ice (blue line) in dominating the evolution of the mixed layer (grey/black line).

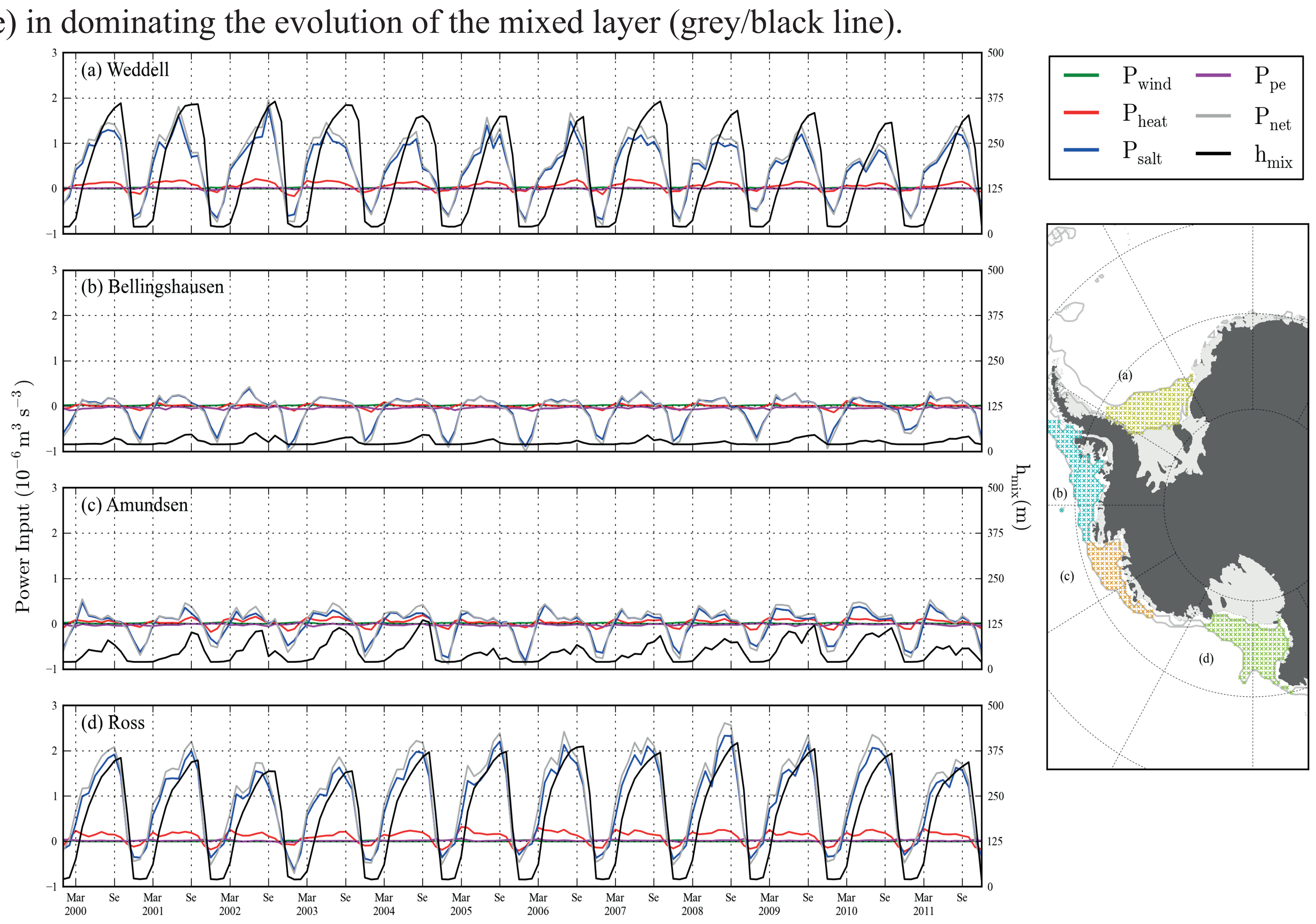

Figure 5: Power input to the mixed layer for the years 2000-2011. (a) - (d) Regional power input from wind mixing (green), the ocean-surface layer heat flux (red), the salt input from sea ice growth/melt (blue), net precipitation minus evaporation (pink), net power input from the addition of all these four terms (grey) and the mixed layer depth (black) averaged spatially over each of the four study regions highlighted in the map shown,

6. Sea Ice Mass Balance

An analysis of the sea ice mass balance has demonstrated the contrasting growth, melt and export of ice in each region. The Ross shelf sea has the highest mean annual ice growth of the shelf seas, followed by the Weddell shelf sea, with the two regions growing two/three times as much ice as the Amundsen and Bellingshausen shelf seas. Despite this, the Bellingshausen shelf sea has the highest mean annual ice melt of the shelf seas, driven in large part by the near-zero annual ice export, which explains the strong summer stratification and shallow mixed layers that form here in winter. In contrast, a large percentage of the ice that is grown in the Weddell and Ross is exported to the north of the shelf each year. Comparing our modelled ice growth estimates to polynya ice growth observations suggest the ice growth north of the Weddell and Ross coastal polynyas contribute a significant fraction of the total shelf sea ice growth, making this an important process that currently lacks observational analysis.

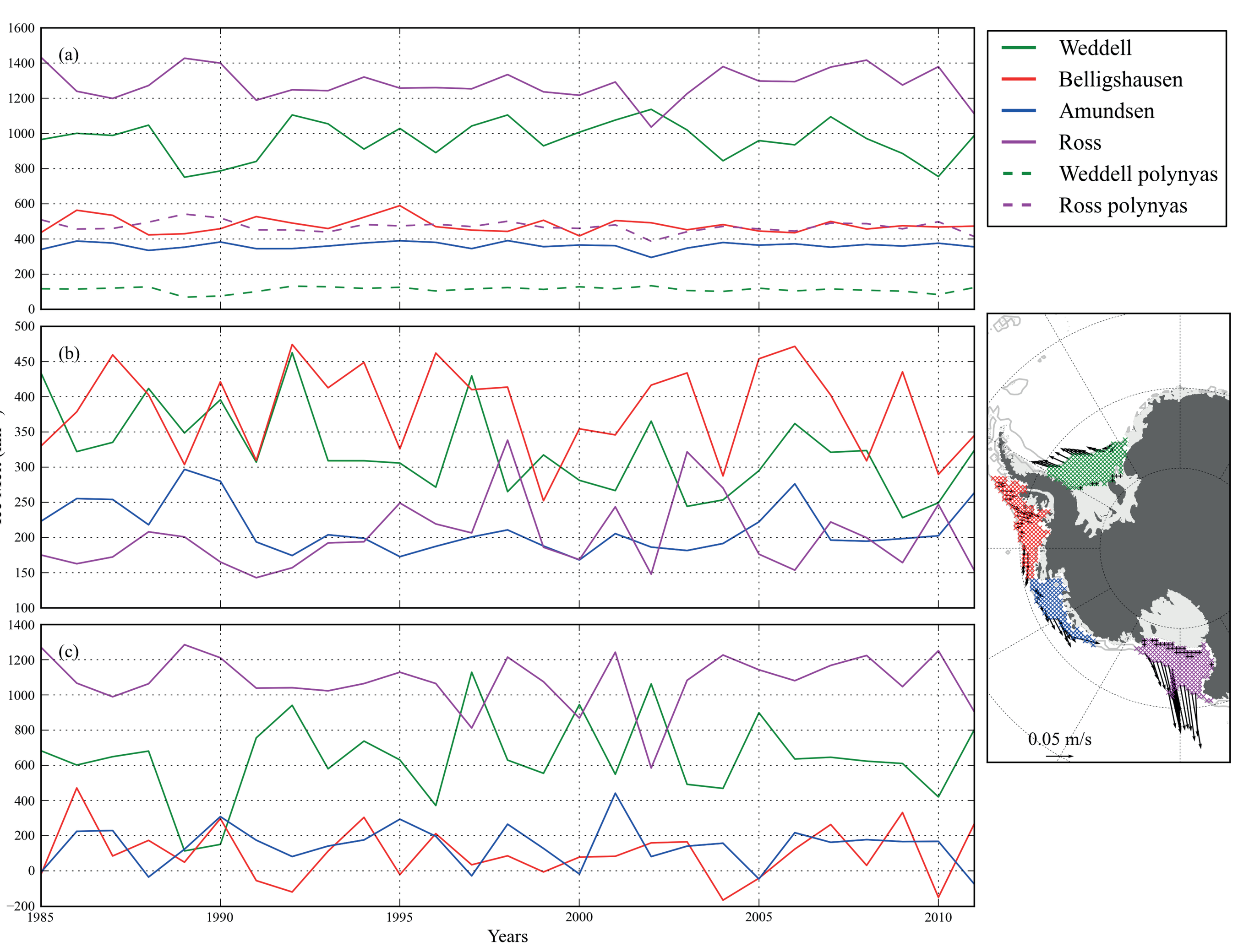

Figure 6: Annual (1985-2011) regional sea ice mass balance (same regions as Figure 5). (a) Annual regional ice production, including the contribution from rapid sea ice growth 'polynya' grid cells (marked by the black crosses) , (b) annual regional ice melt, (c) annual regional net ice export. Mean ice motion vectors for the outer grid cells of each region are shown in the map.

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