Figure 1: Two schematic views of the global overturning circulation. The Southern Ocean plays two key roles in the global overturning: (1) the Antarctic Circumpolar Current connects the ocean basins, establishing a global-scale overturning circulation, and (2) atmosphere-ocean-ice interactions drive water mass transformations that help close the global overturning. (From Talley (2013), following Gordon (1986), Schmitz (1991) and Lumpkin and Speer, 2007)).
Figure 2: Antarctic sea ice extent in summer (March 1, 2008; top) and winter (October 1, 2008; bottom). The total area covered by Antarctic sea ice expands from $4 \times 10^6$ km$^2$ in summer to $19 \times 10^6$ km$^2$ in winter, an increase larger than the area of the Arctic Ocean (Source: AMSR-E, Bremen.)
Figure 3: Key physical processes affecting the Antarctic margin and sea ice zone. (National Research Council of the National Academies (USA), 2011).
Figure 4: Temperature (top) and salinity (bottom) trends in the Southern Ocean. The Southern Ocean has warmed and freshened throughout the upper ocean (200 to 1800 m). Trends are calculated by comparing recent measurements from Argo to a long-term climatology along mean streamlines. (Böning et al., 2008).
Figure 5: Warming of the abyssal ocean. Temperature change in the Antarctic Bottom Water layer (potential temperature < 0°C) is expressed as an equivalent heat flux. The strongest warming signals are observed near Antarctica and along the flow paths that carry AABW northward (Purkey and Johnson, 2010).
Figure 6: Normalized time series (thin line) and their linear trends (thick line): (a) ERA-40 zonal wind stress over the Southern Ocean (45°–60°S), September 1957–August 2002; (b) in situ observations of wind speed at Macquarie Island (54.5°S, 158.9°E), January 1958–December 2003; (c) the SSM/I satellite wind speed data, January 1987–December 2001; (d) the Marshall Southern Annular Mode index based on the observational SLP data, January 1958–December 2003; (e) ERA-40 Antarctic (60°–90°S) total column ozone, September 1957–August 2002; (f) TOMS satellite Antarctic (60°–90°S) total column ozone, January 1979–December 2003; and (g) atmospheric CO2 concentrations at South Pole (89°59S, 24°48W), September 1957–December 2003. (Note that all trends are calculated from a 13-month running mean of respective time series, which can reduce the sensitivity of trend values to marginal effects. Two separate periods: pre-1980 and January 1980–December 1999 are chosen for the linear trend analysis.) (Yang et al., 2007)
Figure 7: Schematic representation of the effect on the climate system for a positive SAM. The schematic of circulation, properties and fluxes for the negative phase of the SAM exhibits the same patterns as displayed above, only with reversed directions of circulation and the opposite sign for property anomalies and fluxes. (Sen Gupta et al., 20XX).
Figure 8: Schematic of current systems in the Southern Ocean. [Illustrate ACC, subpolar gyres, Antarctic Slope Front and coastal currents, circulation on shelf where possible]
Figure 9: Trends of sea ice extent in September in the Antarctic (top) and Arctic (bottom). (National Snow and Ice Data Center, USA).
Figure 10: Change in duration of Antarctic sea ice cover (in days yr$^{-1}$, evaluated between years 1979 and 2004). (Stammerjohn et al., 2008).
Figure 11: Loss of ice from the grounded portion of the Antarctic ice sheet (colours on the Antarctic continent). Ocean temperature near the sea floor is shown around the margin of the continent (right hand colour bar). From Pritchard et al. (2012), who conclude “the most profound contemporary changes to the ice sheet and its contribution to sea level can be attributed to ocean thermal forcing.”
Figure 12: Basal melt rates of Antarctic ice shelves color coded from $<-5$ m/year (freezing) to $>+5$ m/year (melting) and overlaid on a 2009 MODIS mosaic of Antarctica. Ice-shelf perimeters in 2007–2008, excluding ice rises and ice islands, are thin black lines. Each circle graph is proportional in area to the mass loss from each shelf, in gigatons (1 Gt = 1012 kg) per year, partitioned between iceberg calving (hatch fill) and basal melting (black fill). See Table 1 and table S1 for additional details on ice shelf locations, areas, and mass balance components. (Rignot et al., 2013)
Figure 13: Schematic of ocean – ice shelf interaction (Smethie and Jacobs, XXXX).
Figure 14: Seawater properties observed in the ocean cavity beneath the PIG ice shelf. Potential temperature (°C) (a), salinity (b), as measured by Autosub. (Jenkins et al., 2010).
Figure 15: Vertical temperature and salinity sections. a, b, Vertical temperature and salinity sections (a) from the CTDs shown in the Fig. 1 inset and extended beneath the PIG and (b) along the PIG calving front, looking toward the ice shelf. Both panels show temperature in colour relative to the *in situ* freezing point, salinity by black contours and the surface-referenced 27.75 isopycnal and potential temperature maximum by thick and thin white lines. Open circles in b show ice draft above the ridge crest (black dots) beneath the PIG, from airborne radar and Autosub measurements. (Jacobs et al., 2011).
Figure 16: The Antarctic sea ice zone includes several physical environments, each with distinct characteristics that mean a different mix of platforms is needed for each regime.

Five domains in the sea ice zone, each with own sampling needs/opportunities:
1. Open ocean above 2000 m
2. Deep ocean
3. Continental shelf and slope
4. Ice shelf cavity
5. Sea ice and atmosphere
Figure 17: Argo float trajectories. Note the large voids in the sea ice zone (partially filled in the Weddell Sea by acoustically-tracked profiling floats).
Figure 18: Location of acoustic sound sources in the Weddell Sea (top). Temperature and velocity in the Weddell Sea, derived from 5633 float profiles (note that the WOCE CTD data base includes 800 casts in this region) (middle). The floats provide year-round data, including under the sea ice (bottom, sea ice indicated in white) (O. Boebel, AWI).
Figure 19: Location of oceanographic profiles collected by instrumented seals.
Figure 20: Location of repeat hydrographic sections contributing to the Southern Ocean Observing System (SOOS) and GO-SHIP.
Figure 21: Location of hydrographic sections (lines) and moorgins (circles) occupied during the SASSI program of the International Polar Year. Sustained occupations of these sections and arrays would make a substantial contribution to an under-ice observing system.
Figure 22: An Arctic example of an integrated under-ice observing system (J.-C. Gascard).
Figure 23: A strategy for observing the sub-ice shelf cavity. AT = acoustic sound source/receiver for tomography and navigation of floats and gliders; ITP = ice-tethered profiler. Sampling by autonomous vehicles within the cavity by long range submersibles (yellow oval) and across the ice-front by gliders (dashed line) is needed.
Figure 24: Schematic of a strategy for observing the ocean over the continental shelf and slope offshore of an ice shelf to measure ocean circulation and heat transport to the sub-ice shelf cavity.
Figure 25: Example of an integrated sea ice observing array to make simultaneous measurements of sea ice, snow, atmosphere and ocean (Ackley).
Figure 26: Schematic of surface fluxes and related processes for high latitudes. Radiative fluxes are both shortwave (SW) and longwave (LW). Surface turbulent fluxes are stress, sensible heat (SHF) and latent heat (LHF). Ocean surface moisture fluxes are precipitation and evaporation (proportional to LHF). Processes specific to high-latitude regimes can strongly modulate fluxes. These include strong katabatic winds, effects due to ice cover and small-scale leads and polynyas, air-sea temperature differences that vary on the scale of eddies and fronts, deep and bottom water formation, and freshwater input associated with blowing snow. (Bourassa et al., 2013).