Sea ice and ocean convection

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The Weddell Polynya, child of the 1970s

The stratification within the Weddell gyre is characterized by a thick layer of relatively warm, saline deep water drawn from the lower Circumpolar Deep Water. Along the southern limb of the gyre the warm deep water is \(1.0^\circ\)C, with salinity 34.7. The warm deep water is capped by the 100-m-thick surface layer of near-freezing temperature in the winter. In the summer a warmed surface layer induces a temperature minimum near 50–100 m marking a residue of the winter condition. The surface layer is separated from the warmer deep water by a weak pycnocline (density gradient).

Below the warm deep water are the Weddell Sea Deep Water and Weddell Sea Bottom Water, both cooled and freshened relative to the warm deep water by input from the continental margins of Antarctica.

During each winter, the polynya area shifted westward at a rate of 0.013 m s\(^{-1}\), the approximate barotropic flow within the Weddell gyre once away from the topographic effects of the continental margins and Maud Rise (Gordon 1978, 1982). As the Weddell Polynya was observed near the very start of the satellite-based time series one might have reasonably expected that a winter persistent polynya was the norm, but since 1976 a winter-long polynya has not been observed. What has been observed are much smaller (10\(^{10}\) km\(^2\)), sporadic polynyas with characteristic time scale of 1 week in the vicinity of Maud Rise near 65°S, 2°E (Comiso and Gordon 1987; Lindsay et al. 2004) induced by circulation-topographic interaction (Gordon and Huber 1990).

The Weddell Polynya of the mid-1970s represents an anomaly relative to the last three decades of direct sea ice observations. Comparison of water column characteristics before and after the Weddell Polynya indicates that it was maintained in the cold winter months by ocean convection reaching to a nearly 3000-m depth that injected relatively warm deep water into the surface water (Gordon 1978, 1982; Fig. 2). The Weddell Polynya is an example of a sensible heat polynya (the ocean to atmosphere heat flux is maintained by lowering the surface water temperature) in contrast to latent heat polynyas (where ocean to atmosphere heat flux is maintained by latent heat release of forming sea ice, which is subsequently removed by the wind) that form along much of the coastline of Antarctica. An estimate of the 3-yr average winter ocean heat lost to the atmosphere within the Weddell Polynya is 136 W m\(^{-2}\) (Gordon 1982). This ocean heat loss is supported by deep reaching ocean convection of 1.6 to 3.2 Sv (1 Sv = 10\(^{16}\) m\(^3\) s\(^{-1}\)) that exchange freezing-point surface water with relatively warm Weddell Deep Water. Moore et al. (2002) using National Centers for Environmental Prediction–National Center for Atmospheric Research (NCEP–NCAR) data find that buoyancy loss within the Weddell Polynya is larger than determined by Gordon (1982) so that the ocean convection may have been significantly more vigorous. However, the NCEP freshwater flux estimate does not include the convergence of freshwater into the polynya associated with the movement of sea ice floes (e.g., by wind stress associated with passing weather systems) with subsequent melting. Gordon (1982) and Comiso and Gordon (1987) suggest that the influx of sea ice from the polynya edges acts to dilute the deep-water salt injected into the surface layer and therefore is a factor in modulating the convective intensity.

The sea surface salinity measured in the austral summer of 1977 shows that in the area of the Weddell Polynya the surface water was markedly saltier than that of the surrounding area and relative to the regional climate average (Fig. 3). It is reasonable to conclude...

![Color-coded sea ice concentration maps](https://example.com/fig1.png)

**Fig. 1.** Color-coded sea ice concentration maps derived from passive microwave satellite data in the Weddell Sea region during (a) 30 Aug 1974, (b) 30 Aug 1975, and (c) 29 Aug 1976. The Weddell Polynya is the extensive area of open water (in blue) near the Greenwich meridian roughly between 65° and 70°S. (Adapted from Gordon and Comiso 1988.)
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Fig. 1. Satellite record of ice distribution for June–November from 1973–79. Dashed polynya in August 1979 is reduction in ice, of up to 40% (from the Fleet Weather Weekly Ice Charts, 1973–1979).
The density of water

\[ \rho \text{ [kg/m}^3\text{]} \]

\[ T[\text{oC}] \]
T-S-diagram

Growth, properties and salinity evolution

IPY International Sea-Ice Summer School
Zonally averaged ocean density
Deep ocean properties must be set at the surface.

All deep (dense) water originates in polar regions.

From OCCA - Forget (2008)
A two-box model of an ocean column

STATE 1

\[ T, S, \rho \]

\[ T_2, S_2, \rho_2 \]

STATE 2

\[ T_1, S_1, \rho_1 \]

\[ -K_s(S_2 - S_1) \]

\[ K_T(T_2 - T_1) \]

\[ F \rightarrow -Q_w \]

STATE 3

\[ T, S, \rho \]

\[ T_1, S_1, \rho_1 \]

\[ -K_s(S_2 - S_1) \]

\[ K_T(T_2 - T_1) \]

\[ F \rightarrow -Q_i \]

STATE 4

\[ T_2, S_2, \rho_2 \]

\[ T_1, S_1, \rho_1 \]

\[ -K_s(S_2 - S_1) \]

\[ K_T(T_2 - T_1) \]

\[ F \rightarrow -Q_i \]

Fig. 3. Schematic representation of the four model states. Sign conventions are noted and symbols are as described in the text.
Keep in mind: the Martinson model is a simple toy

- Designed to look at small perturbations from a reference state that is just barely stratified, to study a relatively short-lived and small-scale phenomenon
- It’s not a climate model: no conservation of energy, salt, etc.
- Can’t use it to explore long-term changes in deep water mass properties
- No feedback between ice cover and atmospheric processes.
- Could be interesting to couple this model to a toy sea ice / atmosphere model (e.g. Thorndike 1992, Eisenman and Wettlaufer 2009)
Take home messages

- Polar oceans tend to be weakly stratified, typically with fresh, cold water overlying warmer, saltier water.

- Small changes in heating/cooling or freshwater input can have large consequences, by releasing stored heat from below.

- Sea ice: reduces winter heat loss (stabilizing), rejects brine (de-stabilizing), stores seasonal snow at surface (de-stabilizing)

- When conditions are just right, convection can be initiated by winter sea ice formation, leading to abrupt ice melt and polynya formation.

- The convective polynya is a transient phenomenon, but can persist over several seasonal cycles.

- Salt makes the ocean complicated.