Polynyas, Leads in the Southern Ocean - Encyclopedia of the Antarctic

The sea ice surrounding Antarctica and covering much of the Southern Ocean is far from homogeneous, instead it is littered with patches of open water and cracks. Larger, persistent areas of open water within the sea ice pack are called polynyas (a word of Russian origin); while linear cracks in the sea ice are called leads. These areas of open water have an important impact on both the ocean and the atmosphere, as they enhance energy and moisture exchange between the two. The elevated heat and moisture fluxes within polynyas and leads are signalled by what Cherry Apsley-Gerrard called “frost smoke” – a condensation fog that occurs a few metres above the surface as the air becomes saturated and water vapour condenses out. The impression one gets is of the ocean boiling like a kettle and, given the enormous air-sea temperature differences (perhaps 30-40^{o}C), the physics is not that different. Another signal of polynyas and leads is the dark “water sky” reflections that they cast upwards onto any low-level cloud. In the featureless often all-white seascape of the sea-ice pack these water skies stand out. To the present day they provide a navigational beacon for ships crossing the sea-ice pack, indicating where the easy passages of open water areas are situated.

Polynyas are typically rectangular or ellipical in shape and occur regularly in the same location. They can be classified by location as either coastal (or shelf-water) polynyas if they are over the continental shelves; or as open-ocean (or deep-water) polynyas if they are located further offshore. Polynyas are typically tens to hundreds of kilometres in scale. Leads are typically much narrower across, from tens of metres to a few kilometres, but can be up to hundreds of kilometres long.

The topological distinction between polynyas and leads is reinforced by a causal distinction. Polynyas are formed by a coherent external forcing mechanism that either moves or melts the sea ice, for example, advection by strong winds and ocean currents or melting by warm water. In contrast, leads are formed by an internal deformation of the sea-ice pack, where cracks develop somewhat at random as a result of sea-ice dynamics. This means polynyas tend to occur in fixed and predictable locations, for example, tied to particular parts of the coastline or to seamounts; whereas leads occur seemingly at random as the sea-ice cover is shattered by internal stresses. Of course the sea ice is also externally forced, by wind stress, ocean currents and tides for example.

Figure 1 shows an infra-red satellite image of the southern Weddell Sea on August 27, 1997. The image is largely cloud free so is essentially a map of surface temperature, with white representing cold and black representing warm surface temperatures. To the south is the Ronne Ice Shelf, the surface of which is very cold at this time of year, to the west are the mountains of the Antarctic Peninsula, partly covered in cloud, while to the northeast is the Weddell Sea. This is largely covered in sea ice (grey) but there are areas of open water, or very thin ice, seen as warm surface temperatures (black). In front of the Ronne Ice Shelf is a large coastal polynya, approximately 250 by 50 km. One can see that to an extent the sea ice matches the shape of the coastline, as if it has just been blown offshore by the strong southerly winds at this time. There is another shelf-water polynya in the southeast corner of the image, in the lee of a large iceberg. There are leads throughout the sea ice pack – the shattering pattern appears as if the ice could have been struck by a hammer. The resolution of this image is approximately 1 km, suggesting most of the visible leads are order 1 km wide (see also **Remote Sensing**).

Coastal polynyas generally form when strong persistent winds blow the sea ice offshore. Hence they tend to be located on coastlines prone to persistent offshore winds, often topographically-driven, such as katabatic winds or barrier winds (see also **Wind**). For example, there are recurrent coastal polynyas off the Ronne Ice Shelf, the Ross Ice Shelf, the Mertz Glacier and in Terra Nova Bay. As the sea ice is advected offshore an area of near-freezing water opens up and fluxes of heat from the relatively warm water into the cold atmosphere result in new sea ice being formed. The latent heat that is released during this freezing means these polynyas are traditionally known as “latent heat” polynyas; although in this case “wind-driven” would be a better description as this is what drives their lifecycle.

During an episode of relatively strong offshore winds a coastal polynya will act as a site of enhanced ice production. In particular millimetre-scale frazil ice crystals are formed throughout the water column. The frazil ice rises and is collected into slurries, often organised into downwind-oriented band by circulations in the surface waters called Langmuir circulations. These slurries, also known as “grease ice”, are of order 10 cm deep and damp the surface waves. The frazil and grease ice are advected downwind with this mixture eventually piling up against the downwind consolidated ice pack. During this advection the ice will coalesce and freeze into a more solid ice covering, but also be broken into metre-sized discs, or “pancake ice”, through swell and wave action (see also **Sea ice, types and formation**). Coastal polynyas have been dubbed “ice factories”, producing on the order of 10 metres of ice a year, ten times more than the average sea ice thickness around Antarctica. Once the winds drop, offshore ice advection slows, and the new ice that is being formed will gradually seal over the polynya. The balance between ice advection and ice production determines the width of coastal polynyas. For the same wind speed, lower air temperatures lead to higher ice production and so narrower polynyas, while higher air temperatures lead to lower ice production and so wider polynyas.

Open-ocean polynyas form over deeper waters, that is, off the continental shelves, although they are often associated with submarine mountains. The most intriguing example has been the “Weddell Sea Polynya” of 1974-1976, when an area the size of France remained largely ice free for three consecutive winters, yet has not occurred to the same extent since. It was only observed by the very new (at that time) satellite-borne passive microwave remote sensors. It originally formed over the Maud Rise seamount (65^{o}S, 5^{o}E), but moved westwards during the three-year period. There are also recurrent open-ocean polynyas over Maud Rise and in the Cosmonaut Sea. Open-ocean polynyas are generally formed by oceanic warming, thus traditionally they are known as “sensible heat” polynyas. The warm waters melt existing sea ice and prevent new ice from forming, thus keeping the polynya open. They are driven by an upwelling of warmer waters from depth, triggered by submarine topography, weak vertical stratification, eddy formation, tidal motion, or some combination of factors – indeed their formation is still a matter of debate. They are to some degree self-sustaining, as the surface waters of the polynya are cooled by the atmosphere, leading to sinking and turbulent convection. The convection will cease as the cooling decreases in spring, or can be shut off earlier by a fresh-water cap formed by lateral advection or melting and precipitation.

Most coastal polynyas tend to be wind-driven, or current-driven, while most open-ocean polynyas tend to be thermally-driven. However some polynyas have combinations of these mechanisms, for example the Ross Ice Shelf polynya is primarily controlled by synoptic-scale weather systems forcing ice divergence in front of the ice shelf, but an upwelling of warm water also contributes to this region being prone to thin ice and open water areas.

Radiation is also important in controlling the surface energy balance of polynyas and leads. During winter, the relatively warm surface means a relatively large upward longwave (infra-red) radiative flux, contributing to a cooling of the ocean. During spring and summer polynyas and leads absorb more shortwave (solar) radiation, due to their lower albedos, and so contribute to an enhanced warming of the ocean, compared to the surrounding ice-covered areas.

Polynyas and leads are significant for the ocean, the atmosphere, human activities and biology. For the ocean, their importance lies in their ability to change water properties. The role of coastal polynyas as zones of enhanced sea-ice production means they are sources of salt (as some salt is rejected as sea water freezes) and so act to make the surface waters more saline and dense. Over continental shelves such as in the southern Weddell Sea, this creates High Salinity Shelf Water, which sinks and then predominantly circulates underneath, and interacts with, the Ronne-Filchner Ice Shelf, eventually leaving this cavity as Ice Shelf Water. This then mixes with other water masses ending up leaving the continental shelf to form Antarctic Bottom Water – the most prevalent deep water mass of the world’s oceans. The rate of ice formation within coastal polynyas is a key component in this chain of events and so plays a role in forcing the ocean’s thermohaline circulation. Open-ocean polynyas also create dense water masses through a cooling throughout the depth of the ocean by open-ocean convection, i.e. a cooling into the atmosphere. Water mass transformations will also be enhanced by elevated cooling and brine rejection under leads, however due to their more random location such transformations are not as concentrated into particular locations and so perhaps less directly relevant for ocean circulation (see also **Thermohaline and Wind-driven circulation; Antarctic Bottom Water**; **Weddell Sea, Oceanography; Amundsen and Ross Seas, Oceanography).**

During winter, exposing areas of relatively warm open water also has a dramatic impact on the atmosphere, acting as a source of heat and moisture at the surface. Polynyas and leads act to warm and moisten the atmosphere and induce a convective well-mixed boundary layer. The convective circulation will be of a similar horizontal scale to the heating source, i.e. the polynya or lead. So polynya-induced atmospheric modifications can be tens to hundreds of kilometres in scale, and reach thousands of metres in height. Polynyas act through warming and, in general, accelerating the atmospheric boundary layer to: develop mesoscale cyclones, enhance synoptic-scale cyclones, and accelerate katabatic flows through an “ice-breeze” mechanism. In contrast, lead-induced atmospheric circulations will tend to be much smaller, only hundreds to thousands of metres across and generally limited to tens to hundreds of metres vertically (see also **Polar lows and mesoscale weather systems; Atmospheric Boundary Layer**).

In addition to local changes to the atmospheric circulation, the integrated affect of polynyas and leads is to enhance the transfer of heat and moisture from the ocean to the atmosphere. For much of the year, a great deal of the Southern Ocean is insulated from the atmosphere by sea ice. Any areas of open water break through this insulation. So within polynyas and leads the air-sea turbulent heat exchange can be up to 2 orders of magnitude higher than over the surrounding sea ice. Therefore although the areal coverage of polynyas and leads is small, only a few percent of the total area covered by sea ice, their contribution to warming the atmosphere and cooling the ocean is large.

As mentioned earlier, polynyas and leads provide natural routes for ships crossing the ice-covered seas. In addition to aiding immediate navigational choices, the larger predictable areas of open water or thin ice have for years been used as preferred shipping lanes for the resupply of Antarctic bases. For example, during the resupply of the British Antarctic Survey’s Halley Research Station, on the Brunt Ice Shelf, in the southeastern Weddell Sea, the ships always curve well to the East of a straight line from the Falkland Islands, or South Georgia, to pass through the recurrent polynyas and thin ice in the vicinity of Maud Rise around 0-5^o East.

Polynyas and leads are havens of biological and wildlife activity. Sea mammals need breathing holes in the sea ice, so tend to concentrate in polynyas; while during summer, their lower ice concentration means an earlier melt back, a larger annual absorption of solar radiation (due to a lower albedo) and so higher primary productivity. This attracts krill and so penguins, birdlife and sea mammals to these areas (see also **Sea ice microbial communities and primary production**).

Numerous mathematical models of individual polynyas and leads have been developed, to examine polynya dynamics, sea-ice dynamics and the impact of polynyas and leads on the circulation of the atmosphere and the ocean. It is now realised that some representation of polynyas and leads is also required in large-scale climate models, but due to their relatively small size their primary affects – heating the atmosphere and cooling the ocean – have to be represented in a simplified manner. Given the limited observations and developing understanding of the physics of polynyas and leads, their representation in climate models is presently crude and very much an area of active research (see also **Sea ice, weather and climate**; **Climate modelling**).

Further reading

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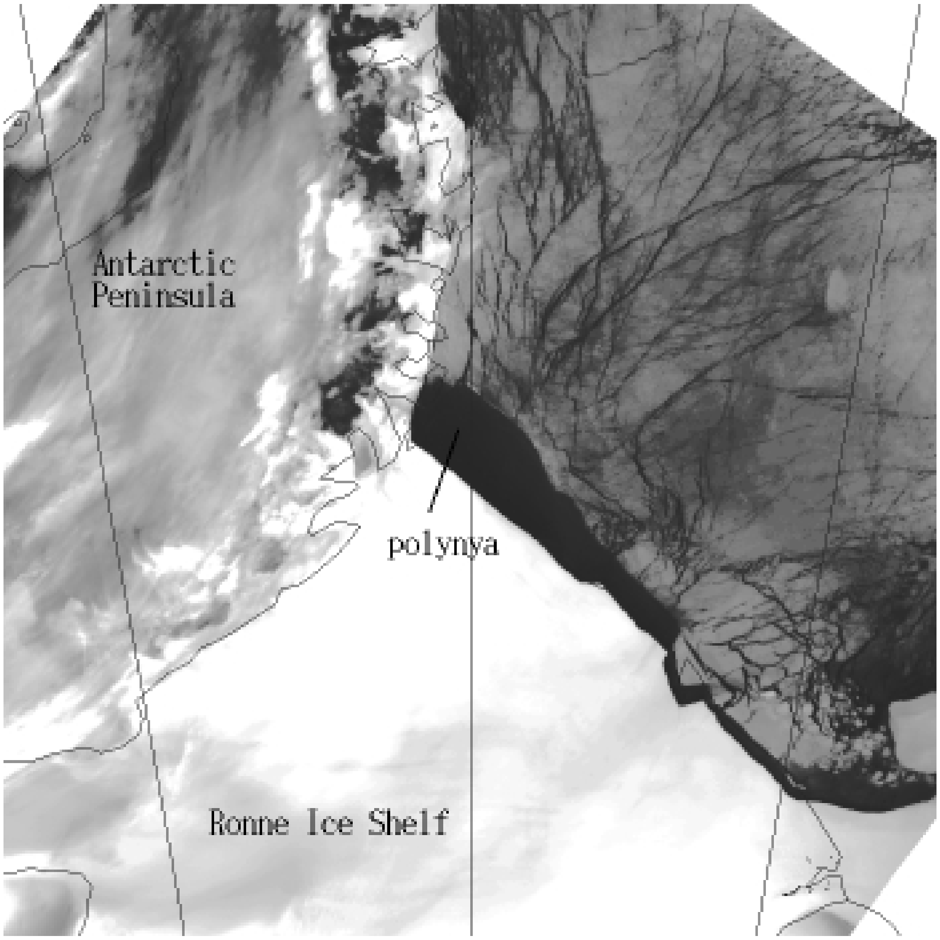

Figure 1 Infra-red satellite image of the southern Weddell Sea from the AVHRR instrument, at August 27, 1997, courtesy the British Antarctic Survey. Light colours represent cold brightness temperatures, dark colours warm brightness temperatures. The width of the image is about 750 km. There is a coastal polynya in front of the Ronne Ice Shelf, while the sea ice to the north is cracked with leads.