Chapter 4: Specific events 2017

4.1. The Weddell Sea Polynya

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Statement of main outcome: During the year 2017 a large hole in the winter sea ice cover (polynya) appeared in the Weddell Sea, a region of the Antarctic Ocean. It stayed open for almost three months and was the first reappearance of such an event since 1976. Deep vertical oceanic mixing started after the polynya opened but was stopped after just two months, probably as sun-induced sea ice melting released enough freshwater to stabilise the water column. Such deep mixing is crucial for the global ocean circulation, deep ocean ventilation, and carbon and heat storage. The Weddell Polynya must therefore be actively monitored to understand why this deep mixing starts and stops.

Products used:

Ref. No.	Product name and type	Documentation
4.1.1	SEAICE_GLO_SEAICE_L4_REP_OBSERVATIONS_011_009 Global Ocean Sea Ice Concentration Time Series Reprocessed from EUMETSAT OSI SAF	PUM: http://marine.copernicus.eu/documents/PUM/CMEMS-OSI-PUM-011-009.pdf QUID: http://marine.copernicus.eu/documents/QUID/CMEMS-OSI-QUID-011-001to007-009to012.pdf
4.1.2.	GLOBAL_REANALYSIS_PHY_001_026 Global ocean ensemble physics reanalysis	PUM: http://marine.copernicus.eu/documents/PUM/CMEMS-GLO-PUM-001-026.pdf QUID: http://marine.copernicus.eu/documents/QUID/CMEMS-GLO-QUID-001-026.pdf

Every winter at both poles, strong winds push the sea ice away from the coast (Smith and Barber 2007), opening small holes in the sea ice or so-called 'coastal polynyas'. Via these holes, the comparatively warm ocean is in direct contact with the cold atmosphere, which results in strong oceanic heat loss, sea ice formation and dense water production (e.g. Cavalieri and Martin 1994; Kusahara et al. 2010). In stark contrast with these small coastal polynyas, in austral winter 2017 a very large hole opened unexpectedly in the sea ice in the open ocean in the Weddell Sea – the Atlantic sector of the Southern Ocean. That hole, the Weddell Polynya, has been a modelling mystery for the last decades, occurring regularly in climate projections (e.g. Heuzé et al. 2013) yet only twice to date in the observational record. It is hence crucial to study this second occurrence, not only to help improve global climate models but also due to the potential large role of the Weddell Polynya on the global oceanic circulation (Orsi et al. 2001) and on local ecosystems (Smith and Barber 2007).

The first satellites to routinely observe the Antarctic sea ice detected the Weddell Sea polynya, a huge hole that opened three winters in a row, from 1974 to 1976 and reached up to 350,000 km^2 (Carsey 1980). Then, nothing happened for forty years. A small 'halo' with sea ice concentrations never exceeding 90% (Lindsay et al. 2004) was regularly observed, but the polynya itself did not re-open until 27 July 2016 and closed shortly after on 17 August 2016. In 2017 however, the Weddell Polynya stayed open continuously from mid-September until the seasonal retreat of sea ice early December, and at its maximum reached approximately 300,000 km^2 (Figure 4.1.1).

There have been too few observed events to determine the exact reasons why the Weddell Polynya only opens occasionally. The Weddell Polynya is a latent heat polynya, meaning that it opens because sea ice is melted locally from below by upwelled warm waters (Morales-Maqueda et al. 2004). The sea ice halo indicates that this upwelling happens often, most likely because of the presence of the underwater seamount Maud Rise (Holland 2001). However, additional processes are required to trigger a full polynya opening but there is no consensus as to which they are, owing notably to a lack of in-situ measurements. The trigger could be an event in the atmosphere, e.g. persistent anomalous winds (Gordon et al. 2007; Cheon et al. 2014); or a weakening of the oceanic stratification (Comiso and Gordon 1987; Heuzé et al. 2015; Kjellsson et al. 2015); or even low frequency variations in the Weddell Sea heat content (Martin et al. 2013; Dufour et al. 2017).

The Weddell Sea and the other seas surrounding Antarctica are vast and cannot be sampled effectively with conventional automated in-situ observations (drifters, profilers, etc), and ship-based campaigns are too seldom to allow for the monitoring of such rapidly evolving phenomena as the polynya. The main direct observation of the polar ocean and its sea ice cover is thus made using satellite-based products. Figure 4.1.1 shows the temporal evolution of the Weddell Sea polynya in austral spring 2017 (15 September, 25 October, 15 November, and 1 December). Daily maps of sea-ice concentration are computed from passive microwave radiometer observations from the Special Sensor Microwave Imager/Sounder (SSMIS). Raw brightness temperature measurements are converted to sea-ice concentration by the EUMETSAT Ocean and Satellite Application Facility (OSI SAF, http://www.osi-saf.org/) and redistributed by CMEMS as SEAICE_GLO_SEAICE_L4_NRT_OBSERVATIONS_011_001 (product reference 4.1.1).

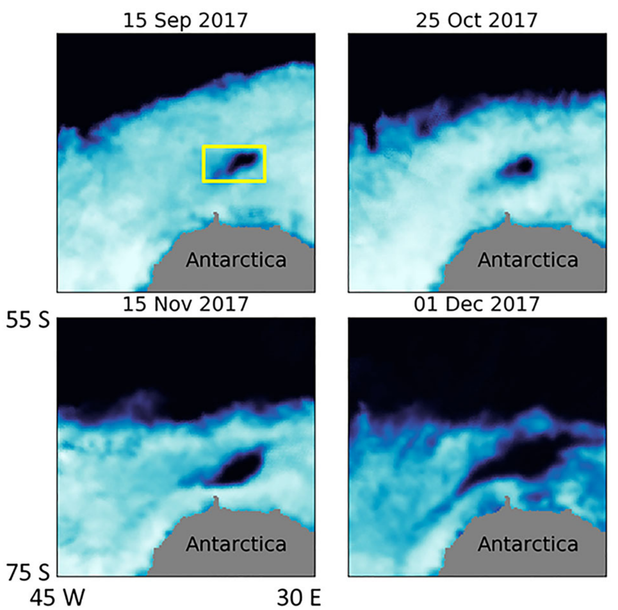

Figure 4.1.1. Evolution of the Weddell Sea Polynya in austral spring (15 September, 25 October, 15 November, and 1 December) 2017 as monitored by product 4.1.1. Yellow box highlights the area used for the output averaging of GREP (product 4.1.2) shown on Figures 4.1.2 and 4.1.3.

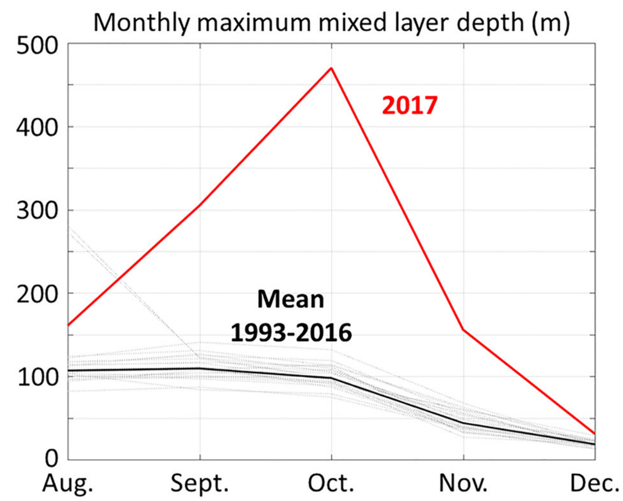

Figure 4.1.2. Monthly mixed layer depth over Maud Rise (yellow box, Figure 4.1.1) from product 4.1.2. Black line indicates the mean of 1993–2016 (individual dotted lines). Red line is 2017, with the polynya opening in September. Based on product 4.1.2 (GREP).

In the following section, we use the ensemble mean global reanalysis product GREP (product reference 4.1.2). GREP consists of GLORYS2V4 from Mercator Ocean (Fr), ORAS5 from ECMWF, FOAM/GloSea from the UK Met Office (UK) and C-GLORS from CMCC (It). All these reanalyses assimilate sea ice concentration from passive microwave observation data and the vertical mixing is parameterised according to a turbulent closure model adapted by Blanke and Delecluse (1993).

Observations (Martinson et al. 1981) and coupled models (e.g. Heuzé et al. 2013) both show a deepening of the mixed layer during a polynya event. The GREP product correctly reproduces this phenomenon (Figure 4.1.2): in 2017, the monthly mixed layer depth (MLD) departs from an average value in August to peak at 470 m in October 2017, 350 m deeper than the mean value of 1993–2016, and returns to a normal value in December. The deep mixed layers, by bringing warm water up, are thought to keep the polynya open. GREP in contrast shows that in November, as the polynya grew exponentially, the MLD had decreased again (Figure 4.1.2), suggesting that from November onwards the polynya continued growing because of melting of sea ice by the atmosphere, not by further upwelling of warm oceanic water.

The evolution of both temperature and salinity with time and depth in the polynya region (Figure 4.1.3) confirms these findings. After the opening of the polynya, notably in September 2017, the surface waters are warmer and saltier than previously (resp. 0.05°C and 0.01, thick black line on Figure 4.1.3(b,d)) whereas from 70 m depth onwards they are colder and slightly fresher than before the polynya opened. This pattern of warming of the surface waters in winter coincident with a cooling of the subsurface, all while the MLD deepens, is indicative of convection. From November 2017 onwards however, the surface signal is dominated by the large freshening induced by the growth of the polynya (Figure 4.1.1) while at subsurface temperatures around 100 m increase again as the mixed layer shoals, further suggesting that the convection was limited to September–October 2017. It is worth noting that the hydrography from GREP is remarkably similar to that measured by the autonomous SOCCOM floats that accidentally sampled the 2017 polynya (see Figure SB6.2 of Swart et al. (2018) compared to Figure 4.1.3(a,c) here). Since modelling approaches are routinely used in the ice-covered Southern Ocean where observations are lacking, it is crucial that reanalysis such as the four members of the GREP product remain as accurate as possible, even when having to react to an unexpected polynya event.

In summary, although the opening of the Weddell Polynya in winter 2017 was unexpected, it was accurately detected by the passive microwave observations (product 4.1.1), which were then assimilated by GREP (product 4.1.2) resulting in GREP's hydrography matching that opportunistically observed (Swart et al. 2018). The GREP results presented here suggest that the 2017 Weddell Polynya had two different stages of development: first, in September and October, the mixed layer

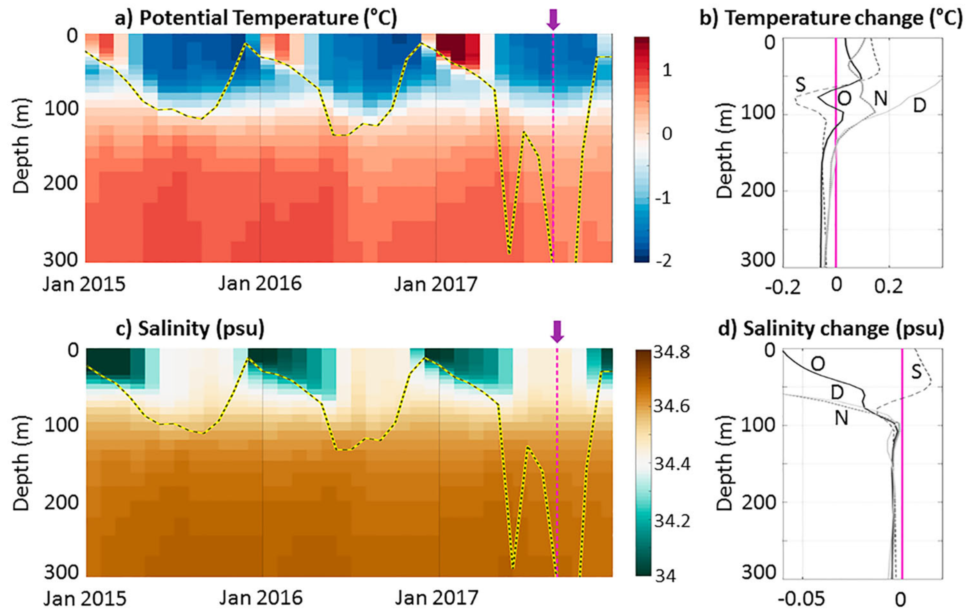

Figure 4.1.3. Evolution of the monthly hydrographic properties in GREP (product 4.1.2) with depth and time over Weddell Polynya region (yellow box, Figure 4.1.1): (a) Potential Temperature from January 2015 to December 2017; (b) change in that temperature after the opening of the polynya in September (S, dashed black), October (O, plain dark grey), November (N, dashed grey) and December (D, plain light grey) 2017 when compared with August 2017; (c) and (d) same as (a) and (b) respectively for the salinity. On (a) and (c), yellow dashed line is the monthly MLD from product 4.1.2; vertical purple dashed line and associated arrow, the opening of the polynya in September 2017; vertical dashed black lines, the turn of the year.

deepened and heat was redistributed through the water column, indicative of convection bringing warm water to the surface to further melt the sea ice from below; then, in November, the water column was stabilised, convection stopped, and the polynya grew only because of seasonal surface melting from above, hence producing even more freshwater to stabilise the water column. It is however too early to say whether the dynamics in the model are correct. Longer observational time series with more openings of the large Weddell Polynya than just the 1970s and 2017 are needed, along with measurements of its effect on the rest of the climate system in terms of heat and carbon fluxes and volumes of deep water formation. Since sea ice has been struggling to close over the polynya region in May and June 2018, we may be able to extend our analysis by one year soon.

4.2. Temperature and salinity anomalies in the North Atlantic subpolar gyre

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Statement of outcome: A regional cold and fresh anomaly appeared in the North Atlantic in 2014. It is associated with the onset of a positive North Atlantic Oscillation phase and intense deep convection in the Labrador Sea. The previous Ocean State Report indicates that in 2016, this cold and fresh anomaly was located to the south of Iceland and primarily associated with an eastward migration of the eastern boundary of the subpolar gyre. In 2017, a similar cold and fresh anomaly is detected further to the north-east with temperature anomalies of smaller amplitude and salinity anomalies of similar amplitude as observed previously.

Products used:

Ref. No.	Product name and type	Documentation
4.2.1	INSITU_GLO_TS_OA_REP_OBSERVATIONS_013_002_B INSITU_GLO_TS_OA_NRT_OBSERVATIONS_013_002_A **In situ TS data**	PUM: http://marine.copernicus.eu/documents/PUM/CMEMS-INS-PUM-013-002-ab.pdf QUID: http://marine.copernicus.eu/documents/QUID/CMEMS-INS-QUID-013-002b.pdf http://marine.copernicus.eu/documents/QUID/CMEMS-INS-QUID-013-002a.pdf
4.2.2	GLOBAL_REANALYSIS_PHY_001_030 **Reanalysis**	PUM: http://marine.copernicus.eu/documents/PUM/CMEMS-GLO-PUM-001-030.pdf QUID: http://marine.copernicus.eu/documents/QUID/CMEMS-GLO-QUID-001-030.pdf

The North Atlantic subpolar gyre is a region characterised by substantial variability on interannual to decadal