Review of Pickup et al. "Cold lenses in the Amundsen Sea: Impacts of sea ice formation on subsurface pH and carbon" submitted to Ocean Science.

We are grateful to the reviewer for their helpful comments and suggestions. Our responses to their feedback are provided below, in bold. Any text amended and copied from the manuscript is also in blue.

Brief summary

This study investigates subsurface "cold lenses" found beneath the Dotson Ice Shelf region of the Amundsen Sea polynya, Antarctica. These lenses are distinct pockets of cold ($\Theta < -1.7$ °C), salty, and dense water located at 240–500 m depth. High-resolution ocean glider measurements (temperature, salinity, dissolved oxygen, pH, and dissolved inorganic carbon, DIC) reveal that these lenses are colder, more saline, and denser than the overlying Winter Water (WW), but fresher and less dense than underlying modified Circumpolar Deep Water (mCDW). They exhibit slightly higher dissolved oxygen, lower pH, and elevated DIC, indicating intense surface cooling and brine rejection during sea ice formation. Two formation mechanisms are proposed: (1) formation in shallow coastal polynya regions (e.g., Martin Peninsula), where strong cooling and brine rejection drive dense water downslope to its neutral buoyancy depth (~400 m), and (2) local deep convection ("convective chimneys") during winter, with subsequent subsurface trapping. Seal tag data support high surface heat loss and deep mixed layer formation, suggesting sea ice production rates of ~3 cm/day.Ten lenses were identified, ranging from ~5 to 25 km in horizontal extent, and are likely recurring features formed annually. These lenses potentially reduce subsurface heat content, possibly limiting heat transport beneath ice shelves and acting as a barrier to basal melting if advected under the Dotson Ice Shelf. Furthermore, they may provide a mechanism for transporting carbon-rich water deeper than typical WW, influencing regional carbon budgets. Overall, the lenses highlight the importance of shallow shelf processes in shaping Antarctic subsurface water properties and carbon dynamics.

The paper is overall well written and presented. The topic is highly relevand and add to the few studies of ice-ocean interaction. Before I can recommend the paper for publication I would like the authors to take into account my specific comments below.

Thank you for your positive comments on our work and helpful suggestions to strengthen it. We would just like to clarify that the study investigates subsurface cold lenses as captured by the glider and ship's CTD observations in the area north of the Dotson Ice Shelf region.

Specific comments:

Figure 2: In order for the reader to easily follow what is shown, I suggest that you spell out the names of the water types e.g. AASW, mCDW, WW, Lens. Can be difficult to follow for scientists that is not local to the area. Suggest to change the depth bar so the cold water lences between 200-500 m has a distinct color. Then it will be easier to localise the cold lenses in the T-S space.

We agree with the suggestion to spell out the names of the water masses, and have updated the figure accordingly so that AASW, mCDW and WW are written in full. Regarding the depth colourbar, we appreciate the suggestion to use a distinct colour to highlight the 200–500 m depth

range. However, not all water within this depth interval corresponds to the cold-water lenses, so a uniform change of colour along the depth axis could be misleading. Instead, we have added a boundary that delineates the lens properties directly in the T–S diagram. This makes the cold-water lenses easier to identify while ensuring that the depth colourbar continues to represent depth consistently.

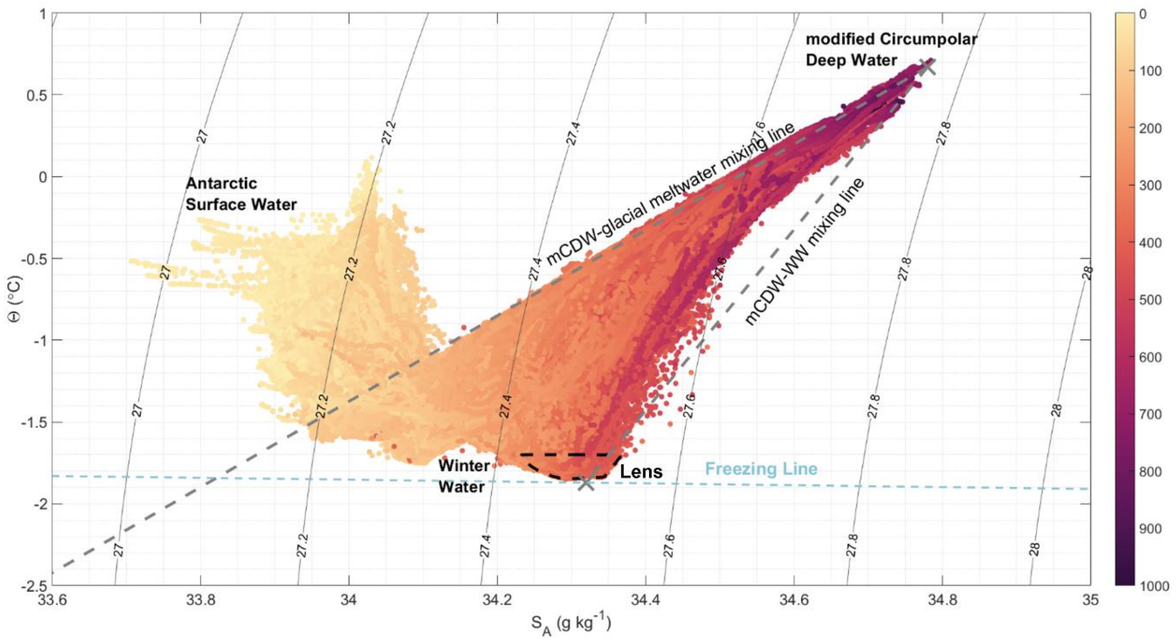

Figure 2. Temperature-salinity diagram for measurements in the study area from the gliders and CTD casts coloured by depth. Local water masses are labelled and the freezing line was calculated using TEOS-10 (McDougall et al., 2010}. End members are shown with a cross and grey dashed lines indicate water mass mixing lines. Black sloping lines depict potential density (kg m^3). The black dashed line depicts the location and properties of the lenses.

You have indicated a mCDW-glacial meltwater mixing line. Could that be similar to the "Gade-line"? In a T–S diagram below an infinit ice cover, a melt line with an observed slope of 2.5 °C per salinity unit corresponds to the Gade slope.

Reference: Gade, H. G. Melting of ice in sea water: a primitive model with application to the Antarctic ice shelf and icebergs. J. Phys. Oceanogr. 9, 189–198 (1979).

Yes, that is correct. Where it is introduced, we have now noted that the mCDW-glacial water mixing line can also be known as the Gade line and referenced Gade (1979) for clarity.

Line 211: During sea ice formation, lighter oxygen isotopes are favoured in the ice and heavier isotopes remain in the water, lowering the δ18O of the water. This is not correct.

The fractionation effect during freezing is relatively small but tends to favour the 18O isotope in the ice compared to the residual liquid water. Sea ice typically has a δ18O value close to that of the source seawater, with a slight enrichment (more positive δ18O). In contrast, meteoric ice (ice formed from precipitation) is strongly depleted in 18O (more negative δ18O) compared to seawater. See

Moore et al. (2017) Fractionation of hydrogen and oxygen in artificial sea ice… Cold regions Science and Technology 142:93-99.

We agree with the reviewer and have amended the text appropriately to ensure the interpretation of δ18O is correct (see response to comment on Line 207 – 245 to see this). As it is true that sea ice formation has a small effect on fractionation, we have rewritten elements of Section 3.3 that focus on δ18O. The point we want to make overall is that a sea ice formation signal is present within the lenses. Instead of relying on δ18O to do this, we will focus more on the freshwater fractions in Figure 6. Here there is a negative contribution from sea ice melt (suggesting sea ice formation) at the depth of the lenses, where there is also a decrease in δ18O.

Line 219: The more negative δ18O within the lenses than in WW suggests more intense sea ice formation as the water has gotten more isotopically light. This is confusing. Do you mean:

The more depleted δ18O values within the lenses than in WW suggest a more intense sea ice formation (as the sea ice brine is more depleted in δ18O)…?

We thank the reviewer for these clarifications (including the comment above and below), and we note that this section of the paper has been fully revised (see response to comment below).

Line 207-245: I suggest to rewrite this section where you specify if an isotope is "enriched" or "depleted".

We agree, this section has been amended to ensure the correct interpretation:

Lenses observed in each CTD cast are located at different depths, with the Θ minimum found within the range of 240 and 405 m (Fig. 5). The varying profile shapes within the lenses possibly reflect the same feature observed by the glider transects, where the difference in lens shape and size depends on which part of the lens was captured by the single profile. Three of the CTDs with lenses (Fig. 4) were additionally sampled for δ18O and DIC as shown in Fig. 5d and e. For CTD 8 the δ18O decreases from -0.45 ‰ at 200 m in WW to -0.50 ‰ at 300 m within the lens. For CTD 18 the decrease in δ18O is from -0.40 ‰ at 200 m (WW) to -0.48 ‰ within the lens at 400 m. For CTD 279 the decrease is from -0.47 ‰ at 245 m (WW) to -0.55 ‰ at 345 m, just below the lens. In the WW (depths between 100 - 200 m) δ18O is approximately 0.5 ‰ lower than in mCDW (depths greater than 450 m). The δ18O values of the lens cores are more negative to those of WW (Table 1). However, it is important to consider that there are only seven data points of δ18O within the lenses and the depth at which a measurement was taken may skew interpretation.

The effect of sea ice formation and melt is small on δ18O in relation to meteoric inputs. During sea ice formation, the heavier isotope, 18O, is favoured in the ice, and lighter 16O remains in seawater, lowering the 18O of the water affected by sea ice formation. To separate the effects of meteoric input and sea ice formation, the calculated freshwater fractions from δ18O are used to interpret the processes affecting the lenses. The freshwater fractions shown in Fig. 6 highlight a negative sea ice contribution to the lenses which indicates net sea ice formation. The most notable decrease is in CTD 18, with CTD 8 being less pronounced. There is no δ18O measurement at the depth within the lens from CTD 279, but the measurement just below the lens shows a decrease in the sea ice melt contribution. Water above the lenses, especially close to the surface, has a positive sea ice contribution, indicating net sea ice melt which has occurred locally in the spring.

DIC concentrations in the lenses are slightly higher than in WW, by a maximum of 10 µmol kg−1 (Table 1). Similar to pH and O2, mCDW has the highest DIC concentration (2261 µmol kg−1) as it has spent the longest time not exchanging with the atmosphere. Additionally, DIC accumulates in the water column due to the breakdown of organic matter which produces DIC. The CTD casts with a lens are compared with a CTD profile where a lens was not observed (Fig. 5). For temperature, salinity, O2 and δ18O, the comparison CTD cast (CTD 194) was in the same location as the lens CTD cast (CTD 18), 20 days later (Fig. 4). No additional CTD casts were carried out in the region of the Dotson-Trough where DIC was sampled, so, two CTD casts from the ASPIRE campaign, which was carried out in December 2010 - January 2011 (Yager et al., 2012), within 25 km of CTD 18 were used for comparison (Fig. 4). Three consecutive dives made by SG579 after those within lens A were selected for a comparison of pH profiles in the lens with surrounding water.

Temperature and salinity are lower in the lenses than in nearby water at the same depth (Fig. 5) by a maximum of 1.50 ◦C and 0.16 g kg−1, respectively. The dissolved O2 concentration is higher in the lenses than in surrounding water and the δ18O in the lenses is approximately 0.18 ‰ lower than surrounding water, indicating a process that has occurred in the lens water mass, but not in nearby surrounding water. The lens has DIC concentrations very similar to one of the ASPIRE CTD casts (CTD 9) but approximately 18 µmol kg−1 lower than the other (CTD 72, collected about 2 weeks later in the season and over a deeper part of the trough). The lower DIC concentration is consistent with pH which is 0.02 higher in the lens than in surrounding water at the same depth.

Evidence of deep convection from the surface to depths less than 400 m or to the seabed (if shallower than 400 m) as indicated by seal profiles, were observed in the shallow shelf around Martin Peninsula and to the east of the Dotson-Getz Trough. There are also a few profiles in deeper water across the trough (Fig. 7a). Temperatures within these profiles reach a minimum of -1.85 ◦C at depths of approximately 300 - 400 m (Fig. 7b). These temperatures are associated with a SA greater than 34.25 g kg−1, mirroring the properties of the lenses.

Line 254: The mCDW contribution would also have a low O2 concentration, high δ18O, high DIC concentration and low pH content. This should be changed to: The mCDW contribution would also have a low O2 concentration, less depleted δ18O values, high DIC concentration and low pH content.

Yes, thank you. This statement has been revised accordingly.

Line 308: same comment as in line 207-245.

This has been amended as well: The lenses are colder, saltier and denser than overlying WW and are associated with a higher DIC concentration, lower pH and an enhanced fraction of net sea-ice formation (as determined from delta18O-derived freshwater fractions).

Figure 8: Very simple figure. Do not think it is needed. If decided to keep, I would suggest you to change the left horizontal arrow to follow more the bedrock and point out just above the “depth of lenses”. You could also consider to add the information on 18O, DIC, O2 and pH to the conceptual figure.

We have decided to keep the figure for clarity, but are grateful to the reviewer on points to improve it. Please see below for the amended version. We have included information on the properties of the lenses and how these differ from overlying WW.

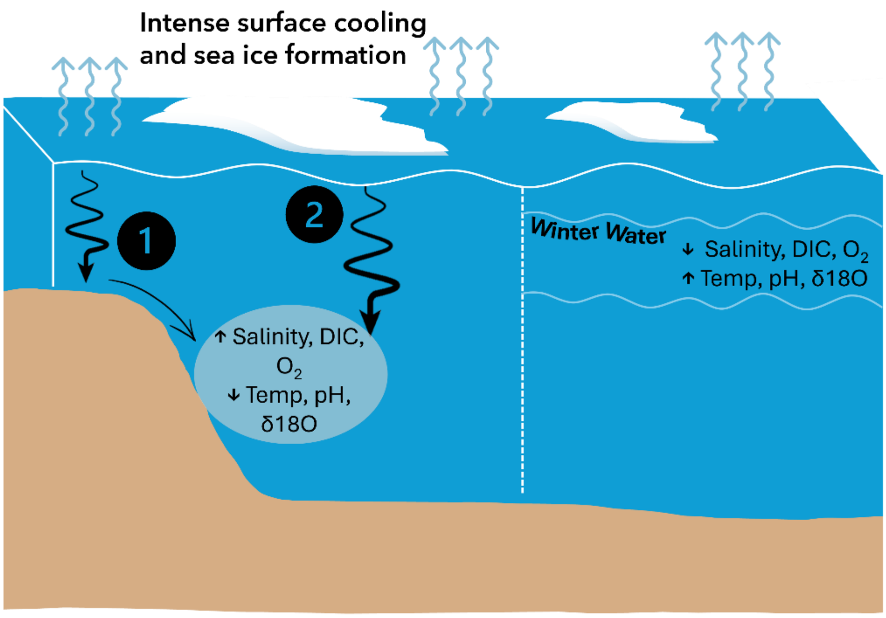

Figure 8 - Schematic depicting the two possible formation processes of the lenses on the left and their properties. The numbers reference the formation theory with (1) formation in shallow water due to sea ice formation and spilling into deeper water and (2) local chimneys of convective mixing. The right depicts the properties of the overlying WW.