General comments

This study has revealed extremely high ice production via underwater frazil ice formation and the importance of intense events of frazil ice production in the Antarctic polynyas, based on direct observation under PIPERS project. The finding is novel and the method/analysis are appropriate. The study demonstrates that process of under- water frazil ice formation should be properly considered in the polynya process. In addition, observed polynyas are the sites where dense water, precursor of Antarctic Bottom Water, is formed. Therefore, I have no doubt that the contents of the paper contribute to understanding of sea ice –ocean interaction and the Antarctic oceanography significantly. Therefore, I highly recommend that the paper should be published in "Cryosphere", but with moderate revision. The revising points are listed below.

Major comments

1. This study estimated ice production for each event and shows large variance of ice production ranging from 7 to 378 cm day-1. Although these estimates are very valuable, an important quantity is the averaged ice production or annual (monthly) ice production, which controls the formation of dense water and thus Antarctic Bottom Water. Therefore, it is desirable to infer the averaged ice production based on the two-weeks' PIPERS project. The authors took the median value of 26 cm day-1 as a representative ice production. This is better than taking the average of all the events, considering the very large variance. Even so, the median seems somewhat ad hoc way. More reasonable estimate of representative or average ice production may be possible. For example, if ice production can be related to atmospheric (and oceanic) conditions, more reasonable estimate of average ice production would be possible. Once average or monthly ice production can be inferred, then comparison or discussion with the previous satellite estimates would be possible. The present study probably suggests that the previous satellite estimation underestimated the polynya ice production.

Thank you for the comment. We found that the production rate varied with respect to the wind and with respect to the location in the polynya. There was a direct relationship between wind speed and production rate. There was an inverse relationship between the distance from the coastline and the production rate.

We have taken careful consideration to produce the requested up-scaling to a seasonal average. This includes neglecting Station 35 as an outlier, because of possible ice shelf influence (See Section 6.0 for discussion). We have added a new section to the discussion, titled " 6.1 Seasonal Ice Production", which describes the method for up-scaling. Additional detail on the computation of the seasonal average can be found in Supplemental 7 and Supplemental Figure 6.

The results yielded a seasonal ice production of 29 cm day^{-1}.

2. Ice production has very large variance from 7 to 378 cm day-1. What are the key points (reasons) for this large variance? Brief statement for this is needed, because this seems very important part of this paper. Associated with this, as shown in Table 2, the life time is very short

in the case of Stn.32. This is because Lm-o is very small. As such, the value of Lm-o has very large variance. What is the key factor for this?

The large variance is due in part to varying wind conditions and varied geographic position. The large difference at station 32 is due to a difference in the turbulent kinetic energy dissipation rate. It varies from the other stations by one order of magnitude. Station 32 experiences the most wind stress and a different SWIFT deployment was used to derive the TKE dissipation.
For station 35, the LMO is very small. That is due to a higher salt flux at that station and slower wind speeds. Station 35 represented the highest salt flux and the second smallest wind speed/stress. When the LMO is small mixing is buoyancy dominated, as opposed to wind shear dominated. We feel that the buoyancy is likely dominant due to ISW contributions.

Minor comments
3. Description in the paper is overall understandable. On the other hand, it is somewhat redundant and lacking in compactness. I think that the length of the paper can be reduced by 10-20%.
4. Line 362-363: Please describe the temperature trend and the starting location more specifically. Not easy to understand at this stage.
Thank you clarified.
5. Line 378-379: Lf=330 kJ kg-1: What is the reference for this value? I think that use of Lf=334 kJ kg-1 is more appropriate by referring Martin (1981), which showed that frazil ice crystals do not retain any brine and thus Lf should be equal to that of freshwater. Although 330 and 334 is not so different, the basis of the value should be described in the scientific paper.
Thank you corrected.
6. Line 380: Equation (2); Table 1: Conceˆtemp_ice is not understandable quantity. The total volume of frazil ice can be calculated by integration over the water column and this value can be represented by thickness of ice. This quantity is easier to under- stand. Heat loss occurs at the ocean surface, and thus a quantity per unit area is more meaningful than a quantity per unit volume. I know that ice production represented by thickness per day is introduced using Conceˆtemp_ice later in section 6. But integrated frazil ice thickness should be introduced at this stage. This comment is also applied to Conceˆsalt_ice (Equation 5).

We had an error in our calculation for the column integral of ice production. This has changed our estimate of the total column integrals by about 10%. One of the authors felt that the standard and most intuitive way to present frazil ice inventories is to present them as a concentration in kg/m^3. We have followed this protocol, and the calculation of ice concentration is defined in section 4.1. Arguably, few people have intuition for frazil amounts, but the representation as concentration can be related to other quantities.

7. Line 398: How did you determine the starting location from below the anomaly?

There were a small number of profiles, so this procedure was done graphically, using the profiles as they are shown in Figure 7. We have revised Section 4.1 to clarify the approach.

"Because we lacked multiple profiles at the same location, we were not able to observe the time evolution of these anomalies. Consequently, T_b represents our best inference of the temperature of the water column prior to the onset of ice formation; it is highlighted in Figure 7a with the dashed line. We established the value of T_b by averaging the temperature over a 10 m interval directly beneath the anomaly. In most cases, this interval was nearly isothermal and isohaline, as would be expected within a well-mixed layer. The uncertainty in the value of T_b was estimated from the standard deviation within this 10 m interval; the average was 7.5 x 10^{-5} °C, which is 1% of the temperature."

8. Line 417: Remove one of the double heat.
Thank you corrected.
9. Line 489: How "t" is finally represented using the known quantities?
Thank you, added from supplemental to main text.
10. Table 2: How "the life time" is finally represented (by an equation)?
Thank you, added.
11. Figure 10: color at Stn.32 looks like purple, not red.
Thank you figure updated.
12. Regarding the estimate of average or annual (monthly) ice production, there have been several satellite (microwave) investigations for these polynyas (e.g., Comiso et al., 2011; Drucker et al., 2011; Nihashi and Ohshima, 2015; Tamura et al., 2016), because the satellite microwave can provide daily sea ice condition. For example, data set of monthly ice production from Nihashi and Ohshima (2015) is now in public, and can be downloaded from http://www.lowtem.hokudai.ac.jp/wwwod/polar-seaflux/. As well as comparison with the model studies as was done in section 6.2, comparison and discussion with these satellite studies would enhance the value of this paper.

Thank you for pointing out these additional resources. We have included these references in the manuscriptWe have revised section 6.2 – the discussion of previous sea ice production estimates. That section includes this paragraph on remote sensing: "Overall, these ice production estimates from in-situ data are larger than the seasonal production estimates derived from remote sensing products. Drucker et al (2011) used the AMSR-E instrument to obtain a seasonal average of 12 cm day^{-1} for years 2003-2008. Oshima et al, (2016) estimated 6 cm day^{-1} of seasonal production for the years 2003-2011, and Nihashi and Ohshima (2015) determined 7 cm day^{-1} for years 2003-2010. Finally, Tamura et al (2016) found production rates that ranged from 7-13 cm day^{-1}, using both ECMWF and NCEP Reanalysis products for 1992-2013, reflecting a greater degree of consistency in successive estimates, likely because of consistency in the estimation methods. "

References

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