Final Author Comments - responses to Reviewer 1 comments

21 April 2021

1 Responses to Reviewer 1 Comments

We thank Reviewer 1 for their comments on our submission as a Brief Communication within criteria (c): "to disseminate information and data on topical events of significant scientific and/or social interest". We provide the following responses to the points that they have raised.

Reviewer 1 requested that alternative fast ice breakout mechanisms to wind-driven breakout be briefly discussed in the manuscript. Reviewer 2 has also requested more explanation on the fast ice breakout mechanism as well as consideration of other breakout mechanisms.

We agree with both reviewers that these would be valuable additions to the manuscript and will look to include an expanded discussion on breakout mechanisms in the revised manuscript that will include:

1.) Describing how offshore surface winds in McMurdo Sound activate the McMurdo Sound Polynya (MSP), which influences the fast ice cover in the sound. This discussion will reference the findings of Ebner et al. (2013) regarding surface wind forcing and polynya opening and draw on the findings of Dale et al. (2017) who found strong negative correlations between sea ice concentration (SIC) and AWS wind speed data within the Ross Sea Polynya (RSP), which they attributed to strong winds causing advection of sea ice in the region. Dale et al. (2017) also observed that a rapid decrease in SIC during a strong wind event was followed by a more gradual recovery in SIC. The MSP is proximal to the RSP and typically activates under the same strong offshore (southerly) wind conditions.

2.) A brief investigation of other potential breakout mechanisms, including thermodynamic, as referenced by Reviewer 1, and sea swell, as referenced by Reviewer 2, as a potential breakout mechanism. Regarding themodynamic drivers, we note that the entire water column in McMurdo Sound during winter is characterised by cold and very cold (supercooled) water outflow from underneath the McMurdo Ice Shelf (Leonard et al., 2006), and the water column is nearly isothermal and very close to its freezing point (Lewis and Perkin, 1985; Mahoney et al., 2011). During summer, surface waters flowing into the sound from the northeast exhibit higher temperatures (above the freezing point but mainly below 0 °C) (Robinson et al., 2014), but this is not the case during the months this study examines. Regarding sea swell, we agree that a study of sea swell effects on McMurdo Sound fast ice would be profitable. However, we note that there was no sea swell data available during the period of our study, as the frequency at which the sea level was recorded by the tide gauge was not sufficient to resolve waves. Thus, the available data in the region and the scope of the manuscript did not allow us to study the effect of sea swell on the McMurdo Sound fast ice in 2019 or the synoptic weather patterns associated with the AWS data. We agree with Reviewer 2 that due to the absence of fetch upstream of the fast ice in the direction of the wind, no significant swell can be formed prior to the polynya having opened. We note that previous studies on fast ice break up in Antarctica did find that the fast ice broke without a clear association to a wave event (Voermans et al., 2020).

Regarding the minor comments made by Reviewer 1, we generally accept the suggestions made will improve the manuscript and thank the reviewer for them. We make the following comment on some of the particular suggestions. Reviewer comments have been italicized for clarity. The numbers refer to the line numbers in the manuscript.

R1 comment:

47: The "biased" in here implies that these studies didn't correctly account for the icescape change. Is this what you really mean - if so, for both studies?

Our response:

We did not wish to imply that the studies did not correctly take into account the effect of the icebergs. Rather what we meant was that the time-period over which both of these studies investigated the sea ice in McMurdo Sound was influenced by the icebergs and that they thus only have limited ability to describe the normal, non-iceberg state.

R1 comment:

58: Was this IW mode Sentinel-1 imagery? What resolution?

Our response:

The three SAR images shown in Figure 1 are Extra Wide (EW) medium resolution mode with a pixel spacing of 40 m. The wider set of SAR imagery used to identify the presence of the McMurdo Sound Polynya also included some Interferometric Wide (IW) high resolution mode images with a native pixel spacing of 10 m that were re-sampled to 40 m pixel spacing for this study.

R1 comment:

59: "MSP event" is a little ambiguous. Do you mean a large polynya size event?

Our response:

Yes, we mean a large polynya size event, where the polynya impacts the previously established fast ice cover, breaking it up, rather than where a polynya is formed offshore of the fast ice edge.

R1 comment:

Also here, I'm curious how an active polynya looks in ice surface temperature - presumably a warm temperature? Or is it masked because largely open water?

Our response:

Yes, it is warm, but there are well known issues due to cloud masking with the MODIS Ice Surface Temperature (IST) products (MYD029 and MOD029) that make it difficult to resolve the area of the active polynya with MODIS IST. We did see warming in the thermal imagery generally correlating to polynya breakout, but it was not always clear. Hence, we used thermal imagery as a secondary source (to corroborate SAR observations) rather than the primary source to define fast ice breakout events.

R1 comment:

117: Although a brief communication, the "big picture" could do with a little more expansion. E.g., this is one of few case studies on fast ice stability, an area where more research is needed, etc. It occurs to me that this region might be a good one for testing forthcoming fast ice tensile strength parameterisations in prognostic fast ice models (e.g., Lemieux et al., 2016, "Improving the simulation of landfast ice by combining tensile strength and a parameterization for grounded ridges"). Also, are there other regions you know of which have a similar fast ice regime (i.e., deep embayment and lack of grounded icebergs) to which the results of this study might be applicable?

Our response:

We agree with that McMurdo Sound would make a fascinating site for testing fast ice break-out processes. Other areas where similar conditions are found would be Arctic fjords, though here the influence of warm water intrusions from below could potentially play an additional role. As far as we are aware, McMurdo Sound is unique in being a deep embayment experiencing strong cold water outflow from an adjacent ice shelf and not influenced by large ice tongues or icebergs. However, a study into wind regimes facilitating fast ice break out would be profitable for other fast ice locations both in the Arctic and Antarctic.

R1 comment:

Fig 1: It would be helpful to please annotate the area of active polynya in each SAR image (manually is fine). Similarly for the fast ice edge.

Our response:

We think this a great suggestion and will do this for the revised manuscript.

R1 comment:

Fig 2: Does the truncation of the upper half of each wind rose remove any/much information? I'd quite like to see the whole thing (if there's detail in the northerly half) but happy to stick with the half roses if no wind from that half.

Our response:

The northern half of the wind roses for both columns (all years, and 2019 only) are saturated with high-frequency, low-speed (0 – 10 m s^{-1}) NE winds, indicating that these are the prevailing surface wind conditions at the site. As the inclusion of these winds obscures the comparatively large increases in (discrete) high-speed surface wind events from the south (as the maximum frequency of the wind roses has to increase dramatically to include them), we believe that the inclusion of the northern half of the wind roses is counter-productive to the data narrative.

Below we have included two versions of the full wind roses to illustrate this point; one with a 3% maximum frequency (see Figure 1) and one with a 30% maximum frequency (see Figure 2). We will emphasise this point in the revised manuscript by adding the following sentence to the figure caption "The low-speed (0 – 10 m s^{-1}) prevailing winds from the NE are not shown, in order to highlight the comparative increase in strong but short-lived extreme winds from the south in 2019."

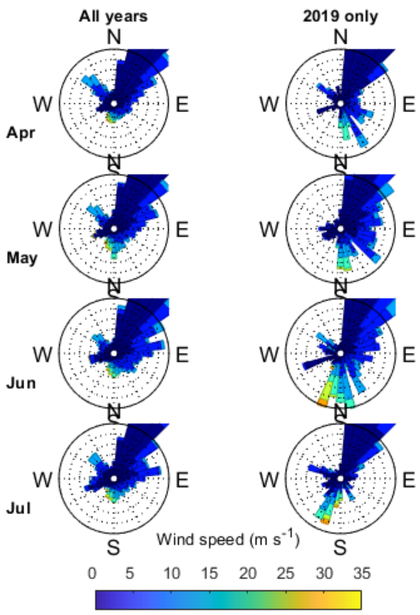

Figure 1: Full wind roses using the same scaling as per Figure 2 in the manuscript.

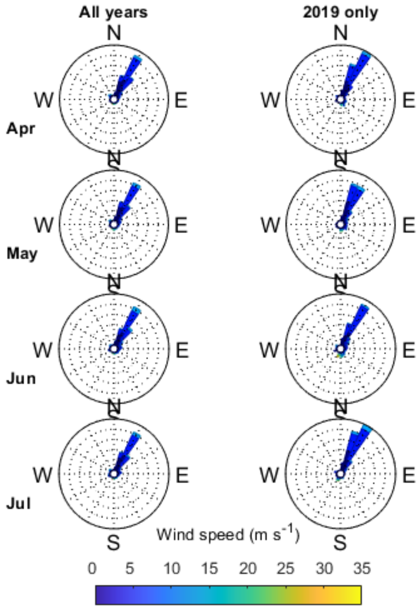

Figure 2: Full wind roses with an adjusted scaling that is required to show all of the NE winds.

R1 comment:

Fig 3: A little unusual to not have a colour legend for the upper two plots, although I recognise that they're only shown to indicate the envelope of previous years (and the reader doesn't necessarily need to know which year is which).

Our response:

We acknowledge it is unusual not to have a legend for all figure objects, however, we believe that the particular years in the data record that each timeseries relates to is not important, and a legend would complicate the figure. However, the ability to compare the same year (same colour) between sub-figures a) and b) is important, as it allows the reader to perceive that within the data record (2002 – 2019), 2019 contains the largest number of KWI events. This is an important aspect of the manuscript as the KWI index extends further back in time than the relatively shorter sea ice concentration dataset. So although we are not able to relate sea ice concentrations to KWI prior to 2013, we can show that the KWI signature in 2019 was significantly different from the other years in the record.

For this reason, we do not wish to apply a common colour for all years other than 2019 when sea ice fraction data is available (2013 – 2018), and propose to retain the current figure layout with individual colours and no legend.

2 References

Bogardus, R., Maio, C., Mason, O., Buzard, R., Mahoney, A. and de Wit, C.: Mid-Winter Breakout of Landfast Sea Ice and Major Storm Leads to Significant Ice Push Event Along Chuckchi Sea Coastline, Front. Earth Sci., https://doi.org/10.3389/feart.2020.00344, 2020.

Brunt, K. M., Sergienko, O., and MacAyeal, D. R.: Observations of unusual fast-ice conditions in the southwest Ross Sea, Antarctica: preliminary analysis of iceberg and storminess effects, Annals of Glaciology, 44, 183–187, https://doi.org/10.3189/172756406781811754, 2006.

Dale, E.: Interactions Between Changing Weather Patterns and the Antarctic Cryosphere in the Ross Sea Region, PhD Thesis, University of Canterbury, New Zealand, 2020.

Dale, E. R., McDonald, A. J., Coggins, J. H. J., and Rack, W.: Atmospheric forcing of sea ice anomalies in the Ross Sea polynya region, The Cryosphere, 11, 267–280, https://doi.org/10.5194/tc-11-267-2017, 2017.

Ebner, L., Heinemann, G., Haid, V. and Timmermann, R.: Katabatic winds and polynya dynamics at Coats Land, Antarctica, Antarctic Science, 26(3), 309-326, https://doi:10.1017/S0954102013000679, 2013.

Leonard, G H., Purdie, C. R., Langhorne, P. J., Haskell, T. G., Williams, M. M. J., Frew, R. D.: Observations of platelet ice growth and oceanographic conditions during the winter of 2003 in McMurdo Sound, Antarctica, J. Geophys. Res., 111, C04012, doi:10.1029/2005JC002952, 2006.

Lewis, E. L. and Perkin, R. G.: The Winter Oceanography of McMurdo Sound, Antarctica. In Oceanology of the Antarctic Continental Shelf, S.S. Jacobs (Ed.), https://doi.org/10.1029/AR043p0145, 1985.

Mahoney, A. R, Gough, A. J., Langhorne, P. J., Robinson, N. J., Stevens, C. L, Williams, M. M. J., and Haskell, T. G.: The seasonal appearance of ice shelf water in coastal Antactica and its effect on sea ice growth, J. Geophys. Res., 116, C11032, doi:10.1029/2011JC007060, 2011.

Robinson, N. J., Williams, M. J. M., Stevens, C. L., Langhorne, P. J., and Haskell, T. G.: Evolution of a supercooled IceShelf Water plume with an actively growing subice platelet matrix, Journal of Geophysical Research: Oceans, 119, 3425–3446, https://doi.org/10.1002/2013JC009399, 2014.

Voermans, J., Rabault, J., Filchuk, K., Ryzhov, I., Heil, P., Marchenko, A., Collins, C., Dabboor, M., Sutherland, G., and Babanin, A.: Experimental evidence for a universal threshold characterizing wave-induced sea ice break-up, The Cryosphere Discussions, pp. 1–24, https://doi.org/10.5194/tc-2020-201, 2020.