Title
The Regional, Seasonal, and Lagged Influence of the Amundsen Sea Low on Antarctic Sea Ice

Journal
Geophysical Research Letters, 45(20)

ISSN
0094-8276

Authors
Holland, Marika M
Landrum, Laura
Raphael, Marilyn N
et al.

Publication Date
2018-10-28

DOI
10.1029/2018gl080140

Peer reviewed

Geophysical Research Letters

RESEARCH LETTER
10.1029/2018GL080140

Key Points:
- The Amundsen Sea Low is an important driver of regional Antarctic sea ice variability
- The influence of the Amundsen Sea Low on sea ice varies by region, season, and lag
- The Amundsen Sea Low can have an opposite sign influence on sea ice in some regions depending on the season

Supporting Information:
- Supporting Information S1

Correspondence to:
M. M. Holland,
mholland@ucar.edu

Citation:
Holland, M. M., Landrum, L., Raphael, M. N., & Kwok, R. (2018). The regional, seasonal, and lagged influence of the Amundsen Sea Low on Antarctic sea ice. *Geophysical Research Letters*, *45*. https://doi.org/10.1029/2018GL080140

Received 24 AUG 2018
Accepted 5 OCT 2018
Accepted article online 10 OCT 2018

The Regional, Seasonal, and Lagged Influence of the Amundsen Sea Low on Antarctic Sea Ice

Marika M. Holland[1], Laura Landrum[1], Marilyn N. Raphael[2], and Ronald Kwok[3]

[1]National Center for Atmospheric Research, Boulder, CO, USA, [2]Department of Geography, University of California, Los Angeles, CA, USA, [3]Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA, USA

Abstract The Amundsen Sea Low (ASL) is an important driver of Antarctic sea ice variations largely because of wind-driven sea ice and ocean transport anomalies. However, the nature of the relationship between the ASL and sea ice is complicated by large seasonality in the ice cover and the ASL location and depth. Here we explore these relationships as a function of region, season, and lag. We find that the ASL can have a markedly different and sometimes opposite sign influence on sea ice in some regions, such as the western Ross Sea, depending on the season. This is in part due to differing influences of ASL-related meridional and zonal winds for ice transport in different times of year. The sea ice response to ASL variations is often largest at a lag of some months and can persist for up to 8 months.

Plain Language Summary The Amundsen Sea Low (ASL) is a dominant feature of the atmospheric circulation in the Southern Ocean. Variations in this low pressure center influence winds over the Antarctic sea ice that can cause anomalies in sea ice transport and ice concentration. However, because the location of the low and the sea ice cover differ seasonally, the influence of ASL variability on sea ice differs by region and season. Additionally, the sea ice can exhibit a lagged response to the ASL, resulting in sea ice anomalies many months following variations in the ASL.

1. Introduction

The Amundsen Sea Low (ASL) is a climatological feature of the high southern latitude atmospheric circulation. It exhibits considerable seasonal and interannual variability with implications for Antarctic climate (e.g., Fogt et al., 2012; Hosking et al., 2013; Raphael et al., 2016, 2018; Turner et al., 2013). The location and strength of the low vary seasonally, with the ASL being further west and south during winter. Large-scale modes of variability, such as the El Niño–Southern Oscillation and the Southern Annular Mode, are associated with ASL anomalies (e.g., Marshall, 2003; Turner et al., 2013; Yuan & Martinson, 2001). Anthropogenic forcing can also influence the ASL, with ozone loss leading to a deepening of the ASL in austral summer (England et al., 2016; Turner et al., 2009).

Amundsen Sea Low–associated wind variations have the potential to influence the underlying sea ice. Indeed, previous work has documented sea ice anomalies, primarily in the Pacific sector, that are associated with the ASL (Hosking et al., 2013; Landrum et al., 2017; Raphael et al., 2018; Turner et al., 2009). These studies have often focused on ASL-sea ice relationships for single seasons. Although in recent work, Raphael et al. (2018) found that relationships can change within and across the advance and retreat seasons. Given the large seasonality in both sea ice and the ASL, it is perhaps not surprising that the relationships between them can differ at different times of year. Since sea ice can also exhibit a lagged response to wind variations (e.g., Doddridge & Marshall, 2017; Holland et al., 2017; Stammerjohn et al., 2012), it is likely that the ASL in a particular month can influence sea ice in future seasons.

Because of these complexities, sea ice in a particular region and at a particular lag may respond differently to ASL variability in different months. Here we build on previous work by providing a comprehensive view of the influence of monthly ASL variability on Antarctic sea ice and sea surface temperatures (SSTs). We assess the regional, seasonal, and lagged responses of sea ice and diagnose mechanisms that give rise to different responses for different seasons and lags. We focus on conditions in the Pacific sector and Weddell Sea because these are the regions directly influenced by the ASL.

2. Data

To assess relationships between the ASL and sea ice, we use information from 1979 to 2015. This includes monthly average gridded fields of sea level pressure (SLP) from ERA-Interim reanalysis (ERA-I; ECMWF, 2012). An ASL index of pressure is defined as the minimum of the monthly averaged gridded SLP in the region 170–290°E and 60–75°S. Because this uses gridded SLP data, it will depend on the ERA-I resolution. The location of this ASL pressure minimum will also vary both seasonally and interannually (Figures S1 and S2 in the supporting information). Note that the region used to obtain the ASL index assessed here is the same as that in Hosking et al. (2013) and Raphael et al. (2018) but a somewhat smaller region than used in other studies (Fogt et al., 2012; Turner et al., 2013). To focus on interannual variations, the ASL index is detrended prior to analysis.

Amundsen Sea Low variations are compared to monthly mean sea ice concentration since 1979 (Comiso, 2017). Using this ice concentration data, ice area is computed for 1.15 degree longitude sectors around the Antarctic continent. Monthly average sea ice data are used here for consistency with the other data products. We have also assessed relationships using daily values of sea ice area (not shown) and find very similar results.

As discussed by Kwok et al. (2017), variations in the geostrophic wind explain about 60% of the ice drift variability. Given this, it is likely that ASL variability drives ice motion anomalies that ultimately affect the ice concentration. To assess these relationships, we analyze sea ice motion using data from Kwok et al. (2016). These data are available as monthly averages for March through November from 1982 to 2015. Comparisons of the ASL to SSTs make use of NOAA's Optimum Interpolation Sea Surface temperature version 2 data set, which is available from 1982 to 2015 (Reynolds et al., 2007). The location of the ASL causes direct effects on wind variations in the Pacific sector and the Weddell Sea. Given this, we focus our analysis of ice and ocean conditions on 140–360°E longitude.

3. Results

To illustrate the effect of the monthly ASL anomalies on sea ice, we compute the correlation of gridded monthly averaged sea ice concentration and SST coincident with ASL variations. The lagged sea ice response in following months is also assessed using the correlation of the longitudinal ice area with the ASL variations. The sign convention is such that a positive correlation indicates an increase in sea ice area (increase in SST) associated with a deepening of the ASL.

3.1. Late Summer and Fall ASL

Figure 1 shows the sea ice and SST correlated with the ASL in the late summer through the austral fall (February–May). The SLP regressed on the ASL index is shown in the lined contours on the bottom of the panels. The sea ice is at its minimum extent in February and increases thereafter until late September. From February to May, the minimum SLP associated with the ASL occurs just north of (in February and March) or very close to (in April and May) the ice edge in contrast to winter months (shown below) when it occurs within the ice edge. Notably, the longitude of the minimum SLP regression (dashed vertical line on Figure 1) is often displaced from the ASL climatological location (solid vertical line on Figure 1), indicating that interannual variability is often expressed as both a variation in the strength and the location of the ASL. This is further illustrated in Figure S1, which shows the SLP climatology and regression of SLP on the ASL index for different months. The location of ASL-related SLP anomalies has implications for the sea ice and SST response to this variability.

During late summer and austral fall, correlation analysis reveals that a deeper ASL is associated with increased sea ice (and hence positive correlations) over much of the Pacific from about 150°E–250°E, although the location and magnitude differs with the ASL month and lag. The lagged response generally indicates an eastward propagation of ice anomalies, which is consistent with an advection of anomalies by the mean ocean current (e.g., Holland et al., 2005). The region of increased sea ice is generally aligned with negative correlations in SST to the north, hence colder SSTs at zero lag, except in April. The maximum sea ice correlation typically occurs at a lag of several months following the ASL variability. This lag is particularly long for ASL anomalies in February, with significant sea ice increases in this region occurring 5–6 months after the ASL variations. This may be related to the limited amount of ice in February and the significantly correlated cold SSTs northward of the ice edge that will be encountered as the ice advances through the fall (Figure 1a). Similarly, sea ice anomalies associated with the March ASL persist until October. The regions of increased sea ice area are

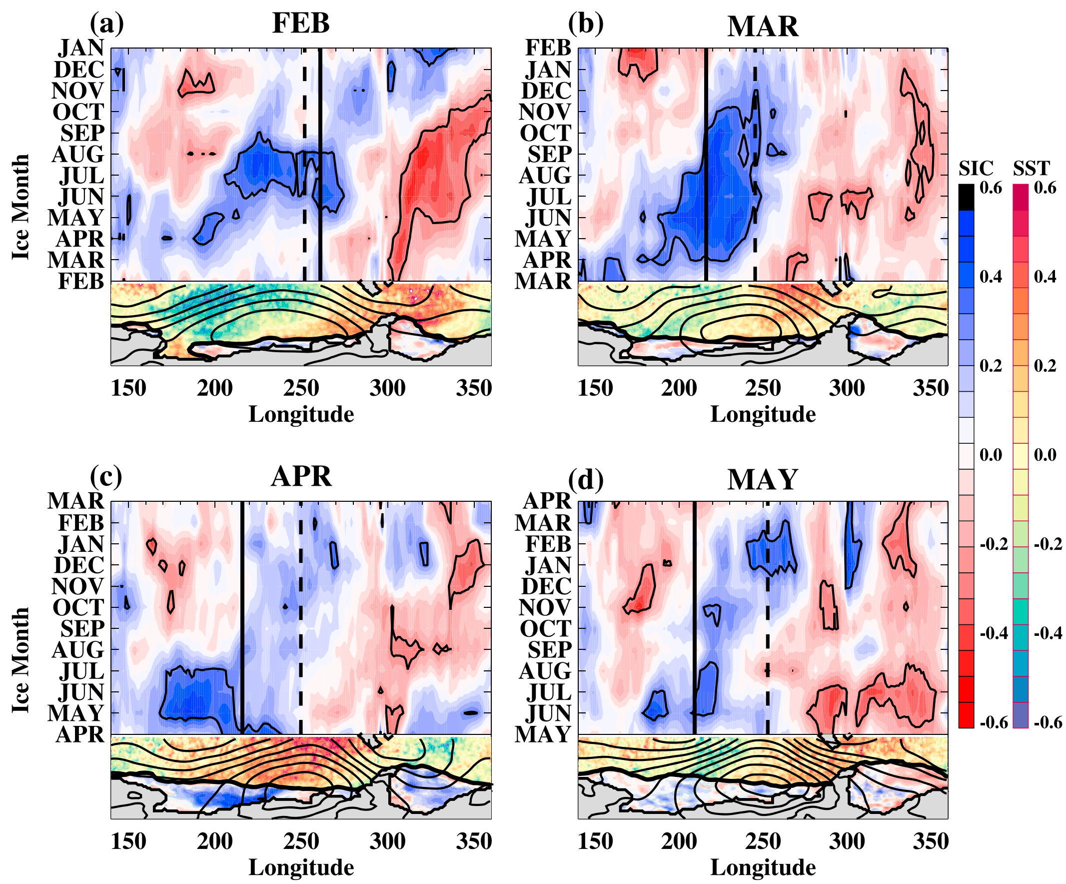

Figure 1. The relationship of ice concentration, sea surface temperature (SST) and sea level pressure (SLP) to the monthly Amundsen Sea Low (ASL) index. The bottom part of each panel shows the coincident correlations of ice concentration and SST with the ASL in shading and the regression of SLP on the ASL in the lined contour. The bold black contour indicates the sea ice edge as defined by the 15% ice concentration contour. The SLP regression contour interval is 1 hPa per standard deviation of the ASL. The upper part of each panel shows the correlation of ice area as a function of longitude and lag following the ASL index. In the upper part of the panels, the line contour indicates the 95% significance level. The solid vertical line is the location of the climatological ASL, and the dashed line is the location of the minimum in the regression of SLP on the ASL index. The values are shown for the ASL index in (a) February, (b) March, (c) April, and (d) May.

consistent with ASL-related southerly wind anomalies that occur to the west of the anomalous low (around 180–250°E, depending on the month). These would drive an anomalous transport of cold waters and sea ice northward, thereby enhancing the expansion of the sea ice edge during the ice growth season. To further assess this, ice motion is regressed on the ASL index (Figure 2). The correspondence between the ASL-related ice motion and SLP anomalies is quite striking and is consistent with the high correlations found by Kwok et al. (2017) between ice drift and geostrophic wind. For the late summer and fall period, northward sea ice transport anomalies associated with the ASL in the 150–200°E region are particularly prevalent in May.

The correlations in Figure 1 indicate that reductions in sea ice along the Antarctic Peninsula, extending into the Weddell Sea, are also generally associated with a deeper ASL during the late summer and fall. Warmer SSTs are also indicated in this region at zero lag, particularly for ASL variations in February and May. There is a significant lagged response in the sea ice, particularly to the February ASL (Figure 1a) for which significant ice area anomalies occur over a large fraction of the Weddell Sea domain starting in May and June likely because the seasonal advance of ice has encountered the anomalously warm ASL-related waters. This lagged response is consistent with the sea ice response to El Niño–Southern Oscillation (Yuan, 2004). The negative anomalies of sea ice along the Antarctic Peninsula into the Weddell Sea also are related to anomalous meridional (and in this case, northerly) winds and southward ice transport (Figure 2).

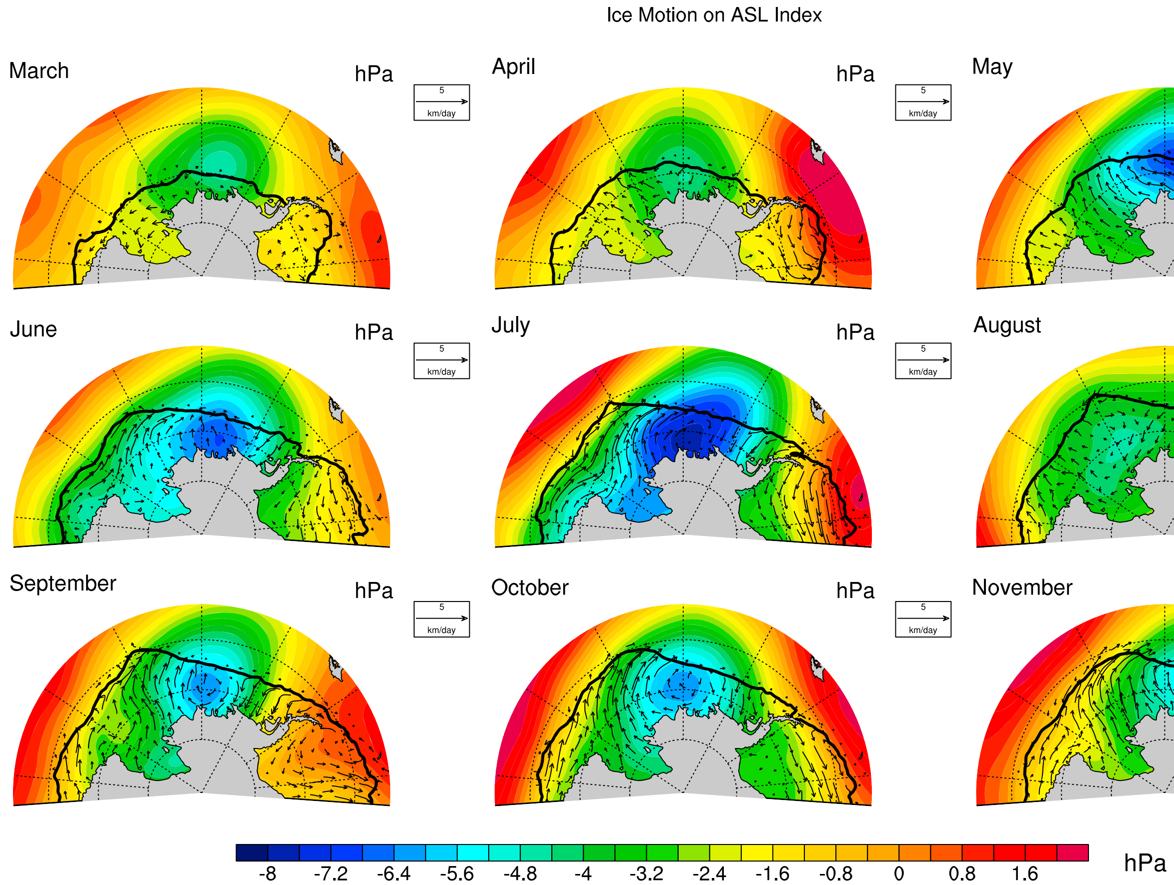

Figure 2. The regression of sea level pressure (shading) and ice motion (vectors) on the Amundsen Sea Low index for different months. Ice motion data are not available for January, February, and December and so those months are not shown.

For late summer and fall, the anomalous ASL-associated ice transport across the domain considered is primarily meridional, suggesting that meridional wind variations associated with the ASL play a dominant role in driving sea ice variations across the entire 140–360°E domain. Zonal winds play little role at this time because the ice edge is close to the continent and ASL-related zonal wind anomalies that are present to the north and south of the anomalous low pressure are not in a location to directly impact ice transport.

3.2. Early Winter ASL

A quite different picture emerges from an analysis of sea ice variations driven by the ASL in June and July (Figures 3a and 3b). During this period, a tri-pole of ice anomalies with reduced ice from approximately 150–200°E increased ice from 200 to 270°E and reduced ice east of 270°E is associated with the ASL. On 1 June, the total Antarctic sea ice extent is rapidly increasing and will continue to do so for the next 2 months. During June and July, the minimum ASL-related SLP anomalies occur further south and closer to the Antarctic continent. Note that this is displaced eastward from the climatological ASL location and the minimum ASL-related SLP is within the sea ice pack during June and July (Figures 2 and 3a and 3b). ASL-related meridional wind anomalies contribute to anomalous meridional ice transport that expands the sea ice edge in the 200–270°E region and decreases sea ice area in the Antarctic Peninsula region (Figure 2). Consistent sign correlations with SST, indicating cold conditions, are also apparent in these regions.

In contrast to the earlier fall months shown in Figure 1, zonal ice transport anomalies are also associated with the ASL, particularly in the outer Ross Sea region (Figure 2). These zonal transport anomalies act to redistribute ice from west to east in the Pacific sector. This contributes to the decreased ice in the 150–200°E region and increased ice from 200 to 250°E. Notably, other studies (Kwok et al., 2017) have also found that zonal wind driven ice drift can lead to ice edge variations. The ice anomalies associated with the June and July

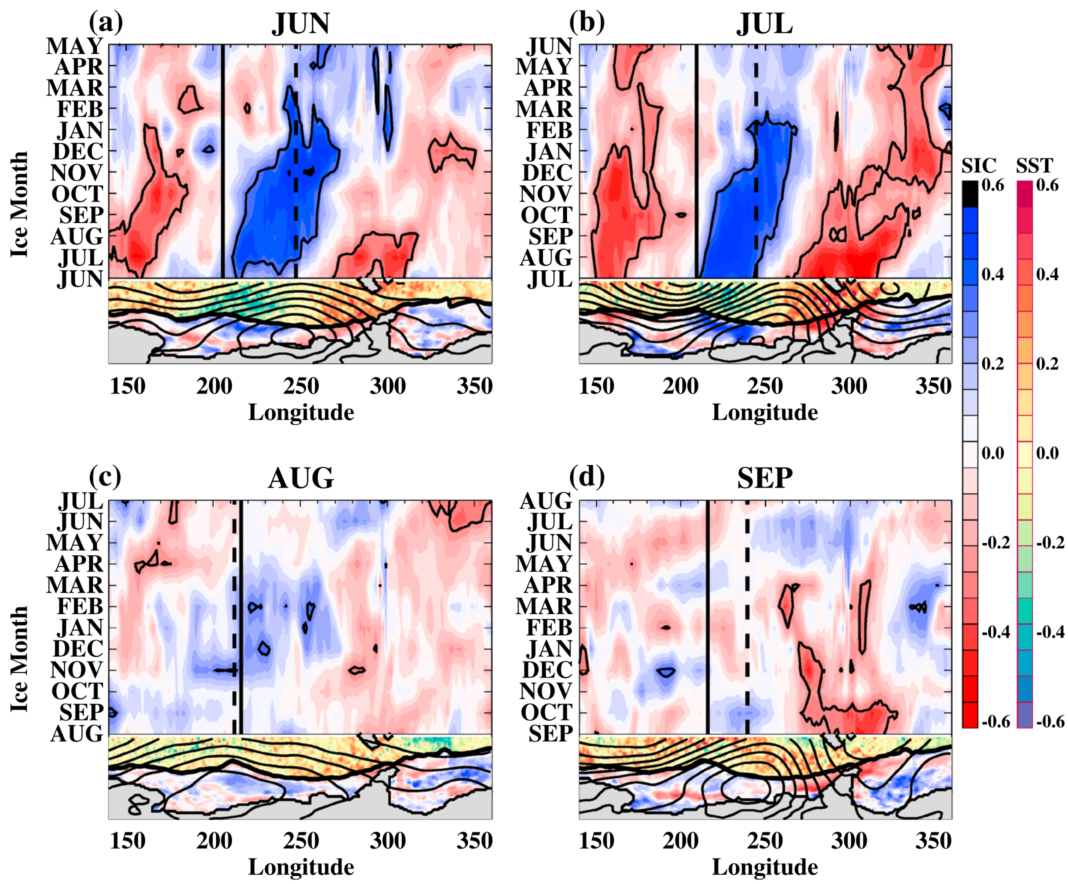

Figure 3. As in Figure 1 but for values of the Amundsen Sea Low index in (a) June, (b) July, (c) August, and (d) September.

ASL are apparent at lag zero. They then persist into the next summer (about 8 months later) with significant correlations remaining across large regions of the 150–350°E domain until the next January and for the negative ice anomalies associated with the July ASL for up to a year later.

3.3. Late Winter ASL

Interestingly, ASL anomalies during August and September (Figures 3c and 3d) have little influence on the sea ice concentration, with significant correlations only along the peninsula for ASL variations in September. In August, the regression of SLP on the ASL index (Figure 3c) reveals that the ASL-related SLP gradient and thus the associated geostrophic wind anomalies are relatively weak over much of the Pacific sector sea ice region. Ice motion regressed on the ASL shows a consistently weak response (Figure 2). In September, the ASL-related SLP gradient and associated wind anomalies are stronger (Figure 3d). However, this has minimal influence on the ice concentration variations in September or following months except along the Antarctic Peninsula. Instead, September sea ice variability is most strongly determined by factors earlier in the winter, such as the ASL variability in June and July (Figures 3a and 3b and 3). This is reminiscent of the important role that seasonal lags play in driving trends in ice concentration (Holland, 2014).

3.4. Spring ASL

In October, the sea ice is undergoing melt back toward the continent and the ASL-related minimum SLP remains quite far south and within the region of sea ice cover (Figure 4a). The ASL variability at this time (and also in November and more weakly in December) drives a tri-pole pattern in sea ice concentration that is similar to the response of ice to the ASL in June and July (Figures 3a and 3b). The ice transport anomalies that in part drive the pattern of sea ice variations (Figure 2) are similar to what occurs in June and July, with an important zonal ice motion component from around 160°E that contributes to ice transport from the western Ross Sea to the east. The January ASL (Figure 4d) has limited influence on the ice or SST variability.

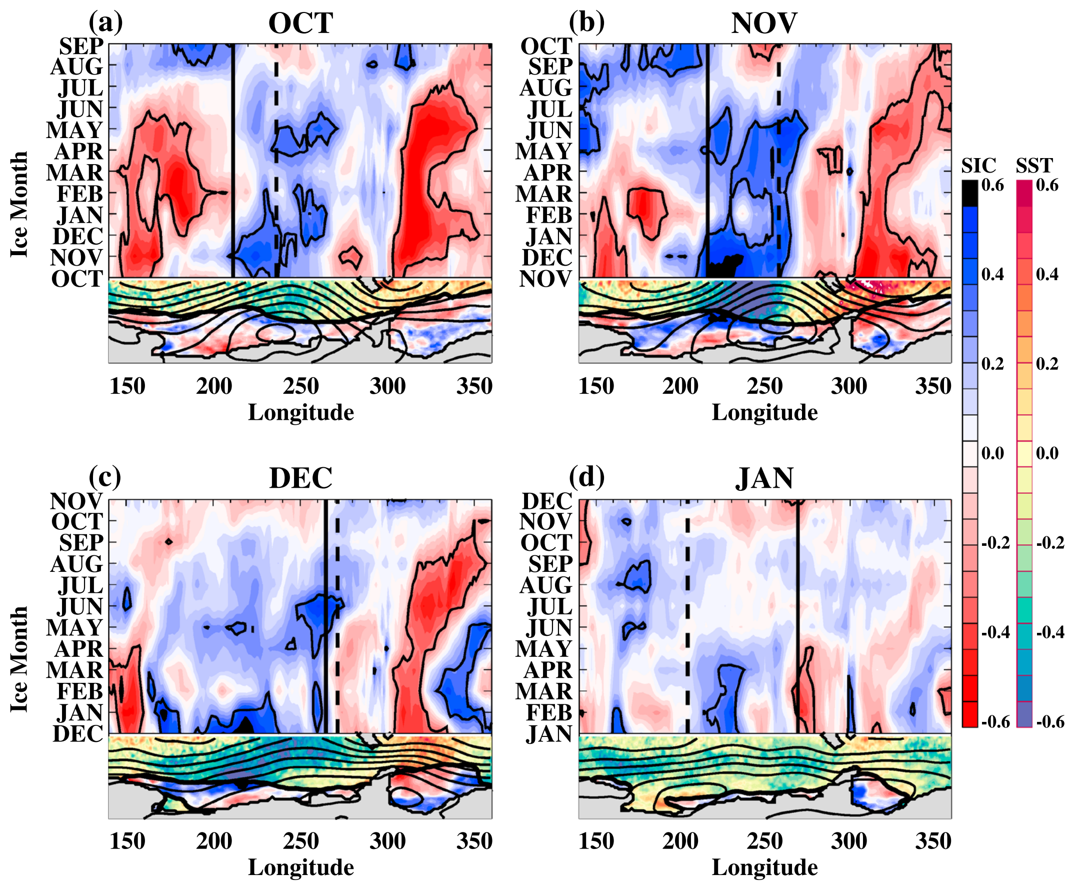

Figure 4. As in Figure 1 but for values of the Amundsen Sea Low index in (a) October, (b) November, (c) December, and (d) January.

Interestingly, for the October ASL (and less so for the November ASL), the correlation indicating reduced ice area in the 150–200°E region strengthens and grows in areal extent with lag. Indeed, the negative correlation of sea ice with the October ASL in the 150–200°E is a maximum in the following February and March and is significant into May, a lag of 7 months. As diagnosed by Holland et al. (2017), this lagged response is associated with October ice transport variations that allow dynamical thinning of sea ice in the region, resulting in earlier melt out, a longer ice-free season, more shortwave absorption, and delayed ice growth in the next fall. This mechanism requires wind anomalies that can affect the melt out timing, which is why it is particularly effective in October (and to a lesser extent in November).

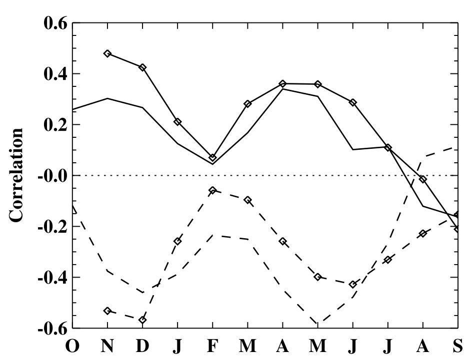

Figure 5. The correlation of sea ice area at 330°E (solid) and 240°E (dashed) with the Amundsen Sea Low (ASL) in October and November (line marked with diamonds). The correlations are shown for ice coincident with and lagging the ASL.

There are also indications of a seasonal reemergence of the ASL-related sea ice increases in the 210–260°E region and decreases in the 320–350°E region. In particular, for October and November ASL variations, initial significant sea ice correlations in these regions transition to minimal correlations in the summer (most notable in February) but then a reemergence of a significant correlation the next fall (Figure 5). It is likely that significant correlations with SSTs (Figures 4a and 4b), which then persist for several months, allow for a memory of the anomalies to be retained during the ice-free period and contribute to this lagged sea ice response into the following fall. This has implications for the seasonal predictability of sea ice in these regions. The various lagged sea ice relationships for the springtime ASL variations that are documented here highlight the importance of seasonal dynamics when considering the sea ice response to wind variations in the Southern Ocean.

4. Conclusions

Variability in the depth of the ASL is an important driver of Antarctic sea ice anomalies. Notably though, the ASL influence differs regionally, seasonally, and with lag. This is in part due to the annual cycle of the sea ice, the ASL location, and the relationship between the two. This allows for a difference in the relative importance of ASL-driven meridional versus zonal wind anomalies for different times of year. As a result, for particular regions, the ASL may drive increased sea ice during some times of year, but decreased sea ice in others. For example, over much of the Ross Sea from about 150–200°E, the austral fall ASL drives increases in sea ice, but the austral spring (particularly October) ASL drives reductions.

The ASL has a direct impact on sea ice through anomalous wind driven sea ice transport. This is consistent with previous work (e.g., Holland & Kwok, 2012; Kwok et al., 2017), which has illustrated the importance of wind-driven ice drift anomalies for Antarctic ice concentration trends. However, while the ice transport responds quickly to the ASL wind variations, the ice concentration often exhibits a delayed response, sometimes by many months. As a result, sea ice variations in some months may be most strongly driven by ASL variations several months prior. For example, ice variability in September shows little correlation to September ASL variations but is significantly correlated to the ASL in the previous June and July. This lagged influence of the ASL has implications for the predictability of Antarctic sea ice on seasonal time scales with the ASL explaining an important fraction of sea ice area variance for some locations and times of year (Figures S3 and S4). Sea ice forecasting systems should adequately represent the ASL and account for its monthly varying regional and seasonal sea ice influences in order to realize this source of predictability.

Different lagged influences occur in part due to feedbacks that are active in different seasons that can prolong the ice concentration anomalies. During ice advance, anomalous winds can influence ocean temperatures northward of the ice edge. As the ice advances into those waters, a lagged response of sea ice can occur. We find evidence of this mechanism for some months (i.e., February, June, and July). However, significant correlations of the ASL and SST are not always present and so this mechanism does not necessarily explain all of the lagged sea ice response. Instead, the persistence (and even strengthening) of sea ice anomalies may be related to the influence of ice anomalies on the environment, given that they modify the surface heat flux and consequently the atmosphere and ocean state. In general, this seasonal persistence of sea ice anomalies is consistent with previous work (e.g., Holland et al., 2013; Stammerjohn et al., 2008; Stammerjohn et al., 2012).

Other mechanisms can allow for the reemergence of sea ice anomalies from spring to fall. Springtime ASL wind anomalies can affect the timing of ice melt out and the length of the ice-free season. Through a surface albedo feedback, this can prolong the influence of the wind anomalies by affecting summer ocean temperatures and the following fall freezeup. This mechanism, which is documented in Holland et al. (2017), appears to be particularly effective for the October ASL influence on sea ice in the western Ross Sea. The imprint of spring ASL variations on ocean temperatures, for example, through anomalous ocean transport, can also provide a mechanism to retain the signal through the ice melt season. This appears particularly effective for sea ice increases in the 210–260°E region and sea ice reductions in the 320–350°E region that are driven by the November ASL (Figure 4b). These ice anomalies disappear during the height of summer but then reemerge during the following fall.

The ASL influence on sea ice is complicated and dependent on season, region, and lag. Dynamics that are seasonally dependent can affect the longevity and location of sea ice anomalies. This complexity needs to be considered when attributing sea ice change in a particular location and season to ASL variability or trends. The important influence of the relative locations of the ASL and sea ice edge for the ice variability is also a relevant consideration for how variability in sea ice might change in a future and warmer climate with a modified mean sea ice cover.

Acknowledgments
M.M. Holland and L. Landrum acknowledge support from NSF FESD 1338814 and NASA 1048926. R Kwok was supported by the Jet Propulsion Laboratory, California Institute of Technology, under contract with the National Aeronautics and Space Administration. NOAA_OI_SST_V2 data are provided by the NOAA/OAR/ESRL PSD, Boulder, Colorado USA from their Web site at https://www.esrl.noaa.gov/psd. Ice motion data are available from https://rkwok.jpl.nasa.gov/antarc_icemotion/index.html. ERA-I data are available from https://apps.ecmwf.int/datasets.

References

Comiso, J. C. (2017). *Bootstrap sea ice concentrations from Nimbus-7 SMMR and DMSP SSM/I-SSMIS, version 3*. Boulder, CO: NASA National Snow and Ice Data Center Distributed Active Archive Center. https://doi.org/10.5067/7Q8HCCWS4I0R

Doddridge, E. W., & Marshall, J. (2017). Modulation of the seasonal cycle of Antarctic sea ice extent related to the Southern Annular Mode. *Geophysical Research Letters*, *44*, 9761–9768. https://doi.org/10.1002/2017GL074319

ECMWF (European Centre for Medium-Range Weather Forecasts) (2012-updated). ERA-Interim project, single parameter 6-hourly surface analysis and surface forecast time series. Research Data Archive at the National Center for Atmospheric Research, Computational and Information Systems Laboratory. doi:https://doi.org/10.5065/D64747WN

England, M., Polvani, L., Smith, K., Landrum, L., & Holland, M. (2016). Robust response of the Amundsen Sea Low to stratospheric ozone depletion. *Geophysical Research Letters*, *43*, 8207–8213. https://doi.org/10.1002/2016GL070055

Fogt, R. L., Wovrosh, A. J., Langen, R. A., & Simmonds, I. (2012). The characteristic variability and connection to the underlying synoptic activity of the Amundsen-Bellingshausen Seas Low. *Journal of Geophysical Research*, *117*, D07111. https://doi.org/10.1029/2011JD017337

Holland, M. M., Bitz, C. M., & Hunke, E. (2005). Mechanisms forcing an Antarctic dipole in simulated sea ice and surface ocean conditions. *Journal of Climate*, *18*(12), 2052–2066. https://doi.org/10.1175/JCLI3396.1

Holland, M. M., Blanchard-Wrigglesworth, E., Kay, J., & Vavrus, S. (2013). Initial-value predictability of Antarctic sea ice in the community climate system model 3. *Geophysical Research Letters*, *40*, 2121–2124. https://doi.org/10.1002/grl.50410

Holland, M. M., Landrum, L., Raphael, M., & Stammerjohn, S. (2017). Springtime winds drive Ross Sea ice variability and change in the following autumn. *Nature Communications*, *8*(1), 731. https://doi.org/10.1038/s41467-017-00820-0

Holland, P. R. (2014). The seasonality of Antarctic sea ice trends. *Geophysical Research Letters*, *41*, 4230–4237. https://doi.org/10.1002/2014GL060172

Holland, P. R., & Kwok, R. (2012). Wind-driven trends in Antarctic sea-ice drift. *Nature Geoscience*, *5*(12), 872–875. https://doi.org/10.1038/ngeo1627

Hosking, J. S., Orr, A., Marshall, G. J., Turner, J., & Phillips, T. (2013). The influence of the Amundsen-Bellingshausen Seas Low on the climate of West Antarctica and its representation in coupled climate model simulations. *Journal of Climate*, *26*(17), 6633–6648. https://doi.org/10.1175/JCLI-D-12-00813.1

Kwok, R., Comiso, J. C., Lee, T., & Holland, P. R. (2016). Linked trends in the South Pacific sea ice edge and Southern Oscillation Index. *Geophysical Research Letters*, *43*, 10,295–10,302. https://doi.org/10.1002/2016GL070655

Kwok, R., Pang, S. S., & Kacimi, S. (2017). Sea ice drift in the Southern Ocean: Regional patterns, variability, and trends. *Elementa: Science of the Anthropocene*, *5*, 32. https://doi.org/10.1525/elementa.226

Landrum, L., Holland, M. M., Raphael, M. N., & Polvani, L. M. (2017). Stratospheric ozone depletion: An unlikely driver of the regional trends in Antarctic sea ice in austral fall in the late 20th century. *Geophysical Research Letters*, *44*, 11,062–11,070. https://doi.org/10.1002/2017GL075618

Marshall, G. J. (2003). Trends in the Southern Annular Mode from observations and reanalyses. *Journal of Climate*, *16*(24), 4134–4143. https://doi.org/10.1175/1520-0442(2003)016<4134:TITSAM>2.0.CO;2

Raphael, M. N., Holland, M. M., Landrum, L., & Hobbs, W. R. (2018). Links between the Amundsen Sea Low and sea ice in the Ross Sea: Seasonal and interannual relationships. *Climate Dynamics*. https://doi.org/10.1007/s00382-018-4258-4

Raphael, M. N., Marshall, G. J., Turner, J., Fogt, R. L., Schneider, D., Dixon, D. A., et al. (2016). The Amundsen Sea Low variability, change, and impact on Antarctic climate. *Bulletin of the American Meteorological Society*, *97*(1), 111–121. https://doi.org/10.1175/BAMS-D-14-00018.1

Reynolds, R. W., Smith, T. M., Chunying, L., Chelton, D. B., Casey, K. S., & Schlax, M. G. (2007). Daily high-resolution blended analyses for sea surface temperature. *Journal of Climate*, *20*(22), 5473–5496. https://doi.org/10.1175/2007JCLI1824.1

Stammerjohn, S., Massom, R., Rind, D., & Martinson, D. (2012). Regions of rapid sea ice change: An inter-hemispheric seasonal comparison. *Geophysical Research Letters*, *39*, L06501. https://doi.org/10.1029/2012gl050874

Stammerjohn, S. E., Martinson, D. G., Smith, R. C., Yuan, X., & Rind, D. (2008). Trends in Antarctic annual sea ice retreat and advance and their relation to El Niño–Southern Oscillation and Southern Annular Mode variability. *Journal of Geophysical Research*, *113*, C03S90. https://doi.org/10.1029/2007JC004269

Turner, J., Comiso, J. C., Marshall, G. J., Lachlan-Cope, T. A., Bracegirdle, T., Maksym, T., et al. (2009). Non-annual atmospheric circulation change induced by stratospheric ozone depletion and its role in the recent increase of Antarctic sea ice extent. *Geophysical Research Letters*, *36*, L08502. https://doi.org/10.1029/2009GL037524

Turner, J., Phillips, T., Hosking, J. S., Marshall, G. J., & Orr, A. (2013). The Amundsen Sea Low. *International Journal of Climatology*, *33*(7), 1818–1829. https://doi.org/10.1002/joc.3558

Yuan, X. (2004). ENSO-related impacts on Antarctic sea ice: Synthesis of phenomenon and mechanisms. *Antarctic Science*, *16*(4), 415–425. https://doi.org/10.1017/S0954102004002238

Yuan, X., & Martinson, D. G. (2001). The Antarctic dipole and its predictability. *Geophysical Research Letters*, *28*, 3609–3612. https://doi.org/10.1029/2001GL012969