Climate Change and Variability in the East Antarctic Icescape

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Abstract

In the Adelie Sea region of East Antarctica, atmospheric and oceanographic forcing influence sea ice concentration, thickness, and summer sea ice melt, particularly in the local Dumont d'Urville (DDU) Sea. Previous work demonstrated that the sea ice coverage in the DDU sea is out of phase with the overall patterns of sea ice concentration on the East Antarctic Coast near Adelie Land. However, the cause(s) of this variation has not yet been fully explored. Using a combination of fourteen years (2005-2019) of in-situ observations from instrumentation located at and around the French research station, Dumont d'Urville, and ERA5 climate reanalysis data (gridded 0.25°x0.25° hourly) from the European Centre for Medium-Range Weather Forecasts (ECMWF), we construct a summertime (NDJF) climatology of the surface, atmospheric and oceanographic conditions at DDU and in the surrounding area (area in a box bounded by 120°E -54°S and 160°E -70°S). To gain insight into the local-to-regional processes that drive sea ice concentration and thickness, we analyze in-situ environmental observations and reanalysis variables including air temperature, humidity, precipitation, radiative fluxes, cloud cover, wind speed and direction, as well as ocean surge as they relate to satellite-derived weekly sea ice extent and concentration. The observational data are compared with the World Meteorological Organization (WMO) climatological standard period of 1991-2020 to understand variance and anomaly trends. We also analyze the periods before and after the Mertz Glacier tongue calving (Feb 12-13, 2010) to identify how the relative strength of meteorological and oceanographic forcing were impacted by the calving event. For the region around DDU, we find an association between changes in sea ice area, extent, and thickness with respect to atmospheric relative humidity, downwelling radiation, cloud cover and katabatic winds from in-situ data. Further studies will investigate whether these correlations are also representative of the forcing at the larger scale of the Adelie Sea.

Introduction

Satellite observations over the past 40 years have shown a marginal trend of increase in total Antarctic sea ice (Eayrs et al., 2019), though there is strong temporal and regional variability (Kusahara et al., 2019). The drivers of the variability are still not fully understood, but the role of local atmospheric forcing is considered to be a significant factor along with regional-scale atmospheric and oceanic processes (Eayrs et al., 2019). Though sea ice extent has been consistent, future projections and trend detection rely on a comprehensive understanding of the processes that drive interannual and seasonal sea ice cycles.

The sea ice off the Eastern Antarctic coast, particularly in and around the Dumont d'Urville Sea off the Terre Adelie coastline (between 139 and 146 °E and south of 65°S), exemplifies this observed variability. The Dumont d'Urville region, which houses a permanent French research station on Petrel Island (66 39' 48" S and 140 0' 4" E) provides a unique opportunity to study the sea ice regime with a focus on investigating the interplay of atmospheric and oceanic forcings with the sea ice. Smith et al. (2011) analyzed sea ice concentration from 2003-2009 in the Dumont d'Urville Sea using AMSR-E remotely sensed data and demonstrated that the high seasonal and interannual variability is out of phase with the larger surrounding area.

The Adelie coast, and Dumont d'Urville particularly, are subject to strong gravitational (katabatic) winds that sweep downslope towards the coast from the Antarctic Plateau and play a role in the creation and driving away of sea ice (Wendler et al., 1997). The strength of the katabatic and relative presence of katabatic winds varies significantly from year to year.

We examine sea ice concentration and sea ice thickness in the Dumont d'Urville Sea and in two larger encompassing regions to identify areas of relatively stable sea ice distribution and areas of greatest variability. We investigate the relative importance of atmospheric and oceanic forcings in those areas in hopes of building a better understanding of the scale, timing, and impact of these forcings.

Materials and Methods

Our analysis is built on a combination of remotely sensed sea ice data, ERA5 climate reanalysis datasets (Hersbach et al., 2020) and in-situ observations from Dumont d'Urville station and surrounding instrumentation. This unique combination of data allows for a comprehensive interrogation of the atmospheric and oceanic forcings over multiple scales during the summer sea ice melt seasons of November 15th to February 15th.

In-situ observations from the permanently occupied Dumont d'Urville station along with additional meteorological observations from nearby continental research station at Cap Prudhomme are utilized to develop a 14-year climatology of the atmosphere and oceanographic variables that may affect sea ice distribution. ERA 5 reanalysis data from the European Centre for Medium-Range Weather Forecasts (ECMWF) are used to create a 30-year climatology baseline for the entire study area. The data are gridded at 0.25° x 0.25° for atmospheric variables and 0.5° x 0.5° for ocean wave data with hourly temporal resolution. We consider a diverse range of near-surface atmospheric properties including air temperature, humidity, radiative flux, cloud cover, wind speed and direction, sea swell and surface pressure.

Atmospheric data from DDU station, and the GLACIOCLIM observational campaign (Amory et al., 2015) that includes stations located 3-, 10-, and 17-km inland from the coast is used. Observations from these stations are made by suites of instruments mounted on towers in locations where buildings and topographical features have the least influence on the observations. Data from the stations were available on either hourly or three hourly intervals and used to calculate daily means for analysis. Seasonal averages (summer only) and variances were computed for each atmospheric variable for covariance comparisons.

ERA5 reanalysis data are analyzed for the largest study area (120-160°E, 70-54°S), then independently for the DDU region (139-146°E), the western area adjacent the Mawson Sea (120-139°E) and the eastern area adjacent the Somov Sea (146-160°E).

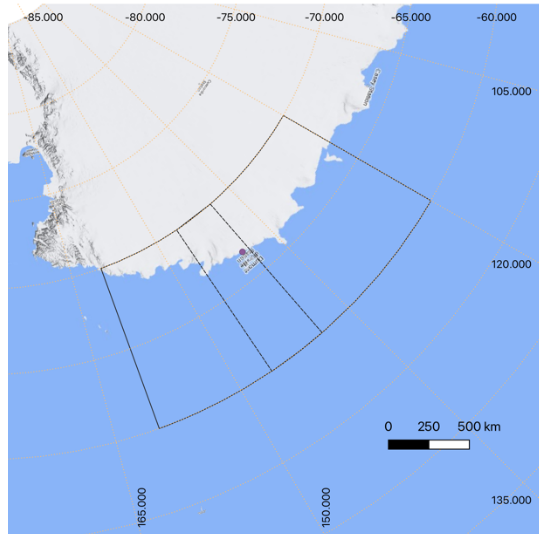

Figure 1: Large study area from 120-160E. Inset box is the DDU study area from 139-146E. Marker is DDU station at 140E, 66.66S.

We also examine the smaller area immediately around the DDU coast (140°E, 66.66°S), and the area of the Mertz Glacier tongue and polynya (~144.75°E, 67.5°S). Using 30 years of reanalysis data from 1991-2020 (WMO recommended baseline period), we identify anomalies during the 2005-2019 austral summers to help understand the larger picture of atmospheric variability over time. Seasonal means and distributions of the atmospheric variables over the scaled study areas and period are compared with in-situ observations to determine the scale of influence.
Further exploration of the reanalysis data includes empirical orthogonal function (EOF) analysis on the normalized anomalies throughout the large study area and respective sub areas to determine principal spatial-temporal modes of variability.

Remotely sensed sea ice data were retrieved from the National Ice Center for the full study area on a biweekly basis from 2005 to 2014 and a weekly basis from 2015 through 2019. Gridded and polygon sea ice data were used in regression analysis with atmospheric forcing variables (in-situ and reanalysis) to compare to the changes in sea ice thickness, area, and extent.

Results and Discussion

In the region of DDU (139-146°E), area-averaged sea ice thickness demonstrates high interseasonal and intraseasonal variability each summer. We find that initial average thickness cannot be used to ascertain the rate of decline or eventual minimum over the melt season.

Regression of sea ice thickness and percent change in area relative to various atmospheric properties indicated a strong negative relationship between katabatic winds and the percent change in area of sea ice around DDU, along with a positive association between relative humidity and percent change in sea ice area. In the mesoscale reanalysis data, the association with the katabatic winds is much weaker.

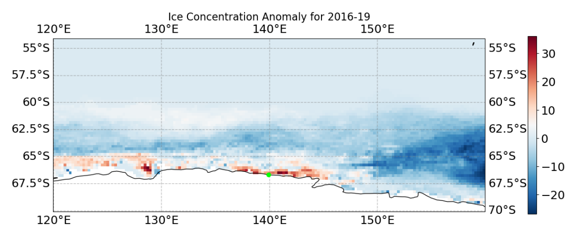

Figure 2: Anomaly of percent total ice concentration over the entire study area during summer seasons 2016-2019. Green marker is DDU station.

Our continued analysis will include exploring oceanic variables (swell height and direction), a more detailed analysis of lagged radiative fluxes, and teleconnection indices with lower latitude processes, and a study of the area around the Mertz Glacier tongue before and after the February 2010 calving event (Tamura et al., 2012).

Conclusion

Analysis of the sea ice distribution from the National Snow and Ice Data Center confirms that change in sea ice coverage from 2005-2019 near Dumont d'Urville station is frequently out of phase with larger area changes. The summer sea ice extent at the end of the melt season changed significantly between the first half of the observational period and the second, perhaps influenced by the Mertz Glacier calving event. Preliminary assessment of atmospheric forcing variables indicate that the sea ice concentration is influenced by the longwave radiative flux, the katabatic winds, and the atmospheric humidity, although the relative importance of each forcing mechanism varies intraseasonally and interannually. Further investigation of the pre-calving and post-calving periods will assess whether the loss of the glacial tongue reconnected the D'Urville Sea ice distribution to the larger region, or further enhanced the anomalous summertime concentrations.

References

Eayrs, Amory, C., Trouvilliez, A., Gallée, H., Favier, V., Naaim-Bouvet, F., Genthon, C., et al. (2015). Comparison between observed and simulated aeolian snow mass fluxes in Adélie Land, East Antarctica. *The Cryosphere*, *9*(4), 1373–1383. https://doi.org/10.5194/tc-9-1373-2015

Hersbach, H., Bell, B., Berrisford, P., Hirahara, S., Horányi, A., Muñoz-Sabater, J., et al. (2020). The ERA5 global reanalysis. *Quarterly Journal of the Royal Meteorological Society*, *146*(730), 1999–2049. https://doi.org/10.1002/qj.3803

Tamura, T., Williams, G. D., Fraser, A. D., & Ohshima, K. I. (2012). Potential regime shift in decreased sea ice production after the Mertz Glacier calving. *Nature Communications*, *3*(1), 826. https://doi.org/10.1038/ncomms1820

C., Holland, D., Francis, D., Wagner, T., Kumar, R., & Li, X. (2019). Understanding the Seasonal Cycle of Antarctic Sea Ice Extent in the Context of Longer-Term Variability. *Reviews of Geophysics*, *57*(3), 1037–1064. https://doi.org/10.1029/2018RG000631

Kusahara, K., Williams, G. D., Massom, R., Reid, P., & Hasumi, H. (2019). Spatiotemporal dependence of Antarctic sea ice variability to dynamic and thermodynamic forcing: a coupled ocean–sea ice model study. *Climate Dynamics*, *52*(7–8), 3791–3807. https://doi.org/10.1007/s00382-018-4348-3

Wendler, G., Stearns, C., Weidner, G., Dargaud, G., & Parish, T. (1997). On the extraordinary katabatic winds of Adélie Land. *Journal of Geophysical Research: Atmospheres*, *102*(D4), 4463–4474. https://doi.org/10.1029/96JD03438