U.S. DEPARTMENT OF ENERGY | Office of Science

DOE/SC-ARM-18-001

Sea Ice Effect on Arctic Precipitation Field Campaign Report

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January 2018

ARM CLIMATE RESEARCH FACILITY

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Work supported by the U.S. Department of Energy,
Office of Science, Office of Biological and Environmental Research

Acronyms and Abbreviations

ARM	Atmospheric Radiation Measurement
DOE	U.S. Department of Energy
HYSPLIT	hybrid single-particle Lagrangian integrated trajectory
iisPacs	Isotope Investigation of Sea-ice and Precipitation in the Arctic Climate System
LANL	Los Alamos National Laboratory
MMCR	millimeter cloud radar

Contents

1.0 Summary

This campaign, entitled Sea Ice Effect on Arctic Precipitation, started in January 2010 and ended in December 2016. The campaign involved sampling precipitation, storm by storm, within the U.S. Department of Energy (DOE) Atmospheric Radiation Measurement (ARM) Climate Research Facility observatory at Barrow, Alaska. Before the ARM Atqasuq, Alaska site was closed in September, 2014, precipitation samples were also collected at Atqasuq.

The objective of this campaign was to study how sea ice retreat under warming conditions affects the arctic hydrological cycle, namely evaporation and precipitation, using oxygen and hydrogen isotopic measurements in precipitation. One of the roles of sea ice in the arctic climate system is to influence evaporative fluxes from the sea surface. When sea ice melts, the evaporation is promoted from the newly opened sea surface, which increases the moisture supply, and precipitation. Reduction of sea ice cover may feed back to the climate system in several ways. First, it affects the latent heat flux from the sea surface. Second, the increased precipitation in the Arctic may change the surface albedo. For example, if the increased precipitation falls as snow, it would increase the albedo in spring due to delayed melting. Both mechanisms would affect the radiation balance of the Arctic and thus induce additional climate change.

Stable isotopic ratios in precipitation record meteorological conditions from the moisture source through the transport path and to the precipitation site. If moisture from the arctic sea surface increases, the average transport distance would decrease. This would result in an enrichment of oxygen-18 and deuterium in precipitation. Samples collected at Barrow allow us to track the moisture source areas for each sampled storm and analyze if the sea ice change is associate with systematic shift of hydrological conditions.

Between July 2011 and December 2014, Barrow was one of the sites in a network of pan-Arctic precipitation observations in the project called iisPacs, standing for Isotopic Investigation of Precipitation in Sea ice in the Arctic Climate System. The project included eight stations where precipitation was collected following the protocols developed in Barrow and Atqasuq. These stations included Barrow and Atqasuq, Alaska, Cambridge Bay, Canada, Ny Ålesund, Norway, Ikerasaarsuk and Summit, Greenland, and Chersky and Tiksi, Russia. Currently, synthesizing data from all of these stations is in progress.

2.0 Results

This project has resulted in three professional publications, six conference abstract/presentations, and two MS theses. Three contributions in international professional journals are described below.

The first paper is published in *Atmospheric Chemistry and Physics* (Putman et al., 2017a), entitled "Annual Variation in Event-Scale Precipitation at Barrow, AK, Reflects Vapor Source Region". In this study, we tracked each sampled precipitation event between January 2009 and March 2013 to their source areas using the hybrid single-particle Lagrangian integrated trajectory (HYSPLIT) air parcel tracking program in the back-cast mode. Then we are able to assess how the meteorological conditions at the source region affect the isotopic variations in the precipitation samples. This study is significant in that it provides an analysis of the complete set of conditions (including those at the source, during the moisture transport, and at the precipitation site) that control the isotopic composition at the precipitation site. In the past, the isotopic variations are interpreted based only on the conditions (primarily temperature) at the precipitation site. Typically, these earlier studies are based on monthly observations rather than storm-by-storm samples.

The Barrow samples allowed us to study seasonal as well as inter-storm variations in isotopic variations and the associated moisture sources. We found that the vapor source region migrated annually, with the most distal (proximal) and southerly (northerly) vapor source regions occurring during the winter (summer). This may be related to equatorial expansion and poleward contraction of the polar circulation cell and the extent of arctic sea ice cover. Three variables explain >50% of the variance in deuterium to hydrogen ratios (δD values) of precipitation, including 1) the dew point at the moisture source region, 2) the total temperature decrease with cooling of the air mass from source to site, and 3) whether the vapor transport path crossed the Brooks and/or Alaskan ranges. It is the ability of obtaining source conditions for each storm that allows assessment of sea ice effects on the hydrological cycles. Currently, all storm samples from Barrow are being studied, by Annie Putman, a Master's student at Dartmouth College, and now a Ph.D. student at the University of Utah, with a focus on assessing the effect of sea ice extent on moisture source areas.

The second paper is published in *Journal of Atmospheric and Oceanic Technology* (Putman et al., 2017b), entitled, "Testing a Novel Method for Initializing Air Parcel Back Trajectories in Precipitating Clouds Using Reanalysis Data" This work benefited the intensive instrumental deployment at the ARM sites, particularly the millimeter cloud radar (MMCR) products. When tracking moisture source regions using HYSPLIT, it is important that we find the altitude range where condensation is actually occurring. While Barrow has the MMCR product to guide that process, MMCR deployment is uncommon in many other locations where the moisture tracking would be desirable to conduct. Therefore, we developed a method to use the reanalysis data, which have a global coverage, to identify condensation latitudes. This novel method is then compared with the MMCR data for its accuracy and robustness. We concluded that for two thirds of the storms the match between two methods is good to very good. We have shared our code in the publication with other investigators.

The third paper is published in *Hydrological Processes* (Throckmorton et al., 2016), in collaboration with a group in Los Alamos National Laboratory (LANL). The study investigated water sources contributing to the pore water in the active layer of the permafrost in Barrow. Since isotopic data provided by our project have shown great season contrasts, the LANL group was able to track the pore water in the active layer seasonally, providing insight to permafrost processes involving evaporation, freezing, exchange, and mixing of water.

3.0 Publications and References

3.1 Journal Articles

Throckmorton, HM, BD Newman, JM Heikoop, GB Perkins, X Feng, DE Graham, D O'Malley, VV Vesselinov, J Young, SD Wullschleger, and CJ Wilson. 2016. "Active layer hydrology in an arctic tundra ecosystem: quantifying water sources and cycling using water stable isotopes." *Hydrological Processes* 30(26): 4972-4986, doi:10.1002/hyp.10883.

Putman, A, X Feng, LJ Sonder, and ES Posmentier. 2017a. "Annual variation in event-scale precipitation δ2H at Barrow, AK reflects vapor source region." *Atmospheric Chemistry and Physics* 17(7): 4627-4639, doi:10.5194/acp-17-4627-2017.

Putman, AL, X Feng, ES Posmentier, AM Faiia, and LJ Sonder. 2017b. "Testing a novel method for initializing air parcel back trajectories in precipitating clouds using reanalysis data." *Journal of Atmospheric and Oceanic Technology* 34(11): 2393-2405. doi:10.1175/JTECH-D-17-0053.1.

3.2 Conference Presentations

Putman, AL, R Fiorella, X Feng, D Noone, ES Posmentier, and GJ Bowen. 2017. Changes in the seasonal cycle of δ^{18}Op at Barrow, AK, US between 1962 and 2016 indicate role of changing transport and evaporation patterns for coastal arctic hydrology. Abstract PP53B-1133 presented at 2017 Fall Meeting, American Geophysical Union, New Orleans, USA, 11-15 December.

Feng, X. 2015. How much does sea ice influence Arctic precipitation? International Workshop on Frontiers in Earth Sciences, International Professionals for Advancement of Chinese Earth Sciences 15th Anniversary, Nanjing University, Nanjing, China, 26 to 28 June.

Putman, A, ES Posmentier, AM Faiia, LJ Sonder, and X Feng. 2014. A comparison of two methods for initiating air mass back trajectories, Abstract PP31D-1184 presented at 2014 Fall Meeting, American Geophysical Union, San Francisco, USA, 15-19 December.

Putman, A, ES Posmentier, LJ Sonder, and X Feng. 2013. Annual variation of precipitation δD and δ^{18}O at Barrow, AK related to seasonal shifts in moisture source. Abstract PP23C-1995 presented at 2013 Fall Meeting, American Geophysical Union, San Francisco, USA, 9-13 December.

Posmentier, ES, AM Faiia, K Everhart, D Whiteman, and X. Feng. 2012. Sea ice and the atmospheric cycle of water vapor and its isotopologues. Abstract, presented at 2012 International Polar Year Conference, From Knowledge to Action, Montréal, Canada, 22-27 April.

Posmentier, ES, AM Faiia, KK Everhart, D Whiteman, and X Feng. 2011. Feedbacks among arctic sea ice, evaporation, and precipitation – an isotopic approach. Abstract U33A-0024 presented at 2011 Fall Meeting, American Geophysical Union, San Francisco, USA, 5-9 December.

3.3 Masters Theses

Putman, AL. 2013. Tracking the moisture sources of storms at Barrow, Alaska: Seasonal variations and isotopic characteristics, Dartmouth College.

Everhart, KK. 2011. Sea ice and the Arctic water cycle: a novel application of stable isotope meteorology in Barrow and Atqasuk, Alaska, Dartmouth College.

4.0 Lessons Learned

An important contribution of this project was to experiment and test the sampling protocol under the Arctic environment. Collecting snow is challenging under strongly windy conditions often experienced in Arctic winters. We developed a technique (thanks to the effort of Doug Whiteman) to use a Nylon sampling bag. The bag was hanging on a horizontal arm, allowing it to move freely with the wind direction and to capture falling/blowing snow. This method was used for the pan-Arctic precipitation collection system during the iisPacs campaign. A manuscript for the study of precipitation isotopes at the Summit Greenland site is currently under revision, and reviewers are very complimentary about this sampling method.

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