Preferred States of the Winter Arctic Atmosphere, Surface, and Sub-Surface

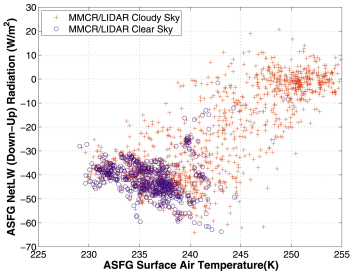
Research Highlight

The climate of the Arctic appears to be extremely sensitive to human influences, but it is relatively poorly understood because it is inadequately observed and involves interactions among the ocean, the overlying sea ice, snow resting on the sea ice, and the atmosphere above. Climate models predict significant future Arctic sea ice decline as the planet warms, but the models disagree over the rate at which this will occur, and the rate of sea ice retreat observed during the satellite era is actually faster than the model predictions, suggesting that the models do not adequately simulate the physical processes that regulate sea ice thickness and extent.

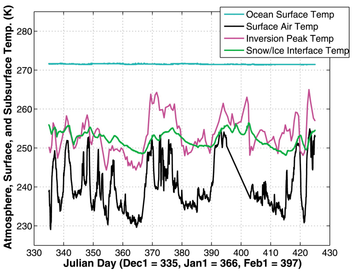
More than a decade ago, during the Surface Heat Budget of the Arctic (SHEBA) field experiment, a variety of instruments were deployed on the Beaufort Sea ice pack north of the ARM North Slope of Alaska (NSA) site for almost a year, including a NOAA cloud radar and depolarization lidar and ARM radiometers. We revisited the SHEBA data set, focusing first on the Arctic winter when there is no sunlight and the ice is too cold to melt, to understand how winter weather "prepares" the sea ice for the spring melt season. Most previous papers about the Arctic atmosphere have focused on the monthly average climate and how it varies over the seasons. However, the Arctic atmosphere and its effect on the surface are very different depending on whether a storm is passing and skies are overcast or whether high pressure is in place and skies are mostly clear. Overcast skies act as a blanket that absorbs longwave radiation and then re-emits it down to the surface, warming the sea ice and snow, while clear skies allow heat to be radiated away to space, cooling the snow and sea ice. These effects are exaggerated in the Arctic because the cold air is too dry for water vapor molecules to absorb much infrared radiation, and because the clear and cloudy episodes last longer than in other parts of the world, giving the snow and sea ice more chance to react.

The Arctic mostly oscillates between these two states during the SHEBA winter, producing a distinct bimodal distribution of surface longwave radiation flux, surface temperature, and atmospheric thermodynamic structure and spending little time in between (Figure 1). The snow-sea ice interface also oscillates in response to the atmospheric variations; it cools when skies are clear because more heat is conducted up through the snow to the surface than it receives by conduction from the ocean through the sea ice below, and it warms during overcast conditions when much less heat is lost upward to the surface by conduction (Figure 2). Thus, the average winter climate over the Arctic sea ice almost never occurs—it is usually much colder or much warmer than the average, losing heat or gaining heat. Five years of similar observations over the ARM NSA Barrow site show a similar bimodal behavior in downward longwave radiation but not in upward longwave radiation because of greater surface temperature variability over the land surface. Barrow winters resemble SHEBA to a greater extent when there is less than normal southerly flow.

The behavior observed during SHEBA has several implications for predictions of future sea ice decline. In winter, the clear and cloudy states occur just often enough so that sea ice temperature fluctuates between warm and cold but has no systematic upward or downward trend (Figure 2). In spring, however, cloudy conditions begin to dominate, causing temperatures to warm on average and move the ice closer to its melting temperature, even before the incident shortwave flux from the newly risen sun is strong enough to matter (K. Stramler 2006, Ph.D. dissertation, Columbia University). Thus, models that simulate the seasonal cycle of Arctic cloudiness incorrectly may also predict the wrong time of onset and duration of sea ice melting, perhaps explaining some of the spread in model predictions of the future. Also, to date the models have been evaluated almost exclusively by asking whether they



SHEBA winter hourly surface net (down - up) longwave radiation flux versus surface temperature. Blue circles indicate times when a combined radar-lidar cloud detection indicated clear skies, and red plus signs indicate times when clouds were detected.



Time series of SHEBA winter hourly temperatures at the atmospheric temperature inversion altitude (magenta), surface (black), snow-sea ice interface (green), and ocean surface (cyan).

can reproduce the average conditions in the Arctic. If they do so by simulating near-average conditions most of the time, they are getting the right answer for the wrong reason, and their predictions of future sea ice decline should be discounted.

Reference(s)

Stramler K, AD Del Genio, and WB Rossow. 2011. "Synoptically driven Arctic winter states." Journal of Climate, 24(6), doi:10.1175/2010JCLI3817.1.

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Cloud Life Cycle