AOS 2018 Short Statement
Sub-theme 3. Operating Observing Systems and Networks

Arctic Heat Transfer Mechanisms between Ocean and Atmosphere during Autumn and Winter

Anja Rösel, anja.rosel@npolar.no, Norwegian Polar Institute, Norway (contact)
Lana Cohen, lana.cohen@npolar.no, Norwegian Polar Institute, Norway
Glen E. Liston, glen.liston@colostate.edu, Colorado State University, CO, USA
Stephen Hudson, stephen.hudson@npolar.no, Norwegian Polar Institute, Norway
Polona Itkin, polona.itkin@npolar.no, Norwegian Polar Institute, Norway
Sebastian Gerland, sebastian.gerland@npolar.no, Norwegian Polar Institute, Norway

The changing Arctic shows us two key realities. First, Arctic air temperatures are increasing faster and are more extreme than in almost all other areas of the world (e.g. Hansen et al., 2010; Cohen et al., 2014; AMAP 2017). Second, current Earth System Models (ESMs) as well as operational forecasting and regional models are unable to reproduce recent observed Arctic sea ice and air temperature trends (e.g. Stroeve et al., 2007, updated; Stroeve and Notz, 2015). The enhanced Arctic warming is primarily an autumn and winter phenomenon (e.g. Serreze and Barry, 2011), thus a focus on Arctic processes in these seasons is of particular importance.

Based on N-ICE2015 expedition results, which took place from January through June 2015 in the Arctic north of Svalbard (Granskog et al., 2016), we have identified autumn- and winter-related Heat Transfer Mechanisms (HTMs) that have not been adequately observed and are therefore not ideally represented in current modeling systems. We conclude that creating more accurate Arctic and global predictive models requires, at least in part, improved representations of the most important factors controlling heat fluxes between the Arctic Ocean and atmosphere, which in turn requires better observations of these fluxes. We therefore propose that the following HTMs should be a focus of near-future observational and modeling research.

Atmosphere:
The atmosphere has a large impact on heat and moisture transfer to and within the Arctic (e.g. Graversen et al., 2008; Overland and Wang, 2010, 2016), and atmospheric processes that drive heat and moisture transport are important on a wide range of temporal and spatial scales (Serreze and Barry, 2011). There is also evidence of strong regional variability within the Arctic (e.g. Francis et al., 2005; Park et al., 2015), making it vital to demonstrate which processes exhibit Arctic-wide controls and which are more regionally important. The following atmospheric processes have the greatest impacts on Arctic heat and moisture budgets and require additional and improved observation and modeling efforts.

- Clouds and cloud properties are highly variable in time and space, and with today's observations and models it is challenging to quantify and parameterize these properties. Macro- and micro-physical properties greatly affect the surface energy budget and precipitation processes.

- Precipitation is also highly variable in time and space, and its distribution is not well known over Arctic sea ice. Precipitation amounts are notoriously difficult to measure in cold regions, so even a realistic Arctic climatology does not exist. Evaluating precipitation amounts in models is therefore challenging. Yet the amount and phase of the precipitation, as well as the timing of ice formation in autumn and winter, ultimately determines the thickness, mass, and mobility of the snow deposited on sea ice. This precipitation-related snow accumulation imposes critical controls on heat transfers and is often the key to accurate interpretation of remote sensing data.

- Near-surface air temperature, humidity, wind, and mixing are strongly affected by the extreme stratification common in the winter Arctic atmospheric boundary layer. Unfortunately, most of today's ESMs do not adequately represent atmospheric processes and fluxes in stable boundary layers. Among other problems, this often leads to substantial overestimation of surface temperatures during clear, calm periods.

- Observations of the impacts of synoptic events, especially storms, on sea ice and snow processes are also needed.

ESMs represent the atmospheric synoptic variability quite accurately, and thus future focus on observations and modeling of the processes and system-wide impacts is necessary to ensure these are also well represented in ESMs.

Snow and ice thermodynamics:
Snow on sea ice strongly regulates the thermodynamic processes of sea ice growth. Due to the low thermal conductivity of the snowpack, snow largely controls heat fluxes between the atmosphere and ocean (Sturm et al., 2002a, 2002b) and thus directly impacts ice growth and melt. Since Arctic snow depths are largely controlled by unknown precipitation inputs, it is hard to quantify the actual snow thickness and its spatial variability on sea ice using just models; some kind of additional observation is required. In addition to its relevance for the energy fluxes, knowledge about snow thickness is also crucial for sea ice thickness calculations from altimetry such as CryoSat-2 (e.g. Laxon et al., 2013), or the coming ICESat-2 (Markus et al., 2017).

- Heat fluxes between the atmosphere and sea ice are generally regulated by the presence of a snow layer. At the floe scale, heat fluxes are strongly modified by spatial variability of the snow thickness at scales of tens of cm to tens of m. Modeling studies indicate this spatial patchiness may play a crucial role in ice growth and heat fluxes to the atmosphere, and that the associated processes may lead to significantly enhanced heat fluxes during the early-winter when the snow and ice are relatively thin. In ESMs, and even in regional models, snow is represented as a homogeneous layer and small scale variability is generally not accounted for. Observational and modelling efforts are needed to assess the importance of this variability and to determine how its effects can be incorporated into ESMs.

- The spatial variability in snow depth covers large areas of the Arctic Basin and persists throughout the winter. The integrated effect of locally thin snow-covered areas over long periods of time, particularly during the early snow-formation phase, as well as during the onset of ice formation plays an important role in Arctic ocean-to-atmosphere heat fluxes and needs to be better observed and addressed in ESMs.

- A thick snow layer on relatively thin ice causes negative freeboard and can allow relatively warm ocean water to flood the sea ice surface, causing snow-ice formation if temperatures are low enough. The thinning of Arctic sea ice makes this process more likely in the present and future Arctic than it was in the past. These mechanisms strongly modify conductive and latent heat fluxes in the system and thus impact the ice mass balance. Flooding and snow ice formation are included in some ESMs, but these processes are not well studied in the Arctic and further observations of their extent and impacts are needed. Knowledge and identification of flooded areas are also expected to be useful for remote sensing applications.

Sea ice dynamics:
Recent observations suggest that the increasing mobility of sea ice has led to an increase in sea ice deformation (Rampal et al, 2009; Itkin et al, 2017). More observational and remote sensing studies are necessary to confirm this finding Arctic-wide. Combining observational data and numerical models is especially challenging due to the spatial and temporal dependencies of deformation. Direct observations of ocean and atmosphere heat fluxes through resulting leads remain a challenge because the sea ice pack is highly dynamic and the fluxes are localized.

- Leads in sea ice enhance heat and moisture exchange to the atmosphere. In addition, sea ice leads drive new sea ice growth. It is important to improve observations of heat fluxes through leads to ensure these processes are adequately represented in ESMs.

- Where sea ice is compressed into pressure ridges, the roughness of the top and bottom ice surfaces enhances the momentum transfer between the atmosphere and ocean. Mixing of the oceanic surface layer in areas where relatively warm ocean water lies at shallow depths, such as in the area of Atlantic Water inflow, can then lead to stronger ocean heat fluxes, which then melt the sea ice and enhance heat transport into the atmosphere. The impact of sea ice roughness on ocean mixing is highly variable in space and time, and it is not well observed over all regions and spatial scales. ESMs typically use constant values for sea ice form drag.

- Rough sea ice surfaces and leads are sinks for snow. Large fractions of snow can be redistributed into drifts adjacent to ridges or lost in the open water of leads. The redistribution of snow in drifts and loss to leads has yet to be quantified by observations and are not represented in the ESMs.

Conclusions:

These winter HTMs and their controls on fluxes between the Arctic Ocean and the atmosphere are critical areas for improvements in our understanding and ability to model Earth's climate system. In addition, these mechanisms are generally thought to be high-resolution, sub-grid processes that require parameterization within the next (or current) generation of ESMs. They are Arctic system features that often evolve quickly in time; vary from region to region and seasonally; have important consequences for ecosystem, light, and ocean heat fluxes; and are expected to drive important teleconnections.

In addition, there is a need to implement observing programs that focus on processes represented by these HTMs, and to use those observations to develop sub-grid-process parameterizations for implementation within ESMs.

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