2017 Arctic Change Workshop
Opportunistic strategies to integrate measurements and modeling to enhance understanding of Arctic change

Workshop aims.
Upcoming field activities, such as the Multidisciplinary drifting Observatory for the Study of Arctic Climate (MOSAiC) and the Year of Polar Prediction (YOPP), provide an opportunity to better integrate Arctic measurements and modeling. To explore this opportunity, a workshop was held in June 2017 that brought Arctic scientists together to discuss strategies and practical steps forward. The themes of the workshop were to find better ways to utilize models for planning observational programs and also better ways to use observations in model development. The main goals of the workshop were to identify the processes that are key to these themes, find ways to facilitate these themes, and potentially form collaborations around them.

Workshop structure
The workshop took place on June 22-23 2017 at the NCAR Mesa Lab in Boulder, CO. It included presentations on planned observations and model developments and discussions about priority areas of work. The agenda allowed considerable time for discussion and brainstorming about potential ways forward. Breakout groups were formed around three science themes including biogeochemical cycles, heat budgets, and momentum exchange. Starting from a science question within each theme, meeting participants were asked to identify the processes of interest, the observations required to constrain those processes, and modeling tools and experiments needed to further understanding. These breakout sessions allowed small groups of scientists with varied areas of expertise to work through science examples and identify needed synthesis datasets, i.e. a collection of several coordinated observations and model experiments, to address questions of interest. Results from breakout groups were then presented back in a plenary discussion to allow for further discussion.

Breakout Group Discussions
The breakout sessions used MOSAiC as a guide to explore observational and modeling needs and integration of the two. The groups addressed the following:

1. Biogeochemical cycles theme: How is diminishing sea ice going to affect the carbon cycle?

To resolve this question, it was felt that a better process understanding is needed on
- the controls on biogeochemical cycles,
- factors influencing trace gas exchange, and
- how sea ice conditions influence primary productivity.

It was acknowledged that many of these processes have elements that are somewhat unique to the Arctic, such as the presence of ice algae and sea ice controls on trace gas exchange. To better constrain these processes, measurements are needed on the trace gas flux, nutrients, biological, and environmental conditions (sea ice properties, temperature, salinity, light). A spatial distribution of measurements over different ice types and over time would allow for relationships between sea ice and controls on the carbon cycle to be explored. Investigating how models incorporate these relationships would provide guidance on where model improvements may be needed. Using constrained simulations, for example a MOSAiC column in which environmental conditions are prescribed using observational data, would be a useful means to explore and validate simulated sea ice-biogeochemical interactions.

Challenges regarding the integration of models and observations in the context of the carbon cycle were discussed. It was felt that to facilitate the synthesis of observations and models, standard methods and data formats are needed (as in Miller et al., 2016). Additionally, it is important to understand the spatial representativeness of measurements and consider errors associated with comparisons of point measurements to simulated gridcell quantities.

2. <u>Heat budget theme: Can MOSAiC measurements be used to constrain the flow of energy between the ocean-ice-atmosphere in the central Arctic?</u>

The breakout group that addressed this question acknowledged that to better understand the MOSAiC column heat budget required understanding of factors influencing

- ocean mixing and stability,
- atmospheric boundary layer conditions,
- cloud properties and associated fluxes,
- sea ice and snow conditions, including porosity and spatial distributions,
- lateral transports in the atmosphere and ocean, and
- ocean-ice-atmosphere flux exchange.

Measurements for both the mean state and variability across the ocean, sea ice and atmosphere are needed to understand these factors and constrain the column budgets. For the ocean, this includes the lateral transport of heat and how that heat is mixed vertically within the water column. For the atmosphere, measurements on boundary layer stratification and associated conditions are needed. Information on the coupling of components is also required. MOSAIC is well positioned to address this question in that measurements of this type will be taken, with plans for more atmospheric soundings, higher temporal resolution, and more coordinated ocean-ice-atmosphere measurements than has been done previously in the central Arctic.

It was felt that these measurements would be particularly valuable to validate models. For example, multiple factors influence atmospheric boundary layer structure. It is important to understand the relative importance of these and how they compare to climate model simulations since this influences boundary layer variability and associated feedbacks. Similarly, MOSAiC data will also allow for validation of factors influencing the mean state and variability of ocean stratification within models, which are typically highly parameterized. Synthesis datasets that incorporate this information for model validation would be particularly helpful.

A number of open questions about MOSAiC measurements should be considered for the column heat budget constraints. These include:

- Will MOSAiC cover enough area to have good representation of sea ice and snow heterogeneity?
- How should MOSAiC measurements be scaled to validate processes produced in a climate model?
- Can validating processes on short (hourly-seasonal) time scales reduce biases in climate model projections on longer time scales (interannual-decadal)?

It was also acknowledged that equivalent definitions of variables, like sea ice melt onset, across models and observations are needed for valid comparisons. Finally having information on climate model simulated variability along the (proposed) MOSAiC track, perhaps prior to the campaign, would provide context for measurements.

3. <u>Momentum exchange theme: What are the dominant & relevant momentum factors forcing the kinematics and deformation of the ice? Where does the energy/momentum come from & how is the energy distributed?</u>

To understand momentum exchange requires process understanding on the following, among others,

- how momentum is transferred between the atmosphere, ocean, and sea ice.
- drivers of momentum from the troposphere and above the atmospheric boundary layer (e.g. low-level jets)
- the contribution of waves, from the marginal ice zone to the open ocean

Understanding how these and other factors affect the kinematics of sea ice also requires measurement and modeling thermodynamic processes affecting drag on the ice.

Full atmosphere-sea ice-ocean column observations are needed to constrain this problem. This includes information on ice drift and deformation, atmospheric boundary layer state, sea ice morphology and roughness, upper ocean currents and structure, and turbulence measurements at high spatial and temporal resolution. Direct and derived measurements of the macroporosity of deformed ice caused by fragmentation would aid in understanding of the effect of ridges on momentum exchange and sea ice conditions. It was suggested that a roving surface turbulence site would help to identify significant lead openings and deformation events that warrant enhanced measurements.

Integrated observational products from the above measurements would facilitate improvements in process understanding and allow for validation and development of models. Conversely, new model developments focused on turbulence, boundary layer structure, form drag and deformation, including ridging, may be useful in guiding observational campaigns. A survey of momentum transport as simulated in current coupled models would provide information on the uncertainties across models and be a useful diagnostic for comparison to observations.

Workshop Outcomes

Some common factors emerged from the plenary and break out group discussions regarding useful observational and modeling datasets. This included the need for full column information to assess coupled interactions, the usefulness of datasets that incorporate multiple variables to address for science application ("synthesis datasets"), and datasets of model simulated fields to put measurements in context.

Workshop participants acknowledged the need for **synthesis datasets** from MOSAiC and other field campaigns (e.g. Seasonal Ice Zone Reconnaissance Surveys – SIZRS). These should be science driven and relevant for coupled problems. Modelers should be included in the design of these datasets to ensure that they are useful for model development and validation. There is value in having a **"0th order" dataset** with a common format that is easily and quickly accessible. For MOSAiC, this could include core, hourly averaged measurements for a ship "column" from the atmosphere, sea ice, and ocean as well as fluxes between these. This dataset should be determined in advance to help guide data acquisition and processing. There is also value in a "gridcell" relevant dataset that is more directly comparable to model simulated fields. This would likely require more coordination and need to consider the spatial representativeness of different measurements.

On the issue of spatial scale, it was also recognized that this is a limitation for field campaigns which occur at a single location for a single point in time. Model simulated data for many ensemble members can help to put these measurements into a broader spatial and temporal context. This is particularly relevant given the recent availability of large ensemble model simulations which are designed to more accurately sample internal variability. While model bias and process representation needs to be carefully considered, this can help to provide information on how representative field observations may be for different applications. For specific field campaigns, like MOSAiC, **column-relevant track information obtained from existing climate model simulations** could be particularly useful.

It was also noted that the use of a **hierarchy of modeling tools** from Large Eddy Simulation, to single column models, to fully coupled Earth system models is useful. This hierarchy can be used to bridge the gap between field observations, processes driving the observed state and variability, and how those processes are represented in large-scale models. A single column model could be used in a MOSAiC like domain to understand the vertical exchanges of heat, moisture, and momentum. This would help constrain these processes in larger scale regional and global Earth system models.