BAMS
Meeting Summary

Advancing Marine Arctic Science through Facilitating International Collaborations

Wilbert Weijer,[a,b] Milena Veneziani,[a] Jaclyn Clement Kinney,[c] Wieslaw Maslowski,[c]
Jiaxu Zhang,[d] and Michael Steele[d]

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Inaugural Workshop and Early Career School of the Consortium for the Advancement of Marine Arctic Science (CAMAS)

What: Participants met to discuss key marine Arctic processes that contribute to the rapid changes in the Arctic and to develop collaborative activities to address knowledge gaps.

When: 13–16 February 2024

Where: Santa Fe, New Mexico, and remote

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Corresponding author: Wilbert Weijer, wilbert@lanl.gov

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AFFILIATIONS: [a] Los Alamos National Laboratory, Los Alamos, New Mexico; [b] International Arctic Research Center, University of Alaska Fairbanks, Fairbanks, Alaska; [c] Naval Postgraduate School, Monterey, California; [d] University of Washington, Seattle, Washington

1. Introduction

The Consortium for the Advancement of Marine Arctic Science (CAMAS) held its inaugural Workshop and Early Career School in Santa Fe, New Mexico, from 13 to 16 February 2024. The event brought together 80 Arctic marine scientists from around the world to discuss current research and to develop ideas for collaborative research projects that can be executed in the next few years to advance our understanding of the marine Arctic system.

2. Background

The Arctic environment is changing rapidly. Air and water temperatures are increasing, sea ice is declining, permafrost is thawing, storminess is increasing, coastal erosion is accelerating, and biological species are responding to all of these environmental changes with biomass changes and habitat shifts. Numerical models that accurately capture key processes in the Arctic Earth system are critical tools for understanding the drivers of these rapid changes and for anticipating their consequences. Arctic Earth system modeling has made significant progress in the past decades, as regional models have matured, and global regionally refined approaches are emerging. Yet, many challenges remain, as the pace and scope of Arctic change seem to elude even the best models.

Comparing different models in coordinated experiments, and confronting them with observations, has been an excellent way to identify model bias, refine system understanding, and improve physical and numerical approaches. The Arctic Ocean Model Intercomparison Project (AOMIP) was initiated in 1999 to facilitate such model intercomparison activities by creating a broad international community of Arctic modelers, observationalists, and theoreticians who collaborated on improving coupled ice–ocean models. One result was a 2007 *Journal of Geophysical Research* (JGR) special issue with fundamental papers on ocean circulation, climate restoring, mixing schemes, and other topics (Proshutinsky and Kowalik 2007). Subsequently, the project Forum for Arctic Modeling and Observational Synthesis (FAMOS) continued the success of AOMIP in two stages, FAMOS I (2013–15) and FAMOS II (2016–18). FAMOS facilitated continuous collaboration among this vibrant community, organized annual workshops typically attended by 100–150 scientists, organized an annual FAMOS School for early career scientists, and documented collaborative activities in over 120 publications and 2 special issues (Proshutinsky et al. 2016, 2020). FAMOS also expanded the AOMIP community to include stronger collaboration with marine observationalists, experts in related fields (e.g., meteorology, hydrology, and glaciology), and marine biogeochemical modelers and observationalists. The success of these initiatives highlighted the continuing need for opportunities that facilitate collaborations between modelers and observationalists and actively encourage the participation of early career scientists.

3. The Consortium for the Advancement of Marine Arctic Science

The CAMAS aims to fill this need. The goal of CAMAS is to advance the understanding and model representation of key marine Arctic processes that contribute to the rapid changes in the Arctic, by facilitating and enhancing international collaboration on marine Arctic science. In particular, CAMAS focuses on the following themes:

- Drivers and impacts of ocean heat and freshwater transport into and out of the Arctic
- Ocean–ice–atmosphere interactions in a warming Arctic
- Biophysical impacts of Arctic marine biogeochemistry

The objective is to organize at least three workshops in subsequent years during which participants can develop, execute, and finalize collaborative research activities. In addition, CAMAS also aims to engage early career scientists in marine Arctic research by organizing early career schools preceding each workshop, during which the participants will enjoy lectures from experts in the field. CAMAS is funded by the Department of Energy's Regional and Global Model Analysis (RGMA) program area and is a contribution to High-Latitude Application and Testing of Earth System Models, in collaboration with the Regional Arctic System Model (HiLAT-RASM) project.

4. The 2024 CAMAS Workshop and Early Career School

The 2024 Workshop and Early Career School set the stage as the first of these annual events. The workshop was held in beautiful Santa Fe, New Mexico, from 13 to 16 February. The workshop engaged 80 participants, 35 of which identified as early career. Participants came from around the world: in addition to 59 U.S. participants, 12 came from Canada, 7 from Europe, and 2 from Asia.

The event started with the Early Career School on 13 February. Early career participants enjoyed lectures about current issues in Arctic modeling and observing. In particular, they learned about the latest advances in Arctic marine modeling, observations, reanalysis, and model evaluation. Each of these lectures was followed by discussion time with insightful interactions between the lecturers and the participants.

The day was concluded by a hands-on tutorial on the use of the state-of-the-science model evaluation capability the Program for Climate Model Diagnosis and Intercomparison (PCMDI) Metrics Package (PMP; Lee et al. 2024). The tutorial was organized by members of DOE's PCMDI project. It allowed the participants to access a DOE machine from their laptops and to run several example problems that demonstrated the evaluation of sea ice metrics in a suite of coupled Earth system models. The goal of this exercise was to acquaint CAMAS participants with these software tools, with the expectation that new metrics will be developed during CAMAS, and added to existing software tools like PMP. The development and implementation of metrics of the Arctic marine system for routine model evaluation will be a primary deliverable of CAMAS.

The first day of the workshop featured three sessions organized around the topical areas listed above. Each session featured four contributed presentations that showcased current research in the areas of drivers and impacts of ocean heat and freshwater transport into and out of the Arctic; ocean–ice–atmosphere interactions in a warming Arctic; and biophysical impacts of Arctic marine biogeochemistry. Several speakers introduced ideas for potential collaborative activities. These and other ideas were discussed during a series of breakout sessions. The day was concluded by a poster session that featured exciting research by 29 of the workshop's participants. Workshop day 2 started our series of "advances" sessions. Each of these sessions featured one or more experts that discussed recent advances in the areas of Arctic Ocean modeling, sea ice modeling, conceptual modeling, reanalysis, metrics, observations, and remote sensing. These presentations provided an excellent overview of the current state of Arctic marine science, highlighting both successes and challenges. Day 2 also featured a series of flash talks by remote participants, as well as an additional round of breakout sessions. Day 3 concluded with two more advances sessions, a final round of breakout discussions, and report-outs from the working groups.

5. Workshop outcomes

CAMAS participants identified several gaps in our knowledge of the Arctic marine system and are collaboratively developing numerical and observational approaches to address these gaps. A few of these knowledge gaps are summarized below.

a. Arctic Ocean mixing. The Arctic Ocean is a unique environment that is changing faster than anywhere else on Earth with important implications for the climate system. Climate models exhibit systematic biases in their representation of these changes, failing, for example, to accurately reproduce the observed sea ice evolution (Notz and Sea–Ice Model Intercomparison Project Community 2020), upper Arctic Ocean properties (Muilwijk et al. 2023), and water properties of deeper layers (Heuzé et al. 2023). It is important to understand how these biases are affected by the representation of different processes in these models in order to better understand the sources of model biases and to suggest ways they can be addressed in order to build more robust and useful climate models in the future.

The representation of ocean mixing in these models is a useful focus because the specified mixing rate and its space–time geography can have significant impacts on the modeled Arctic Ocean heat and freshwater distribution which in turn impact the modeled stratification, circulation, and sea ice properties. Further, mixing in these models is represented by a set of parameterizations that rely on mixing rate coefficients that are poorly constrained and typically do not capture important aspects of spatiotemporal variability of mixing known to exist. To address these issues, CAMAS participants are planning to examine and compare the representation of mixing fluxes and mixing rates (i.e., diffusivities) of heat and salt in the Arctic Ocean in a set of climate model runs. In addition, they will examine how differences in the representation of mixing across models correlate to differences in these models' representation of the Arctic Ocean state, e.g., heat and freshwater distributions, stratification, circulation and sea ice properties. This exercise may provide insight into how the representation of mixing processes can impact model biases in the representation of the Arctic Ocean state and its dynamics.

b. Freshwater distribution. Another process affecting the stratification in the Arctic Ocean is the distribution of freshwater from its diverse sources. As the Arctic Ocean changes rapidly under anthropogenic climate change, so has the balance of its freshwater transport, storage, and distribution. These changes are complex and nonlinear and have implications for Arctic Ocean stratification and dynamics. Since salinity stratification mediates the vertical transfer of subsurface oceanic heat from the Atlantic and Pacific water layers, strong stratification can shield sea ice from warmer waters below which may enhance melt or delay freeze-up. Thus, linking the impacts of freshwater sources to changes in stratification can allow us to better understand the oceanic drivers of sea ice decline, warming of the Arctic atmosphere, as well as the dynamics of the Arctic ice–ocean system as a whole (Aksenov et al. 2016). Yet, the sources, pathways, and distribution of freshwater through the Arctic Ocean are still poorly understood. This is partly due not only to the sparseness of observations but also to the complexities of modeling the unique physics of the Arctic Ocean. CAMAS participants are planning to perform tracer release experiments in a suite of ocean models, in order to identify which aspects of the Arctic freshwater budget are robustly represented across models, and which elements are variable, and to identify the processes responsible for this diversity.

c. Arctic cyclones. Another knowledge gap is the impact of extreme atmospheric events, in particular Arctic cyclones, on the Arctic Ocean and sea ice system. Arctic cyclones are the most energetic weather systems in the Arctic, bringing powerful winds, driving elevated oceanic waves, and heavy precipitation. Particularly in summertime, Arctic cyclones have great impact on the sea surface temperature and sea ice concentration (e.g., Inoue and Hori 2011), which are two of the key parameters governing atmosphere–ice–ocean interactions. As the climate warms, the sea ice is retreating substantially, causing a poleward shift of the summertime sea ice edge and an increasingly larger area of direct interactions between atmospheric storms and the surface ocean. This might lead to enhanced upper-ocean mixing and dynamically driven vertical ocean heat transport, which are the leading factors in driving the sea ice melt in response to Arctic storms. CAMAS participants are proposing to investigate the impact of historical Arctic cyclones on the ocean/sea ice system by examining specific historical extreme events, in observations, and in ocean models forced by atmospheric reanalysis products. In the next phase of this project, Arctic cyclones will be investigated in a number of free-running coupled Earth system models.

d. Phytoplankton under sea ice. Two large knowledge gaps in Arctic marine biogeochemistry were identified during CAMAS including 1) pelagic, under sea ice phytoplankton biomass and growth, and 2) the impact of riverine inputs on carbon dynamics. We plan to address the first topic by utilizing multiple regional and global climate models to intercompare historical values of under sea ice phytoplankton biomass and primary production. At present, very few studies exist from either the observational or modeling community on this topic. A limited set of observational in situ datasets indicate high values of chl-*a* and primary production under ice during late spring and early summer; however, there is uncertainty in space and time, especially due to the lack of data from satellite remote sensing (Arrigo et al. 2012). Early modeling work has shown that this source of carbon may be very important to the total carbon stock in the Arctic and might even supersede the observable open water fraction (Clement Kinney et al. 2023). In addition, the project will provide information on possible temporal trends over the past 6 decades in these variables with respect to a changing sea ice cover that is known to have a strong impact on the biogeochemistry of this high-latitude environment.

e. Riverine inputs and carbon dynamics. To address the second topic on the impact of riverine input on the coastal ocean, we plan to compare the results of multiple regional and Earth system models to determine the relative importance of the riverine drivers on the Arctic Ocean. Examining how river inputs can drive changes to coastal Arctic heat, nutrients and carbon production, and thus the ocean–atmosphere carbon flux in the Pacific Arctic, will help us predict changes to the system in the future. For our initial case study, we plan to focus on the Mackenzie River outflow and our intercomparison will compare both the representation of each of the river drivers in each model (temperature, dissolved organic carbon, dissolved inorganic carbon, total alkalinity, and nutrients) and the way river inflow is added into the ocean, i.e., location, depth distance from river mouth, and associated mixing and the resultant impact on marine ecosystem dynamics (primary production, alkalinity, and ocean–atmosphere CO_2 flux), such that we expand our understanding of river impacts and quantify uncertainty in model estimates.

6. Next steps

The primary goal of CAMAS is to encourage and facilitate collaborative projects to advance the synthesis between models and observations. Discussions during the workshop so far resulted in 13 research ideas that are currently being considered for further development.

Each of these ideas have been further developed in white papers that provide context for the problems at hand, as well as strategies to address them. Summaries of these projects can be viewed at the website (https://www.hilat.org/camas-projects.html). Community members are invited to review these ideas and to reach out to the activity leads if they are interested in participating. It is expected that each of these activities will start during the summer of 2024, so that preliminary progress can be discussed during the second CAMAS workshop, expected for spring 2025.

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