Improving understanding and modeling of Arctic climate change with process resolving climate models

Wieslaw Maslowski[1], Andrew Roberts[1], Robert Osinski[2], Anthony Craig[1], Dominic DiMaggio[1], John Cassano[3], Alice DuVivier[3], Joseph Hamman[4], Mimi Hughes[3], Bart Nijssen[4]
[1]Naval Postgraduate School, [2]Institute of Oceanology, Polish Academy of Sciences, [3]University of Colorado in Boulder, [4]University of Washington

Abstract: While historical reconstructions of Arctic climate change from Global Climate and Earth System Models (GC/ESMs) are in broad agreement with observations, 21st century projections of the magnitude of arctic climate change vary widely in the latest suite of global climate predictions and generally remain outpaced by observations. There are a number of reasons why GC/ESMs may not be able to simulate rapid change in the Arctic, which stem from a combination of coarse model resolution, inadequate parameterizations of sub-grid processes, and a limited knowledge of physical interactions.

We demonstrate the capability of the Regional Arctic System Model (RASM) in addressing some of the GC/ESM limitations in simulating observed seasonal to decadal variability and trends in the sea ice cover and climate. RASM is an example of limited-area, process-resolving, fully coupled earth system model, which due to the additional constraints from lateral boundary conditions and nudging within a regional model domain facilitates detailed comparisons with observational statistics that are not possible with GC/ESMs. We use RASM to investigate and present examples of the role of local processes, feedbacks among them, and sensitivities of simulated sea ice states and surface climate to scale dependence of model parameters to better understand model uncertainties in simulating variability and predicting seasonal to decadal change in Arctic climate.

Overarching Objective: Response to DoD and National Arctic Strategic Requirements

U.S. Navy Arctic Roadmap (2014) - Appendix 3: Arctic Roadmap Implementation Plan

2.2 Science and Technology

2.2.6: Increase ONR's Arctic Research Efforts and brief milestones annually to Chief of Naval Research. Improving the Navy's ability to understand and predict the Arctic physical environment at a variety of time and space scales.

2.3 Environmental Observation and Prediction

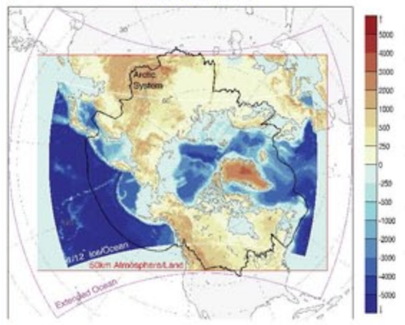
2.3.5: Encourage research into and development of comprehensive Arctic System Models

Implementation Plan for the National Strategy for the Arctic Region (2014)

- Pursue Responsible Arctic Region Stewardship
  - Develop a Framework of Observations and Modeling to Support Forecasting and Prediction of Sea Ice
    Objective: Improve sea ice forecasts and predictions at a variety of spatial and temporal scales
    Lead Agency: Department of Defense (ONR)
  - Integrate Arctic Regional Models
    Objective: Coordinate an integrated and focused effort to improve Arctic modeling to benefit understanding of ongoing processes, better project future Arctic changes, and guide future process research and decisions
    Lead Agency: Department of Energy

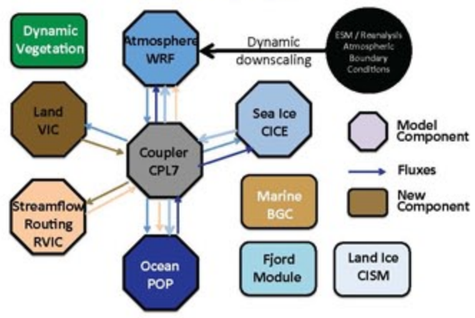
Regional Arctic System Model (RASM) - Overview

RASM Domains



Pan-Arctic domain to include:
- all sea ice covered ocean in the NH
- Arctic river drainage
- critical inter-ocean exchange and transport
- large-scale atmospheric weather patterns (AO, NAO, PDO)
- WRF/VIC domain cover the entire colored region
- POP/CICE domain cover the inner colored region

RASM Wiring Diagram



RASM Configuration

RASM 1.0	Code	Configuration / Domain Pan-Arctic including all sea ice covered ocean in the NH
Atmosphere	WRF3	50km, 40 levels, 2.5 minute time step.
Land	VIC RVIC	50km, 3 Soil Layers, 20 minute time step. Streamflow routing scheme: VIC-CPL7-POP
Ocean	POP2	1/12˚ (eddy-permitting), 45 levels (7 in the top 42 m), 10 timesteps / 20 minute flux exchange.
Sea ice	CICE5	1/12˚, 5 thickness categories 20 minute thermodynamics Anistropic(EAP)/Isotropic(EVP) rheology
Coupler	CPL7x	Flux exchange every 20 minutes for all components, inertial resolving with minimized lags.

RASM Rationale

Overarching Science Hypothesis: Mesoscale processes and resulting feedbacks are critical to improved representation of the Arctic Climate System state and prediction of polar amplification of climate change.

Arctic Climate Predictive Models need to:

- ❑ Resolve critical processes (e.g. sea ice deformation) and resulting feedbacks (e.g. air-ice-ocean coupling),
- ❑ Understand space dependence & optimize parameter space,
- ❑ Expand validation data (e.g. fluxes and coupling across the air-ice-ocean interface),
- ❑ Reduce computational cost / guide requirements of future high-resolution coupled climate simulations

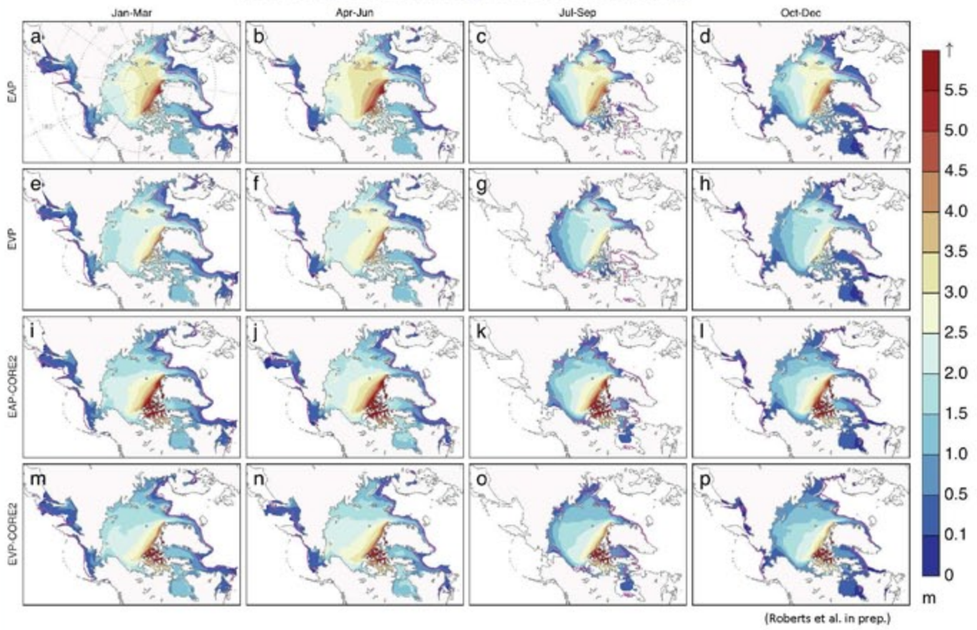
RASM - a tool toward a climate model hierarchy to:

(i) Resolve / understand Arctic processes and feedbacks,
(ii) Guide Future Field Campaigns and Earth System Model (ESM) Development,
(iii) Reduce uncertainty and
(iv) Improve prediction

(Maslowski et al. 2012)

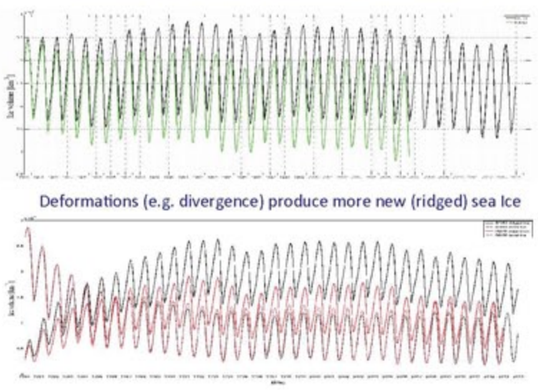
Selected RASM Results

RASM Sea Ice State & Sensitivity: 1979-2009 Seasonal Means



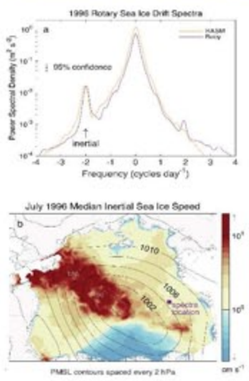
(Roberts et al. in prep.)

Sensitivity of Sea Ice State to Rheology Parameterzation

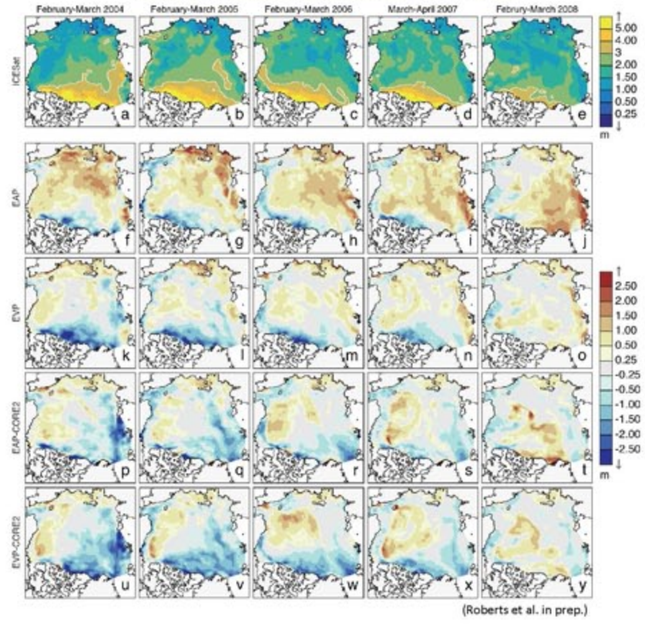


Deformations (e.g. divergence) produce more new (ridged) sea Ice

Inertial Air-Ice-Ocean Coupling

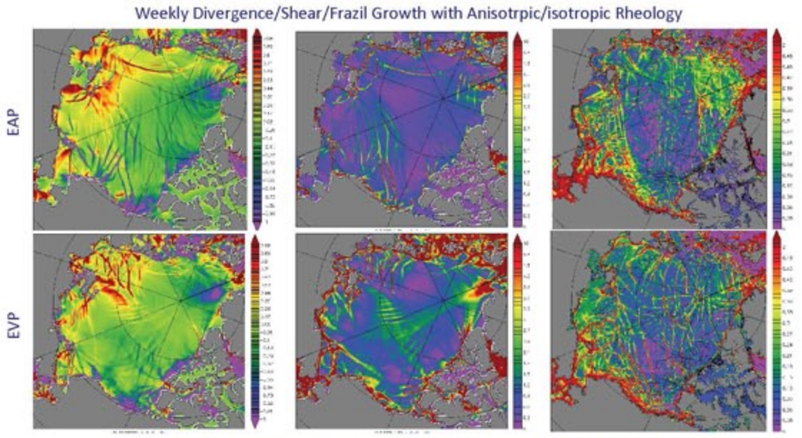


ICESat / RASM Winter Sea Ice Thickness: 2004-2008

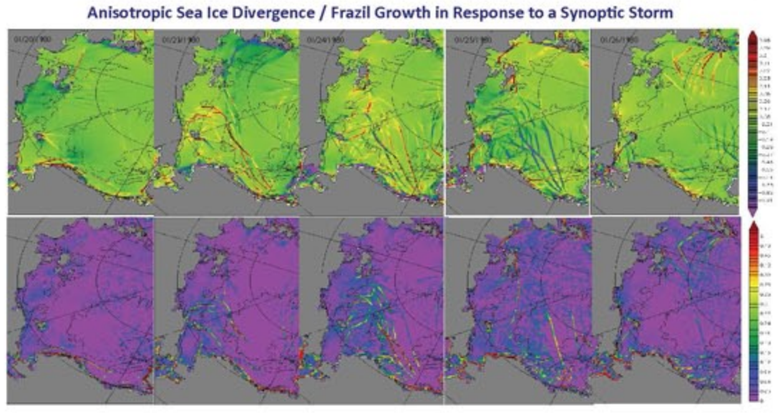


(Roberts et al. in prep.)

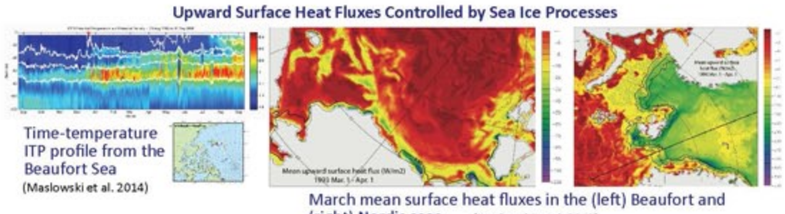
Weekly Divergence/Shear/Frazil Growth with Anisotrpic/isotropic Rheology



Anisotropic Sea Ice Divergence / Frazil Growth in Response to a Synoptic Storm



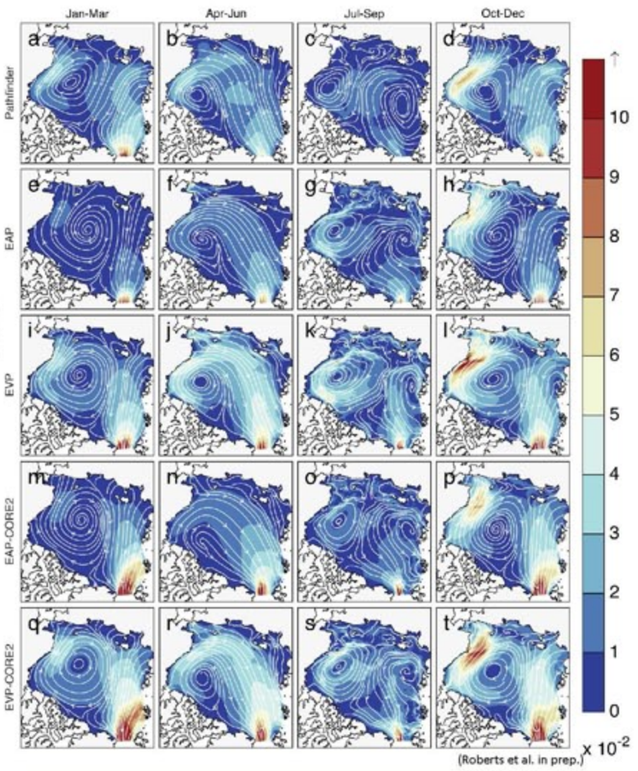
Upward Surface Heat Fluxes Controlled by Sea Ice Processes



Time-temperature ITP profile from the Beaufort Sea
(Maslowski et al. 2014)

March mean surface heat fluxes in the (left) Beaufort and (right) Nordic seas. (Maslowski et al. 2012)

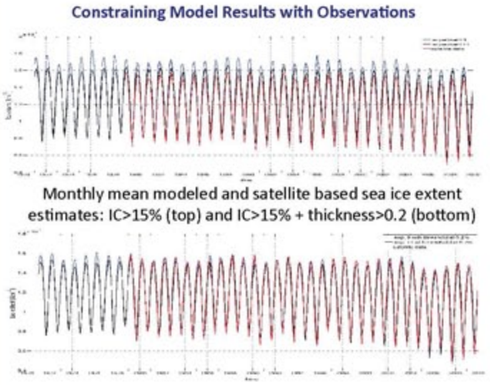
Pathfinder / RASM Mean (1979-2009) Seasonal Sea Ice Drift



(Roberts et al. in prep.)

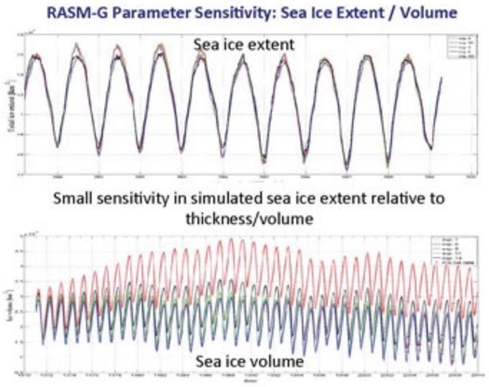
RASM G-case (Forced Ice-Ocean) Results

Constraining Model Results with Observations



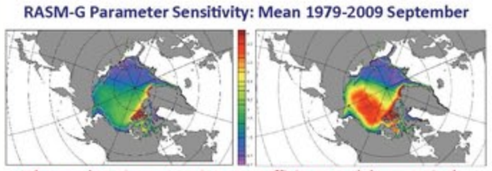
Monthly mean modeled and satellite based sea ice extent estimates: IC>15% (top) and IC>15% + thickness>0.2 (bottom)

RASM-G Parameter Sensitivity: Sea Ice Extent / Volume



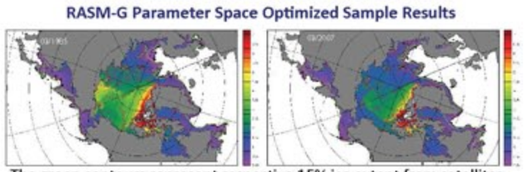
Small sensitivity in simulated sea ice extent relative to thickness/volume

RASM-G Parameter Sensitivity: Mean 1979-2009 September

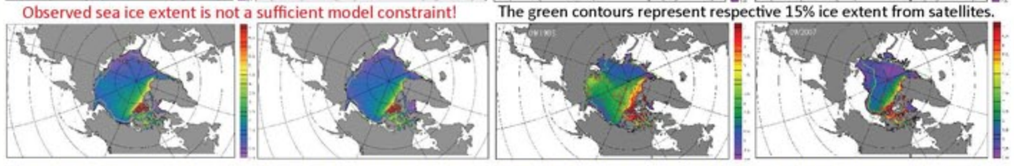


Observed sea ice extent is not a sufficient model constraint!

RASM-G Parameter Space Optimized Sample Results



The green contours represent respective 15% ice extent from satellites.



Sea ice thickness distribution in 4 RASM-G ensemble members.

Sea ice thickness distribution in March (top) and September (bottom) 1985 (left) and 2007 (right).

References:

Maslowski, W., J. Clement Kinney, M. Higgins, and A. Roberts (2012), The Future of Arctic Sea Ice, *Annu. Rev. Earth Planet. Sci.*, *40*(1), doi:10.1146/annurev-earth-042711-105345.

Maslowski, W., J. Clement Kinney, S. Okkonen, R. Osinski, A. Roberts, and W. Williams (2014), The Large Scale Ocean Circulation and Physical Processes Controlling Pacific-Arctic Interaction, In *The Pacific Arctic Region: Ecosystem Status and Trends in A Rapidly Changing Environment* (Eds. J. Grebmeier and W. Maslowski), Springer.

Roberts, A. F., A. Craig, W. Maslowski, R. Osinski, A. DuVivier, M. Hughes, B. Nijssen, J. Cassano, and M. Brunke (2015), Simulating transient ice – ocean Ekman transport in the Regional Arctic System Model and Community Earth System Model, *Ann. Glaciol.*, *56*(69), 211–228, doi:10.3189/2015AoG69A761.

Roberts et al. Inter-comparison of isotropic and anisotropic sea ice rheologies in the Regional Arctic System Model, J. Geophys. Res., In prep.

Acknowledgements: This research has beed supported by the grants from the Department of Energy Regional and Global Modeling Program, Office of Navala Rewearch Arctic and Global Prediction Program and National Science Foundation Arctic System Science Program. Computer resources have been provided by the Department of Doefense High Performance Computing Modernization Progrm.