Regional Arctic System Model (RASM): A Tool to Address the U.S. Navy / IARPC Arctic Climate Modeling and Prediction Priorities

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Abstract: The Arctic is undergoing some of the most coordinated rapid climatic changes currently occurring anywhere on Earth, including the retreat of the perennial sea ice cover, which integrates forcing by, exchanges with and feedbacks between atmosphere, ocean and land. While historical reconstructions from Earth System Models (ESMs) are in broad agreement with these changes, the rate of change in ESMs remains outpaced by observations. Reasons for that stem from a combination of coarse resolution, inadequate parameterizations, unrepresented processes and a limited knowledge of physical interactions.

We demonstrate the capability of the Regional Arctic System Model (RASM) in addressing some of the ESM limitations in simulating observed variability and trends in the sea ice cover and climate. RASM is a high resolution, fully coupled, pan-Arctic climate model. It uses the Los Alamos Sea Ice Model (CICE) and Parallel Ocean Program (POP) configured at an eddy-permitting resolution of 1/12° as well as the Weather Research and Forecasting (WRF) and Variable Infiltration Capacity (VIC) models at 50 km resolution. All RASM components are coupled via the CESM flux coupler (CPL7) at 20-minute intervals. RASM is an example of limited-area, process-resolving, fully coupled earth system model, which due to the constraints from boundary conditions facilitates detailed comparisons with observational statistics that are not possible with ESMs.

The overall goal of RASM is to address some of the key requirements published in the Navy Arctic Roadmap: 2014-2030 (TFCC 2014), and in the Implementation Plan for the National Strategy for the Arctic Region (Office of the President 2014), regarding the need for advanced modeling capabilities for operational forecasting and strategic climate predictions through 2030. The main objectives are to advance understanding and model representation of critical physical processes and feedbacks of importance to sea ice thickness and area distribution and to use RASM to quantify relative contributions by the resolved processes and feedbacks to better understand their importance in reducing uncertainty and improving prediction of arctic climate change.

ADM James Watkins – The Legacy

"The nation lacks effective mechanisms for incorporating scientific information into decision-making processes in a timely manner."

Our challenge over the coming decades is to balance the demands of current requirements with investment in development of future capabilities. We will continue to support the national security interests of the United States and prepare for potential Arctic Region security contingencies through strengthened relationships with the U.S. Coast Guard, interagency, and international Arctic partners. The focus on prioritized near-term (today through 2020) and mid-term (2020-2030) tasks in this Roadmap will ensure our investments are informed, focused, and deliberate as the U.S. Navy approaches a new maritime frontier.

JONATHAN W. GREENERT
Admiral, U.S. Navy
Chief of Naval Operations

U.S. Navy Arctic Roadmap 2014 - 2030

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.

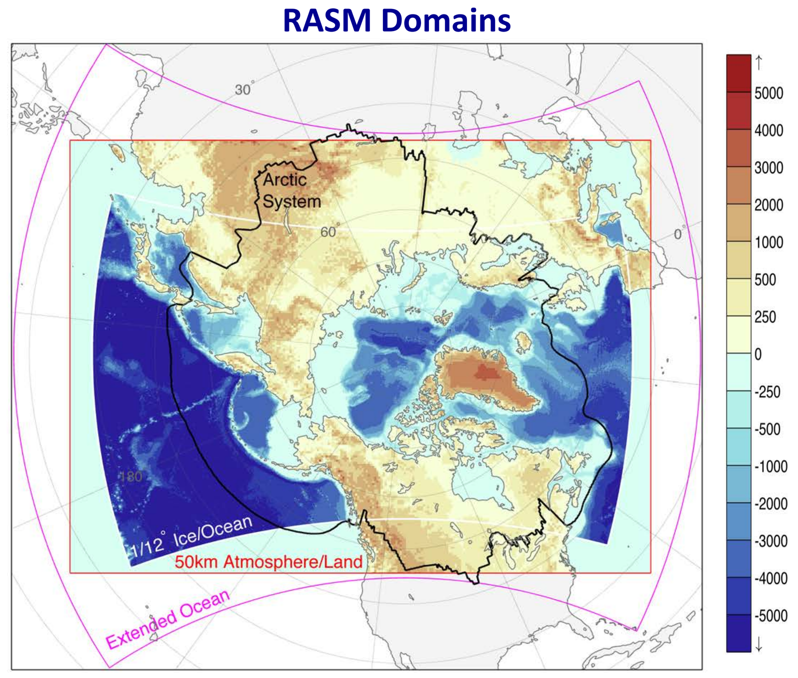
2.3 Environmental Observation and Prediction
- 2.3.5: Encourage research into and development of comprehensive Arctic System Models

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
  - Integrate Arctic Regional Models; Objective: Coordinate an integrated and focused effort to improve Arctic modeling to benefit understanding of ongoing processes, netter project future Arctic changes, and guide future process research and decisions; Lead Agency: Department of Energy

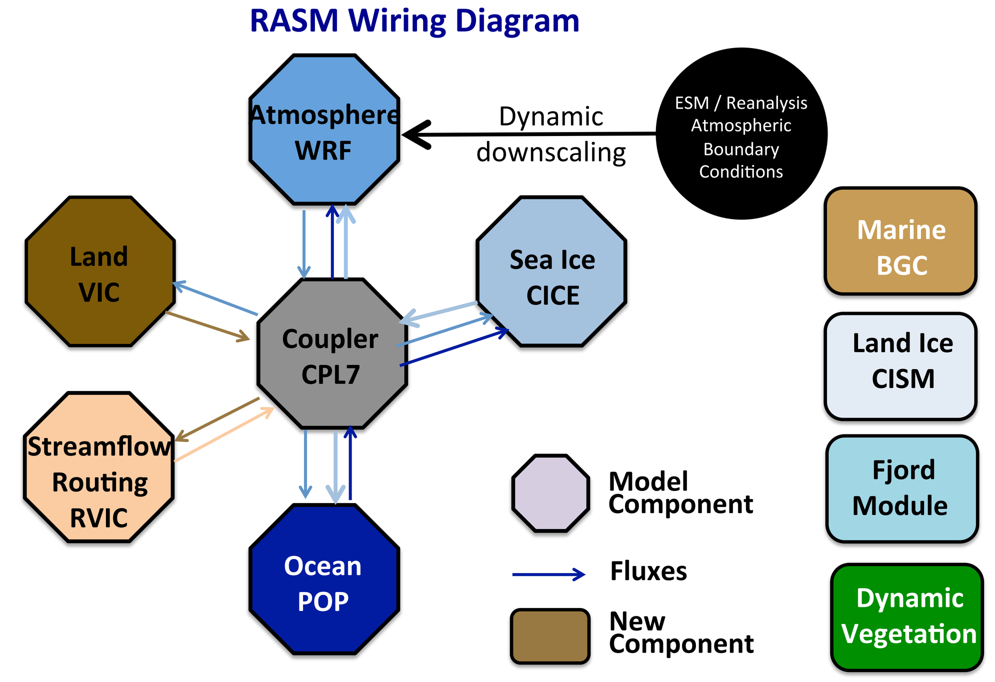
Regional Arctic System Model (RASM) - Overview

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	50km, 3 Soil Layers, 20 minute time step.
Ocean	POP2	1/12˚, 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.

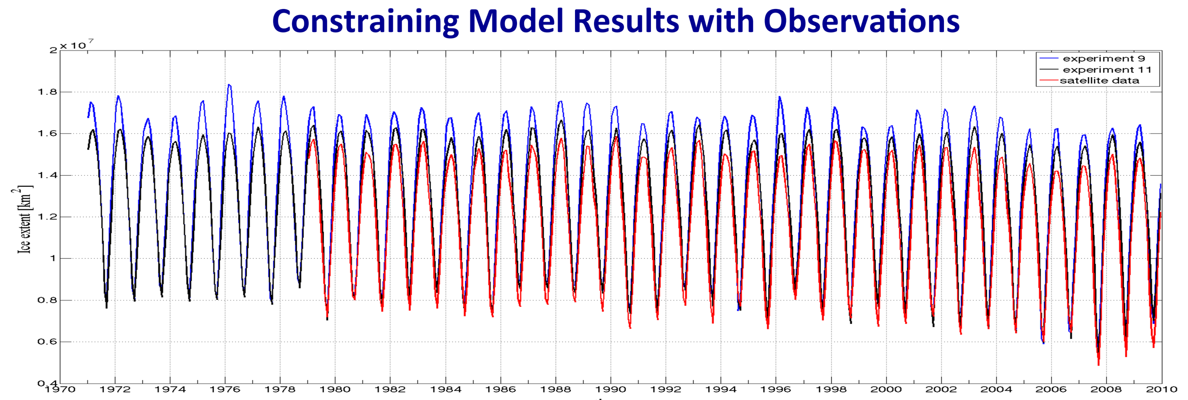
Arctic Climate Predictive Models need to:
- ❑ Resolve critical processes (e.g. sea ice deformation) and resulting feedbacks (e.g. air-ice-ocean coupling),
- ❑ Understand space dependence & optimize parameter space,
- ❑ Expand validation data (e.g. fluxes and coupling across the air-ice-ocean interface),
- ❑ 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

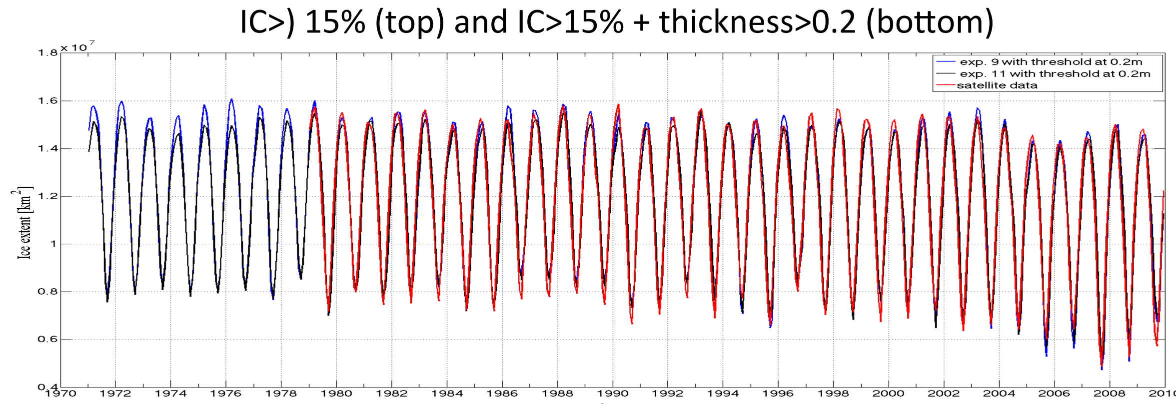
RASM Results

RASM G-case (Forced Ice-Ocean) Results

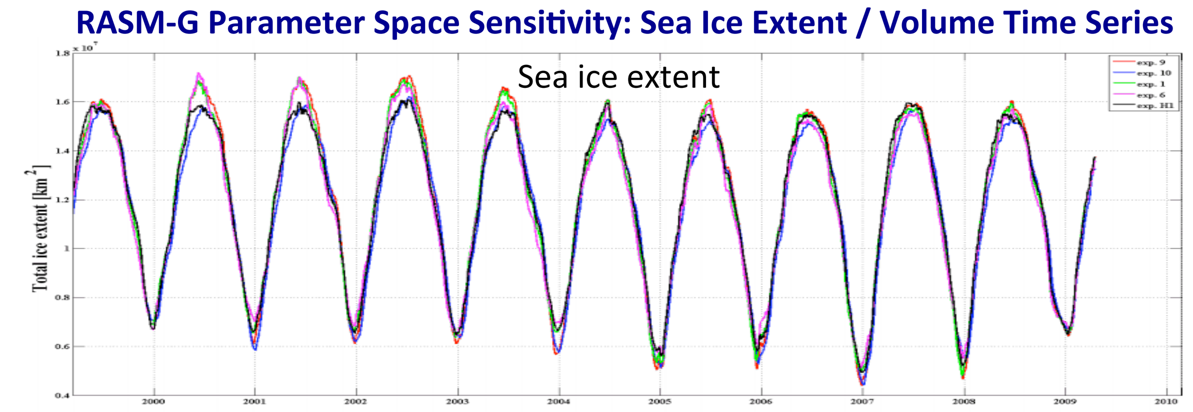
Constraining Model Results with Observations



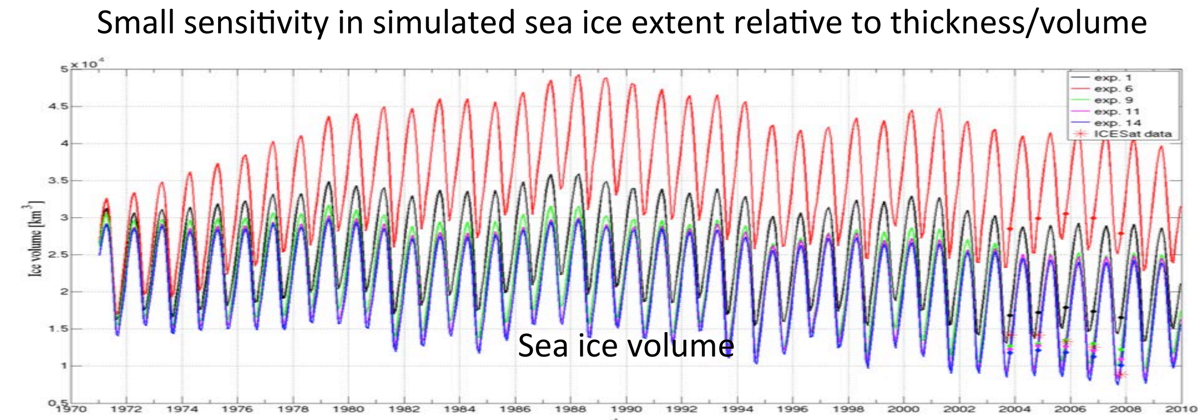
Monthly mean modeled and satellite based sea ice extent estimates: IC>) 15% (top) and IC>15% + thickness>0.2 (bottom)



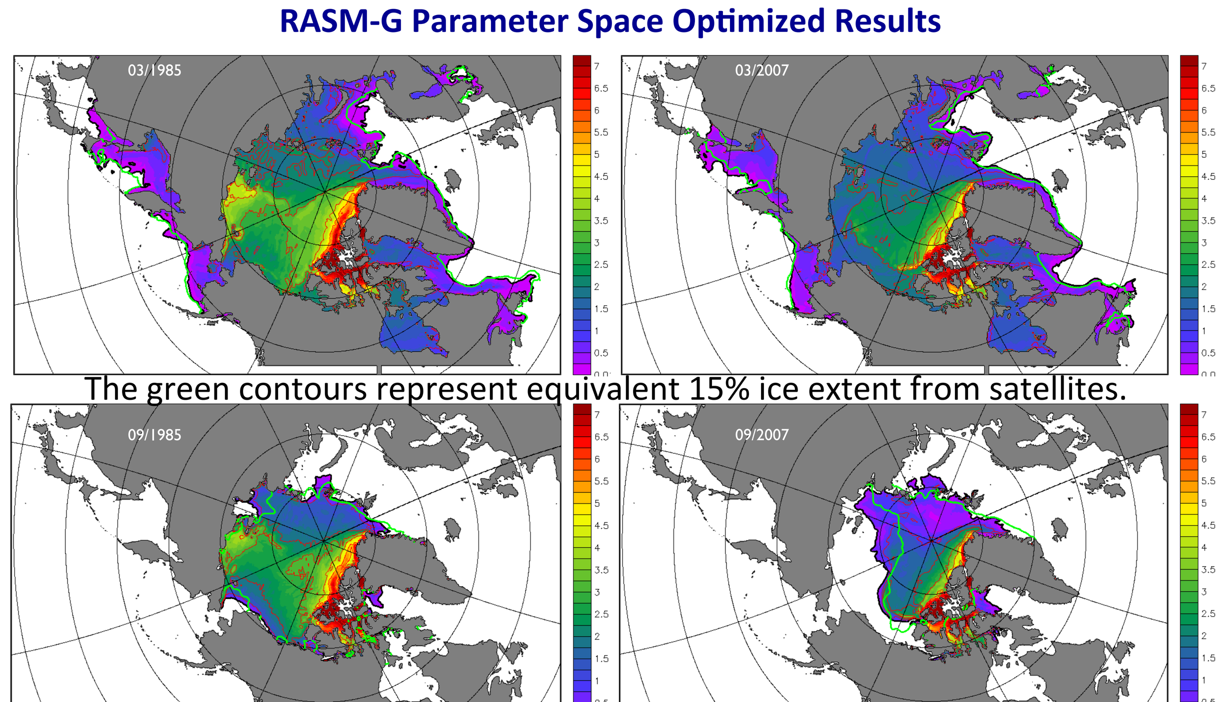
RASM-G Parameter Space Sensitivity: Sea Ice Extent / Volume Time Series



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



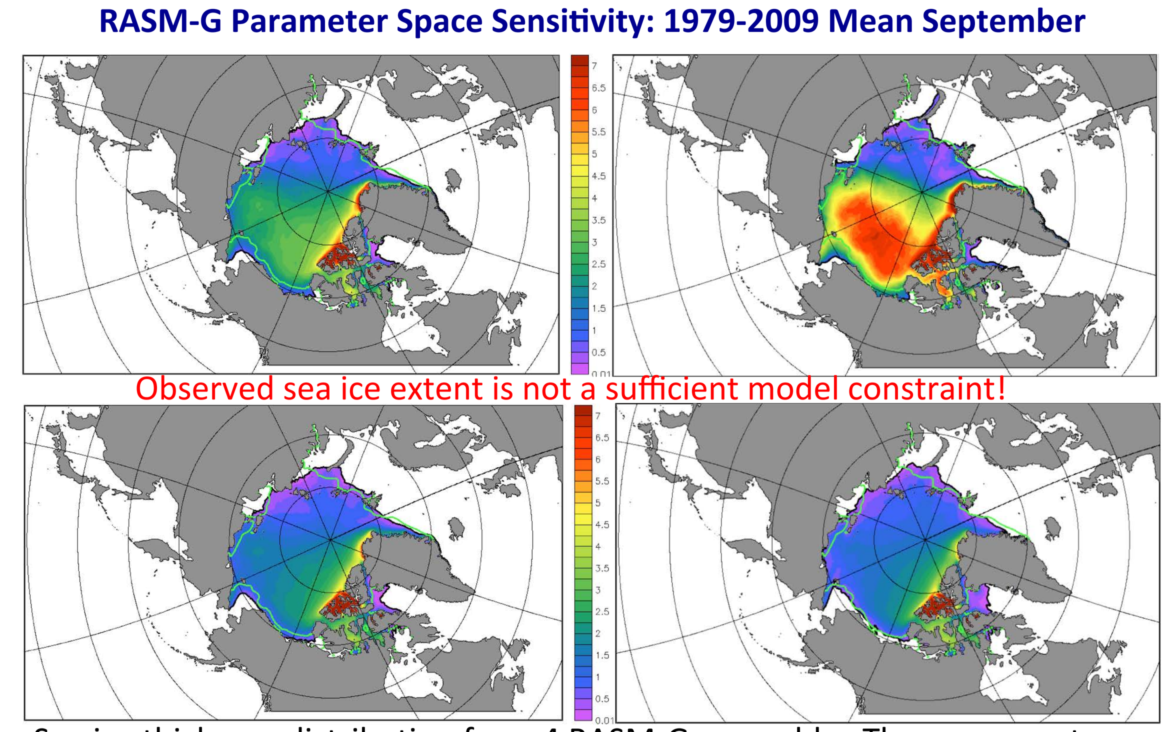
RASM-G Parameter Space Optimized Results



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

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

RASM-G Parameter Space Sensitivity: 1979-2009 Mean September

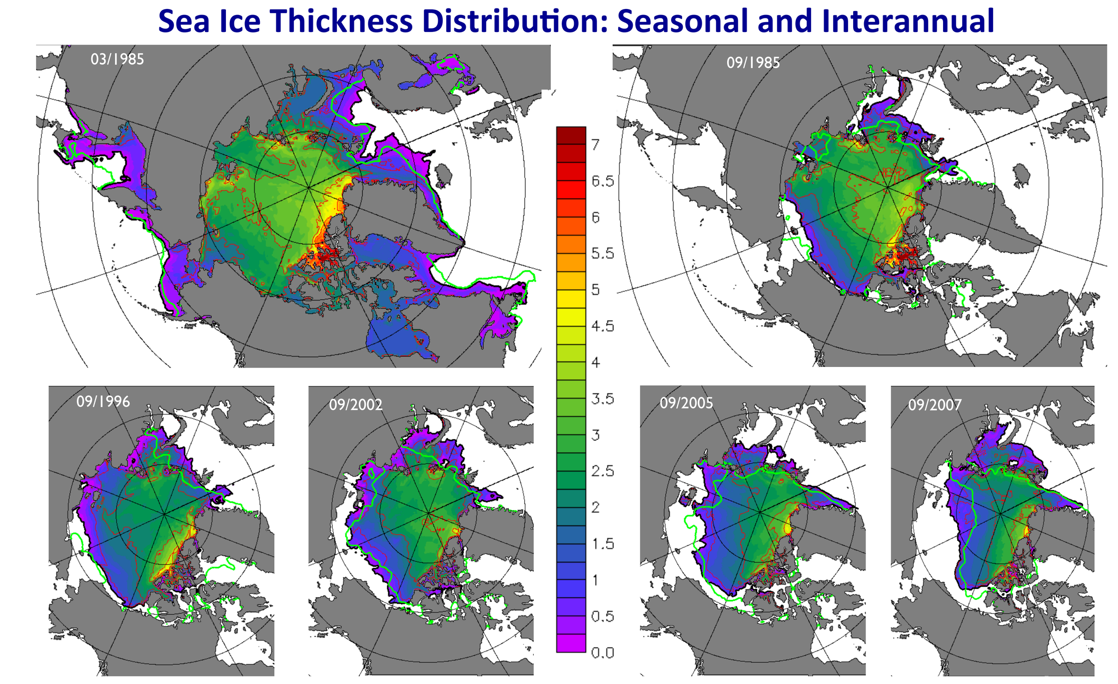


Observed sea ice extent is not a sufficient model constraint!

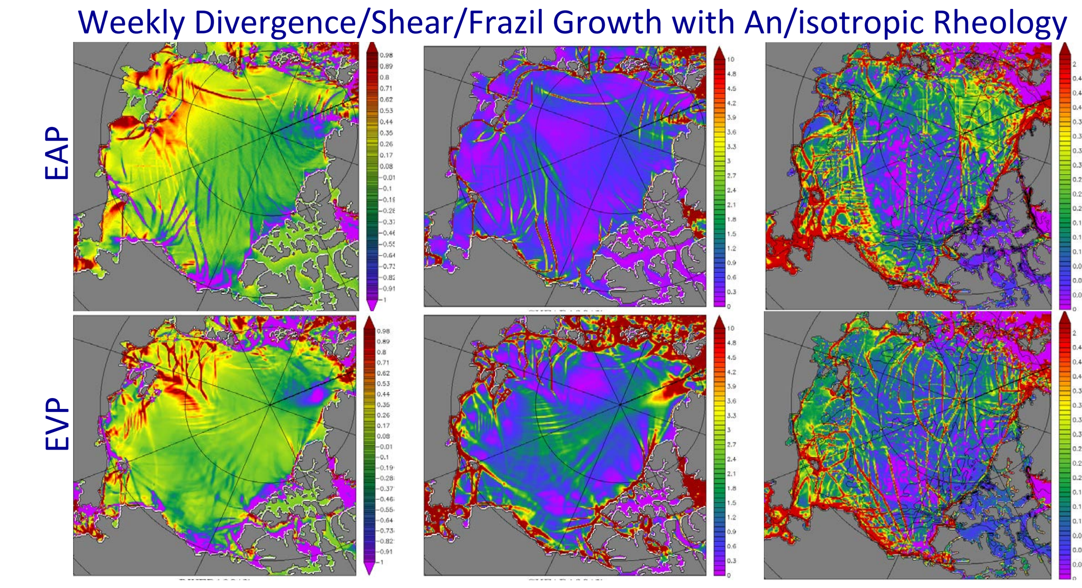
Sea ice thickness distribution from 4 RASM-G ensembles.The green contour represent the 1979-2009 mean 15% ice extent from satellites.

RASM 1.0 (Fully coupled) Results

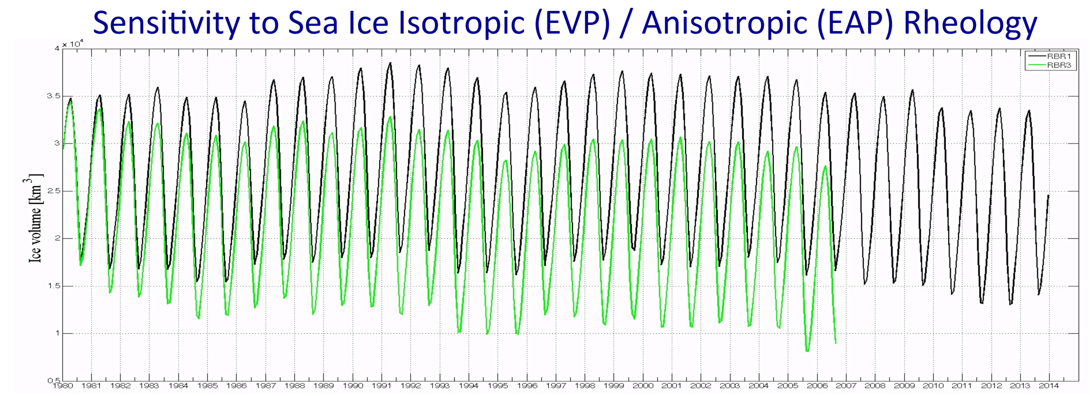
Sea Ice Thickness Distribution: Seasonal and Interannual



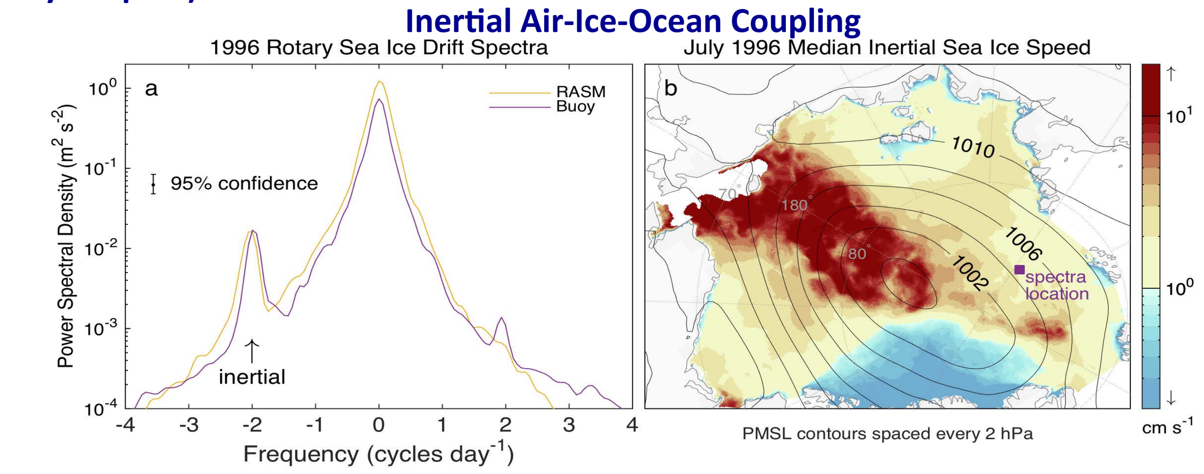
Weekly Divergence/Shear/Frazil Growth with An/isotropic Rheology



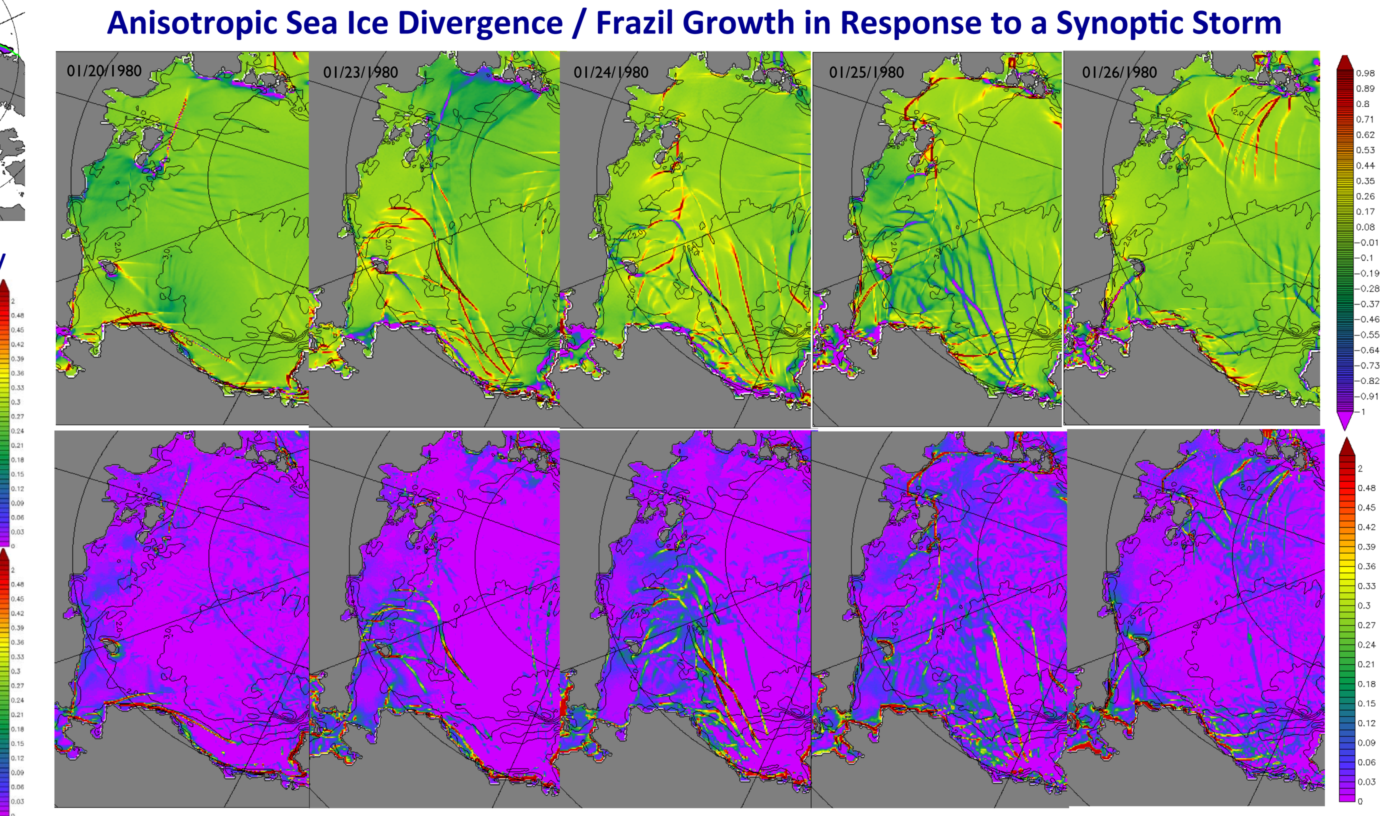
Sensitivity to Sea Ice Isotropic (EVP) / Anisotropic (EAP) Rheology



Inertial Air-Ice-Ocean Coupling



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



Sea Ice Deformations (e.g. Divergence) Produce New (Ridged) Ice