Sea Ice Coupling in the Regional Arctic System Model and CESM

A. Roberts[1*], A. Craig[1], W. Maslowski[1], R. Osinski[2], A. DuVivier[3], M. Hughes[3], B. Nijssen[4]
J. Cassano[3], J. Hamman[6], E. Hunke[5], M. Brunke[6], X. Zeng[6], B. Fisel[7], W. Gutowski[7]
1. Naval Postgraduate School; 2. Institute of Oceanology, Poland; 3. University of Colorado Boulder; 4. University of Washington;
5. Los Alamos National Laboratory; 6. University of Arizona; 7. Iowa State University
*afrobert@nps.edu | Department of Energy Climate Modeling Principal Investigator Meeting | Maryland, May 2014

Summary

The Regional Arctic System Model (RASM) is a fully coupled regional climate model developed by a group of U.S. institutions as a regional counterpart to the Community Earth System Model (CESM), and incorporates the Los Alamos Sea Ice Model (CICE), Parallel Ocean Program (POP), Variable Infiltration Capacity (VIC) hydrology model and the Weather Research and Forecasting (WRF) Model. The model is coupled using the same coupling infrastructure as CESM (CPL), with version 1.0 of RASM configured with a 1/12° ice-ocean mesh and 50km land-atmosphere grid. Development of a 1/48°- 25km version is also underway. During development of RASM, we encountered several obstacles in simulating high-resolution sea ice evolution in the Arctic, including a strong sea ice sensitivity relating to cloud droplet size and concentration and a previously undetected physical instability that arises from delayed ice-ocean-atmosphere coupling in the presence of strong mesoscale wind regimes. Here we highlight work on this second problem to improve dynamic WRF-POP-CICE coupling. A new method has been established using a RASM version of CPL, based on a theoretical set of stability criteria, and we show results of this being applied to CESM for the first time. This configuration is now being tested in combination with the latest version of CICE (Version 5), which itself is being incorporated jointly into RASM and CESM in collaboration with Los Alamos National Laboratory and the National Center for Atmospheric Research.

Regional Arctic System Model Coupling

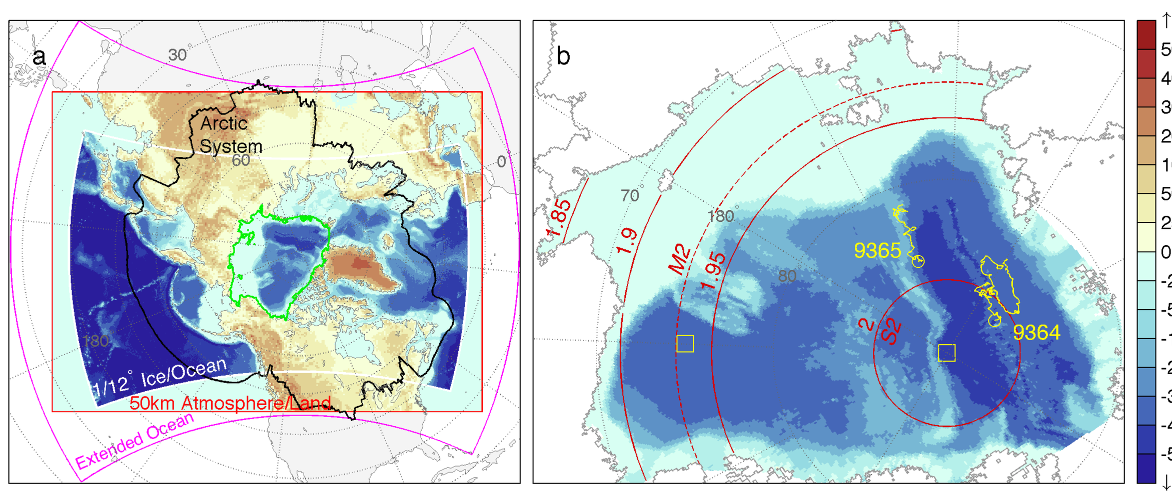

Figure 1: a) RASM configuration and topobathymetry. The ocean-ice domain (POP/CICE) includes the maximum sea ice zone and large marine ecosystems relevant to the Arctic. The atmosphere-land domain (WRF/VIC) includes the Arctic System watershed. An extended ocean domain provides boundary surface state to WRF outside the POP/CICE domain that is commensurate with WRF lateral boundary conditions. For simulations presented in this poster, POP uses climatological lateral boundary conditions, and WRF uses ERA-Interim 6-hourly reanalysis as boundary conditions and spectral nudging of the wind and temperature at wave numbers 4 and 3 in the abscissa and ordinate axes above 500hPa, respectively. b) The left panel indicates the location of buoys used in Figures 4 and 7 within the green encirclement in (a). Red contours indicate inertial frequencies and coincident tidal frequencies (M2, S2) in cycles/day.

RASM uses the same coupling infrastructure as CESM (CPL7), but with important changes to coupling physics and synchronization that we have found to be important in our high-resolution model, including changing the sequencing of interchanged field accumulators in the coupling cycle, setting identical coupling times for all component models, instead of different times for the ocean and sea ice, and changes to flux calculations to accommodate a variable sea ice roughness length scheme.

Table 1: Spatial and temporal resolution in RASM.

Component	Code	Case Study Configuration
Atmosphere	WRF	50km, 40 levels, dt=2.5 *min*
Land	VIC	50km, 3 Soil Layers, dt=20 *min*
Ocean	POP	1/12°, 45 levels, dt=10 per coupler step
Sea Ice	CICE	1/12°, 5 cats, dt=20(td)/2(dyn) *min*
Coupler	CPL7	Coupling every 20 *min*

In contrast to CESM 1°, which uses daily oceanic coupling, RASM couples the ocean at the same frequent interval as other models, which allows inertial oscillations to be resolved in the ice-ocean boundary layer. However, since ice-ocean Ekman mass transport behaves as a forced harmonic oscillator, calculating the ice and the ocean components of this transport separately splits the boundary layer into a system of coupled oscillators. Moreover, placing a coupling infrastructure between them introduces a time delay, so that the ice-ocean boundary layer becomes a Time-Delayed Coupled Oscillator. This is not how the real ice-ocean boundary layer works. In contrast to the real world, this model system has natural stability criteria required to avoid a chaotic ice-ocean Ekman transport solution (Figure 2). CPL7 in RASM has been configured to have only one coupler timestep lag between the ice and ocean models, as against the standard CESM version of CPL7 which implicitly has a 6 coupler step lag between them.

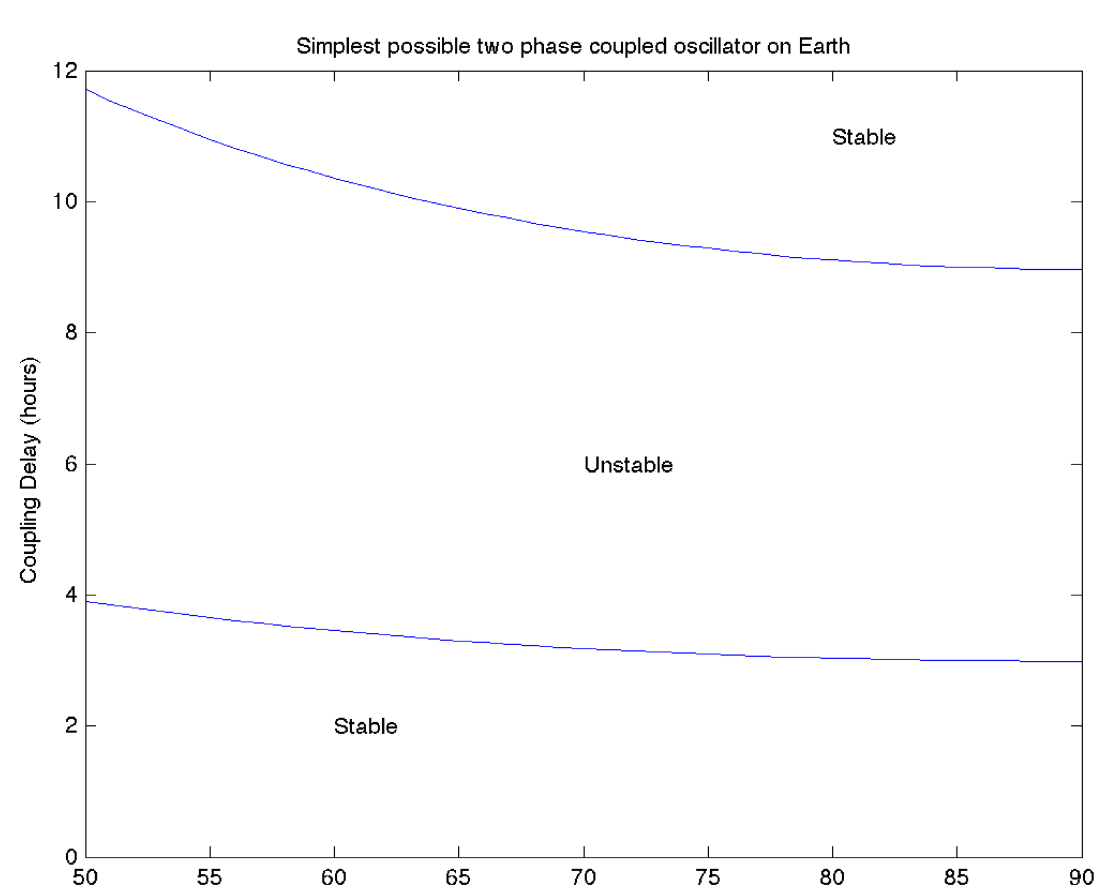

Figure 2: Kuramoto Stability criteria for a set of two coupled oscillators analogous to the coupled mass transport of sea ice and ocean models when passing fluxes between them with time delays.

Ice-Ocean Ekman Transport in RASM

RASM enables season-on-season comparison of modeled and observed surface variables using a fully coupled system, knowing that the surface climatic bias is small in the decadal geostrophic flow (Figure 3), contrary to typical global model ensemble members. This is a useful RASM attribute suited to assessing the modeled inertial response for work toward replicating observed ice-ocean Ekman mass transport.

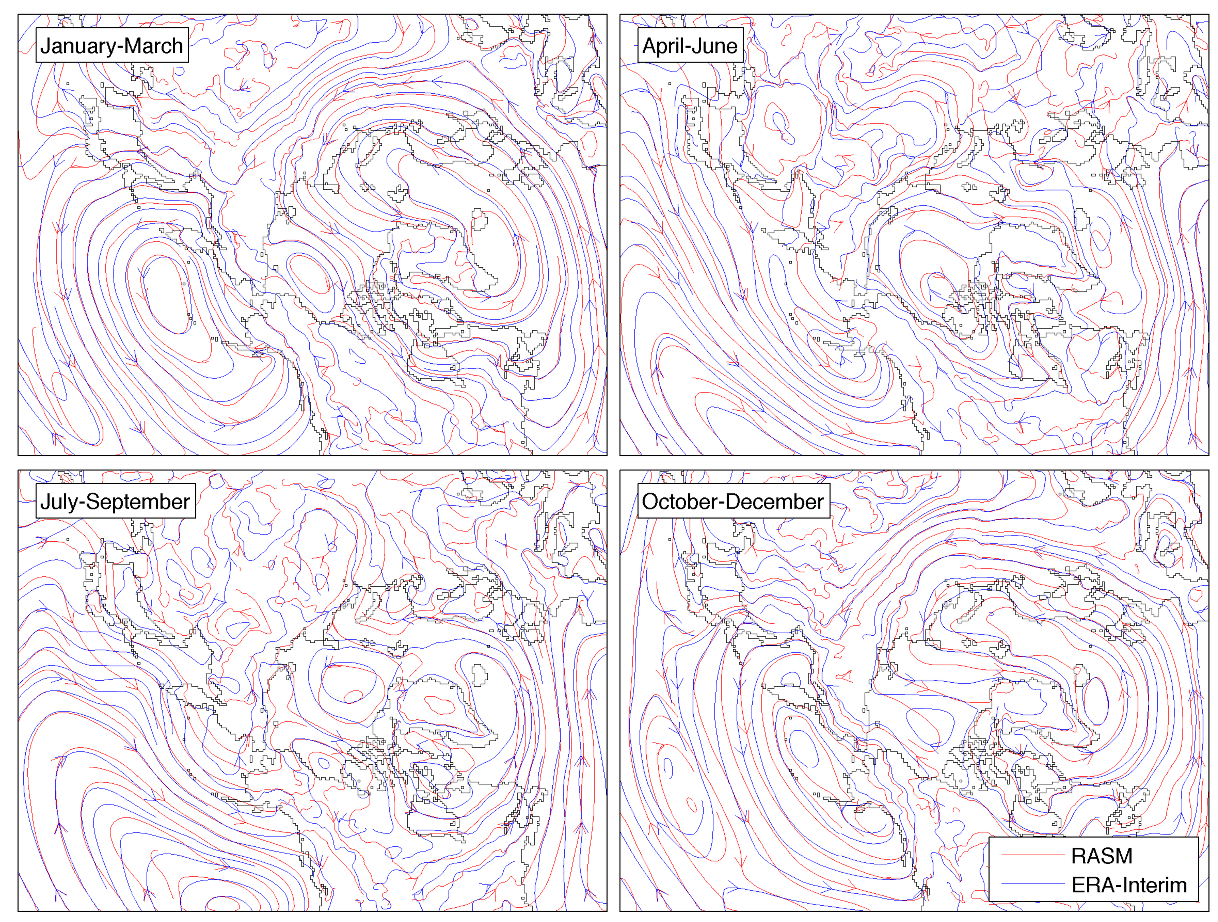

Figure 3: 1992-1996 mean seasonal surface geostrophic streamlines for the ensemble member RASMe1 used in this study (red) and ERA-Interim (blue).

Results for our 1996 case study of a single RASM ensemble member indicate that the model is able to simulate inertial oscillations in sea ice, which is a proxy for ice-ocean Ekman transport (Figure 4).

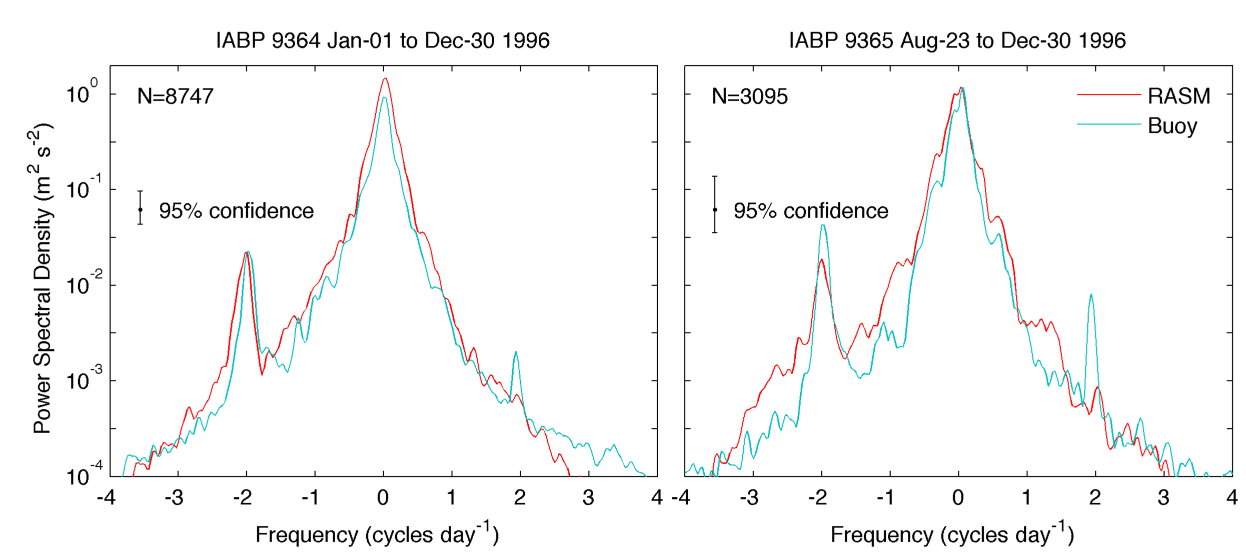

Figure 4: Rotary power spectral density for IABP buoys 9364 and 9365 (blue), located in Figure 1, and the corresponding spectra for RASMe1 (red). Negative frequencies indicate clockwise motion, and positive frequencies indicate anticlockwise motion. N indicates the total number of hourly samples used to construct spectra.

There is strong coherence between measured and modeled inertial oscillations in summer, as indicated by rotary wavelet analysis in Figure 5. Further results indicate that the deformation signal is especially sensitive to modeling the high-frequency sea ice dynamics component.

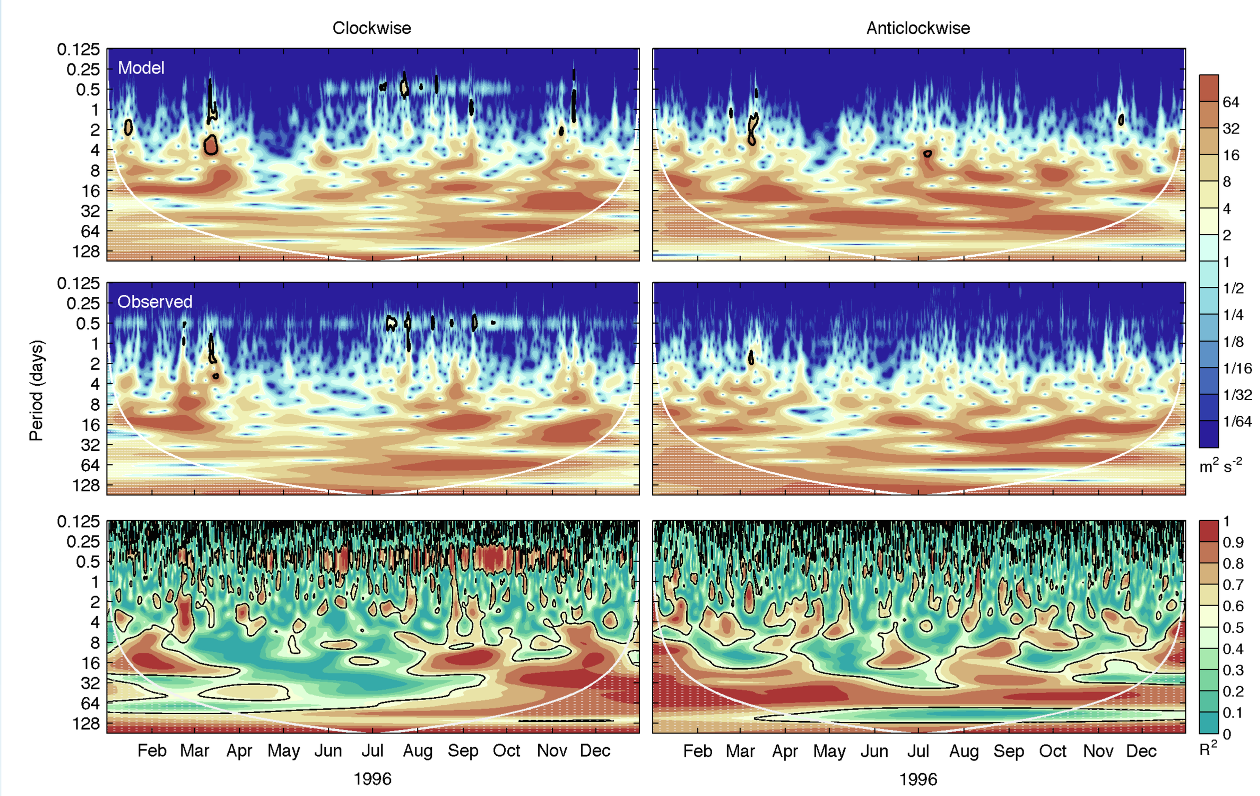

Figure 5: RASMe1 (upper) and observed (middle) rotary wavelet power of sea ice drift for IABP Buoy 9364 corresponding to the rotary spectra in Figure 3 (left panel). The modeled and observed wavelet cross-coherence squared (R2) is indicated in the lower panel for clockwise (left) and anticlockwise (right) motion. Black contours indicate 95% confidence against red noise, and white hatching indicates the cone of influence subject to edge effects. Time series used to construct this figure are summarized in Figure 5.

The primary driver of high-frequency sea ice drift and deformation is the presence and location of storms, with important coupled feedbacks to oceanic mixing and sea ice thickness (Figure 6).

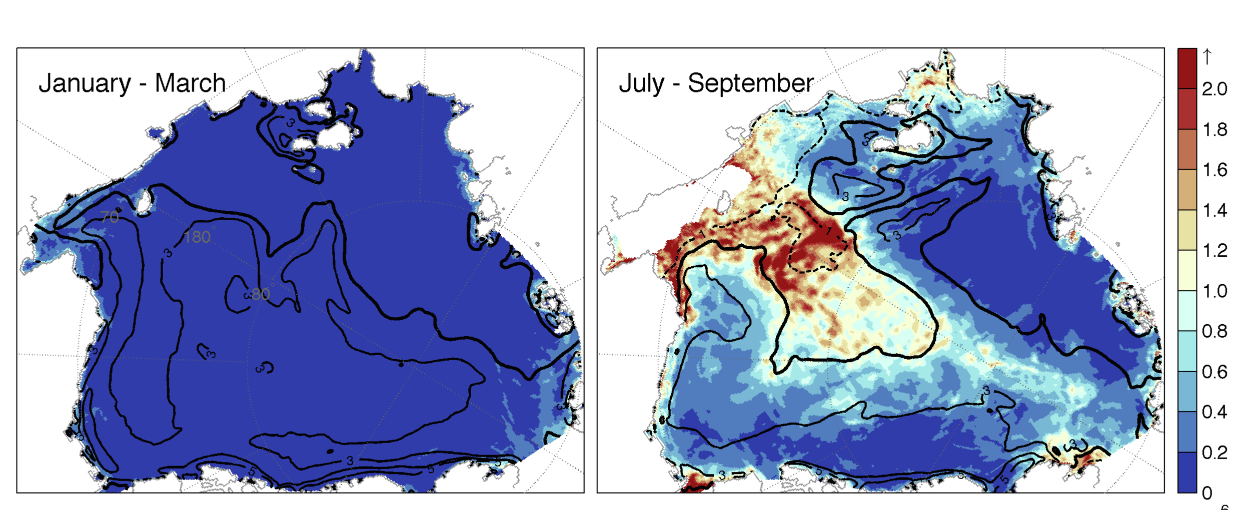

Figure 6: RMS Divergence of 1.8-2.1/day sea ice drift for the RASMe1 ensemble member, with sea ice thickness contours superimposed (bold is 2m mean thickness). Most inertial oscillations and associated deformation occurs in summer in proximity to storm tracks, with only a small thickness bias in the statistics.

High-Frequency CESM

We have taken changes made to CPL7 in RASM, and used them to switch on high-frequency ice-ocean dynamics in CESM. We present here some of the first results from this work. Figures 7, 8 and 9 indicate the difference between using the default CESM 1 degree daily ocean coupling as against coupling the ocean every 30 minutes in synchronization with the atmosphere, land and sea ice components (RASM coupling). The reason this works is due to the coupler changes in RASM CPL7, and without these changes CESM becomes unstable in this mode. In the high frequency mode, 17 POP timesteps are used per 30 minute coupling period, as against 24 POP timesteps per daily coupling period in the CESM default setup.

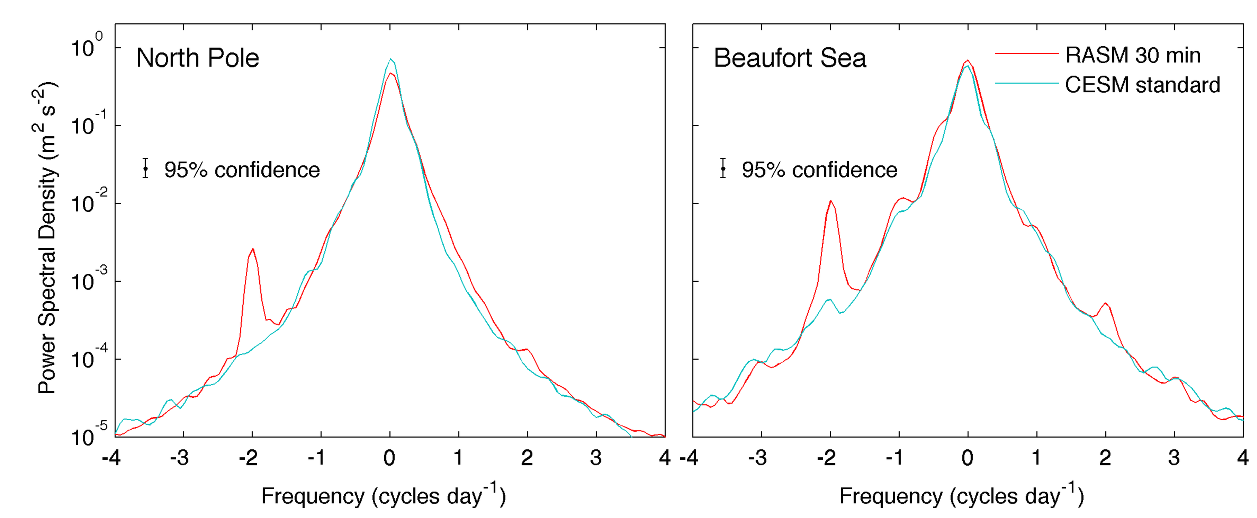

Figure 7: Rotary power spectral density for two Arctic locations including the North Pole. The blue curves indicate low frequency oceanic coupling, while the red curves indicate high-frequency ice-ocean RASM CPL7 coupling applied to CESM for the same year and initial conditions as for the standard CESM case.

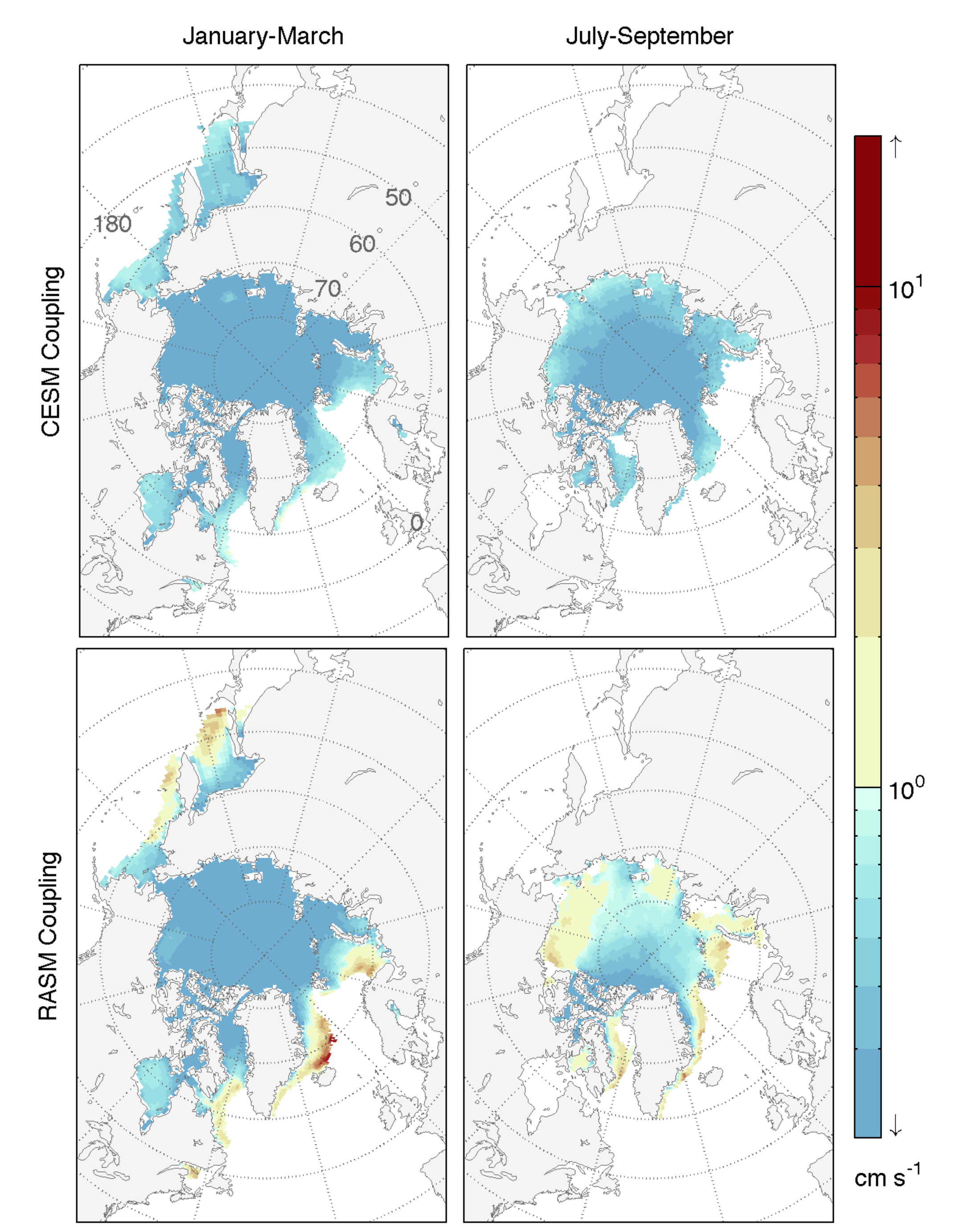

Figure 8: Median Arctic clockwise inertial sea ice speed from a 1-year preindustrial simulation of CESM 1.1 within the RASM code base. The same initial conditions were used for both the CESM coupling and RASM coupling simulations. This is an acceptable way to compare high frequency components. The statistics here indicate the clockwise component of sea ice speed in a band ±0.1 cycles/day around the inertial frequency.

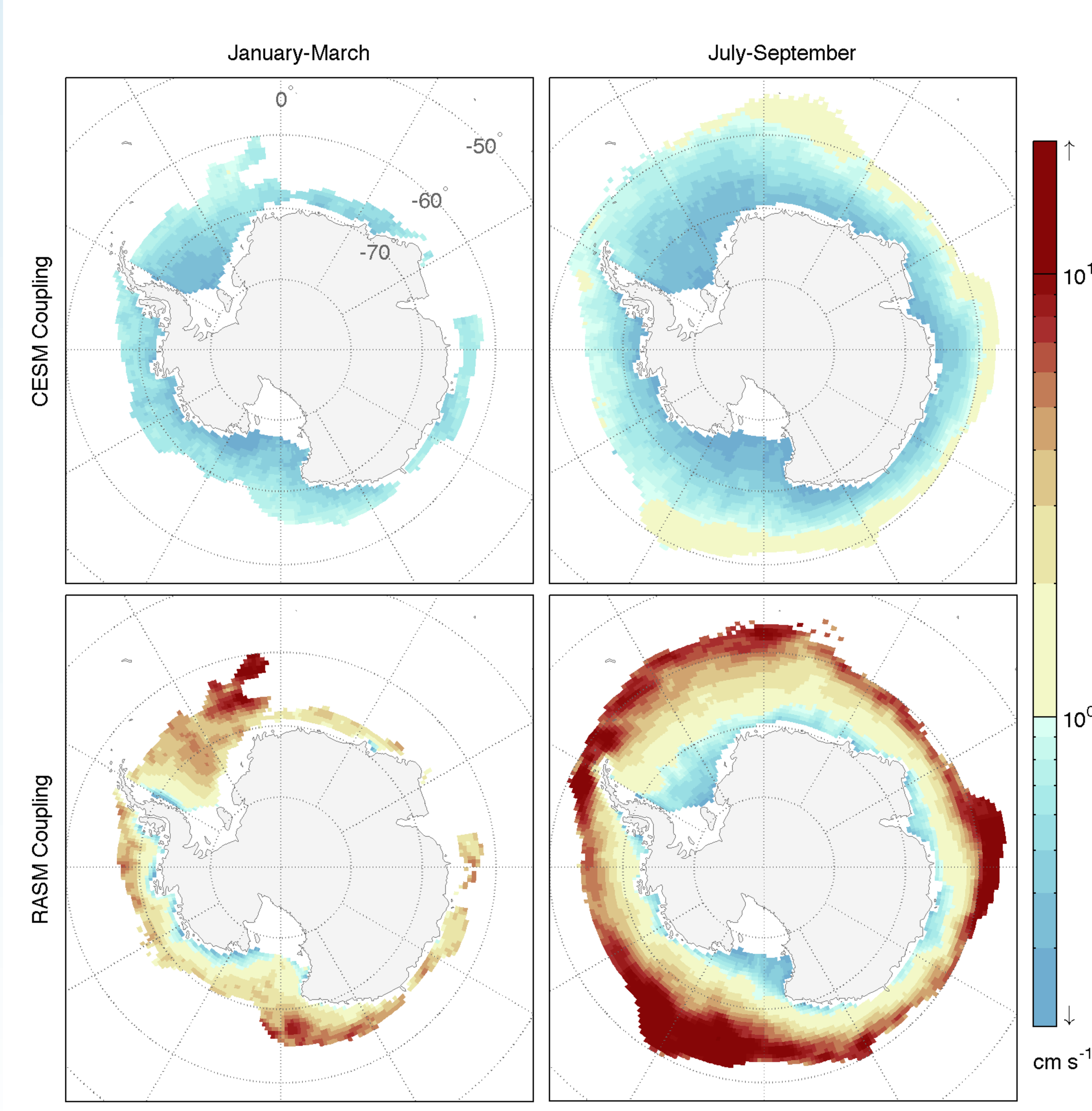

Figure 9: As for Figure 8, but for anticlockwise (Antarctic) inertial oscillations.