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U.S. DEPARTMENT OF ENERGY | Office of Science

FY 2015 Fourth Quarter Performance Metric: Use of a Global Model to Determine the Relative Roles of External Forcing and Internal Model Ice Physics in Determining Sub-Decadal Variability of Sea Ice

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1.0 Product Definition

The rapid decrease in Arctic sea ice has been dramatic, with record minima observed in 2007 and 2012. This decrease in ice extent has generated increased interest in Arctic shipping, oil exploration, and other activities, while also impacting Arctic and marine ecosystems. Improved understanding and prediction of ice thickness and extent will be required to support the increase in scientific and commercial activities in the Arctic. At the same time, the transition to a more seasonal ice pack and thinner ice will likely result in more inter-annual variability of ice extent and less predictability. In the Antarctic, ice extents have been stable or slowly growing for reasons that are not yet fully understood.

Sea-ice and climate models are key to understanding and predicting ongoing changes in the Arctic and Antarctic. There are, however, uncertainties arising from both external forcing and internal sea-ice model physics that affect model results. The Los Alamos Sea Ice Model (CICE) includes complex parameterizations of sea-ice physics (such as ice rheology treatment or biogeochemistry), with a large number of parameters for which accurate values are still not well established. To enhance the credibility of sea-ice predictions, it is necessary to understand the relative sensitivity of model results to choices of model physics parameters and external forcing. We describe here studies undertaken to evaluate the relative importance of physical representations in the CICE model to its prediction of ice extent, area, and volume. We also describe work that illuminates the sensitivity to external forcing. Our results indicate that agreement of the model with observations is good when driven by observed external forcings and is maximized by adjusting poorly constrained parameters. The most important of these are snow conductivity and grain size, the time-scale for drainage of melt ponds, the thickness of the ice radiative scattering layer, ice density, and the ice-ocean drag coefficient. In general, these are features that are particularly important in determining the radiative properties of the ice. Finally, results show that external forcing plays a more dominant role in sub-decadal variability and seasonal prediction.

2.0 Product Documentation

In this work, we conduct a global sensitivity analysis of sea-ice extent, area, and volume. A variance-based approach allows exploration of a complete set of 40 parameters representing sea-ice dynamics, ridging, and recent new formulations of radiative properties, melt ponds, and ice hydrology (brine channels and mushy-layer thermodynamics). Model sensitivity is quantified in terms of effects on extent, area, and volume metrics. A large ensemble of over 500 global CICE (v5.1) simulations for the period 1980-2009 was performed with observed atmospheric fields and a mixed-layer ocean. Such a large ensemble allowed 10 to 20 simulations for each input parameter with the parameters sampled within their acceptable range. Ensemble results were evaluated against observed sea-ice extent, area, and volume to quantify the sensitivity of each parameter, and screen for the most important parameters for later studies. The global sensitivity analysis does not require assumptions of additivity or linearity, implicit in the most commonly used one-at-a-time sensitivity analyses. A Gaussian process emulator of the sea-ice model was then built and used to generate an even larger number of samples necessary to calculate the sensitivity indices, at a much lower computational cost than using the full model. The sensitivity indices are used to rank the most important model parameters affecting Arctic sea-ice extent, area, and volume. These are then used to quantify the physical processes that explain variations in simulated sea-ice variables in terms of the first-order parameter effects and the most important interactions among the processes.

3.0 Results

Results from the 500-member ensemble using the global CICE model are shown in Figure 1. Overall, the model represents sea-ice quantities very well when forced by observed conditions. Ice area and extent near the ice minimum tend to be under-predicted. Agreement is much better near ice maxima with a lower ensemble spread as well. Ice volume is more variable, though observational estimates of total volume are also very sparse and uncertain.

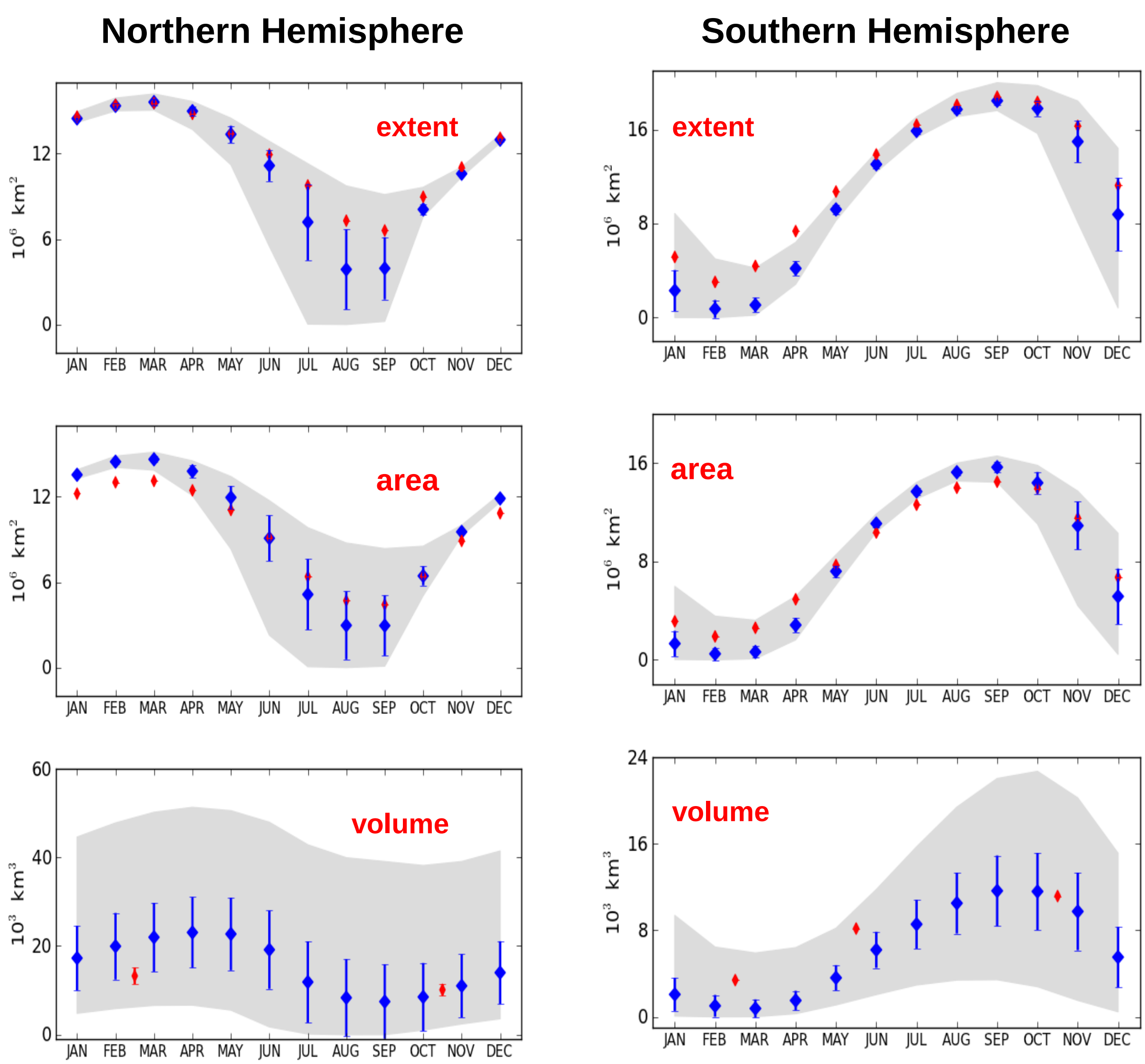

Figure 1. Mean annual cycle of ice extent, area, and volume from the large ensemble of global CICE simulations for the 1980-2009 period. Results from the Northern Hemisphere (Arctic) are on

the left; Southern Hemisphere (Antarctic) on the right. Observations are from combined from NSIDC, Kurtz and Markus (2012), and Zygmuntowska et al. (2014). Whiskers around model results represent one standard deviation from the mean derived from the ensemble. The shaded regions represent the minimum and maximum values from the ensemble.

To assess and quantify the full parameter sensitivity, the large ensemble was used to create a Gaussian Process Regression as a statistical approximation of the full global model. The output of this emulator is a probability distribution of the model output. Sensitivity to model input parameters are based on a decomposition of the statistical variance. Sensitivity to each model parameter for September sea-ice volume in each hemisphere is shown in Figure 2.

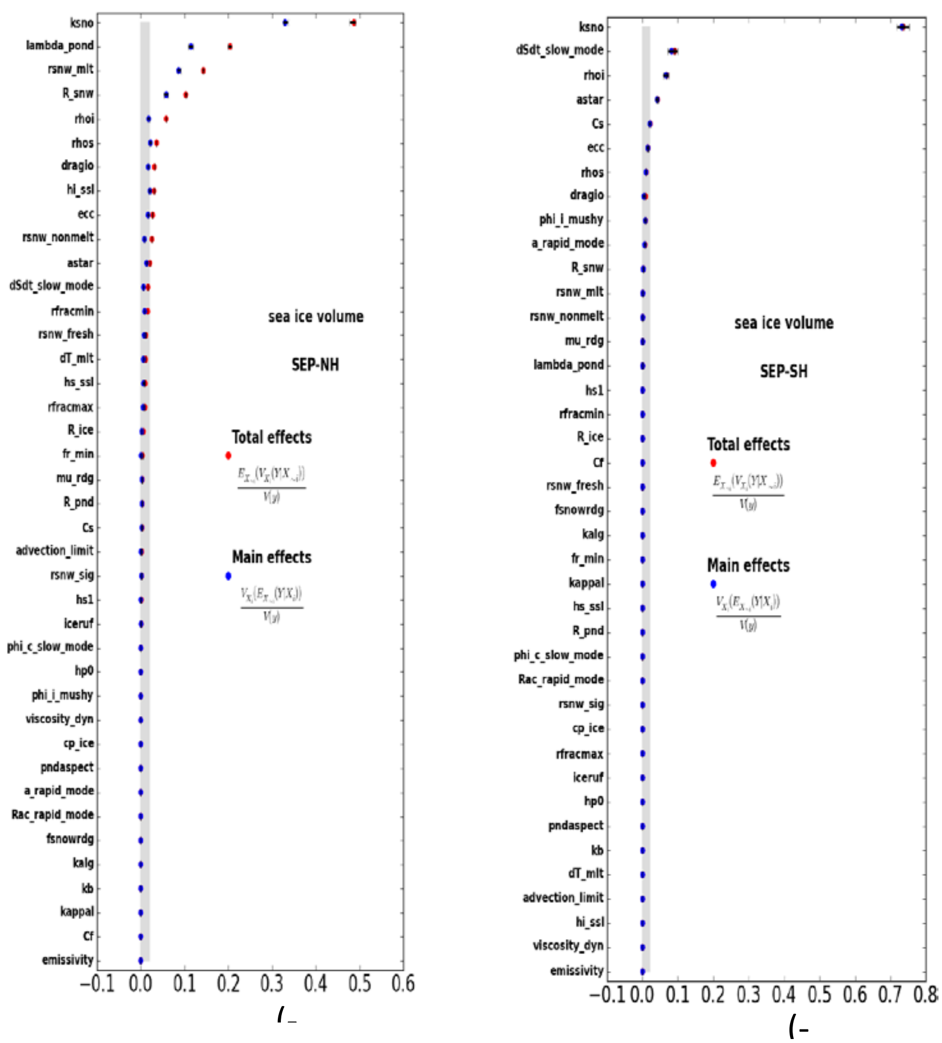

Figure 2. Parameter sensitivity for each of the 40 CICE input parameters in representing September sea-ice volume in the Northern Hemisphere (left) and Southern Hemisphere (right) are shown here. Main effects refer to the first-order variance attributed to the parameter; total effects include the total variance that includes higher-order interactions with other parameters.

The most important parameters contributing to the model variance include snow conductivity and grain size, and the time-scale for drainage of melt ponds. Other important parameters include the thickness of the ice radiative scattering layer, ice density, and the ice-ocean drag coefficient. These results point to a need for improved snow models, an area of active research and development for the CICE model. In addition, the high variance associated with snow and ice optical properties show that, particularly for the Arctic, surface radiation budgets and surface forcing are very important in defining Arctic sea-ice area, extent, and volume. Details will be presented during the 2015 American Geophysical Union fall meeting and published in Urrego-Blanco et al. (2015). Note that while the focus was on internal ice parameters, our simulations have also indicated that the sensitivity to these parameters is far lower than that due to forcing at both the atmosphere and ocean interfaces.

Participation in the multi-agency Sea Ice Prediction Network provides another mechanism for evaluating the CICE model in a seasonal prediction mode (as part of contributions from several collaborators). Results from several years of the Sea Ice Outlook show that predictions are generally good in years that follow the decadal trend line and are poor in years of anomalous forcing (Stroeve et al., 2015). This is another indication that external forcing plays a much larger role than the internal model physics in sub-decadal variability, a result we hope to further quantify using the methods described above.

4.0 References

Urrego-Blanco, J., N. Urban and E. Hunke, 2015. Uncertainty Quantification and Global Sensitivity Analysis of the Los Alamos Sea Ice Model. *J. Geophys. Res.*, in prep.

Stroeve, J., E. Blanchard-Wrigglesworth, v. Guemas, S. Howell, F. Massonnet, and S. Tietsche, 2015. Improving predictions of Arctic sea ice. EOS, 96, doi:10.1029/2015EO031431.

Kurtz, NT and T Markus, 2012. Satellite observations of Antarctic sea ice thickness and volume. *J. Geophys. Res. – Oceans*, 117, doi: 10.1029/2012JC008141.

Zygmuntowska, M., P. Rampal, N. Ivanova, LH Smedsrud, 2014. Uncertainties in sea ice thickness and volume: new estimates and implications for trends. *Cryosphere*, 8, 705-720, doi: 10.5194/tc-8-705-2014.

National Snow and Ice Data Center (NSIDC), http://nsidc.org.

Sea Ice Outlook and Sea Ice Prediction Network: http://www.arcus.org/sipn/sea-ice-outlook.

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