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Title: Climate Modeling and Causal Identification for Sea Ice Predictability

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Climate Modeling and Causal Identification for Sea Ice Predictability

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Project title and participants:

Title: Climate Modeling and Causal Identification for Sea Ice Predictability
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Overview: This project aims to better understand causes of ongoing changes in the Arctic climate system, particularly as decreasing sea ice trends have been observed in recent decades and are expected to continue in the future. As part of the Sea Ice Prediction Network, a multi-agency effort to improve sea ice prediction products on seasonal-to-interannual time scales, our team is studying sensitivity of sea ice to a collection of physical process and feedback mechanism in the coupled climate system. During 2017 we completed a set of climate model simulations using the fully coupled ACME-HiLAT model. The simulations consisted of experiments in which cloud, sea ice, and air-ocean turbulent exchange parameters previously identified as important for driving output uncertainty in climate models were perturbed to account for parameter uncertainty in simulated climate variables. We conducted a sensitivity study to these parameters, which built upon a previous study we made for standalone simulations (Urrego-Blanco et al., 2016, 2017). Using the results from the ensemble of coupled simulations, we are examining robust relationships between climate variables that emerge across the experiments. We are also using causal discovery techniques to identify interaction pathways among climate variables which can help identify physical mechanisms and provide guidance in predictability studies. This work further builds on and leverages the large ensemble of standalone sea ice simulations produced in our previous w14_seaice project.

Parametric Uncertainty and Sensitivity Analysis in the Coupled HiLAT Climate Model:

A climate model for high latitude processes has recently been developed as part of DOE's HiLAT project which uses CICE, CAM5, and POP as the sea ice, atmosphere and ocean components, respectively. Our group has developed CICEv5.1 and has contributed to HiLAT's model calibration efforts. The behavior of this model, however, has not been extensively tested particularly with regard to feedbacks and impact of model parameters on different high latitude climate variables. In this study, we examined model sensitivities to 5 parameters that previous studies conducted in uncoupled settings identified to produce large uncertainties in climate models: the thermal conductivity of snow (*ksno*) and the maximum snow grain size (*rsnw_mlt*) in CICE, the threshold for conversion of water vapor to clouds (*cldfrc_rhminl*) and of ice crystals to snow (*micro_mg_dcs*) in CAM5, and a coefficient (*C*) for the calculation of air-ocean turbulent exchanges. We used an elementary effects approach to address sensitivity of sea ice and Arctic related variables to these parameters. The approach is an improvement over one-at-a-time sensitivity analyses in that the sampling of the parameter space is done efficiently along random trajectories to assess sensitivity at different model configurations. We assessed model output uncertainty by evaluating the climate model on 24 different parameter configurations and ranking them based on elementary effects indices. Overall, we found that the conversion of water vapor to clouds has a large influence in simulated Arctic sea ice and other atmospheric variables. By examining relationships between climate variables across the model ensemble, we identified mechanisms that are important for the radiative balance at the ocean-ice surface. In particular, we found a strong positive (negative) correlation between sea ice and the net longwave radiation at the surface during the melting (freezing) season, which is modulated by clouds (sea ice). We also identified a significant relationship between Arctic sea ice coverage and the atmospheric circulation regime over the Beaufort Gyre in the fall season, which is likely due to interactions between clouds, sea ice, and atmospheric stability in the boundary layer.

Causal Identification:

We are applying a causal discovery technique to investigate interactions among high-latitude variables simulated in this study. The technique uses conditional partial correlations to remove confounding effects and spurious correlations among variables. Using the control run experiment, for instance, we were able to elucidate possible causal pathways for the simulated dependencies of atmospheric circulation in the Beaufort Gyre and sea ice coverage in the Artic. In particular, causal networks suggest a pathway in which negative (positive) sea ice anomalies in fall increase (reduce) evaporation rates the following spring, and this in turn has the effect of weakening (strengthening) the Beaufort High circulation in the fall. Sea ice anomalies in this season are associated with cloud anomalies at zero lag, suggesting a causal path between clouds and atmospheric circulation, which is mediated first by sea ice and then by evaporation rates. A plausible explanation that needs further examination is that enhanced evaporation rates (caused by reduced ice coverage) produce anomalous large-scale upward motions in the atmosphere. This induces cyclonic motions that slow down the general anticyclonic character of the Beaufort Gyre circulation.

Sensitivity of Spatial Distributions in Standalone model:

We also collaborated with Hannah Director, a summer student intern who applied Bayesian Lasso regressions to examine spatial distributions of sensitivity of sea ice model biases to 40 sea ice parameters in an ensemble of 400 standalone model simulations. The results obtained generally confirm previous findings made for total sea ice volume and extent. Over the interior of the sea ice pack, in particular, it was found that snow parameters such as conductivity and snow grain size as well as drainage of melt ponds are important drivers of uncertainty in sea ice model output. Because the Lasso technique applied to every model grid point, we obtain new spatial results for the parameter sensitivities. In particular, the effect of dynamical parameters involved in ridging and deformation of the ice pack can be significant near the marginal ice zone.

Financial Impact:

Our IC resources underpin DOE's contribution to the Sea Ice Prediction Network, exploring parameters and processes that affect the predictability and survivability of sea ice. DOE's participation strengthens this international, collaborative, community based effort, particularly in its status as a broadly supported, multi-agency initiative within the US. Our project is part of the High-Latitude Application and Testing (HiLAT) of Global and Regional Climate Models SFA funded under DOE's Regional and Global Climate Modeling Program ($2.5M per year to LANL, of which approximately $300,000 supports the sea ice team's contributions, including this subproject).

Presentations:

- Urrego-Blanco, J.R., Hunke, E., and Urban, N., Study of sea ice sensitivity and causal relationships in the HiLAT coupled climate mode, Joint HiLAT/RASM workshop, Seattle, WA, May 9, 2017.
- Urrego-Blanco, J.R., Hunke, E., Urban, N., Jeffery, N., Turner, A., Langenbrunner, J., and Booker, J., Uncertainty quantification in sea ice models: model validation and sensitivity analyses, Regional, Global, and Climate Modeling Program webinar, April 20, 2017.
- Urrego-Blanco, J.R., Studies of ocean and sea ice processes, and uncertainty quantification in models of the Earth climate system, Clima seminar, Penn State University, April 27, 2017.
- Urrego-Blanco, J.R., Hunke, E., and Urban, N., Uncertainty quantification and sensitivity studies in standalone and coupled sea ice models, Caspo Seminar, Scripps Institution of Oceanography, San Diego, CA, October 24, 2017.

Publications:

Urrego-Blanco, J., Hunke, E., and Urban, N., Sensitivity analysis of the Arctic climate in a perturbed parameter ensemble of the HiLAT coupled climate model. In prep.

Urrego-Blanco, J., Hunke, E., and Urban, N., Examining seasonal Arctic sea ice predictability using a causal network approach. In prep.

Urrego-Blanco, J. R., E. C. Hunke, N. M. Urban, N. Jeffery, A. K. Turner, J. R. Langenbrunner, and J. M. Booker (2017), Validation of sea ice models using an uncertainty-based distance metric for multiple model variables, J. Geophys. Res. Oceans, 122, doi:10.1002/2016JC012602.

Urrego-Blanco, J., N. Urban, E. Hunke , A. Turner, N. Jeffery (2016). Uncertainty Quantification and Global Sensitivity Analysis of the Los Alamos Sea Ice Model Journal of Geophysical Research - Oceans, 121, DOI:10.1002/2015JC011558.