Project title: Improving the Simulation of Arctic Clouds in CCSM3 (SGER Award)
Project ID: 0012849
PI: Stephen J. Vavrus
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This project has focused on the simulation of Arctic clouds in CCSM3 and how the modeled cloud amount (and climate) can be improved substantially by altering the parameterized low cloud fraction. The new formula, dubbed "freeezedry", alleviates the bias of excessive low clouds during polar winter by reducing the cloud amount under very dry conditions. During winter, freezedry decreases the low cloud amount over the coldest regions in high latitudes by over 50% locally and more than 30% averaged across the Arctic (Fig. 1). The cloud reduction causes an Arctic-wide drop of 15 W m^{-2} in surface cloud radiative forcing (CRF) during winter and about a 50% decrease in mean annual Arctic CRF. Consequently, wintertime surface temperatures fall by up to 4 K on land and 2-8 K over the Arctic Ocean, thus significantly reducing the model's pronounced warm bias (Fig. 1). While improving the polar climate simulation in CCSM3, freezedry has virtually no influence outside of very cold regions (Fig. 2) or during summer (Fig. 3), which are space and time domains that were not targeted. Furthermore, the simplicity of this parameterization allows it to be readily incorporated into other GCMs, many of which also suffer from excessive wintertime polar cloudiness, based on the results from the CMIP3 archive (Vavrus et al., 2008). Freezedry also affects CCSM3's sensitivity to greenhouse forcing. In a transient-CO_2 experiment, the model version with freezedry warms up to 20% less in the North Polar and South Polar regions (1.5 K and 0.5 K smaller warming, respectively) (Fig. 4). Paradoxically, the muted high-latitude response occurs despite a much larger increase in cloud amount with freezedry during non-summer months (when clouds warm the surface), apparently because of the colder modern reference climate.

These results of the freezedry parameterization have recently been published (Vavrus and D. Waliser, 2008: An improved parameterization for simulating Arctic cloud amount in the CCSM3 climate model. *J. Climate*, 21, 5673-5687.). The article also provides a novel synthesis of surface- and satellite-based Arctic cloud observations that show how much the new freezedry parameterization improves the simulated cloud amount in high latitudes (Fig. 3). Freezedry has been incorporated into the CCSM3.5 version, in which it successfully limits the excessive polar clouds, and may be used in CCSM4. Material from this work is also appearing in a synthesis article on future Arctic cloud changes (Vavrus, D. Waliser, J. Francis, and A. Schweiger, "Simulations of 20th and 21st century Arctic cloud amount in the global climate models assessed in the IPCC AR4", accepted in Climate Dynamics) and was used in a collaborative paper on Arctic cloud-sea ice coupling (Schweiger, A., R. Lindsay, S. Vavrus, and J. Francis, 2008: Relationships between Arctic sea ice and clouds during autumn. *J. Climate*, 21, 4799-4810.).

This research was presented at the 2007 CCSM Annual Workshop, as well as the CCSM's 2007 Atmospheric Model Working Group and Polar Working Group Meetings. The findings were also shown at the 2007 Climate Change Prediction Program's Science Team Meeting. In addition, I served as an instructor at the International Arctic Research

Center's (IARC) Summer School on Arctic Climate Modeling in Fairbanks this summer, where I presented on the challenges and techniques used in simulating polar clouds. I also contributed to the development of a new Arctic System Model by attending a workshop in Colorado this summer on this fledgling project. Finally, an outreach activity for the general public has been the development of an interactive web site (<http://ccr.aos.wisc.edu/model/visualization/ipcc/>) that displays Arctic cloud amount in the CMIP3 climate model archive under present and future scenarios. This site allows users to make polar and global maps of a variety of climate variables to investigate the individual and ensemble-mean GCM response to greenhouse warming and the extent to which models adequately represent Arctic clouds in the modern climate. This site was used extensively in the IARC summer school projects.

This work has also led to a collaboration this year during a 4-month visit I made to NCAR through its Faculty Fellowship Program. I worked with scientists Marika Holland, David Bailey, Andrew Gettleman, and Jen Kay, who are researching polar climate and/or clouds. I met with this group frequently during my visit, leading to some fruitful interactions. This work led to the discovery of a tightly coupled response of clouds and sea ice during intervals of rapid sea ice loss in greenhouse simulations, as well as advising on the evolving CCSM3.5 to CCSM4 model development. This involvement with NCAR also led to a longer-term connection, as I have recently begun a two-year stint on the SSC for CCSM.

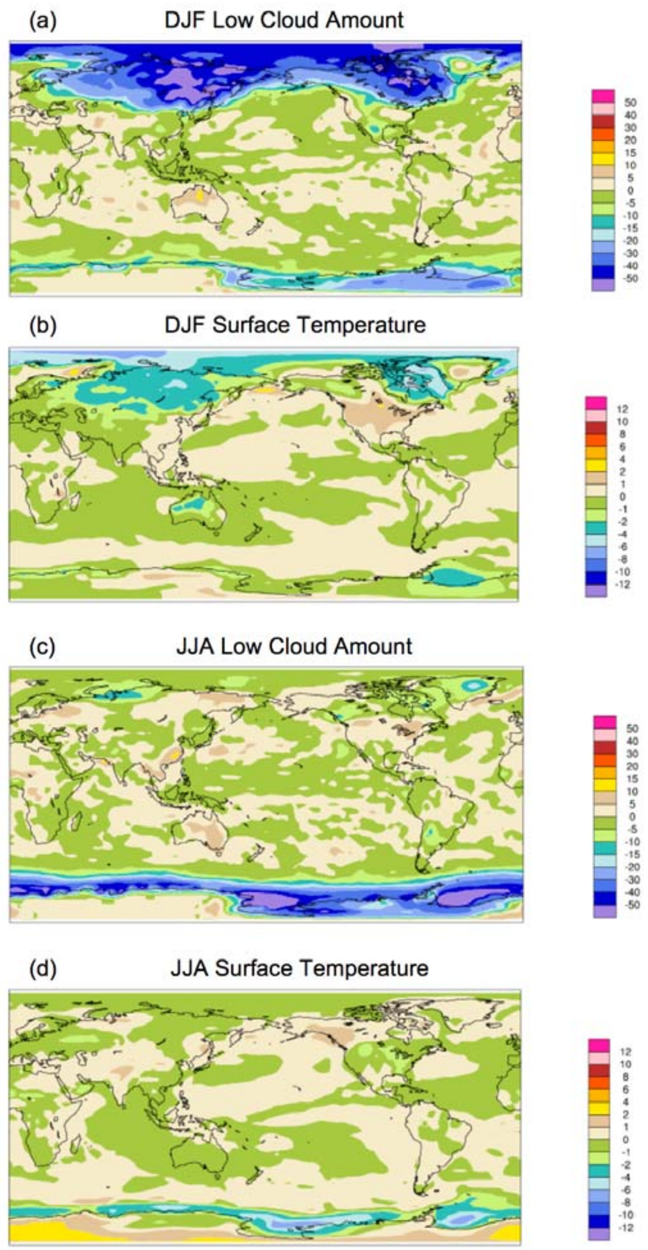

Figure 1. Changes in low cloud amount (%) and surface temperature (K) produced in FREEZEDRY during (a,b) DJF and (c,d) JJA.

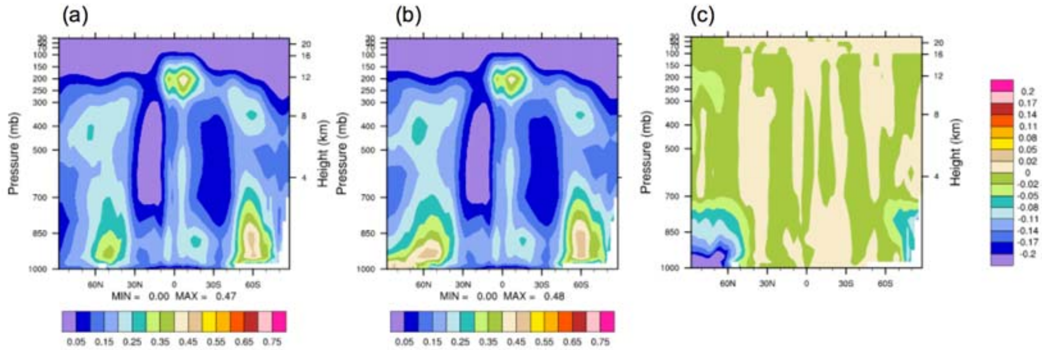

Figure 2. Vertical cross section of cloud fraction during boreal winter in (a) FREEZEDRY, (b) control, and (c) FREEZEDRY minus control.

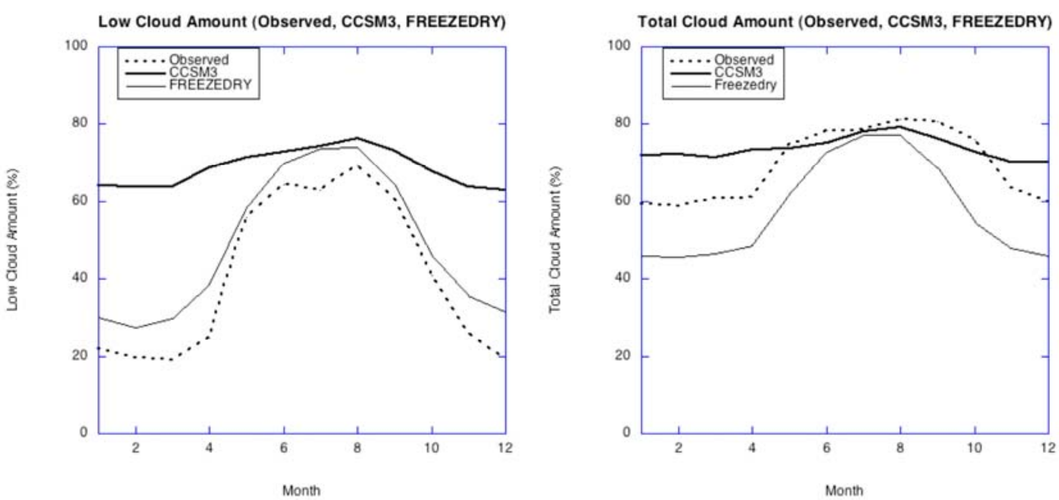

Figure 3. Observed annual cycle of low and total cloud amount (%) averaged over the Arctic (dashed) and simulated by CCSM3 with its standard cloud formula (bold) and with freezedry (thin).

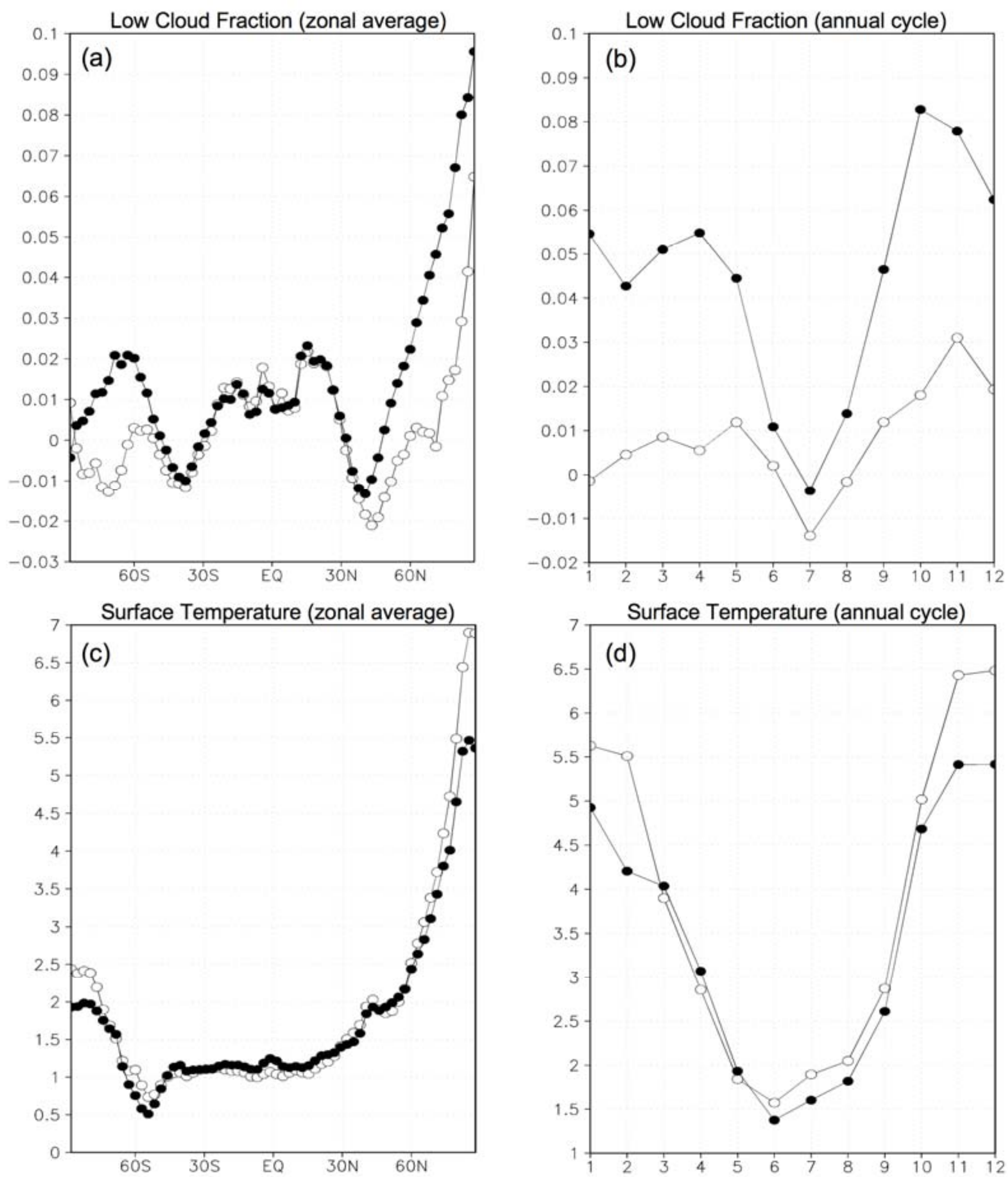

Figure 4. Changes in Arctic low clouds and temperature (70-90^{o}N) in the transient greenhouse simulations: FREEZEDRYCO2 (solid circles) and CCSM3's standard 2xCO_2 run (open circles). Shown are changes in (a) annual low cloud fraction, (b) annual cycle of low cloud fraction, (c) annual surface temperature, and (d) annual cycle of surface temperature.