Advances in the representation of permafrost and permafrost hydrology in an Earth System Model (CCSM4):

Present-day and future permafrost conditions

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Reference: Lawrence, D.M., et al., 2011: Simulation of Present-day and Future Permafrost and Seasonally Frozen Ground Conditions in CCSM4. *In Press J. Climate CCSM4 Special Collection.*

1. Abstract

The representation of permafrost and its projected 21st century state is assessed in the Community Earth System Model (CCSM4) and the Community Land Model (CLM4). The combined impact of advances in CLM and a better Arctic climate simulation, especially for T_{air} (Fig. 1), improve the permafrost simulation in CCSM4 compared to CCSM3 (Fig. 2). Present-day continuous plus discontinuous permafrost extent is comparable to that observed (12.5×10^6 versus $11.8\text{-}14.6 \times 10^6$ km^2), but active layer thickness (ALT) is generally too thick and deep ground (>15m) temperatures are too warm in CCSM4. ALT and deep ground temperatures are better simulated in offline CLM4 (i.e., forced with observed climate) which indicates that climate biases degrade the CCSM4 permafrost simulation.

Near-surface permafrost area is projected to decline substantially during the 21st century (Fig. 3). The permafrost degradation rate is slower (2000-2050) than in CCSM3 by ~35% due to improved soil physics. The trajectory of permafrost degradation is affected by CCSM4 climate biases, especially the wintertime high snowfall (and associated snow depth) bias. In offline simulations in which this climate bias is ameliorated, permafrost degradation in RCP8.5 is lower by ~29% (Fig. 3). Further reductions in Arctic climate biases will increase the reliability of permafrost projections and permafrost thaw-related feedback studies using CESM.

The representation of cold region hydrology is inadequate to permit a holistic study of the Arctic permafrost carbon problem. To address this limitation, we are conducting a targeted effort to improve Arctic terrestrial hydrological processes in CLM. A new cold region hydrology scheme for CLM includes a prognostic wetlands module, 2-way river/soil interactions, and a supra-permafrost saturated zone and water table. The improved scheme exhibits a much better simulation of Siberian river hydrographs (Fig. 4).

2. Simulated Arctic Climate

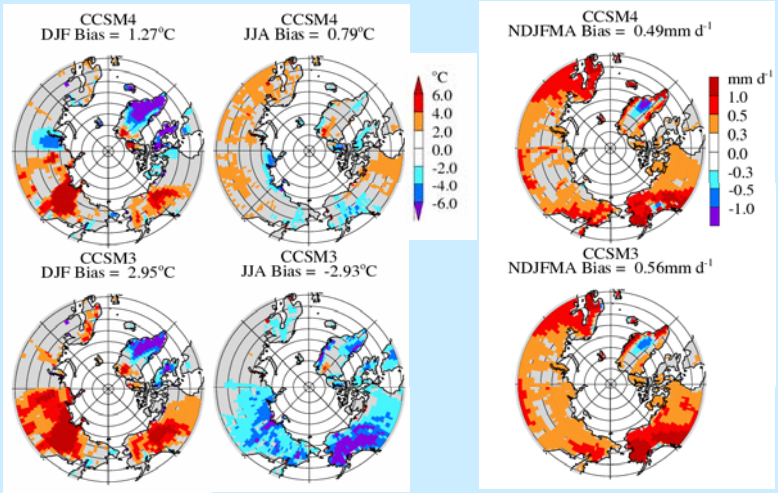


Fig. 1: 2-m air temperature and winter precipitation (snowfall) bias maps for the period 1980-1999 for CCSM4 and CCSM3 for Arctic land areas. Observational data for T_{air} is CRU TS 2.1 and P is CMAP.

3. Permafrost in CCSM4

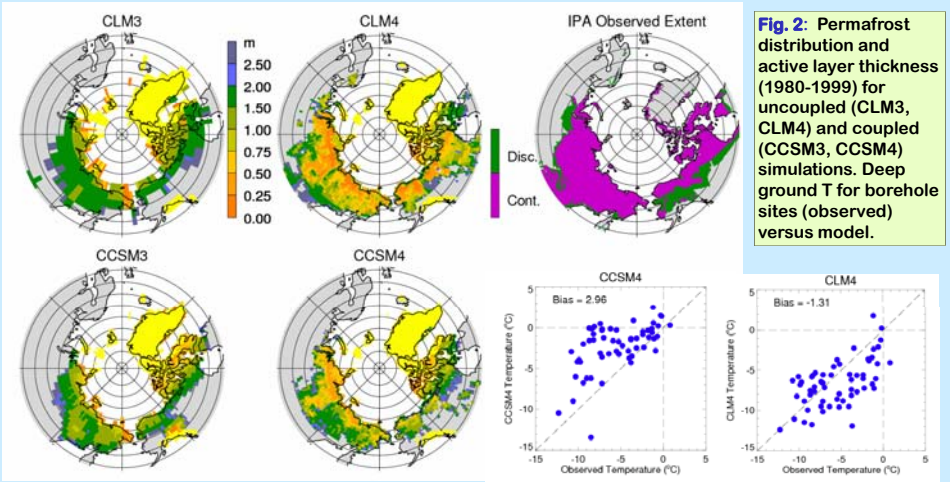


Fig. 2: Permafrost distribution and active layer thickness (1980-1999) for uncoupled (CLM3, CLM4) and coupled (CCSM3, CCSM4) simulations. Deep ground T for borehole sites (observed) versus model.

4. Permafrost projections

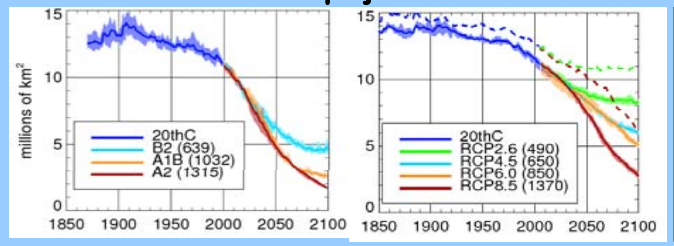
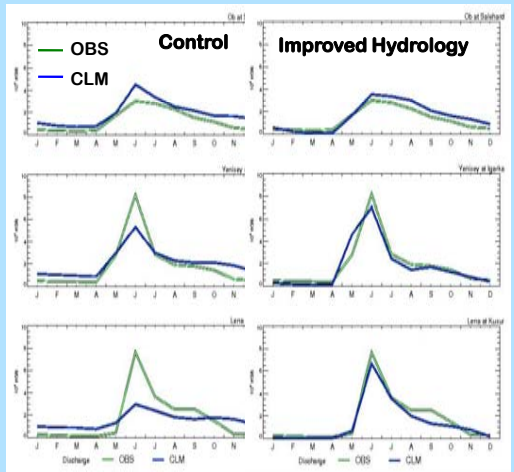


Fig. 3: Time series of near-surface permafrost extent (integrated area with permafrost within top 3.5m) for CCSM3 and CCSM4 for historical and projection periods. Dashed lines show offline CLM4 simulations forced with climate bias-corrected data from a CCSM4 simulation.

5. Cold Region Hydrology



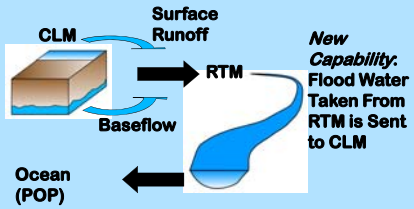


Fig. 4: Model vs obs hydrograph for Ob, Yenisey, and Lena rivers for Control and Improved Hydrology (ice impedance, prognostic wetland, perched water table, 2-way River / Soil interactions) (Swenson and Lawrence, in prep)