Toward Understanding the Simulated Phase Partitioning of Arctic Single-Layer Mixed-Phase Clouds in E3SM

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Background

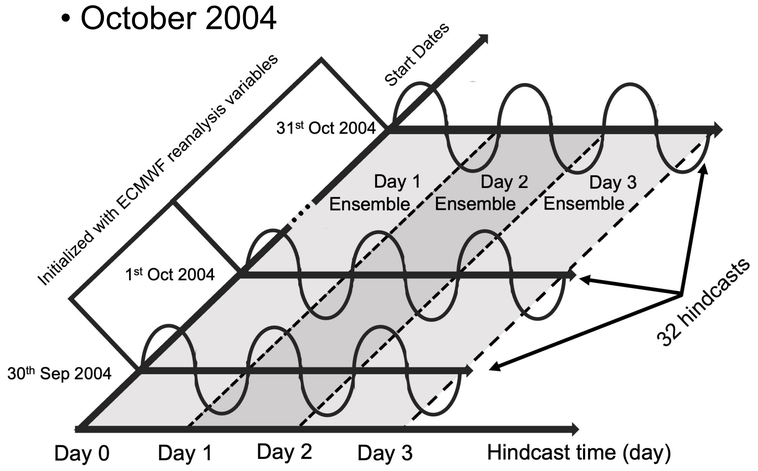
- Mixed-phase cloud is one of the key components of the climate system. They are critical for global energy and hydrologic cycles.
- Large uncertainties exist in the simulations of mixed-phase cloud phase in General Circulation Models (GCMs):
  - Microphysical processes such as Wegener-Bergeron-Findeisen (WBF) and ice nucleation process;
  - Detrainment from convective clouds.
- Cloud physical parameterizations are updated in the U.S. DOE state-of-the-art E3SM model. But biases can still be identified in the phase partitioning of high-latitude mixed-phase clouds.

Objective

Understand how the changes in model parameterizations are related to the bias of high-latitude mixed-phase clouds based on a process-level analysis

Model Experiments

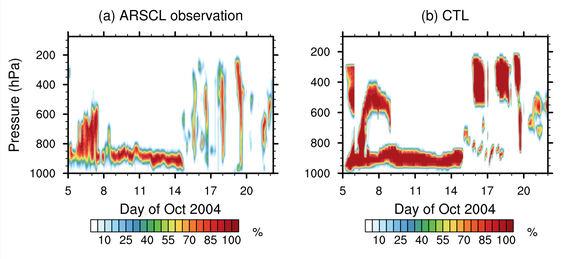
- Short-term hindcasts are performed under the DOE LLNL Cloud-Associated Parameterizations Testbed (CAPT)
  - Large-scale circulations remain close to reality in the first several days of hindcasts;
  - Errors in simulated clouds are attributed to model parameterizations.
- EAMv1 runs for the Mixed-Phase Arctic Cloud Experiment (M-PACE) field campaign
  - North Slope of Alaska (**NSA**, 71°19′22.8″N, 156°36′32.4″W)
  - October 2004



Summary of physical parameterizations in EAMv1 sensitivity experiments

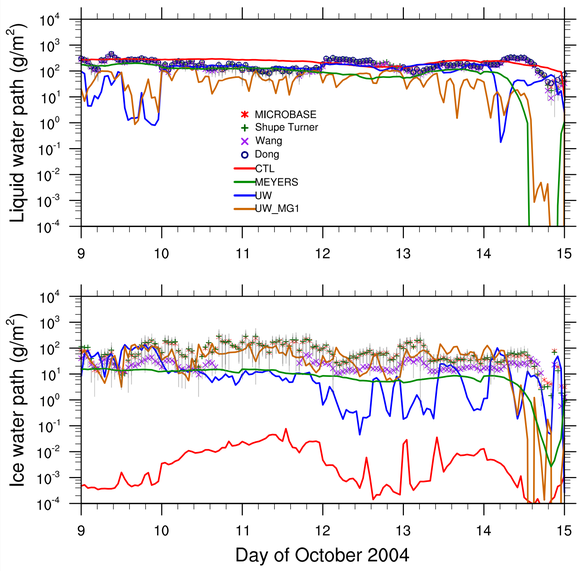
Experiment	Description	Note
CTL	E3SM Atmosphere Model version 1（**EAMv1**）, without WBF process tuning	Base results
Meyers	Same as CTL, but replace the **CNT ice nucleation** scheme with **Meyers**	Examine the effect of heterogeneous ice nucleation
UW_MG2	Same as CTL, but replace **CLUBB** by the CAM5 **UW schemes** (shallow convection, turbulence, and cloud macrophysics)	Examine the effect of CLUBB
UW_MG1	Same as UW_MG2, except with the **MG1 microphysics**	Examine the effect of updated cloud microphysics

Simulated Mixed-phase Clouds



- Time-pressure cross sections of observed and simulated **cloud fraction** during the M-PACE.

- Time-pressure cross sections of simulated total **cloud liquid water mass mixing ratio** (upper panel) and total **cloud ice water mass mixing ratio** (lower panel) during the M-PACE.

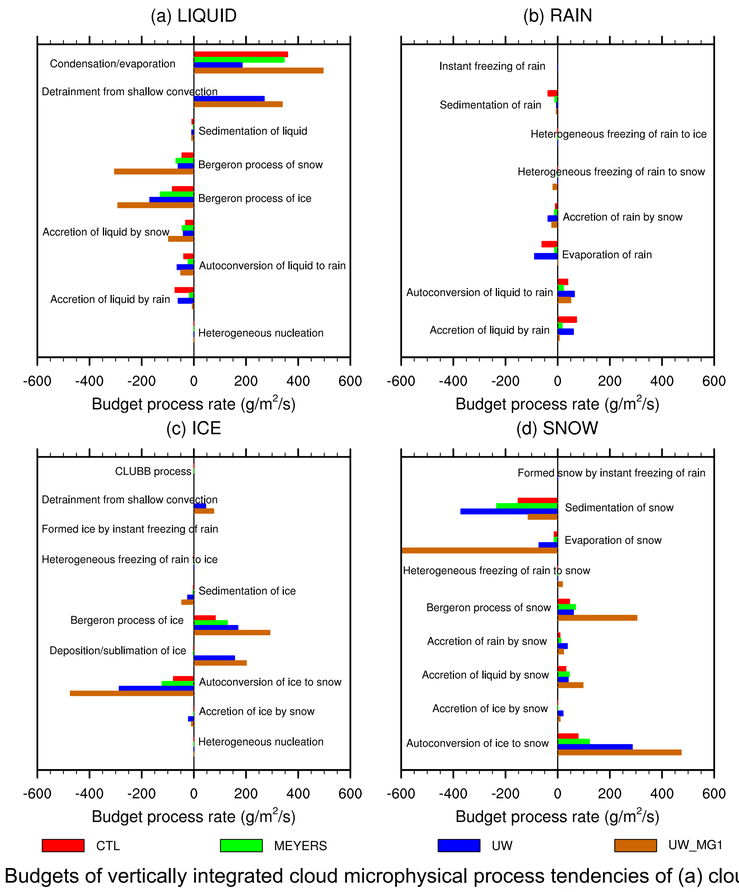


- Time series of **LWP** (upper panel) and **IWP** (lower panel) from the EAMv1 hindcasts and ARM ACRED dataset.

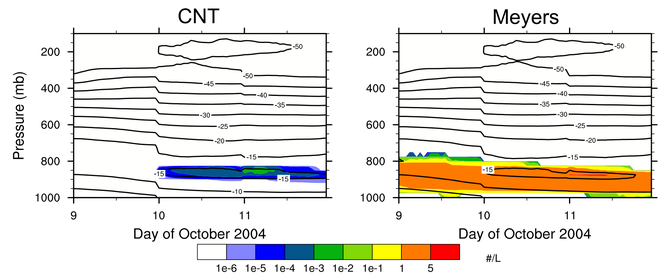
ACRED dataset

Provide a general idea of the uncertainties of observed cloud microphysical properties that are associated with retrieval algorithms.

Budget Analysis to Understand Source of Biases



- Budgets of vertically integrated cloud microphysical process tendencies of (a) cloud liquid, (b) cloud ice, (c) rain, and (d) snow hydrometeors from Day-2 hindcast results.
- Integrated tendencies are averaged between 9-11 October 2004 during the M-PACE.



- INP concentration from different immersion freezing parameterizations between 9-11 October.

Summary

- ✓ Source of biases in the modeled high-latitude mixed-phase clouds are analyzed utilizing a short-term hindcast approach with EAMv1;
- ✓ EAMv1 modeled Arctic mixed-phase cloud phase differs substantially from earlier GCM (e.g., CAM5) results. Negligible cloud ice mass mixing ratios are simulated in the single-layer boundary-layer mixed-phase clouds in M-PACE;
- ✓ The lack of initial ice particles from heterogeneous ice nucleation at temperatures warmer than -15℃ or convective detrainment diminishes the cloud ice water content through subsequent ice mass growth processes.

Reference. *Zhang, et al. (2020). Toward understanding the simulated phase partitioning of arctic single-layer mixed-phase clouds in E3SM. ESS. https://doi.org/10.1029/2020EA001125*

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