Sensitivity of Cloud Feedbacks to Turbulence Closure, Microphysics Scheme, and Grid Size in Cloud-Resolving RCE Simulations

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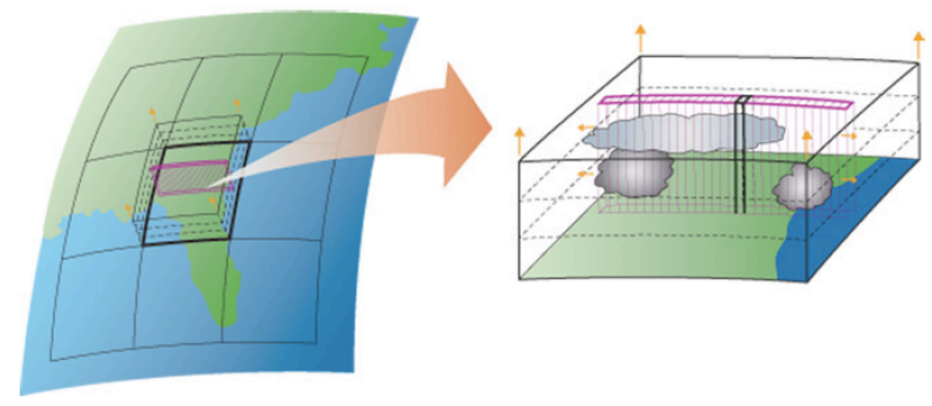
Introduction

There has been rapid development and increasing use of high-resolution global climate models (GCMs). The horizontal grid sizes of such models range from about 25 km down to a few kilometers in global cloud-resolving models (CRMs) and in the Multiscale Modeling Framework (MMF), which embeds a 2D CRM in every GCM grid column. With a grid size of a few kilometers, deep convection and mesoscale convective systems are resolved, but boundary-layer clouds are not. In order to improve the representation of boundary-layer clouds in coarse-grid CRMs, we developed an economical approach based on the assumed PDF method.

Multiscale Modeling Framework (MMF) embeds a 2D CRM (dx ~ 4 km) in every GCM grid column.



- Our approach has been to integrate several existing components:
  - A **prognostic SGS TKE** equation.
  - The **assumed PDF** method of Golaz et al. (2002).
  - The **diagnostic second-moment closure** of Redelsperger and Sommeria (1986).
  - The **diagnostic closure for <w'w'w'>** by Canuto et al. (2001).
  - A **turbulence length scale** related to the square root of SGS TKE (Teixeira and Cheinet 2004) and eddy length scales.
- We implemented our approach in a CRM and **tested** it **using LES** (Bogenschutz and Krueger 2013).
- We also **implemented** it in a **MMF.**

Standard SAM vs SAM-SHOC

The CRM that we used is SAM (System for Atmospheric Modeling) developed by Marat Khairoutdinov (Khairoutdinov and Randall 2003). Our approach, Simplified Higher-Order Closure (SHOC), was incorporated into SAM as an alternative option to the SGS TKE scheme used in standard SAM.

- **Standard SAM**
  - SGS TKE is prognosed.
  - Length scale is specified as dz (or less in stable grid boxes).
  - No SGS condensation.
  - SGS buoyancy flux is diagnosed from moist Brunt Vaisala frequency.
- **SAM-SHOC**
  - SGS TKE is prognosed.
  - Length scale is related to SGS TKE and eddy length scales.
  - SGS condensation is diagnosed from assumed joint PDF.
  - SGS buoyancy flux is diagnosed from assumed joint PDF.
  - Add'l moments req'd by PDF closure are diagnosed, so ***no additional prognostic equations are needed.***

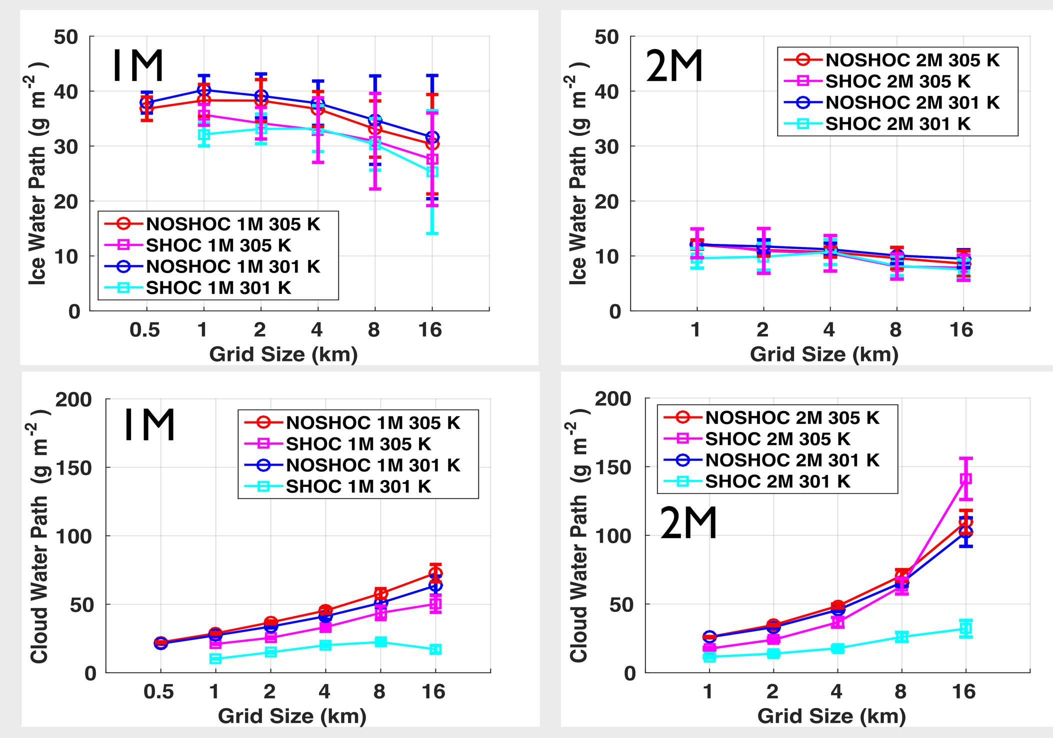
RCE Simulation Setup

Radiative convective equilibrium (RCE) is often used as a simple proxy for the Earth's climate. We have performed a large set of RCE simulations in order to evaluate the dependence of simulated cloud and radiation properties on a range of cloud-resolving model configurations.

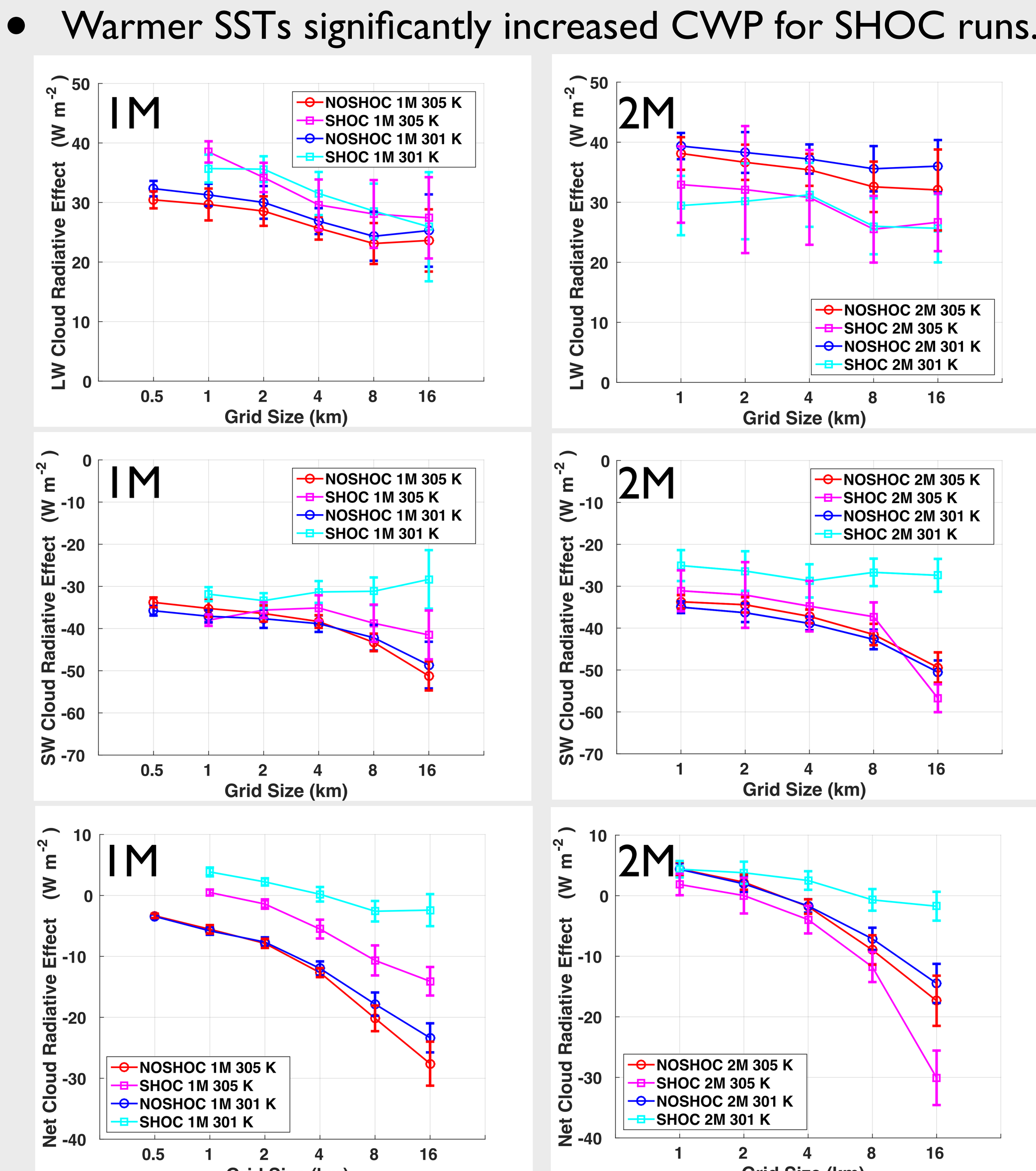
Each configuration used a different set of physics parameterizations and a range of horizontal grid sizes (0.5, 1, 2, 4, 8, and 16 km). The SST was 301 K or 305 K. The turbulence closure scheme was standard SAM or SAM-SHOC. The microphysics scheme was SAM's single-moment microphysics or M2005 double-moment microphysics (Morrison et al. 2005). The simulations were run for 50 days with all results shown here displaying averages of the latter 25 days.

By performing RCE simulations at two SSTs, we have also been able to determine how the cloud and radiation properties change due to SST changes, and have quantified the climate feedbacks using "radiative kernels" (Soden et al. 2008).

RCE Results

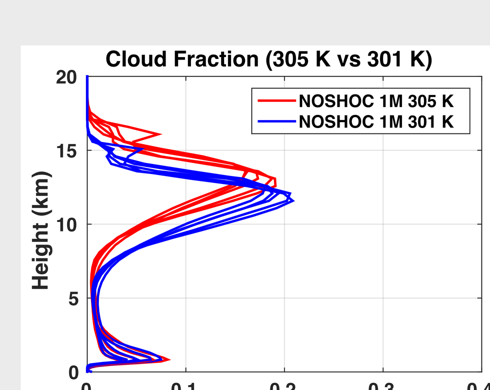


- The microphysics choice significantly affects CWP and IWP with higher CWP and lower IWP in double moment runs.
- SHOC single-moment runs have lower CWP and IWP than NOSHOC runs.
- CWP increases and IWP decreases as grid spacing increases.
- Warmer SSTs significantly increased CWP for SHOC runs.

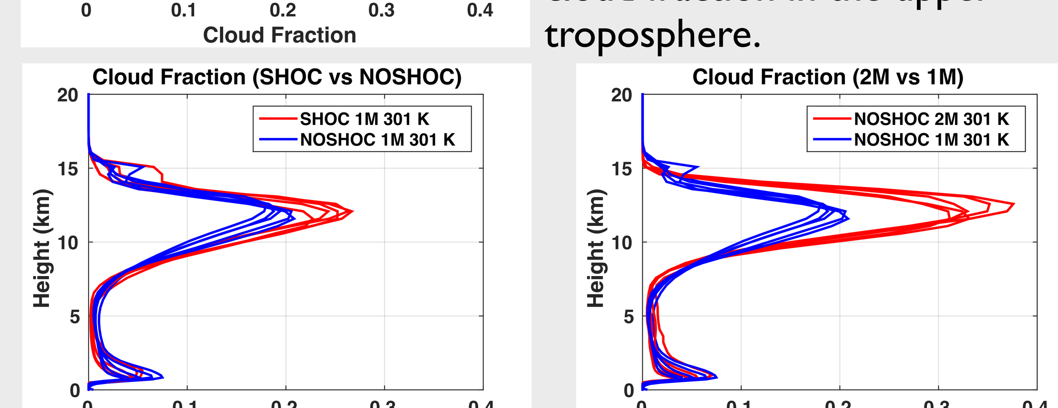


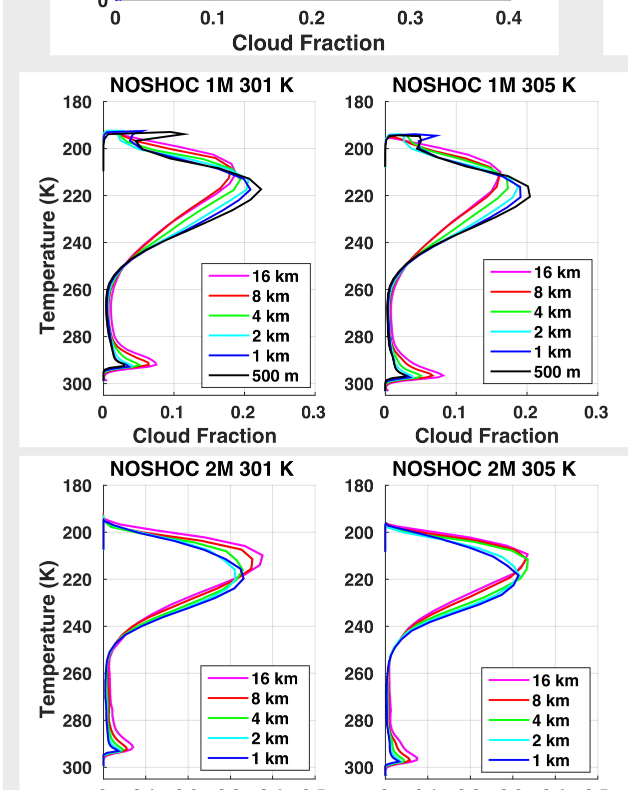
- LW cloud radiative effect is higher for 1M SHOC runs than 1M NOSHOC; however, the reverse is true for 2M.
- SW cloud radiative effect has a large grid size dependence.
- Net cloud radiative effect is more negative for larger grid sizes but positive for 1km runs except for 1M NOSHOC.

Cloud Fraction Profiles



- ***SST***: Upper tropospheric cloud level is higher for warmer SST.
- ***SHOC vs NOSHOC:*** SHOC increases the cloud fraction in the upper troposphere.
- ***2M vs 1M:*** 2M increases the cloud fraction in the upper troposphere.

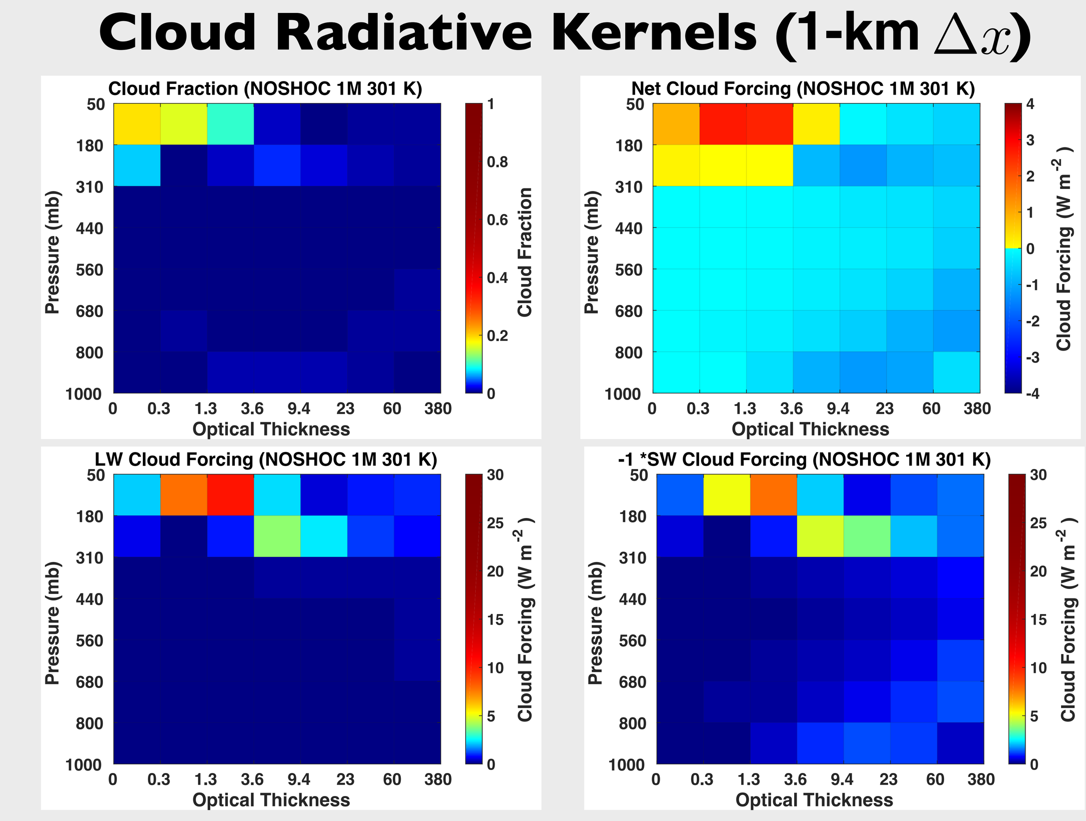




- Cloud fraction increases at higher resolution in the upper troposphere for 1M NOSHOC. The reverse is the case for 2M NOSHOC.
- Cloud fraction decreases at higher resolution near the surface.
- Cloud-top temperature is similar regardless of SST.
- SHOC results are similar to the 1M NOSHOC pattern, regardless of microphysics scheme.

RCE Results

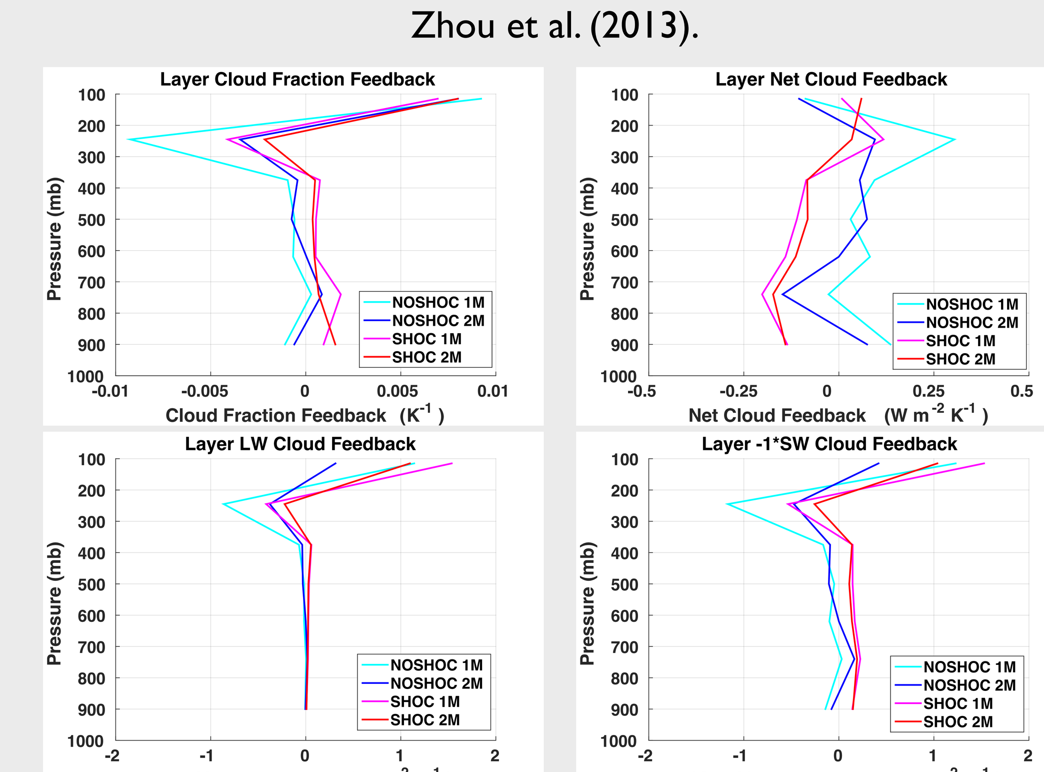
Cloud Feedbacks Derived From Cloud Radiative Kernels (1-km Δx)



- The primary cloud type is upper-level cirrus. As a result, upper levels contribute most to both LW cloud feedback and SW cloud feedback.

25-day avg. cloud feedback (W m^{-2} K^{-1})	1M NOSHOC	2M NOSHOC	1M SHOC	2M SHOC
LW	0.17	-0.12	1.27	1.01
SW	0.36	0.17	-1.82	-1.51
Net	0.53	0.05	-0.55	-0.50

Kernel-derived cloud feedbacks. Kernels used are based on Zhou et al. (2013).



- Peak cloud fractions shifted from the 180-310 mb level to the 50-180 mb level as SST increased from 301 K to 305 K.
- The SW cloud feedback is negative with SHOC and positive with NOSHOC.
- The LW cloud feedback changes sign between the 1M and 2M NOSHOC runs.

Summary

RCE case study results show:

- Horizontal grid size significantly influences CWP.
- Different microphysics parameterizations can produce significantly different CWP and IWP values.
- SHOC produces greater upper-troposphere cloud fractions.
- 2M microphysics produces greater upper-troposphere cloud fractions.
- SHOC runs have a negative net cloud feedback while NOSHOC runs have a positive net cloud feedback.

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