Climate and Cloud response of super-parameterized CAM with additional super-parameterization of low-level clouds

Marat Khairoutdinov
Stony Brook University
Long Island, New York, USA
SP-CAM has large low-level cloud bias...

SP-CAM Annual Low-level cloud climatology

SP-CAM (ISCCP simulator) mean = 22.0476

ISCCP mean = 28.1133

Bias in Shortwave Cloud Forcing, W/m²

MMF minus ISCCP-FD mean -2.5

0 6 12 18 24 30 36 42 48 54 60

0 30E 60E 90E 120E 150E 180 210E 240E 270E 300E 0

90N 60N 30N 0 30S 60S 90S
MiniLES: SP with an LES-like horizontal grid spacing;

- MiniLES allows no condensation above 5000m to suppress deep convection;
- Vertical grids of CRM and MiniLES are collocated with GCM;
- Grids of CRM and LES are NOT attached to GCM grid;
- All communication between CRM/MiniLES and GCM is through 1D profiles;
- SP: 32x28, Δx=4000m, Δt=20s
- MiniLES: 32x28, Δx=250m, Δt=20s
- Horizontal domain of MiniLES is about as wide as a single cell of the SP

**The SP-MiniLES model is 70% more expensive than SP-CAM**
MiniLES-CRM-GCM Coupling

Dynamics Step:

\[ S^n \rightarrow S^* \]

\[ \Delta t_{GCM} \]

MiniLES steps (subcycling)

\[ S^n_{LES} \rightarrow S^*_{LES} \]

\[ \Delta t_{LES} \]

CRM steps (subcycling)

\[ S^n \rightarrow S^{n+1} \]

\[ \Delta t_{CRM} \]

MiniLES Forcing:

\[ -\nabla s V - \frac{\partial \bar{s} \bar{\omega}}{\partial p} = \frac{S^* - S^n_{LES}}{\Delta t_{GCM}} \]

CRM Forcing:

\[ -\nabla s V - \frac{\partial \bar{s} \bar{\omega}}{\partial p} = \frac{S^*_{LES} - S^n}{\Delta t_{GCM}} \]

Column-physics Tendency:

\[ Q_1 = \frac{S^{n+1} - S^*}{\Delta t} \]
Schematic for the radiative transfer in the SP+MiniLES framework

Radiative transfer is computed in each column of CRM only with MiniLES average clouds added to the cloud-free CRM cells.

Also, that's what the ISCCP (Satellite) Simulator gets as input.
Annual total cloud cover (ISCCP simulator)

SP−CAM  mean = 53.3094

SP  mean = 65.2369

SP−CAM + MiniLES  mean = 68.9329

Annual total cloud cover change due to MiniLES

SP−MiniLES minus SP  mean = 15.1318
Annual Low cloud fraction (ISCCP simulator)

SP

SP–CAM

mean = 22.0476

SP+MiniLES

SP–CAM + MiniLES

mean = 30.4308

SP+MiniLES

mean = 28.1133

ISCCP

mean = 28.1133

Change due to MiniLES

SP-MiniLES minus SP

mean=6.08266

Big improvements in low cloud cover
Annual High & Mid cloud fraction (ISCCP simulator)

SP

SP–CAM

mean = 31.2618

SP

SP–CAM + MiniLES

mean = 34.8061

SP+MiniLES

SP+MiniLES minus SP

mean = 0.478068

ISCCP

mean = 33.106

Little change in high cloud cover (expected)
Low-cloud water is still mostly represented on CRM grid rather than on MiniLES grid.
Climate-change Time-Slice Test

- Control (Present): Prescribed climatological monthly SSTs
- Perturbed (Future): Prescribed AR4 IPCC (A1B) composite SST anomalies (with respect to their late 20th century climatology)
- Duration: 3 years + 4-month spinup

AR4 Models’ Composite 2000s-2090s SST Change
Change in Low and High Clouds in Response to IPCC A1B SST late 21st century anomaly

SP-CAM & MiniLES

Low
-0.5

High
-1.1

SP-CAM

0.2

0.5
SP-CAM with MiniLES has higher climate sensitivity than SP-CAM and positive Cess’ cloud feedback

Plot is from Cess et al (1989)
Omega 500 mb PDF change in Tropics
(Monthly, 30S-30N)

In warmer climate, in Tropics, both SP-CAM GCMs with and without MiniLES predict robust increase in shallow trade cumulus clouds and reduction in stratocumulus clouds.
Probability of finding Omega (mb/day) at 500 mb
(SST climate-change SP-CAM Monthly climatology)

\[ 5 < \omega_{500} < 25 \]

\[ 25 < \omega_{500} \]
Summary/Conclusions

- ‘MiniLES’ super-parameterization approach considerably improves climatology of low level clouds in SP-CAM at relatively modest computational expense (~70%).

- Tropical response to ‘climate-change’ SST anomaly is robust for both versions of SP-CAM, that is to increase area of shallow convection and decrease area of Sc in response to weakening overturning circulation.

- Mini-LES in SP-CAM tends to
  - Increase model’s climate sensitivity (from 0.5 to 0.6 K W⁻¹m²)
  - Switch CRF feedback from weakly negative (-0.36) to weakly positive (0.24)