High-resolution Multiscale Modeling Framework
Simulation of Low Clouds

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Multiscale Modeling Framework
(Grabowski 2001; Khairoutdinov and Randall 2001)

- A CRM is embedded at each grid column (~100s km) of the host GCM to represent cloud physical processes
- The CRM explicitly simulates cloud-scale dynamics (~1s km) and processes
- Periodic lateral boundary condition for CRM (not extend to the edges)

Upgraded CRM with a third-order turbulence closure (IPHOC):
- Double-Gaussian distribution of liquid-water potential temperature, total water mixing ratio and vertical velocity
- Skewnesses, i.e., the three third-order moments, predicted
- All first-, second-, third- and fourth-order moments, subgrid-scale condensation and buoyancy based on the same PDF
Objectives for MMF climate simulation

✧ to improve the simulation of low-level clouds in an MMF
✧ to evaluate and compare the performance of model simulations against state-of-the-art observations

Models and observational data

• Standard SPCAM, at T21 resolution, 2-yr run (semi-Lagrangian)
• Upgraded SPCAM, called SPCAM-IPHOC, at T21 resolution (with semi-Lagrangian dynamic core); 2-yr run
• SPCAM-IPHOC-hires: SPCAM-IPHOC with finite-volume dynamic core (1.9°x2.5°); doubling the number of levels below 700 hPa (6 to 12); 10-yr run
• C3M (CloudSat, CALIPSO, CERES, MODIS) observations
Highlights of results

- Improved low cloud simulation from the upgraded CRM and the higher-resolution finite-volume dynamic core-based SPCAM-IPHOC model, compared to the standard SPCAM and the lower-resolution SPCAM-IPHOC with semi-Lagrangian dynamic core, respectively
- Improved surface precipitation distributions, esp., in the tropics
- Radiative energy balance, compared to CERES observations
- Overall performance from the higher-resolution SPCAM-IPHOC is better than SPCAM and SPCAM-IPHOC


Off-line sensitivity test to vertical resolution

ATEX Cumulus

a) LES
b) 75L
c) 6L
d) 12L

ASTEX Stratocumulus

a) LES
b) 75L
c) 6L
d) 12L
Low-level (sfc - 700 hPa) cloud amount (%)
Annual mean cloud fraction (color) and cloud liquid water (contour) west of South America (15°S)
Annual-mean surface precipitation rate

- **a) SPCAM**
  - Mean: 2.67 (mm d⁻¹)

- **b) SPCAM-IPHOC**
  - Mean: 2.74 (mm d⁻¹)

- **c) SPCAM-IPHOC-hires**
  - Mean: 2.87 (mm d⁻¹)

- **d) Legates**
  - Mean: 3.12 (mm d⁻¹)

The maps illustrate the distribution of annual-mean surface precipitation rate across the globe, with variations in precipitation density indicated by color coding from light purple (low values) to red (high values).
Summer precipitation in China
Oceanic surface latent heat flux

(a) SPCAM  mean = 87.1
(b) SPCAM-IPHOC  mean = 90.3
(c) SPCAM-IPHOC-hires  mean = 105.5
(d) JRA25  mean = 111.0
TOA albedo

a) mean=0.3105  rms=0.0522  corr= 0.9501

b) mean=0.2941  rms=0.0424  corr= 0.9649

c) mean=0.2977  rms=0.0391  corr= 0.9707

d) CERES  mean= 0.2928
TOA outgoing LW flux

a) mean=230.83  rms=14.0780  corr= 0.9599

b) mean=236.21  rms=9.6268  corr= 0.9745

c) mean=241.22  rms=7.7769  corr= 0.9841

d) CERES  mean= 239.58
Shortwave cloud radiative effect

a) mean = -54.5  rms = 18.1429  corr = 0.8347

b) mean = -48.8  rms = 13.6016  corr = 0.8759

c) mean = -50.5  rms = 13.4871  corr = 0.8929

d) CERES  mean = -46.6
LW cloud radiative effect

a) mean = 30.5  rms = 9.2934  corr = 0.8534

b) mean = 23.9  rms = 9.9890  corr = 0.8532

c) mean = 23.0  rms = 10.2885  corr = 0.8678

d) CERES  mean = 29.5
## TOA and surface energy balance

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Summary of results: the Taylor diagram
Summary of results: the Taylor diagram
Summary of results: the Taylor diagram
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Summary and conclusions

• Both upgraded SPCAM-IPHOC simulations show improved representation of
  • the global distributions of low-level clouds
  • the amounts of low-level clouds in the subtropics
  • surface precipitation (for higher-resolution one)
• The comparison against C3M observations shows further improved results in the higher-resolution MMF, for example, near-coast thin stratus clouds and deep convection in the tropics
• The TOA radiative energy balance is nearly perfect in the higher-resolution simulation
• There are rooms for further improvements
Summary of results: the Taylor diagram
SPCAM-IPHOC vs. SPCAM

Significant improvement
Low-level cloud
SW CRF
LW CRF

Small/no improvement
Surface pressure
Middle-level cloud
High-level cloud
Surface precipitation
Latent heat flux

Degraded
Surface sensible flux
Summary of results: the Taylor diagram SPCAM-IPHOC-hires vs. SPCAM-IPHOC

- Significant improvement: Surface pressure, Surface precipitation, Mid-level cloud, High-level cloud, Latent heat flux, SW CRF
- Small/no improvement: Low-level cloud, LW CRF, Sensible heat flux