CRCP IN CLOUDS-IN-CLIMATE PROBLEM

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NCAR
• Moisture-convection feedback in the tropics and Intraseasonal Oscillations

• from CRCP to super-parameterization ("CRCP as a physics coupler")

boundary layer and shallow convection: diurnal cycle over land

→ Hamlet's dilemma: "2D or not 2D, this is the question..."

• CRCP in CAM over tropical western Pacific
MJO-like coherent structures on a rotating Earth-size constant-SST aquaplanet

impact of free-tropospheric moisture and moisture-convection feedback on large-scale convection organization in the tropics

Grabowski, JAS 2003
prescribed radiation, equator
rainfall
precipitable water

days

vertical velocity (cm s$^{-1}$)

zonal wind (m s$^{-1}$)

rainfall (mm day$^{-1}$)

surface flux (W m$^{-2}$)

height (km)

longitude

longitude

80

0

0

180

180

360

360

0

0

200

600
32 x 16
zonal
meridional

EQUATOR

RESOLVED PRECIP 1 and 10 mm/day

CONV PRECIP 1 and 10 mm/day

time (days)

longitude (deg)

CRCP replaced by traditional convective parameterization (Emanuel scheme)
200 x 100

RESOLVED PRECIP 1. and 2. mm/day

time (days)

longitude (deg)

Zonal distribution of precip (20°S; 20°N)
$200 \times 100$

CONV PRECIP 1. and 2. mm/day

zonal distribution of precip (20°S; 20°N)
CRCP over land

representation of diurnal cycle of convection over land (shallow convection and transition from shallow to deep convection)

\textit{can a 2D cloud-resolving model with horizontal/vertical resolution of }\sim 1 \text{ km}/\sim 0.1 \text{ km capture these processes?}

\rightarrow \text{ diurnal cycle of shallow convection over land: GCSS WG1 case based on ARM observations}

\rightarrow \text{ shallow to deep convection transition over land: GCSS WG4 case based on TRMM/LBA observations}
Large-eddy simulation of the diurnal cycle of shallow cumulus convection over land

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Figure 3. Observed surface sensible-heat and latent-heat fluxes at the central facility (symbols) and the values imposed in the models (solid lines).
Figure 4. Profiles of potential temperature (Θ) and total-water mixing ratio (τ) at various times UTC from the eight different models. In almost all panels the lines from the different models are sufficiently close together that they overlap, and so we actually see the range of LES results rather than individual solutions. The light lines in each panel show the initial profiles.

Figure 5. Time series (smoothed over one hour) from the eight simulations. (a) Total cloud fraction, (b) maximum cloud fraction at any one level, (c) cloud-base height and (d) cloud-top height. In (a) and (c) the stars are the observations of the micro-pulse lidar, while the crosses are the observations of the Belfort ceilometer at the central facility.
diurnal cycle of shallow convection over land:
GCSS WG1 case based on ARM observations

3D LES (*benchmark*)

$96 \times 96 \times 111$; 66.7m horizontal, 40 m vertical

2D "LES-type"

$192 \times 111$; 66.7m horizontal, 40 m vertical

→ aligned E-W (along geostrophic wind)

→ aligned N-S (perpendicular to geostrophic wind)

CRCP, along lowest 2 km winds

$101 \times 23$; 1 km horizontal, stretched in vertical

$(0, 90, 220, 390, 570, 760 \text{ m...})$

→ nonlocal 1D mixing scheme to represent boundary layer transports (Troen and Mahrt 1986)
3D LES

Total cloud fraction

Maximum cloud fraction

Cloud base height

Cloud top height
diurnal cycle of shallow convection over land: GCSS WG1 case based on ARM observations

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CRCP

- too much
  - too late

- too shallow

**total cloud fraction**

**maximum cloud fraction**

**cloud base height**

**cloud top height**
evolution of surface fluxes

local time (hour)

latent
sensible

simulation

7:30 am
1:30 pm

Wm$^{-2}$
horizontal domain (x-y)
vertical domain (x–z)
shallow to deep convection transition over land:

GCSS WG4 case based on TRMM/LBA observations

ensemble of 3D simulations *(benchmark)*

2 sets: $128 \times 128 \times 201, 192 \times 192 \times 201$

$(\Delta x, \Delta z): (50, 25) \rightarrow (100, 50) \rightarrow (200, 100) \rightarrow (400, 100)$

CRCP, along lowest 2 km winds

$101 \times 61$; 1 km horizontal, stretched in vertical

$(0, 100, 260, 440, 650, 870 \text{ m}...)$

$\rightarrow$ nonlocal 1D mixing scheme to represent boundary layer transports *(Troen and Mahrt 1986)*
set L

Cloud fraction

0.0
0.4
0.8

fraction

0
5
10

km

0
1
2
3
4
5
6

hours

Height of the center of mass
shallow to deep convection transition over land:
GCSS WG4 case based on TRMM/LBA observations

**ensemble of 3D simulations** (*benchmark*)

2 sets: $128 \times 128 \times 201$, $192 \times 192 \times 201$

$(\Delta x, \Delta z)$: $(50, 25) \rightarrow (100, 50) \rightarrow (200, 100) \rightarrow (400, 100)$

**CRCP, along lowest 2 km winds**

$101 \times 61$; 1 km horizontal, stretched in vertical

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$\rightarrow$ nonlocal 1D mixing scheme to represent boundary layer transports (Troen and Mahrt 1986)
Cloud fraction

Height of the center of mass
Super-parameterization in CAM over TWP
Michał Ziemianski

systematic evaluation of the impact of CRCP on cloud-radiation interactions over the tropical western Pacific (TWP):

→ 1. applying CAM large-scale forcing from a set of 56 columns over TWP (150E to 170E and 10S to 10N) to 56 CRMs (i.e., no feedback to CAM)

→ 2. replacing deep convection parameterization in CAM over this area with CRMs (i.e., feedback included)
Fig. 1. The TOGA COARE sounding network. The solid circles indicate ISS stations, and the open circles represent other sounding stations.
cloud condensate (cloud water, cloud ice)
Fig. 3.
Table 1: Cloud radiative forcing on the top of the atmosphere (TOA) and surface (SRF) and its standard deviation (in square brackets), resulting from CRCP and CAM convection parameterization for the whole experiment area and integration period; also WM01 results for their CRM and SCM simulations are shown for comparison (in parentheses).

<table>
<thead>
<tr>
<th>Cloud radiative forcing (W m⁻²)</th>
<th>CRCP (CRM)</th>
<th>CAM (SCM)</th>
</tr>
</thead>
<tbody>
<tr>
<td>TOA shortwave WM01</td>
<td>-132.0 [21.6]</td>
<td>-57.6 [7.3]</td>
</tr>
<tr>
<td>WM01</td>
<td>(-119.3)</td>
<td>(-78.2)</td>
</tr>
<tr>
<td>SRF shortwave WM01</td>
<td>-134.4 [22.8]</td>
<td>-59.6 [7.6]</td>
</tr>
<tr>
<td>WM01</td>
<td>(-124.9)</td>
<td>(-79.9)</td>
</tr>
<tr>
<td>TOA longwave WM01</td>
<td>69.2 [15.6]</td>
<td>55.8 [11.0]</td>
</tr>
<tr>
<td>WM01</td>
<td>(81.4)</td>
<td>(80.7)</td>
</tr>
<tr>
<td>SRF longwave WM01</td>
<td>17.8 [0.9]</td>
<td>16.2 [1.0]</td>
</tr>
<tr>
<td>WM01</td>
<td>(22.6)</td>
<td>(23.8)</td>
</tr>
</tbody>
</table>

WM01 - Wu & Moncrieff 2001
CRM & SCM forced by TOGA COARE observations
CONCLUSIONS AND OUTLOOK, I

● Intraseasonal Oscillations ●

CRCP and a traditional convective parameterization scheme (Emanuel’s scheme) give very different solutions as far as MJO-like coherent structures on a constant-SST aquaplanet are concerned. Why?

This is consistent with improved (over-improved?) MJO in CAM with CRCP (Marat)

→ organized convection? (next talk)

→ moisture-convection feedback? (impact of environmental humidity on deep convection)
CONCLUSIONS AND OUTLOOK, II

- from CRCP to super-parameterization -

*diurnal cycle of convection over land:*

→ CRCP with 2D computational domain aligned along low-level winds, using 1 km horizontal grid spacing and stretched grid in the vertical (100 m near the surface), and applying nonlocal boundary layer scheme captures daytime convective development over land associated with diurnal cycle of surface forcing

→ further improvements likely possible when subgrid schemes included (turbulence, condensation, etc), but these will increase cost of CRCP

*topographic forcing and land-surface processes are next...*
CONCLUSIONS AND OUTLOOK, III

- cloud-radiation interactions over TWP -

CRCP and traditional deep convection parameterization give different picture of clouds over TWP (condensate mixing ratio, cloud fraction, cloud radiative forcing, etc)

results are consistent with a similar study where CRM and CAM SCM were driven by observed large-scale conditions from TOGA COARE (Wu and Moncrieff 2001)