Progress with convective parameterization for Improved simulation of the MJO

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1. Motivation
2. Various convective parameterizations
3. Modifications of A/S scheme
4. Cloud Radiation Interaction
5. High Resolution Model
6. A New Mass Flux Scheme
CLIVAR Monsoon Intercomparison - MJO

10°S-10°N Time-longitude Cross Section of Precipitation during 1997

(C.I.=5 mm day^-1)
Modification 1: Cumulus Entrainment Constraint

- Minimum cumulus entrainment rate in RAS (Tokioka et al. 1988)

\[ \mu_{\text{min}} = \frac{\alpha}{D} \]

D: PBL depth
\( \alpha \): non-negative constant

Convection can be triggered in case of \( \mu \geq \mu_{\text{min}} \)

Modification 1: Cumulus Entrainment Constraint

\( \alpha = 0.0 \)  \( \alpha = 0.05 \)  \( \alpha = 0.15 \)  \( \alpha = 0.25 \)
SNU Aqua-planet AGCM with a fixed radiation

\( \alpha = 0.0 \) (control)

\( \alpha = 0.1 \) (modified)
ISO with turning on Cloud-Radiation Interaction

- Two Experiments in Aqua-Planet

<table>
<thead>
<tr>
<th>Experiment</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fixed</td>
<td>Prescribed zonally uniform radiative heating rate</td>
</tr>
<tr>
<td>Interactive</td>
<td>Fully interactive radiation</td>
</tr>
</tbody>
</table>

Cloud-radiation interaction simulated in the model (in particular, RAS scheme) prevents the eastward propagation of large-scale waves and make westward moving transients more prominent.
ISO with turning on Cloud-Radiation Interaction

2°S-2°N Time-longitude Cross Section of Precipitation

The longwave ACRF feedback is more crucial for this feature in RAS scheme.
Modification2: Layer-cloud Precipitation time Scale

Sensitivity to Precipitation Timescale: Time-longitude Diagram

Precipitation

200 hPa Velocity Potential
Modification2: Layer-cloud Precipitation time Scale

- **Strategy**
  - For the reduction of longwave ACRF
  - Modulation of model cloudiness
  - Reduction of precipitation time scale for reducing longwave heating induced by ACRF

- **Observational evidence:** Autoconversion precipitation timescale over the tropics is 200–800 sec (Lau et al. 2003)

- **Characteristic precipitation timescale,** $\tau_p$
  \[
  \tau_p = \tau_0 \left\{ 1 - \exp \left[ -\left( \frac{l}{l_0} \right)^2 \right] \right\}^{-1}
  \]  
  (Sundqvist, 1978)

  - $l_c$: critical cloud liquid water content
  - $t_0$: characteristic timescale for conversion of cloud droplets into rain drops

- **Precipitation rate**
  \[
  P = \frac{l}{\tau_p}
  \]
  - $P$: precipitation rate
  - $l$: cloud liquid water content
  - $\tau_p$: characteristic precipitation timescale

- The reduction of $\tau_p$ means fast autoconversion from cloud liquid water to precipitable raindrops

- **Reducing Cloud Lifetime**

- **Longwave ACRF (atmosphere cloud radiative forcing) heating reduced**

- Constant $\tau_p = 9600$ sec (original)
  - smaller value up to 900 sec
Zonal Mean OLR during Sep96 ~ Aug98

Experimental Design

<table>
<thead>
<tr>
<th></th>
<th>Tokioka effect</th>
<th>Layer-cloud precipitation timescale</th>
<th>Coupling with mixed layer</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>RAS cumulus entrainment minimum</td>
<td>Reduced region</td>
<td>LSC time scale $\tau_0$</td>
</tr>
<tr>
<td>Control</td>
<td>Off</td>
<td>No</td>
<td>9600 sec</td>
</tr>
<tr>
<td>Exp1</td>
<td>$\alpha=0.1$</td>
<td>$20^\circ$S~$20^\circ$N</td>
<td>9600/900 sine curve</td>
</tr>
<tr>
<td>Exp2</td>
<td>$\alpha=0.1$</td>
<td>$20^\circ$S~$20^\circ$N</td>
<td>9600/900 sine curve</td>
</tr>
<tr>
<td>Exp3</td>
<td>$\alpha=0.1$</td>
<td>Whole globe</td>
<td>1800 sec</td>
</tr>
</tbody>
</table>
Simulated precipitation

- **RAS**
- **Saturation deficit**
- **Bulk**
Modification 3: Relative Humidity Criteria

- 10°S-10°N Time-longitude Cross Section of Precipitation

(a) Control
(b) Modified

Perpetual Experiment
- Resolution: T31 (3.75x3.75) L20
- 4 months simulation with June condition
- For modified case, \( RH_c \) is 80%
Longitudine-time diagram of total precipitation (5S-5N)

Low Resolution (300km)

unit: [mm/day]
**MJO Variance** (eastward wavenumber 1-6, periods 30-70 days)

(Lin et al. 2006)

**IPCC AR4 models**

- different colors - different climate models
- different colors - different convection schemes

Convection scheme: represent model diversity in MJO variability

(Lin et al. 2008)
Resolution impact with same physics

TRMM: Satellite data (Precipitation)
MJO simulation

200hPa VP (20-70 day filter) : 1999yr

OBS

ENS1

ENS2

ENS3
A new convective parameterization in SNU AGCM

Based on
A Mass Flux Scheme

Representation of cumulus cloud

**Spectral method**

Top-oriented / spectrum

- Cloud Top 1 (LNB)
- Cloud Top 2
- Cloud Top 3

Entrainment rate: $\varepsilon$

Cloud structure

Cloud Base (LCL)

Surface

- Cloud top determination
- deterministic

**Bulk method**

Bottom-oriented / Bulk

- Cloud Top

Entrainment rate: $\varepsilon$

Cloud structure

Cloud Base (LCL)

Surface

- Cloud top determination
- depends on environment

E.g. Arakawa and Schubert (1974)

E.g. Tiedtke (1989)
Practical representation of cumulus ensemble

**Bulk method**  
(Kim and Kang 2010, Clim Dyn.)

- **Bottom-oriented / Bulk**
- **Cloud Top**
- **Cloud structure**
- **Cloud Base (LCL)**
- **Surface**

- **Entrainment rate:** $\varepsilon$

- **In-cloud vertical velocity**

\[
\frac{1}{2} \frac{\partial w_u^2}{\partial z} = aB - b\varepsilon w_u^2
\]

↑ Buoyancy  ↔ Entrainment rate  *$a=1/6, b=2$*

- **Entrainment rate**

\[
\varepsilon = C_{\varepsilon} \frac{aB}{w_u^2}
\]

Gregory (2001)

\[
\varepsilon = \left( \frac{1}{RH} - 1 \right) \frac{aB}{w_u^2}
\]

Environmental RH effect  Bechtold et al. (2009)

- **Detrainment rate**

\[
\delta = \varepsilon + \frac{1}{z_t - z}
\]

*Above max. buoyancy  (linear decrease to zero)*

- **Cloud top determination**

⇒ depends on environment
Equatorial (5S-5N averaged) precipitation

a) TRMM  b) Bulk  c) RAS

*year: 2000
Lag-correlation diagram (U850, 20-100day filtered)

Reference point: 155-160°E, 5°N-5°S averaged
Lag-correlation diagram
(U850, 20-100day filtered)

Reference point:
155-160°E, 5°N-5°S averaged
Northward propagation

<table>
<thead>
<tr>
<th></th>
<th>CMT</th>
<th>No CMT</th>
</tr>
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<tbody>
<tr>
<td>O (9)</td>
<td>8</td>
<td>1</td>
</tr>
<tr>
<td>X (8)</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>
Northward propagation of Monsoon Convection

- Extended EOF (40-110E, 15S-30N)

  EEOF1 60-95E

  a) OBS (19.07%)
  b) CMT (5.82%)
  c) CTRL (3.94%)

  • CMT: more strong northward propagation (northern region of 5N)
Physical interpretation

South Asian Monsoon Region

Convection ➔ momentum mixing
Reducing shear
Secondary circulation
Northward propagation