A scale-aware convective parameterization scheme developed at KIAPS

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Background
Grid size is much bigger than convection cell

Grid size is smaller than convection cell

\[ \sigma = \frac{A_c}{A_g} \]
convection area: \(A_c\)
grid box area: \(A_g\)

**CPS grayzone**

\(\sigma\) is getting bigger with \(\Delta x\) getting smaller
When \(\sigma\) not negligible: need to adjust CPS
\(\rightarrow \) \(\sigma\) dependent CPS

Arakawa et al (2011)
Overview of concept/current grayzone CPSs

Arakawa and Wu (2013)

\[
\overline{w'\varphi'} = (1 - \sigma_u)^2 (\overline{w'\varphi'})_E
\]

\[
\sigma_u = \frac{(\overline{w'\varphi'})}{\delta w \delta \varphi} \frac{\delta w \delta \varphi}{(1 - \sigma_u)^2 + (\overline{w'\varphi'})_E}
\]

Pan et al (2014)

\[
\sigma_u = \frac{\overline{w}}{w_c}
\]
Overview of concept/current grayzone CPSs

Grell and Freitas (2014) and Han et al (2017)

\[ \sigma_u = \frac{3.14 R_c^2}{A_{grid}}, \quad R_c = \frac{0.2}{\varepsilon}, \quad A_{grid} = dx^2 \]


\[ \tau = \frac{H}{W} \beta(dx) \quad \text{Slight modification of Bechtold(2008) with some other changes} \]

\[ \beta = (1 + \ln \frac{25}{dx}) \]

Han et al (2017) demonstrated that the method suggested by Arakawa and Wu(2014) and Pan et al(2014) do not work properly due to

1. smaller \( \bar{w} \) even in fine horizontal resolution
   (e.g. \( \sigma_u \sim 0.1 \) or less at \( dx=2km \))
2. uncertainties of determining key parameters in the current CPSs
Method
With grid getting finer (bigger $\sigma$)

$\rightarrow$ less active sub-grid convection
 weaker sub-grid convection

Three modifications are made:

1. **Cloud-base mass flux is proportional to** $(1 - \sigma)^2$
   
   derivation from Arakawa and Wu(2013)

2. **Convective trigger is proportional to** $(1 - \sigma)$

3. **Convective cloud water detrainment to grid is proportional to** $\sigma$
Define convective fractional area ($\sigma_1$)

\[
\sigma_1 = 1 - \frac{1}{\pi} \left\{ \tan^{-1} \left[ \sigma_{\text{con}} \left( \Delta x - \Delta x_{5\text{km}} \right) \right] + \frac{\pi}{2} \right\}
\]

where \( \sigma_{\text{con}} = \frac{\tan(0.4\pi)}{\Delta x_{5\text{km}} - \Delta x_{1\text{km}}} \)

Adapted from Hong and Pan (1998, MWR)

\( \Delta x \quad \sigma_1 \)
\[
\begin{array}{ll}
9 \text{ km} & 0.1 \\
5 \text{ km} & 0.5 \\
1 \text{ km} & 0.97 \\
0.1 \text{ km} & 1.0 \\
\end{array}
\]

e.g. \( dx = 1 \text{ km} \)

Trigger and CB mass flux are 3% and 1% of the original SAS value

Detrainment is 97% of the original value
Define convective fractional area ($\sigma_2$)

Pan et al (2014)

$$\sigma_2 = \frac{\bar{w}}{w_c}$$

$\bar{w}$: grid point vertical velocity

-wc: convective vertical velocity

averaged from cumulus bottom to top

Revised cloud base mass flux

$$\bar{\omega'}\varphi' = (1 - \sigma_1) (1 - \sigma_2) \bar{\omega'}\varphi'_E$$

For trigger and detrainment, only $\sigma_1$ is used

The sensitivity tests conducted showed, the combination of $\sigma_1$ and $\sigma_2$ to modify the cloud base mass flux worked the best not $\sigma_1$ or $\sigma_2$ alone
## Experimental Design

<table>
<thead>
<tr>
<th>EXP</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>OSAS</td>
<td>NCEP GFS SAS without scale-awareness 27-9-3-1km all with CPS</td>
</tr>
<tr>
<td>NOCP</td>
<td>As in ORIG but no CPS in 3-1km</td>
</tr>
<tr>
<td>GSAS</td>
<td>Modified SAS for scale-awareness CIN, mass flux, and detrainment</td>
</tr>
<tr>
<td>GCIN</td>
<td>Only active scale-awareness CIN</td>
</tr>
<tr>
<td>GCMF</td>
<td>Only active scale-awareness mass flux</td>
</tr>
<tr>
<td>GDTR</td>
<td>Only active scale-awareness detrainment</td>
</tr>
</tbody>
</table>

WRF ARW, one-way nest (27-9-3-1km), SAS, WSM5, YSU, NOAH, RRTMG
Initial, boundary condition: NCEP FNL 1°×1°
Initial time: 2011 July 26 0000UTC +48hr forecast
Result shown 24hr accumulated rainfall from July 2612UTC to 2712UTC
Results
24-h acc. Precipitation at 12UTC 27 July 2011 (dx=3km)

Max. rainfall: 442.3mm

Max. rainfall: 190.6mm

Max. rainfall: 665.4mm

Max. rainfall: 477.2mm

OSAS

NOCN

GSAS
24-h acc. Precipitation at 12UTC 27 July 2011 (dx=1km)

Observed Precip (TMPA)

Max. rainfall: 442.3mm

Max. rainfall: 788.8mm

Max. rainfall: 2168.6mm

Max. rainfall: 765.3mm

OSAS

NOCP

GSAS
The role of CPS in $dx=1$km

Max. rainfall: 2168.6mm
Max. rainfall: 765.3mm

NOCP

GSAS

Rainfall from GSAS CPS
24-h acc. Precipitation at 12UTC 27 July 2011 (dx=27km)

Observed Precip (TMPA)

Max. rainfall: 442.3mm

OSAS

Max. rainfall: 117.1mm

GSAS

Max. rainfall: 136.2mm
Vertical profiles of convective heating and drying over main rainfall area

Convective heating rate (OSAS)

Convective drying rate (OSAS)

dx=27km

dx=9km

dx=3km

dx=1km
Convective rainfall ratio \(= \frac{\text{convective rain}}{\text{total rain}}\)
Results of using only $\sigma_1$ and $\sigma_2$ for mass-flux adjustment at $dx=3$km

$(1 - \sigma_1)^2 \cdot CMF$, total rainfall

$(1 - \sigma_2)^2 \cdot CMF$, total rainfall
Sensitivity of lateral boundary impacts

OSAS with GSAS BDY, total rainfall

GSAS with OSAS BDY, total rainfall
### One-month simulation Results (July 1 – 31 2011)

**Verification score**

<table>
<thead>
<tr>
<th>Experiments</th>
<th>RMSE</th>
<th>PC</th>
<th>Category</th>
<th>ETS</th>
<th>FAR</th>
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<tbody>
<tr>
<td>NOCP</td>
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<td>0.55</td>
<td>&lt;5mm</td>
<td>0.37</td>
<td>0.28</td>
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<td></td>
<td></td>
<td></td>
<td>10mm</td>
<td>0.36</td>
<td>0.29</td>
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<td>15mm</td>
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<td></td>
<td></td>
<td>25mm</td>
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<td>0.34</td>
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<td><strong>0.38</strong></td>
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<tr>
<td></td>
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<tr>
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<td>25mm</td>
<td>0.32</td>
<td>0.28</td>
</tr>
</tbody>
</table>

**Total rainfall time series**

![Graph showing total rainfall time series for July 1 – 31 2011]
Summary and Conclusion

1. Model resolution depend SAS scheme (GSAS) proposed in this study seems working better than original scheme over all model resolution ranges (1km to 27km)

2. Three parameters modified in this study show different effects on model resolutions. Modification of detrainment impacts mostly to lower resolution simulation (9-27km), while cloud base mass flux change improves higher resolution regimes (1-3km)

3. The original SAS scheme does not show the much sensitivity of convective rain ratio (CRR) over grid resolution, GSAS show steady decreases of CRR with finer resolution (95% at 27km, 10% at 1km)
Summary and Conclusion

5. The uses of two different convective fractional areas seems to complement each other’s weakness.

6. The sensitivity results show that the modifications on CPS is greater impacts on the simulation results that lateral boundary effects.

Change of perspective on grayzone CPS(?)

- smart way to perturb sigma (function of PDF and/or dx)
- revisit Quasi-Equilibrium assumption (especially dx is small)
- grid mean value vs. it’s deviation → grid resolution becomes finer, then CPS scheme acts like subgrid turbulence scheme
Thank you
24-h acc. Precipitation at 12UTC 27 July 2011 (dx=9km)

- **Observed Precip (TMPA)**
  - Max. rainfall: 442.3mm

- **OSAS**
  - Max. rainfall: 135.2mm

- **GSAS**
  - Max. rainfall: 197.0mm
Sensitivity results at dx=3km