Exploring Two Coupling Strategies of the Boundary Layer and Convection Schemes in GFDL AM4

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Close interactions between PBL and Convection

Zhang and Klein (2013)
Close interactions between PBL and Convection

Convection scheme

PBL scheme

Zhang and Klein (2013)
PBL-then-Conv coupling

\{T_0, q_0, \text{etc}\}

PBL scheme

turbulent heating/moistening

\{\text{updated} \ T_0, q_0, \text{etc}\}

Convection scheme

convective heating/moistening
**PBL-then-Conv coupling**

- PBL scheme
  - turbulent heating/moistening
  - \{\text{updated } T_0, q_0, \text{ etc}\}
- Convection scheme
  - convective heating/moistening

**PBL-and-Conv coupling**

- PBL scheme
  - turbulent heating/moistening
  - \{\text{same } T_0, q_0, \text{ etc}\}
- Convection scheme
  - convective heating/moistening
How do these two coupling strategies impact the simulated climate?

PBL-then-Conv coupling

- PBL scheme
  - turbulent heating/moistening
  - $\{T_0, q_0, \text{etc}\}$

- Convection scheme
  - $\{\text{updated } T_0, q_0, \text{etc}\}$

PBL-and-Conv coupling

- PBL scheme
  - turbulent heating/moistening
  - $\{T_0, q_0, \text{etc}\}$

- Convection scheme
  - $\{\text{same } T_0, q_0, \text{etc}\}$
AM4 uses “PBL-then-Conv” coupling strategy.

Turbulent heating/moistening are computed using the implicitly-updated surface fluxes.
We create a “PBL-and-Conv” version of AM4. Note that the turbulent effects are not included in cloud macrophysics and microphysics. This complements previous studies on the impact of ordering of parameterizations (e.g. Donahue and Caldwell 2018).
### Recap - Two coupling strategies in AM4

<table>
<thead>
<tr>
<th>Version of AM4</th>
<th>Input states for the PBL scheme</th>
<th>Input states for the convection scheme</th>
<th>Input states for the cloud macrophysics and microphysics schemes</th>
</tr>
</thead>
<tbody>
<tr>
<td>PBL-then-Conv</td>
<td>φ₀ (\varphi = {T, q_v, q_l, \ldots})</td>
<td>(\varphi_0 + (d\varphi/dt)_{\text{turb}} \times dt)</td>
<td>(\varphi_0 + (d\varphi/dt)_{\text{turb+conv}} \times dt)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td><strong>turbulence effects</strong></td>
</tr>
<tr>
<td>PBL-and-Conv</td>
<td>φ₀ (\varphi = {T, q_v, q_l, \ldots})</td>
<td>(\varphi_0)</td>
<td>(\varphi_0 + (d\varphi/dt)_{\text{conv}} \times dt)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td><strong>No turbulence effects</strong></td>
</tr>
</tbody>
</table>

\(dt = 30\) minutes in AM4
### Simulation design

<table>
<thead>
<tr>
<th>Model</th>
<th>GFDL AM4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Resolution</td>
<td>~1° lat x 1° lon, 33 vertical levels</td>
</tr>
<tr>
<td>Experiment</td>
<td></td>
</tr>
<tr>
<td></td>
<td>● <strong>PBL-then-Conv</strong></td>
</tr>
<tr>
<td></td>
<td>○ Convection scheme “sees” the state updated by the PBL. Turbulence effects are included in the large-scale cloud scheme</td>
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<td>● <strong>PBL-and-Conv</strong></td>
</tr>
<tr>
<td></td>
<td>○ Both PBL and convection schemes “see” the same state. Turbulence effects are <em>not</em> included in the large-scale cloud scheme</td>
</tr>
<tr>
<td>Simulation</td>
<td>1979-2014 AMIP. The last 35 years are used for analysis.</td>
</tr>
</tbody>
</table>
The largest SW↑ differences happen over the marine stratocumulus regions, where convection is very weak.
The OLR difference is much smaller than the SW counterpart
• Most precipitation differences are not statistically significant
“PBL-and-Conv” has smaller convective mass flux by ~10%, likely because the convection scheme sees less unstable state.
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Over the equator, the decrease in deep plume mass flux is compensated by the increase in shallow plume mass flux.
“PBL-and-Conv” has stronger PBL activities over the ocean and more low clouds.

The largest changes happen in marine stratocumulus regions, where convection is very weak.
Domain-avg PBL depth and ED coeff
Peruvian Sc region (10°-20°S, 80°-90°W)

深度 of planetary boundary layer

- PBL depth
  - PBL-then-Conv (612.76)
  - PBL-and-Conv (697.69)

Vert diff coeff for temp

- Eddy-diffusivity coeff for heat/moisture, ANN
  - PBL-then-Conv
  - PBL-and-Conv

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Domain-avg low cloud and LWP

Peruvian Sc region (10°-20°S, 80°-90°W)

Low cloud amount
- PBL-then-Conv (0.40)
- PBL-and-Conv (0.58)

Liquid water path
- PBL-then-Conv (0.03)
- PBL-and-Conv (0.05)
Domain-avg EIS and $\omega$

Peruvian Sc region
($10^\circ$-$20^\circ$S, $80^\circ$-$90^\circ$W)

Estimated Inversion Strength
PBL-then-Conv (7.30)
PBL-and-Conv (7.64)

Vertical pressure velocity, ANN
PBL-then-Conv
PBL-and-Conv
Domain-avg Iscloud tendencies

Peruvian Sc region
(10°-20°S, 80°-90°W)

T tend from Iscloud
PBL-then-Conv
PBL-and-Conv

Q tend from Iscloud
PBL-then-Conv
PBL-and-Conv
PBL depth

Low cloud

“PBL-and-Conv” v.s. “PBL-then-Conv”

Why do the largest differences in PBL activities and low clouds happen in marine stratocumulus regions, where convection is very weak?

- Large-scale states? But EIS and $\omega$ do not differ much
- The coupling between PBL and the large-scale cloud scheme? But the respective $T$ and $Q$ tendencies do not differ much
- Others?

slash: diff pass 1% significance level
Summary

- We explore two coupling strategies of the PBL and convection schemes in GFDL AM4
  - **PBL-then-Conv**: Convection scheme “sees” the state updated by the PBL. Turbulence effects are included in the large-scale cloud scheme
  - **PBL-and-Conv**: Both PBL and convection schemes “see” the same state. Turbulence effects are not included in the large-scale cloud scheme

- Compared to “PBL-then-Conv”, “PBL-and-Conv” has weaker convection, likely because the convection scheme sees less unstable state

- The largest differences between these two coupling strategies are PBL activities and low clouds in marine stratocumulus regions, where convection is very weak. The reason is under investigation.
backup
Domain-avg shflx and evap

Peruvian Sc region
(10°-20°S, 80°-90°W)

SH flx
PBL-then-Conv (13.56)
PBL-and-Conv (16.19)

Evap
PBL-then-Conv (4.10)
PBL-and-Conv (4.38)
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