Using a Multi-Physics Ensemble for Exploring Diversity in Cloud-Shortwave Feedback in GCMs

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Did climate sensitivity get converged in CMIP5?

Equilibrium climate sensitivity (ECS) to $2\times CO_2$ in CMIP models

<table>
<thead>
<tr>
<th>IPCC report</th>
<th>FAR</th>
<th>SAR</th>
<th>TAR</th>
<th>AR4</th>
<th>AR5</th>
</tr>
</thead>
<tbody>
<tr>
<td>climate sensitivity</td>
<td>1.5-4.5K</td>
<td>1.0-3.5K</td>
<td>1.5-4.5K</td>
<td>2.1-4.4K</td>
<td>2-4.6K* as of Oct 2011</td>
</tr>
</tbody>
</table>

*as of Oct 2011

Mitchell et al. (1990), Kattenberg et al. (1996), Cubasch et al. (2001), IPCC (2007)

Change in cloud-shortwave flux

<table>
<thead>
<tr>
<th>Model</th>
<th>Change in SAT</th>
<th>Change in cloud-shortwave flux</th>
</tr>
</thead>
<tbody>
<tr>
<td>CanESM2</td>
<td>Positive cloud feedback</td>
<td>Negative cloud feedback</td>
</tr>
<tr>
<td>CNRM CM5</td>
<td>Positive cloud feedback</td>
<td>Neutral cloud feedback</td>
</tr>
<tr>
<td>CSIRO Mk3.6</td>
<td>Positive cloud feedback</td>
<td>Neutral cloud feedback</td>
</tr>
<tr>
<td>HadGEM2 ES</td>
<td>Positive cloud feedback</td>
<td>Neutral cloud feedback</td>
</tr>
<tr>
<td>INM CM4S</td>
<td>Neutral cloud feedback</td>
<td>Neutral cloud feedback</td>
</tr>
<tr>
<td>IPSL CM5A-LR</td>
<td>Positive cloud feedback</td>
<td>Neutral cloud feedback</td>
</tr>
<tr>
<td>MIROC5</td>
<td>Negative cloud feedback</td>
<td>Neutral cloud feedback</td>
</tr>
<tr>
<td>MRI CGCM3</td>
<td>Neutral cloud feedback</td>
<td>Neutral cloud feedback</td>
</tr>
<tr>
<td>NorESM1</td>
<td>Neutral cloud feedback</td>
<td>Neutral cloud feedback</td>
</tr>
</tbody>
</table>

Courtesy of K Taylor
Filling the gap between two PPEs

Replacing one or more schemes in MIROC5 with old ones:

- Std (=MIROC5)
- (old)CLD
- (old)CNV
- (old)VDF
- (old)CLD+CNV
- (old)CNV+VDF
- (old)CLD+VDF
- (old)CLD+CNV+VDF

~ MIROC3

- Structural difference > Parametric difference
- Any strategy to link them?

Watanabe et al. (2012, JC)
Filling the gap between two PPEs

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Any strategy to link them?

Watanabe et al. (2012, JC)
Coupling processes making differences

Feedback occurs thru the interaction of a suite of parameterized processes rather than from any single process’ (Zhang & Bretherton 2008)

MIROC MPE:
For each of 8 models,
✓ 6y CTL
✓ 6y 4xCO2
✓ 6y +SST (from CGCM) runs are performed w/ AGCM
After slight re-tuning

Processes are nonlinear, e.g.,

CLD  ->  Small impact
VDF  ->  Small impact
CLD+VDF  ->  Large impact  !!
Robust positive feedback for the tropical subsidence regimes (at least in MIROC3/5)

Large difference for the weak convective regime

Trade cumulus response?

Watanabe et al. (2012)
Cloud regimes

Circulation regime sorted by $\omega$

Altitude (model's hybrid coordinate)

High cloud
Middle cloud
Low cloud

$C$, STD
Cloud diagnosis

Cloud fraction is a function of grid-scale saturation excess, $Q_c$, and PDF moments, $\mu_i$:

$$C = f \left( Q_c, \mu_i \right)$$

$$Q_c = a_L \left\{ q_t - q_s (T_l, p) \right\}$$

$$a_L = \left( 1 + L\alpha_L / c_p \right)^{-1}$$

$$\alpha_L = \partial q_s / \partial T \bigg|_{T=T_l}$$

Change in +SST run ($\Delta$) can be decomposed into 4 terms (overbar is the mean value in CTL)

$$\Delta Q_c = a_L \left( \Delta q_t - \Delta q_s \right) + \Delta a_L \left( \bar{q}_t - \bar{q}_s \right)$$

$$= a_L \left[ (\bar{H} - 1)\alpha_L \Delta T + \Delta H\bar{q}_s + \left\{ 1 - (\bar{H} - 1)\alpha_L L_e^{-1} \right\} \Delta q_l \right] + \Delta a_L \left( \bar{q}_t - \bar{q}_s \right)$$

- Temperature effect
- RH effect
- Condensate effect
- CC effect
Sources of Qc change

In the middle troposphere of the convective regime, temp. effect (-) cancels the CC effect (+), with the net being weakly negative.

In the low level, positive RH effect due to slight increase in RH (~2%) is crucial.

\[ \Delta H \approx \left( \Delta q \bar{q}_s - \bar{q} \Delta q_s \right) / \bar{q}_s^2 \]

Positive \( \Delta H \) comes from positive \( \Delta q \), which is attributed to more active turbulence transport at \( \eta > 0.8 \).

Negative \( \Delta H \) is due to positive \( \Delta q_s \), which results from a drying by larger \( \Delta T \) than the effect of enhanced transport of \( q \).
Cloud regimes

$\Delta Q_c$ is similar among models

$
\bar{Q}_c \text{ & } \partial C / \partial Q_c \text{ are very different}
$

$\Delta C$,

increase

decrease

no response

Cloud fraction at $\eta = 0.85$
Given *two* base models showing different cloud feedbacks, MPE can be a useful approach to understand sources of the different behaviour.

In MIROC MPE, no single process controls $\Delta SW_{cld}$, but the coupling of two processes does:
- cloud and turbulence schemes
- convection and cloud schemes

Change in the saturation excess has a similar structure among the models, but difference in the mean and sensitivity may cause an opposite response of low clouds.