Role of Ocean Dynamical feedback in the climate response to GHG warming

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Gokhan Danabasoglu
Background

Under global warming forcing, some robust patterns start to emerge:

- Enhanced Equatorial Pacific Warming (EEW, Liu et al., 2005) Or El Nino-like?
- Strengthening of the southeasterly trade over SE subtropical Pacific.
- Minimum warming is mid-lat southern oceans centered at 55° S.
- Drying of the subtropical land areas (particularly the American SW).
- SAM-like response in the atmospheric circulation.
El Niño-like warming?

SST trend between 2001–2100 in A2 scenario

DeNezio (2010)

EEW, Liu et al., 2005

Lu et al., 2008
Acceleration of the SW trade wind

GFDL CM2.1

NCAR CCSM3

Xie et al 2010
Drying of the subtropical land
Does the ocean dynamics have anything to do with all these?
Methodology

Overriding

Naturally coupling

ATM

Heat
Momentum
buoyancy

OCN

Overriding

ATM

Heat
Momentum
buoyancy

OCN
Methodology

Overriding (for same forcing)

Naturally coupling

ATM:  
OCN:  

Overriding

ATM overriding:  
OCN:  

year

year

time
# Experiments to unravel the role of ocean dynamics

<table>
<thead>
<tr>
<th>NAME</th>
<th>RUN (yrs)</th>
<th>DESCRIPTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>1x</td>
<td>500</td>
<td>Control with pre-industrial CO2 (1xCO2)</td>
</tr>
<tr>
<td>2x</td>
<td>240</td>
<td>Doubling CO2 (2xCO2)</td>
</tr>
</tbody>
</table>

**Freely Coupled Experiments with UOM of CCSM3.0 (T31x3)**

**Overriding Experiments with UOM**

<table>
<thead>
<tr>
<th>NAME</th>
<th>RUN (yrs)</th>
<th>DESCRIPTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>W1x_1x</td>
<td>240</td>
<td>Overriding with wind stress from 1x, 1xCO2</td>
</tr>
<tr>
<td>W1x_2x</td>
<td>240</td>
<td>Overriding with wind stress from 1x, 2xCO2</td>
</tr>
<tr>
<td>W2x_2x</td>
<td>240</td>
<td>Overriding with wind stress from 2x, 2xCO2</td>
</tr>
<tr>
<td>E1x_1x</td>
<td>240</td>
<td>Overriding with wind speed from 1x on the evaporation term, 1xCO2</td>
</tr>
<tr>
<td>E1x_2x</td>
<td>240</td>
<td>Overriding with wind speed from 1x on the evaporation term, 2xCO2</td>
</tr>
<tr>
<td>E2x_2x</td>
<td>240</td>
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</tr>
<tr>
<td>WE1x_1x</td>
<td>240</td>
<td>Overriding with wind stress and wind speed from 1x, 1xCO2</td>
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<td>WE1x_2x</td>
<td>240</td>
<td>Overriding with wind stress and wind speed from 1x, 2xCO2</td>
</tr>
<tr>
<td>WE2x_2x</td>
<td>240</td>
<td>Overriding with wind stress and wind speed from 2x, 2xCO2</td>
</tr>
</tbody>
</table>

\[
\tau = \rho_A C_D \left\| \Delta U \right\| \Delta U \\
E = \rho_A C_E \left\| \Delta U \right\| \Delta q \\
H = \rho_A C_p C_H \left\| \Delta U \right\| \Delta \theta
\]

Effect of wind on sensible heat is not considered
Upper Ocean Dynamics of CCSM3

1. The deep layers of the POP is restored towards the equilibrium DOM of the CCSM3.

2. Reduce the equilibrating time at least a factor of 10.
1. The weakening Walker Cell hypothesis for the EEW.

2. Formation of the SST pattern.

3. Feedback of ocn dyn to Annular mode response.
Wind stress/speed changes

(a) CONTROL (1x)

(b) 2xCO2 – CONTROL (2x-1x)

(c) CONTROL OVERIDING (W1x)

(d) 2xCO2 OVERIDING – CONTROL (W1x-1x)
Weaker Walker circulation hypothesis (e.g., Vecchi et al., 2008, EOS; IPCC AR4):

- An El Niño like response to increased greenhouse gases may be expected since models and theory indicate that the tropical atmospheric circulation should weaken in response to a warming climate. This weakening is manifested primarily as a reduction in the intensity of the Walker circulation and a decline of the equatorial easterlies along with other atmospheric feedbacks. The westerly anomalies deepen the thermocline in the east, acting to warm the eastern ocean (thermocline feedback).
Test of WWC hypothesis

- Coupled 
  \((2x - 1x)\)

- Fixed wind stress 
  \((W_{1x\_2x} - W_{1x\_1x})\)

- Effect of wind stress changes 
  \((W_{2x\_2x} - W_{1x\_2x})\)
WES hypothesis (Xie et al. 2010)

\[ T' = \frac{D_o + Q_a}{\alpha \bar{Q}_E}, \quad Q_a : \bar{Q}_E \frac{W'}{\bar{W}} \]

SST

Wind Stress
W-E-S feedback

2x minus 1x

WE1x_2x minus WE1x_1x

WE2x_2x minus WE1x_1x

WE2x_2x minus WE1x_2x
W-E-S feedback in Southern Ocean

-2x-1x

WE1x_2x
WE1x_1x
WE2x_2x
W2x_2x
W1x_2x

-8 -4 0 4 8
deg K
Effect of oceanic feedback on SAM

2x minus 1x  \[ \text{Pa} \]

W1x_2x minus W1x_1x  \[ \text{Pa} \]

W2x_1x minus W1x_1x  \[ \text{Pa} \]

W2x_2x minus W1x_1x  \[ \text{Pa} \]
Time scale of SAM vs lat of jet

- Y of mean max surface wind
- lag 1 corr coef

Legend:
- 1x_uom
- 2x_uom
- w2x_2x
- w1x_2x
- w1x_1x
- we2x_2x
- we1x_2x
- we1x_1x
- w2x_1x
Time scale of SAM vs lat of jet
Time scale of SAM vs shift of jet

To be completed
Effect of oceanic feedback on N. Amr precip

2x minus 1x

WE1x_2x minus WE1x_1x

W2x_2x minus W1x_1x

WE2x_2x minus WE1x_2x
Concluding remarks

• Weaker Walker circulation seems to be an oversimplification for the EEW response.

• WES plays a substantive role in shaping the tropical Pacific SST response.

• (wind-driven) Ocean dynamical feedback to the SAM response is positive.

• Feedbacks from changing (wind-driven) ocean dynamics does not matter as much to the extratropical (NA) as to the tropical hydrological response to global warming. --- A slab model will do.

• Application to ocean circulation response.
Note of caution

• Resolution and model dependence.
• Similar experiments with more updated CCSM and other CMIP models