Model Biases & Uncertainties in CMIP5 Models: Ocean Carbon Uptake & Climate Feedbacks

Scott Doney (WHOI), Matt Long & Keith Lindsay (NCAR) & CESM-BGC Working Group

Useful References

- IPCC WG1 Chapter 6 (Cias, Sabine et al. 2013)
- J. Climate Special Collection "Climate–Carbon Interactions in the CMIP5 Earth System Models" (C4MIP)
- Biogeosciences Special Issue "REgional Carbon Cycle Assessment and Processes (RECCAP)"
Human Perturbation to Global Carbon Cycle

Canadell et al. PNAS 2007; LeQuere et al. Nature Geosciences 2009
Data-based Ocean $\Delta$C Inventory Patterns

WOCE/CLIVAR Repeat Hydrography & CO$_2$ Data
- multiple approaches based on analysis of CO$_2$ system, biogeochemical & transient tracer data combined with diagnostic modeling

Khatiwala et al. Biogeosciences 2013
Regional Variations in Data & Model Estimates

Khatiwala et al. Biogeosciences 2013
Diagnosing Model Biases

Anthropogenic Carbon

Data (GLODAP) versus Ocean-ice Hindcast Model - Data

Atlantic Zonal Mean

Global ΔC Inventory in 1994

CESM1-BGC  90 Pg C
GLODAP data  118±19 Pg C

Long et al.
J. Climate 2013
Diagnosing Model Biases

Anthropogenic Carbon

Data (GLODAP)

Ocean-ice Hindcast

Model - Data

Chlorofluorocarbons

Model - Data

Atlantic Zonal Mean

Global ΔC Inventory in 1994

CESM1-BGC  90 Pg C

GLODAP data  118±19 Pg C

Long et al.
J. Climate 2013
Ocean Uptake Trends & Variability

Anav et al.
J. Climate 2013
### CMIP5 Ocean Model Skill

#### Variable

- NPP
- \( F_{\text{CO}_2} \)
- MLD
- SST

#### Skill Metric of Bias & Interannual Variability

<table>
<thead>
<tr>
<th>Variable</th>
<th>Skill Metric of Bias &amp; Interannual Variability</th>
</tr>
</thead>
<tbody>
<tr>
<td>NPP</td>
<td>#14 #5 #8 #13 #11 #12 #4 #6 #10 #7 #9 #3 #2 #1</td>
</tr>
<tr>
<td>( F_{\text{CO}_2} )</td>
<td>#7 #13 #8 #1 #4 #2 #5 #11 #15 #17 #14 #16 #9 #6 #12 #10 #3 #18</td>
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<tr>
<td>MLD</td>
<td>#10 #11 #6 #8 #2 #1 #7 #5 #9 #4 #3 #13 #12 #14</td>
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<tr>
<td>SST</td>
<td>#5 #6 #7 #2 #3 #16 #13 #11 #10 #4 #15 #8 #18 #14 #12 #9 #1 #17</td>
</tr>
</tbody>
</table>

#### Models

- BCC-CSM1
- BCC-CSM1-M
- BNU-ESM
- CanESM2
- CESM1-BGC
- GFDL-ESM2G
- GFDL-ESM2M
- HadGEM2-CC
- HadGEM2-ES
- INMCM4
- IPSL-CM5A-LR
- IPSL-CM5A-MR
- MIROC-ESM
- MIROC-ESM-CHEM
- MPI-ESM-LR
- MPI-ESM-MR
- NorESM1-ME

#### Skill Metrics

- Seasonal cycle amplitude & phase
- Spatial bias
- Interannual Variability (spread of probability distribution)

#### References

Anav et al.
J. Climate 2013
Sensitivity experiments with prescribed atmospheric CO$_2$ increasing at 1%/y

Arora et al. J. Climate 2013
Linear decomposition of cumulative ocean carbon inventory

\[ \Delta C = \beta \Delta C_{\text{atm}} + \gamma \Delta T \quad \beta (\text{PgC/ppm}); \quad \gamma (\text{Pg C/K}) \]

\[ \Delta C_{\text{coupled}} = \Delta C^\beta + \Delta C^\gamma \]

Full-CTRL   T1850-CTRL   Full-T1850

\[ \Delta C_{\text{coupled}} = \Delta C^\beta + \Delta C^\gamma_{\text{nat}} + \Delta C^\gamma_{\text{anthro}} \]

Full-CTRL   T1850-CTRL   C1850-CTRL   residual
Climate Feedbacks on Natural & Anthropogenic C

Proper accounting for “non-linear” climate terms on both natural & anthropogenic carbon fields

Schwinger et al. J. Climate 2014
Feedback parameters sensitive to scenarios
- rate of change of atmospheric CO₂
- prescribed concentration vs. emissions
Scenario & Time Dependence of Climate Feedback

- RCP8.5 + ECP8.5
- Full Anthro Forcing
- Non-CO$_2$ Forcing
- No Anthro Forcing

Cumulative Ocean Heat Uptake

Randerson et al. in prep.
Time-Integrated Air-Sea Flux Components

\[ \Delta C^\beta \]

\[ \Delta C^{\gamma}_{nat} \]

\[ \Delta C^\gamma \]

\[ \Delta C^{\gamma}_{ant} \]

positive := downward

Long et al. in prep.
Ocean CO$_2$ Uptake Trends

changing physics
fixed physics

Wanninkhof et al. Biogeosci. 2013
Khatiwala et al. Biogeosci. 2013
Diagnosing Processes Controlling CO$_2$ Uptake

M. Long et al. in prep.
Diagnosing Vertical Transport Terms

M. Long et al. in prep.
Ocean Carbon Uptake Biases & Uncertainties

-Skill Metrics Against Contemporary Observations

- Coupled ocean-atmosphere model biases
- Joint physical-biogeochemical errors
- Southern Ocean biases
- Detection & attribution of climate change signal

-Model Derived Atmospheric CO\textsubscript{2} & Climate Feedbacks

- Scenario dependence
- Southern Ocean & North Atlantic hotspots
- Diagnosing physical transport terms
- Unaccounted for biogeochemistry