ESMs in CMIP5
Some carbon cycle results

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Rationale

• Why should we care about the carbon cycle?
• What’s in current ESMs?
• How do they perform?
• Are we getting any better?
• What are the lessons for IAMs?
Fate of Anthropogenic CO$_2$ Emissions (2000-2009)

1.1 PgC y$^{-1}$

7.7 PgC y$^{-1}$

+$

4.1 PgC y$^{-1}$

2.4 PgC y$^{-1}$

26%

2.3 PgC y$^{-1}$

47%

27%

Peters et al., 2011, Friedlingstein et al., 2010, Le Quéré et al. 2009, Canadell et al. 2007
Land and ocean uptakes are driven by atmospheric CO$_2$ and climate (land surface temperature, soil water content, ocean temperature, salinity, oceanic circulation, surface winds,...)
Carbon cycle feedbacks

• CO2 concentration-carbon cycle feedback
  – Strong negative feedback

• Climate-carbon cycle feedback
  – Positive feedback
What is an Earth System Model?

Basic structure of GFDL’s Earth System Model
Outlaw at the time of AR4

In IPCC AR4

- OAGCM models driven by CO2 concentration
- C4MIP models driven by CO2 emissions

General findings:
- Large uncertainty in CO$_2$ projections
- Adds uncertainty on climate projections
- Positive climate-carbon cycle feedback leads to larger warming.

Meehl et al., 2007
Within CMIP5 and AR5

- CMIP5 has 2 suites of experiments: near-term and long-term.
- For long term, most are driven by CO$_2$ concentration, allowing GCMs and ESMs to participate.
- Some ESM specific experiments for carbon cycle feedbacks evaluation.

Taylor et al., 2011
Within CMIP5 and AR5

- 20C for model evaluation.
- RCPN.N for future C-cycle projections, compatible emissions
- 1%CO2 for feedback analysis
- E-driven historical and RCP8.5 for projections of climate and C-cycle

Taylor et al., 2011
Within CMIP5 and AR5

- In CMIP3: 0 ESMs (?)
- In C4MIP: 7 ESMs
- For CMIP5: ~10 groups, ~18 models versions.
ESM carbon cycle evaluation

Also, models evaluation on LAI, GPP, MLD, NPP, DIC CO₂,…
If the pools are off (in particular the soil carbon pool), it quite likely that you land sinks will be off (hence the CO$_2$, hence the ocean sink,…)

Anav et al., 2012
ESM carbon cycle evaluation

- Some models (MPI-ESM) severely overestimate soil carbon and land sink.

- Reasons for “missing the target”
  - too slow soil turnover time (especially for arid ecosystems)

\[\text{Vegetation carbon content} \quad \text{Soil Carbon content} \quad Anav et al., 2012\]
ESM carbon cycle evaluation

• Some models (CESM, NorESM) severely underestimate soil carbon and land sink. These two ESMs share the same land model (CLM). Only CMIP5 models with interactive Nitrogen cycle (which should be a plus…)

• Reasons for “missing the target”
  – too fast soil turnover time
  – Nitrogen limits ecosystems response to CO₂

Anav et al., 2012
RCP forcing to ESMs

Van Vuuren et al., 2011
RCP global surface warming

Knutti et al., 2012
Change in ocean carbon

- Overall, fair agreement between models
- One known outlier (INMCM4), already off for historical uptake
- Scenario spread is larger than models spread.
Change in land carbon

- Models don’t always agree on the sign of the change
- some “known outlier (INMCM4, no land use)
- models spread is larger than scenario spread...
- Land use is partly responsible for this. Unclear how ESMs differ in their LUC estimate (no appropriate diagnostic)
We can’t just blame land use…

1% CO2 increase (no land use)

Same story: ocean models agree land models don’t…

Models with Nitrogen largely explain the spread here.
Back to RCPs, compatible emissions

- ESMs Allow to compute compatible emissions for each RCP:

\[
\frac{dC_A}{dt} + \frac{dC_L}{dt} + \frac{dC_O}{dt} = E_F
\]

- Broadly comparable with the IAMs RCP emissions
- Models average is slightly lower for RCP4.5 and above
Back to RCPs, compatible emissions

- “Broad agreement” is quite remarkable knowing that some of these models do LUC some don’t; some have Nitrogen, some don’t,…
- Remember that

\[
\frac{dC_A}{dt} + \frac{dC_L}{dt} + \frac{dC_O}{dt} = E_F
\]

and \([\text{CO}_2]\) is given
- Agreement is not that impressive after all…
Back to RCPs, compatible emissions

RCP2.6 compatible emissions

- RCP2.6 does not always require negative emissions.
Change in airborne fraction

- AF increase for the RCP8.5 (consistent to what was found before with SRESA2), but AF decreases in RCP2.6 or 4.5.
- AF trends are primarily driven by trends in emissions (i.e. in [CO2] growth rate)
- Future change in AF is not a “metric” of carbon cycle feedback
ESMs forced by emissions

RCP8.5 driven by CO$_2$ emissions. ESMs calculate both atmospheric CO$_2$ and climate change.

Simulated CO$_2$ is generally larger than the prescribed CO$_2$ given by MAGICC6.

Larger warming when ESMs use prescribed emissions (black) than when using prescribed CO$_2$ concentration (red)

But, mainly due to 2 models that over-predict CO2 for present-day… Not sure what to conclude!
ESMs and IAMs

ESMs simulate larger atmospheric CO$_2$ than the prescribed CO$_2$ given by MAGICC6. Also MAGICC6 CO$_2$ range has a much lower lower bound (820 vs 920).
MAGICC6 lower bound is due to its higher estimates of ocean carbon uptake (by a factor of 2)
MAGICC6 was tuned to all CMIP3 GCMs for climate and C4MIP models for carbon. That includes a "suspicious" C4MIP model…
Present-day land and ocean uptakes for that "suspicious" C4MIP model...

We might have wanted not to use it for tuning…
Conclusions

- ESMs historical land carbon pools and fluxes are still embarrassingly all over the place.
- Obviously, not enough tuning/validation has been done in the model development phase (lack of time?)
- It is quite tempting not to treat all of them equally for model projections
- CMIP5 ESMs are not significantly better than C4MIP models
- More processes are included (land use change, nitrogen cycle) 😊 but this artificially enhances the models spread 😞

- CMIP5 projections of compatible emissions are broadly consistent with the IAMs estimates
- Still, don’t blindly trusts ESMs, we also have better (and worst) models…
- Any IAMs tuning on ESMs behaviour needs to have this in mind.