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}
47%

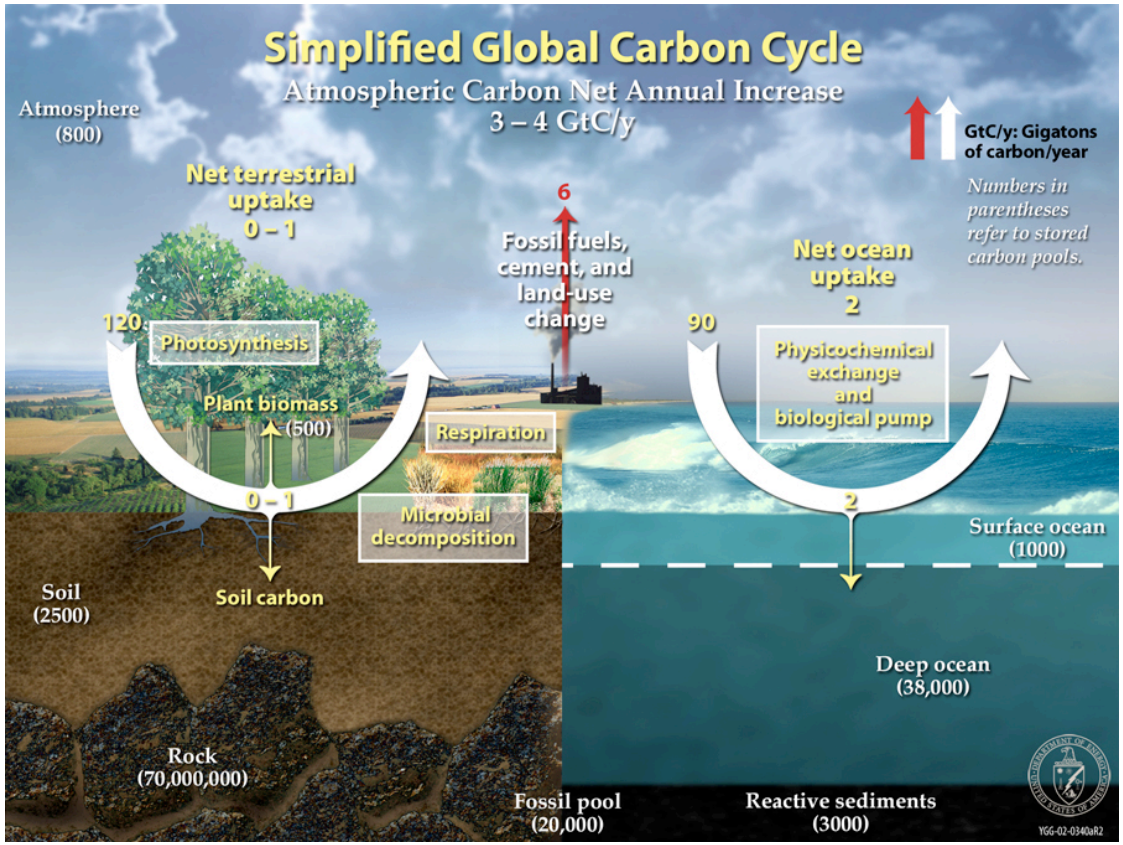
2.4 PgC y^{-1}
27%

26%
2.3 PgC y^{-1}

Global Carbon Project

Peters et al., 2011, Friedlingstein et al., 2010, Le Quéré et al. 2009, Canadell et al. 2007

Carbon cycle feedbacks



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,…)

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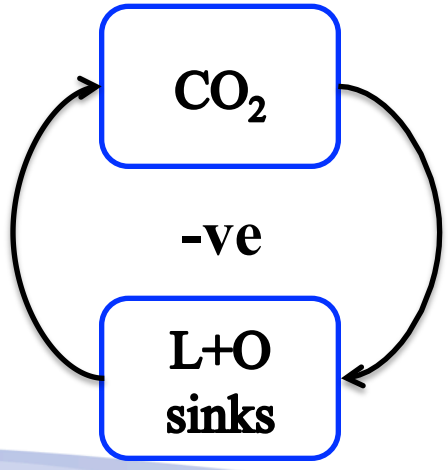
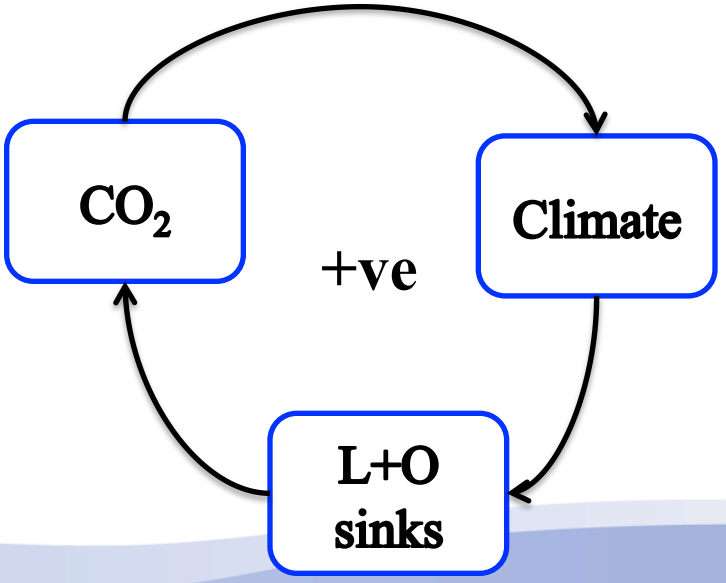
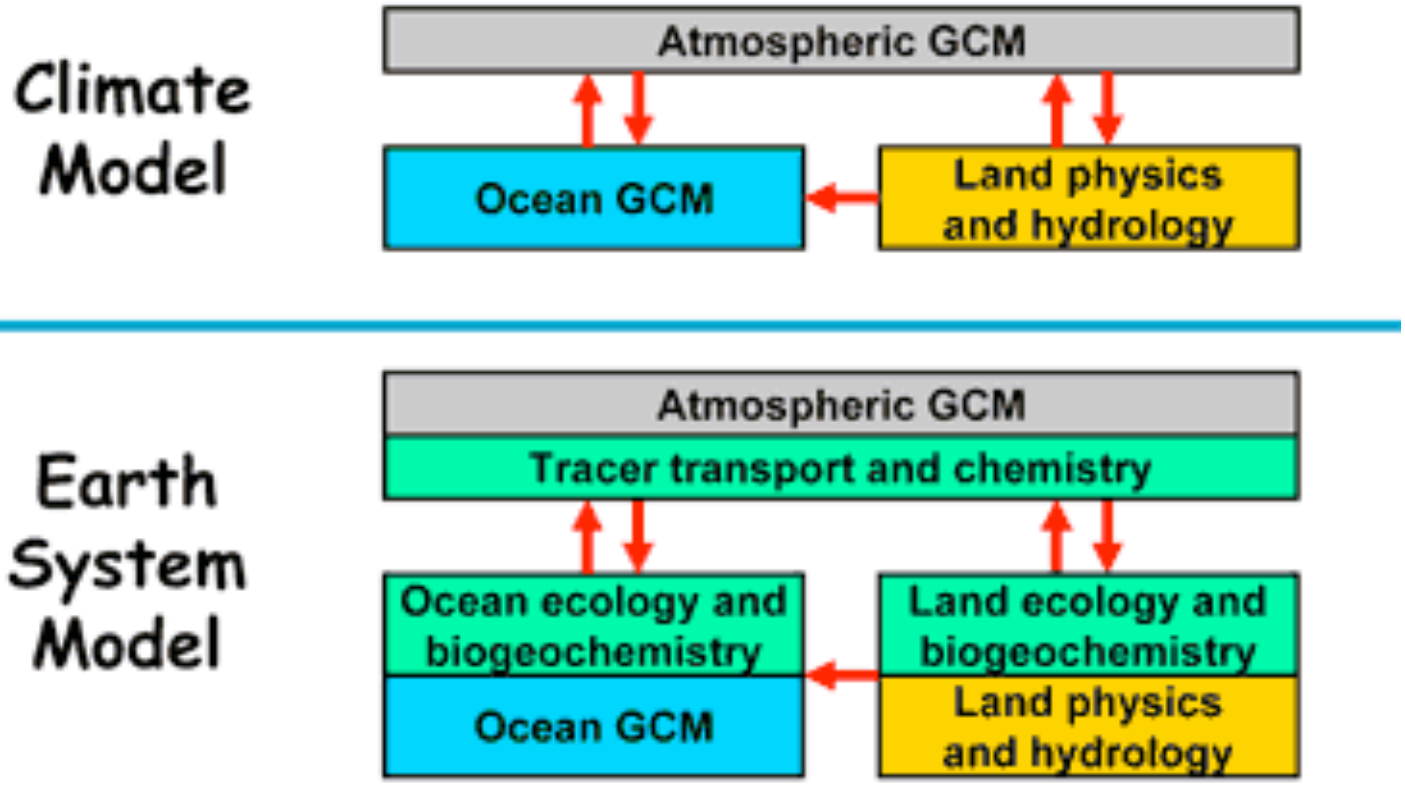
Carbon cycle feedbacks

- 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

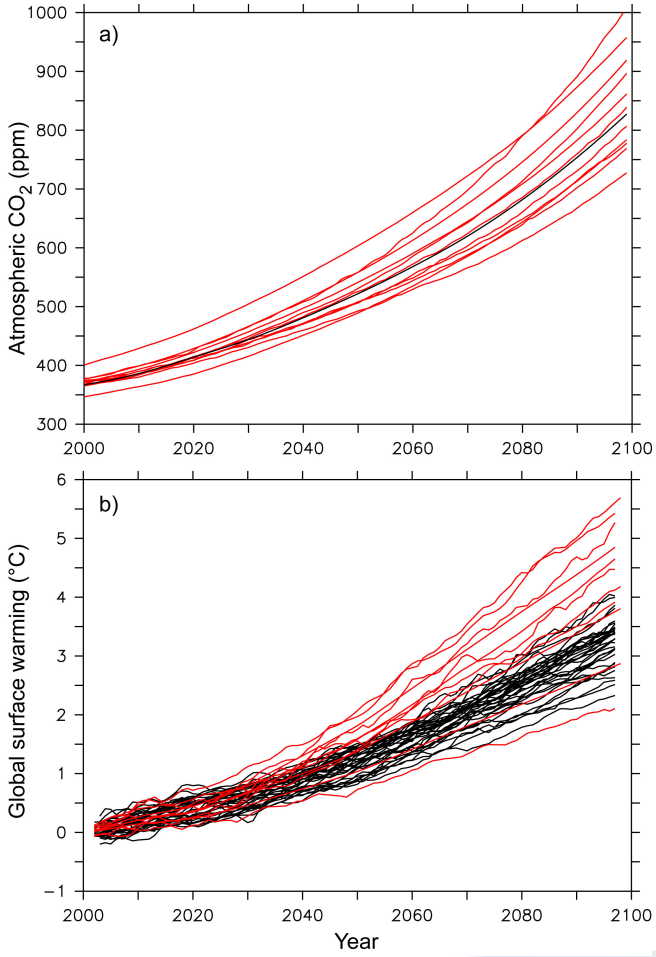
Outlaw at the time of AR4

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

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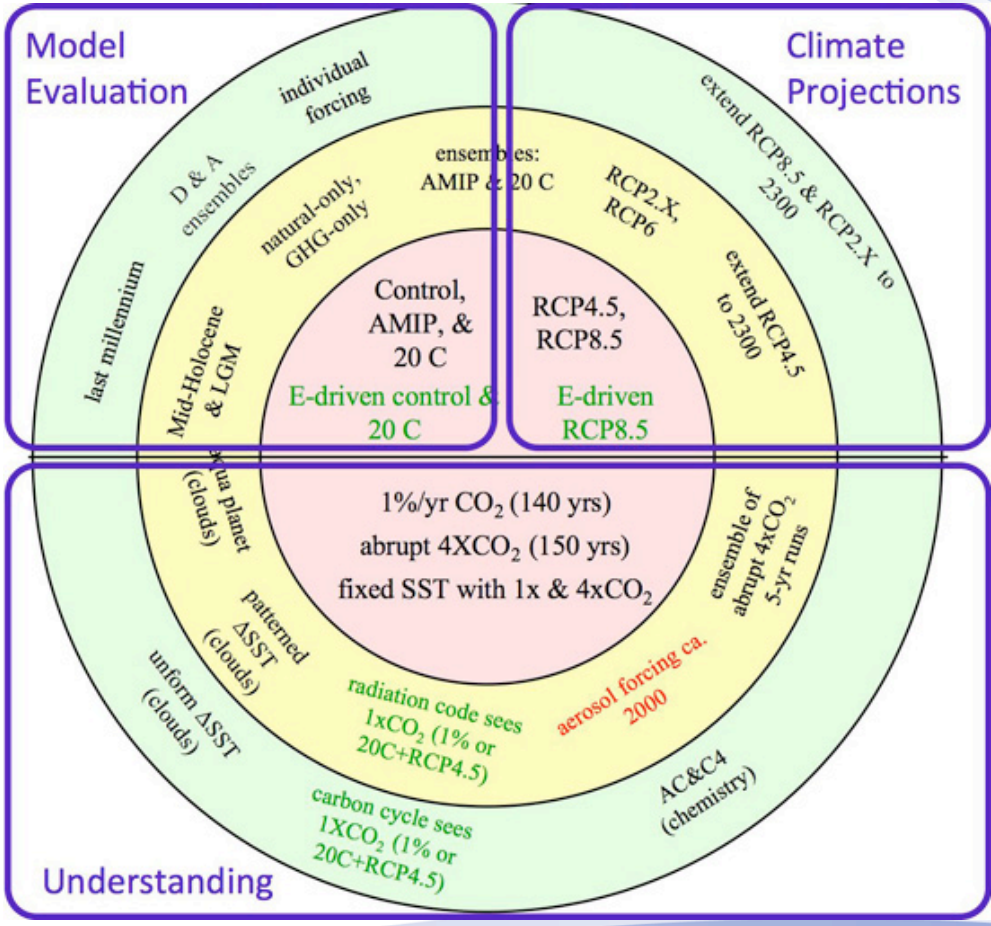
Within CMIP5 and AR5

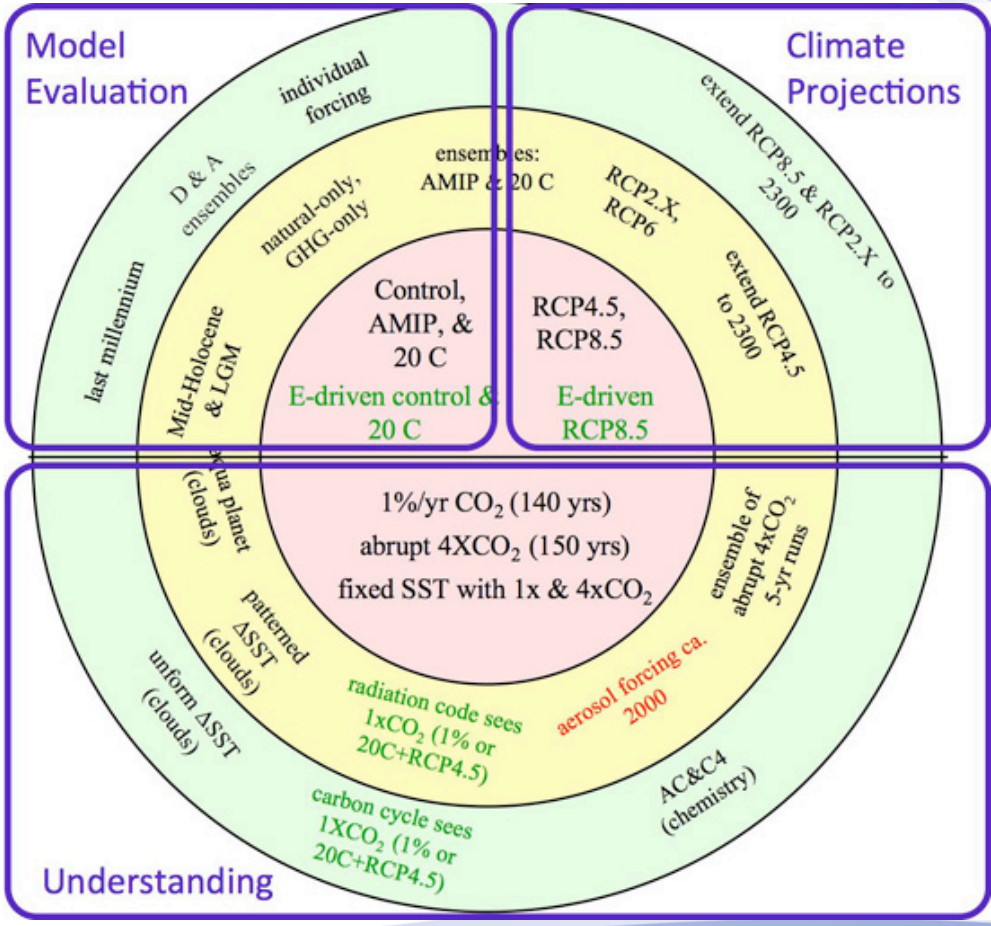
- CMIP5 has 2 suites of experiments: near-term and long-term.
- For long term, most are driven by CO_2 concentration, allowing GCMs and ESMs to participate
- Some ESM specific experiments for carbon cycle feedbacks evaluation



Taylor et al., 2011

Within CMIP5 and AR5

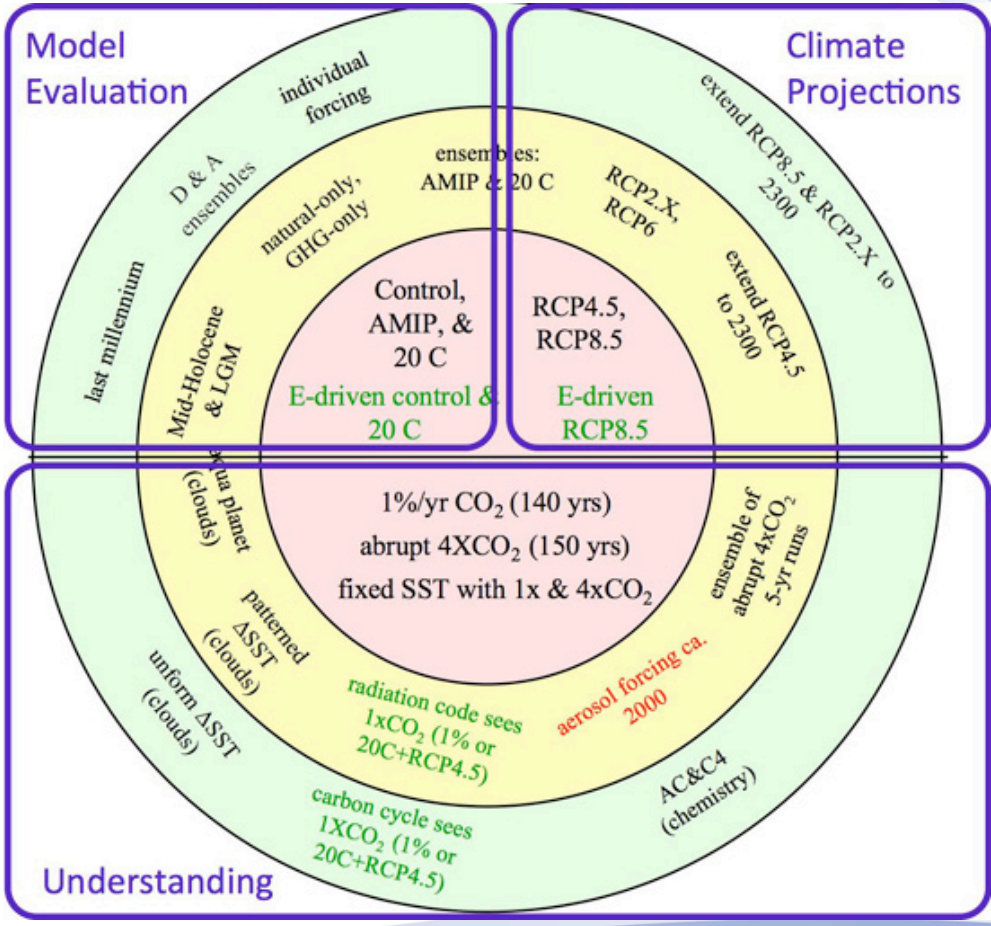
- 20C for model evaluation.
- RCPN.N for future C-cycle projections, compatible emissions
- 1%CO2 for feedback analysis
- E-driven historical and RCP8.5 for projections of climate and C-cycle



Taylor et al., 2011

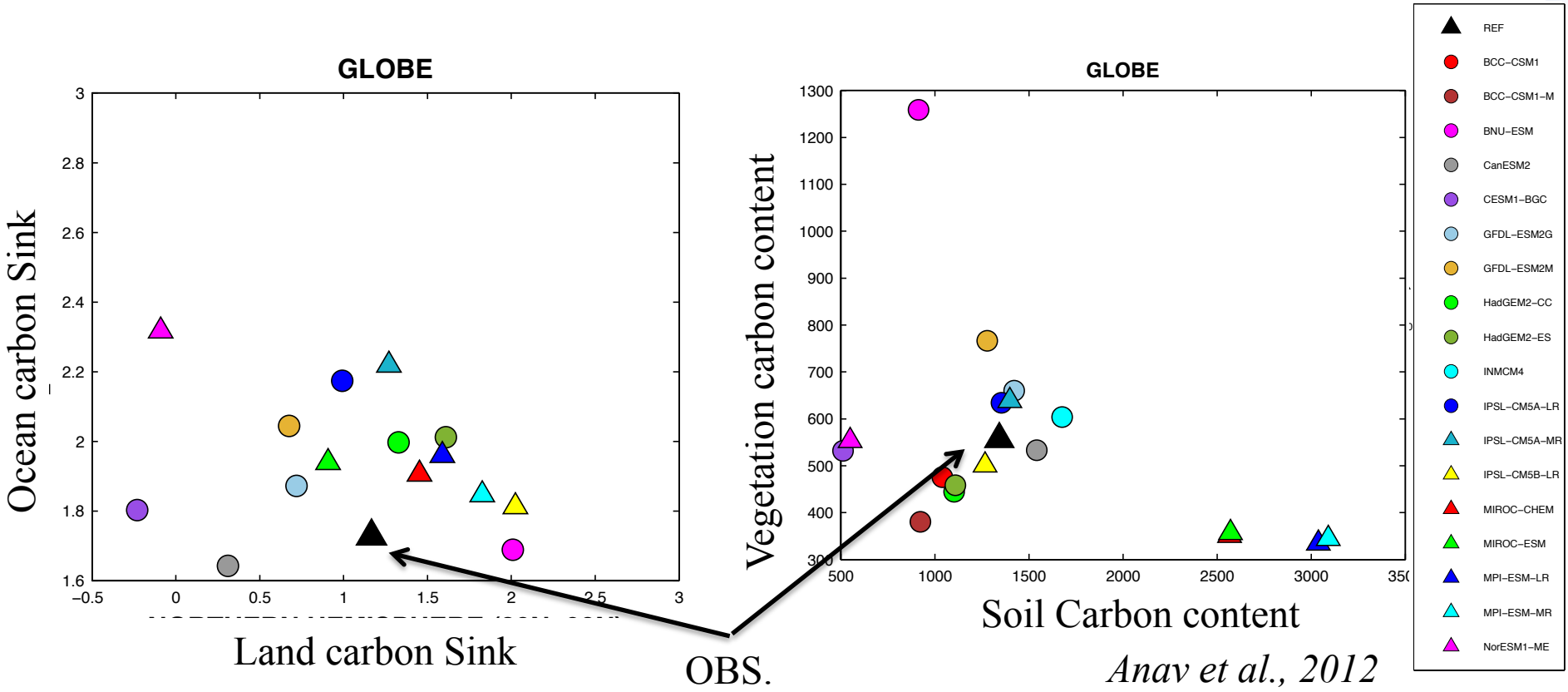
Within CMIP5 and AR5

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



Taylor et al., 2011

ESM carbon cycle evaluation



Anav et al., 2012

Also, models evaluation on LAI, GPP, MLD, NPP, DIC CO_2,…

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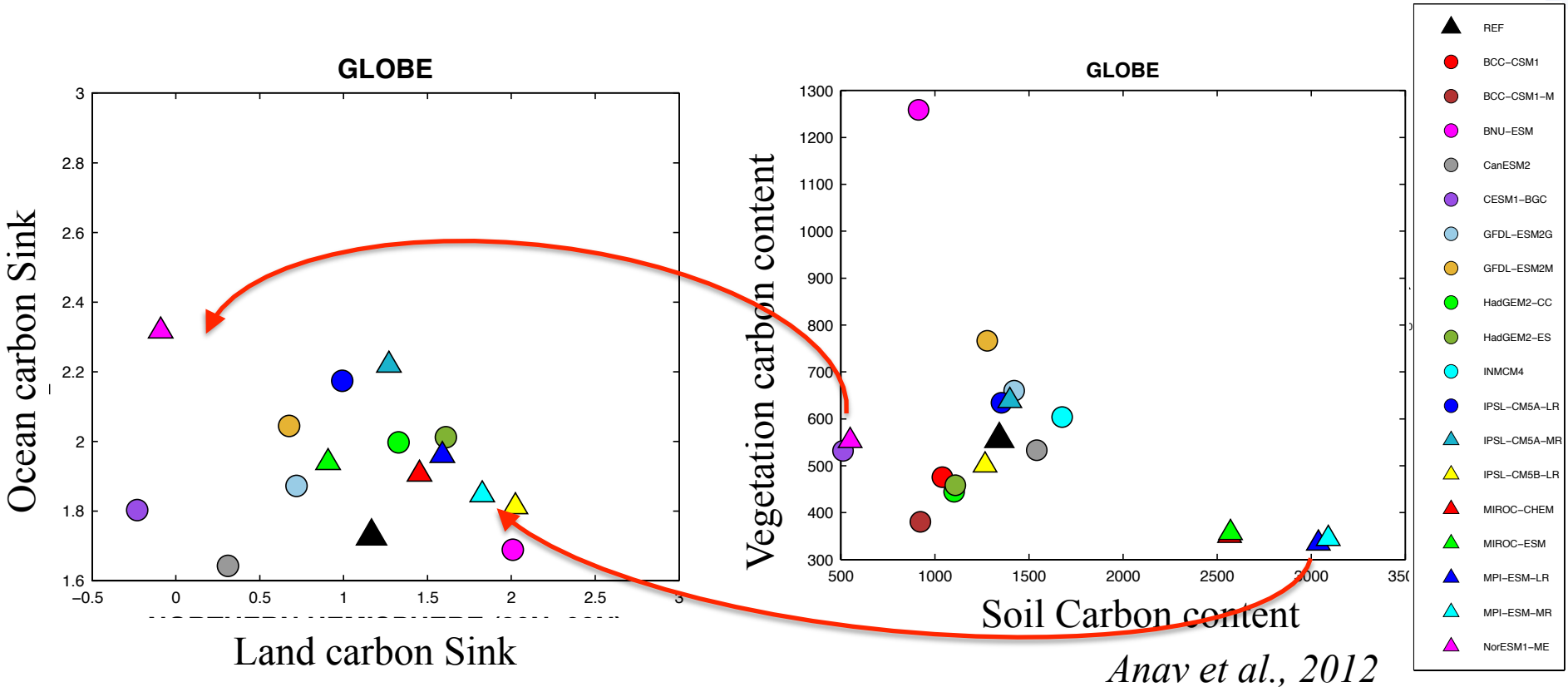
ESM carbon cycle evaluation



Anav et al., 2012

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,…)

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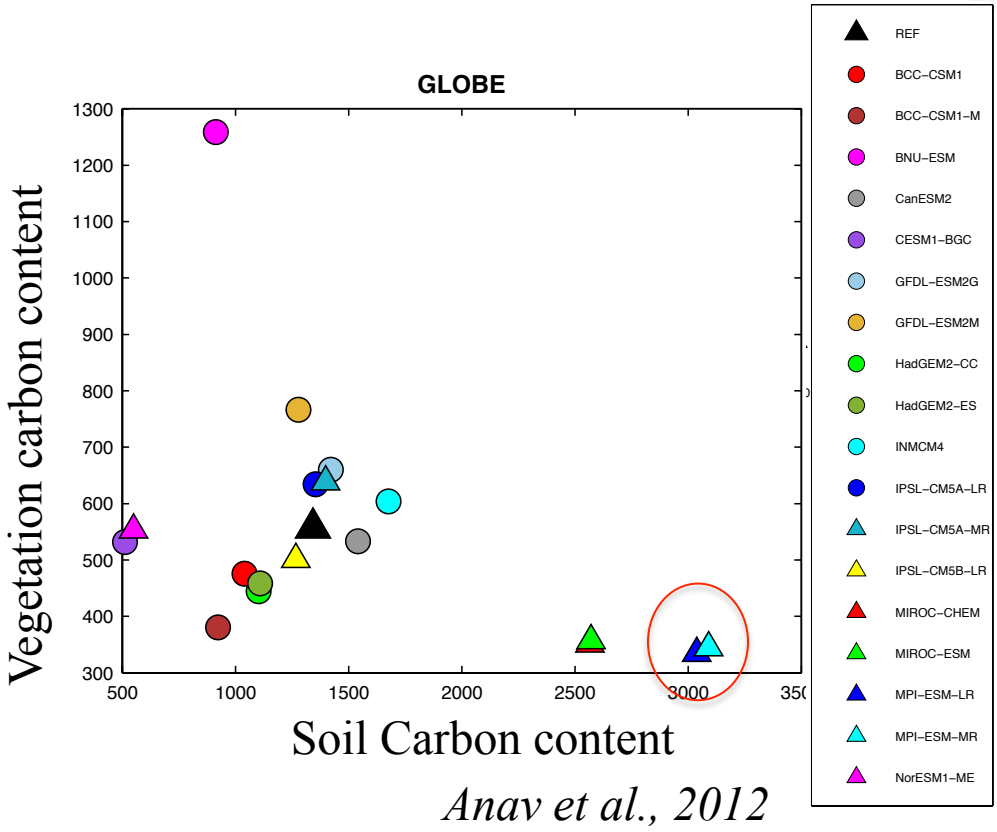
ESM carbon cycle evaluation

- 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)



Anav et al., 2012

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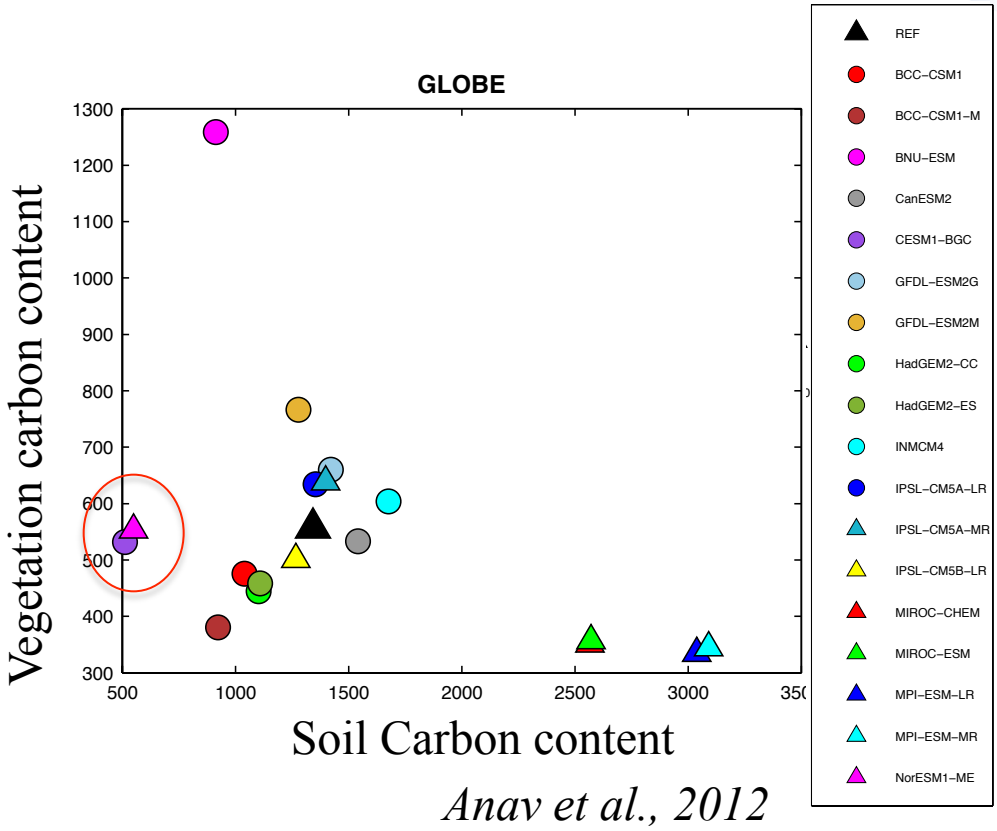
ESM carbon cycle evaluation

- 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 CO_2



Anav et al., 2012

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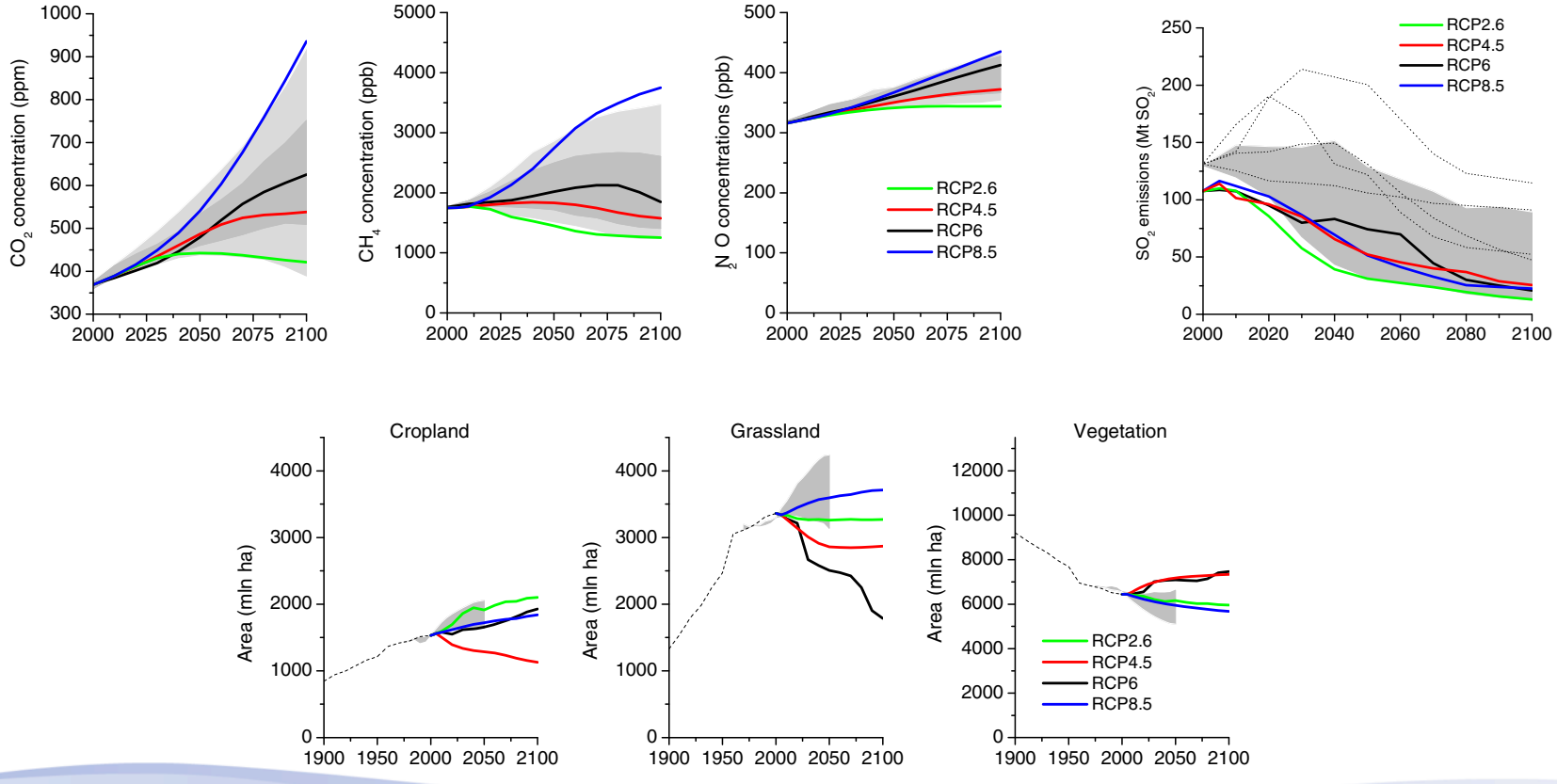
RCP forcing to ESMs



Van Vuuren et al., 2011

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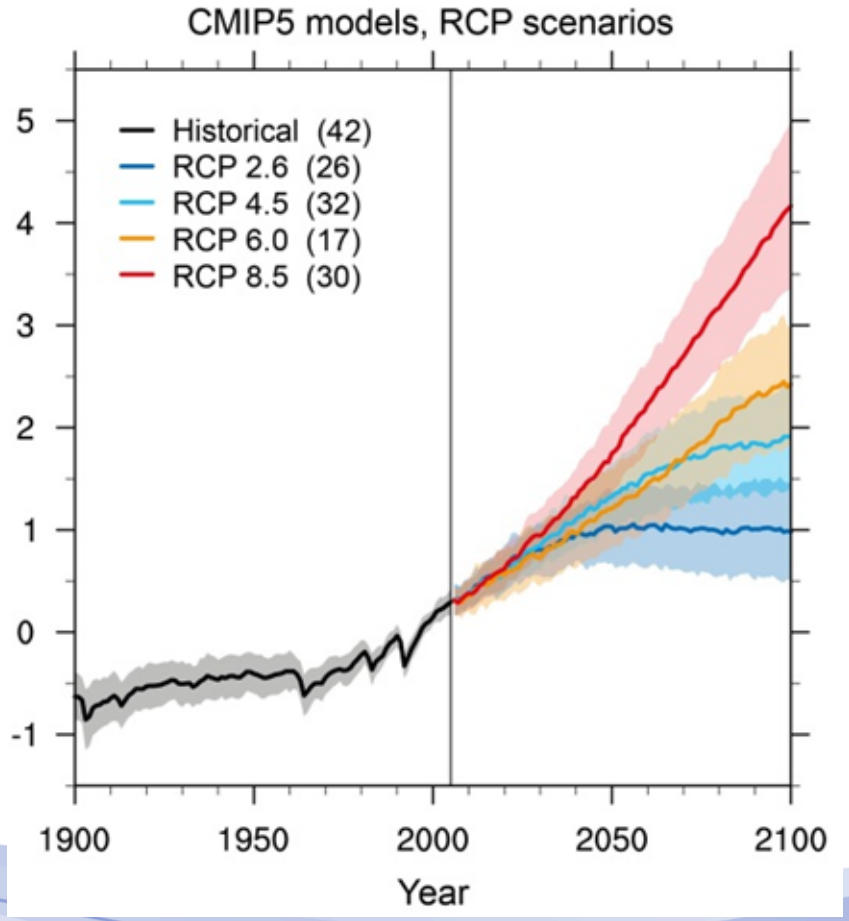
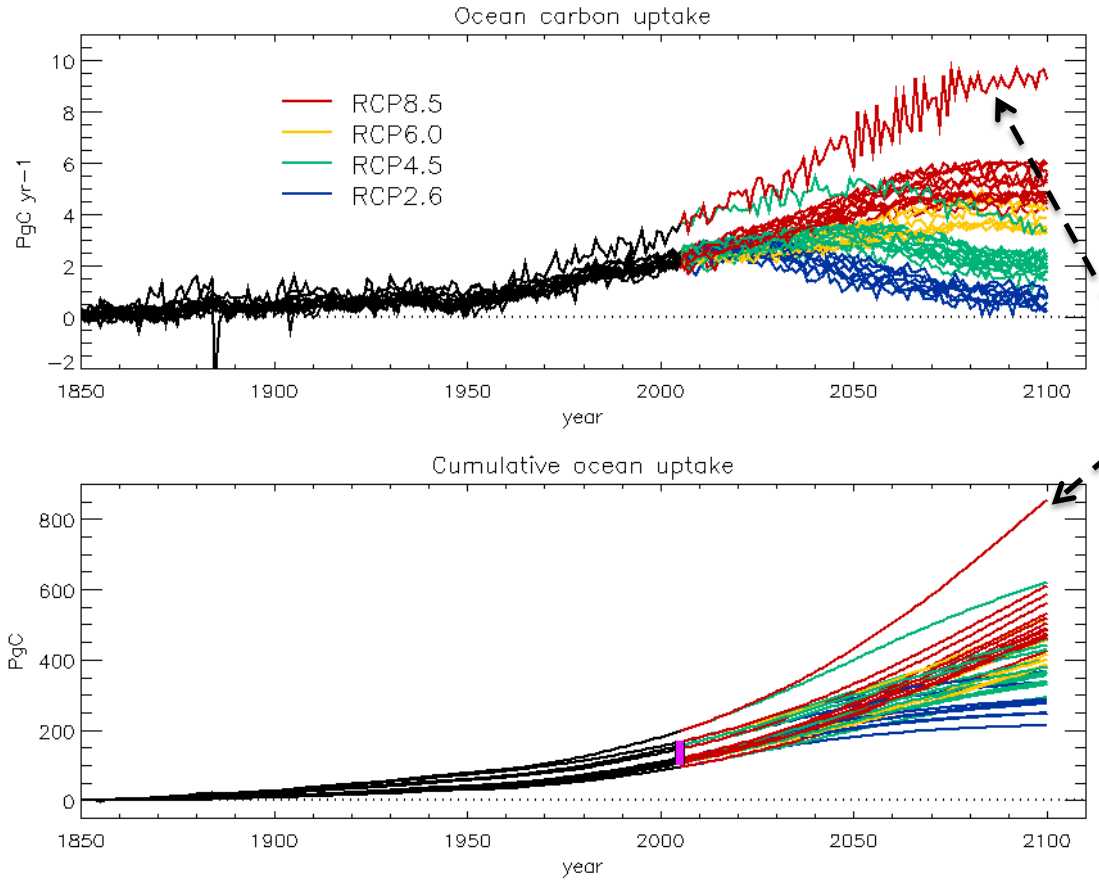
RCP global surface warming



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.

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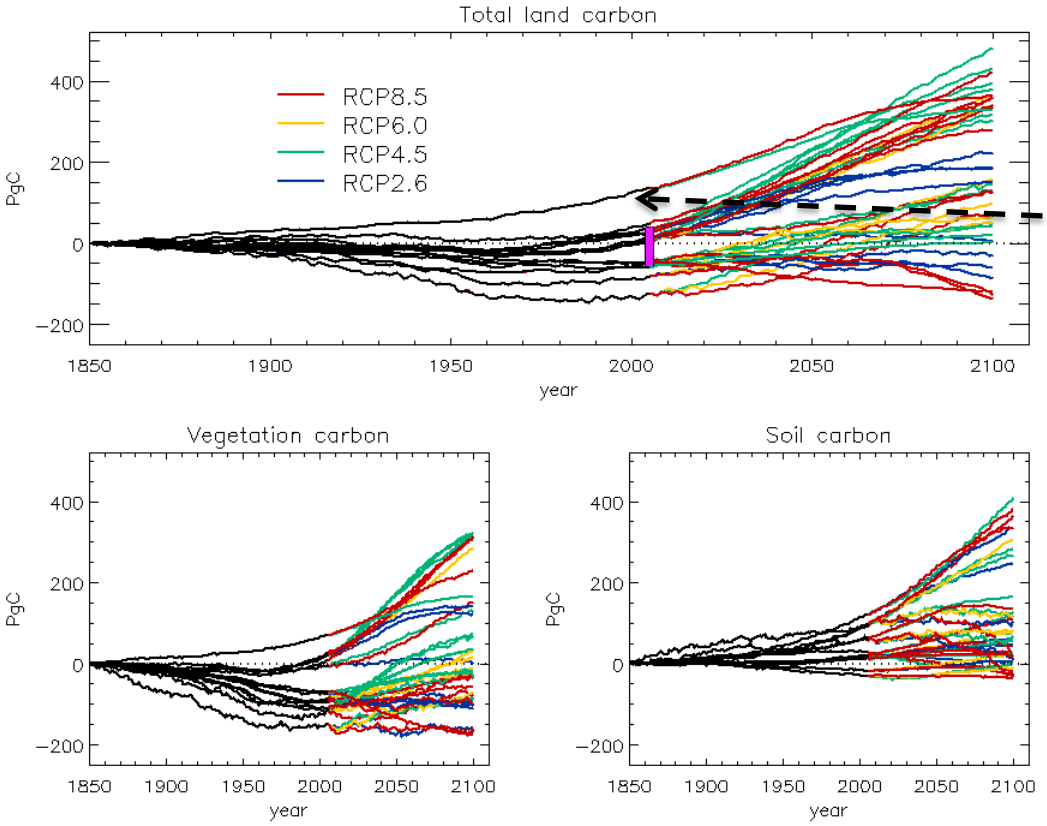
Change in land carbon



- 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)

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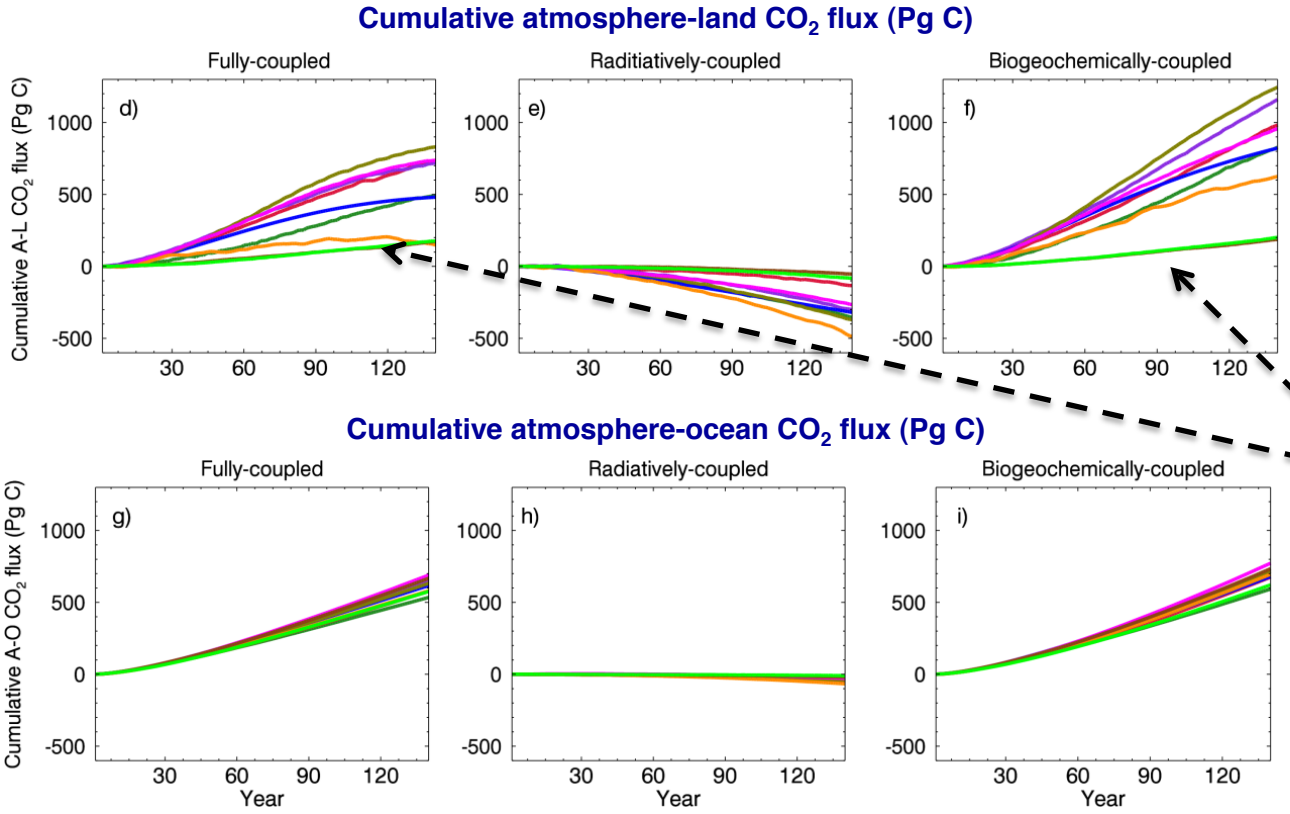
We can't just blame land use…



1% CO2 increase (no land use)

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

Models with Nitrogen largely explain the spread here.

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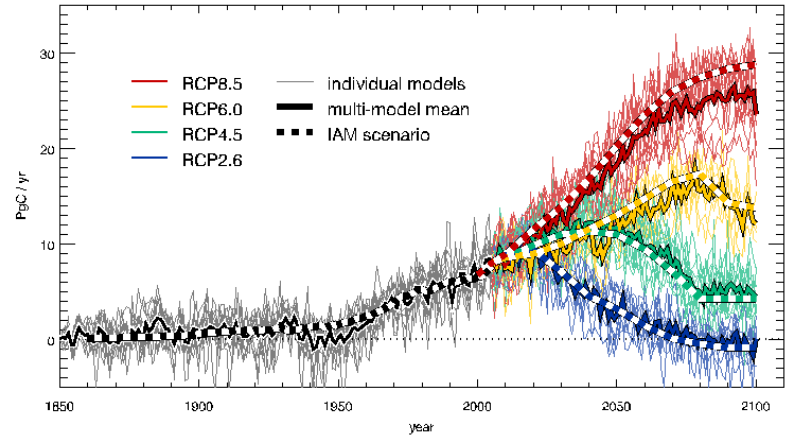
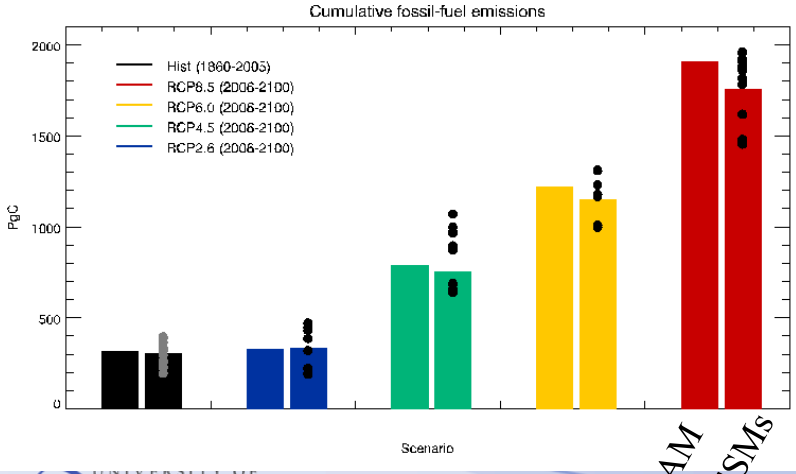
Back to RCPs, compatible emissions





- ESMs Allow to compute compatible emissions for ech 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

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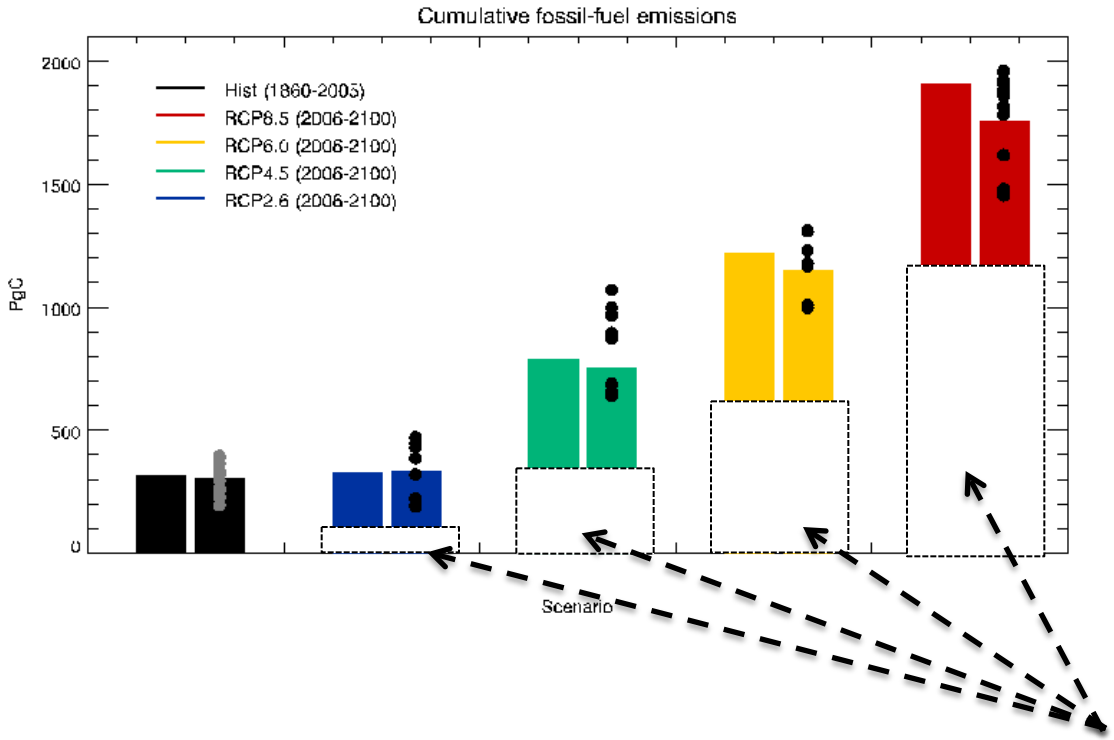
Back to RCPs, compatible emissions



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

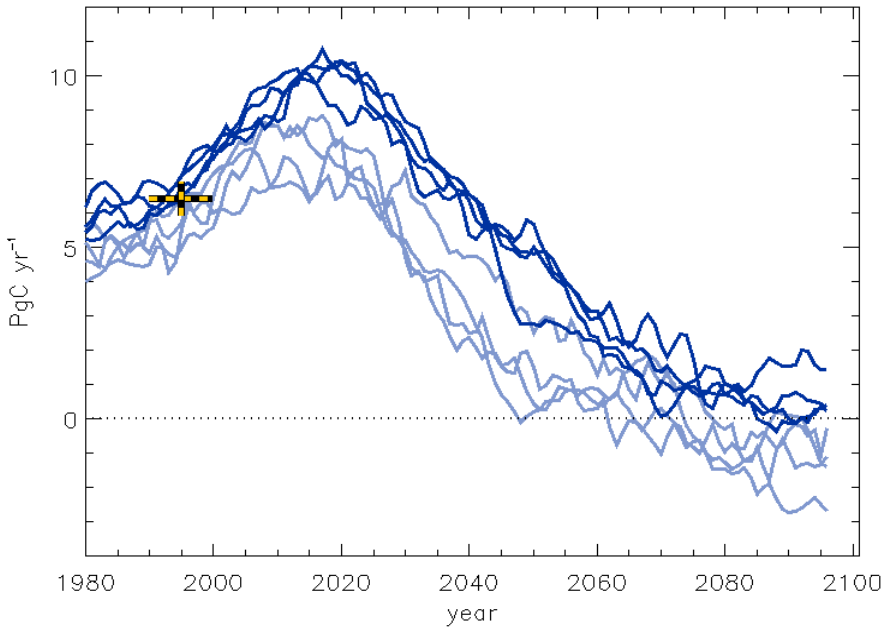
$$\frac{dC_A}{dt} + \frac{dC_L}{dt} + \frac{dC_O}{dt} = E_F$$

and $[CO_2]$ is given

- Agreement is not that impressive after all…

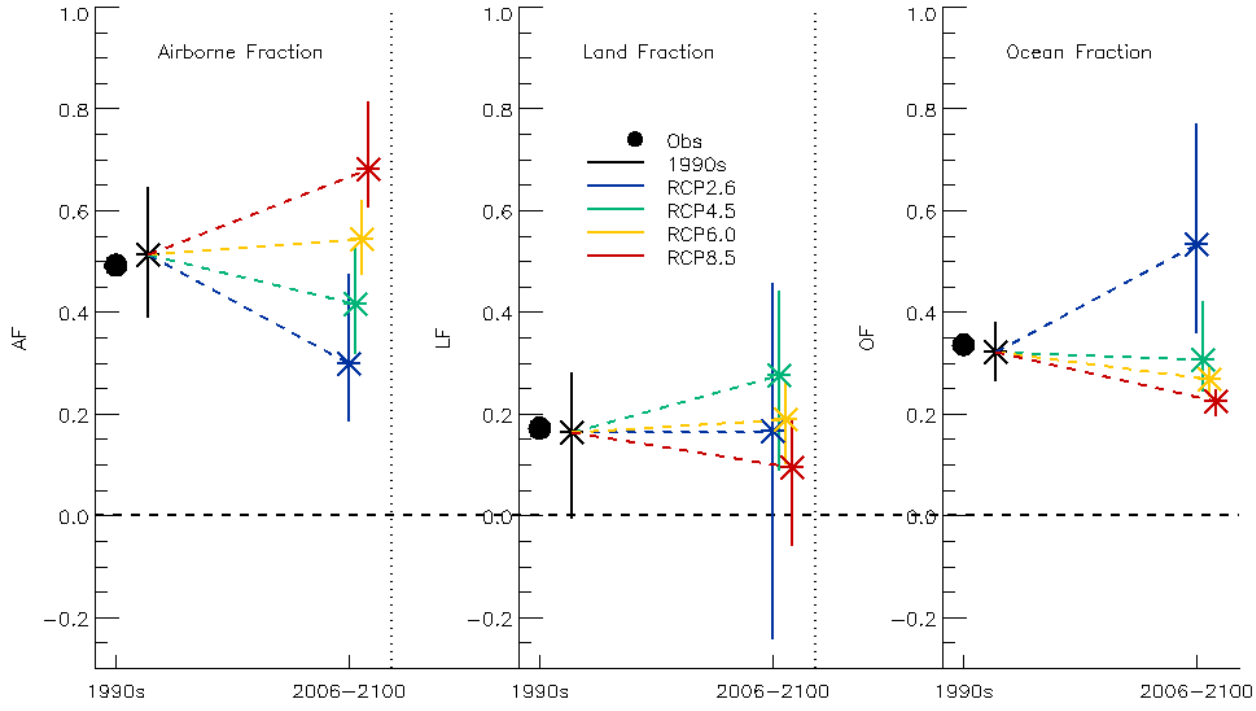
Back to RCPs, compatible emissions

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

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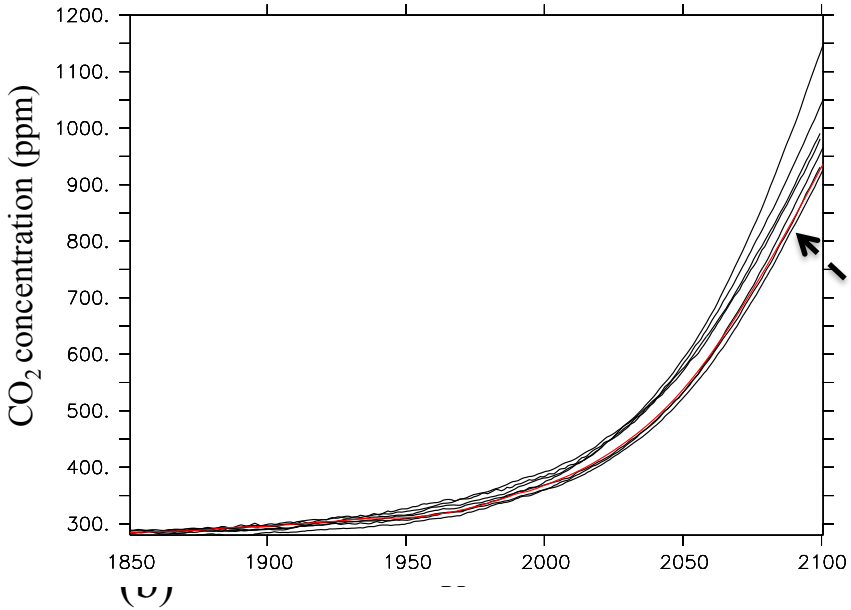
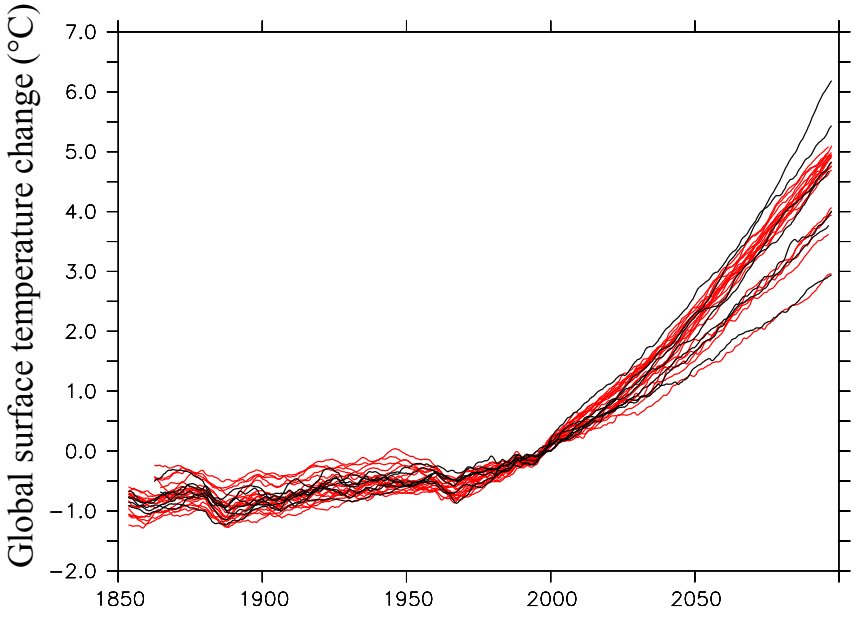
ESMs forced by emissions





RCP8.5 driven by CO_2 emissions. ESMs calculate both atmospheric CO_2 and climate change

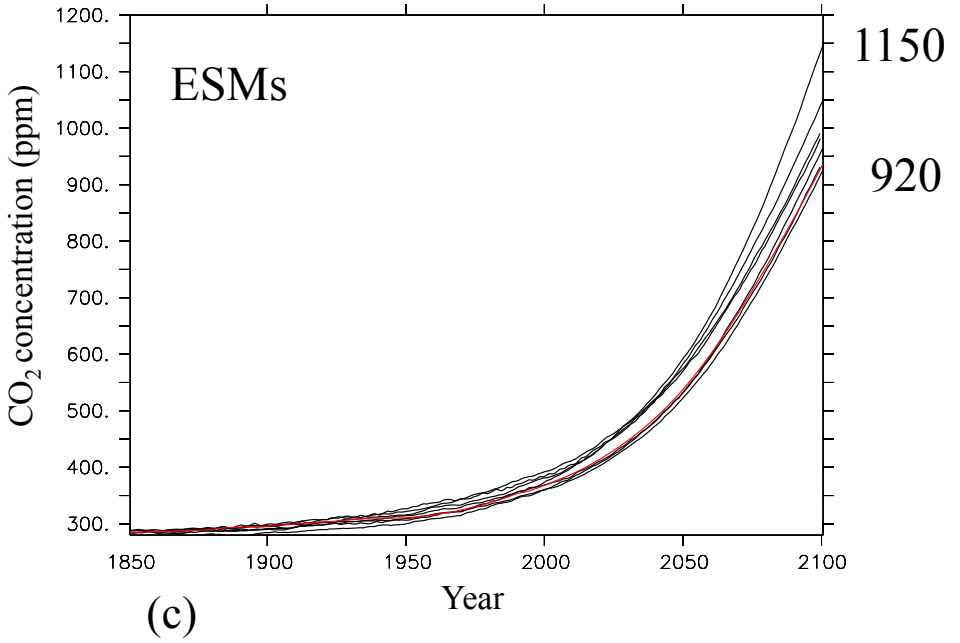
Simulated CO_2 is generally larger than the prescribed CO_2 given by MAGICC6.

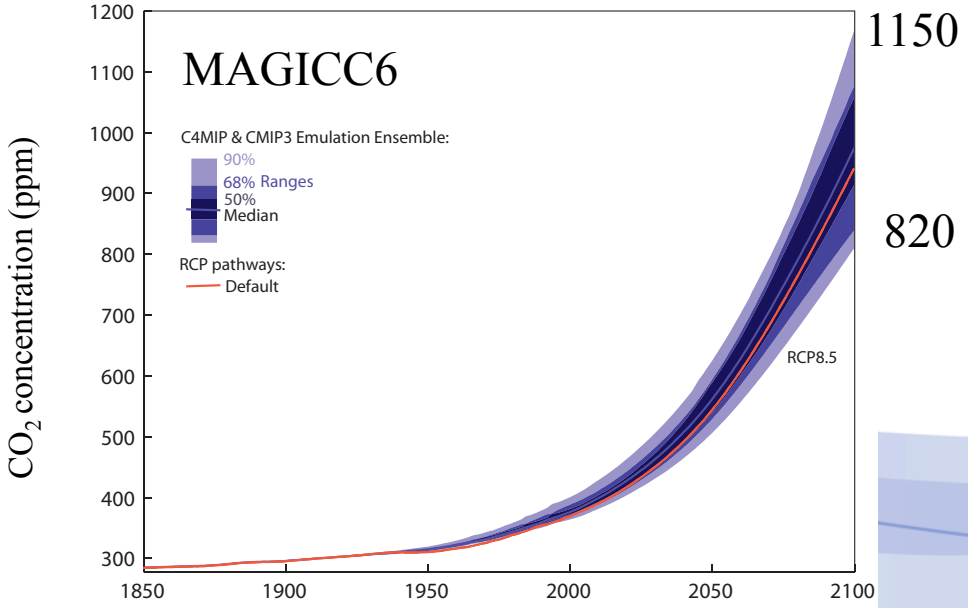
Larger warming when ESMs use prescribed emissions (black) than when using prescribed CO_2 concentration (red)

But, mainly due to 2 models that over-predict CO2 for present-day…

Not sure what to conclude !

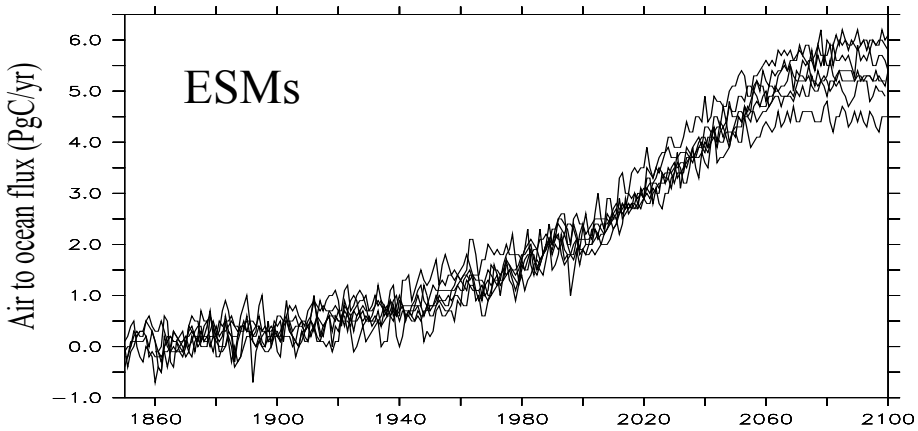
ESMs and IAMs

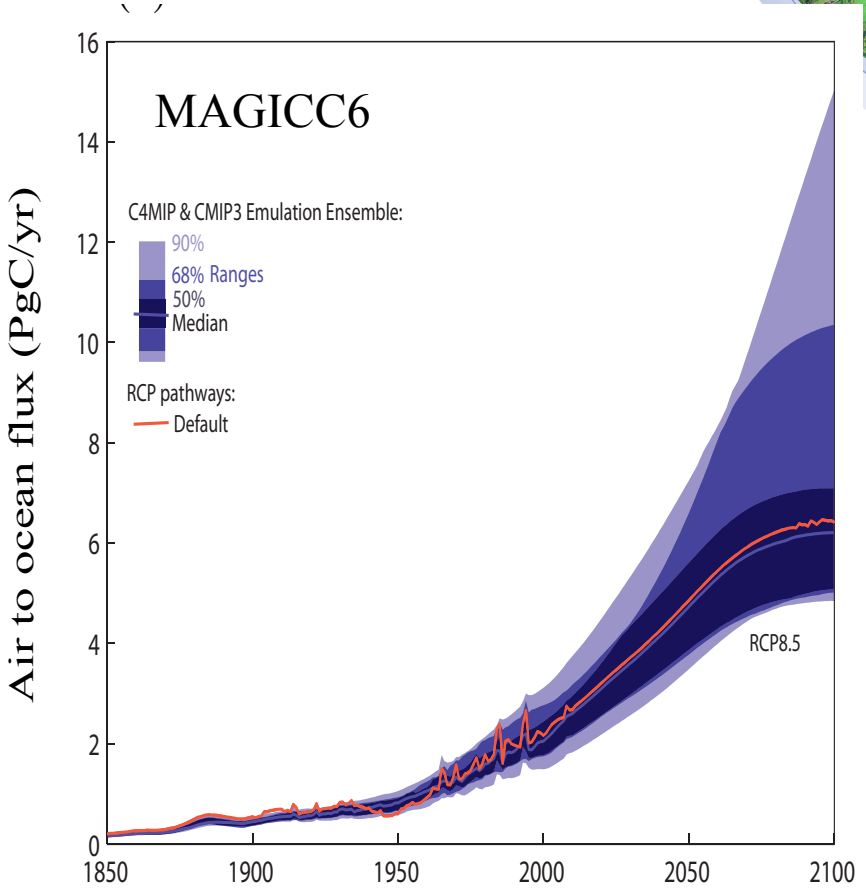




ESMs simulate larger atmospheric CO_2 than the prescribed CO_2 given by MAGICC6. Also MAGICC6 CO_2 range has a much lower lower bound (820 vs 920)

MAGICC6 lower bound is due to its higher estimates of ocean carbon uptake (by a factor of 2)





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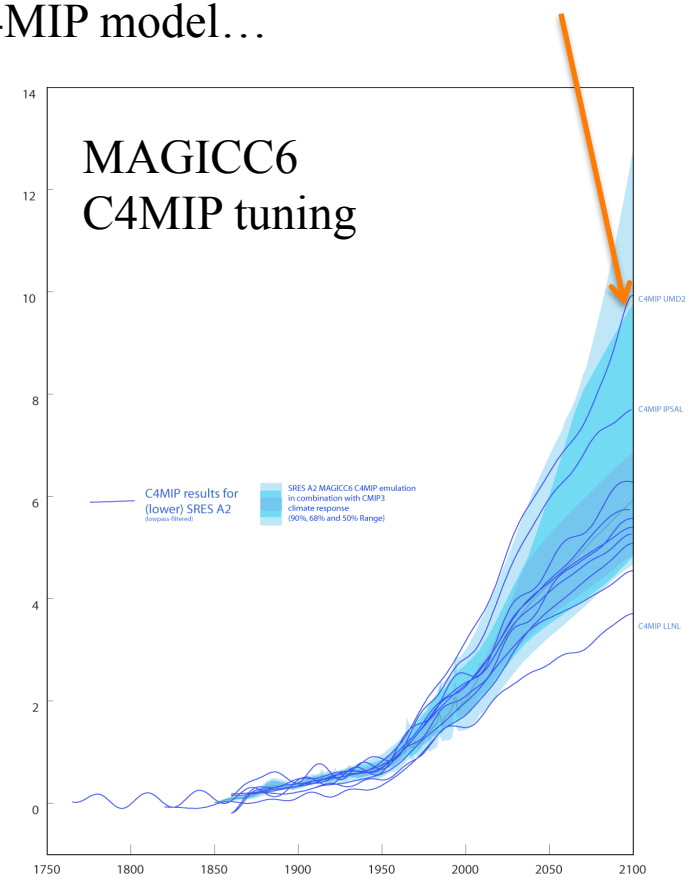
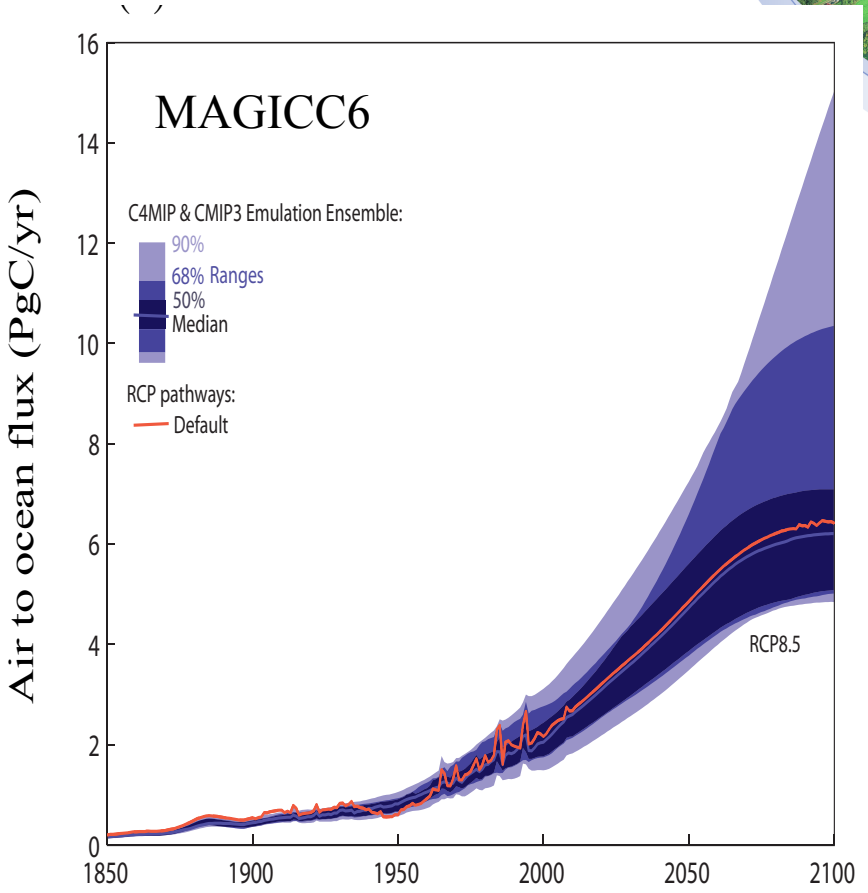
MAGICC6 was tuned to all CMIP3 GCMs for climate and C4MIP models for carbon. That includes a ”suspicious” C4MIP model…





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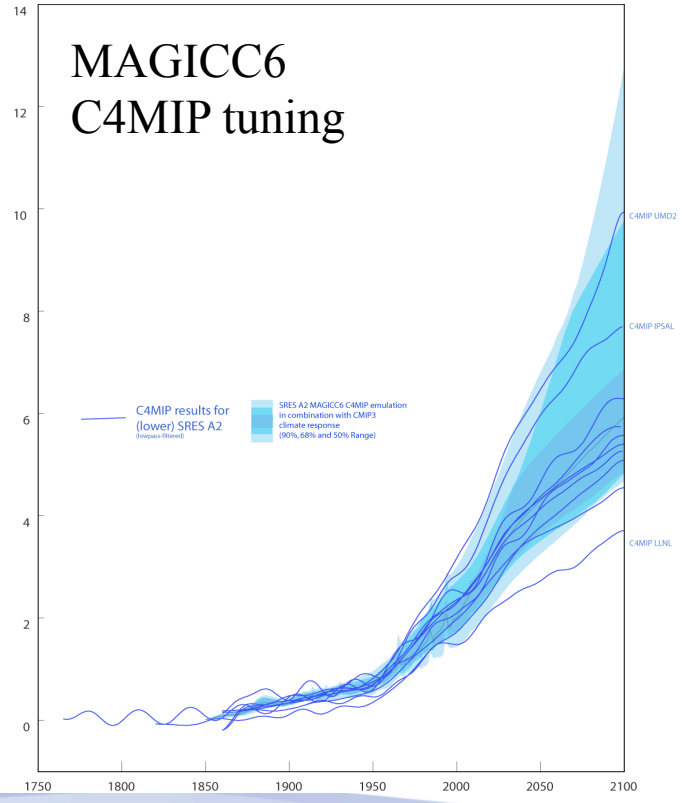
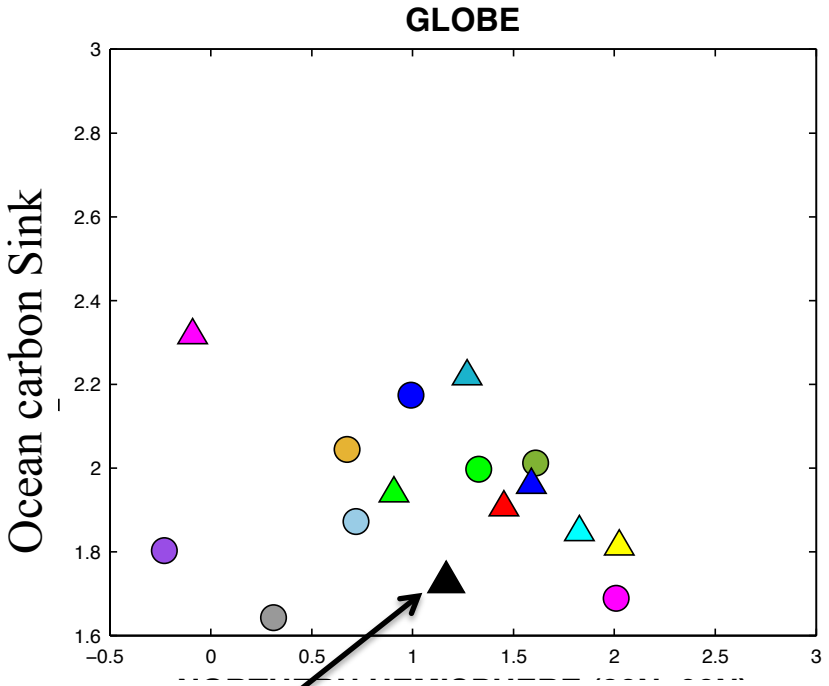
Present-day land and ocean uptakes for that ”suspicious” C4MIP model…

We might have wanted not to use it for tuning…





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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.