Towards Improved Projections

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This initiative aims at improving the ESMs used for projecting future climate change based on the work in the land, ocean, and observation initiatives.

Investigate prospects for improving and potentially extending the \((\beta, \gamma)\) framework.

Particular focus on the response of the carbon cycle to regional forcing.

Investigate processes contributing to non-linearity of the carbon cycle.

New scenarios (e.g. 1.5 °C and BECCS-driven land-use)
Uncertainties in Future Climate-Carbon Cycle Feedbacks
Ocean Carbon Change in CMIP5 Models (1% per year increase in CO$_2$)

Coupled

Uncoupled

Arora et al., 2013
Land Carbon Change in CMIP5 Models (1% per year increase in CO₂)

Coupled

Uncoupled

Arora et al., 2013
GROUP A (Thomas): What defines an improved projection? What do we want our projections to deliver?

GROUP A/B: What new projections are likely to be required over the next 5-10 years (e.g. negative emissions scenarios, SRM geoengineering, Trump World)?

GROUP B (Peter): Do we need a feedback analysis that extends beyond ($\beta$, $\gamma$)?
Beyond \((\beta, \gamma)\)

➢ Yes, we would like an improved conceptual model to understand and analyze carbon cycle feedbacks!

➢ Design criteria:

    Should ideally build-on \((\beta, \gamma)\) approach;

    Should recognise different system timescales (i.e. difference between quasi-equilibrium and transient responses), especially for the ocean;

    Should reduce scenario-dependence of \((\beta, \gamma)\);

    Will ideally connect to other conceptual models of (a) TCRE (e.g. Williams & Goodwin, 2016, 2016); (b) linear response theory (impulse-response functions).

    May provide a theoretical basis for Emergent Constraints…😊
Beyond \((\beta, \gamma)\) Workshop?

- **Proposal:** We would like to run a focused workshop (<20 people) to derive an extension to the \((\beta, \gamma)\) approach, which includes turnover times and other system timescales, and which makes connections to other recent analyses.

- **Length:** 2-3 days.

- **Potential invitees:** this working group plus Rick Williams (Liverpool), Phil Williamson (Southampton), Jonathan Gregory (Reading), Martin Heimann (Jena), Vivek Arora (UVic), Damon Mathews (Concordia), Jean-Louis Dufresne (IPSL).

- **Output:** hands-on testing of extended frameworks against ESM time-series; Conclusion on the best way forward; review paper.
QA: What defines an improved projection? What do we want our projections to deliver?

QA1) What are the sources of uncertainty in future projections?

QA2) How do we improve our confidence in future projections of land and ocean carbon sinks?
1. Scenario uncertainty
   • Different scenario (SSPs)
   • New scenarios are required (Negative emissions, SRM technologies, Trump world)

1. Model structural uncertainty
   • Different MIPs (C4MIP, OMIP/LUMIP, PMIP, LongrunMIP) → Link to R1/R2/R3
   • Sensitivity simulations (changes in remineralization depth scales, variable stoichiometry, changes in land-ocean carbon exchange; different model resolutions)
   • Use existing and emerging datasets (paleo/contemporary) to constrain models.
   • New feedback analysis

1. Internal variability
   • Large ensemble simulations to assess predictability → Link to R3
   • Decadal climate predictions of land and ocean carbon sink (10 years, 20-30 years); DCPP; Can we predict the evolution of the carbon sink over the next decades?
Emergent Constraints:

Using Earth System Models to identify the relationships between observable contemporary variations and future sensitivity
Archetypal Example of an *Emergent Constraint*

**Snow-albedo feedback in climate change and seasonal cycle contexts**

- Climate change (% °C⁻¹)
- Seasonal cycle (% °C⁻¹)

- Estimate based on observed seasonal cycle

Hall & Qu (2006)
Emergent Constraints

➢ **Emergent** because it a relationship that emerges from the ensemble of ESM projections.

➢ **Constraint** because it enables an observation to constrain the estimate of the ES sensitivity in the real world.

➢ *Allow model ensembles to be more than the sum of the parts.*

➢ *Identify metrics of current system which are most relevant to projected changes.*
Recipe for Finding Emergent Constraints

1. Identify a key uncertainty in future projections.
2. Identify an observed variation that could plausibly be related to that uncertainty.
3. Check for an *Emergent Relationship* between the Uncertainty and the Observation, across the ESM ensemble.
4. Apply the *Observational Constraint* to the *Emergent Relationship*, to derive an *Emergent Constraint* on the key uncertainty in future projections.
Emergent Constraints on Carbon Cycle Sensitivities
(some recent examples)
Interannual Variability in CO$_2$ Growth-rate

Evolution of the fraction of total emissions that remain in the atmosphere

![Graph showing CO$_2$ Partitioning (PgC y$^{-1}$) vs. Time (y) from 1960 to 2010. The graph compares Total CO$_2$ emissions with CO$_2$ Partitioning in the atmosphere.](image)

Updated from Le Quéré et al. 2009, Nature Geoscience; Data: NOAA 2010, CDIAC 2010
Emergent Constraint on Tropical $\gamma$
from Interannual Variability in CO$_2$

Cox et al., 2013
Emergent Constraint on CO$_2$ Fertilization from trends in the seasonal cycle of CO$_2$
Emergent Constraint on T sensitivity of Tropical Ocean PP from Interannual Variability in Chlorophyll

Kwiatkowski et al., submitted