ZEC-MIP: Quantifying the Zero Emissions Commitment

Chris Jones*[1]*, Thomas Frölicher, Charlie Koven, Andrew MacDougall, Damon Matthews, Kirsten Zickfeld, Joeri Rogelj, Kasia Tokarska
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[1] corresponding email: chris.d.jones@metoffice.gov.uk

Executive summary

- ZEC is a crucial component for calculating the remaining carbon budget
- Simulations to quantify it are missing from CMIP6
- We request just ONE tier-1 simulation from ESMs. EMICs and ESMs may perform additional simulations too
- Participating model groups will be offered co-authorship on a manuscript to be submitted this year (by Dec 2019)

The Zero Emissions Commitment (ZEC) is a key component of calculating the remaining carbon budget to stay within climate targets as well as being important to understand for issues of impacts and reversibility. Much effort is put into measuring and constraining TCRE - the Transient Climate Response to cumulative carbon Emissions (e.g. Matthews et al. 2009; Allen et al. 2009, Zickfeld et al. 2009, Raupach et al. 2011, Gillett et al., 2013, Tachiiri et al. 2015, Steinacher and Joos, 2016; Macdougall 2016; Millar and Friedlingstein, 2018; Ehlert and Zickfeld, 2017; Goodwin et al. 2015) - but also required is parallel information on the ZEC: TCRE quantifies the warming up to the point of emission of a given cumulative amount of CO2, ZEC quantifies the subsequent temperature change following cessation of emissions. Both are required to relate carbon emissions to the eventual warming.

It has been shown (e.g. Matthews and Caldeira, 2008, Solomon et al. 2009; Joos et al, 2013) that there is an offset of continued warming following stopping emissions by continued CO2 removal by natural sinks. This is partly due to the fact that ocean uptake of both heat and carbon share some similar processes and timescales and is therefore expected to lead to ZEC being small (e.g. Gillett et al., 2011; Ehlert & Zickfeld, 2017; Allen et al., 2018), and that this is a general result across models (e.g. Zickfeld et al. 2013). Most such literature focused on long timescales (up to and beyond a century). This led IPCC SR15 (Rogelj et al, 2018) to make the assumption for the estimation of carbon budgets that on the short-to-near term ZEC was zero. But more detailed studies (Frölicher et al. 2014, Frölicher and Paynter 2015) have shown that ZEC can be (a) non-zero, possibly either positive or negative and this changes in time during the period following emissions ceasing (Frölicher et al. 2014, Frölicher et al., 2015); (b) it can be both state and rate dependent - i.e it varies depending on the amount of carbon emitted and the time profile of its emissions prior to cessation (e.g. Krasting et al., 2014; Ehlert & Zickfeld, 2017).

When we consider very low climate targets, such as 1.5 or 2 degrees, and in light of the 1 degree warming to date and warming from non-CO2 GHGs, then a small uncertainty in ZEC (of even just 0±0.1ºC) leads to a very substantial fractional uncertainty in the remaining carbon budget.

It has therefore emerged that quantitative information on ZEC is a key gap in our knowledge, and one which is not filled by currently planned CMIP6 simulations.

ZEC-MIP aims to fill this gap as efficiently as possible. It is inconsistent to apply a single model estimate, or from a limited number of studies, of ZEC from the literature to the coordinated multi-model CMIP6 assessment of TCRE. Much more preferable is to coordinate parallel studies, with ESMs and EMICs, to measure both TCRE and ZEC in a common scenario. Hence the 1% per annum CMIP6 DECK simulation is chosen as a baseline to build on - this simulation can be used to diagnose TCRE, and from the same point must be used to quantify ZEC.

The ZEC-MIP committee is very (VERY!) aware of the huge time pressure on modelling groups during 2019 to run and deliver output from CMIP6 simulations. Hence ZEC-MIP has been designed to address this vital question with only ***ONE*** tier-1 simulation.

A paper is planned for submission before the end of December 2019 to quantify ZEC from ZEC-MIP simulations. Any participating group will be invited for co-authorship. Beyond this it is anticipated that IPCC AR6 WG1 report will draw on ZEC-MIP simulations in their assessment of remaining carbon budgets. Data available in the ESGF by the data submission cutoff of circa Sept. 2020 will be eligible to contribute to that assessment even if it was not included in the submitted paper.

The remainder of this document lays out the ZEC-MIP simulations, with a focus on the details needed for ESMs and EMICs to contribute the single top priority simulation of a ZEC run from the point of 1000 GtC emissions following 1% year growth in CO2.

ZEC-MIP is not yet a stand-alone, CMIP-endorsed, MIP. For now information is being hosted on C4MIP and CDR-MIP websites to facilitate dissemination. Both C4MIP and CDR-MIP encourage participation in the ZEC-MIP top priority simulation. The data request will be kept to a minimum and will not disrupt existing simulations planned or in progress. No new variables for example will be added. Our suggestion is to output the same model variables as from the 1% run which forms the basis of ZEC-MIP. The mechanism for submitting to ESGF (for EMSs), or the equivalent for EMICs has not yet been finalised.

Simulation Protocol

Due to time pressures on ESM model groups ZEC-MIP has just one simulation required, with a lower priority second suggested simulation.

For EMIC model groups there is an extended protocol with longer and additional experiments. ESM groups are welcome to perform these additional simulations also but this neither expected nor required.

A. Abrupt-zero emissions

Based on CO2-only, 1% run (DECK: "1pctCO2"). After following the prescribed CO_2 concentration up to the level described below, branch off with interactive CO_2 (a.k.a. "Emissions driven") but with emissions=0. Simulate the subsequent reduction in CO_2 and change in climate for at least 100 years. Branch off at given cumulative emissions of:

1. 1000 PgC. Tier-1. This corresponds to approximately 2 degrees above pre-industrial.
2. 750 PgC (circa 1.5-degrees). Tier 2 (optional)

The experiment design is for all models to branch off at a common cumulative carbon emission, acknowledging that this will mean slightly different CO_2 and ΔT for each model. Calculate the inferred compatible emission according to mass balance of CO_2 and sources/sinks:

$$\Delta CO2 = E - \sum(sinks)$$

Therefore:

$$E = \Delta CO2 + (\Delta C_L + \Delta C_O)$$

where E is emissions, C_L and C_O denote land and ocean carbon stores, and all quantities are expressed in units of PgC.

The simulations should be run in emissions configuration with emissions set to zero from this point for (at least) 100 years. EMICs to run for longer as their model allows, up to 1000 years.

If your model has internal variability, consider ensembles, but again acknowledging ESM time pressure only one ensemble member is required. Additional members are optional

Note: Some ESMs may not have the capability to switch from concentration-driven to emissions-driven configuration, or model groups may not have confidence that they can do so without a shock to the model system. In this case ESMs may need to re-run an emissions-driven version of 1pctCO2 to get to the step-off point. This is a model-by-model decision. In this case the compatible emissions described above should be calculated year-by-year and used from PI-control to approximately replicate the 1% profile up to the desired cumulative emission before setting emissions to zero from this point.

EMICs in addition should perform:

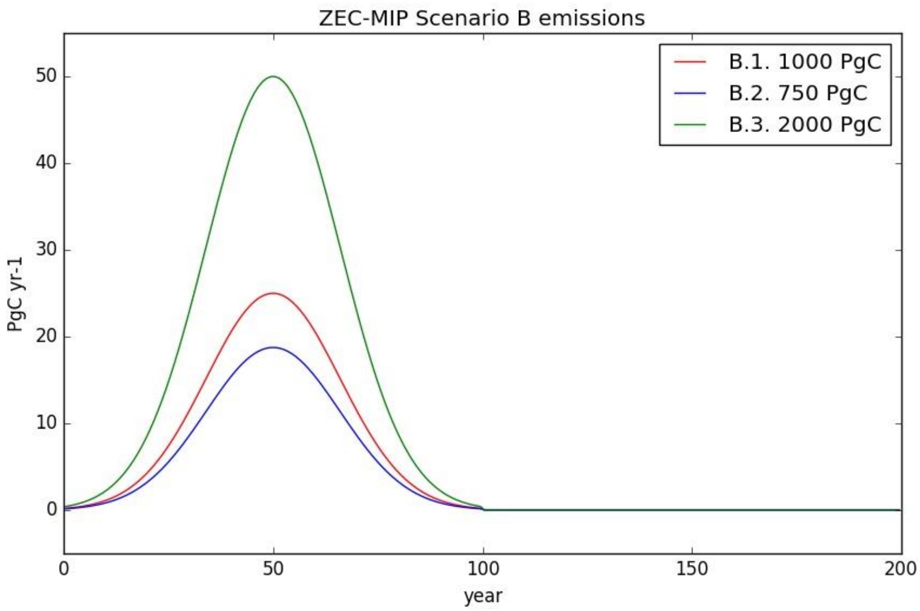
Experiment A.1 aims to quantify ZEC at 1000 PgC at the point where TCRE will be calculated. A.2 explores the ***state*** dependence of ZEC at approximately 1.5 degrees. A third experiment, A.3, explores the ***state*** dependence of ZEC at higher cumulative emissions:

3. 2000 PgC. Tier 3/2.

B. Bell-shape zero emissions

This second set, B.1-3 aims to explore the ***rate*** dependence by following a pathway emitting the same cumulative emissions as A.1-3 but with a smooth transition to zero, followed by 1000 years of E=0 (ESMs running this just need 100 years).

Run in emissions-driven configuration (CO2-only: all non-CO_2 forcing fixed at pre-industrial). Run with “bell shaped” emissions profile (figure 1). At end of 100 years emissions profile, continue with zero emissions for 1000 years.



The bell-curve is designed to give cumulative emissions of:

1. 1000 PgC
2. 750 PgC
3. 2000 PgC

I.e. the same cumulative emissions as “A”, over 100 years, then zero emissions for 100 years (ESMs) or 1000 years (EMICs). A model decision is required on the spatial pattern of emissions – we suggest globally uniform at surface.

The timeseries of global CO_2 for the above curves is provided by ZECMIP and will be hosted on the C4MIP and CDR-MIP websites:

- C4MIP: www.c4mip.net
- CDRMIP: https://www.kiel-earth-institute.de/CDR_Model_Intercomparison_Project.html

Priorities

ESMs (red) are requested to do just one tier-1 simulation and an optional tier-2 simulation. Extension beyond 100 years, or ensemble members of A.1, may be beneficial but are optional lower priority runs.

EMICs (green) are requested to do a much fuller set of simulations, extended up to 1000 year. Ensembles may be required if your EMIC has internal variability.

Priorities

		ESM (100 years)			EMIC (1000 years)	
A1		1			1	
A2			2		1	
A3						2
B1					1	
B2						2
B3						2

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