Impulse response function of climate-carbon cycle models: a model intercomparison study

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Documents and updates are available online: http://www.climate.unibe.ch/~joos/IRF_Intercomparison

Global warming potentials (GWP) of different gases are used as a metric to compare emissions of various greenhouse gases in the Kyoto Basket approach. The response in atmospheric CO_2 to an instantaneous release of carbon into the atmosphere, the atmospheric CO_2 impulse response function (IRF), is used for the computation of global warming potentials (GWP) and global temperature change potential (GTP) (Shine et al., 2005).

The goal of this exercise is to determine the atmospheric CO_2 impulse response function (IRF) by a suite of carbon-cycle climate models to explore model-model differences. Results will be written up for publication in a peer-reviewed journal in spring 2012 (IPCC AR5 WG1 deadline is summer 2012) in order to be available for calculations of GWPs in IPCC AR5. The results will also be useful for metrics and simplified climate models in other contexts.

Model requirements

The model must be able to compute the redistribution of anthropogenic carbon among the principal carbon reservoirs atmosphere, land biosphere, and ocean. Further compartments such as ocean sediments may also be included. Preferentially, the model simulates changes in climate in response to CO_2 radiative forcing and includes a representation of the relevant carbon cycle-climate feedbacks.

Model runs: overview

The scenario setup is inspired by the calculation of the IRF function as done for the Second Assessment Report (SAR) and as used in the Kyoto GWP with the Bern SAR model version and as repeated in preparation of the Fourth Assessment. The setup relies on that described in Enting, Wigley, Heimann, CSIRO Division of Atmospheric Research. Technical Paper No 31, 1994:

Three simulations are performed:
(a) The model is forced with historical concentration up to a reference year (here t_{ref}=2010) and then concentration are kept fixed thereafter at a constant value (here $CO_{2,ref}$=389 ppm). The allowed emission are calculated from the change in total inventory (prescribed atmospheric change plus modelled ocean and terrestrial uptake)
(b) A simulation with prescribed emissions from (a)
(or concentration prescribed up to the reference year and emissions prescribed thereafter)
(c) same as (b) but an impulse of carbon, here of 100 GtC, added instantaneously to the atmosphere five years after the reference year (here in 2015).

The normalised IRF is then approximately:

$$IRF(t=t_{model}\text{-}2015.0) = (CO_2(t_{model})\text{-}CO_{2,ref})/(100\ GtC/2.123GtC/ppm) \qquad \text{for } t_{model} > 2015$$

Model runs: detailed description

A) CO_2 background concentration of 389 ppm

1. PresCO2_389ppm: The simulation starts from preindustrial conditions. Atmospheric CO_2 is prescribed and compatible emissions (=change in all carbon reservoirs) diagnosed. Atmospheric CO_2 is prescribed to follow the historical evolution up to year 2010. After 2010, the concentration is kept fixed at the value of 389.0 ppm. The diagnosed emissions should be written frequently (at least annually); these will be used to drive the model in run 2 and 3. An input file with the historical concentrations is provided
   (file name: co2ccn_irf_850_2010_v1.0.dat).
   A restart file may be written in 2010 to start simulation 2 and 3 in 2010
2. PresEmiss_389ppm: run 2 may either start in 2010 as a continuation of run 1 or at the same preindustrial initial conditions used in run 1. Atmospheric CO_2 is evolving freely. Diagnosed emissions from run PresCO2_389ppm are used to force the model. (Expected result: the computed CO_2 evolution should be close to the evolution prescribed in run PresCO2_389ppm, see Figure 1).
3. PresEmiss100_389ppm: Atmospheric CO_2 is evolving freely. Diagnosed emissions from run PresCO2_389ppm are used to force the model as in run PresEmiss_389ppm. In addition, 100 GtC are released at the beginning of year 2015. (Expected results: Atmospheric CO_2 will increase by 47.1032 ppm above the background concentration (~389 ppm) in 2015 and then slowly decline over the coming decades, see Figure 1)

Remarks:

- It is crucial that the carbon pulse will be added to a constant background concentration of 389 ppm for comparability (roughly 2010 value).
- run 1 (PresCO2_389ppm): An existing run or setup from the EMIC Intercomparison may be used up to a concentration of 389 ppm.
- run 3 (PresEmiss100_389ppm): Instead of releasing 100 GtC at the beginning of year 2015, the atmospheric CO2 concentration may be increased at the beginning of year 2015 by 100 GtC/2.123 GtC/ppm = 47.1032 ppm

B) Preindustrial Set

Runs 4 to 5 start from preindustrial conditions

4. CTRL: Control simulation with constant boundary conditions and freely evolving atm. CO_2
5. PI100: Freely evolving atm. CO_2. 100 GtC are released into the atmosphere during year 10 of the control simulation and then continued. (Expected result: atm CO2 will increase from the preindustrial value of around 280 ppm by about 45 ppm to 325 ppm in year 10. Afterwards, the CO2 concentration will then decrease due to uptake by the ocean and the land biosphere).
6. PI5000: as PI100, but 5000 GtC are released instead of 100 GtC

Remark: an available control simulation may be used to minimize work

Resulting IRFs

We will use your results to compute impulse response functions for CO_2 and other variables:

a) IRF_100GtC_389ppm: The difference in atm. CO_2 of run PresEmiss100_389ppm and PresEmiss_389ppm divided by the pulse size of 47 ppm will yield the (normalized) IRF for a background concentration of 389 ppm and a pulse size of 100 GtC (see Figure 2)
b) IRF_100GtC_PI: The difference in atm. CO_2 of run PI100 and CTRL will yield the IRF for preindustrial background conditions and a pulse size of 100 GtC
c) IRF_5000GtC_PI: The difference in atm. CO_2 of run PI5000 and CTRL will yield the IRF for preindustrial background conditions and a pulse size of 5000 GtC

Duration of runs

Preferentially, simulations are run for 2000 years after the pulse release until a complete equilibrium between atmosphere-ocean-land biosphere is re-established. If this is not feasible, runs of shorter duration are also welcome. Usually models are close to equilibrium after 1000 years. Global Warming Potentials for which the IRFs will be used were tabulated in past IPCC reports for 500, 100, and 20 years. A time horizon of 100 years is used in the Kyoto protocol.

A minimum of 100 years after the pulse release is requested.

Models that include ocean sediments and/or weathering and that are cost-efficient enough may also be run over many millennia (e.g. 100 ka).

Priority of runs

The *top priority* is to get results needed to compute the IRF for a background concentration of 389 ppm (IRF_100GtC_389ppm). For this, *runs 1, 2, and 3* are required.
Alternative: If computing requirements are too high for run 1 to 3, please provide at least results for runs 4 and 5 (PI100, CTRL).

Conversion factor GtC to ppm

Please use a conversion factor of 2.123 GtC per ppm

Preindustrial condition

It is up to the researcher to define the exact preindustrial state and the exact evolution how to reach the 2010 atmospheric CO2 value of 389 ppm. However, model runs should start before 1900 AD and concentration should be kept fixed at a value of 389 ppm a few years before and during the pulse release. The idea is that the carbon pulse is added for the same background concentration of 389 ppm in all models.

Other forcings

Non-CO2 forcings are preferentially set to zero. Alternatively, you may include non-CO2 forcings in run 1 to 3, but keep non-CO2 forcing constant after 2010 at the level of year 2010. A suitable set of forcing is provided by the EMIC Intercomparison Project (http://climate.uvic.ca/EMICAR5/forcing).

Output

Ascii files with global mean values, provide at least 5 significant digits for each run.

a) File name: RUNNAME_MODELNAME_Modelversion_startyear_endyear.dat, e.g. "PresCO2_2010_Bern3DLPX_v1.0_1750_4015.dat" for run 1 with the Bern3DLPX model, version 1.0 and simulation starting at 1750 AD and ending at 4015
b) Header:
   - start each comment line with: #
   - indicate run name
   - provide contact address,
   - indicate model name and version and model components included,
   - indicate climate sensitivity of model
   - conversion factor used to convert GtC into ppm and/or pulse size in ppm
   - description of non-CO2 forcing applied
   - indicate whether tabulated data show annual averages or instantaneous values
   - column headers with units

c) Tabulated data including year, global mean values of atmospheric CO2 in ppm (CO2atm), global mean net air-to-sea carbon flux in GtC per year (Fas,net), global mean net air-to-land carbon flux in GtC per year (Fab,net), global mean surface temperature in Celsius (T) , global mean sea level rise in cm (SLR), change in ocean heat content in Joule (DHeat)
   # year CO2atm [ppm) Fas,net [GtC/yr] Fab,net [GtC/yr] T [deg Celsius] SLR[cm] DHeat[J]

A text file in ascii describing the model, model resolution, model components, climate sensitivity, and appropriate references. File name: MODELNAME_Modelversion_description.txt. Include contact address.

Deadlines

Please let us know by *15 December 2011* whether you plan to contribute and submit the runs until **15 February 2012** to joos@climate.unibe.ch and roth@climate.unibe.ch

Further Reading

Section 2.10,page 210 ff in

Forster, P., et al. (2007), Changes in Atmospheric Constitutents and in Radiative Forcing, in *Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to Fourth Assessment Report of the Intergovernmental Panel on Climate Change*, edited by S. Solomon, D. Qin, M. Manning, Z. Chen, M. Marquis, K. B. Averyt, M. Tignor and H. L. Miller, pp. 129-234, Cambridge United Kingdom and New York, NY, USA, New York, NY, USA.

Enting, I.G., Wigley, T.M.L., Heimann, M., 1994. Future Emissions and Concentrations of Carbon Dioxide: Key Ocean/Atmosphere/Land Analyses. CSIRO Division of Atmospheric Research Technical Paper no. 31.

Results obtained with the Bern3D-LPX model for a CO_2 background of 389 ppm

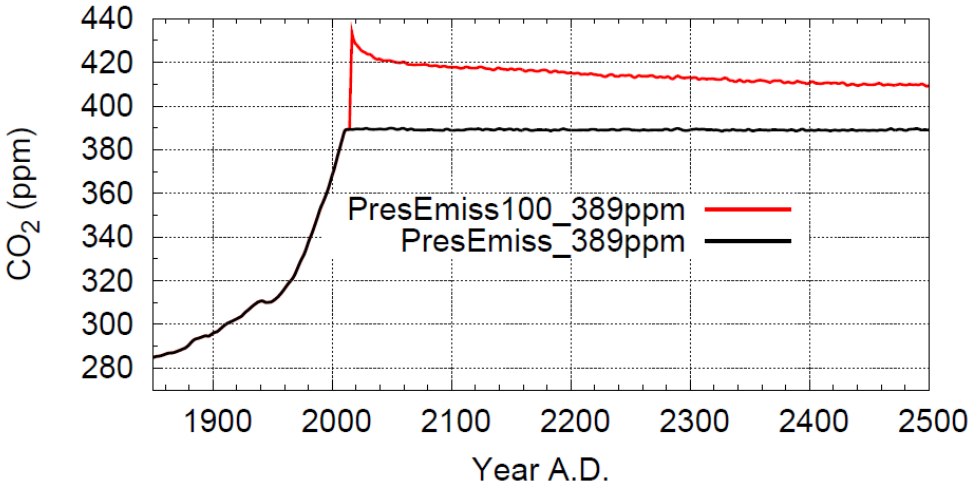

Figure 1: Simulated evolution of atmospheric CO_2 for runs 2 and 3 (PresEmiss_389ppm PresEmiss100_389ppm). 100 GtC are instantaneously released at the beginning of year 2015 in simulations PresEmiss100_389ppm (red) in addition to the emissions prescribed in run PresEmiss_389ppm (black). Prescribed emissions were diagnosed from a run in which atmospheric CO_2 was prescribed to follow the observed evolution until 2010 and kept constant at 389 ppm after 2010.

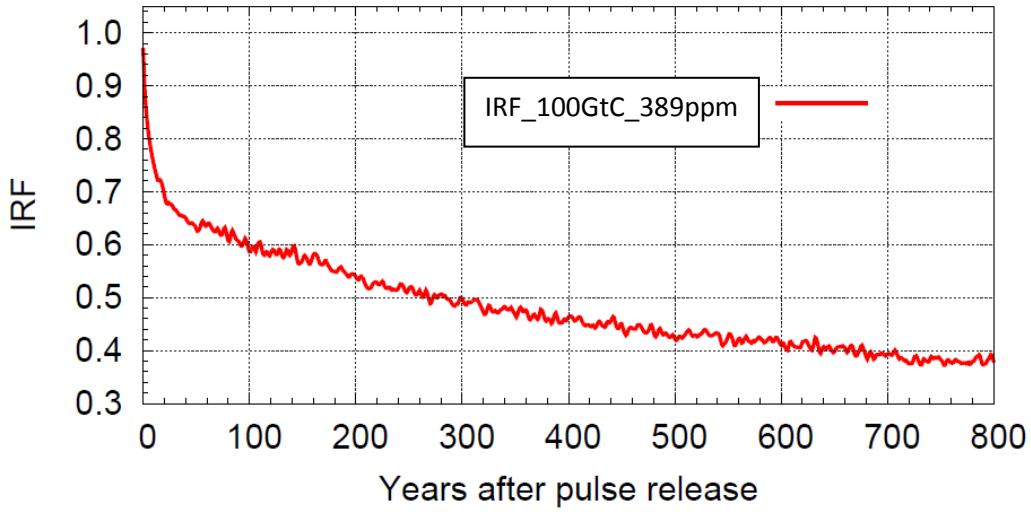

Figure 2: CO_2 impulse response function (IRF) as obtained from the difference of the runs shown in figure 1. The IRF is normalised by the size of the pulse input. Time is shifted such that year 0 corresponds to the time when the pulse of 100 GtC was released into the atmosphere.