University Library



A gateway to Melbourne's research publications

Minerva Access is the Institutional Repository of The University of Melbourne

Author/s:
Nicholls, Z;Lewis, J

Title:
OpenSCM Two Layer Model: A Python implementation of the two-layer climate model

Date:
2021-06-15

Citation:
Nicholls, Z. & Lewis, J. (2021). OpenSCM Two Layer Model: A Python implementation of the two-layer climate model. Journal of Open Source Software, 6 (62), pp.2766-2766. https://doi.org/10.21105/joss.02766.

Persistent Link:
https://hdl.handle.net/11343/281159

License:
CC BY

The Journal of Open Source Software

OpenSCM Two Layer Model: A Python implementation of the two-layer climate model

Zebedee Nicholls[1, 2, 3] **and Jared Lewis**[1, 2, 3]

1 Australian-German Climate & Energy College, The University of Melbourne, Parkville, Victoria, Australia **2** School of Geography, Earth and Atmosphere Sciences, The University of Melbourne, Parkville, Victoria, Australia **3** Climate Resource, Northcote, Victoria, Australia

DOI: 10.21105/joss.02766

Software

- Review
- Repository
- Archive

Editor: Leonardo Uieda

Reviewers:

- @sadielbartholomew
- @ashiklom

Submitted: 07 October 2020
Published: 15 June 2021

License
Authors of papers retain copyright and release the work under a Creative Commons Attribution 4.0 International License (CC BY 4.0).

Summary

The evolution of the climate is controlled by highly complex physical dynamics. However, simplified representations are surprisingly powerful tools for understanding these dynamics (Held et al., 2010) and making climate projections (Meinshausen, Smith, et al., 2011). The field of simple climate modelling is widely used, in particular for assessing the climatic implications of large numbers of different emissions scenarios, a task that cannot be performed with more complex models because of computational constraints.

One of the most commonly used models of the climate's response to changes in the "Earth's energy balance" (energy input compared to energy output of the earth system) is the two-layer model originally introduced by Held et al. (2010). While this model must be given energy imbalances (more precisely, radiative forcing) rather than emissions, it is nonetheless a widely used tool within climate science. Approximately speaking, the model represents the Earth System as an ocean with two-layers. The upper layer absorbs excess heat in the Earth System and then exchanges heat with the deep layer. As a result, in response to a perturbation, the model responds with a distinctive two-timescale response, commonly referred to as the "fast" and "slow" warming components. Since Held et al. (2010), the model has been extended to include updated representations of the efficiency of ocean heat uptake (Geoffroy, Saint-Martin, Bellon, et al., 2013) as well as a state-dependent response to radiative forcing (Bloch-Johnson et al., 2015; Rohrschneider et al., 2019).

There are many simple climate models in the scientific literature (Nicholls et al., 2020). Given the context of this paper, we provide below a table of openly accessible models, their programming language, and their approach. These models are conceptually similar to the two-layer model implemented here except they use different parameterisations for ocean heat uptake and the relationship between ocean heat uptake and warming. On top of the relationship between ocean heat uptake and warming, these models also implement many other components of the climate system, e.g., carbon cycle, methane cycle, and the relationship between changes in atmospheric greenhouse gas concentrations and atmospheric energy fluxes. The exception is the FaIR model (Smith et al., 2018), which uses the two-layer model as its thermal core.

OpenSCM Two Layer Model is an object-oriented and open-source implementation of the two-layer model. It is written in Python, a user-friendly open-source language that is popular in the climate sciences, and uses the Pint package (Grecco & others, 2020), a widely used units library, for unit handling. It provides an extensible interface for the two-layer model, which could then be coupled with other modules as researchers see fit. The implementation also provides an easy way to convert between the two-layer model of Held et al. (2010) and the mathematically equivalent two-timescale impulse response model, used most notably as the thermal core of the FaIR model (Smith et al., 2018). The conversion between the two is an implementation of the proof by Geoffroy, Saint-Martin, Olivié, et al. (2013).

Table 1: Brief overview of other simple climate models available in the scientific literature. Shown is the model name, a brief description and relevant URL(s), and the programming language in which the model is written. The programming language shown is the one used for the model's core; other languages might be used in the development repositories for, e.g., plotting. For a more extensive list of simple climate models and references which describe the models in detail, see Table 1 of Nicholls et al. (2020).

Model	Brief description and URL	Language
FaIR	Modified impulse response (Smith et al., 2018), github.com/OMS-NetZero/FAIR	Python
GREB	Coarse grid energy balance (Dommenget & Flöter, 2011), github.com/christianstassen/greb-official	Fortran 90
Hector	Upwelling-diffusion ocean energy balance (Hartin et al., 2015), github.com/JGCRI/hector	C++
MAGICC	Upwelling-diffusion ocean four-box (hemispheric land/ocean) energy balance (Meinshausen, Raper, et al., 2011), live.magicc.org (Pymagicc (Gieseke et al., 2018) provides a Python wrapper in github.com/openclimatedata/pymagicc)	Fortran 90
OSCAR	Energy balance with book-keeping land carbon cycle (Gasser et al., 2020), github.com/tgasser/OSCAR	Python
WASP	Energy balance with 8-box carbon cycle (Goodwin et al., 2019), github.com/WASP-ESM/WASP_Earth_System_Model	C++

Statement of need

OpenSCM Two Layer Model was designed to provide a clean, modularised, extensible interface for one of the most commonly used simple climate models. It was used in Phase 1 of the Reduced Complexity Model Intercomparison Project (Nicholls et al., 2020) as a point of comparison for the other participating models.

The FaIR model (Smith et al., 2020) implements a mathematically equivalent model (under certain assumptions) but does not provide as clear a conversion between the two-layer model and the two-timescale response as is provided here. We hope that this implementation could interface with other simple climate models like FaIR to allow simpler exploration of the combined behaviour of interacting climate components with minimal coupling headaches.

As implemented here, the OpenSCM Two Layer Model interface is intended to be used in research or education.

Acknowledgements

We thank Robert Gieseke for comments on the manuscript and for all of his efforts within the OpenSCM project.

References

Bloch-Johnson, J., Pierrehumbert, R. T., & Abbot, D. S. (2015). Feedback temperature dependence determines the risk of high warming. *Geophysical Research Letters*, *42*(12), 4973–4980. https://doi.org/10.1002/2015GL064240

Dommenget, D., & Flöter, J. (2011). Conceptual understanding of climate change with a globally resolved energy balance model. *Climate Dynamics*, *37*(11), 2143–2165. https://doi.org/10.1007/s00382-011-1026-0

Gasser, T., Crepin, L., Quilcaille, Y., Houghton, R. A., Ciais, P., & Obersteiner, M. (2020). Historical CO_2 emissions from land use and land cover change and their uncertainty. *Biogeosciences*, *17*(15), 4075–4101. https://doi.org/10.5194/bg-17-4075-2020

Geoffroy, O., Saint-Martin, D., Bellon, G., Voldoire, A., Olivié, D. J. L., & Tytéca, S. (2013). Transient climate response in a two-layer energy-balance model. Part II: Representation of the efficacy of deep-ocean heat uptake and validation for CMIP5 AOGCMs. *Journal of Climate*, *26*(6), 1859–1876. https://doi.org/10.1175/JCLI-D-12-00196.1

Geoffroy, O., Saint-Martin, D., Olivié, D. J. L., Voldoire, A., Bellon, G., & Tytéca, S. (2013). Transient climate response in a two-layer energy-balance model. Part i: Analytical solution and parameter calibration using CMIP5 AOGCM experiments. *Journal of Climate*, *26*(6), 1841–1857. https://doi.org/10.1175/JCLI-D-12-00195.1

Gieseke, R., Willner, S. N., & Mengel, M. (2018). Pymagicc: A python wrapper for the simple climate model MAGICC. *Journal of Open Source Software*, *3*(22), 516. https://doi.org/10.21105/joss.00516

Goodwin, P., Williams, R. G., Roussenov, V. M., & Katavouta, A. (2019). Climate sensitivity from both physical and carbon cycle feedbacks. *Geophysical Research Letters*, *46*(13), 7554–7564. https://doi.org/10.1029/2019gl082887

Grecco, H. E., & others. (2020). Pint: Operate and manipulate physical quantities in python. In *GitHub repository*. GitHub. https://github.com/hgrecco/pint

Hartin, C. A., Patel, P., Schwarber, A., Link, R. P., & Bond-Lamberty, B. P. (2015). A simple object-oriented and open-source model for scientific and policy analyses of the global climate system – hector v1.0. *Geoscientific Model Development*, *8*(4), 939–955. https://doi.org/10.5194/gmd-8-939-2015

Held, I. M., Winton, M., Takahashi, K., Delworth, T., Zeng, F., & Vallis, G. K. (2010). Probing the fast and slow components of global warming by returning abruptly to preindustrial forcing. *Journal of Climate*, *23*(9), 2418–2427. https://doi.org/10.1175/2009JCLI3466.1

Meinshausen, M., Raper, S. C. B., & Wigley, T. M. L. (2011). Emulating coupled atmosphere-ocean and carbon cycle models with a simpler model, MAGICC6 – part 1: Model description and calibration. *Atmospheric Chemistry and Physics*, *11*(4), 1417–1456. https://doi.org/10.5194/acp-11-1417-2011

Meinshausen, M., Smith, S. J., Calvin, K., Daniel, J. S., Kainuma, M., Lamarque, J.-F., Matsumoto, K., Montzka, S., Raper, S., Riahi, K., & others. (2011). The RCP greenhouse gas concentrations and their extensions from 1765 to 2300. *Climatic Change*, *109*(1-2), 213. https://doi.org/10.1007/s10584-011-0156-z

Nicholls, Z. R. J., Meinshausen, M., Lewis, J., Gieseke, R., Dommenget, D., Dorheim, K., Fan, C.-S., Fuglestvedt, J. S., Gasser, T., Golüke, U., Goodwin, P., Hartin, C., Hope, A. P., Kriegler, E., Leach, N. J., Marchegiani, D., McBride, L. A., Quilcaille, Y., Rogelj, J., … Xie, Z. (2020). Reduced complexity model intercomparison project phase 1: Introduction and evaluation of global-mean temperature response. *Geoscientific Model Development*, *13*(11), 5175–5190. https://doi.org/10.5194/gmd-13-5175-2020

Rohrschneider, T., Stevens, B., & Mauritsen, T. (2019). On simple representations of the climate response to external radiative forcing. *Climate Dynamics*, *53*(5-6), 3131–3145. https://doi.org/10.1007/s00382-019-04686-4

Smith, C. J., Forster, P. M., Allen, M., Leach, N., Millar, R. J., Passerello, G. A., & Regayre, L. A. (2018). FAIR v1.3: A simple emissions-based impulse response and carbon cycle

model. *Geoscientific Model Development*, *11*(6), 2273–2297. https://doi.org/10.5194/gmd-11-2273-2018

Smith, C. J., Nicholls, Z. R. J., & Gieseke, R. (2020). FaIR: Finite amplitude impulse-reponse simple climate-carbon-cycle model. In *GitHub repository*. GitHub. https://github.com/OMS-NetZero/FAIR