
GENERAL

This paper describes the coupled Earth System Model (ESM) ACCESS-ESM1, integrating components for the atmosphere, land, sea ice, and the ocean. The innovation that goes into the model presented here is the coupling of carbon (C) cycle models on land and in the ocean, that (potentially) interact with climate. These climate-carbon cycle feedbacks arise due to the fact that all C (CO2) exchange fluxes between reservoirs on land and in the ocean are sensitive to climate and because climate itself is sensitive to atmospheric CO2, affected by these exchange fluxes. Tremendous amounts of work goes into the development of each of these components, and the coupling of these components itself is a major step forward and and will provide a highly desired addition to the relatively small ensemble of ESMs available already today. The components integrated into ACCESS-ESM1 themselves are not new and are used in other ESM in different constellations. Hence, the characteristics of the ESM presented here should not deviate substantially from other ESM predictions. Nevertheless, developing a new coupled model setup is all but trivial, it’s like taking the training-wheels off the uncoupled components, and the coupled system should satisfy a set of key checks and benchmarks.

Considering the size of the type of models presented here (in terms of number of processes represented, amount of code, computational resources required, etc.), a comprehensive description of such a model is impossible and model testing is a major task that can fill a books. From the perspective of a reviewer, it is thus impossible to really judge on the science that goes into this model, let alone to reproduce results (although GMD requires open-access and the possibility for reviewers to replicate results). Nevertheless, an transparent overview should be provided and key tests and benchmarks should be satisfied. As noted by the authors, this model should be used for future model intercomparison projects, like CMIP6, and the present paper should demonstrate that the model is up to this task.

First, I would like to define the challenge better. What does a coupled ESM model have to satisfy and be able to predict? The setup chosen here is to simulate the coupled Earth System, with a focus on climate, ocean circulation, and the C cycle, under constant preindustrial conditions. Given this, the system should equilibrate, i.e. gross C exchange fluxes between atmosphere, ocean, and land may persist, but the net fluxes should attain zero (no model drift). However, a non-zero net flux e.g. into ocean sediments may persist over longer time scales. It has to be acknowledged that limiting computational resources may inhibit a perfect equilibration, this is common also for other ESMs. But even more crucially, mass should be conserved within the system. E.g., the total amount of C present in ocean, plus atmosphere, plus land should be constant.

I have major concerns about whether the ACCESS-ESM1 is ready for publication regarding these aspects. Both equilibration and mass conservation are not satisfied here, as the authors note on several occasions. Even after 1000 yr, land still emits 0.4 PgC/yr (ProgLAI case). Similarly, the ocean outgassing after 1000 yr is 0.6 PgC/yr. This is on the order of one fourth of the present-day global net flux in from these respective reservoirs.

The other major concerns I have is whether the model is even tested for what it is supposed to provide. Coupled ESMs are used to quantify climate-carbon cycle feedbacks and predict atmospheric CO_2 under future CO_2 emission (and climate) trajectories. This is a notable difference to providing climate projections given atmospheric CO_2. A coupled model should be able, after equilibration and under constant boundary conditions (radiative forcing from other agents, solar radiation), to simulate constant atmospheric CO_2 concentrations, with gross exchange fluxes between the atmosphere land and ocean (GPP on land and in the ocean) being broadly consistent with observations. This is not tested here. Atmospheric CO_2 concentrations are prescribed in both simulations. I argue that this is not a sufficient setup for a test of a coupled ESM.

I acknowledge that a balance has to be found between depth and conciseness in the assessment that can be handled under limited resources and published as a GMD paper. I also acknowledge that such a model development is always work-in-progress but should still be publishable. However, I am not convinced that the work in progress presented here has yet reached a state from where it can be taken further (e.g., by adding complexity, as noted by the authors). I am listing a set of variables/aspects that may be addressed by a coupled model under constant boundary conditions and assessed *by comparison agains observations*. This is a suggestion for a next round of review. Some of these are already addressed (e.g. meridional overturning) but in many instances only as a comparison to a previous model version is given and not to observations.

- mass conservation (C in different components, salinity, alkalinity, other ocean tracers)
- equilibration of pools in an emission-driven simulation
- gross CO_2 exchange fluxes, predicted vs. observed/estimated
- temperature fields (land surface and SST)
- surface albedo
- sea ice cover
- meridional overturning
- vegetation and soil C distribution and total pool sizes
- CO_2 seasonality at different locations where observations are available (This is kind of an ultimate test, and is technically possible given that the UM model, in emission-driven setup, transports CO_2 through the atmosphere and that the land model simulates NEE across space.)
- other “standard” benchmarks (Benchmarking of coupled models has been a high priority for years now and helpful tools are freely available. See e.g., ESMValTool by Eyring et al., 2015, GMD).
- Open access: Not satisfied, in that the model code used to produce the results presented here is not available. Code for individual components may be accessed, but not for all components. Some links provided are inactive.
- Provide a very general description of some model characteristics, deficiencies and limitations (e.g. prescribed phenology, fixed N fixation and P weathering), to give at least a feeling for what the model can and cannot do. The balance between generality and detail in section 2 is not appropriate. E.g., Eq. 1 and 2 are unnecessary. It is ok to refer to other publications where these components are described.
- It’s ok not to evaluate individual components in depth, but then the coupled system must be working ok (see above).

I hope my critical review helps to improve this manuscript. In many instances, the material and results are already available and a presentation with a focus on the most important aspects of what a coupled ESM should be able to simulate would much improve the present manuscript.

This would lead to a convincing and transparent presentation of key features and variables, e.g. some of the ones I have listed above.

SPECIFIC POINTS

- In abstract, it needs to be made clear what type of simulations are used for evaluation (forcing? emission/concentration-driven?) and against what it is evaluated.
- In abstract, refer to model components presented in Fig 1.
- Introduction puts strong emphasis on climate-carbon cycle feedbacks. However, the paper does not address feedbacks (constant atmospheric CO_2).
- Many different setups may be chosen for comparison of effects. It remains unclear why prescribed and interactive LAI are given such an emphasis.
- Description of model configuration not sufficient: concentration of GHGs, albedo, areosol, solar radiation, other radiative forcing to drive simulation?
- To initialise the model prescribed observational DIC and Alk are used or variable values are “taken from identical test simulations”, and no spin-up is done —> how does this work? Identical test simulations with 100% identical setup?
- C conservation in land C cycle: Why not 100% satisfied? Could this be a bug in the code? Numerical precision not sufficient? Or is this linked with the fact that CABLE does not simulate land C loss from disturbance (see p. 8071, l.1)? (this confused me anyway...)

Citation:

Eyring, V., Righi, M., Evaldsson, M., Lauer, A., Wenzel, S., Jones, C., Anav, A., Andrews, O., Cionni, I., Davin, E. L., Deser, C., Ehbrecht, C., Friedlingstein, P., Gleckler, P., Gottschaldt, K.-D., Hagemann, S., Juckes, M., Kindermann, S., Krasting, J., Kunert, D., Levine, R., Loew, A., Mäkelä, J., Martin, G., Mason, E., Phillips, A., Read, S., Rio, C., Roehrig, R., Senftleben, D., Sterl, A., van Ulft, L. H., Walton, J., Wang, S., and Williams, K. D.: ESMValTool (v1.0) – a community diagnostic and performance metrics tool for routine evaluation of Earth System Models in CMIP, Geosci. Model Dev. Discuss., 8, 7541-7661, doi:10.5194/gmdd-8-7541-2015, 2015.
