The manuscript „Quantifying memory and persistence in the atmosphere–land/ocean carbon system" is really unusual and sticks out of usual approaches to model carbon cycle, and this is one of the reasons why I agreed to review it. In particular, I was curious how do the authors define the memory and persistence. However, as the field of climate and carbon cycle dynamics is well established and presented by a range of models from zero-dimensional to fully-fledged Earth System models, the authors have to link their definitions and approaches to the ones existing in the field. For example, what does resilience mean in terms of remaining carbon budget until climate goal? What are stress and strain of the Earth system, and how can we measure them? What does it mean that the memory is exploited?

The chosen model suggests the Earth System is under stress from high CO2. Rates of global warming and CO2 growth are indeed unprecedented, and ecosystems are in stress to adapt. However, high level of warming was seen in the Earth history many times and the term "stress" is simply not that easy to interpret. I also anticipated that the model could be more universal and be applied to the other periods in the Earth periods such as glacial cycles.

I also expected that the model could explain fundamental features of the carbon system, for example, why the combined anthropogenic carbon uptake by land and ocean today is about 60%, and not 40% or 80%. Unfortunately, the model parameters are tuned to reproduce observations, assuming that pre-industrial state is without stress. Actually, most of the time during the last million years the Earth System was in cold conditions under low CO2 concentrations. If one uses the Last glacial maximum ca. 20 thousand years ago as a reference, would the pre-industrial state be a stress for the Earth System?

In summary, using the new approach such as rheological model is useful in case the method brings something new comparing to the current set of models used for policy applications. However, I just do not see what new can we learn from this approach. It looks more as reformulation of the problem in new variables which are non-measurable and have little content to be interpreted by policy makers, such as remaining carbon budget. I think the approach is interesting, so I do not recommend to reject the manuscript, but without substantial rewriting and interpreting terms in measurable quantities this study will miss the auditorium.

Specific comments

P.2, l.6: "**the CO2 concentration in the atmosphere increases (rather quickly).** Concomitantly, the atmosphere warms and expands, while **part of the carbon is locked away (rather slowly) in land and oceans**, likewise under the influence of global warming." This statement is in disagreement with data. Over last decades, airborne fraction of CO2 emissions is rather constant, see for example Chapter 5 in IPCC AR6 WGI (Canadell et al., 2021). That means that CO2 in atmosphere is increasing as fast as sinks on land or in the ocean.

l.11: "It is not known how reversible and how much out of sync the latter process is in relation to the former." I think we know it, see for example ZECMIP study (MacDougall et al., 2020). If CO2 emissions are reduced to zero, atmospheric CO2 concentration will start to

decline, as well as sinks. The warming will stop, but not decrease because of the heat accumulated in the ocean. So on centennial timescale the warming is irreversible.

l.13: “Here we ask three (nontrivial) questions: (1) Can this global-scale memory–Earth’s memory–be quantified?” Firstly, you need to define memory and how do you measure it. If it is a memory (timescale) of anthropogenic CO2 in the atmosphere, it is quantified in many studies, see eg Archer et al. (2009) or Joos et al. (2013).

l.14: “(2) Is Earth’s memory a buffer which is negligently exploited; and in the case that it is even a limited buffer, what is the degree of exploitation?” I do not understand at all the concept of “exploitation of the Earth’s memory”. Sounds as you try to formulate a policy-relevant point. However, if you cannot translate it into the terms already accepted in the climate policy framework, such as remaining carbon budget until certain climate target, you miss the policymaker auditorium. See my point above.

l.22: “We find that since 1850, the atmosphere–land/ocean system has been trapped progressively in terms of persistence (i.e., it will become progressively more difficult to train-relax the system)”. Again, you need to translate that language (“tapped”, “persistence”) into more common terminology used in physics and biogeochemistry.

p.3, l.2. “Approximately 60% of Earth’s memory had already been exploited by humankind prior to 1959.” And what is if it is 100% of memory used? Also, how much could be exploited since last glacial maximum or PETM?

l. 3: “We expect system failures globally well before 2050.” What kind of failures are you talking about? Ice sheet collapse, heatwaves, etc.? Be explicit.

Page 4. l.21 to p5., l3. Here is a repetition of the questions from the abstract without any detail why these terms are used and why the questions are important.

Page 5, l. 19: “In view of the aforementioned questions, we chose a rheological stress-strain (σ-ε) model” I do not see a link between questions and the model choice. I do not see why this formulation is better than a standard climate-carbon box model formulation used for emulators. Is it more universal and less empiric?

p.12, l. 23: the units for NPP are missing, as well as for GPP called global photosynthetic carbon influx in l. 7 on page 13. This renaming of well-known terms and absence of units (eg PgC/yr for NPP, ppmv for the CO2 concentration) in many places is really annoying. Units for most variables are also absent on many plots. This complicates understanding as readers have no idea whether the values are on a global scale, normalized or not, etc.

p.13, l.3: what is “CO2L” – a variable? Multiplication of CO2 and L?

l. 6: what are L units?

l.8: “biomass production” and productivity are different, as there is autotrophic respiration which doesn’t turns into biomass. Again, units for beta are missing.

Figs.2, 3, 4,5,6: units are missing on x and y axes.

Fig. 7: what does time in units of 1 means? Is it normalized to some reference time?

Page 29, l.11-12: “They may simply collapse globally”. This is a pure speculation. What “they” means here: natural regimes or natural elements (like land or ocean)? How can land or ocean collapse? The carbon uptake would not collapse, but relative uptake fraction will decrease. See Canadell et al. (2021).

l.17: what are “upstream emissions”?

p. 32, l. 1: “land and oceans became less viscous”. What do you mean by land viscosity? Viscosity of carbon uptake?

l.6-8: “while its persistence (path dependency) increases by approximately a factor 2–3 if the release of emissions globally continues as before.” So what? Are there any consequences for climate if the factor rises up to 10? This should be discussed.

References

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