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Earth System Dynamics
Discussions



# *Interactive comment on* "Earth system modelling with complex dynamic human societies: the copan:CORE World-Earth modeling framework" *by* Jonathan F. Donges et al.

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## 1 General comments

This manuscript by Donges and colleagues introduces the core technology and concept behind a new software tool called "copan", that should serve as "a framework for developing, composing and running World-Earth models". The authors motivate the development of such World Earth Models (WEM) that encompass dynamic descriptions of both the anthroposphere as well as the Earth System, they contrast WEM to integrated assessment and Earth System models, they describe the concepts of the



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developed software package pycopancore and they show simple example applications of the software.

The contribution is within the scope of the Special Issue “Social dynamics and planetary boundaries in Earth system...” in Earth System Dynamics, although the preferred outlet for this kind of technical model description could also be Geoscientific Model Development. The novelty of the approach is the complexity of a World model combined with a stylized version of an Earth model; the innovation is in the open framework and theoretical embedding of the World Earth Model approach.

The paper is overall well written, but suffers from resilience theory and technical jargon, which should be reduced to address a wider readership. Figures are appropriate but they are of mixed graphical quality and accessibility and should be improved on. Tables are appropriate throughout; code examples examples are useful but in need of better quality. The supplementary material is well presented and useful.

The theory-laden motivation somewhat contrasts with the very technical model description. Reviewer one already remarked on the need for better embedding of these two major perspectives the manuscript assumes. I agree with that assessment, but for brevity I will concentrate in my detailed review below on other aspects of the manuscript. A major missing part is a description of how the presented copan:CORE framework fits into and operates with much of the existing coupling and model infrastructures in Earth and Social sciences; claims to interoperability, modularity and flexibility remain unsubstantiated.

I recommend that this paper is published after substantial revisions.

## 2 Title, Abstract and related parts of Introduction

**title** There is an inconsistency in the spelling of “modelling” right in the title. Also, consider to spell out WEM as World Earth Model without hyphens; carefully consider lowercase/uppercase for “Model” in WEM. Nowhere in the paper the authors motivate the naming “copan:CORE”; please add a sentence on this naming and add to a table of abbreviations, if any of this is an acronym.

**p1 l1ff** That first sentence “Possible future trajectories of the Earth system in the Anthropocene are determined by the increasing entanglement of processes operating in the physical, chemical and biological systems of the planet, as well as in human societies, their cultures and economies” is very debatable. “Possible” is redundant, the choice of Anthropocene (capitalized) possibly politically motivated, the word “determined” raises concern of confusion with “deterministic” approaches and the conjunctions are not well placed. If I may rephrase this, the “Anthropocene (sic!) is characterized by close entanglement between the Earth system and its physical, chemical and biological processes and the World system with its economic, social, and cultural interactions.” And certainly there is no need for eight (!) citations to entanglement in the Anthropocene; possibly, authors who argue for entanglement in the anthropocene (minuscule “a”) should be cited instead.

**p1 l3ff** Second sentence “Here, we introduce the copan:CORE open source software library that provides a framework for developing, composing and running World-Earth models...” This sentence should foremost and first emphasize that this publication introduces a new term and concept, namely that of a WEM, and second that it also provides a software library for modeling such WEM. Also the definition of WEM as “social-ecological co-evolution up to planetary scales” does not agree exactly with the later definitions given in the manuscript. Please elaborate in the abstract on your term WEM, on the theoretical embedding and reduce the room

given to technicalities.

## 3 Introduction

**p2 l25ff** Please provide a reference your historical examples. In the discussion of the "Tragedy of the Commons" it would not hurt to point to related works that make Ostrum's work operational in model simulations.

**p2 l34f** I believe the term "planetary social-ecological system" needs more explanation. SES are usually understood as local in much of the literature, and as multiple instances that behave very different. Thus, also the implementation of SES mostly in agent-based models (as you mention yourself later in the introduction). Elaborate and contrast your "planetary" approach to the local SES. You might also consider to reduce usage of the term SES altogether in favor of your new term WEM to avoid this confusion.

**p3l 7ff** Congratulations on the choice of the term "World Earth Model". This is to date the best term I have yet heard to describe the type of model you've developed. I suggest to elaborate on how you come to this term, and to set it off from other terms including, but not limited to, SES and CHANS (Coupled Human and Natural Systems).

## 4 Blueprinting World Earth Models

**p3 l6ff** Please use precise language, do not "outline guidelines" or "address leading research questions". Check entire manuscript for this type of bloated wording.

**p3 l7ff** For the definition of an Anthropocene you already need to say how it differs from the Holocene and other paleoclimatic stages. So the first half of question type 1 is circular. As for the second part "how might it alter the evolution", it is unclear what "it" refers to. Certainly the "Anthropocene" is not an actor (so it cannot alter) but a diagnostic term for the World-perturbed Earth. Please clarify.

**p3 l8ff** Avoid general valueing statements like "disastrous" or specify; check entire manuscript for further occurences of such type. Avoid jargon here and explain all domain-specific terms.

**p3 l27** Here you use "framework" in the management sense, later you use (software) "framework" for the technical description. Then you both consider Netlogo as well as copan:CORE frameworks, but both are very different things. I would prefer to term NetLogo a modeling platform. The term "framework" is a difficult one, please try to use it consistently in only one sense (and explain that sense by giving your definition of a framework) throughout the paper.

**p3 l27** The "high degree of modularity and flexibility and coupling capabilities" is not substantiated. While there is some software modularity and role modularity (see my later comment), there is no effort made towards coupling capabilities in a more general sense (there is a statement later on interoperability with LPJml, see my comment below). There is also no elaboration of what you mean by flexibility.

**p4 l14ff** I don't see how the stylized biophysical description in the WEM can help answer this question. Would we not need a "whole" WEM where both the Earth System and the Socio-cultural system are described process-detailed (ref your Fig 1)?

**p4 l25ff** You argue that environmental and societal processes should be described on a similar level complexity, yet in Figure 1 you argue for a stylized description of the biophysical world. Please explain better or resolve this conflict between text

and figure. As for your list of five characteristics of WEM, I suggest to give each item a short title. You might want to consult our modeling framework paper (see references, we had to argue for biological models on par with physical oceanography models and called this “equitability”). Others could be “nonlinearity“ and ”aggregation”.

## 5 copan:CORE WEM framework

**p6 l22ff** Your modularity is achieved through object-oriented programming. This is not enough to justify modularity as an eminent feature of your software. This is mere good software practice. Object-oriented programming then does not per se allow interoperability and dynamics coupling to other models, as you claim. To this end, much more (like coupling frameworks, data exchange standards, computational bridging infrastructures) are needed, all of which are absent from the manuscript. Please elaborate on the specific coupling solution to LPJml and to IMAGE to substantiate your interoperability claim.

**p8 l14ff** Consider making this list of process-types identical to the one found in figure 2

**p9 l16ff** It should also be the role of the “master” model to ensure interoperability with other modeling frameworks, of which you make no mention. A prominent framework that you should reach out to is the CSDMS BMI (basic model interface) idea. Your master component could implement that BMI/CMI and thus make all user-contributed models also interoperable. We have, e.g., done this with the FABM (Framework for Adaptive Biogeochemistry) for ESMF interoperability. If you don’t want to add a BMI (to CSDMS, OpenMI or ESMF, or other frameworks) please add a section outlining your plans to do so or your reservations against doing so.

**p13 l 3ff** The term “modular” is in your context the software modularity typically found in modern software architecture. This is *not* an emanating feature of co-pan:CORE. There is modularity beyond software modules in other frameworks and I would encourage you to rethink modularity in that broader sense.

**p16 l 4** A section on performance is missing (e.g. at end of section 3). Many thousands of cells, individuals or other entities might have to be simulated with this framework. What is your approach to ensuring that integrations of differential equations (exemplary for one of your process-types) is efficiently handled for large numbers of entities? Is there consideration for optimization (you already mention communication with MPI and JSON) for high-performance computing architectures? What tradeoffs to performance do you expect by using “slow” packages like sympy? Did you perform any scaling experiments?

## 6 Figures

Overall, the figures are of mixed quality and style. A more consistent layout, style, coloring and fonts across all figures would make the paper more pleasing to the eye and also more readable. Please spend some efforts towards this goal. Especially Figs 1 and 2 are very clear and could serve as a template.

**fig 1** The white box could contain text, such as “none”

**fig 2** For consistency with text, use “process type”, not “modelling approach”

**fig 3** This entity–relationship diagram in UML style is only understandable to a small fraction of readers. Please explain the notation used in the diagram (for example by giving an example of the cell–person relationship). I do not at all understand

the circular relationships for entities with themselves, especially for the SocialSystem entity. Please clarify. This figure does not need color, in fact, color distracts here.

**fig 4** This "spaghetti" diagram is not helpful. Please create an entirely new graph. Rearrange the information, e.g., choose a UML style for consistency with fig 3. Avoid crossing lines, strange coloured shapes without obvious semantics, use typewriter font consistently for code parts. Make graphical markers (colors, line widths, boxes) easily accessible by adding a legend instead of explanation in caption.

**fig 5** see comments for code figures later

**fig 6** Change colours entirely to be consistent with figure 2 (CUL, MET, ENV). Don't use background color. Change layout to something visually appealing; currently the table structure suggest as semantic for rows and columns that is not evident.

**fig 7** Table layout conveys meaning, but could be highlighted (columns are scenario (is that what you call "runs" in the caption?, rows are taxa). Avoid mixing colour semantics with those of previous figures. Avoid mixing color semantics between panels: How to top and middle row colors align? If they do, don't add two legends but use only one. Explain why for CUL/ENV there are only four quantities shown, but for MET there is an ensemble (each four) of three quantities shown. Upper left: where is the blue line (I guess hidden behind the grey one ...)? Find a way to display lines that are on top of each other without hiding any (also upper right figure). Possibly add events on time axis, especially for understanding middle right panel events with sudden transitions from fossils to biomass.

**figs 5,8-10** Try improved syntax colouring and choose different font. Fixed width is important, but better use a smaller width. Consider light grey for comments, for

example. A light (cream) background might help to set the code apart from the title, which is barely visible (and which uses inconsistent font with main text).

## Technical comments

**p7 l 10** There is no such thing as “sharp criteria”. Criteria alone is sufficient.

**p14 l14** The link to pycopancore (http://github.com/pik- 15 copan/pycopancore) does not work yet (so make sure it does work on publication day)

**p14 l29ff and Figure 5** Use a consistent form for presenting code, do not alternate between text and figure.

**p16 l 4** Examplary => Exemplary

**p16 l 9** “not intended to be a serious representation”. A representation cannot be serious. I suggest “is intended to be a toy representation”. BTW, what is the “real” world anyway :=)

**p17 l3ff** Avoid double parentheses throughout this paragraph and manuscript.

## References

Lemmen, C., Hofmeister, R., Klingbeil, K., Nasermoaddeli, M. H., Kerimoglu, O., Burchard, H., Kösters, F., and Wirtz, K. W.: Modular System for Shelves and Coasts (MOSSCO v1.0) – a flexible and multi-component framework for coupled coastal ocean ecosystem modelling, Geosci. Model Dev., 11, 915-935, https://doi.org/10.5194/gmd-11-915-2018, 2018.

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