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Earth System Dynamics
Discussions

Interactive comment on "Topology of sustainable management in dynamical Earth system models with desirable states" *by* J. Heitzig and T. Kittel

Anonymous Referee #2

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GENERAL COMMENTS

This article offers a new framework to analyze and manage the earth system dynamics, using qualitative modelling to keep the dynamics within a desirable region. This is a major contribution to the growing literature on planetary boundaries, also referred to as "tolerable windows" or "safe operating space" of the earth system. While much of the previous research has focused on quantitative simulations and optimal control of dynamic systems, a major innovation of this paper is the aim to understand the internal dynamics and management options of the system in qualitative terms. Although this is not the first attempt to apply qualitative modeling in earth system dynamics, it goes beyond previous research by proposing an integrative framework and new terminology with intuitive meaning.

The literature cited in the paper is quite selective and refers mainly to the sources of the exemplary models, references on viability theory and a few own publications. The work is seen as complementary to the existing quantitative literature on optimal control and integrated assessment. Useful are the references to mathematical viability theory. It would be helpful to include a few more references to qualitative modeling of global change patterns and related issues such as the tolerable windows and guardrails concept.

Using a topological perspective, the paper introduces a formal classification of the possible states with regard to concepts of desirability, reachability, stability, safety, connectedness. Interesting is the terminology of qualitatively different regions that follow life-world experiences. The paper uses the comparison with a boat floating and rowed through a physical water world, classifying regions according to the concepts as upstream, downstream, shelter, glade, lake, eddy, abyss and trench, as well as harbour, port and dock. This novel approach facilitates the translation of complex mathematical concepts into a language accessible to a wider audience.

Although the main messages of the paper can be presented in verbal and visual form, part of this is complicated by the way the mathematical framework is presented. Although much of the mathematical notations, proposition and proofs are placed into an appendix, the main text is difficult to follow for an audience attracted by the title's subject of sustainable management of the earth system. Rather than introducing the framework in one section and then moving to applications, bits and pieces of the framework are scattered throughout the different parts of the paper and associated with various exemplary conceptual models, from classical mechanics to economics and environmental science. Figures 1 and 3 are meant to help understanding of the framework and related concepts but do not serve this purpose being placed early in the paper as long as the terms given in the figures are not explained. Their meaning only becomes clear after reading the whole paper.

Apparently the paper aims to explore the methodological framework rather than to gen-

erate concrete results for specific problems of earth system dynamics. The research questions and objectives are quite general and oriented towards reachability and safety of state space regions as a consequence of the topological structure. The examples and graphs, which are not related to each other and somewhat arbitrary, serve more the purpose of illustration and visualization of the model framework and related concepts rather than to generate clear results for real-world phenomena. Some examples (like example 9) do not have a clear meaning or relevance for earth system dynamics and are purely methodological.

With this scattered approach the paper is hard to read and requires major efforts to move through the many concepts and cases before getting used to the formalism and seeing the bigger picture. Then it is possible to recognize the merits of the approach, in particular in the discussion of the different dilemmas, such as choosing between desirability, safety and flexibility. Here one would expect more to make the framework really relevant for both modelling and policymaking, for instance, how tradeoffs between these criteria play out. These issues are only shortly sketched in the end. There are no clear results under which conditions criteria and boundaries are met and will be reached. With this end, the high expectations raised in the beginning of the paper regarding a new theory for analyzing planetary boundaries are not fully met and leave the fruits of the time and effort spent on the paper to later research. The limits of the paper could be made more clear from the beginning to avoid expectations that cannot be met.

Considering the critical comments, the paper is innovative as a theoretical contribution and recommendable for publication. It shows major avenues of future research that eventually may lead to important results in the future.

SPECIFIC COMMENTS

The presentation can be improved in several ways:

The paper is difficult to read as the overall logic only appears in the end. The exam-

ples somewhat distract from the main thread. Figures 1 and 3 are meant to illustrate the general concepts but placing them early in the paper without explaining them sufficiently in the main text is rather confusing. Figure 1 is not as easy to grasp as it is supposed to be as many of the terms are not introduced. More helpful would be a two-dimensional graph illustrating the idea of a boat floating through the landscape and visualizing the key terms.

Helpful would be a section 1.2 that better explains the overall framework as well as the key terms (so far there is only 1.1 which is incomplete numbering of sections). Most useful would be to have a list of terms or glossary here in tabular format, summarizing the verbal meaning in one column and the mathematical definition in another column. Such a reference point allows the reader to get used to the terms early, both intuitively and if necessary look at the formal definitions when they are used later on.

One should make clear that the terms “desirable”, “sunny” and “dark” are based on value judgements. Would be good to have a discussion in the beginning or end of the paper what the implications of value changes are. How do the results change when the degree of desirability is lowered or increased? In Figure 1 this could mean that the whole region could either become sunny or dark.

TECHNICAL CORRECTIONS

p.437-438: Clarify which of the concepts are new and which rely on earlier work. Include a few more explanations and references to qualitative modeling of global change and related concepts which would be helpful to the non-expert in this field.

p. 442, line 15: Why is the reachability between two sets limited to both being “arbitrarily close”? Wouldn’t reachability also make sense for any pair of sets, whatever their distance?

p.444, line 23: Arrow shown here is from right to left but is defined from left to right above.

p. 446: Why is Example 3 without figure?

p. 449: Is there a reference for Example 5?

p. 450: There are some repetitions between the last two paragraphs. To which variable does the value (0.079) refer to (is not specified in both paragraphs). What is the "widest" admissible trajectory?

p. 451, line 25: Not clear what function g(r) means here.

p. 453, line 4: Please give individual names of each of the five parameters; difficult to distinguish y and gamma because they look very similar: perhaps use different letter?

p. 455- 461: Clarify better in words what some of the term mean (transitional, rapid, channel, fairway, finer partition).

p. 455, line 18: Here you give D a second meaning. It meant downstream before, now it means dock. This is not consistent terminology for this paper.

p. 457: Does Example 9 represent any real-world example? Why was it chosen? What is its source?

p. 479, Figure 1: This includes terms not defined before.

p. 481, Figure 3: This figure is far too small in regular printout. Break up in two figures and enlarge. Upper part is not very instructive.

p. 484, Figure 6: This figure is a bit confusing with its four different forms. Besides the upper right part, there are no labels on the axes making the meaning questionable. Why are there no trajectories like in other figures?

p. 485, Figure 7: Not sure how to read this figure and the numbers given in the text. What is the difference between gamma_0 and gamma_1? Strangely, in my printout the gamma and beta appear as Phi (not on the computer screen).

p. 487, Figure 9: What is "Extreme admissible. . ."

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