A Review of

On defining climate by means of an ensemble

by Gábor Drótos and Tamás Bódai

General. This paper is a wide-ranging discussion of various approaches to describing, simulating and possibly defining climate. It is rather descriptive, while attempting to be normative. I found it hard to read and will try to offer some suggestions on how to make it more readable as opposed to being all-inclusive.

Overall, the paper does contribute to bringing to the attention of the *ESD* readership — and to a fairly rapidly increasing community of mathematicians and physicists interested in climate and its change — concepts and methods from the theory of nonautonomous dynamical systems (NDSs). This theory is clearly well-adapted to the description, understanding and prediction of the way that time-dependent forcing or coefficients affect a system that has both chaotic and random elements, like the climate system. A major problem in applying this fairly novel mathematical theory effectively to the difficult problems at hand is the use of different language by two distinct communities of practitioners: some that rely on a somewhat fuzzy "physical" background and those that try to use efficiently the advances of the rigorous mathematical theory. Clearly the authors are respected members of the former community and the reviewer belongs to the latter.

The recommendation is publication after improvements.

Major comments

Philosophical issues. The reviewer (hereafter MG, to avoid the pretentious "I".) has as much of a philosophical bend as the authors. As such, he would like to recall the difficulties that Ludwig Wittgenstein already pointed out in the communication among different "language communities," into which he definitely included scientific communities. This is certainly the case in the communication among the physical scientists of IPCC's Working Group (WG) I and the socioeconomic experts of WG II and WG III. But it is also the case in the problems at hand, among the authors, who only quote as their dynamical systems bibles Tél & Gruiz (Cambridge UP, 2006), a fine undergraduate book, and Ott (Cambridge UP, 1993), published before the evolution of NDS theory.

The refusal to take to heart and to bed recent books like Caraballo & Han (Springer, 2016) or Kloeden & Yang (World Scientific, 2020) — which not only have the word "nonautonomous" in the title but also treat the latest developments in NDS theory — is not helpful in overcoming the Wittgenstein-type miscommunication between the two communities. It might also be worth recalling Galilei's words on the role of mathematics in understanding the world and how it functions: "Philosophy is written in this grand book — I mean the Universe — which stands continually open to our gaze, but it cannot be understood unless one first learns to comprehend the language and interpret the characters in which it is written. It is written in the language of mathematics, and its characters are triangles, circles and other geometrical figures, without which it is humanly impossible to understand a single word of it." (translated from "Il Saggiatore, vol. VI, p. 232" in Galileo, *Opere*, A. Favaro, Ed., Barbèra, Firenze, 1929–1939). One does not have to spend one's life proving theorems, but it is helpful to have an idea of what they are about.

MG appreciates the reference in the paper to the work of Charlotte Werndl, but does not find that the mixture of trying to proceed in a similar mode in this paper, on the one hand, with ignoring entirely the major ingredient of rigorous mathematics, on the other, is helpful in advancing the subject.

Practical issues. It is not clear to MG in which way what is purported to be a definition of climate is really different from the ensemble simulations that are practiced by the IPCC's Assessment Reports and the successive Coupled Model Intercomparison Projects (CMIPs) that they rely upon. It is nice to do to small models what has become the *modus operandi* in dealing with very large ones. But this is just a mode of describing climate and hoping to predict its change, rather than a definition thereof.

Recommendation. Shorten and sharpen the text of the paper and change the title to "**Describing climate by means of an ensemble."**

Michael Ghil

P.S. In trying to properly place the problem of time-dependent forcing of a chaotic and random system like the climate system among those posed by the system's nonlinearity in general, it might be worthwhile citing

Ghil, M., 2019: A century of nonlinearity in the geosciences, *Earth & Space Science*, **6**, 1007–1042, doi: 10.1029/2019EA000599,

and its several "lamp posts."

Likewise, in another EGU journal than the one to which this paper is submitted, namely *NPG*,

Ghil, M., 2020: Review article: Hilbert problems for the climate sciences in the 21st century – 20 years later, *Nonlin. Processes Geophys.*, 27, 429–451, https://doi.org/10.5194/npg-27-429-2020.