BOOK REVIEW

Eric Winsberg, ***Philosophy and Climate Science.*** Cambridge: Cambridge University Press (2018), 270pp., $29.99 (paperback).

There are several related aspects that make climate science extremely interesting from the philosophy of science point of view. Climate science is part of the scientific background for understanding and addressing the climate challenge. It is also "literally awash with all the conceptual, methodological, and epistemological issues that perennially preoccupy philosophers of science'' (3) and in many ways, Eric Winsberg's *Philosophy and Climate Science* nicely demonstrates that this is the case. Indeed, Winsberg's book discusses in its 14 chapters the main philosophy of science topics related to climate science, engaging to some extent with the current debates on these topics. Moreover, as briefly discussed in the introduction, the book (somewhat indirectly) illustrates how philosophy of climate science can be "socially relevant": for instance, if this book is not explicitly about a defence of anthropogenic climate change or about climate ethics (even if several aspects of the book are related to climate ethics), the philosophy and epistemology of science perspective it develops on climate science and its foundations can clearly be helpful for both issues (it is also directly relevant for other socially relevant issues, such as climate decision making).

Chapters 2 to 5 first consider general (methodological/foundational) features of climate science and climate modelling. Chapter 2 addresses a standard philosophy of science issue, namely the complex relationship between raw data and scientific hypotheses in the context of climate science. Besides summarising the case of satellite data, which has been discussed in the philosophy of science literature, the chapter provides a very quick overview of the main body of evidence for global warming from the perspective of this issue of the theory-ladenness of data (many examples of mentioned data could actually have benefited from a more detailed discussion, for instance articulating concretely how and to what extent these various data are theory-laden).

Chapter 3 addresses the issue of the nature and the role of models in climate science, taking simple energy balance models (and their limitations) as an example; indeed, despite the idealizations they involve, these latter illustrate the importance of considering models from the perspective of their adequacy for a certain purpose. In particular, this adequacy for purpose is crucial for computer simulation models, which are essential to complex, state-of-the-art climate models; this is the topic of chapter 4. Besides understanding, the main purposes of climate models are various types of climate predictions and "climate experiments", in particular "in order to attribute causes to measured changes in the climate over the last century" (43). Winsberg then reviews the main features of climate simulations, and discusses in some more details the important issue of parameterization and the perhaps less discussed (but also important) feature of modularity. The adequacy for purpose perspective is crucial for understanding parameterization: indeed, since parameterization aims to encode what is not captured in the discretization procedure (such as the sub-grid processes), the corresponding parameters are "artifacts of the computation scheme" (49), and so have no true or correct values, but rather may be more appropriately considered to have best values relative to certain purposes or relative to a certain context.

Chapter 5 introduces certain elements of chaos theory (such as, of course, the exponential sensitive dependence on initial conditions, also commonly called "butterfly effect") and emphasizes the different ways in which they are mitigated in the weather and climate contexts. If weather forecasters mainly make use of what Winsberg calls "probabilistic initial condition ensemble forecasting", climate scientists actually mainly aim to produce climate projections rather than predictions, that is, possible responses of the climate system that are consistent with the external forcings, and, to some extent, that are not dependent of actual initial conditions. The end of the chapter, as well as the appendix at the end of the book, critically discusses the implications of the lack of structural stability of climate models (which has been called the "hawkmoth effect" in the philosophy of science literature). Winsberg actually spends some time explaining "why philosophers interested in climate science should not pay attention" to the hawkmoth effect (70). The fact that the appendix, which is entirely devoted to the "hawkmoth effect", is longer than certain chapters actually suggests that the issue is subtle and requires some careful attention. There are several aspects to Winsberg's objection to the relevance of the lack of structural stability for climate projections, but the main point concerns the topological rather than metrical nature of the structural stability notion. As a consequence, the argument goes, the absence of structural stability does not say much about how 'large' and how 'fast' small discrepancies in model structure can grow, and so this notion is not relevant for evaluating the predictive capacities of climate models. This seems a bit quick though. Indeed, the topological nature of structural stability (and lack thereof) does not mean that it cannot have (topological and metrical) implications that may be relevant for climate projections, for instance in terms of the attractors and dynamical invariants. It is clear that there are many open issues (e.g. about relevant universality classes and relevant time scales) regarding the exact implications of the absence of structural stability for concrete climate modelling projects, but at this stage it does not seem justified to dismiss them.

Chapters 6 to 9 discuss probabilities and uncertainty in climate science and climate modelling, as well as decision-making and the role of values in this context. The main claim of chapter 6 is that weather forecasting is (sometimes) about 'objective' chances---in the sense of probabilities corresponding to "features of the mind-independent world" (79), such as in the case of statistical mechanics---in a way that climate science is not, this latter being rather mainly about 'subjective' probabilities or degrees of belief (credences). However, the relevance of making this distinction between the two cases can be disputed, especially given the importance of a subjective understanding of probabilities also in the weather forecasting context and the fact that weather and climate models are getting closer in certain ways.

Chapter 7 considers the limitations of ensemble methods in ("mechanically") quantifying certain types of uncertainty, hence the need for taking a wider perspective on climate science probabilities estimate, in particular integrating relevant physical understanding of the situation and expert knowledge. This naturally brings the discussion to the ("second-order") notion of confidence---central to the reports of the Intergovernmental Panel on Climate Change (IPCC)---which is best understood in subjective (i.e. involving degrees of belief) and qualitative terms.

How the probabilistic quantifications of uncertainty---to the extent that they are available---can be put at use for decision-making is the topic of chapter 8. After presenting the general Bayesian perspective on statistical inference, Winsberg considers expected utility theory and critically discusses the optimization integrated assessment model, which aims to provide a scientific approach to the best climate mitigation strategy.

Chapter 9 addresses the issue of the role of values in science and in climate science in particular. Winsberg argues that climate science and climate modelling provide a further strong case for the "ineliminable role" of values in science---however, he clearly emphasizes that he does not "*regard climate science to be special in its failure to meet the value-free ideal*" (138). Values typically enter the picture through the notion of purpose, which is central to climate model building and evaluation, as well as through the many (entangled) choices that have to be made in the long and complex development of climate models. However, the impact of these choices (and more generally of the underlying values) is often very hard to clearly identify.

The last part of the book addresses central epistemological issues in climate science and climate modelling. Chapter 10 argues that the specific and complex features of climate models make the standard "verification and validation" framework---where the two are understood as separate activities---not really applicable and useful for evaluating the skills of climate models. Building on his previous work on the topic, Winsberg rather argues for a more intricate "alternative picture" (§10.3), where the notion of understanding plays a central role. The chapter also discusses the important issue of tuning.

The chapters 11 and 12 are both about robustness analysis in climate science. Chapter 11 mainly reviews the debate about robustness between the two philosophers of science Elisabeth Lloyd and Wendy Parker. Winsberg then argues for a wider perspective on robustness analysis, one that allows for some "diversity of evidence", beyond the usual focus on model agreement. An appropriate notion of diversity ("explanatory RA-diversity") is articulated in the climate context in chapter 12, building on the work of Jonah Schupbach. The crucial point is that diversity should be considered "*with respect to a particular hypothesis and its rivals*" (193), which may require some understanding of the relevant physical mechanisms. Indeed, in many ways, the notion of understanding seems central to the epistemic foundations of climate modelling. Finally, chapter 13 discusses topics in the social epistemology of climate science, such as the epistemological implications of the various sorts of (dis)agreements among experts and the notion of group authorship.

Philosophy and Climate Science provides a good overview of the main philosophy of science issues in climate science and climate modelling. Many points in Winsberg's book also open interesting perspectives for future research in the field. For instance, the epistemic foundations of climate science and climate modelling would benefit from articulating the nature and the role of the scientific understanding and background knowledge invoked in many places throughout the book (e.g. in the context of uncertainty quantification in chapter 7, model skill evaluation in chapter 10, robustness analysis in chapters 11 and 12). Several chapters contain helpful 'boxes' explicating important notions used in the text and useful "suggestions for further readings" are given at the end of each chapter. However, certain topics are treated rather quickly, and may sometimes lack some depth, while others more specifically reflect Winsberg's views in some details. Because of that, and despite the many examples and illustrations provided, the book is not always an easy reading and is sometimes not really suitable for "a wider general audience". But Winsberg does a very good job at showing the philosophical richness of climate science, and his book will be an important reading for philosophers of science interested in the philosophy and foundations of climate science.

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