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Issues in the theoretical foundations of climate science

Joel Katzav [a, *, 1], Wendy S. Parker [b]

[a] School of Historical and Philosophical Inquiry, University of Queensland, Australia
[b] Department of Philosophy, Durham University, UK

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ABSTRACT

The theoretical foundations of climate science have received little attention from philosophers thus far, despite a number of outstanding issues. We provide a brief, non-technical overview of several of these issues — related to theorizing about climates, climate change, internal variability and more — and attempt to make preliminary progress in addressing some of them. In doing so, we hope to open a new thread of discussion in the emerging area of philosophy of climate science, focused on theoretical foundations.

1. Introduction

Philosophers of science have become increasingly interested in climate change and climate science. Thus far, attention has focused primarily on the epistemology of climate science, especially climate modelling. Philosophers have analysed how climate models are constructed and evaluated, and they have debated how uncertainties associated with model-based projections of climate change should be characterized (e.g., Parker, 2009 , 2010b; Lloyd, 2010; Katzav, 2014; Katzav, Dijkstra, & de Laat, 2012; Betz, 2015; Frigg, Thompson, & Werndl, 2015). They have also investigated conflicts between climate models and observational data (e.g. Lloyd, 2012), how non-epistemic values might influence climate model projections (Intemann, 2015; Parker, 2014; Winsberg, 2012) as well as how various sources of evidence for climate change are amalgamated and synthesized (e.g. Katzav, 2013; Vezér, 2016).

The theoretical foundations of climate science, by contrast, have received very little attention from philosophers (the sole exceptions, as far as we can tell, are Werndl (2016) and Lawhead (forthcoming)). However, these foundations merit scrutiny and development just as do those of biology, chemistry and physics. This includes theorizing about climate states, climate change, climate sensitivity, radiative forcing, and more. Indeed, climate scientists themselves recognize the need for work on the theoretical foundations of their discipline. Thus, for example, Lovejoy and Schertzer (2013, p. 337), argue that the standard ways of characterizing climate states are not sufficiently objective. Ghil (2015) and von der Heydt et al. (2016) argue that available ways of thinking about climate sensitivity are not sufficiently general. The U.S. National Research Council (USNRC, 2005, p. viii) makes a similar point, but about the standard notion of radiative forcing (cf. Sherwood et al., 2015).

The present paper aims to provide philosophers interested in climate science with a brief, non-technical overview of these and several other key issues in the theoretical foundations of contemporary climate science. We focus our attention on the notions of climate system, climate state, climate change, climate sensitivity, internal variability and radiative forcing. Addressing in detail any one of the issues that we identify would be a major undertaking in itself; here our main aim is rather to give a sense of what some of the key issues are and of how they are related to one another. In other words, our aim in this paper is more agenda-setting than problem-solving. We do, however, offer some preliminary suggestions for ways of tackling some issues as well as an indication of how doing so relatively systematically might be advantageous.

Our discussion aims to be responsive to foundational issues that climate scientists encounter in their research and, accordingly,

* Corresponding author.
E-mail addresses: uqjkatza@uq.edu.au (J. Katzav), wendy.parker@durham.ac.uk (W.S. Parker).
[1] Joel Katzav is the main author of this paper.

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primarily focuses on pragmatic issues; such issues arise because available notions are, in one way or another, less than optimal for realizing the inferential and explanatory goals of climate science. Thus, the issues we identify largely concern the usefulness of specific notions for the purposes of interpreting and explaining observations of the climate system, developing and using climate models for predictive and other purposes, and drawing conclusions about the behaviour of the climate system in one period from its behaviour in another – e.g., using palaeo-data to inform conclusions about future climate change. Importantly, we will see that it is a challenge to develop notions of climate states and climate sensitivity that are general enough to accommodate what we know about the climate system and, at the same time, sufficiently informative about physical aspects of climate to guide inference and explanation in climate science. We will also see that the current focus on reductive notions of climate states and climate systems might be less than optimal, given the goals of explaining and predicting climate.

Alongside pragmatic issues, we present issues that may have a pragmatic dimension but that appear primarily to be conceptual. The conceptual issues include tensions within ways of thinking about the boundary of the climate system as well as a lack of clarity about what exactly should count as internal variability and what should count as external variability.

Our discussion proceeds as follows. In Section 2, we focus on issues that arise when trying to characterize Earth's *climate system*. We discuss the challenge of identifying the boundaries of the system and consider whether the climate system should be characterized in a wholly reductive way, i.e., solely in terms of material constituents and their causal interactions. Section 3 is concerned with theorizing about *climate states*. We consider the limitations of the standard statistical approach to characterizing climate states, and we argue for the benefits of a proposed alternative approach, which contends that climate states should be characterized in part in physical terms. The issue of reductionism resurfaces in this section as well, as we examine the suggestion that climate states can be characterized in part in terms of emergent properties.

Section 4 focuses on *climate change* and the closely related notion of *climate sensitivity*. We note that it is an open question which aspects of the climate system should be appealed to in characterizing climate change, though very often the focus is on changes in global mean near-surface air temperature. It is this change that is the focus, for instance, in standard analyses of the sensitivity of the climate system to external forcing. We also explain why (as noted above) this standard notion of climate sensitivity is insufficiently general – the fact that it is focused on equilibrium conditions is only part of the problem – and consider the challenges that remain for some alternative, more general notions that have been developed.

Section 5 is concerned with *internal variability* and *radiative forcing*. We note that internal variability is sometimes assumed to be a separable, independent component of total climate variability; this, we argue, does not seem to take into account the very plausible situation in which external forcing is changing the magnitude and frequency of climate system phenomena that are commonly taken to be expressions of internal variability, such as El Nino. With regard to radiative forcing, we explain why a more general notion of forcing seems to be required, highlighting connections with issues raised for the notions of climate system and climate sensitivity. Indeed, throughout the paper, we call attention to interconnections among the issues discussed.

Finally, in Section 6, we offer a concluding discussion. We review the issues that we have identified along the way, note some of the progress that has been made in addressing them, and suggest, partly on the basis of the work done here, that there is room for philosophers of science to contribute to addressing issues in the theoretical foundations of climate science. We close with some remarks on the importance of doing so.

2. Climate system

All of the issues we will examine concern climate systems or their features – their states, components, evolution and responses to external influences. A natural place to start our investigation is thus with the standard notion of Earth's climate system. The Intergovernmental Panel on Climate Change provides what is, minor variations aside, the standard notion of Earth's climate system:

> **Climate system.** The climate system is the highly complex system consisting of five major components: the atmosphere, the hydrosphere, the cryosphere, the lithosphere and the biosphere and the interactions between them. The climate system evolves in time under the influence of its own internal dynamics and because of external forcings such as volcanic eruptions, solar variations and anthropogenic forcings such as the changing composition of the atmosphere and land-use change [IPCC, 2014, p. 121].

Here, the climate system is characterized in terms of its material components, especially a set of subsystems, and their causal interactions. Two issues that arise in connection with the standard notion are where to draw the boundary of our climate system and whether the system should be characterized in a wholly reductive way. We look at each of these issues in turn.

The standard notion specifies the boundary of the climate system in terms of the spatial boundaries of the system's components and, in doing so, makes clear that some factors, e.g., changes in solar irradiance, are external to our climate system. Yet, as climate scientists are well aware, it is not obvious that changes in volcanic aerosol concentrations, anthropogenic land-use changes or anthropogenic increases in CO_2 concentrations should be considered external. After all, these are changes in the biosphere or the atmosphere and thus seem to be, according to the standard notion, *within* our climate system.

An alternative suggestion that climate scientists sometimes make is that something counts as external to Earth's climate system on a given timescale if it is causally independent of changes in the system on that timescale (USNRC, 2005, p. 14). This would imply that volcanic aerosol concentration changes are external to the climate system on century timescales, because changes in the Earth's climate system do not impact volcanic activity except on much longer timescales. It is not clear, however, that this approach successfully renders ‘external’ other elements that are usually so classified in practice. For example, anthropogenic CO_2 concentrations over the 20th and 21st centuries may well depend (via human intentions and actions) on their effects during this period; efforts have already been made to reduce emissions, for instance, in light of occurring and anticipated harmful consequences of increased emissions. Further, the suggestion appears to be circular as it explicates being external to Earth's climate system in terms of what can affect the system in a certain way.

This circularity could be avoided by refining the characterization slightly, such that something counts as being external to the climate system if it is causally independent of changes in paradigmatic climate variables (e.g., temperature and precipitation) on that timescale. A definition modified along these lines, however, would require a non-circular specification of which variables count as paradigmatic climate variables, would raise the issue of why certain variables and not others are selected, and would still seem to imply