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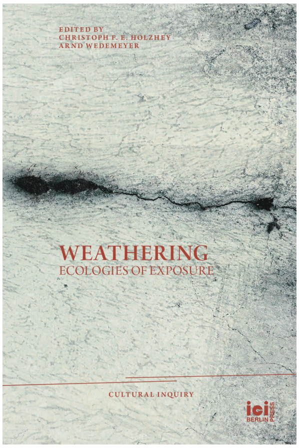

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Scaling from Weather to Climate

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ABSTRACT: One of the theoretical tensions that has arisen from Anthropocene studies is what Dipesh Chakrabarty has called the 'two figures of the human', and the question of which of these two figures of the human inheres in the concept of the Anthropocene more. On the one hand, the Human is conceived as the universal reasoning subject upon whom political rights and equality are based, and on the other hand, humankind is the collection of all individuals of our species, with all of the inequalities, differences, and variability inherent in any species category. This chapter takes up Deborah Coen's argument that Chakrabarty's claim of the 'incommensurability' of these two figures of the human ignores the way both were constructed within debates over how to relate local geophysical specificities to theoretical generalities. This chapter examines two cases in the history of science. The first is Martin Rudwick's historical exploration of how geologists slowly gained the ability to use fossils and highly local stratigraphic surveys to reconstruct the history of the Earth in deep time, rather than resort to speculative cosmological theory. The second is Coen's own history of imperial, Austrian climate science, a case where early nineteenth-century assumptions about the capriciousness of the weather gave way to theories of climate informed by thermodynamics and large-scale data [...]

Scaling from Weather to Climate

DANIEL LIU

> The interaction of all meteorological elements at a particular time in a particular place provides what we call the 'weather' [Wetter]. The weather is not an average atmospheric state, but rather the total impression or total effect of actually occurring atmospheric phenomena all at once within a particular, short period of time, at a certain hour, or even more strictly in a given moment. We speak of the weather of a certain day, but only of the 'climate' [Witterung] and hardly of the 'weather' of a whole year, because the longer the period, the more manifold and heterogenous are the weather phenomena that have occurred, which can be summarized only through the term 'climate.' Climate already indicates an abstraction, while weather is a real condition, an individual event singled out of the changing sequence of climate phenomena. A weather map shows the atmospheric phenomena taking place over a part of the earth's surface at a particular moment. There is no such thing as a weather map for months or a whole year, because the interplay of average temperature, average cloud cover, average wind, average rainfall, or monthly rainfall is not the weather.
>
> Julius Hann, *Lehrbuch der Meteorologie* (1901), p. 483

The theme 'weathering' in this volume assumes a set of climatic forces — both material and metaphorical — that act with some constancy or predictability on an object, as well as specifying the kind or kinds of temporalities with regard to the thing being weathered. One of our motivations for choosing 'weathering' as our theme is the clear and distinct ambiguity of the concept. In English, at least, the concepts 'weather' and 'weathered/weathering' are at once global and local, e.g., the way a thunderstorm is a locally contained event caused by larger-scale climatological patterns; they invoke recent events, historical disruptions across a handful of centuries, and even processes that stretch well into Earth's deep history. The weathering or weathering away of an object is temporally relative to both the object and the forces acting upon it. Weather is also an omnipresent condition — there's good weather and bad weather, but there's never *no* weather — and yet, from within the ivory tower, it's both containable and temporarily escapable thanks to durable construction methods and modern climate control technologies like fibreglass insulation, air conditioning, a steady supply of electricity, central heating, and cognitive dissonance.[1] As a friendly concept, weathering manages to tick all of the boxes of being everywhere and not everywhere at the same time, working as a capacious-enough concept that's both helpfully meaningful and vague, impossible to ignore and (as aforementioned) conveniently ignorable if need be.

Are all of these possible meanings of the weather actually commensurable with one another? Or is part of the appeal their incommensurability? One of the more powerful intellectual currents within Anthropocene discourse and the environmental humanities is a stress on incommensurability of individual thinkers or political actors when compared to the geographical, geological, and historical scales of anthropogenic climate change. The problem of scaling individual experience — be it through pragmatic experience, social contract theory, the Kantian a priori, the Cartesian criterion of clarity and distinctness, etc. — up to encompass the scale and nature of climate change has been a manifest political problem around global climate science since the mid-1980s, and has dramatically intensified since the early 2000s.[2]

1 Christina Sharpe, *In the Wake: On Blackness and Being* (Durham, NC: Duke University Press, 2016), chapter 4; on air conditioning see Bruno Latour, *Facing Gaia: Eight Lectures on the New Climatic Regime*, trans. by Catherine Porter (Cambridge: Polity, 2017), pp. 123–24.

2 Naomi Oreskes and Erik M. Conway, *Merchants of Doubt: How a Handful of Scientists Obscured the Truth on Issues from Tobacco Smoke to Global Warming* (New York: Bloomsbury, 2010).

A running exchange with Dipesh Chakrabarty, Julia Adeney Thomas, Robert Stockhammer is a good case in point. In 2009, Chakrabarty reflected that his own scholarship left him ill-equipped to conceptually tackle the political crises of global climate change:

> I realized that all my readings in theories of globalization, Marxist analysis of capital, subaltern studies, and postcolonial criticism over the last twenty-five years, while enormously useful in studying globalization, had not really prepared me for making sense of this planetary conjuncture within which humanity finds itself today.[3]

In 2012, Chakrabarty sensed that the problem of scale was becoming more acute within postcolonial historiography and theory, which has emphasized differences of cultural experience juxtaposed against processes of globalization. The sheer scale of climate change left 'experience' behind, in that, 'We cannot ever experience ourselves as a geophysical force — though we now *know* that this is one of the modes of our collective existence. We cannot send somebody out to experience in an unmediated manner this "force" on our behalf.'[4] More troublingly for Chakrabarty,

> We now also have a mode of existence in which we […] are 'indifferent' or 'neutral' to questions of intrahuman justice […]. This is why the need arises to view the human simultaneously on *contradictory* registers: as a geophysical force and as a political agent, as a bearer of rights and as author of actions; subject to both the stochastic forces of nature (being itself one such force collectively) and open to the contingency of individual human experience; belonging at once to differently scaled histories of the planet, of life and species, and of human societies.[5]

Even though the individual versus the general will has long been a stock problem in social contract theory, Stockhammer, following Chakrabarty's lead, has noted that global climate change in the last century

3 Dipesh Chakrabarty, 'The Climate of History: Four Theses', *Critical Inquiry*, 35.2 (Winter 2009), pp. 197–222 (p. 199) <https://doi.org/10.1086/596640>.

4 Dipesh Chakrabarty, 'Postcolonial Studies and the Challenge of Climate Change', *New Literary History*, 43.1 (2012), pp. 1–18 (p. 12) <https://doi.org/10.1353/nlh.2012.0007>.

5 Ibid., p. 15, emphasis added.

has created or intensified a fissure in the history of Western philosophy that had remained hidden: the two separate concepts of humanity, the rational *homo* of the philosophers and the species *Anthropos* of natural history. Whereas *homo* gestures to the universality of human reason and experience, the *Anthropos* signifies what is collectively common *despite* human diversity and inequality. This distinction leads Stockhammer to write, 'I am skeptical whether this model of individual enlightenment [*Homo*] can directly carry over to seven billion specimens of the species [*Anthropos*]', and, 'The commonality of *homo* is not comparable to the inequality within the *Anthropoi*.'[6] Picking up on Stockhammer's terminology and highlighting the contradictory or even 'incommensurable' concepts of the human, Chakrabarty responds,

> By introducing new questions of scale — astronomical scales for space, geological scales for time, and scales of evolutionary time for the history of life — all in search of understanding the relationship between the history of the planet's atmosphere and its life-carrying capacity, and thus promoting what may be called a life, or zoecentric, view of the history of the planet, the literature on global warming works at a tangent to the completely homocentric narrative of globalization.[7]

Not that either Chakrabarty or Thomas believe this incommensurability is *only* a hindrance. Thomas argues that just as paleobiology, microbiology, and biochemistry 'produce visions of "the human" that are incommensurable with one another, as well as with the historian's usual conception of personhood and society', for historians such in-

6 Robert Stockhammer, 'Philology in the Anthropocene', in *Meteorologies of Modernity: Weather and Climate Discourses in the Anthropocene*, ed. by Sarah Fekadu, Hanna Straß-Senol, and Tobias Döring (= *REAL: Yearbook of Research in English and American Literature*, 33 (Tübingen: Narr Francke Attempto, 2017)), pp. 43–64 (pp. 49–50).

7 Dipesh Chakrabarty, 'The Human Condition in the Anthropocene', in *The Tanner Lectures on Human Values, 35*, ed. by Mark Matheson (Salt Lake City: University of Utah Press, 2016), pp. 139–88 (p. 159), available online: <https://tannerlectures.utah.edu/Chakrabarty%20manuscript.pdf> [accessed 1 August 2020]. Chakrabarty replaces Stockhammer's term *Anthropos* with his quasi-Aristotelian *zoe* to come up with 'zoecentric' history.' On 'human agency over multiple and incommensurable scales' see Chakrabarty, 'Postcolonial Studies and the Challenge of Climate Change', p. 1.

commensurability and diversity are usually strengths, or at least are tolerated well enough.[8]

The historian of science Deborah Coen offers a different take on such ‘incommensurability’, that scaling, as well as awareness of scale effects, are themselves human concepts, and that the point at which different scales become ‘incommensurable’ is not fixed:

> The spatial and temporal dimensions of human life are historically and culturally contingent: they vary with differences in life span, degree of mobility, communications technologies, and cultures of remembering the dead. There is therefore no fixed meaning to the ‘human scale’ that could be set in opposition to ‘the planetary’.[9]

In other words: How did we get to the point where individual experience, never mind community or even species experience, is assumed to be so small, while conceptions of either regional environments or planetary climates are assumed to be so large?[10] The problem is perhaps analogous, in early twenty-first-century political discourse, to the way the individual’s experience has become politically and epistemologically unassailable against prevailing or ‘dominant’ narratives, especially when dealing with the experiences of those who are marginalized, forgotten, or historically oppressed. In both, the relationship between the general and the particular becomes undone, either by accident or through acts of deliberate resistance.[11] The question is not so much one of whether *all* grand narratives and generalities need to be done away with, but which generalities are now most useful, and how the contours of general theories are negotiated. As Coen writes, paraphrasing the nineteenth-century Austrian writer, Adalbert Stifter (1805–1868): ‘In nature, as in human life [...] often the little things

8 Julia Adeney Thomas, ‘History and Biology in the Anthropocene: Problems of Scale, Problems of Value’, *American Historical Review*, 119.5 (December 2014), pp. 1587–1607 <https://doi.org/10.1093/ahr/119.5.1587>.

9 Deborah R. Coen, ‘Big Is a Thing of the Past: Climate Change and Methodology in the History of Ideas’, *Journal of the History of Ideas*, 77.2 (April 2016), pp. 305–21 (p. 308) <https://doi.org/10.1353/jhi.2016.0019>.

10 On the concept of regional, as opposed to local and national scales, see Jeremy Vetter, *Field Life: Science in the American West During the Railroad Era* (Pittsburgh, PA: University of Pittsburgh Press, 2016).

11 Ibid., pp. 62–63.

are most significant, once they are recognized as instances of a more general pattern, perceptible to observers everywhere.'[12]

The concepts *Homo*, *Anthropos*, the human, and the Anthropocene are not only abstractions, but extrapolations from a highly specific set of scientific and social scientific practices, and we need to pay attention to how these extrapolations are made. Likewise, rigorous conceptions of the weather and weathering demand more than just conceptual gesturing or figuration: it requires paying attention to the methods by which particular phenomena, experienced at the individual or immediately local scales, are stitched together to create accurate pictures of regional and ultimately global conditions. If we take 'weather' in its *most* everyday sense, then we ordinarily say it is the job of the weather reporter or *meteorologist* to take into account a wide range of regional patterns and information coming from a variety of well-placed sensors in order to generate a weather report, an anticipation of how much rain, wind, dryness, or thunderstorms I can expect in a given place. In this volume, by focusing on weather and weathering, we are re-examining how we transform a single weather event or the weathering of a single object into broader notions respectively of climate or maintenance. In contrast to the way Stockhammer's figurative *Homo* and *Anthropos* are simply *assumed* to be universal, the basic constructivist approach to the history and sociology of science demands that we explain empirically *how* scientific concepts become universal. There are, of course, a great many ways of doing so within science studies, but in this essay, I will assume that this 'how' demands examination of practices and methodologies. As the editors of a recent special journal issue on 'Experiencing the Global Environment' have written, 'Ways of experiencing the global[…]are by necessity always produced locally.'[13]

The remainder of this essay will examine two areas of scholarship in the history of sciences of scaling: Martin Rudwick's foundational work on the history of geology and Deborah Coen's recent study of

12 Deborah R. Coen, *Climate in Motion: Science, Empire, and the Problem of Scale* (Chicago: University of Chicago Press, 2018), p. 154.

13 Lino Camprubí and Philipp Lehmann, 'The Scales of Experience: Introduction to the Special Issue *Experiencing the Global Environment*', *Studies in History and Philosophy of Science Part A*, 70 (August 2018), pp. 1–5 <https://doi.org/10.1016/j.shpsa.2018.05.003>.

the origins of physical geography and climatology. These two cases provide important contrasts, illuminating the differences between natural philosophy and natural history, theory versus empirical research. Rudwick has argued that the major theoretical innovation that established modern geology was the shift from a relatively rigid style of ahistorical and deterministic geotheory to a geoscience that is highly attentive to historical contingencies of time and place. In other words, geologists had to learn how to scale up from local particularities and contingencies to reconstruct the history of the earth. Coen, by contrast, argues that modern climate science developed in the reverse fashion, from the active attempt to collect and synthesize local differences into physical theories of climatic change, effective at regional and global scales. How does this relate to the volume's overall theme of weather/weathering? Obviously, in the case of climatography, observation and recording of the weather at special observatories and stations was the new science's empirical foundation. In the case of early geology, scientists (Rudwick prefers the period-appropriate *savants*) travelled looking for places where the weather had worn away the Earth in a way that allowed one to see layers of different rocks or strata. Both sciences deal with the earth as a physical system, both sciences are clearly borne out by quite particular local human efforts, and both sciences were fundamental in the late twentieth-century formulation of the concept of the Anthropocene.

GEOLOGY: ENLIGHTENMENT IN ACTION

The evolutionary theorist and historian of science Stephen Jay Gould (1941–2002) wrote in 1988 that Sigmund Freud had forgotten the fourth great intellectual revolution of European scientific modernity. Freud had enumerated three: Copernicus' de-centring of the Earth into one of a multitude of planets, Darwin's demotion of man's special creation into the spectrum of the descent of species, and of course Freud's own revolution of subordinating rational action to the impulses of the subconscious. The fourth revolution, which Freud missed and Gould insisted upon, was the early nineteenth-century discovery of geological and cosmological deep time, the extension of the history of nature to millions and billions of years, in both breadth and depth.[14] But it has been Martin Rudwick's contention since his 2005 book *Bursting the Limits of Time* and emphasized in the 2008 sequel *Worlds Before Adam* that geology's essential modernity is not in its mere *extension* of time, a concept other sciences have potentially entertained. Rather, Rudwick argues that modern geology embraced a very particular *kind* of historicity and temporality unique to the history of the geosciences. Modern geology for Rudwick — perhaps modernity generally — is characterized by emphasis on the *contingency* of geohistory, not just its depth. Contingency in the history of nature means, to Rudwick, that the history of nature is 'as unrepeated, and as unpredictable, as human history itself'.[15] Modern geological theory that embraces this sense of deep historical contingency can help take local and regional rock formations and reconstruct the past in stepwise fashion. By analogy, this is akin to comparing the reconstruction of the evolutionary history of *Homo sapiens* to theories of the state of nature in moral philosophy: these clearly related endeavours to understand the human and the subsequent history of humanity nevertheless have totally different relationships to the distant and proximate past. This sense of historical contingency is, Rudwick argues, the product of the late eighteenth-century habit by natural philosophers to import methodological concepts from the history of Christian theology, specifically Biblical *chronology*, into the theories of the Earth. Without denying the importance of deep time, Rudwick's contention is particularly useful in our general consideration of weather/weathering, in that it insists on the duality of the contingency of particular events alongside the universality of the laws that govern them.

It is perhaps easier to understand what this contingent historicity is by contrasting it with the alternative temporalities that have been extant in European intellectual history. It is also a helpful way of qualifying what Rudwick means by history being unrepeatable and unpredictable: to be more exact, this means that a genuinely contingent human history or history of nature must be directionally cumulative

14 Stephen Jay Gould, *Time's Arrow, Time's Cycle: Myth and Metaphor in the Discovery of Geological Time* (Cambridge, MA: Harvard University Press, 1988), pp. 1–2.

15 Martin J. S. Rudwick, *Bursting the Limits of Time: The Reconstruction of Geohistory in the Age of Revolution* (Chicago: University of Chicago Press, 2005), p. 6. See also Rudwick, *Worlds Before Adam: The Reconstruction of Geohistory in the Age of Reform* (Chicago: University of Chicago Press, 2008).

(and therefore unrepeatable), and it also must not be preordained. For the most part, ancient Greek and Roman natural philosophy only provided its Latinate and Arabic descendants with a conception of nature as eternal, cyclical, and governed by forces that acted out of necessity. This was particularly true in Platonic cosmology, Aristotelian cosmology, and Ptolemaic astronomy, which took the eternal rotation of the stars around the earth, and the evident perfection of circles and spheres as the archetypes for both nature and causality generally. This kind of natural philosophy stood in stark contrast with the emphasis on free will in Christian theology and the Biblical drama of salvation. One of the great tasks of European and Arab scholarship through the Middle Ages was precisely to find ways to reconcile Greek philosophy's emphasis on the eternal on the one hand, and, on the other hand, Mosaic theology's emphasis on both the provisional nature of God's will and the voluntary nature of human faith. The histrionics surrounding the papal Condemnations of 1277 was but one famous episode, with church authorities alarmed by the radical Aristotelians' claims that an eternal universe was more logically consistent than the account of creation in Genesis.[16]

Additionally, the Aristotelian foundations of medieval Latin and Arabic natural philosophy provided only very crude ideas for understanding different scales of natural phenomena. Privileging the eternal, circular motion of the celestial sphere relegated the terrestrial as the realm of linear, or 'accidental' as opposed to perfectly circular and eternal 'natural' motion. The physics of the terrestrial sphere were effectively governed by the natural motions of the four elements in Aristotelian matter theory — i.e., that earth, water, air, and fire tended to sort themselves in layers, with earth 'falling' to the centre of the cosmos and fire rising to the interface of air and the celestial aether (*e.g.* in pre-Newtonian definitions of gravity). In this cosmology, the elements' terrestrial disorder meant this overarching, law-like tendency towards order would be interrupted by the proliferation of local events and causes. The terrestrial as the realm of the accidental proved to be a source of inspiration for natural philosophers seeking to reconcile

16 David C. Lindberg, *The Beginnings of Western Science*, 2nd edn (Chicago: University of Chicago Press, 2007), chapter 10.

the overarching eternalist framework of Greek metaphysics with the demand for theological contingency: for example, for the Lutheran reformer and pedagogue Phillip Melanchthon (1497–1560), elucidating the providential meaning of accidents (generally, in the metaphysical sense) was an essential way of fitting the Aristotelian natural philosophical corpus into reformed Christianity based on justification by faith alone.[17]

The terrestrial was therefore not *historical* so much as merely *accidental*, and terrestrial natural history was thus merely the corrupted subset of a naturally eternal cosmos. At least when it came to nature, Greek natural philosophy and its descendants up to the Scientific Revolution could explain specific natural phenomena with reference to extremely local causes and agents (e.g., in theories of vision),[18] but they were not capable of wholesale discovery, ordering, and reconstruction of events in time, deep or otherwise, according to Rudwick. In contrast, Biblical chronology, dynastic chronicles, epics, and narratives generally place events in a temporal sequence and seek to explain their sequence with any number of causes. Nor did this lack of interest in specific historical sequence substantially change during the Scientific Revolution. The introduction of the new mechanical philosophy by Descartes and the neo-Epicurean atomists in the sixteenth and seventeenth centuries managed to replace the eternalism of Aristotelian cosmology with a linear history of the universe, albeit one strongly shot through with determinism. The mechanical philosophy's determinism was directional — linear motion was now 'natural', while active intervention was required for circular motion — but although it could in principle be used to reconstruct the history of the universe, in practice the mechanical philosophy's explicitly abbreviated causality limited scientists to ad hoc guesses about particular types of geological events. These ad hoc 'theories of the earth' traced their lineage to Descartes own theory of the creation of mountains in his 1644 *Principia Philosophiæ* (part 4, sections 41–44), in which Descartes suggested mountains were caused by differential heating and cooling of

17 Sachiko Kusukawa, *The Transformation of Natural Philosophy: The Case of Philip Melanchthon* (Cambridge: Cambridge University Press, 1995).

18 David C. Lindberg, *Theories of Vision from Al-Kindi to Kepler*, rev. edn (Chicago: University of Chicago Press 1996).

the Earth by the Sun (Fig. 1). This kind of directional, if broadly deterministic theory culminated in Buffon's theory of the cooling earth: in his *Histoire Naturelle* (1749–89), he argued that all of the planets formed when comets struck the Sun, tearing off lumps of superheated material that cooled as over time. Inspired by the evident fact that mines become hotter the deeper they are excavated, Buffon went as far as commissioning a blacksmith to heat iron balls of different sizes, and studied the way heat loss varied by the size of the sphere: based on these studies, Buffon argued in print that the Earth was approximately 75,000 years old, though in private he speculated that it was as high as 10 million.[19] Whatever the particular age of the Earth might be in these theories, however, they were largely based on a premise that a small set of initial conditions and mechanisms could account for the entire course of geohistorical events in a deterministic, predictable fashion, 'from Fireball to Snowball, under the constant laws of nature.'[20] They were, by definition, global in scope, albeit 'global' relative to cosmology, rather than relative to anything approaching human history of human experience. This indoor theorizing was often dismissed as indulgent speculation. Nevertheless, these kinds of 'Fireball to Snowball' theories by Buffon and others provided for a deeper history of the Earth, now conceivably millions of years old.

They also created the first tentative link between theories of the Earth's development with a different domain of investigation: geognosy, what today we might call stratigraphy, the description of the ordering of *layers* of different kinds of rocks into strata (Figure 2). In the eighteenth century and earlier, geognosy was a descriptive part of the sciences of mining and quarrying: layers of rock were studied in order to anticipate where in the Earth valuable ores or minerals could be found. In most areas, the layers of rock formed regular *sequences* from topsoil down to bedrock granite: mine engineers knew that these sequences of strata were fairly regular across local and even regional distances, since they had already dug into the earth or examined exposed outcrops.[21] The clearly layered and seemingly orderly sequence

19 Martin J. S. Rudwick, *Earth's Deep History: How It Was Discovered and Why It Matters* (Chicago: University of Chicago Press, 2014), pp. 65–66.

20 Ibid.

21 Rudwick, *Bursting the Limits of Time*, chapters 2 and 4.

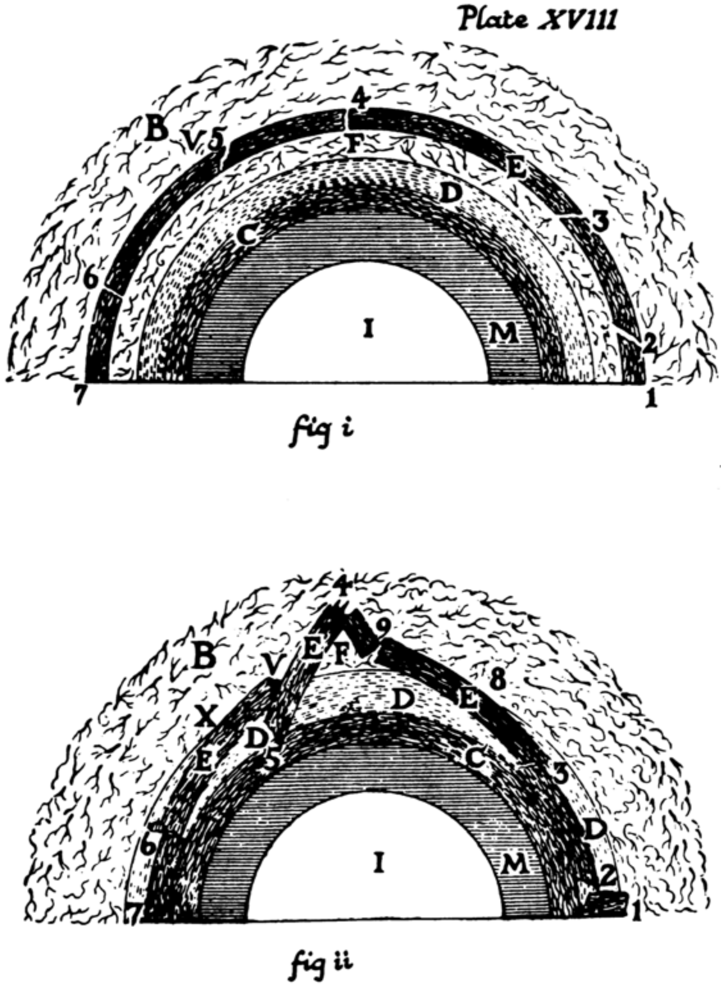

Figure 1. Descartes' 'buckling crust' theory of the Earth, from *Principia Philosophiæ* (1644). The surface crust of the Earth (*E*) has pores or cracks (1–7) that connect the atmosphere (*B*) and *F*, a layer of rarefied matter beneath the Earth's crust; when the sun heats the Earth, heated fragments of *F* push themselves up through the crust *E*, but then cooled air *B* sinks through the pores of the Earth's crust, expanding this body and causing the crust to buckle upward. These buckles cause both the formation of mountains and press the lower masses *D* and *C* upward, causing the creation of oceans at fragments 2–3 and 6–7.

of strata had made early geotheory plausible, and early geotheory likewise tried to mobilize the regularity of rock strata to create theories of the Earth. In what Rudwick calls the 'standard model' of pre-modern geology, as the Earth cools, its surface becomes a giant ocean, and further cooling causes minerals to precipitate and sediment into layers, with each layer differing due to its relative age and by its chemical composition.[22] These theories could thus explain why 'basement' or 'Primary' rocks like granite, schist, gneiss, and marble were usually found below the lighter, 'Secondary' rocks like sandstone, shale, and limestone. Buffon's and other theories following the standard model could potentially take geognosy — ordinarily a descriptive, classificatory, and structural science — and transform it into evidence of the Earth's deep history.

But the Earth is not so regular, and planetary-scale causal theories like the late eighteenth/early nineteenth-century standard model struggled to account for the increasing amounts of local variation being studied and recorded by miners, physical geographers, and mineralogists. Critics of 'Enlightenment rationality' tend to miss the way that amateur and expert savants in the eighteenth century also obsessively collected examples of nature's diversity, often desiring particularly strange specimens that explicitly defied extant theories or rationalizations of nature. Strange or beautiful rocks and fossils would be removed from their original context precisely for their peculiar or exemplary character and be placed in mineralogical collections; these collected specimens could be compared by simple visual examination, through more advanced optical analysis, or even through more destructive chemical analysis. Chemical analysis could raise some uncomfortable questions about the standard model. Why, for instance, was heavy basalt so often found in strata *on top of*, for example, lighter sedimentary strata like sandstone or limestone? Did this mean basalt was a compressed sandstone? Or, as some geotheorists in the eighteenth century suggested, was basalt *volcanic* in origin — thus adding unexpected complexity to the standard model of geological history?[23]

22 Ibid., pp. 172–74.

23 Ibid., pp. 62–63.

Figure 2. Angular unconformity at Praia do Telheiro, near Sagres in Algarve Portugal. It shows Late Triassic red and yellow planar sandstones resting on top of tilted black shales and greywackes of Carboniferous age, deformed during the Variscan orogeny. Photograph by André Cortesão, Creative Commons Attribution 3.0 Unported license <https://commons.wikimedia.org/wiki/File:Angular_Unconformity_at_Praia_do_Telheiro_in_Algarve_in_Portugal.png>.

The most broadly synthetic method of addressing these questions about the Earth's geological diversity would, by the middle of the nineteenth century, be found in physical geography and geognosy, which, above all else, privileged outdoor fieldwork over the collection and comparison of objects. The turn of the century in Europe witnessed a unique boom in geological fieldwork, though the reasons for the boom varied in different places: in Britain it became inexplicably fashionable for leisured gentleman to explore their physical environments, while in Central Europe minor and major states alike established mining schools as a cameralistic response to the economic devastation of the Seven Years' War.[24] Initially, both these amateur and professional en-

24 Ursula Klein, *Humboldts Preussen: Wissenschaft und Technik im Aufbruch* (Darmstadt: Wissenschaftliche Buchgesellschaft, 2015).

deavours were much alike in scale but unlike in dimension. As already mentioned, mining scientists in places like the Ore Mountains on the border of Saxony and Bohemia sought to understand the local sequence of the Earth's strata in order to anticipate where veins of ore (and later coal) might be found before undertaking the costly work of digging mine shafts. Mining savants above all, like Abraham Gottlob Werner (1749–1817), thus sought to understand the sequence of strata on the *vertical* axis in particular mining districts. Strata are not simply layered in parallel sequences as the standard model — or, for that matter, the Aristotelian model — would suggest, like a cake, but rather many sit at different angles. Certain well-established strata could be found in vastly different thicknesses in different places. Most critical were *unconformities*, places where some strata might be layered at sharp angles to others, or a stratum is highly uneven, or perhaps missing entirely, or even found unexpectedly intruding on a predicted sequence. Some unconformities are visibly evident, others quite subtle and visible only to someone looking for it; some strata simply do not show clear orientation at all, looking more like a mass of rubble. These difficulties made expertise valuable particular in the professional setting of mining and geognosy, but amateurs could nevertheless do the basic work, since the basic instruments were quite minimal: all one needed was a hammer, shovel, a hand lens, free time, and transportation to seek out weathered cliff faces or hills with exposed layers of rock. At the same time, long personal experience with the rocks of a local region was necessary to understand all of the variation that was possible, and to discriminate between similar-looking strata, in order to correlate the sequence of formations from one place to another.[25]

The mining professionals had the advantage of being able to enlist labour to dig, but they also considered their knowledge to be both relatively localized and purely descriptive: initially, geognosy was not tied to particular theories of the Earth or ideas about Earth's history. But over the course of the first half of the nineteenth century, as more and more local areas had their strata mapped, the early geologists grew increasingly confident that they could understand the stratigraphy of

25 Martin J. S. Rudwick, *The Great Devonian Controversy: The Shaping of Scientific Knowledge Among Gentlemanly Specialists* (Chicago: University of Chicago Press, 1985), pp. 37–54.

whole regions by induction, without needing to direct empirical evidence from each individual locale. Moreover, the growing network of amateurs in Britain meant that studies of local formations could be compared: by 1822 the Geological Society of London counted 313 members living in or near London, and an additional 328 'non-resident' members living overseas, all of whom received published *Proceedings* that summarized members' reports.[26] The amateurs in Britain had the advantage of sheer numbers and a growing system of scientific sociability that could coordinate the efforts of a larger number of less-expert local explorers. These collective efforts would culminate in some of the most impressive examples of the synthesis of experiential knowledge in natural history: George Bellas Greenough (1778–1885) and William Smith's (1769–1839) grand geological maps of regions as large as the entirety of England (Fig. 3), with Smith making his map entirely through his own surveying work. By mid-century, British geologists were crisscrossing the globe, taking advantage of global travel secured by Britain's naval supremacy, in order to conduct intensive geological surveys in the field. The Scottish geologist Roderick Murchison (1792–1871) made expeditions to nearly every corner of the globe, from Australia to British-controlled India to the Russian Baltic: his work in stitching together the stratigraphy of so many areas of the Earth was not only in service of geological theory, e.g. determining the global distribution of the sequence of strata, but equally importantly his work aided imperial and colonial authorities in planning gold, coal, and other mining projects that ultimately sustained the imperial endeavour. At every point in Murchison's journey, the basic tools of investigation were the same: travel to many locations, examine extant outcroppings, map and chart formations along horizontal and vertical axes.[27]

Identifying and associating the order of strata across such large distances ultimately required more than just the examination of the rocks themselves, the differences among which could be exceedingly subtle, or, in the case of some unconformities, absent entirely. The great success of unlocking the sequence of strata across the globe owed

26 Ibid., pp. 18–27.

27 Robert A. Stafford, *Scientist of Empire: Sir Roderick Murchison, Scientific Exploration, and Victorian Imperialism* (Cambridge: Cambridge University Press, 1989).

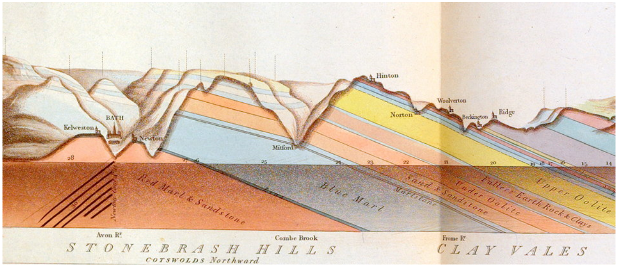

Figure 3. Part of William Smith's map of geological sections in Somerset, England, 1819, showing the sedimentary strata of sandstone, marl, and limestone. William Smith, *Section of the Strata through Hampshire and Wiltshire to Bath, on the Road from Bath to Salisbury* (London: John Cary, 1819).

much to the growing recognition in the nineteenth century that the order of rock strata were correlated to the kinds of *fossils* that geologists and geognosists found in each of the strata. The distinctiveness of the fossil bones, shells, and occasionally plants in each stratum became aids for identifying the order of strata across regions where the rocks themselves were not the same, or just hard to identify: Smith's grand maps of the strata of England owed much to his ability to use 'characteristic fossils' to identify strata. But these observable consistencies across strata and fossil beds eventually became a way to understand both fossils and strata as clues for the reconstruction of a linear, progressive, and contingent history of the Earth. As early as 1801, the naturalist Georges Cuvier (1769–1832) remarked, 'the older the beds in which these bones are found, the more they differ from those of animals we know today.'[28] As geologists and collectors alike started to plot out where certain kinds of fossils were found — a task that required experience both out in the field and inside the museum — it became apparent that the top-most, 'youngest' strata bore fossils that were similar to many known living species, while fossils in deeper, 'older' strata were often much stranger. Whereas in the late eighteenth century early geologists had suggested that the presumably law-like character of geological change might make the history of the Earth cyclical or eternal, the fossil evidence accumulating in the early nine-

28 Georges Cuvier, 'Espèces de quadrupèdes' (1801), p. 260, quoted in Rudwick, *Bursting the Limits of Time*, p. 424.

teenth century seemed to show otherwise. The fossils that were being found were simply not like bones of known animals, suggesting that large scale extinctions accompanied the successive deposition of rocks into strata. Moreover, as the correlations of fossil types and strata became stronger, it became possible to imagine a reconstruction of the actual past world that these fossils came from. A most dramatic case in 1822 by the English theologian and geologist William Buckland (1784–1856) demonstrated that it was even possible to reimagine not only ecosystems, but even the daily lives of animals that lived in a very distant time. The cave, discovered by miners in 1821 working in a limestone quarry in Kirkdale, in Yorkshire, was filled with fossil bones of elephants, hyenas, rats, horses, bears, oxen, and rhinoceroses. Yet both the entrance of the cave and the cave itself was too small for any of these larger animals to go in. Buckland realized that the cave must have been home to a hyena den, and that the largest bones must have been dragged into the cave by the hyenas, as shown by the toothmarks on the large bones and abundant 'calcareous excrement' found within the gravel and silt. The petrified dung would be the key to the reconstruction: by comparing the fossil excrement with specimens from English zoos, Buckland demonstrated that the fossils were most likely dragged in as scavenged food by the hyenas, and not washed into the cave — either by periodic flooding or by Biblical deluge.[29]

Buckland's reconstruction of the Kirkdale cave made it possible to, as Rudwick puts it, 'construct a conceptual time machine' moving backward from recent cases into the deep past.[30] This kind of stitching together of the past from localized elements into maps and narratives stood in stark contrast to earlier attempts to create theories starting from cosmological scales. As Rudwick argues in *Earth's Deep History*, by the middle of the nineteenth century geology had adopted many of its conceptual frameworks not from geophysics but rather from secular and sacred history: the coins, artefacts, and documents of history and historiography were made analogous to the rocks, fossils, and formations of geology. Although elements of this analogy can be debated, it nevertheless suggests how modern geology can be considered as a

29 Ibid., chapter 8.

30 Rudwick, *Earth's Deep History*, p. 125.

science of *scaling up* localized, individualized experience into grand narratives of the history of the Earth.

CLIMATOLOGY: FROM EXPERIENCE TO THEORY

The epigraph at the top of this chapter, taken from the meteorology textbook by the Austrian climatologist Julius Hann (1839–1921), highlights the fundamental epistemological difference marked by the concepts 'weather' and 'climate': we can go outside and experience the weather through our senses and instruments, but if we are to collect our experience into knowledge about the climate, then we have to resort to something other than experience. It does not follow that weather is real and climate a fiction: it simply means that the two are grasped by different means. The history of climatology and meteorology in some sense runs in the opposite direction from the history of geology and theories of the Earth. Whereas the latter began at cosmological scales and gained local-historical granularity, the sciences of weather and climate began with the assumption that local weather events were both highly variable and highly place-specific. Climate science only later acquired a theoretical generality that could tie large-scale movements of air, water, and heat together with the particularities of a local landscape.

Meteorology and weather forecasting have probably been practiced by every human society through some means, though the modern combination of ship-borne observation of navigable winds and long-term records from weather stations to analyse large-scale climatic phenomena began in the late-1700s, with the mobilization of the thermometer, barometer, and hygrometer.[31] Well into the nineteenth century, alerts for potentially catastrophic weather events required someone to directly observe an incoming storm — by ship in many colonial coastal ports, by observation stations everywhere else.[32] The historian Richard Grove has argued that the first global climatic

31 H. Howard Frisinger, *The History of Meteorology: To 1800* (New York: Science History Publications, 1977).

32 See Robert M. Rouphail, 'Cyclonic Ecology: Sugar, Cyclone Science, and the Limits of Empire in Mauritius and the Indian Ocean World, 1870s–1930s', *Isis*, 110.1 (March 2019), pp. 48–67 <https://doi.org/10.1086/702729>.

event to be accurately recorded was probably the Great El Niño of 1790–1794, when the British imperial officials simultaneously recorded barometric readings, droughts, and reports of crop failures in the Caribbean, northern China, Australia, Mauritius, and most critically Madras and Bengal.[33] But noticing the simultaneity of far-flung events does not amount to noticing and naming one climatic event: in the case of the El Niño Southern Oscillation, a complete theory only emerged in the 1960s, with major revisions made through the 1980s. Until the 1870s, the gathering of data and creation of meteorological maps and tables had only a very limited theoretical payoff.[34] As Deborah Coen argues in *Climate in Motion*, taking climatology from rules of thumb to scientific theories of global climate required new physical theories of heat as well as literary techniques for describing movement across scales.

For Coen, the Austro-Hungarian Empire was a political entity that was particularly suited for the creation of an integrated science of climatology: a contiguous land empire that encompassed many peoples, languages, and terrains. Coen argues that finding political unity in the Empire meant searching for the forces and tensions that tied together the parts into the whole through *dynamics*, rather than simply assuming parts are instantiations of an *a priori* whole or natural category.[35] Mapping and collecting, which were so crucial to British, Dutch, and Spanish imperial projects, were augmented by projects to determine why diversity persisted across an integrated space: it was important to fully catalogue local contrasts, but an additional step was needed to turn this collection of facts into scientific knowledge.[36]

In Austrian climatology, the additional force came through different applications of thermodynamics in order to explain the accumulation, movement, and dispersal of atmospheric energy. For example,

33 Mike Davis, *Late Victorian Holocausts: El Niño Famines and the Making of the Third World* (London: Verso, 2002), pp. 216–18; Richard Grove and George Adamson, *El Niño in World History*, Palgrave Studies in World Environmental History (London: Palgrave Macmillan, 2018), chapter 4.

34 Azadeh Achbari and Frans van Lunteren, 'Dutch Skies, Global Laws: The British Creation of "Buys Ballot's Law"', *Historical Studies in the Natural Sciences*, 46.1 (February 2016), pp. 1–43 <https://doi.org/10.1525/hsns.2016.46.1.1>.

35 Coen, *Climate in Motion*, p. 32.

36 Ibid., pp. 139–42, 153.

the Austrian geographer Alexander Supan (1847–1920) pioneered the discovery and use of pressure and temperature gradients, mapped to particular geographical regions, where atmospheric energy accumulated and dispersed along predictable lines.[37] Doing so revealed that the distribution of climatic patterns was not itself driven by measured wind speed, but rather by the movement the pressure systems that drove the wind. But by far the most important climatological theory to come out of imperial Austrian climate science was Max Margules' (1856-1920) theory of the 'available potential energy' (APE) of the atmosphere.[38] Margules, a physicist at the Austrian Imperial *Zentralanstalt für Meteorologie und Geomagnetismus* (ZAMG), argued that the stability of pressure gradients themselves had to be accounted for by measuring the energy capacity and (thermodynamic) work done by moving masses of air and moisture. By considering the dynamics of weather as 'pendulous oscillations' of unequal masses of air as a first principle (Fig. 4), Margules' APE model implies that winds, storms, and pressure gradients were caused by the movement of warm and cold bodies of air — a concept that is fundamentally a mathematical abstraction of direct experience — and that movement of warmer or colder air horizontally across the landscape has significant effects on the vertical distribution of atmospheric heat, pressure, and moisture.[39] Here was the grand unifying theory: all weather phenomena must be understood as the energetic effect of bodies of air moving across the land and up and down the atmosphere, and the terrain itself thus has a powerful effect on the movement of these masses of air. In the 1950s, the American meteorologist Edward Lorenz (1917–2008) would broaden Margules' theory of storm generation into a general theory of atmospheric circulation, a theory that makes the movement of heat into the root cause of all weather phenomena.[40]

37 Ibid., pp. 172–74.

38 Ibid., pp. 199–202.

39 Max Margules, 'On the Energy of Storms', in *The Mechanics of the Earth's Atmosphere*, trans. by Cleveland Abbe (Washington, DC: Smithsonian, 1910), pp. 533–95.

40 Edward N. Lorenz, 'Available Potential Energy and the Maintenance of the General Circulation', *Tellus* 7.2 (January 1955), pp. 157–67 <https://doi.org/10.3402/tellusa.v7i2.8796>; Edward N. Lorenz, *The Nature and Theory of the General Circulation of the Atmosphere* (Geneva: World Meteorological Organization, 1967).

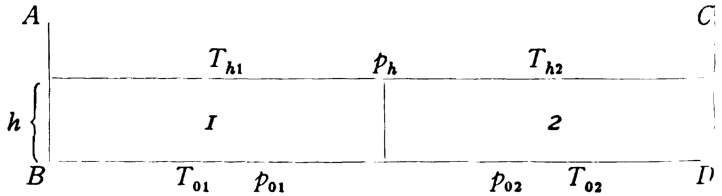

FIG. 1*a*.

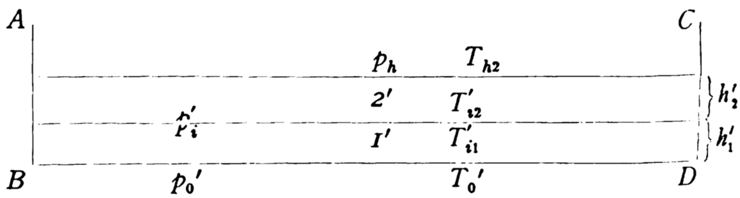

Figure 4. Max Margules' 1904 schematic showing an initial state (above) of vertically differentiated temperature (T_n) and pressure (P_n) differences (spatially divided by P_h), which results in the subsequent state (below) of horizontally differentiated layers of air at different temperatures and pressures. Max Margules, 'On the Energy of Storms', p. 536.

CONCLUSION

Experience, Lino Camprubí and Phillip Lehmann argue, scales.[41] Models and theories of the climate are not generated solely by abstraction, but historically come from people observing rolling clouds near and far, measuring the fall of atmospheric pressure, feeling their skin becoming clammier as the humidity rises: the dynamic experience of the weather is not only felt by one individual, but by many, and these experiences and measurements are recorded, sorted, and eventually calculated to become the science of the climate. This is in large part because there is not one monolithic 'experience'. Experience has different modes of feeling and seeing that are augmented by time, technologies, and, once accumulated, in expertise. The instruments and techniques of experience in early geology were collections, reports, and eventually maps and guides to landscapes. The scale of geographical and geological maps provides a good case in point: they are clearly generated by experience, but a map in the hands of its user becomes a tool to

41 Camprubí and Lehmann, 'The Scales of Experience'.

augment experience as well. The study of the cumulative and recursive effect of experiences turned into tools and representations has become one of the core tenets of empirical science studies in the twenty-first century,[42] despite the fact that such recursiveness can lead to a sense of vertigo and disorientation.[43]

In this essay I have tried to juxtapose two different ways experience and science scaled. In Rudwick's studies of the history of geology, theories of the Earth originate from the Aristotelian and Cartesian theories operating at essentially cosmological scales, and much of what makes geology 'modern' is its contrasting ability to account for very small-scale, local variations of phenomena within the context of planetary laws. Coen's account of the history of climatography and climatology, in contrast, begins with the historically widespread assumption of the local, small-scale specificity and variability of the weather, and only through the use of high-quality record keeping and modelling using thermodynamic laws does a picture of climatological dynamics arise. In both, the interplay of natural history and natural philosophy is centre stage, and one does not operate well without the other.

But what are we to make of the kinds of distant theorizing and exploration of nature, which in both of the cases presented here is conceptualized largely as a world prior to or absent the human species — the *Anthropos* and the *Homo* mentioned at the start of the essay? As Julia Adeney Thomas observes of Chakrabarty's original analysis of the concept of the Anthropocene, the challenge is not *only* in scaling as such, which would be a problem of method and methodology in the historical sciences, but in what is being scaled. For Thomas, the distinction between *Homo* and Anthropos, or 'the Human' and 'the human species'

> is not something humanist historians can *understand* through self-reflection in Wilhelm Dilthey's sense, where historical consciousness is 'a mode of self-knowledge', or in R. G. Collingwood's sense, where historical comprehension rests fundamentally not on reconstructing the past but on reen-

42 Bruno Latour, *Pandora's Hope: Essays on the Reality of Science Studies* (Cambridge, MA: Harvard University Press, 1999).

43 Coen, 'Big Is a Thing of the Past', p. 309.

> acting 'in our own minds the experience of the past.' While 'species' may work for paleobiologists comparing, say, the fossil records of Eemian biota from 130,000 years ago with modern organisms, theirs is a labor of reconstruction as opposed to one of self-reflection or mental reenactment.[44]

I would like to close this meditation on weathering by suggesting that this disjuncture Chakrabarty highlights between the human as a political actor and humanity as a planetary force is loosely analogous to the distinction between the self-reflective subject and the self-negating analyst. During the early-1990s debates on historical and scientific objectivity, the historian Thomas Haskell argued that attempts to cast the concept of objectivity itself as both fictional and disingenuous ran the risk of turning any historical scholarship into propaganda, and any possible utterance into an expression of will:

> But to shrug off the capacity for detachment as entirely illusory — to claim that since none of the standpoints the self is capable of imagining are *really* that of 'the other', but are self-produced (as is certainly the case), and to argue that all viewpoints therefore are *indistinguishably* contaminated by selfishness or group interest or the omnipresent Nietzschean will — is to turn a blind eye to distinctions that all of us routinely make and confidently act upon, and thereby to blur all that distinguishes villainy from decency, veracity from mendacity, in everyday affairs. Not to mince words, it is to defame the species. Fairness and honesty are qualities we can rightfully demand of human beings, and those qualities require a very substantial measure of self-overcoming.[45]

Since these debates, historians of science have argued that objectivity is itself a historically specific kind of subjectivity and set of values that scientists work to cultivate, so much so that objectivity has itself become essentially synonymous with scientific knowledge and practice.[46] Haskell argues that the species — Stockhammer's *Homo*

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44 Thomas, 'History and Biology in the Anthropocene', p. 1592.

45 Thomas L. Haskell, 'Objectivity Is Not Neutrality: Rhetoric Vs. Practice in Peter Novick's *That Noble Dream*', *History and Theory*, 29.2 (May 1990), pp. 129–57 <https://doi.org/10.2307/2505222>.

46 Lorraine Daston and Peter Galison, 'The Image of Objectivity', *Representations*, 40 (1992), pp. 81–128; Theodore M. Porter, 'The Objective Self', *Victorian Studies* 50.4

— must be capable of some kind or kinds of detachment, alienation, impartial judgement, and empathy towards the other, and this itself requires a degree of personal cultivation. It is precisely this recasting and scaling-up of the personal experience of the weather to a global understanding of climate, and the scaling-down of geological theory to understand one's local landscape or patch of the Earth, that demands personal experience as well as alienation from it.

(2008), pp. 641–47; Jimena Canales, *A Tenth of a Second: A History* (Chicago: University of Chicago Press, 2009).

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