Temperature and Capital

Measuring the Future with Quantified Heat

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ABSTRACT: The quantification of human environments has a history—a relatively short history. This article explores how the notion of quantifiable reality has become naturalized through the privileging of predictive utility as the primary goal of knowledge production. This theme is examined via the invention and application of temperature—how it was sociomaterially constructed and how it is globally restructuring social organization today. Temperature does not exist pervasively throughout all space and time. Physicists may affirm that fluctuations in relative heat are ubiquitous, but as a measurement of these fluctuations, temperature only emerges through arrangements of political and environmental observations. What phenomena do populations deem worthy of observation? How do populations manipulate materials to make such observations? By tracing the origins of thermometry and investigating modern efforts to reconstruct and model ulterior temperatures, I illustrate that temperatures, like other measurements, are cultural artifacts pliable to sociopolitical efforts of control and domination.

KEYWORDS: Anthropocene, capitalism, global warming, measurement, risk, temperature, uncertainty

My iPhone tells me the temperature this Saturday will be 99°F. Is this appliance of mine making a benign assertion about sensible heat, or reifying the hypothetical future of capital by suppressing uncertainty? Both, perhaps, but the latter is far more interesting. My concern with the politicization of measurement is not centered on quotidian debates over the reality of anthropogenic climate change that pervade cable news and blogs, or whether or not we reside in the Anthropocene or Holocene. Rather, my focus is on how groups sociopolitically determine what is worthy of observation. Of the endless reserve of properties in this universe capable of being measured, what information and knowledge do we valorize, and what do we dismiss as irrelevant?

To address such concerns, the following investigates the materiality of measurement, that is, the material culture of knowledge production. Specifically, my focus is on the measurement of heat. More broadly, I engage with the quantification of reality that is implicit in today's dominant modes of knowledge production, arguing that this is derived from a historically situated epistemology that is employed to construct a capitalized ontology. Such an ontology is one that posits the reality of perpetual, accelerating, asymmetrical growth. Temperature was developed by a capitalized (or capitalizing) population, and thus, as a system of measurement, temperature observes a reality in which this manner of hypothetical growth is practiced and pursued.

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To bolster these assertions and unfold their implications, I first review work regarding the concept of measurement. I then discuss distinctions between heat (or hotness) and temperature—so often conflated in popular and academic writing. This will be followed by an investigation into the history of thermometry and the sociopolitical circumstances out of which temperature emerged, from the invention of the thermometer to the supercomputers producing today's most sophisticated temperatures. Finally, I examine contemporary efforts at measuring world ocean temperatures and corollary efforts to eradicate uncertainty from our observational mechanisms.

Drastic Measures

Karen Barad has problematized the assumption that isolated phenomena can be measured without simultaneously being co-constituted by the apparatus of observation. A measurement does not observe preexisting inherent properties of an object. Qualities and attributes emerge from the interaction (or "intra-action" in Barad's language) of observational device and observable subject (2007: 342–350). As others have elaborated: "The specific material arrangement or setup of the measuring device in conjunction with the object produces the physical parameters of the object measured—the result. If you change the apparatus a different object is produced" (Marshall and Alberti 2014: 26).

While measurement is ostensibly the observation and recording of properties, Barad's contentions cast measurement and observation as generative processes—observational devices actually create the properties they are designed to detect. The attributes of an object (its weight, length, temperature, density) are not inalienable; they emerge from the interaction of observer and observed. For Barad, objects do not have inherent properties. To assert otherwise is to essentialize and naturalize (see also Haraway 1988 on situated knowledges and Viveiros de Castro 2014 on multinaturalism). Following Barad's deconstruction of measurement, the suggestion herein is that thermometers do not measure temperature; they create temperature.

As evidence for this notion of measurement, Barad dissects twentieth-century debates and experiments that tried to resolve whether light is composed of waves or particles. The answer is that it depends on how you construct your observational apparatus, but the conclusions drawn from this answer vary and illustrate a critical difference between uncertainty and indeterminacy. Heisenberg's well-known uncertainty principle suggests that there will always be uncertainty about the location and behavior of a particle because by looking at subatomic phenomena our observations "disturb" them. In Heisenberg's interpretation the particle has a determinate behavior and trajectory, but our primitive observational tools are not able to simultaneously "catch" and "record" this trajectory. From the same evidence, Niels Bohr drew a slightly different conclusion, suggesting that there is no preprogrammed determinate behavior or properties of the particle prior to the observation. It is not as though the particle has a teleological historical trajectory that our lack of cunning precludes us from catching, but rather the manner of the observation is included in the causality of the particle's behavior (Barad 2007: 261–262, 301–302). Subsequent experiments (Herzog et al. 1995; Kwiat et al. 1994; Scully et al. 1991; Scully and Walther 1989) have validated Bohr's interpretation through retroactively observing what outcomes would have occurred in the absence of observation. Conclusively, it appears, observing something does not alter its predetermined state; it generates a new state that is inclusive of the observation.

Lest solipsism tempt us, Barad is quick to point out that every object (human or otherwise) observes—human measurement does not bring the world into existence. Barad (2012) alludes to interpretation as the catalyst of causation; thus, everything capable of changing is capable of receiving signals. This work echoes themes that Charles Peirce (1998) put forth a century earlier, but grounds them in a materialist realism that gives "sign" a radical new constitution within Peirce's "Object > Sign > Interpretant" framework. Like some geographers (Couper 2007; Olsson 1978), ecologists (Morton 2010, 2013), philosophers (Harman 2007), and physicists (Arkani-Hamed and Trnka 2014), Barad suggests the framing of an observation directly impacts which causes and effects pass through the aperture of experience.

For scientists, this means that based on the properties their measuring apparatus is designed to detect, a reality is extracted that reflects this specific design. For a goldfish, this means the specific material configuration of its physical system distinguishes predators and prey ("carnivorous" is not an inherent property of a shark but becomes a property of the shark based on certain frames of observation—the shark is not carnivorous to a tree because neither are designed to observe this relationship). For a rock, this means it is indiscernible from the grass it sits on until something (a gust of wind) observes (encounters) the material difference of the rock-grass configuration and responds differently to each. This affords both rock and grass distinct (but not inherent) wind-centric properties (Morton 2013). In short, nothing has any properties of its own until a relationship is cut out via an observation ("interpretation" or "response" could be used interchangeably with "observation" here depending on how much agency one is comfortable allotting rocks or goldfish).

Given this, how might we consider an attribute such as the intensity of heat prior to its quantification through thermometry and classification as temperature? Body temperature hovers around 37°C, but what was the body temperature of someone five hundred years ago? What is the body temperature of an uncontacted Ayoreo in South America? Are these questions nonsensical? Is this the same as asking a tree if a shark is a predator? Not exactly.

Certainly, those who live in a world in which temperature (quantified heat) does not exist possess the capacity to have their body temperature observed, but would the resulting number mean anything? Temperature is a categorical piece of information that has proved useful for some to observe, but it is meaningless outside of its social context and the relevance afforded it by society. Traditional Chinese mathematics did not discern a category for numbers that were only divisible by themselves and one (Wen-Tsun 1986). This does not mean that the concept "11" did not exist for Chinese mathematicians. The number 11 existed just fine, but it did not have the categorical distinction of being prime. Chinese mathematicians knew that 11 was only divisible by itself and one, but this was not a characteristic worthy of distinction. Thus, being prime is not an attribute inherent to the number 11. It is an attribute that was parsed by the (social) development of a set of rules (an algorithm) that simultaneously observes and generates prime numbers. Among a population that distinguishes numbers only divisible by themselves and one, the number 11 has the attribute of being a prime. Among populations that do not make such categories, primacy is *not* an attribute of 11.

The same may be said of temperature. Populations that have not quantified sensible heat are aware that this lamb fur is hotter than that grinding stone. Touch is enough to make this observation. Further, populations without quantified heat are perfectly capable of feeling "20°C"; they just might not denote this experience with such a numerical signifier. To think otherwise is to slide into Sapir-Whorfian linguistic relativism, in which vocabulary determines reality. Cross-cultural distinctions in vocabulary do not indicate the inability to experience unsignified phenomena; neither do social determinations of what is measured. Rather, these distinctions in vocabulary and knowledge production are reflections of what concepts a group values.

Any information can be codified via measurement. A society that places great value on the economy of language could engineer an apparatus that monitors how many words per day one speaks. This would generate a host of attributes based on the quantification of this information. Those that speak more than four thousand words per day might be considered semantically wasteful. There is no material-technological barrier impeding the creation of such a measuring apparatus. If this information was deemed of great value, an "utterance counter" could be on the market within the year. This information is not valued, so energy and resources are not focused on developing instruments to quantify verbosity. It may be true that I speak 2,238 words per day, but the truth of this observation does not give it meaning. Mary Poovey (1998) and, more recently, Sally Merry (2016) address similar concerns about quantification.

Truth is of scandalously little importance in measurement. Any apparatus can be devised that produces internally coherent results. Einstein was alleged to have mischievously suggested that "every theory is true, provided you suitably associate its symbols with observed quantities" (Barad 2007: 68). A system called temperature was created, it has certain rules, and according to the rules of temperature my body is 37°C. The truth of this property has been socially determined to be of relevance. It is the decisions and motivations that go into deciding what to observe and measure that are of greater consequence to the production of knowledge than the results of measurements. Measurement does not objectively observe categorical attributes that exist ontologically outside of the measuring apparatus. Rather, measurement is a system of creating attributes through the process of discernment.

Quentin Meillassoux's (2008) arche-fossils demonstrate this well. Such "fossils" include the light that Hubble detects from 13 billion years ago, or the geological markers that indicate Earth's formation 4.5 billion years ago. How was this knowledge produced? No human was around to observe such events. Such facts are produced out of various "parts" (evidence). We can observe the ratio of uranium-238 to lead-206 isotopes in the mineral zircon in the present. We can observe the rate at which the ratio of U-238 to Pb-206 changes over time. Thus, we can determine that the oldest zircon on this planet is around 4.5 billion years old. The fact is assembled out of various subobservations, like the assembly of any cultural product.

One need not doubt the veracity of these conclusions, but one can certainly consider the social circumstances under which it became valuable to *know* that the planet is 4.5 billion years old as opposed to eternal, as many Greek scholars thought. Martin Rudwick (2005) suggests in *Bursting the Limits of Time* the concept of "billion" was probably comically large before three hundred years ago. Declaring the planet to be a billion years old would be similar to saying it was "a bazillion years old." It may be more comprehendible to just say the planet has been around forever.

There are well-documented ethnographic accounts of languages that do not possess a word for numbers above two. There might be the word "one," the word "couple," and then the word "many" (Everett 2013; Everett and Madora 2012; Spaepen et al. 2011). Numeric knowledge is not a more correct, more advanced, or a better kind of knowledge, but certainly a quantified appreciation of the world facilitates a different spectrum of possible interactions with our environments. Over the past seven hundred years, European populations began valuing quantified information, and pursued knowledge that was numerical and sequential (Crosby 1997).

The thermometer was not the first apparatus designed to observe variations of heat. The configuration of flesh and nervous system (skin) is quite capable of observing that the attic is warmer than the basement. What the nervous system cannot do is quantify this attribute. However, measurement is not intrinsically numerical. "It's hotter today than yesterday" is a relative measurement. The fallacious notion that measurements must be quantified stems, I argue, from an emphasis on standardization that allows for greater pattern recognition and predictive capacity—an occurrence that has a specific situated history and politics (to be explored below).

This Is Getting Intense

Before the seventeenth century, temperature did not exist. Of course, cosmologists assure us, fluctuations in heat are as old as the universe; such fluctuations are implicated in the very behavior of matter that allows celestial bodies to emerge. Temperature, however, is a discursive concept produced approximately three hundred years ago, depending on your preferred innovator (see Sherry 2011 for a review of this debate).

Temperature is not heat, though many are guilty of this conflation. For example, this passage commits such a transgression: "The basic concept of the thermal resistor was known since 1833 when Faraday noted that the conductivity of certain elements was affected by changes in temperature" (Abraham et al. 2013). Perhaps it is pedantic to scrutinize this misrepresentation too closely, but changes in temperature have no effect on the conductivity of elements. It is changes in the heat energy that impact conductivity. Temperatures are cultural products denoted by Celsius, Fahrenheit, or Kelvin that allow human groups to better conceptualize gradations in heat. Unless it is meant metonymically, the rising and falling of temperatures does not affect particles or ice sheets or harvests; rather, they affect humans and their perceptions (which may certainly have subsequent repercussions for particles, ice sheets, or harvests). Just as a ruler does not measure centimeters (it measures distance or space), a thermometer does not measure temperatures (it measures the effects of heat).

I do not believe this is a pedantic distinction. Surely, such fleeting semantic slips are meant innocuously enough, and in such instances the authors' meaning is usually conveyed fluently. I am not accusing such "mistakes" of being consciously political acts intended to naturalize a Western ontology that perceives the world as inherently quantitative and amenable to domination, but the mere fact that such lingual misuse slides by our perception so seamlessly is an indication that such an ontology has been reified. I will return to the history of this reification, but here a deeper parsing of heat and temperature may be useful.

Temperature is an intensive description of heat (Sherry 2011). There are intensive properties, like density or momentum, and extensive properties, such as distance or weight. Extensive properties are accumulative and extractable. Intensive qualities describe noncardinally divisible internal compositions of objects—halving a log changes its weight but not its density. Unlike extensive properties, intensive qualities are not composed of discrete units. Ten meters of rope can become eight meters by cutting off (extracting) two meters. However, a 10°C stone cannot simply have two degrees extracted to make it 8°C. While 10 meters is an accumulation of 10 divisible extents, 10 degrees Celsius is not composed of 10 iterations of Celsius; it is a whole (Châtelet 2000: 40–41, 111–114). Changing the temperature of the stone demands changing the conditions of its surrounding environment. It could be put next to a fire or placed in an ice bucket—that is, energy (heat) must either be transferred into it (from the warmer fire) or transferred from it (into the ice bucket). Altering the heat of an object requires altering how it integrates with its environment. Temperature is an intensive observation of extensive shifts in distributions of energy.

While temperature is designed to serve as an intensive indication of relative warmth, most thermometry devices actually make extensive observations that are used as proxies for the intensive concept of temperature. Mercury thermometers work by measuring the extensive expansion of liquid (mercury) under variations in sensible heat. The extensive distance that mercury moves within the narrow glass tube is the actual observation. This thermometer observes how much heat is absorbed by mercury, converting extensive interactions into a standardizable unit. Modern thermistors measure change in the extensive electric resistance of platinum as a proxy for generating intensive temperature. Temperature is more about accurately determining how certain materials respond to energy fluctuation in a controlled environment than about relative warmth.

Efforts to quantify intensive properties are relatively recent. Aristotle did not think such quantification of intensity was possible. "One particular disposition or one particular quality, such as whiteness, is by no means compared with another in terms of equality and inequality but rather in terms of similarity" (quoted in Sherry 2011). Just as it would feel awkward to say, "That strawberry is five degrees more red than that apple," it would strike Aristotle as equally awkward to say, "It's five degrees hotter in Alexandria than in Athens." However, subsequent innovations in mathematics (see the work of fourteenth-century geometer Nicole Oresme) and the design of observational instruments cast doubts on Aristotle's conclusion.

The principles that would ultimately lead to the creation of the thermometer (i.e., substances may expand if heated) were known since Aristotle's time. Galileo and Renaissance contemporaries developed thermoscopes that operated on these principles in the late sixteenth and early seventeenth centuries. These instruments consisted of vertical glass shafts with large empty bulbs at the top (reservoirs for air) and a basin of liquid (usually water) at the bottom. Increases in heat would cause the air in the top bulb to expand downward, displacing the water. However, these early efforts at thermometry were not quantified or standardized. They were based on relative periodic observations of the position of the liquid—if the liquid in the thermoscope looks higher today, then it is getting warmer. Each device created its own specific knowledge. The readings of one thermoscope were not interchangeable with those of another.

Thermometers with a numerical scale denoting the expansion of mercury began circulating in Northern Europe at the beginning of the eighteenth century, 1659 being the oldest recorded temperature (Manley 1974). A number of scales were developed and persist today. Interestingly, Anders Celsius conceived the freezing point of his scale at 100° and the boiling point at 0° (Bolton 1900: 85), certainly troubling the normalization of temperatures rising (heating) or falling (cooling), and reminding us that it has always required the same amount of energy to make water boil. We have just named this amount of energy 100°C.

The thermometer is designed theoretically to isolate sensible heat as the exclusive causal actant on the expansion of mercury. This isolation of causal actants is critical to generating confidence in measurement, and remains a persistent problem in advanced thermometry today. Obviously, many forces besides heat act on a thermometer—light, gravity, pressure. Thermoscopes were "flawed" in that they inadvertently observed air pressure along with sensible heat. Thermoscopes relied on the expansion of the air inside the glass to displace inert water. By substituting alcohol or mercury for water and enclosing the liquid within the glass tube, the expansion of the liquid, not the air, became observed, and air pressure was eliminated as a causal agent. Mercury did not stick to the sides of the glass, so it became preferred over alcohol (Taylor 1942).

The standardization of mercury thermometers is worth investigating. The primary commercial use of mercury in the eighteenth century was to extricate silver from ore, predominantly in Spain's American colonies (Lang 1968). Mercury mining was undertaken across Europe and many of its overseas "holdings"—Spain, Slovenia, and Italy were the largest European exporters. Thus, there was no shortage of mercury available to tinkerers like Ole Rømer or Daniel Fahrenheit. Measurements of phenomena like heat are based on observations of patterned behaviors of materials. The material mercury behaves in a predictive pattern when enduring fluctuations in atmospheric warmth. From this predictability of mercury's behavior we can invent and codify something called temperature.

Human groups have long possessed the capacity for thermal regulation. The forging of elements in metallurgy requires fire to be sustained at a precise heat, which is regulated by the amount and type of fuel used to feed the fire. Could this practice have inspired some form of thermal metric like temperature? Could "0°" have been the heat required to ignite the fuel and "100°" the heat at which iron becomes pliable? Could a quantification of heat be created based on units of fuel (e.g., this fire has a temperature of five logs of timber or seven bricks of peat or the atmospheric heat is negative three jars of seal fat)?

Yes, this could have happened. Earlier populations were certainly savvy enough to quantify heat. The rudimentary mathematics needed to devise a scale for assessing units of heat should be comprehendible to any society practicing metallurgy. Discussing prehistoric smelting techniques, Nissim Amzallag writes, "the temperature within the reactor is the limiting factor for the increase in size of the crucible" (2009: 501). While the population described did not have the temperature system we possess, the implication here is that they could regulate heat just fine, designing the shape of their instruments in response to a desired amount of heat. Temperature was not invented earlier because it did not need to be. It did not take temperature to design a proper-sized crucible for smelting. It was not important to be able to discern relatively slight variations in the intensity of atmospheric heat on a daily or hourly basis. What relevance would it be to a mediaeval merchant to know if it was 15° or 17° outside? Perhaps knowing if it is "hotter" or "colder" could be a useful bit of information for the merchant, but "15°" would be useless. Similar conclusions have been drawn regarding the standardization of time in industrializing Europe (Thompson 1967).

Counting Chickens Before They Have Hatched

What socioeconomic circumstances occurred that made numerical valuation of fluctuations in atmospheric heat important information? A very short answer: usury. That is, usury (interest) became increasingly normalized in Europe, and futurity became a primary source of wealth. "Futurity" is used here to denote not actual events that unfold subsequent to the present but rather the expectation of *a* subsequent. Interest demands a future.

Despite its modern ubiquity, the widespread employment of interest has a relatively recent history. Within Christendom, the social constraints guarding against compound interest were completely eroded between the Black Death of 1348 and the 1848 political revolutions that entrenched commercial concerns over ecclesiastic. Fifteenth-century banking innovations (notably the Medici) (Goldthwaite 1987; Roover 1963), the joint-stock investments of the East Indian trading companies, and the quantification of vulnerability by insurance companies in the form of valuated risk (commoditized exposure to future harm)—all are implicated in cementing the idea that wealth is kinetic, the idea that if wealth is not growing it is diminishing. Value became a function of its future effect. Hypothetical futurity became highly lucrative (Braudel 1982; Grice-Hutchinson 2009; Tanner 2005).

The unimpeded practice of usury is requisite for capitalism to work. The practice of perpetual, accelerating, asymmetrical growth requires that value appreciate. Capital is excess used to grow itself—wealth used to grow more wealth, most famously. This notion has been around for millennia in the mechanics of interest (it was not invented by Renaissance bankers; they just figured how to sidestep its prohibition). Quantifiable reality was engineered because growth became the driving economic principle. Growth requires a future, so reality became information that best programs that future. Individual perceptions of how hot it is outside are considered less real than the perception of the thermometer because the heat-mercury-glass apparatus generates numerically repeatable and probabilistically programmable information, unlike the nervous system.

The capitalization process that followed the unleashing of interest transformed reality from an experience into an output. Interest demands trends that allude to a "next" or an "around-the-bend." Quantifying temperature (along with much else) transforms the present into data points within a trend. No longer does it simply "feel a bit warmer than yesterday"; instead it is "two degrees warmer than yesterday." Relative measurements of heat, such as those produced by thermoscopes, are less projectable, less pliant to modeling. Predictive capacity is improved through pattern detection (Brown 2004). It is easier and more efficient to detect patterns in quantified information than in qualitative (O'Sullivan 2004). Observations of heat that have been translated into numeric data (temperatures) can be processed much more efficiently—they can be collected, catalogued, standardized, averaged, ranked; they can reveal central tendencies and trends, and most importantly trends can serve as the basis of probabilistically more accurate projections of future states (Crosby 1997; Harrison 2015). Thus, through converting variations of heat into a collection of numbers, thermal reality becomes the output of a trend.

As Paul Edwards (2013) details extensively in his work on the history of meteorology, temperature is much more about collecting data than about heat. Data are the abstracted reality that finance, insurance, and real estate (FIRE) use to incubate probabilistic futures. Again, capital does not exist without a future, and capital's future is built out of data. Data are the fuel of models and projections.

To be clear, my argument is not that temperature (and its privileging as the dominant manner of perceiving heat) directly produces the growth of wealth (capital). Rather, temperature is an example (and one of the earliest) of the transformation of the environment into processable data. Capitalism did not create temperature because of any direct financial benefit or inherent value that "72°F" offers. Rather, capitalism produces temperatures because temperatures can be projected, and projections are valuable. Projections open the future, and the future is the space into which capital's profits grow. In a sense, temperature, as data, contributes to the construction of the future. Temperature is less about turning heat into a number than turning heat into a trend. Wealth does not grow simply because heat is quantified; rather, it grows because trends produce subsequence, an output.

Predictive observational devices were designed to program growth into the future. Ironically, now that these same devices advise us to halt our growth (i.e., because of anthropogenic climate change), those most concerned with growing wealth have begun to doubt the reality produced by these instruments (i.e., deny anthropogenic climate change), affirming that quantifiable information was only categorized as "reality" because it was profitable.

To further unwind what is meant by the assertion that the capitalization process "transformed reality from an experience into an output," I offer the example of quarantine. As a response to the recurring waves of plague that swept Europe after 1348, quarantine is a system that defers the reality of health for 40 days ("quarantine" deriving from the Italian for "forty," *quaranta*). Quarantine could be programmed to isolate for different durations and operate on different subjects (symptomatic individuals, families of victims, incoming travelers), but whatever the parameters, upon running the quarantine program, individual responsibility toward the ill was deferred to the automated responsibility of quarantine with its two outputs: dead or healthy. The reality of the quarantined individual's health was determined by the output of the quarantine apparatus (Blažina-Tomić and Blažina 2015; Crawshaw 2013). Again, this does not suggest that quarantine explicitly grows wealth, but rather demonstrates how, for early modern Europeans, perceptions of reality began shifting from the demonstrative present to the quantified programmability of the hypothetical future. The mathematical formalization of this process is laid out lucidly in Ian Hacking's (1975) *Emergence of Probability.*

Hans Vaihinger eloquently codified this epistemological shift in his philosophy of "As if …" Here he outlines how knowledge is produced based on hypothetical outputs. Fittingly, Adam Smith's *Wealth of Nations* is his example. Smith eliminates indeterminate variables like emotions to diagram the operation of a perfect economy of rational consumers and producers. "Smith didn't regard himself as dealing with more than a fiction. Smith intended his assumption merely provisional … These assumptions don't correspond to reality and deliberately substitute a fraction of reality for the complete range of causes and facts" (1924: 20). Vaihinger was apolitical about this method. However, this epistemology very much needs politicizing.

Risky Business

The character of this emerging epistemological preference for probabilistic and quantifiable knowledge is evident in the development of the insurance industry, and its role in the capitalization of Europe and the world. It was in the guise of insurance instruments that Medici bankers cloaked the bills of exchange they sold in the process of normalizing usury. Bills of exchange were meant to insure the future value of the buyer's wealth. Insurance instruments were developed to suppress the economic harm of unpredictable futures. Insurance outfits as we know them today, such as Lloyds of London, grew out of insuring commercial ships like those of the East Indian trading companies, which, as some of the first joint-stock operations, carried future wealth around the world in the form of investment. Today, insurance is the largest industry worldwide in terms of revenues; its yearly profits would make it the third-largest country in terms of GDP (Mills 2005).

No industry is more dependent on the future than insurance. Insurance companies employ some of the most advanced statistical, probabilistic modeling techniques to set their premiums, drawing on data generated by a reality that has been quantified by observational devices like thermometers, and they are very concerned with the production of future temperatures (Ackerman et al. 2014; Carriquiry and Osgood 2012; Collier et al. 2009; Mills 2005; Picard 2008; Stern 2013). The insurance industry has a peculiar stake in climate change (and thus temperatures). Their focus, though, is not on mitigating climate change; their financial interests do not lie in preventing calamity. Actuarial science valuates the future as a function of vulnerability, such that it does not matter if a calamity occurs, as long as premiums are accurately set to reflect the risk level. Insurance companies do not want a completely safe world. They want a world in which there are persistent contingencies for people to fear. Yes, the disasters that climate change forebodes will mean that insurance companies will have to make more payouts on their policies, but their premiums will be adjusted accordingly to reflect this increased risk.

Again, this illustrates where the value of temperature lies. No individual measurement of temperature on any single day has any value to an insurance company, but the collected numeric data that constitute trends are the lifeblood of an insurance company's profits. Trends are the basis on which premiums are constructed, and profits created. Temperatures, collectively, create highly mathematizable trends, which are incorporated into the work of the actuary.

Climate Control

The planet is getting hotter. What meaning does this observation convey? Hotter than what? Implicit in this statement is the identification of a trend. A pattern has been identified by the suffix "–er." My contention is that the impetus for the invention of temperature was not to make a particularly good system for observing heat, but rather that it was invented as a good system for observing patterns and trends. Edwards's work demonstrates individual temperature measurements are only of value as pulp (data) to feed models: "the analyses produced … matter much more than the raw sensor signals used to produce them" (2013: 289). Edwards further details how the "sensor signals" (the measured numerical temperatures) are not stored (are useless) after they have been incorporated into climate or weather models. "The needs of numerical modeling would increasingly drive agendas in data collection, processing, and communication" (126).

Thermoscopes or skin produce relative observations about heat. These relative observations of heat are not conducive to trendcasting and projection. As noted above, the quantified observations produced by thermometers are much more amenable to standardization and pattern detection. The thermometer is not a *better* measuring instrument than living flesh, but it is better at producing projectable data than living flesh.

Temperature became adopted by a people concerned with perpetual growth. Accuracy in projection and prediction are critical to this pursuit. Some definitions of knowledge even have predictive capacity built into them. "To be practically adequate, knowledge must generate expectations about the world and about the results of our actions which are actually realized" (Sayer 1992). I disagree strongly. This author is conflating knowledge with scientific facts. Aside from being predictive, knowledge can be entertaining, amusing, arousing, or comforting, but for a capitalized population these attributes of knowledge are secondary or irrelevant.

Looking at more complex temperatures highlights that temperature is less about heat than it is about commanding timescales. Glancing at a mercury thermometer and reading the indicated number, it is easy to overlook the production of this information. The thermometer is a relatively simple machine—so simple that we sometimes forget it is a machine with multiple integrated parts. Equally, the habituated performance of checking the temperature on your phone, watching the meteorologist's forecast on TV, or seeing the time and temperature flashed on some digital signage all serve to inure us to the mechanical production of this information. However, the temperatures delivered by the local meteorologist or the smartphone require massive amounts of energy to reach us. The amount of energy needed for me to know that yesterday was 80°F, today is 82°F, and tomorrow will be 85°F is incommensurate with the impact that this five-degree change in Fahrenheit will have on my life or anyone else's. Again, this demonstrates that the primary utility of temperature is not in observing heat but lies in the capacity to accumulate data and generate patterns.

This is more visible in the process through which archaic temperatures are produced—that is, temperatures that are produced to quantify heat that existed before temperature was invented. Despite temperature not being invented until the late seventeenth century, it is still possible to measure temperatures from one thousand or five million years ago. The intensity of heat leaves material traces on a number of elements. Frozen precipitation carries a record of heat differentials. Most of the oxygen in the universe has eight neutrons (99.7 percent); this is known as oxygen-16 (8 protons plus 8 neutrons). However, there is a regularly occurring isotope of oxygen with ten neutrons—oxygen-18 (8 protons plus 10 neutrons). Depending on the heat energy in the atmosphere, H_2O falling to Earth as rain or snow possesses a greater or lesser ratio of oxygen-18 isotopes (Landais et al. 2004).

Paleoclimatologists use millennia-old precipitation trapped in Greenlandic or Antarctic ice cores to observe changes in heat by measuring changes in the ratio of oxygen-18 to oxygen-16. This detection is accomplished by running a sample of the oxygen through an accelerator mass spectrometer, which parses how many of the oxygen atoms have 8 neutrons and how many have 10. Ice cores, like tree rings, produce annual patterning. Thus, annual fluctuations in sensible heat can be correlated to a Celsius scale and read as temperature. The ice core record gives us relatively reliable data on changes in heat over the past eight hundred thousand years (Masson-Delmotte et al. 2006). To go even further back, paleoclimatologists can examine isotope ratios from the fossilized shells of marine life.

What is being observed in this process? Despite the increased complexity (i.e., greater energy required to produce), these temperatures, like the mercury thermometer, aim to translate a collection of numerated extensive material proxies into the intensive concept of temperature. Despite its microscopic dimensions, an oxygen-18 isotope is material, just like mercury. Just as we can grasp how mercury behaves in response to fluctuations in heat, we can observe how atmospheric oxygen behaves. Though highly energy intensive to retrieve (flying a team of scientists to Antarctica, feeding them, keeping them warm enough to survive the cold, coring out a sample of ice one hundred meters deep, transporting this core back to the lab while keeping it frozen, running it through an accelerator mass spectrometer that requires extensive electricity), archaic temperatures are derived from simple extensive counting—out of 1,000 oxygen atoms, are there 999 or 998 oxygen-16 isotopes?

The temperatures produced by this methodology are not the absolute kind used by meteorologists (e.g., 75°F). They are chronologically comparative temperatures. Reading the annual accumulation of oxygen isotopes in an ice core can communicate that from the most recent ice age to just before the Industrial Revolution the temperature changed 10.9 +/− 3.5°C in central Greenland or 4.2 +/− 0.9°C globally (Masson-Delmotte et al. 2006), or the surface of the planet has warmed 0.6°C in the past century (Levitus et al. 2001). Again, a type of temperature like 0.6°C represents a trend, a pattern. This is useful information to capitalized populations. As I have argued, the main point of temperature is to be able to create trends that ultimately allow the enhancement of predictive capacity. The deeper our trends reach back into the past, the greater statistical confidence that can be ascribed to projections of these trends. Producing evidence that extends the time-depth of a trend creates a more believable future, and capital requires a belief in the future.

As scholars researching the circa 1350 to 1850 CE cooling period (sometimes referred to as the Little Ice Age) in the North Atlantic have pointed out, the temperatures produced today to describe the past thousand years may not actually say much about the lived experiences of the people who endured this period. What does our knowledge that it was two degrees colder five hundred years ago offer us (Dugmore et al. 2007; Ogilvie 2010)? This work suggests that the value of producing archaic temperatures is not that we can understand a culture better because we know what the temperature in Iceland was in the year 1425. Rather, the value is in seeing the trend of temperature change over the course of 10, 100, or 1,000 years, including how much it deviates from the norm.

Smoked Glass

I have suggested that within capitalized ontology, reality is a probabilistic output. That is, reality is comprised of information that can most reliably model the future. The Higgs boson particle was predicted before it was observed. The discovery of the particle fulfilled a model of the composition of the universe. An incredible amount of energy was needed to fulfill this prediction (enough to power the CERN supercollider). This energy was expended in proving the predictability of the world, that the hypothetical output of our models is actually “real.” To this end, it may be said that capitalized populations employ the category of “reality” to describe phenomena that are predictable, casting “real” as simply a synonym for causal.

The focus of capitalized knowledge production has thus been on increasing probabilistic confidence (meant here in the statistical sense). This is reflected in today's efforts at producing temperature. Efforts to measure the temperature of the global ocean, and its fluctuations over the past century, are heavily focused on measuring uncertainty and confidence, seemingly more so than measuring heat. Analyzing the work of other climatologists, Stefan Rahmstorf and colleagues (2004: 38–41) write, "[They] conclude that the effect of a doubling of atmospheric CO_2 concentration on tropical sea surface temperature is likely to be 0.5°C (up to 1.9°C at 99% confidence)." They go on: "The [other] authors applied several adjustments to the data to artificially enhance the correlation." The concern herein is not the methodology or accuracy of either camp of climatologists but rather the epistemological approach evinced here, wherein confidence is the focus of measurement.

What does it take to measure the change in global ocean heat over a century? Quite a lot. The following is a prosaic description of one such instrument designed to measure temperature at varying depths:

> The Mechanical Bathythermograph is a cylinder … with a nose weight, towing attachment, and tail. Inside the cylinder is a Bourdon tube enclosing a capillary tube with xylene (a hydrocarbon obtained from wood or coal tar). As temperature [incorrect usage of temperature] increases, the pressure on the xylene increases, causing the Bourdon tube to unwind. A stylus attached to the Bourdon tube captures the movement as temperature [correct usage of temperature] change horizontally scratched on a plate of smoked glass. A spring and piston measuring pressure simultaneously pulls the stylus vertically down the glass, completing the depth/temperature profile. (Abraham et al. 2013: 453)

Obviously, the ocean is three-dimensional, unlike a surface, and one of the biggest obstacles in ocean temperature measurement has been accurately gauging temperatures at different depths. In this undertaking thermometricians have once again encountered the old problem of isolating heat as the sole actant upon their observational devices. Pressure again becomes a problem at greater depths. Salinity and conductivity also bear on the sensitivities of instruments.

The most glaring point of contention for the measurement of ocean temperature at varying depths has been the errors uncovered with expendable bathythermograph (XBT) devices. These devices do not measure their own depth directly; rather, their depth is derived by calculating their rate of descent via an equation provided by the commercial manufacturer. For a few models of the XBT device, the manufacturer provided an inaccurate calculation of the rate of descent of their device. Thus, large swaths of archived data on ocean temperature are based on inaccurate information. Oceanographers have been able to account for this error and provide correcting calculations for data generated from these models. However:

> Complicating any attempt to correct XBT biases is the fact that many historical profiles archived … in World Ocean Database 2005 do not contain metadata indicating the model type … An international meeting was held during March 2008 at the NOAA Atlantic Oceanographic and Meteorological Laboratory in Miami to discuss the XBT fall-rate problem. One of the results of the meeting was to establish a web page. (Levitus et al. 2009: 1)

This conference and website are about these climatologists' lack of confidence in their percentage of certainty, not about fluctuations in heat. As Barad might interject, there are no "incorrect" measurements, only observations that fail to isolate and capture desired attributes.

Millions of dollars are being spent not on measuring temperature but rather on measuring uncertainty. Climatology often seems more focused on increasing confidence than on decreasing heat. Under the paradigm of capitalist ontology, increased heat is not the problem; uncertainty is the problem. The focus of capitalized knowledge production is not on cultivating ways to live without releasing more CO_2 into the air but on how to eliminate uncertainties about future conditions (sometimes as a byproduct "greener" technologies are developed). However, there is nothing inherently damaging about uncertainty. It only becomes unwelcome when predictability is the privileged facet of knowledge production. Rising sea levels do not threaten control as long as they can be predicted. It is uncertainty that threatens control. Vast investment in climate research is motivated by climate's resistance to reliable predictability, and the threat of this uncertainty to the hypothetical futurity on which capital relies for its existence.

Indeterminable Duration

Scientific methods of observation have trended toward requiring greater and greater amounts of energy to extract and accumulate greater and greater amounts of certitude. Reviewing devices that measure heat: the skin requires the amount of caloric energy necessary to keep you alive; the thermoscope requires glass and water; the thermometer requires the mining of mercury; as outlined above, the production of archaic temperatures requires enough energy to get meters of ice from Antarctica to the Northern Hemisphere; and temperatures modeled for the future are created using exascale high-performance computing hardware that must be run at higher voltages to ensure bit reproducibility (Düben et al. 2014).

The reliance on and pursuit of ever greater processing power derives from the fear of uncertainty, not the fear of climate-induced human suffering. Exascale calculations are pursued in order to reduce and overcome uncertainty, not to reduce greenhouse gas emissions or other environmental destabilizers. Exascale computation is capable of doing a billion billion calculations per second (a thousand times the rate of petaflop computation) and is expected to come online by 2020 (Palmer 2015). The amount of energy necessary to run exascale calculations is substantial—monstrous amounts of dead carbon are being extracted and burned to improve confidence in future climate behaviors. Not insignificantly, then, efforts to predict outcomes of climate change are directly contributing to climate change.

This is a sad revelation—just as a thermometer does not just measure temperature but creates it, so too do instruments designed to measure climate change contribute to climate change. It must be said without qualification here that this does not mean that anthropogenic climate change is not real. Equally, I am in no way insinuating that temperature is not real. Anthropogenic climate changes are a product of capitalized ontology, not of climatology; climatology just happens to be one rather small sliver of this ontology. Other slices of this ontology promote mountaintop removal for coal extraction and forest clearing for industrial monocrop agriculture. It is this entire package that drives anthropogenic climate change.

A collection of physicists and climatologists working in Oxford seem aware of the disheartening amount of energy required to measure the climate. In what seems a tacit nod to Bohr's advocacy of an indeterminate model of the quantum world, this research aims to exchange enhanced deterministic precision for savings in power and energy. Tim Palmer writes, "We should question whether all scientific computations need to be performed deterministically—that is, always producing the same output given the same input—and with the same high level of precision" (2015: 32). To this end, Palmer's group has been working on imprecise processing to improve accuracy in weather and climate prediction (Düben et al. 2014). The pursuit of a deterministic reality is as futile as chasing the horizon. "Energy demands and error resilience are two of the major challenges to overcome" (2). The excessive power consumption demanded of exascale computing is not worth the marginal increase it offers in projective confidence.

Yet, while this research is aware of the fallibility of deterministic modeling, it still subscribes to the capitalized emphasis on probabilistic reality: "Hence, climate prediction is inherently probabilistic" (Palmer 2015: 32). This is a bit of tautology. Yes, any kind of prediction is probabilistic, but are there any manners of thinking about climate outside of an epistemology that privileges predictive capacity? Their work is also guilty of demonizing uncertainty: "Against the cost of mitigating climate change—conceivably trillions of dollars—investing, say, [$250 million] to reduce uncertainty in climate-change projection is surely warranted" (Palmer 2014: 338).

To be clear, the aim here is not to undermine pleas for pursuing knowledge for knowledge's sake that are often associated with expensive ventures such as space exploration—outer (NASA) or inner (CERN). Quite the opposite, I am suggesting that we very much pursue knowledge for the sake of knowledge, and not for the sake of growing capital. It is important to remember that the Enlightenment was bought (Poovey 2010). Enlightenment knowledge producers pursued quantifiable observations because they led to more efficient manners of conducting work (from the physical work of extracting and accumulating resources to the cognitive work of developing formulae to solve probability equations rather than relying on repeated observation), which brings the future (the output) ever closer to the present. In its reduction to quantities, the Enlightenment tradition has greatly compressed and oversimplified reality (or demystified, as Nietzsche had it). Anthropology has been struggling to wrestle free from and recomplicate this reality.

Air-Conditioned Nightmare

As Bruno Latour wrote, "Epistemology and politics, as we now understand very well, are one and the same thing" (2004: 28). Sadly, I am not so sure we do understand this very well. The epistemology of the population that developed and utilizes temperature is one that privileges the predictive capacity of knowledge. This is because this population derives value from hypothetical futurity. Temperatures are valuable observations because they comprise data that fuel the projections on which hypothetical futurity is constructed. It is this epistemology that has facilitated a belief in perpetual accelerating growth. It is the pursuit of perpetual accelerating growth that is most implicated in the detrimental alterations of environmental conditions on this planet. Thus, it is dubious whether continuing to produce knowledge using this epistemology will be able to pacify these deleterious planetary transformations. Predicting our way out of disaster seems unlikely given that framing the world as a probabilistic output is what induced Anthropocene conditions.

Noel Castree and George Henderson have criticized this contradiction of attempting to employ solutions derived from capitalized epistemology toward efforts to mitigate climate change: "The self-same rationality that has led to species extinction, polluted oceans and melting ice sheets can … assume a new eco-friendly form—so the argument goes … The recent proposals to protect remaining stocks of valued trees, wetlands, whales, etc. by exposing them to the forces of capital accumulation may thus seem like a contradiction in terms: conservation, after all, is about stasis, non-destruction" (2014: 17). More nefariously, Nick Land once conspired, "What appears to humanity as the history of capitalism is an invasion from the future by an artificially intelligent space that must assemble itself entirely from its enemy's resources" (1993: 479). Well, we are those enemies, and the Anthropocene is that invading future.

Every population that has ever partaken in the accumulation of resources has either constructed taboos and restrictions checking perpetual, accelerating, and asymmetrical growth, or they have imploded. Today, our fortune is to reside within an exception to this pattern. Maybe we will develop measures to restrain this practice. Maybe we will implode. But thermodynamics suggests that we are not clever enough to continue being exceptional.

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