CLIMATE

Deborah R. Coen – *Yale University*

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Standard histories of climate science, such as the version published by the Intergovernmental Panel on Climate Change in 2007, have illustrated the long and distinguished pedigree of research on anthropogenic global warming.[1] Such accounts focus on lone physical scientists of the nineteenth and twentieth centuries who learned that burning fossil fuels might produce a warmer Earth but who were apparently ignored by their contemporaries. These accounts imply that the subject of climate drew minimal scientific or public concern until recently. This entry will focus instead on elements that are missing from the standard narrative. It is organized around three historical trends that have indelibly shaped the science of climate: the theorization of human difference, empire-building, and industrialization. The geographic focus is Europe and its colonies. The history presented here does not cast doubt on the scientific conclusion that human activities are causing the planet to warm. It does call into question the assumption that scientific knowledge alone is adequate to solving the climate problem. Finding a just solution to climate change means addressing historically related forms of injustice. Historical accounts of this science that ignore its ties to European colonialism and racial capitalism risk shoring up a scientific culture that perpetuates these forms of oppression. The entry begins by considering how the meaning of "climate" shifted between the early modern era and the nineteenth century in response to geographical accounts from European travelers and physicians and in conjunction with the transformation of the atmosphere into an object of laboratory study. The final section takes this history up to the present, tracing the legacies of colonialism into the era of digital climate models.

CHANGING CONCEPTS OF CLIMATE, WEATHER, AND ATMOSPHERE, 1500-1900

According to standard scientific definitions today, climate is average weather, or the long-term pattern of weather in a region. This definition came into scientific use in the late nineteenth century. This section explores where it came from and what it replaced.

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[1] Le Treut et al., "Historical Overview of Climate Change Science."

Figure 1: Aristotelian Climate Zones, from *Harmonia Macrocosmia* (1660-61). Source: University of Utah Rare Books Collection, https://collections.lib.utah.edu/ark:/87278/s6cr5r9j.

Climate as Latitude

The word climate and its cognates in other European languages derive from the Greek word for angle of incidence. In early modern Europe, climate was a synonym for latitude, varying solely with the angle of incidence of sunlight on Earth's surface. The Aristotelian natural philosophy that dominated early modern European universities held that Earth was banded by five climate zones: frigid at the poles, temperate at mid-latitudes, and torrid at the equator. (See also "Longitude.")

In medicine, however, early modern scholars made use of a more holistic concept of terrestrial conditions. They drew on the ancient Greek medical texts attributed to Hippocrates, which began to circulate in Europe in Latin translation in the sixteenth century. The Hippocratic corpus interpreted health as the result of a proper balance among the body's four internal fluids or "humors" in relation to its environs. An excess of one humor over the others could be caused by changing seasons, prevailing winds, hydrography, topography, vegetation, or other features of the body's surroundings. To restore health, a physician might prescribe a change of environment or a change in the body's exposure to the environment (for instance, by means of diet, behavior, or exercise). (See "Environment.") Hippocratic medicine spread beyond learned elites to become a popular way of thinking about health in relation to place in Europe and North America. Its influence persisted well into the nineteenth century in the field of "medical geography" and in vernacular medical cultures, even after the so-called bacteriological "revolution."[2]

American Seasons

This contrast between the breadth of factors relevant to Hippocratic medicine and the originally narrow meaning of the word climate raises an important historical question: how did climate come to mean something more complex than mere latitude? The experiences of European colonists in the Americas played a pivotal role in this process, as their observations threw into question the Ptolemaic map of climate zones.[3] For instance, the cold winters of northern New England took English settlers by surprise, since this region lies to the south of England.

What could explain these deviations from Ptolemaic geography? This puzzle spurred the collection of empirical observations in an attempt to trace the influence of the prevailing winds.[4] For much of the eighteenth century and into the nineteenth, the term "accidental factors" was used to designate the influence of winds, altitude, exposure, or proximity to water. This usage preserved the classical meaning of "climate" as dependent only on the sun's angle of incidence. For instance, in *The Climate of London* (1833), Luke Howard distinguished between the mean annual temperature within the city and London's "climate." Howard explained that the measured elevated temperatures within the city resulted from coal-burning and the built environment, while London's climate by definition depended only on the city's latitude and elevation. He took pains to show that the curve of observed mean annual temperature "in the country" followed that of solar declination, and this formed his baseline against which to measure deviations of temperature in the city. Others in the nineteenth century distinguished between "solar climate," referring to the classical definition, and "physical climate," which included the influence of "accidental factors."

However, historians have shown that Europeans' observations of the seasons in the Americas were distorted by preconceptions and biases. For example, seventeenth-century English men of science persisted in describing the lands on the far side of the Atlantic as "temperate" in order to mark them as a natural extension of England's domain.[5] At the same time, English settlers in New England called winter "the starving time" in order to highlight their tales of hardship and personal heroism. By contrast, native Americans have passed down stories of winter as a time of "survivance," a term used by Indigenous scholars to assert

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[2] Valencius, *The Health of the Country*; Nash, *Inescapable Ecologies*.

[3] Kupperman, "The Puzzle of the American Climate"; White, "Unpuzzling American Climate."

[4] White, "Unpuzzling American Climate."

[5] Zilberstein, *A Temperate Empire*.

an active presence. Thomas Wickman shows that the Wabanaki nation celebrated the advent of winter as the beginning of a cherished season, not impending doom. They leaned on knowledge passed down from generation to generation, such as identifying good winter berries and trees that would give sap to eat. They recognized that winter in fact brought enhanced opportunities for hunting, as snow made some animals easier to track, and they articulated the value of solidarity—of sharing shelter, food, and warmth—at this time of year.[6] Wickman's research is important today, as the accumulating effects of European colonialism and industrialization have already altered winter in this region. These impacts of climate change can be said to have violated the rights of Native Americans to their own culture.[7]

Experiences in the Americas also convinced Europeans that the qualities of the landscape were variable in time. Already in the late fifteenth century Christopher Columbus recorded that he knew "from experience" that rain fell more plentifully in forested regions. In the generation since the Spanish and Portuguese had taken control of the Canary Islands, Madeira, and the Azores, their destruction of the islands' forests had reduced cloud cover and rainfall. Columbus concluded that human activities could alter their surroundings in unexpected ways.

Yet most Europeans were optimistic about the possibility of anthropogenic climate change in this early sense. They optimistically reported that forest clearing had the effect of evening out the climatic extremes of the Americas. They were confident of their ability to "improve" this unfamiliar territory. Indeed, they argued on this basis that they had the God-given right to appropriate lands from Indigenous peoples who had failed to "improve" them through European forms of agriculture. Thus evidence of climatic change was less a cause for concern than a propitious sign of imperial sovereignty. On one hand, Europeans understood their bodies to be profoundly responsive to the climates to which they were exposed. At the same time, they had various means by which they felt confident of influencing that response, including diet, migration, and modifications of the landscape. As Sara Miglietti stresses, this was not climate determinism but climate "possibilism."[8]

Early Modern European Traditions of Atmospheric Knowledge

In Aristotelian natural philosophy, which dominated early modern European universities, meteorology was the study of "meteors," a category that included storms, floods,

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[6] Wickman, *Snowshoe Country*.

[7] Sheila Watt-Cloutier, the Inuit leader who first articulated climate change as a human rights issue, has insisted on "the Inuit right to culture based on ice and snow." Watt-Cloutier, *The Right to Be Cold*.

[8] Miglietti, "Mastering the Climate."

earthquakes, and comets. In this sense, the subject matter of Aristotelian meteorology was broader than the discipline of meteorology today. "Meteors" included all phenomena that were understood to originate in the "sublunar" realm, between Earth and Moon. The sublunar realm was the domain in which nature was continuously in flux, aging and decaying, as opposed to the unchanging heavens. Early modern natural philosophers explained meteors in this sense as produced by the "exhalations" of the earth. These exhalations could be hot and flammable, igniting in the atmosphere, or they could be cold and watery, falling back down to earth.

Aristotelian meteorology was not an observational science in the modern sense. Learned men believed that causal explanations must derive from knowledge of the common course of nature, not from experience of particular instances. By contrast, an observational and predictive form of weather knowledge flourished not at universities but at princely courts. Astrometeorology was the practice of forecasting weather on the basis of the positions of celestial bodies. This was most likely the motivation behind the observations of weather that were occasionally recorded in the margins of almanacs and ephemerides in the early Middle Ages. On the basis of such observations, predictions could be tested and discrepancies recorded between predicted and actual weather.

Another early modern tradition of atmospheric knowledge was cosmography. Blending observations of humans and their environments, cosmography was often practiced by navigators and took a narrative form. (See "Cosmography and Transatlantic Voyages.") Cosmography declined as a genre towards the end of the sixteenth century, as the mathematical disciplines of cartography, astronomy, geodesy, and hydrography began to be practiced separately from the descriptive enterprises of natural history and ethnography.

The term "atmosphere" originated in the seventeenth century to designate the height reached by rising exhalations from the earth, a measurement that was important to Muslim scholars for calculating the time of the setting of the sun and thus the call to prayer.[9]

Medical Meteorology

In the eighteenth century, the era when Europeans proclaimed themselves enlightened, European scholars took the study of the atmosphere in new empirical directions. The eighteenth century saw the rise of a new field of "medical meteorology" as well as laboratory experiments on varieties of "airs." (See "Laboratory.")

At the same time as Europeans were charting health and disease in relation to atmospheric conditions across the Americas, smaller-scale investigations in Europe's burgeoning metropoles began to note differences between urban and rural air and between outdoor

[9] Martin, "The Invention of Atmosphere."

and indoor air. In London, complaints about the noxious effects of burning coal for heating date back to the early fourteenth century. In 1661, John Evelyn, a founding member of the Royal Society, warned Londoners about the danger of coal pollution in his treatise *Fumifugium*.[10] By the middle of the eighteenth century, medical practitioners increasingly expressed concern about the "artificial climates" of homes and workplaces.

An influential voice in medical meteorology was the physician George Cheyne (1672-1743), based in London and the spa town of Bath. Following the Hippocratic tradition, Cheyne saw the atmosphere as a key factor for maintaining health. He borrowed Descartes' conception of the body as a hydraulic machine, reasoning that illness resulted from the blockage of fluid flow. Blockages could be cleared by exposure to air of the proper temperature and humidity. He instructed patients to "take care what kind of air it is they sleep and watch, breathe and live in, and are perpetually receiving into the most intimate Union with the principles of Life." As Vladimir Janković observes, this was a call for constant vigilance: thoughtless breathing could be fatal. This meteorological turn was one way for physicians to extend their authority in an era when the medical marketplace was crowded with healers and there was no accreditation system to distinguish among them. Elite physicians were claiming that any aspect of one's surroundings could potentially jeopardize one's health and that they alone could identify those threats.[11] This regime of attention gave rise to a new definition of climate as—in the words of the explorer Alexander von Humboldt in 1845—"all changes of the atmosphere which directly affect our organs."[12]

Laboratory Airs

The eighteenth-century science of "pneumatic chemistry," i.e. the chemistry of gases, transformed the meaning of meteorology. If Aristotelian meteorology was the study of the phenomena of the sublunary realm, the pneumatic chemists showed that atmospheric phenomena could be reproduced in a laboratory. Pneumatic chemistry brought meteorology indoors, severed its connection to particular places, and subjected the atmosphere to experimentation.[13] How did this transformation come about?

Alchemists in early modern Europe were familiar with a variety of (what we would today call) gases. Their experiments occasionally generated one that stank like rotten eggs (hydrogen sulfide) and another made their eyes burn (ammonia). Yet they interpreted these phenomena not as a diffuse state of matter but rather as forms of "impure air." Air was one

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[10] Cavert, *The Smoke of London*.

[11] Janković, *Confronting the Climate*.

[12] Humboldt, *Kosmos*.

[13] Janković, *Reading the Skies*.

of the four Aristotelian elements, basic and irreducible, varying only as it combined with other elements (earth, fire, water). In this respect, air was thought to exist along a spectrum from pure to impure. Differences between airs were assumed to result from contamination by varieties of mineral dust. Far from having any interest in studying the airs that appeared in the course of their experiments, alchemists simply wanted to avoid the disasters that resulted when these "wild spirits" were trapped inside their glass vessels. To alchemists, airs were hazards, not objects of investigation.[14]

A widespread motivation for closer attention to these "spirits" came from the medical market for healing spas and mineral waters.[15] Physicians and chemists speculated that mineral waters derived their therapeutic properties from subterranean "exhalations," which they sought to release and observe. Doing so required new tools. These were instruments that made it possible to manipulate airs and measure their variable properties. Air pumps allowed experimenters to modify the air's pressure (or "spring" in the language of the day). Pneumatic troughs could funnel air from one vessel to another. Thermometers and barometers and a variety of other meters and scopes enabled quantitative comparisons between samples of air. Carried aboard the ships of scientific explorers and on the backs of guides they hired, meteorological instruments became symbols of enlightenment.[16] However, in their propensity to malfunction in new environments or break in transit, instruments also spoke of the vulnerabilities of colonial projects.[17]

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[14] Levere, *Transforming Matter*, chapter 5.

[15] Boantza and Tomory, "The 'Subtile Aereal Spirit of Fountains.'"

[16] Cruikshank, *Do Glaciers Listen?*, 143.

[17] Schaffer, "Easily Cracked."

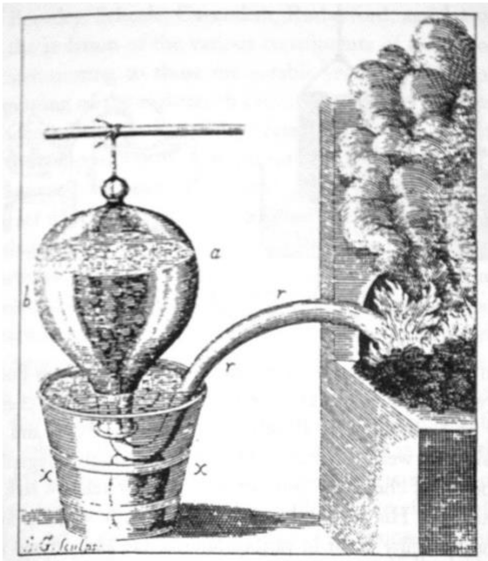

Figure 2: Stephen Hales' pneumatic trough (1727). Source: Wikimedia Commons.

By the late eighteenth century, barometers and thermometers were proudly displayed in bourgeois homes. Personal diaries from this period often include daily instrumental observations of the weather. According to Jan Golinski, these habits gave rise to a modern concept of weather in the sense of the continuity and regularity of atmospheric phenomena.[18] Only in the nineteenth century did *weather* in this sense replace the study of storms, earthquakes, thunder, and other spectacular meteors as the research object of "meteorology." This quantifiable concept of weather, along with disciplined habits of observation, were the pre-condition for the emergence in the nineteenth century of the modern concept of climate as average weather.

CLIMATE AND INDUSTRIALIZATION, 1800-1900

Standard histories of the science of global warming begin in the nineteenth century with studies of the chemical properties of Earth's atmosphere. By the 1860s scientists had laboratory evidence that coal gas (carbon dioxide) could increase the atmosphere's insulating effect on Earth's surface. In a Romantic vein, the physicist John Tyndall wrote that without this effect, "The warmth of our fields and gardens would pour itself unrequited into space, and the sun would rise upon an island held fast in the iron grip of frost."[19] In the 1890s, the chemist Svante Arrhenius conceived the idea that the warming effect of carbon dioxide could be magnified by what we would today call positive feedbacks. A rise in air temperature

[18] Golinski, *British Weather and the Climate of Enlightenment*.

[19] Tyndall, "On radiation through the earth's atmosphere," 204-5.

would cause the atmosphere to hold more moisture; since water vapor is opaque to heat rays, more moisture in the atmosphere would amplify the warming trend. However, as an inhabitant of a cold northern country, Arrhenius was unconcerned. He imagined that industrialization would lead to "more equable and better climates, especially as regards the colder regions of the earth."[20] No one in his day imagined the scale of future fossil-fuel use. As industrialization accelerated in the twentieth century, scientists reasoned that the oceans would absorb excess carbon dioxide.

What this story leaves out is the intimate connection between scientists' interest in the heat-trapping properties of gases and their own investment in industrialization—in the very processes that were beginning to remake Earth's atmosphere. As Joshua Howe notes, the research of celebrated physical scientists like Tyndall and Arrhenius was not about climate for its own sake.[21] Indeed, those who studied climate in the nineteenth century worked in fields like medicine, agriculture, and geography. By contrast, these physical scientists had practical reasons to investigate what Tyndall called "radiant heat"—the mysterious invisible rays that scientists now identify as the infrared range of the electromagnetic spectrum. The question of the properties of heat arose from the historical shift from animal and hydropower to steam-powered production and transportation. Tyndall's research addressed an urgent business question for industrialists of his day: how much coal would produce how much heat, and how much heat would produce how much motion?[22] In this context, observations about Earth's climate were digressions, buried within discussions focused on the lucrative new science of thermodynamics, the physics of heat and energy.

By the same token, industrial culture clouded scientists' interpretation of their findings. Late nineteenth-century scientists tended to view industrialization as part of God's plan for the universe. They understood the law of the conservation of energy to mean that human industry was part of a cosmic cycle of regeneration. As Tyndall put it, "the flux of power is eternally the same. It rolls in music through the ages, and all terresterial energy, - the manifestations of life, as well as the display of phenomena, are but the modulations of its rhythm."[23] What this vision elides is that the "rhythm" of fossil fuels is utterly different than the time scales for renewal of the other power sources familiar in the nineteenth century (wind, water, and animal).[24] On the scale of human history, burning coal is effectively an irreversible process.

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[20] Arrhenius, *Worlds in the Making*, 63.

[21] Howe, "Getting Past the Greenhouse."

[22] Smith, *The Science of Energy*.

[23] Tyndall, *Heat Considered as a Mode of Motion*, 449.

[24] MacDuffie, *Victorian Literature, Energy, and the Ecological Imagination*.

In this respect, it's telling that Arrhenius won a Nobel Prize in 1903, but not for his theory of the greenhouse effect. Rather he won the prize in chemistry for his explanation of the process of electrolytic dissociation, which had a wide range of applications in the chemical industry at the time. Indeed, Arrhenius helped to launch one of the major chemical manufacturing companies in Scandinavia.

Similarly, Europe's obsession with steam power in the nineteenth century inspired the equations of atmospheric motion that still govern climate models today. It was then that scientists like Hermann von Helmholtz and Julius Hann began to liken the atmosphere to a steam engine. They applied the principle of the motive power of heat to explain phenomena like mountain winds and cyclones. Over the course of the next 50 years, researchers worked out the basic equations describing the flow of atmospheric mass, energy, and momentum. However, as the meteorologist Lewis Fry Richardson observed in the 1920s, these equations were so complex that computing a single day's forecast would have required a stadium full of mathematicians.[25]

Nineteenth-century scientists also depended on extractive industries for their knowledge of the *history* of Earth's climate. In the nineteenth century, evidence began to accumulate that the planet's climate had undergone radical transformations in the deep past. Much of this evidence came from fossils. Fossilized plants, for instance, showed that tropical vegetation had once thrived in temperate England. How did men of science obtain these fossils? Often they were turned up accidentally as miners dug for coal and other minerals. After all, what is coal but fossilized plants? Even as the combustion of coal was beginning to transform Earth's atmosphere, it was also a driving force behind the sciences that would elucidate that transformation.[26] Otherwise put, the origin of the science of global warming lies in part in scientists' personal and professional investments in industrial capitalism.

CLIMATE AND SCIENTIFIC RACISM, 1600-1900

The Intergovernmental Panel on Climate Change's history of climate science focuses on the impacts of human activities on climate; it says nothing about the long history of research into the impacts of climate on human bodies and minds. It therefore ignores the tight historical relationship between early modern climate studies and scientific racism. From the seventeenth century through the nineteenth, studies of climate regularly drew conclusions about the nature of human difference. At least since the ancient Greeks, Europeans often explained human difference as a result of climatic exposure. The Hippocratic tradition in medicine attributed skin color as well as other physical and cultural traits to the influence of environmental conditions. In the nineteenth century, race came to be understood as a

[25] Friedman, *Appropriating the Weather*.

[26] Anthony, "Mining as the Working World."

biological, inborn trait—yet theorists of race continued to insist that different races were suited to different climates.

Climate Theory

Historians use the phrase "climate theory" to refer to the idea that differences between human populations can be ascribed to the effects of contrasting climates. Climate theory was popular in Europe from the sixteenth century into the nineteenth. For instance, sixteenth-century Europeans circulated accounts of a race of giants in Patagonia, whose enormous stature was said to be a result of the cold climate. Europeans wondered whether they too might produce "monstrous" offspring if they were to resettle in such an environment.[27]

In keeping with the ancient division of the world into five climate zones, climate theory taught that skin color varied with latitude. As Europeans traveled across Africa, Asia, and the Americas, they reported observations that threw this theory into question. With the growth of the transatlantic slave trade, Europeans began to interrogate the climate theory of race more closely. They turned to science to justify their brutal treatment of African people as commodities. At the Royal Society in London, where several fellows had a financial stake in the slave trade, researchers began to seek anatomical evidence that race was hereditary rather than an effect of climate.[28] By the eighteenth century, men of science were arguing that humans could be grouped into a handful of hard and fast racial categories. Adherents of "polygenism," such as the *philosophe* Voltaire, went so far as to claim that different races were unrelated to each other—that they were products of separate acts of divine creation.

Nonetheless, some eighteenth-century Europeans recognized how arbitrary these racial divisions were. One was George Louis Leclerc, Comte de Buffon, who was a stalwart and influential defender of the climate theory. Buffon pointed out—much as geneticists do today—that there was as much variation within any of the supposed human "races" as between them. Buffon reasoned that humans must have originally resembled each other, given their common descent. Calling on his own theory of Earth's history, Buffon ascribed human differences to "a train of external and accidental causes" operating on a geological time scale. Against those who pointed to the apparent fixity of race among migrants, Buffon argued that the effects of climate worked exceedingly gradually, over the course of generations. He envisioned that future migrations and shifting customs would cause differences of appearance between human groups to "gradually disappear, or, at least, that they will differ from what they are at present, if the causes which produced them should

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[27] Davies, *Renaissance Ethnography and the Invention of the Human*, 171-81.

[28] Malcolmson, *Studies of Skin Color in the Early Royal Society*; on the history of climate theory and race science in eighteenth-century France, see Curran, *The Anatomy of Blackness*.

cease, or if their operation should be varied by other circumstances and combinations." Buffon thus held that differences among human groups were contingent and fluid, but he did not conclude that all humans were equal. He insisted that white Europeans were the original type of human, and all other populations were "degenerate" deviations from that ideal. Again, theories of climate were inextricable from theories of human difference.[29]

Acclimatization

Buffon's *Natural History* was inspired in part by his work overseeing the transformation of the royal garden in Paris: from an early modern medicinal garden to a research-oriented botanical garden that specialized in the study of "acclimatization," the science of transplanting organisms to a foreign climate. Historians have described acclimatization as the quintessential colonial science. In the eighteenth century, the Jardin des Plantes became the central storehouse and testing ground for France's experiments on plants from its colonies. There was no guarantee of success, since most Christians believed that God had created each living thing to be uniquely adapted to its milieu. As Emma Spary writes, "The eighteenth-century garden was thus a site at which the interaction of nature and culture could be closely observed--the place of investigation into the relative importance of natural powers and social intervention in remodeling the living being, and into the limits of such reshaping." Buffon expressed ambivalence about this project of domesticating new species. Might it not lead to the "degeneration" rather than "improvement" of the species?

[29] Curran, *Anatomy of Blackness*; Spary, "Climate Change and Creolization."

Figure 3: François Aubertin's engraving of the Jardin des Plantes in Paris emphasized Buffon's greenhouses. Source: Les Musées de la Ville de Paris, online collections.

Buffon's theory of the degeneration of species under unfavorable climatic circumstances was an argument for colonization and racial hierarchy, one that found echo among climate researchers into the twentieth century.[30] Buffon was convinced that, in the Americas, nature existed in a state of degeneration. In his view, it was the job of Europeans to restore the New World to its "original" state. This program inspired empirical research: what were the meteorological conditions conducive to humanity's original, ideal state, and how could they be engineered? For instance, Buffon argued that the spread of European agriculture would counteract the "degeneration" of climate in the Americas. We can hear echoes of Buffon

[30] Livingstone, "Changing Climate, Human Evolution, and the Revival of Environmental Determinism"; Fleming, *Historical Perspectives on Climate Change*, pp. 95-106.

today among proponents of geoengineering, who believe they have the means of maintaining Earth's climate at a familiar Holocene norm.

Tropical Risk

From the sixteenth century, Europeans used the idea of "the tropics" as a way to contrast Europe with regions of the world that otherwise had little in common. The notion of the tropics connected regions as different as the Caribbean, Southeast Asia, West Africa, and Northern Australia. By the early nineteenth century, the word tropical would have evoked heat, lethargy, and organic excess.[31] Excess connoted not only lush vegetation but also the stereotype of sexual over-indulgence. According to eighteenth-century Swiss physician Albrecht von Haller, girls in the tropics reached sexual maturity years before they would in Europe. European colonists used this emerging distinction between tropical and temperate climes to claim a natural division between the centers and peripheries of their expanding empires.

Medical experts played a central role in advancing the idea of the tropics. They were increasingly called on to advise colonists on the threats of such devastating illnesses as yellow fever, cholera, and malaria. In a Hippocratic framework, these diseases were explained as the result of bad air or miasmas. Upon arrival in the tropics, white bodies were said to need time for "seasoning" (the word for acclimatization when applied to humans). By the 1780s "tropical illnesses" was a recognized medical specialty.[32]

These specialists turned the climate theory on its head. Instead of explaining race in terms of climate, they began to invoke race as an etiological factor for climatically specific diseases. According to Suman Seth, late eighteenth-century British physicians used race to explain illness in two equally dubious ways. They argued that black skin provided protection against the ills of a tropical climate, and they theorized that Black people were less prone to pain. Both claims were desperate attempts to excuse the violence of slavery in the face of the growing abolition movement.[33]

For elite white men, demonstrating immunity to tropical illness was a necessary step towards building a career in Europe's colonies. After a bout with yellow fever, a well-born white man possessed what historian Kathryn Olivarius terms "immunocapital." He was now a prime candidate to profit from the global trade in cotton, sugar, and human beings. Those who managed to survive their seasoning refused to admit that they had been lucky. Instead, they identified as members of a superior class. At the same time, they characterized white women

[31] Stepan, *Picturing Tropical Nature*.

[32] Harrison, "'The Tender Frame of Man.'"

[33] Seth, *Difference and Disease*.

as uniquely threatened by tropical climates. Physicians warned that the fates of settler colonies hinged on protecting the wombs of white women from these debilitating effects. In doing so, they propagated the myth of a feminized white climate vulnerability that required non-white labor to safeguard it.[34]

Figure 4: "The Torrid Zone, or, Blessings of Jamaica," after Abraham James, centers the colonial experience as one at perpetual risk from the effects of climate, particularly yellow fever. Source: Yale University Library Online Exhibitions.

This racialized theory of acclimatization structured subsequent debates over colonization. For instance, it was at the center of late nineteenth-century disputes over resettlement plans for both African North Americans and Jewish Eastern Europeans. As Ikuko Asaka shows, plans to resettle North Americans of African descent in West Africa rested on white abolitionists' belief that Black bodies were innately suited to a "tropical" environment. Black physicians and abolitionists like James McCune Smith disputed this theory. McCune Smith argued that Black and white Americans shared "the physical character and the intellectual being of the American people," benefiting from their common exposure to "a climate the

[34] Olivarius, *Necropolis*; Venkat, "Through a Glass Darkly"; Morgan, "Health, Hearth and Empire."

most favorable for physical and mental development."[35] Similar questions about climate and race structured late nineteenth-century debates over Jewish resettlement. As Netta Cohen argues, the ambiguity of Jewish racial identity sowed conflicting opinions about their suitability to found a colony in Palestine versus East Africa.[36]

By the mid-nineteenth century, the concept of "risk" provided a new framework for reasoning about the dangers posed by different climates. Until then, the idea of risk as a future contingency that could be bought and sold was familiar only to those dealing in marine insurance.[37] Nineteenth-century insurance companies put pressure on ordinary people to insure themselves against misfortunes like illness, drought, and hail, making risk a household word. Research by James Kneale and Sam Randalls shows that life insurance companies raised premiums for those traveling to the tropics. What emerged in the nineteenth century, then, was a geography of climate risk mapped by variations in insurance premiums. Informed in part by climate science, British life insurance for residence abroad "helped constitute imperial subjects and colonial projects, and was not simply a matter of actuarial calculation but remained an intuitive and affective technology securing life against the risk of 'the white man's grave.'"[38]

CLIMATE AND EMPIRE, 1800-1914

This section explores how European empire-building shaped climate science and how climate science in turn served to legitimate imperialism. There is now a large body of scholarship showing that the celebrated discoveries of metropolitan elites often rested on knowledge appropriated from colonial naturalists and Indigenous informers.[39] More recently, historians of science have turned from documenting the role of local "knowledge brokers" to studying the natural knowledge of local and Indigenous communities on their own terms, as dynamic and evolving knowledge systems. Pathbreaking for histories of climate science in this respect was Julie Cruikshank's *Do Glacier's Listen?* (2006), which draws on historical anthropological sources and oral histories to document the mutual influence of Inuit and Euro-American thinking about environmental change. Historians have also begun to study the relationship between climate science and "informal empire," referring to power exerted through military or commercial activity rather than direct governance. In this vein, Andrew Stuhl tracks the linked development of Euro-American science in the Arctic and the encroachment of extractive industries like trapping, whaling, and oil drilling. Similarly, Jamie

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35 Asaka, *Tropical Freedom*.

36 Cohen, "Shades of White."

37 Levy, *Freaks of Fortune.*

38 Kneale and Randalls, "Making Climate Risks Work," 845.

39 Schaffer et al., eds., *The Brokered World*.

Pietruska documents the rise of interest in long-term weather forecasting among US scientists, connecting it to schemes for US economic and political dominance in the western Caribbean.[40]

Seeing Climate Like a Colonial State

Imperial expansion took a devastating toll on landscapes as well as on their human inhabitants. Colonization disrupted ecosystems in ways that sometimes became apparent within one lifetime. In the 1990s, Richard Grove argued that the origins of modern environmentalism lie in the responses of eighteenth-century colonial naturalists to the environmental degradation they witnessed on Pacific islands and for which they knew Europeans to be responsible.[41] More recently, Locher and Fressoz have characterized Grove's efforts to locate the historical origin of "environmental consciousness" as fruitless. Instead, they propose, the burning historical question is how and why modern societies have chosen to continue to tamper with Earth's climate in full knowledge of their destructive impact. Colonialism and neo-colonialism are certainly part of the answer. Many of the toxic consequences of modern industry have been displaced to poorer regions and distant nations, out of sight of the wealthy and powerful. What's more, while climate change is a global problem, its impacts are often most devastating to the same populations that suffered under European colonialism.

For this reason, some historians propose that the Anthropocene—as the term for the geological epoch when humanity became a force of geophysical change—can more accurately be termed the Plantationocene. (See "Anthropocene.") Beginning in the early eighteenth century, Europeans transformed large parts of the Americas and then regions of Asia and Africa into this new type of socio-ecological system, founded on coerced labor, racial segregation, and monocropping. Plantations required endless scientific, technological, and medical innovation, as well as perpetual violence, in order to maintain such a fundamentally unsustainable system. Propping up plantation economies was a motivation for research on the relationship between climate and vegetation well into the twentieth century.[42]

However misguided, Grove's thesis about the onset of an "environmental consciousness" has inspired important research on the history of climate science in colonial contexts. In particular, Grove drew historians' attention to the theory of "desiccation," the idea that deforestation reduces rainfall and that, conversely, planting trees brings climatic benefits.

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[40] Stuhl, *Unfreezing the Arctic*; Pietruska, "Hurricanes, Crops, and Capital."

[41] Grove, *Green Imperialism*.

[42] Mitman, "Reflections on the Plantationocene"; McCook, "The Neo-Columbian Exchange"; Lucier, "Climate Conscious."

This theory initially rested on anecdotal evidence, and research at experimental forest stations in the late nineteenth century was inconclusive. Given this uncertainty, the "forest-climate question" was a topic of fierce debate in many parts of the world in the nineteenth century. Scientists, foresters, and laypeople clashed over claims that human activity had caused the expansion of arid lands on the Central Asian plains, the South American pampas, and New Zealand.[43] This early concern about anthropogenic climate change was part of what James Beattie calls the "environmental anxiety of empire," meaning "the concerns generated when environments did not conform to European preconceptions about their natural productivity or when colonization set in train unintended environmental consequences that endangered everything from European health and military power to agricultural development and social relations."[44] As historians like Diana Davis and Ravi Rajan have demonstrated, French and British colonial officials used the desiccation theory to justify their seizure of lands in Africa and South Asia on the pretext that Indigenous communities had mismanaged forests. Imperial oversight was necessary to protect or restore the climate, they claimed.[45]

By 1900, many professional meteorologists had rejected desiccation theory. It was revived, however, in the 1970s by the atmospheric physicist Jule Charney in the midst of a disastrous drought in the Sahel region of Africa. Charney was able to provide the first physical model of feedback between vegetation and the atmosphere. Today, ecologists argue that this relationship is essential to predicting Earth's future climate, and activists promote afforestation as an important "nature-based solution" to climate change. Nonetheless, the legacy of colonialism lives on in projects to manage forests without the consent of their Indigenous stewards.[46]

Scaling

No less significant for the history of environmental science and politics was the scale of empire in the nineteenth century. Because overseas empires depended for navigation on forecasts of storms and winds, meteorology flourished in particular in London and Paris, as well as in colonial ports like Bombay, Madras, Hong Kong, and Singapore. In the course of the nineteenth century, both the British and the French empires consolidated what had been a loose network of intermittent weather informants into a modern meteorological network.

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[43] Moon, *The Plough That Broke the Steppe*; Cushman, "Humboldtian Science"; Beattie, "Environmental Anxiety in New Zealand."

[44] Beattie, *Empire and Environmental Anxiety*, 6.

[45] Davis, *Resurrecting the Granary of Rome*; Rajan, *Modernizing Nature*.

[46] Bonan et al., "Rethinking the Earth in Earth Science."

Military officers and medical professionals played key roles, but so too did local and Indigenous workers.[47]

These networks of information exchange laid the basis for the global science of the late twentieth century and have been linked suggestively to the emergence of a "planetary consciousness." By virtue of their access to simultaneous weather records on multiple continents, British scientists were able to spot correlations between anomalous changes in air pressure at locations on opposite sides of the earth. They found correlations between periods of drought in India and Australia. The first person to analyze these so-called "teleconnections" with mathematical rigor was the English physicist Gilbert Walker. Walker worked in the Indian Meteorological Department beginning in 1904, studying in particular statistics on the monsoon. In 1924, Walker observed that unusually high pressure over the Azores in the North Atlantic correlates with unusually low pressure over Iceland and vice versa in a see-saw pattern. This North Atlantic Oscillation is associated with characteristic climatic patterns in Europe, North America, and the Middle East, so that the phenomenon serves today as a tool for predicting climate at a seasonal time scale—a tool that can be of great value to farmers, water managers, and public health experts.[48]

And yet for much of the nineteenth century, it was unclear how to piece together atmospheric data collected at disparate sites across the British Empire's scattered territories. Here we see an advantage held by continental or contiguous empires, especially those ruled by the Habsburg, Romanov, Ottoman, and Qing dynasties. Climatology was also a subject of research at non-governmental observatories founded by Jesuits in Asia, Africa, Latin America, and the Middle East, although historians have had more to say about their contributions to storm-forecasting than to climatology.[49] In the late Habsburg Monarchy, nineteenth-century scientists worked closely with government ministries of agriculture, trade, and health to produce practical information about the length of seasons, the likelihood of frost, the navigability of waterways and mountain passes, and the association of climatic conditions with dominant illnesses. These practical goals were reflected in the focus on economically and physiologically relevant measurements, such as the distribution of rainfall and the duration of sunshine, as well as in the introduction of new variables, such as the average number of days with rain, a number crucial to farmers, or the "wintriness" of a region (defined, for the purposes of the winter tourism industry, as the number of snow days as a fraction of total precipitation days). The unique political structure of the Habsburg Monarchy,

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[47] Anderson, *Predicting the Weather*; Locher, *Le savant et la tempête*; Amrith, *Unruly Waters*; Williamson, "Just Doing Their Job"; Mercer, "Atmospheric Archives."

[48] Morgan, "Prophecy and Prediction"; Davis, *Late Victorian Holocausts*.

[49] Udías, "Jesuits' Contribution to Meteorology."

with its multiple levels of governance, set the conditions for practices of "scaling" that generated a new understanding of climate *dynamics*.[50]

Settler Cultures

Scientific ideas about climate in turn influenced settler colonial cultures, including their clothing, food, and architecture. As Sarah Pickman's research shows, nineteenth-century British colonists criticized Indigenous inhabitants of colonial lands for building homes and wearing clothing that failed to insulate them properly from their environment. Fashion and architecture designed for colonists, by contrast, were intended to act as impervious shields. British manufacturers used scientific explorers as spokesmen for their lines of weather-resistant outerwear.[51] Yet plentiful evidence suggested that locals knew better. For instance, hurricanes destroyed the stately homes that British colonists built in the Caribbean.[52] In mandate Palestine, Jewish settlers likewise attempted to adapt to the desert climate by following the dictates of science. In keeping with medical advice of the day, they took to sunbathing to prevent tuberculosis and added spices to their meals to avoid indigestion.[53] In many parts of the world, then, European colonists used food, clothing, and architecture to define a "civilized" approach to climate. They said much less about the technologies and tactics they learned from locals themselves. Wickman, for instance, argues that Europeans learned to survive the harsh winters of New England by imitating the technologies of Native Americans, particularly their use of snowshoes.[54]

When colonists despaired of adapting to a new climate, they often developed grandiose ambitions to transform it instead. In this sense, colonialism gave rise to the first schemes of "geo-engineering." Philipp Lehmann has shown the surprisingly long life of proposals to make Africa more susceptible to European-style agriculture by partially draining the Mediterranean and creating an artificial sea in the Sahara—an idea first floated by the French empire in the mid-nineteenth century and revived by the Nazis in the twentieth. Lehmann's research constitutes a cautionary tale. Like the historical engineering schemes he chronicles, today's proposals to seed the atmosphere with aerosols or float mirrors above the earth would benefit the wealthy and powerful, enabling them to continue to behave in ecologically

[50] Coen, *Climate in Motion*.

[51] Pickman, "The Right Stuff."

[52] Mulcahy, *Hurricanes and Society*.

[53] Helman, "European Jews in the Levant Heat."

[54] Wickman, *Snowshoe Country*.

irresponsible ways, while failing to address the resource inequities that are themselves a legacy of colonialism.[55]

GLOBAL MODELS, GLOBAL INEQUALITY: 1950-2000

The possibility of human-induced planetary warming generated little concern among scientists until the 1970s. Two new forms of evidence came together in that decade to convince most atmospheric scientists of the reality and danger of what they called “the carbon-dioxide problem”: 1) realistic computer models of the response of Earth’s climate to additional carbon dioxide and 2) samples of ice reaching back tens of thousands of years that gave detailed evidence of rapid shifts in Earth’s climate in the past. However, as this section emphasizes, the geopolitics of the Cold War and decolonization have created unequal access to the fruits of the new science of climate change.

With the development of computers for military use in World War Two, a small cadre of elite scientists finally had a means of calculating numerical solutions to the equations of atmospheric motion. In 1948, scientists began to test the power of the US Army’s ENIAC computer to produce a short-term weather forecast. Within two years they had demonstrated that the computer could roughly predict the largest-scale features of the next day’s weather. Meteorologists adapted this novel tool to simulate the evolution of large-scale weather over the course of a month, creating the first “general circulation models” of Earth’s climate in 1955. In 1967, physicists at Princeton used such a model to demonstrate that pumping carbon dioxide into the atmosphere could alter Earth’s climate and do so at a catastrophic pace. This conclusion was bolstered by new atmospheric measurements showing that carbon-dioxide levels were rising steeply. Although these models did not yet account for Earth’s oceans, oceanographers had since disproved the theory that the oceans would absorb excess carbon dioxide.[56]

Global models required global data as input. The International Geophysical Year (IGY) of 1957-58 helped to lay the infrastructure that would produce this data, including polar and high-altitude atmospheric observations.[57] Other research sponsored by the IGY allowed scientists to dig deep into ice sheets and sea beds around the world. These long “cores” contained frozen gas and sediments that provided the first indisputable evidence of rapid climatic shifts in Earth’s history.[58] As we’ve seen, scientists had long debated the reality of

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[55] Lehmann, *Desert Edens*; see too Fleming, *Fixing the Sky*; Harper, *Make It Rain*.

[56] Edwards, *A Vast Machine*; Fleming, *Inventing Atmospheric Science*; Weart, *The Discovery of Global Warming*.

[57] Edwards, *A Vast Machine*.

[58] Weart, *Discovery of Global Warming*.

climate change on the scale of a region. The insight that such swings could occur on the scale of the planet as a whole was a revelation.

Although scientists typically remember the IGY as a high point of international scientific collaboration, historical research indicates other motives. The IGY had a "dual, scientific-cum-military" agenda to produce data in highly secretive fields of Cold War-era military significance, including atmospheric and ocean science.[59] For scientists from the global South who favored non-alignment, there was little room to maneuver. Rejecting calls to make global data widely accessible, each superpower took control of a major World Data Center, with a third center divided among Western Europe, Japan, and Australia.[60]

In 1979, several of the world's leading atmospheric scientists published a definitive statement that the rising level of carbon dioxide in the atmosphere was likely to cause significant planetary warming. Their predictions were right in line with what we are currently experiencing, and overall predictions for the future have changed little since then. In 1988 the United Nations formed the Intergovernmental Panel on Climate Change (IPCC), which was charged with assessing the scientific research and issuing "policy-relevant" but *not* "policy-prescriptive" conclusions. The initial structure of the IPCC prioritized the research of physical scientists and economists from wealthy countries. It sidelined many other groups with knowledge essential to the issue, including interpretive social scientists, Global-South scientists, and Indigenous communities. Nonetheless, a central goal of the IPCC from the start was to forge a consensus that would transcend the divide between wealthy countries and the "developing world." Understandably, countries that had industrialized later felt they were not responsible for the problem and yet were at risk from its effects. The IPCC's First Assessment Report, published in 1990, helped motivate the UN Framework Convention on Climate Change (UNFCCC), signed in 1992. This treaty committed wealthy countries to reduce the consumption of fossil fuels below "dangerous" levels and to aid "vulnerable" countries to adapt to the impacts of climate change.

Despite these warnings and promises, fossil fuel use continued to grow. The 1980s saw mounting resistance to fossil fuel reductions from the Reagan and Thatcher administrations. Historians of science have offered multiple, complementary explanations to account for the disconnect between science and policy. A crucial factor was the disinformation campaign led by the fossil fuel industry, which created the appearance of doubt when scientists were in fact in agreement. Historians Naomi Oreskes and Erik Conway have shown that oil executives employed tactics developed by the tobacco industry in its efforts to discredit cancer researchers. They hired "doubt-mongering" scientists who viewed environmental regulation, like the regulation of tobacco, as part of an anti-capitalist conspiracy.[61] Another obstacle to

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[59] Aronova, "Geophysical Datascapes of the Cold War."

[60] Simone Turchetti, "Decolonize the IGY!"

[61] Oreskes and Conway, *Merchants of Doubt*.

effective policy-making stemmed from the norms of the scientific community. Many scientists feared that advocating for specific policies would jeopardize their reputations for objectivity and impartiality. For instance, when the young atmospheric scientist Steven Schneider raised alarm about global warming in a popular 1976 book, a senior scientist warned publicly that he was taking "his professional life in his hands."[62]

Scholars have argued that the denialist campaign swayed the course of climate research, influencing the topics that scientists prioritized and the methods and language they used to address them.[63] In the U.S. in the 1980s, climate scientists and activists rarely talked publicly about how to prepare for warming that was already unavoidable. They worried that the study of adaptation strategies posed a "moral hazard," as if acknowledging the need to adapt to a changing climate would detract from the will to reduce fossil fuels. Instead, U.S. scientists concentrated on efforts to refine predictions of the global average temperature change to be expected as the concentration of greenhouse gases in the atmosphere rose.[64]

But global averages were of little use to planners and policy-makers. Studies of the projected human-scale impacts of global warming began to gain momentum in Europe in the wake of the Brundtland Report of 1987, which linked environmental degradation to the plight of poor populations in the global South. In the 2000s, some researchers began to involve local communities in the design of climate adaptation research, championing a new paradigm of "usable science."[65]

Over the past 40 years, climate models have gained what scientists call "predictive skill," often measured by their ability to simulate the known history of Earth's climate over the twentieth century. In the 1980s, scientists developed coupled ocean-atmosphere models, followed by "Earth system" models that include elements of the land surface as well. Newer models constitute improvements in terms of their resolution (the finer spatial resolution of their output, now roughly 20 km), and their complexity (how many different components of the Earth system they include).[66] However, the knowledge of future climate that these models produce is spatially uneven. Infrastructure for collecting meteorological data is relatively sparse in much of Africa, southeast Asia, and small Pacific island states. The IPCC's Sixth Assessment Report confirms that vulnerability to climate change is worst in places least responsible for burning fossil fuels, places that have suffered the violence of colonialism and racism for centuries—bearing the burdens of industrial capitalism without sharing in its

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[62] Howe, *Behind the Curve*, 83.

[63] Lewendowsky et al., "Seepage."

[64] Orlove, "The Concept of Adaptation."

[65] Noel Castree, "Global Environmental Change and the New Social Contract for Research"; Coen, "A Brief History of Usable Climate Science."

[66] Edwards, "History of Climate Modeling."

economic benefits. Because wealthy countries have not invested adequately in observing networks in these regions nor shared data freely, the populations most vulnerable to climate change now suffer from an information deficit.[67] Only in the past few years has the World Meteorological Organization begun to address this problem by supporting open data and capacity-building for the global South.[68] Wealthy countries have the scientific and computing capacity to "downscale" the output of global climate models using statistical methods or to build regional models for finer-grained predictions. But that work is out of the reach of many poorer countries, leaving them with an information deficit. The resolution of the most powerful global climate models is still too coarse to answer their questions about how global warming will affect their cities, farms, or highways.

Scholars and activists in the global South have long recognized that climate change is a legacy of colonialism and an issue of justice.[69] In the US, the "climate justice" movement took off in 2005, when Hurricane Katrina made clear that the destructive impacts of climate change are taking the heaviest toll on poor and racially stigmatized populations. Theorists of climate justice recognize that the unequal impacts of climate change are reinforcing a global hierarchy of race and class that has been constructed over centuries. They argue that there can be no racial justice without addressing climate change.[70]

The UNFCCC includes two mechanisms to promote climate justice: an adaptation fund and a loss-and-damage fund. Wealthy countries are required to pay into the adaptation fund (the "Green Climate Fund"), to which low-income countries can apply for money to cover projects that would reduce their vulnerability to climate impacts. In 2022, the parties to the UNFCCC agreed to establish a loss-and-damage fund, which would provide compensation for economic losses due to events like wildfires, storms, and droughts when there is scientific evidence to link these events to anthropogenic warming. However, the efforts of poor countries to make claims on these funds are hampered in part by the data imbalance between wealthy and poor countries. The countries who are most deserving of compensation are typically the ones with least access to the required data. As we have seen, this is in part a legacy of the influence of colonialism on the infrastructure and institutions of global climate science.

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[67] Georgeson, Maslin, and Poessinouw, "Global Disparity."

[68] World Meteorological Organization, "WMO Overhauls Data Exchange Policy."

[69] Agarwal and Narain, *Global Warming in an Unequal World*.

[70] Táíwò, *Reconsidering Reparations*.

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