Evaluating Uncertainty and Public Perception of Developments in Climate Change Modeling

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On my honor as a University Student, I have neither given nor received unauthorized aid on this assignment as defined by the Honor Guidelines for Thesis-Related Assignments

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Introduction

"Scientific knowledge is a body of statements of varying degrees of certainty – some most unsure, some nearly sure, but none absolutely certain" (Feynman, 1988). In the study of climate science, forecast models, specifically enormous Earth System Models (ESM), have become the gold standard of prediction (Edwards, 2010). Complex models merge fundamental ideas or theories and generate predictions through repeated application of these ideas to larger systems or collections of data (Coghill, 2015). Climate science has been under the microscope for decades, becoming the subject of intense political, economic, and public debate, all while the science continues to mature. With an emphasis on uncertainty, this Science Technology and Society (STS) research paper critically evaluates the development and current state of climate science, then utilizes the analysis to provide suggestions for future climate science work as well as future political and public perception of it.

STS Framework

Climate change science and its history fits well into the Sociology of Scientific Knowledge (SSK) STS framework. The SSK field of thought promotes sociological influences over empirical or technical factors to understand the acceptance or dismissal of scientific theories (STS Wiki). This is in contrast to the STS theory of weak sociologies of science. Proponents of this rationale believe that theories fail for sociological reasons, whereas other theories succeed because they reveal something true about the world (Lamont, 2019). What about theories that are sufficient for a period of time, but ultimately prove false or partly inaccurate, such as many climate forecasts? Ultimately, sociological factors determine which theories stand the test of time. SSK does not discriminate against true or false theories (STS Wiki). It would be difficult to discount sociology in the development of any scientific idea; after all, humans are social creatures (STS Wiki). For most, trust dictates what scientific ideals or theories they believe in. An individual cannot validate every scientific theory they trust, or for that matter, even a fraction of them; it is up to scientists to develop, apply, and describe their respective expertise and results to society. The emergence of academic, political, industrial, and public confidence in their findings, subsequent to their work, leads to trust in their science and theories.

In an SSK analysis, it becomes important to understand who is conveying knowledge, whether it is the scientist, an institution, a politician, or the media. The construction of an ESM relies on trust in its various components; this faith is built on social relationships between people and organizations, making it reasonable to assume that bias can taint the overall makeup of the model (Coghill, 2015). For example, consider an institution working on a comprehensive ESM that provides grants to a university research laboratory to explore cloud microphysics; the institution would almost certainly be pressured to endorse and utilize the results from the research lab. The results may be groundbreaking, but the need to describe and promote their results nonetheless illustrates a social method of persuasion. Persuasive arguments supporting those results then supports current and future monetary incentives to continue the research. Every interaction explored here includes relationships and financial interactions between science, industry, policy, and the public, all fundamental social groups in SSK theory, in order provide a more complete picture of climate science.

Origins of Climate Science

Prior to exploring the intricacies of climate science, it is useful to understand its origins. The belief that humans can affect the climate dates back to ancient Greece. Specifically, the Hellenes believed that draining marshes and extending agriculture had affected regional rainfall (Bennett & Barton, 2018). Despite early human theories about their effect on the climate, knowledge of the Earth's historical record was quite limited until the mid-nineteenth century. The middle part of the 1800s saw geological discoveries of past ice ages, and in 1859 it became known that the atmosphere retained heat, predominantly through the presence water vapor and carbon dioxide (Graham, 1999). As far back as 1896, Svante Arrhenius, a Swedish scientist, published the concept that burning fossil fuels would increase carbon dioxide concentrations, possibly warming the earth. Guy Stewart Callendar, a steam engineer, backed Arrhenius's claims in 1938 when significant historical temperature data was collected in the United States and North Atlantic; Callendar believed that greenhouse warming was already occurring (Applegate, 2013). Callendar's paper gained some attention, but not substantial acceptance. (Weart, 2017)

War efforts and research funded by the United States military ultimately laid the groundwork for climate science and global warming studies by the collection and analysis of climactic data. The goal was to better understand the weather, which at times could be the difference between victory and defeat in battle. The 1960s saw increased atmospheric and oceanic measurements, and by the end of that decade, computers were used to more accurately predict the weather. Computational modeling was joined by the environmentalist movement of the 1970s, with the worldwide hottest summer on record at the time, 1988, adding fuel and money to the nascent field of climatology in the latter half of the twentieth century. Eventually, government organizations touted a consensus in the trajectory of climate change, leading to the comprehensive 2005 Kyoto Climate Protocol (unsigned by the United States) (United Nations Climate Change, 2020). (Weart, 2017)

Developments in Public Opinion

Parallel to the development of climatology was fluctuating public opinion, and for some time, the public was not aware of the issue. Often, matters do not become apparent until there is a disaster or enough time has passed to allow substantial shifts in public thought, a heuristic effect known as saliency bias (Kahneman, 2015). Based on his work with carbon dioxide, Svante Arrhenius stated in 1908 that humans "may hope to enjoy ages with more equable and better climates, especially in regard to the colder regions of the Earth, ages when Earth will bring forth much more abundant crops than at present, for the benefit of rapidly propagating mankind" (Malakoff, 2007). Statements like this by early investigators of the climate would not hold much public traction. G.S. Callendar also detailed an inability to educate the public on the climate, lamenting that "the idea that man's action could influence so vast a complex is repugnant to some" (Hulme, 2017). After all, in the 1930s, the sight of smoke meant jobs and prosperity, far from signaling any destructive repercussions of industrial activity. Eventually, the sight of billowing smoke was seen as a sign of poverty and a cause of chronic health conditions. A 1952 deadly smog in London had undoubtedly proven that what we put in the air can be harmful (Klein, 2012). (Weart, 2020)

The problem in the public sphere was that scientists could not reach a consensus on how the emission of greenhouse gases affects the climate. Throughout the 1960s and 1970s, magazines would frequently publish articles warning of global warming one year, then publish articles claiming an impending ice age the next. It is hard to determine how this impacted public opinion of the science: were concerns cultivated by the media being reflected in scientific judgement, or did the public distill all of the scientific facts and respond intelligently? In the early 1970s, a perfect storm of significant climate events occurred almost simultaneously, alarming many. There was a drought in the midwestern United States and Soviet Union, a failed Indian monsoon season, and a rare El Niño event that decimated Peruvian fisheries (Weart, 2020). Director of the Institute for Environmental Studies, Reid Bryson, capitalized on the recent weather anomalies and generated considerable public anxiety, through his panicking reports. Science journals are often guilty of amplifying issues that make a good story and the quotability of Bryson gained him recognition through hundreds of articles. Many experts thought that Bryson had gone too far, but his scientific opinions had already reached millions. In 1976, the CIA, informed by Bryson's theories, published a report containing dire warnings of their own (Morabito, 2009). Some denounced the "prophets of doom," like Bryson, for science that was not fit for the public eye; on the other hand, some argued that if scientists did not draw attention to their findings, significant action to combat climate change might occur too late. (Weart, 2020)

From Ice Ages to Warming

During the 1970s, many scientists could only agree that more research into climate change was needed; however, well-read citizens were made aware of the situation and had developed opinions. The environmentalist movement was underway, and 1970 saw the first worldwide celebration of Earth Day (EarthDay.org). In 1977, the Clean Air Act was passed, limiting certain propellants that were depleting the earth's protective ozone layer, primarily chlorofluorocarbons (CFCs) (EPA, 2020). The public was now acutely aware that human actions could endanger the entire planet and ourselves. Of particular interest was a 1977-1978 shift in media publications. The previous years had seen a spattering of global warming and ice age warnings, but since 1978, the vast majority of articles predicted global warming. The shift was not due to major advances in the science, as evidenced by a 1978 New York Times poll that still showed a divided field (Sullivan, 1978). In fact, the top scientists had gravitated toward global warming as the most plausible climactic change. These scientists, of course, held the highest prestige, funding, and media presence. Such a diversion can cause aftershocks throughout an entire field. (Weart, 2020)

The strongest intellectual relationships, influence, and funding are typically skewed toward the top scientists in all academic fields, as prescribed by SSK theory and realized in practice. Since 1978, the majority of climate scientists have championed global warming as the dominant outcome of human activity. However, it took until 2005 for the media to clearly report that scientists had resolved the warming versus cooling issue. The delay may have been amplified by inadequate funding from presidential administrations that became complacent on the issue. Public interest was dwindling, food prices fell significantly, and the future of humanity generally looked prosperous. (Weart, 2020)

Government Involvement

Social structures are extensions of people, and ultimately bend to the same sociological influences, with the largest of such structures being governments. In an SSK analysis, governments are greatly influenced by powerful people and social structures. In turn, governments project their own poorly or well-informed influence over academia, industry, and the public. Governments around the world have responded differently to developments in climate science, so this paper will focus on the United States' efforts for brevity. To reemphasize, political, economic, cultural, and historical factors influencing the decisions of governments are all social in nature. After World War 2, scientists were worried about funding for basic research while lacking a direct national threat. The economy had been stimulated by the war and in many cases, the government saw no reason to stop scientific funding; research had provided many domestic benefits. By now, thousands, perhaps millions of research papers have the tagline "This work was supported by the Office of Naval Research," indicating the government continues to deploy similar support today. (Weart, 2020)

Radiocarbon dating, atmospheric effects on infrared transmission, and radioactive tracking of ocean currents were all products of military research that greatly aided initial climate change work. Radiocarbon dating, allowing scientists to date artifacts trapped in ice sheets, was developed by Manhattan Project veterans at the University of Chicago with over half of their funding originating from military institutions (American Chemical Society, 2016). Infrared transmission studies that determined energy retained and emitted by the atmosphere were conducted to aid in missile guidance (Guilmartin et. al, 2018). Finally, the first studies of ocean currents were possible because of radioactive debris from open air nuclear detonation tests (Goldschmidt Conference, 2017). The fragmented climate data was not compiled however, taking decades of hard work to make sense of the entire system. As mentioned previously, the 1970s were a tumultuous time for climate scientists, fostering public curiosity, and echoing scientists' requests for more funding and a focused interagency effort. General interest coupled with Cold War military concerns initially provided ample funding for climate studies and other scientific fields. (Weart, 2020)

Presidential Administration Influence

Hinderance to or championing of climate science research is often dictated by the administration in power. Administrations, formed by tightly-bound political, industrial, and cordial relationships, hold more power over a government than any other social group. After the 1970s the future looked hopeful for climatologists as they gained funding and developed focused collaborations. The Reagan administration complicated the matter during the 1980s by making climate science a politically charged issue. Reagan orchestrated many cuts to climate research, including funding for carbon dioxide studies. Under pressure from the administration, the Department of Energy (DOE) cut previously promised funding to a well-respected climatologist, James Hansen, after he published a study concluding that the world had been getting warmer (Fox, 2020). Reagan was generally unconcerned with environmental issues, and substantial lobbying efforts from the oil, coal, and energy sectors further stymied government support of climate research. Al Gore, well known for climate change advocacy, confronted Reagan in a public congressional hearing, ultimately embarrassing the president for his numerous proposed research cuts. In turn, carbon dioxide emission restrictions were established as a major part of energy policy (Little, 2017). Gore is guilty of some manipulation as well. In many instances, Gore called upon Carl Sagan for testimony, an astronomer hardly known for his climatology. Gore chose Sagan because of his captivating demeanor, knowing he could attract attention far better than more distinguished experts. He is now generally touted as being a science popularizer and communicator (Achenbach, 2014). Politicians can, in many cases, manipulate perception and determine who gets to be the expert. (Weart, 2020)

Reagan's Vice President and successor to the presidency, George H. W. Bush, was more receptive to environmental concerns, but still did not want to irritate industrial allies, further stalling climatology research. There was more hope for the research field when Bill Clinton took office with climate science proponent Al Gore at his side. The overarching problem was an American public either confused by climate publications of the 1970s and Reagan's heavy stance, or not privy to any imminent threat. During Gore's 2000 presidential bid, he later admitted that his campaign advisors thought bringing up climate change would be damaging, and as such it was not a critical plank of the Democratic platform. Presidents George W. Bush and Donald Trump have further hindered United States support for climate research and legislation during the twenty-first century; Trump has reversed many of the Obama administration's efforts, including numerous Environmental Protection Agency (EPA) regulations and a complete withdrawal from the 2015 Paris Climate Agreement (Sharrett, 2019). (Weart, 2020)

Model Uncertainty

Most modern climatology predictions are based on the results of ESMs. In interpreting these models, it is crucial to understand that uncertainties are associated with them. The models are nonlinear, contain millions of degrees of freedom, and are formed by linking dozens of different subsystems, most from different contributors. Climatologist Judith Curry, once head of the Department of Earth and Atmospheric Sciences at Georgia Tech, believes there is an "uncertainty monster" that lurks ominously within ESMs (Sorman & City Journal, 2019). The monster is omnipresent, but can be "enraged" or "placated" in its handling or representation by the social groups charged with taming it. Whether academic or not, all groups are inherently social in the view of an SSK analysis. There are two primary classifications of uncertainty: epistemic and ontic. Epistemic uncertainty is associated with imperfections in knowledge that can be improved by further research, whereas ontic uncertainty is associated with the inherent randomness of a system. The boundary conditions and other parameters input into an ESM are subject to epistemic uncertainty; the initial conditions input are subject to both epistemic and ontic uncertainty. In short, we cannot fully understand the climate system, and there will always be unpredictable, random fluctuations. Inspired by Monte Carlo statistical methods, modelers characterize overall model uncertainty by running the simulations multiple times, varying parameters, boundary conditions, and initial conditions along the way. Due to time constraints and limited computational resources, it would be impossible to run the simulations more than a handful of times. This methodology falls short of the numerous simulations, sometimes thousands, that typical Monte Carlo applications employ (Joseph, 2018). Therefore, Curry argues we cannot accurately know what the uncertainty of an ESM is. (Curry & Webster, 2011)

Additionally, kludging is used. Defined as “a haphazard or makeshift solution to a problem and especially to a computer or programming problem,” kludging is a built-in tuning mechanism or program used to coax ESMs into following past climactic trends (Merriam Webster). The goal of kludging is to reduce the prediction error associated with the model by making comparisons to observations, analytical solutions, and other validated simulations. One paper described kludging as “an inelegant botched together piece of program; something functional but somehow messy and unsatisfying, a piece of program or machinery that works up to a point,” (Lenhard and Winsberg, 2010). The “machinery” continually adjusts the model in the background so that any changes or additions to an ESM are accompanied by a kluge, leading to model impenetrability – an uncertainty that arises when the particular component creating an error cannot be identified. For example, if a new model is proven to better represent cloud irradiance or cloud microphysics and incorporated into the ESM, it would be impossible to know whether it worsens or betters the overall accuracy of the model. In a sense, it is a black box; you cannot peek inside the model. Curry acknowledges the usefulness of ESMs; however, she is skeptical of the methods for arriving at conclusions and characterizing their uncertainty. (Curry & Webster, 2011)

IPCC Involvement

The Intergovernmental Panel on Climate Change (IPCC) completes essential climactic work, but many believe it needs to rethink how to address uncertainty and present confident conclusions. The IPCC is a United Nations subsidiary responsible for assessing climate change related science. It compiles research on climate change and produces major Assessment Reports

(ARs) periodically (Clark, 2011). The last report, AR5, was completed in 2014, and the next release is scheduled for 2022. There is still no general protocol for validating climate models, so it is the job of IPCC to distill thousands of simulation results and present recommendations to the world's governments (Guillemot, 2010). The IPCC ARs mention the lack of knowledge about uncertainties in ESMs, but often fail to account for it in their conclusions. Alarmingly, climate scientists and the IPCC do not have enough thorough data to determine the internal variability (ontic uncertainty) of the climate system on a decadal time scale. Measurements from the Pacific Ocean only provide enough data to understand 25 years of natural internal variability; large timescale natural fluctuations may be more extreme than what we have been able to systematically observe (Curry & Webster, 2011). One of the greatest uncertainties known when AR4 was published in 2007 was the effect of aerosols on the radiative properties of clouds. In the report, the IPCC mentions that the effect of aerosol-cloud interactions is so uncertain that its cooling effects could outweigh the warming caused by increases in greenhouse gases. AR4 also ranked the understanding of solar irradiance, overall aerosol effects, stratospheric water vapor from methane, and jet contrails as low (IPCC, 2007). All of these factors could be minor, but the truth is that we cannot be sure. Nonetheless, without significant developments in understanding these uncertainties, the major findings of AR5 were that "human influence on the climate system is clear, and recent anthropogenic emissions of greenhouse gases are the highest in history. Recent climate changes have had widespread impacts on human and natural systems" (IPCC, 2014).

As Curry points out, early IPCC reports gave fair acknowledgement of uncertainties, but have become more alarmist in nature as climate policy proponents have voiced the need for a broad international consensus. These proponents contend that only a confident response can inspire unity around this issue, and have made strong appeals to the authority that such solidarity would bring. Some believe that the IPCC's firm conclusions are a mistake, harming the integrity of the science itself. Michael Oppenheimer, a long-time member of ICPP deliberations, wrote that "the establishment of consensus by the IPCC is no longer as important to governments as a full exploration of the uncertainty" (Oppenheimer et. al. 2007).

Academic Displacements

The consensus in climatology championed by the IPCC and other agencies has displaced many who feel they cannot continue to produce unbiased scientific results and theories. One physicist, Hal Lewis, felt so strongly that he resigned from the American Physical Society in 2016 after 67 years of membership. Lewis wrote in his resignation letter that climate change "is the greatest and most successful pseudoscientific frauds [he has] seen in [his] long life as a physicist." Lewis pointed to times he had been silenced by the APS, specifically when the administration violated its own constitution to prevent Lewis and his peers from forming a climate science topical group. Lewis received the necessary 200 signatures per constitutional requirements, only to be shut down by the organization. Lewis was also appalled by the official APS statement on climate change that used the word "incontrovertible": "incontrovertible describes few items in physics, certainly not this one," he exclaimed (Light, 2016).

Albeit less emotionally invigorated in her statements, Judith Curry resigned from Georgia Tech in a similar fashion. She wrote that "independence of mind and climatology have become incompatible," (Harris, 2013). Curry believes that climate science and policy need to take full account of the uncertainty related to it (Curry & Webster, 2011). She went against the established orthodoxy by expressing her true scientific opinions, creating enough controversy among her peers at Georgia Tech and in the greater scientific community that she no longer felt comfortable in academia. Many of Curry's scientific beliefs have been addressed in this paper, and the coalition of scientists who agree with her is substantial.

Forcefulness of Unfounded Arguments

The stir created by scientists and amplified by the media throughout the late twentieth century was likely premature. Although anecdotal in nature, the following examples illustrate some of the fear mongering that occurred; this had not been a purely scientific endeavor, but also an attempt to emotionally attract the public, usually disguised in a clandestine appeal for attention or financing. Reports by some may have been well intentioned, but the work done was surely incomplete. Many who visited Glacier National Park in the last few decades probably noted the "Gone by 2020" signs scattered around the park. Fortunately, this is not the case, as the glaciers still exist. Now the signs have been updated to read "Gone Soon," a much more accurate report of the current state of affairs. The climate has undeniably been warming, but to what affect and by how much it will continue are not yet known. The park also displays signs illustrating their receding glaciers. They fail to provide dates, simply pasting a black and white picture next to a colored one. As one observant reporter noted, these glaciers cycle between 9 months of growth and 3 months of melting every year; hence the pictures may have been fabricated to appear more alarming (Durden, 2019). The park's rather innocent messages are akin to poor peer-reviewed science, where a mischaracterization of the facts can be misleading and potentially harmful to public opinion. When confronted with the beauty and grandeur of the park, who wouldn't be willing to reach into their pockets after seeing the horrific manifestations of human activity?

Even more dire was a Pentagon report, leaked in 2004, cautioning the Bush administration of climate change destabilization by 2020 and reviewed by *the Guardian*: "Now the Pentagon tells Bush: climate change will destroy us," read the title. Bob Watson, chief scientist for the World Bank at the time, and a former chair of the IPCC, remarked that "there are two groups the Bush Administration tend[s] to listen to, the oil lobby and the Pentagon." The report may have been an effort to get the attention of the administration, well known for close ties to the oil and energy industries; the report was swiftly buried. The analysis stated, "once again, warfare would define human life," warning of nuclear conflict, droughts, famine, and rioting as countries defend food, water, and energy supplies (Harris, 2004). All of these examples are not an attempt to cherry-pick bad predictions, as no scientific forecast is ever completely certain. Instead, by exposing the operations of certain organizations and individuals to advance their narrative, these predictions can be viewed through a prism of public and political manipulation. Effective mobilization of support or denial, in contrast to expressing the conservative opinion of uncertainty, is an effective tool in projecting and upholding the principles and goals of a government, organization, or the public-at-large.

The Path Forward

With persistent confusion, and the current shortcomings of climate science, what is the best path forward? While still at Georgia Tech, Judith Curry and her colleagues believed the remedies were simple; scientists must avoid appealing to emotions, ad hominem attacks, mischaracterization of inconvenient arguments, inappropriate generalizations, misuse of facts and uncertainties, etc. Curry argues that we need to let the science proceed and deal with uncertainty in an "open and honest way," (Curry & Webster, 2011). There have been many promising developments that can move the work forward, such as information technology and a collaborative distribution of knowledge that aids the flow of progress. One group elegantly stated, "being open about uncertainty should be celebrated: in illuminating where our explanations and predictions can be trusted and in proceeding, then, in the cycle of things to amending their flaws and blemishes," (Beck et al, 2009). As Hal Lewis wrote in his resignation letter, referring to a contentious "social/scientific" study he had been a part of, "the APS president noted the complete independence in which we did the job, and predicted the report would be attacked from both sides. What greater tribute could there be?" (Light, 2016). Science is not supposed to bend to popular or political opinion, yet sometimes it falls into that trap. Truly independent work is a lofty goal, but scientists must eliminate and mitigate as many social forces as possible in the search for reliable, trustworthy results.

Conclusion

The analysis developed here is not meant to lend itself to a particular conclusion about our climate's trajectory: be that timing or overall direction. Anthropogenic global warming could be accelerating catastrophically, and in a few hundred years the earth may be uninhabitable, but who can be certain? Humanity's effects on the world will ultimately be understood in hindsight. The vast influences on the development of robust interpretive models of the data accumulated so far make predictions imperfect. The extent of such influences, whether commercial, governmental/political, or academic cannot be quantified or later rectified in the models. Despite the sincere interest in gathering and understanding the data about our world over the last century by scientists, it remains an enormous challenge to deliver a single or optimal truth about the effects of humanity on the climate and world. After all, the energy from fossil fuel supports transportation, heating, cooling, electricity, and materials of all kinds; the petrochemical industry has helped define the modern age of comfort and economic development. We may come to realize we tapped into our finite fossil fuel reservoir for a relatively short-term advantage. And whether that short-term advantage was worth the long-term consequences is yet to be seen. As

Roger Revelle said, “human beings are now carrying out a large-scale geophysical experiment,” and it will be humanity’s choice to continue or cease its involvement (Weart, 2007).

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