Proposal for Thesis

in the Field of History of Science

in Partial Fulfillment of Requirements for

the Master of Liberal Arts Degree

Harvard University

Extension School

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I.

Tentative Title

"Analysis and Contextualization of the Development of the Theory of Climate Change during the Early Twentieth Century."

II.

The Research Problem

During the first half of the twentieth century the hypothesis, which forms the basis of the modern theory of climate change, was fermenting and competing with other hypotheses not to answer whether humans were changing the climate but what caused the ice ages. Brooks[1] lists eleven hypotheses under consideration during this period including the hypothesis, "Changes in the Composition of the Atmosphere." At the time, only a few scientists thought the addition of carbon dioxide from burning fossil fuels could change the climate. The vast majority of scientists did not think the evidence supported this hypothesis, nor did they think is was a major cause of the ice ages.

The carbon dioxide hypothesis sprouted out of the work on the origin of the ice ages. These two research programs, the ice ages and human-caused climate change, provide an opportunity to investigate the development of scientific programs in the early twentieth century. When I reviewed the work of modern historians, they tended to focus on the history related to their main interests. For example, if you are interested in human-caused climate change the history becomes a "process by connecting the dots among more than a thousand of the most

[1] C. E. P. Brooks, *Climate through the Ages - A Study of the Climatic Factors and Their Variations*, (London, UK: Ernest Benn Limited, 1926), 430-2.

important papers in the science of climate change"[2]. As a result, many historians tend not to investigate the complex interactions between hypotheses that are not directly related to their field of interest even if those hypotheses developed during the same period. It has been suggested that scientists in the early twentieth century were overly critical of the carbon dioxide hypothesis as compared to the other hypotheses.[3]

This thesis aims to more fully describe and understand early twentieth century scientific research on the human causes of climate change in the context of similar work on the origin of ice ages. I propose to answer the following questions:

1. How were the theories on the origin of the ices ages at the beginning of the twentieth century viewed and evaluated by the scientific community? By the middle of the twentieth century only a few hypotheses were considered viable.[4] How did the scientific community select those theories and why were other theories rejected?

2. One historian described the early twentieth century as 'toxic' to the carbon dioxide hypothesis and to human-caused climate change.[5] Is this a correct description, was the carbon dioxide hypothesis separated out from the other hypotheses for special criticism or were all hypotheses similarly critiqued?

3. Why was the carbon dioxide hypothesis carried throughout the early twentieth century when it had been critiqued and rejected by the majority of scientists early in the twentieth

[2] Spencer Weart, *The Discovery of Global Warming*, 2 ed. (Cambridge, MA: Harvard University Press, 2008), 198.

[3] Weart Spencer, "Global Warming, Cold War, and the Evolution of Research Plans." *Historical Studies in the Physical and Biological Sciences* 27 (1997): 319-56.

[4] Brooks, C. E. P. "Present Position of Theories of Climatic Change." *The Meteorological Magazine* 84, no. 997 (1955): 204-06.

[5] Weart, "Global Warming," 1997.

century?

I hypothesize scientific work in the early twentieth century on human-caused climate change was, in general, typical of scientific work during this period when there is insufficient data to select among proposed hypotheses. As a result, all the hypotheses that addressed the problem of the ice ages were part of the discussion and the carbon dioxide hypothesis was treated no differently than any of the other hypotheses.

My research will focus, not only on the history of human-caused climate change, but also on the historical development of the cause(s) of the ice ages because both of these theories arose out of the same research program. Investigation the history of the ice ages, a politically non-controversial question, with the human-caused carbon dioxide theory, which today is politically controversial, will provide insight into the history of human-caused climate change hypothesis and whether the scientific work on carbon dioxide differed from the work on causes of the ice ages. To bracket the period in this study, I will study the period from approximately 1896, Arrhenius's first publication on the topic, to shortly after 1938, when Callendar's publication is considered to have revived the hypothesis. I will rely on three types of information: (1) peer-reviewed original scientific literature of the period; (2) monographs and textbooks written in the early twentieth century; and, (3) modern historical treatments to understand the modern view of early twentieth century.

The product of my thesis will provide a description of the scientific work of the early twentieth century, which will elaborate, contextualize and clarify the development of the modern theory of human-caused climate change. Better understanding of this history will provide insight into the development of synthetic scientific hypotheses and whether the development of the carbon dioxide theory.

III.

Definition of Terms

Findlinge: also called erratic blocks. are large, meter sized blocks of rock whose composition differs from the local geology but often matches the geology far from the current location of the block. Often the blocks are found on flat terrain making their presence a clear anomaly begging for an explanation. Explaining the origin of *findlinge* was one of the phenomena that instigated the study what would be known as the ice ages.

Hypothesis: used here is a proposal without sufficient evidence to support it and hence is is not accepted as being 'proved' by the relevant scientific community.

Relevant scientific community: the community of scientists with explicit education and/or experience in the relevant scientific field. For example, in climate studies, relevant fields are climatology, geophysics, etc., not medical biochemistry.

Research Tradition: "is a set of general assumptions about the entities and processed in a domain of study, and about the appropriate methods to be used for investigating the problems and constructing theories in that domain."[6]

STP: standard temperature and pressure, corresponding to 0°C and 1 atmosphere pressure. At 1 STP, one mole of gas occupies 22.4 liters.

[6] Laudan, L. *Progress and Its Problems: Towards a Theory of Scientific Growth*. Vol. 282: (Berkeley, CA: University of California Press, 1978), 72, 78-9.

Synthetic Scientific Theory: A scientific theory that requires research and evidence from multiple scientific domains to solve the problem. An example is the theory of plate tectonics, which required evidence and analysis from geophysics, paleontology, chemistry, geology, materials science, etc. to prove it.

Theory: a proposal with sufficient evidence and experimental verification to be accepted as being ‘proved’ by the relevant scientific community.

IV.

Background of the Problem

Current scientific understanding of human-caused climate change and the discovery of the causes of the ice ages both have their beginnings in the scientific work of the late 19th and early 20th century. The recognition of the existence of ice ages developed during the mid- to late 19th century and scientific work then shifted to identifying the cause or causes of the ice ages. By this time a dozen hypotheses had been identified, one of which was based on changes in the composition of the Earth's atmosphere. A few scientists, e.g. Svante Arrhenius (1859-1927) thought human combustion of fossil fuels might affect future climate by increasing the global atmospheric temperature of the Earth, in addition to causing the ice ages. As a result another research program began to develop that studied possible human-caused changes in the Earth's atmosphere and its effect on climate. Though the discovery of the ice ages is not part of this thesis, I will briefly describe it because it is a prelude to the study of the causes of ice ages and human-caused climate change.

In the early to mid-19th century, naturalists developed theories to explain the presence of *findlinge*, which were found scattered about Europe.[7] *Findlinge* are large blocks of rock whose composition does not match local geology but often matches geological formations far away from where they are now located. *Findlinge* are often found on flat fields where the presence of a large rock, sometimes as large as 5-10 meters in height, clearly stand out and beg an answer as to how they got there. There were two popular hypotheses: deluges of water or mud or depositions of rocks from icebergs when they melted. The first hypothesis is consistent with the idea of the

[7] Tobias Kruger, *Discovering the Ice Ages: International Reception and Consequences for a Historical Understanding of Climate*, (Leiden, The Netherlands: Brill, 2013), 84.

Noachian flood but it was challenged because it did not seem possible for water alone to move such large blocks of rock. The other hypothesis proposed *findlinge* were released when icebergs melted after having drifted from the Arctic during an earlier time when the Earth's surface was completely covered with water. Other phenomena noted by naturalists, such as gouge marks on rocks on the bottom and sides of many valleys, were not explained by either of these two hypotheses.

Louis Agassiz (1807-1873) is credited with the discovery of the ice ages which he thought could explain both *findlinge* and gouges on rock surfaces in valleys and other observations. He first presented the theory at a meeting of the Society des Sciences Naturelles in 1837 at Neuchhatel but the hypothesis was not received well, some scientists laughed at his proposal.[8] As an aside, Kruger points out Scrimper (1803-1867), who collaborated with Agassi in preparing this talk, deserves credit as a co-discover of the ice ages.[9]

Acceptance of the hypothesis was not immediate not only because the evidence was not convincing but also the idea of an ice aged did not fit their understanding of the history of the Earth. It took many more years, till the 1850s, before most geologists accepted the existence of ice ages.[10] With the recognition of the existence of ice ages, focus shifted to identifying the cause(s) of the ice ages.

By the beginning of the 20th century many proposals had been suggested to explain the origin of the ice ages. Brooks described that state of knowledge in 1926: "about fifty different theories of the causes of geological changes of climate, but not one of which was completely

[8] Kruger, *Discovering Ice Ages*, 177-78.

[9] Kruger, *Discovering Ice Ages*, 170.

[10] Kruger, *Discovering Ice Ages*, 456.

satisfactory."[11] Table 1, a condensed version of Brooks' list (reproduced from Fleming[12]), shows the hypotheses of the causes varied considerably from a lunar-solar tidal effect to the now famous carbon dioxide hypothesis.[13]

[11] C. E. P. Brooks, "Unsolved Problem of Climate Change," *The Meteorological Magazine* 76, no. 900, 901 (1947): 126-29, 47-51, 430-32.

[12] James Rodger Fleming, *Historical Perspectives on Climate Change*, (New York: Oxford University Press, 1998), 110.

[13] The references from the table, which are in English, are included in "Working Bibliography: Works to be Consulted". Brooks, *Climate*, 1926, 430-432.

Table 1. Hypotheses on the Origin of the Ice Ages

Theory	Author
Changes in elements of the Earth's orbit	Adhémar (1842), Croll (1864, 1875), Drayson (1873), Ekholm (1901), Spitaler (1907), Milanković (1920, 1930, 1941)
Changes of solar radiation	Dubois (1895), Simpson (1930, 1934, 1939–40), Himpel (1937), Hoyle and Lyttleton (1939)
Lunar-solar tidal influences	Pettersson (1914)
Elevation of land masses—mountain building	Lyell (1830–33), Wright (1890), Ramsay (1909–10, 1924), Brooks (1926, 1949)
Changes in atmospheric circulation	Harmer (1901, 1925), Gregory (1908), Hobbs (1926), Flint and Dorsey (1945)
Changes in oceanic circulation	Croll (1875), Hull (1897), Chamberlin (1899), Brooks (1925), Lasareff (1929)
Changes in continent-ocean distribution	Czerney (1881), Harmer (1901, 1925), Gregory (1908), Brooks (1926), Willis (1932)
Changes in atmospheric composition	Arrhenius (1896), Chamberlin (1897, 1899), Ekholm (1901), Callendar (1938, 1939)
Volcanic dust in the atmosphere	Humphreys (1913, 1920), Abbot and Fowle (1913)
Cosmic dust theory	Hoyle and Lyttleton (1939), Himpel (1947)
Sunspot theory	Czerny (1881), Huntington (1915), Huntington and Visher (1922)
Polar migration and continental drift theory	Kreichgauer (1902), Wegener (1920), Köppen and Wegener (1924)

The early 20th century was a period of exploration of evidence for and against these hypotheses and many came into and out of favor depending on the state of understanding. With one exception, to be discussed later (carbon dioxide), all hypotheses focused only on identifying the cause(s) of the ice ages not on human-caused climate change.

Next, I briefly describe the history of the two key hypotheses: the astronomical hypothesis on the origin of the ice ages and the carbon dioxide hypothesis on human-caused global warming, both of which have turned out to be correct.

The astronomical hypothesis, proposed as the cause of the ice ages, begins with Joseph

Adhemar's (1797-1862) 1842 book, *Revolution in the Sea*.[14] Adhemar looked at shifts in the equinoxes, which would affect solar radiation input to the Earth, and found cycles that appear match the relative dates of the ice ages. However, the proposal was criticized by Baron Alexander von Humboldt (1769-1859) because this mechanism for triggering the ice ages and timing of the cycles did not seem strong enough. Because of this and other criticisms many scientists thought the hypothesis had been disproved.[15]

In 1864, having read Adhemar, James Croll (1821-1890) revised the theory using different astronomical regularities to match the observations of the 'dates' of ice ages.[16] Part of the difficulty with this hypothesis was that though it precisely predicted various astronomical regularities, e.g. shift of the equinoxes with a 22,000-year cycle, the actual ages of the ice ages was not well known. It wasn't till much later when the age of rocks could be quantitatively dated by radiometric dating, in the middle of the twentieth century, that the astronomical hypothesis could be directly tested. Prior to radiometric dating, even though scientists published evidence in support of the hypothesis, e.g. James Geikie (1839-1915) in 1874 and Croll again in 1875, the hypothesis was never widely accepted and by 1894 the majority of scientists had rejected it.[17]

After a long gap: "Twenty-one years after the death of James Croll, and long after his orbital theory of the ice ages ha been discarded"[18] Milankovitch (1879-1958) took up the hypothesis. His first book on the topic, *Mathematical Theory of Heat Phenomena Produced by*

[14] John Imbrie, *Ice Ages: Solving the Mystery*, Edited by Katherine Palmer Imbrie, (Cambridge, MA: Harvard University Press, 1986), 69.

[15] Imbrie, *Ice Ages: Solving the Mystery*, 75.

[16] Imbrie, *Ice Ages: Solving the Mystery*, 80.

[17] Imbrie, *Ice Ages: Solving the Mystery*, 89, 94.

[18] Imbrie, *Ice Ages: Solving the Mystery*, 97.

Solar Radiation (1920) described the climates of the Earth, Mars and Venus and was considered a major contribution to the field.[19] Continuing to develop his ideas, Milankovitch published *Astronomical Methods for Investigating Earth's Historical Climate* (1938) expanding his theory.[20] Nonetheless, again, not all scientists agreed with him and they challenged whether periodic astronomical cycles were sufficient to trigger ices ages and whether the astronomical cycles matched the dates of the ice ages.[21]

Summarizing the state of understanding in1955, Brooks recalls his earlier review: "In 1947…five groups of theories were examined…but the conclusion was advanced that all theories so far advance remain unproven. The seven years which have elapsed have…made the confusion even greater."[22] It was not till late in the 20th century that Milankovitch's theory would be recognized as "one of the most significant theories relating Earth motions and long-term climate change."[23]

The development of the carbon dioxide hypothesis had a similar reception by the scientific community, its acceptance varied depending on the available evidence. Early development of the hypothesis focused not on human-caused climate change, but rather it was one of the hypotheses proposed to account for the origin of ice ages. Because my proposed research focusses on the early 20th century I will end this short review just after the time of

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[19] Imbrie, *Ice Ages: Solving the Mystery*, 103.

[20] Imbrie, *Ice Ages: Solving the Mystery*, 108.

[21] Imbrie, *Ice Ages: Solving the Mystery*, 180-89.

[22] C. E. P. Brooks, "Present Position of Theories of Climatic Change," *The Meteorological Magazine* 84, no. 997 (1955): 204-06.

[23] NASA Earth Observatory, "Milutin Milankovitch (1879-1958)." NASA Goddard Space Flight Center, http://earthobservatory.nasa.gov/Features/Milankovitch. Accessed 10-5-15.

Callendar' where his publication in 1938, is taken to have 'revived' the idea of human-caused climate change from increasing levels of carbon dioxide.[24]

Historical accounts usually start with the 1827 paper by Joseph Fourier (1768-1830) wherein he discusses three sources for the heating of the earth atmosphere: "[1] solar radiation…[2] temperature communicated by interplanetary space…[3] heat from the interior of the earth".[25] However, papers published by Fourier during this period did not actually reference the carbon dioxide greenhouse effect even thought he is often credited as a pioneer in the carbon dioxide hypothesis.[26]

The first scientist to explicitly mention carbon dioxide was John Tyndall (1820-1893) in his 1861 paper where he reported experimental results on the absorption of what we now call infrared radiation (IR) by a number of gases. He found that nitrogen, oxygen, etc. did not absorb IR but that carbon dioxide, water vapor along with others gases did absorb IR. From these unexpected results:

> "Tyndall thought that changes in the amount of any of the radiatively active constituents of the atmosphere–water vapor, carbon dioxide, ozone, or hydrocarbons–could have produced 'all the mutations of climate which the researches of geologists reveal…they constitute true causes, the extent along of the operation remaining doubtful."[27]

Nonetheless, it is Svante Arrhenius (1859-1927) who is considered "the father of the

[24] Fleming, *Historical Perspectives*, 113.

[25] Fleming, *Historical Perspectives*, 60.

[26] Fleming, *Historical Perspectives*, 61.

[27] Fleming, *Historical Perspectives*, 73.

greenhouse theory, even global warming"[28] and it is his work that histories of climate change describe in great detail. In 1897 Arrhenius published "On The Influence Of Carbonic Acid In The Air Upon The Temperature Of The Earth,"[29] a translation of a work originally published in 1896, where he argued decreases in carbon dioxide levels were responsible for the initiation of ice ages. It wasn't until 1908, in his popular book, *Worlds in the Making - The Evolution of the Universe,*[30] that he explicitly proposed that increases in carbon dioxide from human activities would lead to an increase in global temperatures.

Initially some scientists accepted his hypothesis, for example, T. C. Chamberlin (1843-1928), a well-respected American geologist. But doubts soon began to arise after Anders Jonas Angstrom (1814-1874) found that the IR absorption bands of water overlapped those of carbon dioxide, and, because water vapor is more prevalent in the atmosphere, changes in the concentration of carbon dioxide, a minor constituent, would have no effect on the absorption of IR radiation.[31] In addition, studies on the absorption of carbon dioxide found IR radiation is completely absorbed a column of carbon dioxide equivalent to 50 cm in length, at STP. Yet, carbon dioxide in the atmosphere corresponded to a column length of 250 cm thus the carbon dioxide in the atmosphere completely absorbs all the IR possible and adding carbon dioxide

[28] Fleming, *Historical Perspectives,* 79.

[29] Arrhenius, S., and Edward S. Holden. "On the Influence of Carbonic Acid in the Air Upon the Temperature of the Earth." Publications of the Astronomical Society of the Pacific 9, no. 54 (1897): 14-24.

[30] Arrhenius, Svante. *Worlds in the Making - the Evolution of the Universe*. Translated by Dr. H. Borns. (New York, NY: Harper & Brothers Publishers, 1908).

[31] Fleming, *Historical Perspectives,* 90.

would have no effect on the heat balance.[32] Eventually these observations and other critical evidence convinced T. C. Chamberlin to reject the hypothesis:

> "I have no doubt that you may be correct in thinking that the number who accepted the carbon dioxide theory is less now than a few years ago…Unfortunately, however, Arrhenius' deductions from Langley's observations appear to have been unwarranted and when this was discovered a reaction was inevitable…I greatly regret that I was among the early victims of Arrhenius' error." (Quoted in Fleming[33])

As a result, initial support of the carbon dioxide hypothesis changed and it was dismissed as incorrect by the majority of scientists.[34] Weart[35] claims the rejection came earlier than the time proposed by Fleming, that is, Arrhenius's hypothesis was rejected within 10 years of his publication. The rejection of the carbon dioxide hypothesis by the scientific community was documented in 1951 in a report from The American Meteorological Society which stated Arrhenius's theory was not widely accepted, especially after the above mentioned experimental results contradicted the theory.[36]

Weart describes this period as especially critical of research into human-caused effects, it was:

> "...a mental environment that included confidence in the balance of nature was inhospitable to any research plan centered on the idea that human activity was

[32] Fleming, *Historical Perspectives,* 111.

[33] Fleming, *Historical Perspectives,* 90.

[34] Fleming, *Historical Perspectives,* 90.

[35] Weart, Global Warming, 328.

[36] Weart, Global Warming, 328.

overwhelming an entire geophysical system. There were also more specific toxic elements in the environment of scientific opinion…"[37]

The hypothesis of human-caused atmospheric warming by carbon dioxide was resuscitated when Guy Steward Callendar (1898-1964), a steam engineer, published a paper in 1938, "The artificial production of carbon dioxide and its influence on temperature,"[38] which asserted that the release of carbon dioxide from human activities was building up in the atmosphere leading to increased atmospheric temperatures. Yet even he recognized the data for his claim was poor, for he lamented the lack of good IR absorption spectra and measurements of carbon dioxide and water vapor.[39]

The response to Callendar's 1938 publication wasn't straightforward. In 1947, Brooks reviewed the hypotheses for the cases of ice ages, in which he mentioned the carbon dioxide hypothesis "has a checkered career depending on the state of the absorption radiation in the atmosphere" and concluded "changes in the composition of the atmosphere may have had a long-term effect on climate and may have been a contributing factor in the occurrence of ice ages, but they cannot have caused the rapid changes from one glaciation to another within an ice age."[40] Though the review is about the cause of the ice ages, he does mention Callendar's 1938 paper but makes no mention of human-caused climate change, one of Callendar's main proposals. When Brooks updates his review in 1955, no mention is made to carbon dioxide and he

[37] Weart, Global Warming, 328.

[38] Callendar, G. S. "The Artificial Production of Carbon Dioxide and Its Influence on Temperature." Quarterly Journal of the Royal Meteorological Society 64 (1938): 223-40.

[39] Weart, *Discovery of Global Warming*, 18.

[40] Brooks, "Unsolved Problems," 149.

considers the only viable hypothesis from changes in the atmospheric composition of the atmosphere to consist of the effects of volcanic dust.[41]

It was not until Callendar's work is taken up by Gilbert Plass (1920-2004) in the 1950s, after the IR spectroscopy had significantly improved, when it was found the "carbon dioxide bands were not fully saturated and did not entirely overlap with water vapor".[42] This removed one obstacle to the carbon dioxide hypothesis and Plass, using one of the first simple climatological computer models, was later able to show that increases in carbon dioxide could raise the earth's atmospheric temperature. However, the results were not completely convincing due to the many assumptions he used n the model.[43] It required further work by Plass, Harold Urey (1893-1981), Hans Suess (1909-1993) and many others before climate change due to increases in human-caused carbon dioxide was considered proved by 1977.[44]

One challenge to understanding the interactions between scientists in the early 20th century is that many historians often take a linear approach in describing historical events. For example, if your interest is in human-caused climate change you focus on the path of discoveries leading to our current knowledge. This approach is explicitly taken by Weart:

> "I have tried to show this process by connecting the dots among more than a thousand of the most important papers in the science of climate change. For each of these select thousand, scientists published another ten or so papers of nearly the same importance, describing related data, calculations, or techniques...By pulling the main developments

[41] Brooks, "Present Conditions", 204-06.

[42] Weart, *Discovery*, 23.

[43] Weart, *Discovery*, 23.

[44] Weart, *Discovery*, 208.

above the tumult, this book gives a clearer picture than scientists could see at the time."[45]

This approach has been criticized because "existing accounts assume far too much continuity in scientific understanding of the greenhouse gas effect from Fourier to today"[46] and "Arrhenius, who has recently gained renewed attention as the 'father' of the theory of the greenhouse effect, held assumptions and produced results that are not continuous with present-day climate research".[47]

Recall Weart described the scientific community of the early twentieth century in regards to the carbon dioxide hypothesis as: "…a mental environment [that] was inhospitable to any research plan centered on the idea that human activity was overwhelming an entire geophysical system. There were also more specific toxic elements in the environment of scientific opinion."[48]

Is Weart's description of the scientific environment in the early twentieth century accurate and is his description of Callendar correct: "One man challenged the consensus of the experts. In 1938 Guy Stewart Callendar had the audacity to stand before the Royal Meteorological Society in London and talk about climate. Callendar was out of place, for he was no professional meteorologist, not even a scientist, but an engineer who worked on steam power."[49]

The linear approach was used by some historians to describe these two research programs: origin of the ice ages and human-caused climate change. Though the linear approach

[45] Weart, *Discovery*, 198.

[46] Fleming, *Historical Perspectives*, 56.

[47] Fleming, *Historical Perspectives*, 65.

[48] Weart, "Global Warming", 328.

[49] Weart, *Discovery, 2.*

has advantages, as Weart[50] points out, it could result in distortions in understanding the history of a particularly period. For example, it appears scientists writing reviews and textbooks of the period have a less derogatory view of the hypotheses under consideration, for example, in the second edition of Brooks' *Climate Through the Ages,* he notes that the "carbon dioxide question was taken up again by G. S. Callendar" and whether carbon dioxide plays a some small part of the climatic changes of geological time seems to remain open however,"[51] which does not appear overly critical.

Hamblyn, a critic of modern historical writing on climate change, notes that it considers "Svante Arrhenius, the progenitor of so much early climate change imagery, has himself become an environmentalist icon, feted in recent years as 'the father of climate change science', and the founder of a 100-year-old meteorological — and rhetorical — lineage that extends into the present"[52] and because of this the "image of the lone voice has come to occupy a central position at the heart of the global warming story. Historical accounts of the subject tend to hinge on moments of individual conviction or testimony, the 'lone voice in the greenhouse', as a headline in Nature dubbed the early twentieth-century climate scientist Guy Stewart Callendar."[53]

These differing views of scientific work in the early twentieth century raise questions about the scientists and their work on climate change. The goal of this MLA thesis is to fill in the

[50] Weart, "Global Warming".

[51] Brooks, C. E. P. *Climate through the Ages - a Study in the Climatic Factors and Their Variations*. (New York, NY: McGraw-Hill Book Company, Inc., 1949) 117.

[52] R. Hamblyn, "The Whistleblower and the Canary: Rhetorical Constructions of Climate Change," *Journal of Historical Geography* 35, no. 2 (Apr 2009): 223-36.

[53] Hamblyn, "The Whistleblower".

historical record and link the development of both the astronomical ice age and the carbon dioxide global warming hypotheses and along with other hypotheses under consideration at this time to better understand the complex interaction between them and their acceptance or lack of acceptance in the scientific community of the time, and why it was so. The analysis should provide a better understanding of the development of multiple hypotheses in domains of synthetic science and by looking at the development of these two theses, coextensive in time.

V.

Research Methods

Research and analysis will be completed in four phases. First, I will review the twelve hypotheses on the origin of the ice ages and climate change, the number depending how they are grouped, as originally listed by Brooks in 1926[54]. I will analyze the evidence for and against each hypothesis and how challengers used and evaluated that evidence. This will entail looking at the work of forty-three scientists who published fifty-four papers on these hypotheses. There were a number of non-English papers and these will not be investigated; though I will attempt to find English language equivalents of these papers. This study will not include the two hypotheses on the origin of the ice ages developed in the middle to late twentieth century, abrupt ice sheet changes and stochastic models.[55]

The second phase will trace the citations to and from the primary sources to identify other publications that elaborate on the evidence and analysis for and against each hypothesis. This phase will also include review of summary works such as monographs, textbooks, and other publications to understand the reception of these hypotheses during the early twentieth century. If other source materials, such as biographies, journals, or notebooks are identified and available, these will be searched to find comments on the hypotheses, but this last category of material will only be used if it is easy to obtain.

The third phase will analyze the material to identify common threads of support and critique within the early twentieth century climate science community to understand the dynamics of science during this period. From this I will be able to identify why some theories

[54] Brooks, *Climate through the Ages*, 1926, 430-32.

[55] Imbrie, *Ice Ages: Solving the Mystery*, 103.

were accepted or rejected and why some came into and out of favor. This will provide information on whether any theory received special criticism or support beyond that found for other hypotheses. For example, were any theories particularly accepted because of the advocates were well respected scientists or were they not accepted because of some other, non-evidential factor. One area of special interest we be to see if there is a common reason why many of these hypotheses made so little progress in 50 years because no definitive hypothesis(s) had been identified by the mid-1950s. The result of this phase will be a interactions diagram showing the relationships between the various hypotheses, scientists and the evidence. My hypothesis will be supported if all hypotheses were treated substantially the same by the scientific community during this period.

The fourth phase will briefly look at modern historical research on climate studies during this period to identify any issues that were not adequately addressed and what might, if they exist, been the cause for those issues. The final phase will be brief and limited to commonly cited historical works, not popular histories, from the late twentieth and early twenty-first century works.

VI.

Research Limitations

The research will be limited to sources written in English, and translations where available, so the views and commentaries from non-English scientists will not be consulted. This will limit the analysis because certain hypotheses may not be adequately analyzed. Because this research focuses only on published work, many comments both positive and negative, about various hypotheses may not be identified because of the formality of published scientific papers. Less inhibited comments written in journals, diaries, notebooks, etc., which could provide a better insight into the differing views within the scientific community will not be investigated.

In a bibliographic search of papers published on ice ages during from 1860-1940, but not limited to discussion of their causes, identified over 400 papers. Some of these papers may contain comments on the hypotheses of the causes of the ice ages or human-caused climate change, but were not included in Brooks 1926 compilation because they were not primary sources. The comments in these other papers could provide further insight into the views of the scientific community at the time and how they evaluated the various hypotheses. There is insufficient time to review all these papers, instead I will focus on those papers cited by the primary papers referenced by Brooks.[56]

[56] Brooks, *Climate through the Ages*, 1926, 430-32.

VII.

Tentative Schedule

Submit first draft of proposal to Research Advisor (RA)	November 13, 2015
Proposal returned for revision	December 13, 2015
Submit second draft of proposal	January 8, 2016
Proposal returned for revision	January 22, 2016
Submit third draft of proposal	January 29, 2016
Proposal accepted by RA	February 5, 2016
Potential Thesis Director (TD) identified	March 4, 2016
Proposal returned for revision from TD	March 18, 2016
Submit second draft proposal to TD	March 25, 2016
TD agrees to serve and proposal accepted	April 1, 2016
Complete and submit first draft thesis	June 3, 2016
TD returns first draft for revision	July 8, 2016
Complete revisions and submit second draft	August 26, 2016
TD returns second draft for revision	September 23, 2016
Final draft delivered to TD and RA	November 18, 2016
Final draft approved	December 16, 2016
Delivery of bound copy	December 16, 2016

Graduation	May 2017

VIII.

Working Bibliography

Works Cited

Arrhenius, S., and Edward S. Holden. "On the Influence of Carbonic Acid in the Air Upon the Temperature of the Earth." Publications of the Astronomical Society of the Pacific 9, no. 54 (1897): 14-24.
Translation of the original Swedish paper wherein Arrhenius puts forward the evidence and arguments for carbon dioxide as a causal agent for the ice ages. Increases in carbon dioxide result in increasing atmospheric temperature and vice versa. Considered to be one of the first major papers on the role of carbon dioxide and atmospheric temperature.

Arrhenius, Svante. *Worlds in the Making - the Evolution of the Universe*. Translated by Dr. H. Borns. New York, NY: Harper & Brothers Publishers, 1908.
Popular book on the evolution of the universe including a history of the earth. First time Arrhenius puts forward in depth the evidence and calculations suggesting that human activities, by burning of fossil fuels, will increase in atmospheric carbon dioxide and will result in an increase of the earth's atmospheric temperature. His calculations indicate this is a slow process and will not result in a significant increase for many years, perhaps a century in the future.

Brooks, C. E. P. *Climate through the Ages - a Study of the Climatic Factors and Their Variations*. London, UK: Ernest Benn Limited, 1926.
Textbook on climate, physics and chemistry, includes a brief discussion of the theories on changes in the climate through history. States the evidence for carbon dioxides influence on climate changes is weak and the theory is not accepted by most scientists. Appendix III lists eleven different theories of climate change and the papers supporting each theory.

Brooks, C. E. P. "Unsolved Problem of Climate Change." The Meteorological Magazine 76, no. 900, 901 (1947): 126-29, 47-51.
Describes the evidence and timing of the ice ages, reviews the status of five groups of theories for the cause of the ice ages, and finds there are still many theories, none of which have been proven as causing the ice ages. Evidence suggests the carbon dioxide levels have changed over history, but he thinks the change is not sufficient to affect the climate.

Brooks, C. E. P. *Climate through the Ages - a Study in the Climatic Factors and Their Variations*. New York, NY: McGraw-Hill Book Company, Inc., 1949.
Updated version of textbook on climate, physics and chemistry, includes a brief discussion of the theories on historical changes in the climate, that does not differ from the 1926 edition with the exception that he includes a paragraph on the evidence for carbon dioxides influence on climate changes begause it has been revived by the recent work by Callendar. Appendix III lists eleven different theories of climate change and the

papers supporting each theory.

Brooks, C. E. P. "Present Position of Theories of Climatic Change." The Meteorological Magazine 84, no. 997 (1955): 204-06.
Update of the 1947 paper, and finds that the state of the evidence is more confusing than the earlier paper on the causes of the ice ages. This is after Callendars' 1938 paper but it is not mentioned and he argues that changes in volcanic dust is the only remaining atmospheric hypotheses, there is no mention of carbon dioxide.

Callendar, G. S. "The Artificial Production of Carbon Dioxide and Its Influence on Temperature." [In English]. Quarterly Journal of the Royal Meteorological Society 64 (1938): 223-40.
Describes how carbon dioxide can affect the temperature of the atmosphere and argues that man's addition of carbon dioxide from the combustion of fossil fuels will result in an increase in the temperature. Notes that there are limitations to his study, for example, IR spectroscopy has barely advanced since 1900 and measurements of atmospheric carbon dioxide are very limited and of questionable quality but does present evidence of a measured increase in the atmosphere's temperature. Considered the pivotal paper that restarted the investigation of human-caused climate change.

Daniels, S., and G. H. Endfield. "Narratives of Climate Change: Introduction." Journal of Historical Geography 35, no. 2 (Apr 2009): 215-22.
Reviews papers on the history and narratives of human-caused climate change, particularly those that describe history heroically.

Fleming, James Rodger. *Historical Perspectives on Climate Change*. New York: Oxford University Press, 1998.
Overview of various human perspectives of climate change, from the early sixteenth century to the modern research on human-caused climate change. Views have ranged from how humans and civilizations change climate, for example, by changing the landscape in America during the seventeenth and eighteenth centuries, to the role climate has on types and success of civilizations. Describes the history of human-caused climate change research and argues many historians have tried too hard to link the earlier work, for example of Fourier and Tyndall, to modern climate theory.

Hamblyn, R. "The Whistleblower and the Canary: Rhetorical Constructions of Climate Change." Journal of Historical Geography 35, no. 2 (Apr 2009): 223-36.
Argues the history of human-caused climate change has become heroic, for example, early scientists are treated as heroes and 'canaries' warning of impending doom if changes are not made to man's use of fossil fuels. These are interpretations imposed on earlier scientists from the late twentieth and early twenty-first century writing my historians.

Imbrie, John, *Ice Ages: Solving the Mystery*, Edited by Katherine Palmer Imbrie, (Cambridge, Mass.: Harvard University Press, 1986).

Describes the discovery of ice ages and their causes by one of the scientists (John) involved in much of the modern research of the topic. Focus is not on human-caused climate change rather it is the ice ages. Describes the historical and current state of knowledge of the origin of the ice ages and the evidence in support of the Milankovich's theory of astronomical cause.

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Description of the history of the identification of the existence of ice ages and their acceptance within the scientific community. Provides detailed descriptions country by country in Europe during the nineteenth century of the discussion and final acceptance of ice ages. Provides brief description of the work on the causes of the ice ages.

Laudan, L. *Progress and Its Problems: Towards a Theory of Scientific Growth*. Vol. 282: University of California Press, 1978.
Describes scientific progress as the solution of problems and that theories that solve more problems over time, with less issues, have progressed more than other theories. Sees science more as an evolutionary process, though with some major changes, without the need for Kuhn's model of scientific revolutions.

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Short biography of Milutin Milankovitch and his astronomical theory of the causes of the ice ages. Includes technical description and illustrations of the theory.

Sorlin, S. "Narratives and Counter-Narratives of Climate Change: North Atlantic Glaciology and Meteorology, C. 1930-1955." [In English]. Journal of Historical Geography 35, no. 2 (Apr 2009): 237-55.
Describes the narrative of the history of climate change through describing the scientific work in Stockholm where he found two approaches to the research. One focused on data collection and the other international cooperation and methodology.

Weart, S. R. "Global Warming, Cold War, and the Evolution of Research Plans." Historical Studies in the Physical and Biological Sciences 27 (1997 1997): 319-56.
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Weart, Spencer. *The Discovery of Global Warming*. Cambridge, MA: Harvard University Press, 2008.
History of the theory of human-caused climate change, that is, carbon dioxide, from the early work of Fourier, Tyndall and Arrhenius to the mid- and late-twentieth century research. Provides a timeline of the research and various stages of the acceptance of the

research by the scientific community. Mostly focusses on the second half of the twentieth century.

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Discusses how discovery and proof operates in chemistry contrasting and evaluating it to typical philosophy of science approaches, for example, the logical method, and finds that the discovery of chemical knowledge does not always fit well into the logical approach. Uses historical cases to demonstrate the problems to conclude 'we cannot assume that there is such a thin as a *permanent* refutation." [page 88]

Blair, Thomas A. *Climatology: General and Regional. Climatology: General and Regional*. 1942.
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Brooks, C. E. P. "Geological and Historical Aspects of Climate Change." In Compendium of Meteorology, edited by Thomas F. Malone, 1004-18. Boston: American Meteorological Society, 1951.
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Callendar, G. S. "Infra-Red Absorption by Carbon Dioxide, with Special Reference to Atmospheric Radiation." Quarterly Journal of the Royal Meteorological Society 67, no. 291 (1941): 263-75.
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Fleming, James Rodger. *The Callendar Effect - the Life and Work of Guy Stewart Callendar (1898–1964), the Scientist Who Established the Carbon Dioxide Theory of Climate Change*. Boston, MA: American Meteorological Society, 2007. doi:10.1007/978-1-935704-04-1.
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Fleming, J. R. "Climate, History, Society, Culture: An Editorial Essay." Wiley Interdisciplinary Reviews-Climate Change 1, no. 4 (Jul-Aug 2010): 475-78.
Short editorial essay introducing the journal volume, noting he does not think the history of human-caused climate change has been adequately investigated.

Hulme, M. *Why We Disagree About Climate Change: Understanding Controversy, Inaction and Opportunity*. Cambridge, UK. New York: Cambridge University Press, 2009.
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