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THE CARBON DIOXIDE THEORY OF CLIMATE CHANGE: EMERGENCE, ECLIPSE, AND REEMERGENCE, CA. 1850-1950

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1. INTRODUCTION

This paper examines the discovery of the carbon dioxide theory of climate change, its eclipse during the first five decades of the twentieth century, and its reemergence in the work of G.S. Callendar. It provides historical perspectives on the study of climate dynamics (ΔC/Δt) from the perspective of science dynamics (ΔS/Δt).

2. EMERGENCE

In the second half of the nineteenth century scientists working in distinct specialties identified carbon dioxide as a possible agent in climate change. John Tyndall conducted the first convincing experiments on the radiative properties of gases in 1859 and demonstrated that "perfectly colorless and invisible gases and vapours" were able to absorb and emit radiant heat. (Tyndall 1861). In 1896 Svante Arrhenius published an article on the Earth's heat budget as influenced by variations in the concentration of atmospheric carbon dioxide. Arrhenius demonstrated that variations of atmospheric carbon dioxide concentration could have a very great effect on the overall heat budget and surface temperature of the planet and might be sufficient to have caused ice ages and interglacial periods (Arrhenius 1896). In constructing his model, Arrhenius relied heavily on the experimental and observational work of others, including Josef Stefan's new law of radiant emission, Samuel P. Langley's measurements of atmospheric transmissivity, Léon Teisserenc de Bort's estimates of cloudiness, Knut Ånsgström's absorption coefficients of water vapor and carbon dioxide, Alexander Buchan's charts of mean monthly temperatures, and A.G. Högbom's estimates of the carbon cycle. Significantly, anthropogenic increases of carbon dioxide were not of concern in Arrhenius's paper of 1896 (Fleming 1998).

T.C. Chamberlin also outlined a carbon dioxide theory of glaciation (Chamberlin 1897). He proposed that variations of the carbon dioxide content of the atmosphere combined with water vapor feedbacks could account for the advance and retreat of the ice sheets and other geological puzzles. Using an early notion of an oceanic conveyor belt driven by thermal and saline forcing, Chamberlin attempted to connect his theory to glacial history.

Nils Ekholm, an early and eager spokesman for anthropogenic climate control, pointed out that at present rates, the burning of coal could double the concentration of atmospheric carbon dioxide in the atmosphere and would undoubtedly cause a very obvious rise of the mean temperature of the Earth, possibly preventing the arrival of a new Ice Age as predicted by James Croll's astronomical theory.

3. ECLIPSE

The carbon dioxide climate theory soon fell out of favor, however. In 1900, Knut Ångström concluded that carbon dioxide and water vapor absorb infrared radiation in the same spectral regions. Any additional carbon dioxide, it was argued, would have little or no effect. W.J. Humphreys used these results to argue that a doubling or halving of carbon dioxide, as proposed by Arrhenius, would make no difference in the amount of infrared radiation absorbed by the atmosphere and could not appreciably change the average temperature of the Earth or be at all effective in the production of marked climatic changes. Such negative assessments of carbon dioxide were amplified by Charles Greely Abbot who insisted on the primacy of water vapor as an infrared absorber.

By 1929, G.C. Simpson had pointed out that it was "now generally accepted that variations in carbon-dioxide in the atmosphere, even if they do occur, can have no appreciable effect on the climate." Simpson provided three reasons why this was so: (1) The absorption band of carbon dioxide is too narrow to have a significant effect on terrestrial radiation; (2) The current amount of atmospheric carbon dioxide exerts its full effect and any further addition would have little or no influence; and (3) The water vapor absorption band overlaps and dominates the carbon dioxide band. Such negative assessments of the carbon dioxide theory reached wide audiences through articles on climate change in the U.S.D.A. *Yearbook* for 1941 and in the *Compendium of Meteorology* in 1951.

While the carbon dioxide theory was in eclipse, other mechanisms of climatic change, although highly speculative, were given more credence, especially changes in solar luminosity, atmospheric

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transparency, terrestrial geography, and the Earth's orbital elements. Evidence for glaciation in low latitudes was explained by Wladimir Köppen and Alfred Wegener as the result of continents drifting northward under climate zones controlled mainly by latitude. Although this theory was not widely accepted by geologists, it is now seen as a first step in paleoclimatic reconstruction. In the 1930s, the Serbian astronomer and geophysicist Milutin Milankovic, building on earlier work, outlined a comprehensive "astronomical theory of the ice ages" that viewed them as caused by periodic changes in the Earth's orbital elements. Most scientists of the time supported only one of the major mechanisms of climatic change; some grudgingly admitted that other mechanisms might play a secondary role.

4. RE-EMERGENCE

In 1938, G.S. Callendar, a steam engineer and amateur meteorologist, began the revival of the carbon dioxide theory of climate change (Callendar, 1938). Callendar's work combined recent spectroscopic measurements of the absorption bands of carbon dioxide (including the effect of pressure broadening), measurements of rising concentrations of atmospheric carbon dioxide since pre-industrial times, and evidence of climate warming as documented by long-term station records. Callendar constructed a one-dimensional model in which the ten percent increase in atmospheric carbon dioxide concentration measured since 1900 explained the 0.25 C temperature increase observed over the same period. A doubling of carbon dioxide in his model resulted in a mean global temperature increase of 2 C with greater temperature increases in high latitudes. Even in the depths of World War II, meteorologists noted Callendar's valuable contributions to the study of climatic change.

Between 1953 and 1959, Gilbert Plass developed an early computer model of infrared radiative transfer and published a number of articles on carbon dioxide and climate. Plass used new detailed measurements of the infrared absorption bands and newly available digital computers to replace the older graphical methods. The new carbon dioxide theory also nullified old objections, especially those of Simpson.

In 1957, Roger Revelle and Hans Suess published an oft-cited article on the exchange of carbon dioxide between the atmosphere and ocean. Citing Callendar and Plass, the authors provided new estimates of the sequestering of carbon in the atmosphere, oceans, biosphere, and lithosphere using C^{14} techniques pioneered by Suess. After taking ocean reservoirs and other sinks in to account, Revelle and Suess estimated a twenty to forty percent increase in atmospheric carbon dioxide by the end of the century. Suess and Revelle even referred to rising levels of atmospheric carbon dioxide caused by industrial fuel combustion as the "Callendar effect."

During the IGY, Charles Keeling began a long-term series of carbon dioxide measurements. Since then, the Keeling curve, the famous saw-toothed curve of rising carbon dioxide concentrations, has become *the* environmental icon of the century. Still, many meteorologists pointed out uncertainties in the complex interrelationships among atmospheric composition, solar insolation, cloudiness, evaporation, ocean circulation, and global temperatures.

Between 1938 and about 1958 doubts about the efficacy of carbon dioxide as an agent of climatic change gave way to new theories and observations. Rising temperatures, expanding carbon emissions, new measurements of the radiative properties of trace gases, and new models of the Earth's heat budget and carbon cycle convinced a number of scientists that the carbon dioxide theory needed to be taken seriously. By the early 1950s, with Northern Hemisphere temperatures rising, global warming emerged on the public policy agenda.

5. CONCLUSION

The CO_2 theory of climate change has changed dramatically on timescales of decades to centuries in the period 1850 to 1950 and will likely continue to do so. Since climate ideas—in relation to changes in technology, and social organization of science—can change faster than the climate itself, they are worthy of serious historical study. Clearly, a student of climate dynamics must also study the history of science, here referred to as "science dynamics."

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