Climate Science History

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The relations between meteorology and the upstart climate field ....

were full of friction in the 1970s.

Most of the people who sparked the climate field came into meteorology from other fields.

BUT meteorologists had developed a cogent and powerful world view based around the equations of fluid dynamics and thermodynamics ....

and as a result weather research and forecasting has gone from one triumph to another right up till today.

The two subjects needed to part company for a while to allow the nascent climate science room to grow.
Meteorology history in a nutshell

1800s: Fluid dynamics, Navier-Stokes (many people later adapted these equations for the atmosphere)

before 1910: Core discoveries of temperature profile, stratosphere, ozone, etc.

1910s: Bjerknes: frontal theory of midlat storms

1920s: Richardson: Numerical Weather Prediction

1930s: Rossby: Rossby waves, first radiosondes

1940s: Charney: baroclinic theory of midlat storms
Meteorology history in a nutshell - 2


1960s: Lorenz discovers chaos; field reels

1980s: field adapts to chaos using “ensemble forecasts”

1980s: data assimilation (satellite data much later)

2000s: theoretical limit of weather prediction being approached
Meteorology operated within a paradigm where fluid dynamics was central....

while in climate, radiation is central.

Thus, climate attracted many with a radiation background, including myself.

GFDL* and Manabe were shining lights in moving forward into the new world of climate modeling.

By the late 1980s, many meteorologists had entered climate science and added a lot to it.

Currently, weather and climate are trying to reintegrate under the rubric “seamless prediction”.

I still see them as having very different worldviews.

* NOAA Geophysical Fluid Dynamics Lab, Princeton
Climate science only became a distinct field in the 1980s

Before the 1980s, it was growing mostly within meteorology (where some visionaries supported it)

NOTE: oceanography etc. were not players

Until 1980s, the hallmarks of a field were missing:
- climate meetings, conferences were rare
- Journal of Climate started 1988
- “climate scientist” jobs almost non-existent in universities and gov’t labs

NASA’s Bretherton report defined “Earth System Science” and helped establish the field.
The “Bretherton Report”

Goal: To obtain a scientific understanding of the entire Earth System on a global scale by describing how its component parts and their interactions have evolved, how they function, and how they may be expected to continue to evolve at all time scales.

Report of the Earth System Sciences Committee of the NASA Advisory Council

January, 1988
The “Bretherton Diagram” in its full glory

CONCEPTUAL MODEL of Earth System process operating on timescales of decades to centuries

* = on timescale of hours to days  * = on timescale of months to seasons  φ = flux  n = concentration
The Bretherton Diagram Simplified

(from Earth System Science: An Overview, NASA, 1988)
The Earth System

Air

Water

Land

Life
Earth System Science

- Sun-Earth Connection
- Climate Variability and Change
- Carbon Cycle and Ecosystems
- Earth Surface and Interior
- Atmospheric Composition
- Weather
- Water & Energy Cycle
But the pieces of Earth System Science might have remained disjointed if not for....

the Global Warming problem, or

The CO2 Theory of Climate Change
The great scientists of the 1800s

Global warming theory was much more obviously correct to the physicists, chemists and geologists (Chamberlin) of the 1800s, who had great faith in their simple models and who were just discovering the relevant science.

They applied the new science almost immediately to climate issues and were 100% sure that increased greenhouse gases would warm the climate.

BUT they were much more concerned with ice ages.

The scientists of the 1900s increasingly lost the certainty of their 1800s forebears.
The CO2 Theory of Climate Change: A Timeline of its Rising & Falling Fortunes

1827  Fourier

no radiative transfer theory
no CO2, H2O IR absorption meas’ts
confusion between emission & reflection

1861  Tyndall

first good GG IR absorption measurements
Kirchhoff’s Law, 1859

$\sigma T^4$ (Stefan-Boltzmann Law)

(GG = Greenhouse Gas)
John Tyndall (1820–1893)

Investigated radiant (infrared) heat in 1859.

First to show that H2O, CO2 and hydro-carbons (CH4, etc.) are excellent absorbers of IR radiation and to measure their “absorptive powers”.

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Wiscombe: Climate for Space Scientists
In the sequel I shall refer to circumstances which induce me to conclude that the result obtained by Dr. Franz is due to an
inadherence in his mode of observation. These are the only
experiments of this nature with which I am acquainted, and
they leave the field of inquiry now before us perfectly unbroken
ground.

§ 2. At an early stage of the investigation, I experienced the
need of a first-class galvanometer. My instrument was con-
structed by that excellent workman, Suernerwald of Berlin. The
needles are suspended independently of the shade; the latter is
constructed so as to enclose the smallest possible amount of air,
the disturbance of aerial currents being thereby practically
avoided. The plane glass plate, which forms the cover of the
instrument, is close to the needle; so that the position of the
latter can be read off with ease and accuracy either by the naked
eye or by a magnifying lens.

The wire of the coil belonging to this instrument was drawn
from copper obtained from a galvano-plastic manufactory in the
Prussian Capital; but it was not free from the magnetic metals.

In consequence of its impurity in this respect, when the
needles were perfectly atactic they deviated as much as 30° right
and left of the neutral line. To neutralize this, a “compensator”
was made use of, by which the needle was gently drawn to zero
in opposition to the magnetism of the coi.

But the instrument suffered much in point of delicacy from
this arrangement, and accurate quantitative determinations with
it were unattainable. I therefore sought to replace the Berlin
coil by a less magnetic one. Mr. Becker first supplied me with
a coil which reduced the lateral deflection from 30° to 3°.

But even this small residue was a source of great annoyance
to me; and for a time I almost despaired of obtaining pure copper
wire. I knew that Professor Magnus had succeeded in ob-
taining it for his galvanometer, but the labour of doing so was
immense. Previous to undertaking a similar task, the thought
occurred to me, that for my purpose a magnet furnished an
immediate and perfect test as to the quality of the wire. Pure
copper is diamagnetic; hence its repulsion or attraction by the
magnet would at once declare its fitness or unfitness for the
purpose which I had in view.

Frigments of the wire first furnished to me by M. Suernerwald
were strongly attracted by the magnet. The wire furnished by
Mr. Becker, when covered with its green silk, was also attrac-
ted, though in a much feebler degree.

I then removed the green silk covering from the latter and
tested the naked wire. It was repelled. The whole annoyance

* From the Philosophical Transactions, Part I. for 1861, having been
on record at the Royal Society February 7, 1861.
+ La Thermoélectricité, p. 126.
Tyndall's apparatus for greenhouse gas meas'ts
Greenhouse Gas absorption bands in IR
“Those who, like myself, have been taught to regard transparent gases as almost perfectly diathermanous, will probably share the astonishment with which I witnessed the foregoing effects. I was slow to believe it possible that olefiant gas, so transparent to light, could be so densely opaque to any kind of calorific rays.”

(olefiant gas = ethylene = C2H4)
“Now if, as the above experiments indicate, the chief influence be exercised by the aqueous vapor, every variation of this constituent must produce a change of climate.

Similar remarks would apply to the carbonic acid (CO2) diffused through the air, while an almost inappreciable admixture of any of the hydrocarbon vapors would produce great effects on the terrestrial [infrared] rays and corresponding changes of climate...

A slight change in these variable constituents may have produced all the mutations of climate which the researches of geologists reveal.”
Timeline – 1880s to 1911

1880s Langley

1896 Arrhenius

Planck’s Radiation Law (1900)

Two-stream radiative transfer theory (Schuster, 1905)

Earth energy budget (Dines, 1911)
Samuel Langley (1834-1906), American physicist & engineer

Invented bolometer in 1878
Sensitive to very small differences in temperature.

His bolometer could detect IR radiation from a cow 1/4 mile away!
Langley used his bolometer to “map” IR portion of the solar & lunar spectra

Arrhenius used Langley’s IR gas absorption data in his climate model (the first such model).

Langley became deeply interested in the problem of variable solar radiation;
- in 1904 found that “solar constant” is variable;
- also tried to find sunspot effects on Earth.

Thus beginneth a short sidebar: Sun-climate connections have been a staple for >100 yr.
The “solar constant”  
(now TSI = Total Solar Irradiance)

In Langley’s time, atmospheric interference restricted measurements of TSI to 1-3%.

They assumed TSI was constant except for 11- and 22-yr sunspot cycles
Total Solar Irradiance, Kopp & Lean, GRL 2011

(Older meas’ts contaminated by scattered light in instrument)
In Arrhenius’ time (1896), ...

It would have been easy to ascribe all climate change to the Sun, since so little was known about TSI (to the 0.1% accuracy required for climate work).

But Arrhenius didn’t take this easy path. He saw the key role that $CO_2$ had to play.
Svante Arrhenius (1859-1927), Swedish physical chemist

XXXI. On the Influence of Carbonic Acid in the Air upon the Temperature of the Ground. By Prof. Svante Arrhenius.

1. Introduction: Observations of Langley on Atmospheric Absorption.

A great deal has been written on the influence of the absorption of the atmosphere upon the climate. Tyndall has pointed out the enormous importance of this question. To him it was chiefly the diurnal and annual variations of the temperature that were lessened by this circumstance. Another side of the question, that has long attracted the attention of physicists, is this: Is the mean temperature of the ground in any way influenced by the presence of heat-absorbing gases in the atmosphere? Fourier maintained that the atmosphere acts like the glass of a hot-house, because it lets through the light rays of the sun but retains the dark rays from the ground. This idea was elaborated by Pousille; and Langley was by some of his researches led to the view, that the temperature of the earth under direct sunshine, even though our atmosphere were present as now, would probably fall to 200°C, if that atmosphere did not possess the quality of selective absorption.

* Extract from a paper presented to the Royal Swedish Academy of Sciences, 11th December, 1893. Communicated by the Author.

“A great deal has been written about the influence of the absorption of the atmosphere upon the climate.”

(first sentence of Arrhenius 1896 paper)

Has the CO2-climate problem, then, riveted the attention of scientists for so long?

No. The obituary of the CO2 theory of climate change has repeatedly been written by its critics.
**Motivation:** Ice Ages

**Method:** pure energy balance model with 21-waveband IR radiation calculation \((\sigma T^4)\)

**Results:** change in surface temperature is

\[
\Delta T_s = 5\,^\circ C \text{ for } 2 \times \text{CO2}
\]

\[
\Delta T_s \sim \log [\text{CO2}]
\]
Arrhenius' two energy balance equations

For a column of air we have the following expression:

\[ n\sigma T_s^4 = n\sigma (1 - a) \left( T_s^4 - T_A^4 \right) + \alpha S + M \]  \hspace{1cm} (I)

and for the surface:

\[ n\sigma (1 - a) \left( T_s^4 - T_A^4 \right) = \]

\[ (1 - n) \sigma (1 - a) T_s^4 + (1 - \alpha) (1 - a) S + N \]  \hspace{1cm} (II)

where:  
- \( n \) is the absorption coefficient for long wave radiation  
- \( \sigma \) Stefan Bolzmanns constant  
- \( a \) albedo  
- \( S \) solar radiation (1/4 of the solar constant)  
- \( \alpha \) atmospheric absorption of short wave radiation  
- \( M \) atmospheric net heat transport  
- \( N \) net heat exchange with the ground

The temperature of the air can easily be eliminated which gives the following expression:

\[ T_s^4 = \frac{K}{1 + (1 - a) (1 - n)} \]  \hspace{1cm} (III)

where

\[ K = \frac{\alpha S + M + (1 - \alpha) (2 - a) + N \left( 1 + \frac{1}{1 - a} \right)}{\sigma} \]

is considered as a constant.

*Arrhenius (1896)*
Arrhenius solved for how much warmer the surface temp is due to greenhouse

\[ T^4 = K / (2 - \varepsilon_a) \]

\( \varepsilon_a \) = atmospheric emissivity \( \sim 0.7 \) now

\( T_0 \) = surface temperature for \( \varepsilon_a = 0 \) (no greenhouse)

\( T_0 = 288K \implies T - T_0 = -28K \)

(Manabe 1968: \( -30K \))
Arrhenius was far in advance of his time

Role of carbon cycle, including coal-burning (rediscovered 1950s).

$CO_2$ rising in atmosphere due to human industry. (rediscovered 1950s)

$H_2O$ could only be a feedback not a cause (forcing) of climate change.

$H_2O$ feedback with fixed relative humidity (rediscovered Moller, Manabe/Wetherald, 1967)

Ice-albedo feedback (rediscovered Budyko, 1969)
Arrhenius’ Swedish colleague Angstrom was the first “climate skeptic”

In 1900, Angstrom measured the transmission of IR radiation thru a tube filled with CO2
   -(somewhat less than CO2 column amount in air)

Then he reduced the amount of CO2 by 1/3

The transmission changed by only 0.4%

He concluded that the greenhouse effect of CO2 was already saturated.
Disbelief Period #1

CO2 IR absorption bands are “saturated”

H2O absorbs in same IR spectral region

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Wiscombe: Climate for Space Scientists
Beginnings of climate theory in 1920s

Milankovitch theory: Ice Ages caused by variations in Earth’s orbit and by resulting var’ns in amount of sunlight received at northern latitudes.

Plate tectonics, essential to understand ancient climates, proposed by Wegener in 1920s but rejected by geologists (and by Brooks).