Climate Science History

Warren Wiscombe

NASA Goddard

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

1950s: von Neumann: computers for Numerical Weather Prediction

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

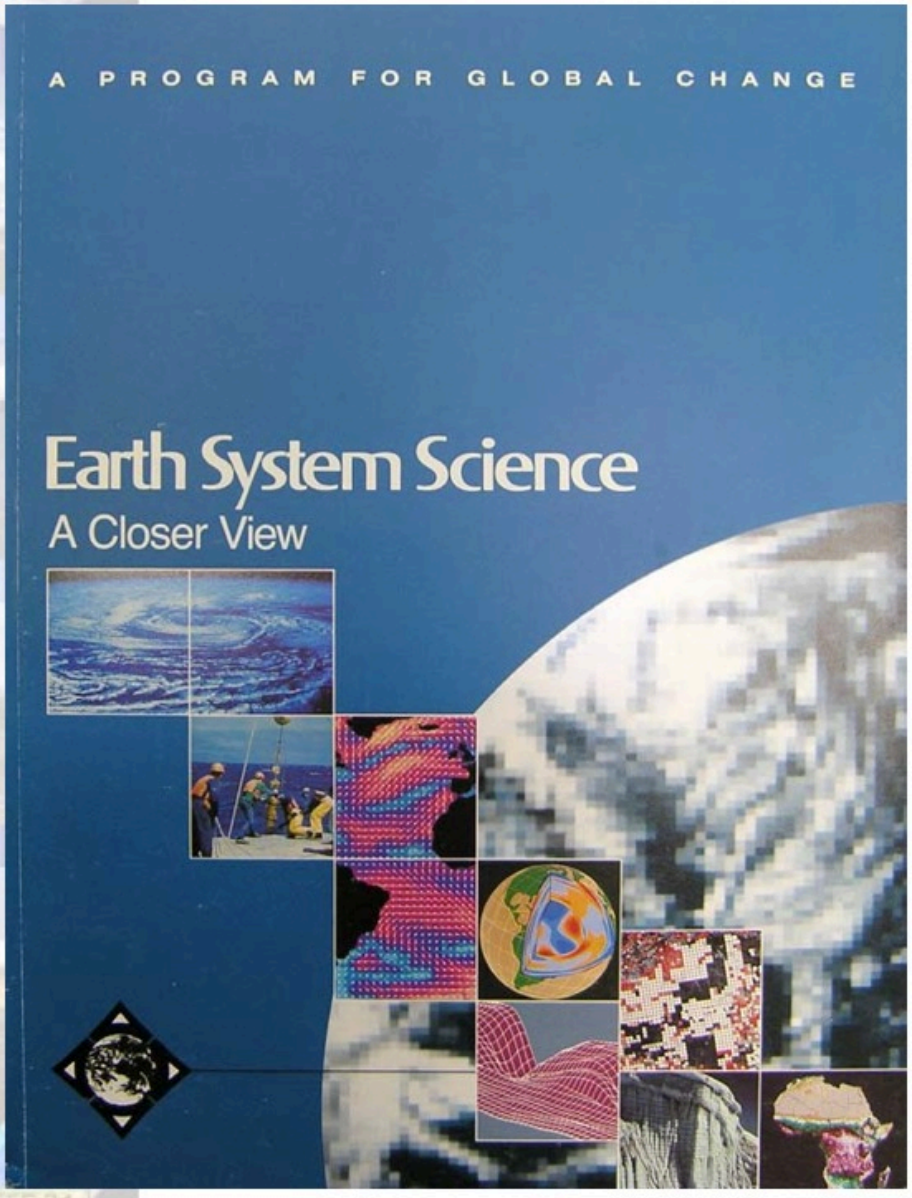
Before the 1980s, it was growing mostly within meteorology (where some visionaries supported it)

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.



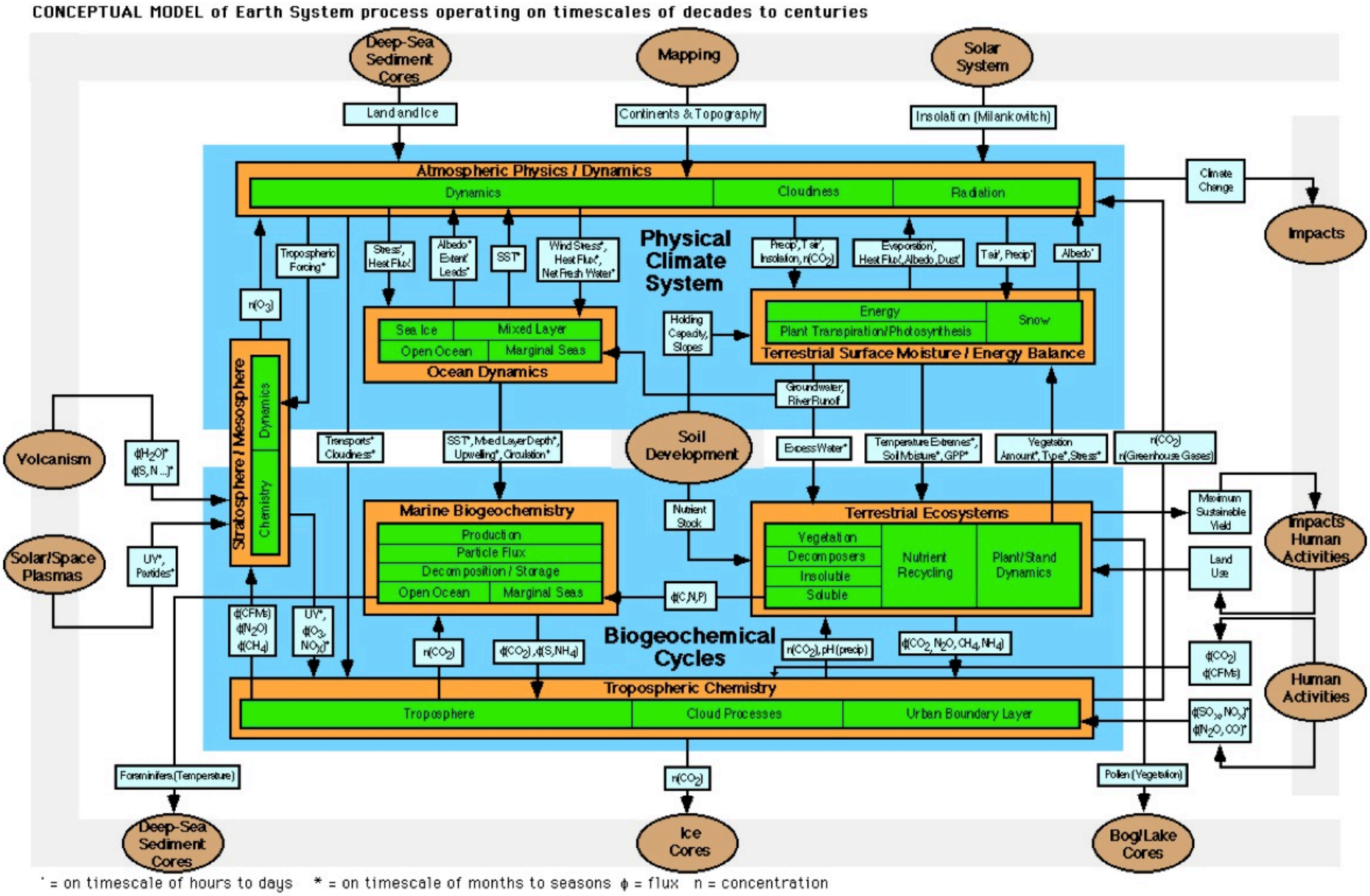
The "Bretherton Report"

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.

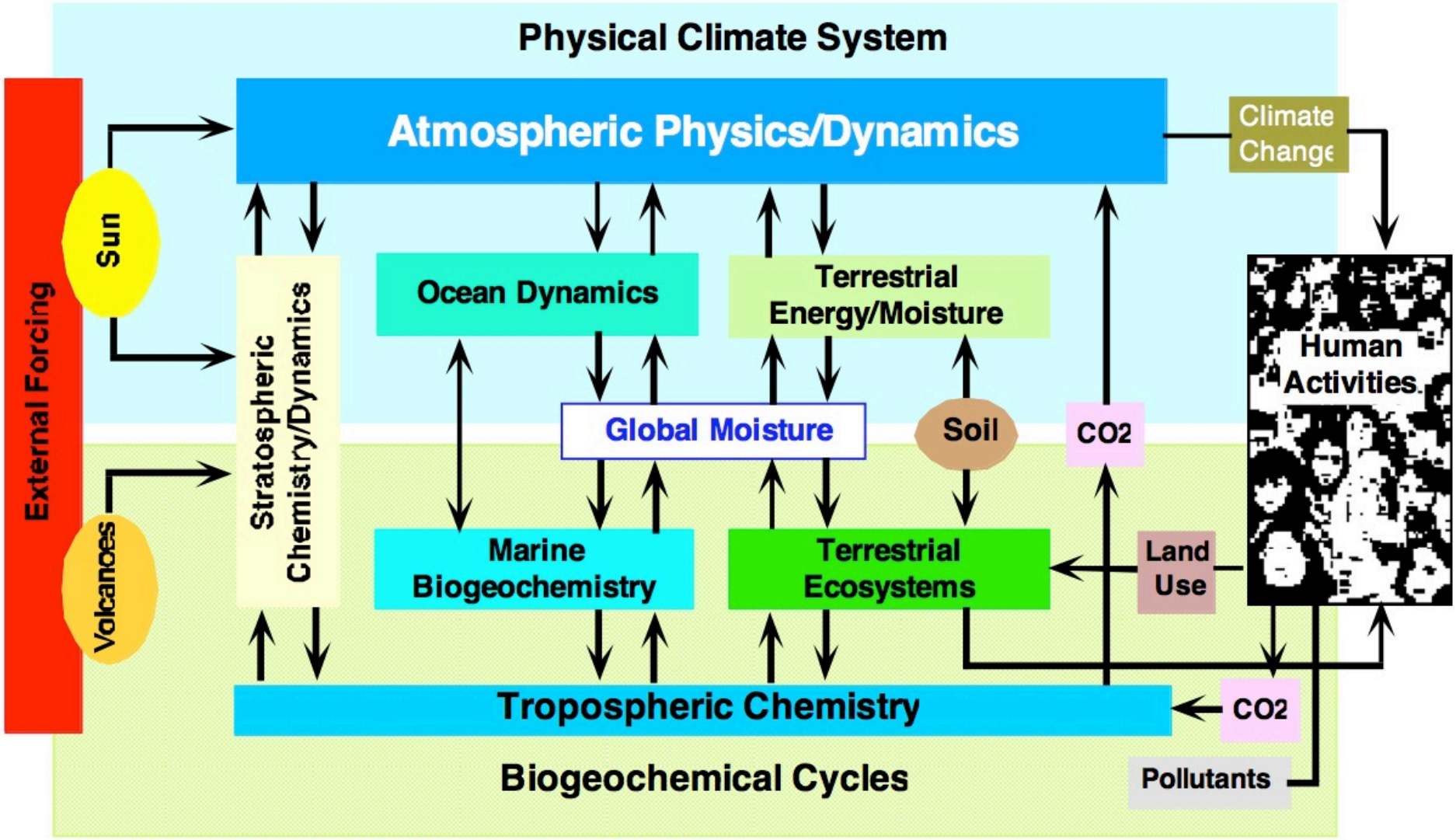
Report of the Earth System Sciences Committee of the
NASA Advisory Council

January, 1988

The "Bretherton Diagram" in its full glory

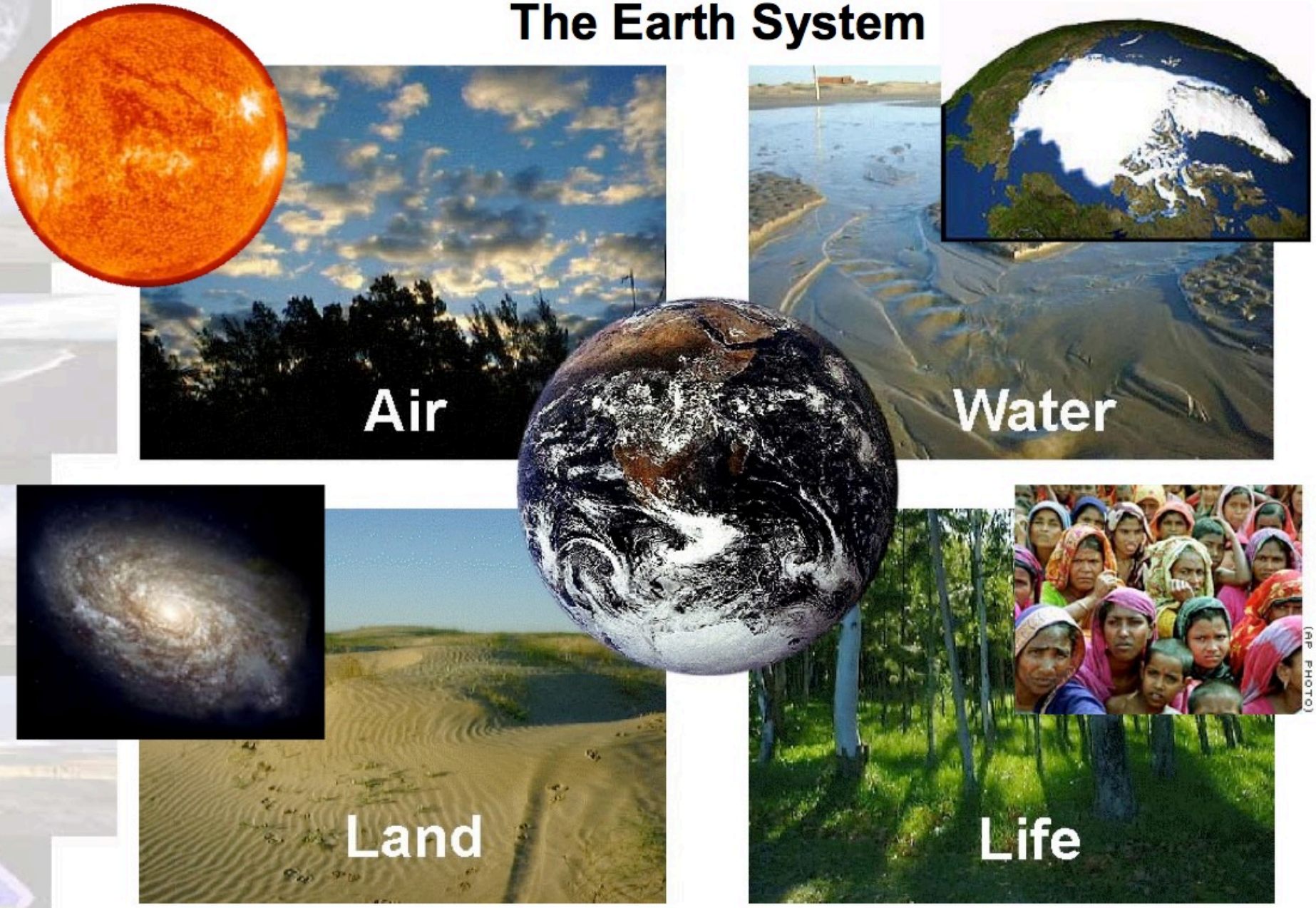


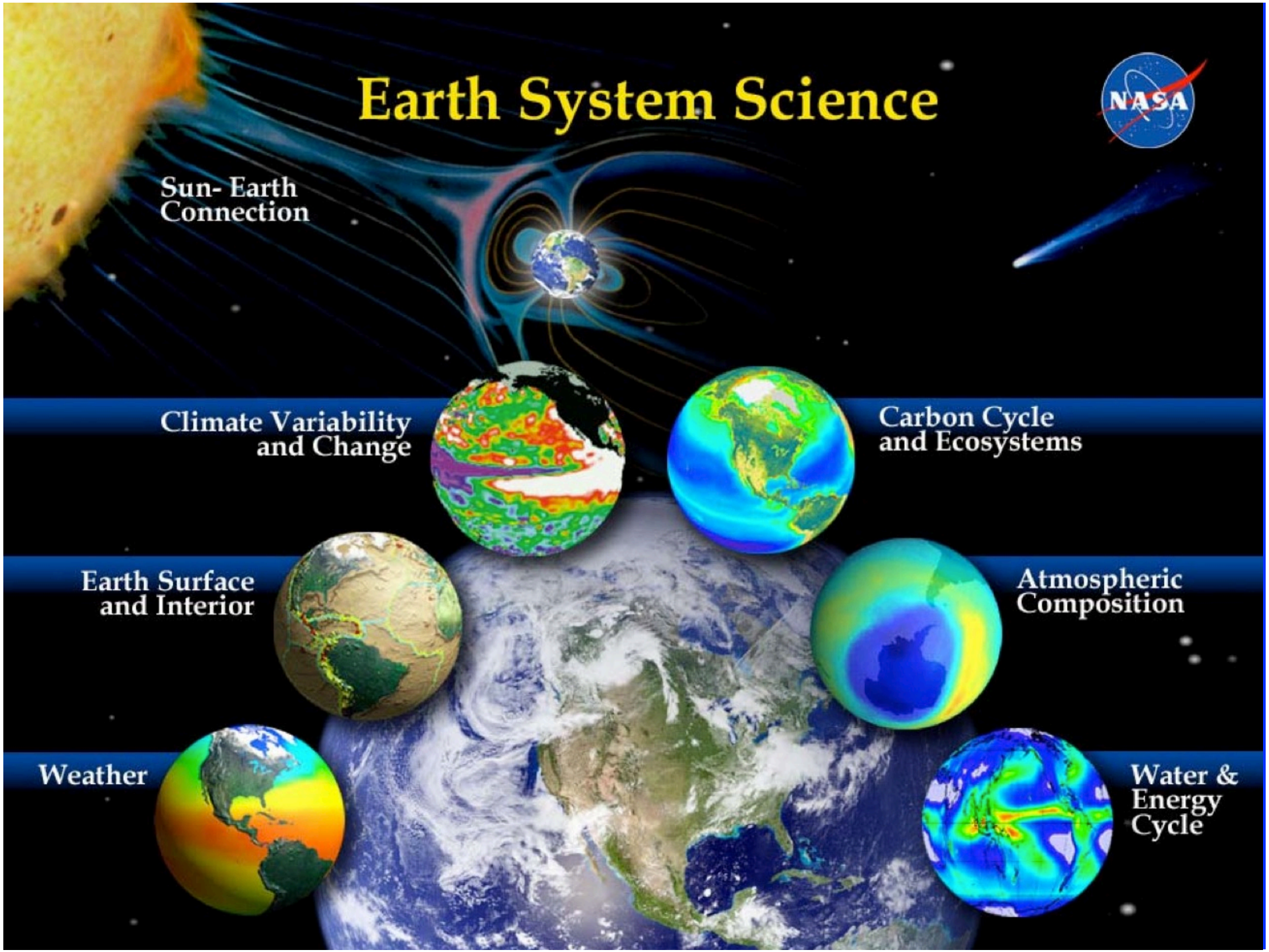
The Bretherton Diagram Simplified



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

The Earth System




Earth System Science
NASA
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

Book: Spencer Weart, "The Discovery of Global Warming", 2nd ed. 2009

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

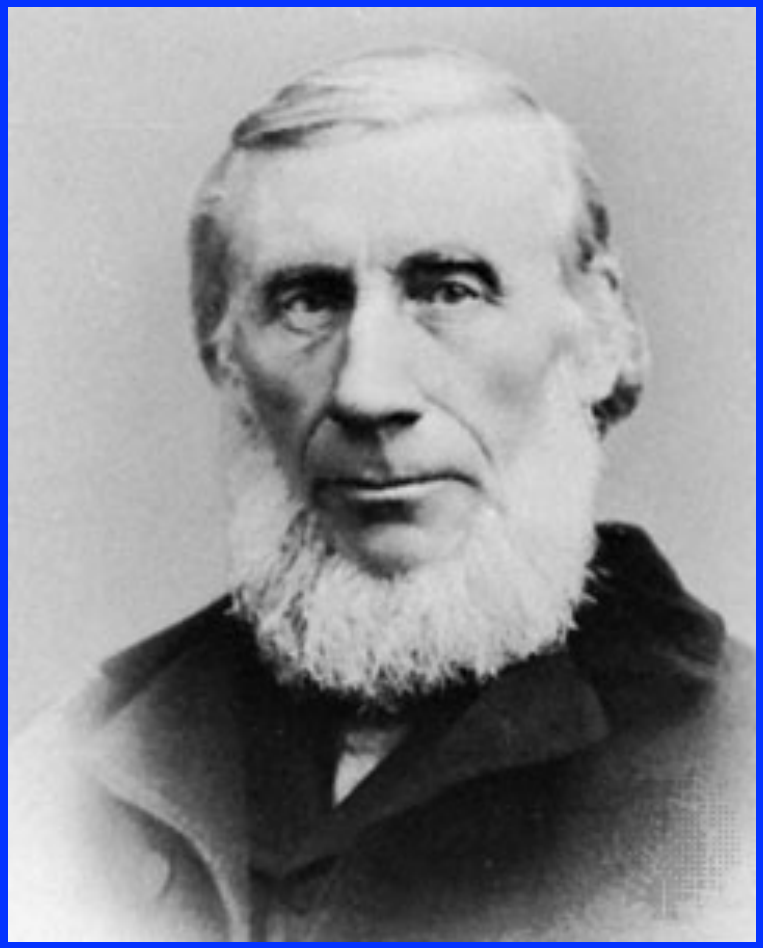
first good GG IR absorption measurements

Kirchhoff's Law, 1859

σT^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".

THE
LONDON, EDINBURGH AND DUBLIN
PHILOSOPHICAL MAGAZINE
AND
JOURNAL OF SCIENCE.

[FOURTH SERIES.]

SEPTEMBER 1861.

XXIII. *On the Absorption and Radiation of Heat by Gases and Vapours, and on the Physical Connexion of Radiation, Absorption, and Conduction.—The Bakerian Lecture.* By JOHN TYNDALL *Esq., F.R.S. &c.**

[With a Plate.]

§ 1. THE researches on glaciers which I have had the honour of submitting from time to time to the notice of the Royal Society, directed my attention in a special manner to the observations and speculations of De Saussure, Fourier, M. Pouillet, and Mr. Hopkins, on the transmission of solar and terrestrial heat through the earth's atmosphere. This gave practical effect to a desire which I had previously entertained to make the mutual action of radiant heat and gases of all kinds the subject of an experimental inquiry.

Our acquaintance with this department of Physics is exceedingly limited. So far as my knowledge extends, the literature of the subject may be stated in a few words.

From experiments with his admirable thermo-electric apparatus, Melloni inferred that for a distance of 18 or 20 feet the absorption of radiant heat by atmospheric air is perfectly insensible†.

With a delicate apparatus of the same kind, Dr. Franz of Berlin found that the air contained in a tube 3 feet long absorbed 3·54 per cent. of the heat sent through it from an Argand lamp; that is to say, calling the number of rays which passed through the exhausted tube 100, the number which passed when the tube was filled with air was only 96·46‡.

* From the Philosophical Transactions, Part I. for 1861, having been read at the Royal Society February 7, 1861.

† *La Thermochrose*, p. 136. ‡ Pogg. *Ann.* vol. xciv. p. 342.

In the sequel I shall refer to circumstances which induce me to conclude that the result obtained by Dr. Franz is due to an inadvertence 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 constructed by that excellent workman, Sauerwald 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 aërial 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 astatic 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 coil.

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 obtaining 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.

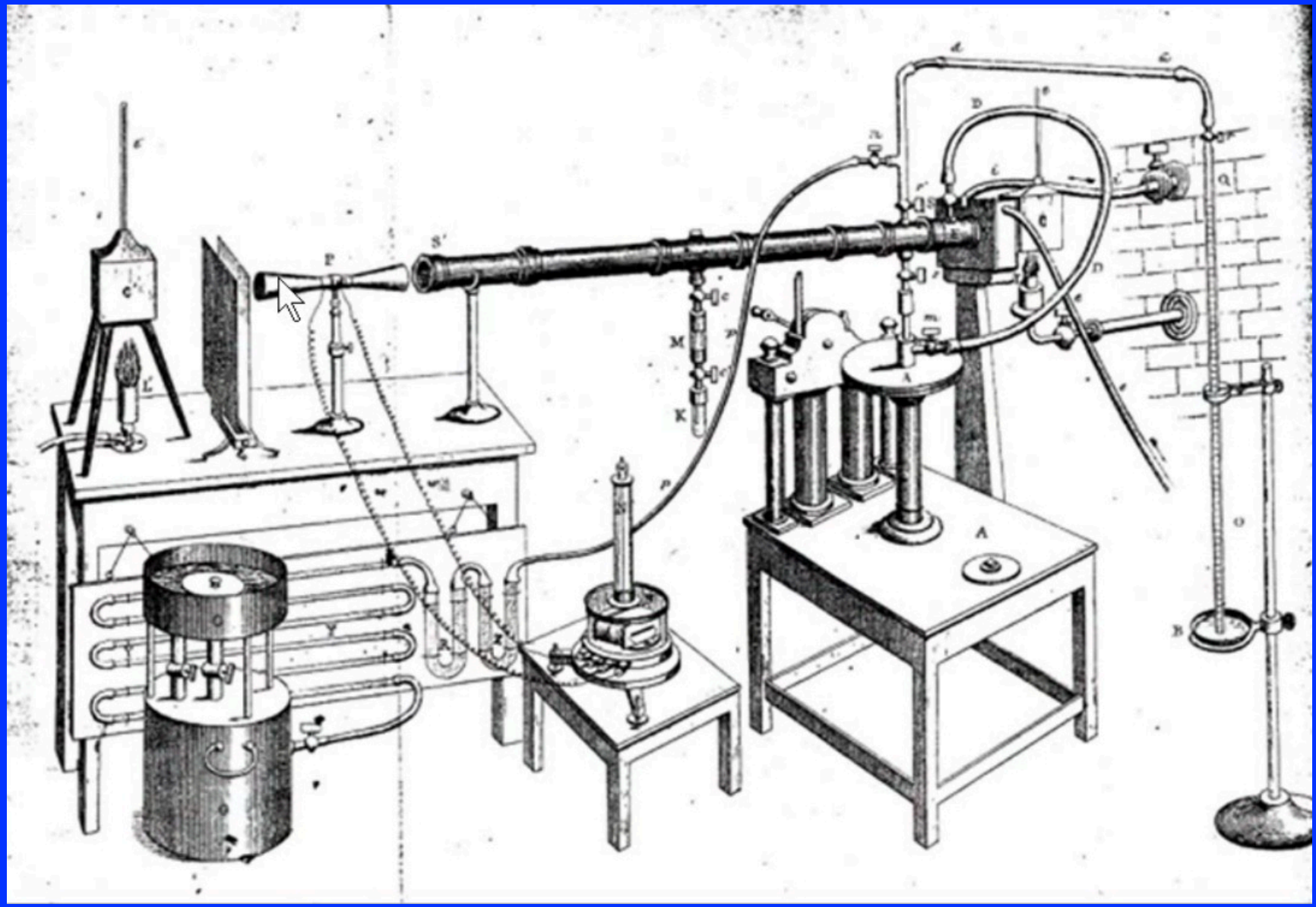
Fragments of the wire first furnished to me by M. Sauerwald were strongly attracted by the magnet. The wire furnished by Mr. Becker, when covered with its green silk, was also attracted, though in a much feebler degree.

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

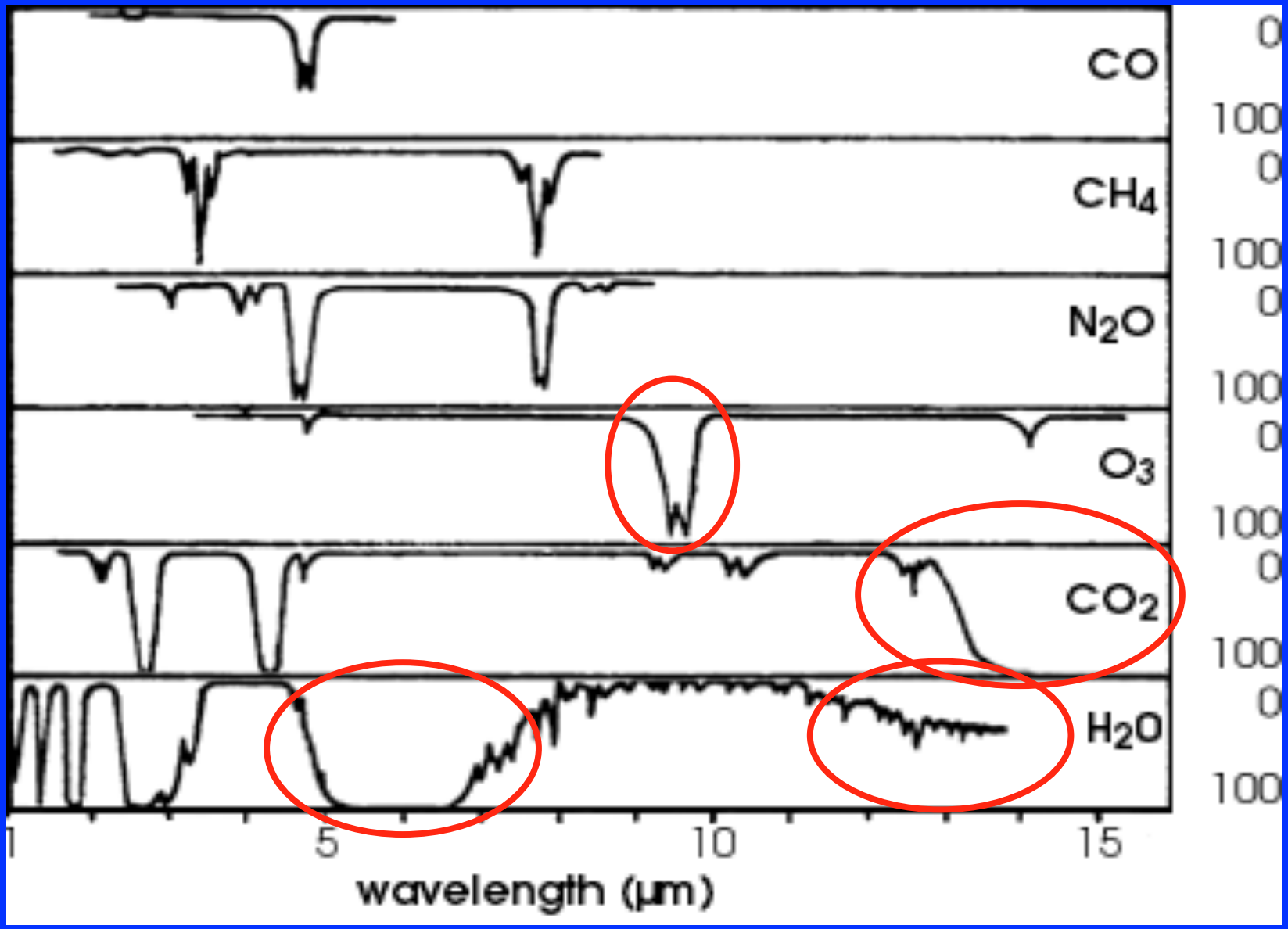
* Pogg. *Ann.* vol. lxxxiii. p. 489; and Phil. Mag. 1852, vol. iii. p. 82.

Classic Tyndall 1861 paper on IR absorption by trace gases

Tyndall's apparatus for greenhouse gas meas'ts



Greenhouse Gas absorption bands in IR



Tyndall (1861 paper)

"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)

Tyndall quotes on climate

"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

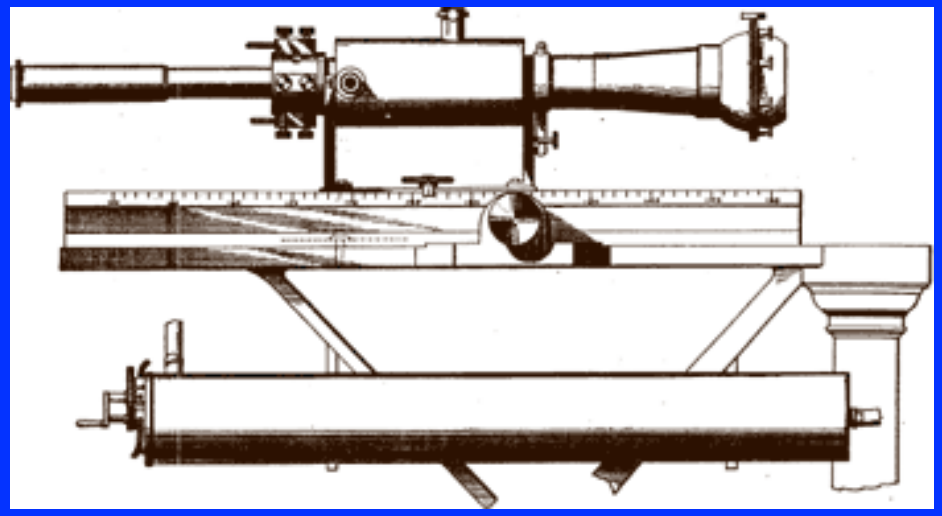
1896 Arrhenius

Planck's Radiation Law (1900)

Two-stream radiative transfer theory (Schuster, 1905)

Earth energy budget (Dines, 1911)

Langley: Measuring temperatures remotely



Invented bolometer in 1878

Sensitive to very small differences in temperature.

Samuel Langley (1834-1906), American physicist & engineer

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.

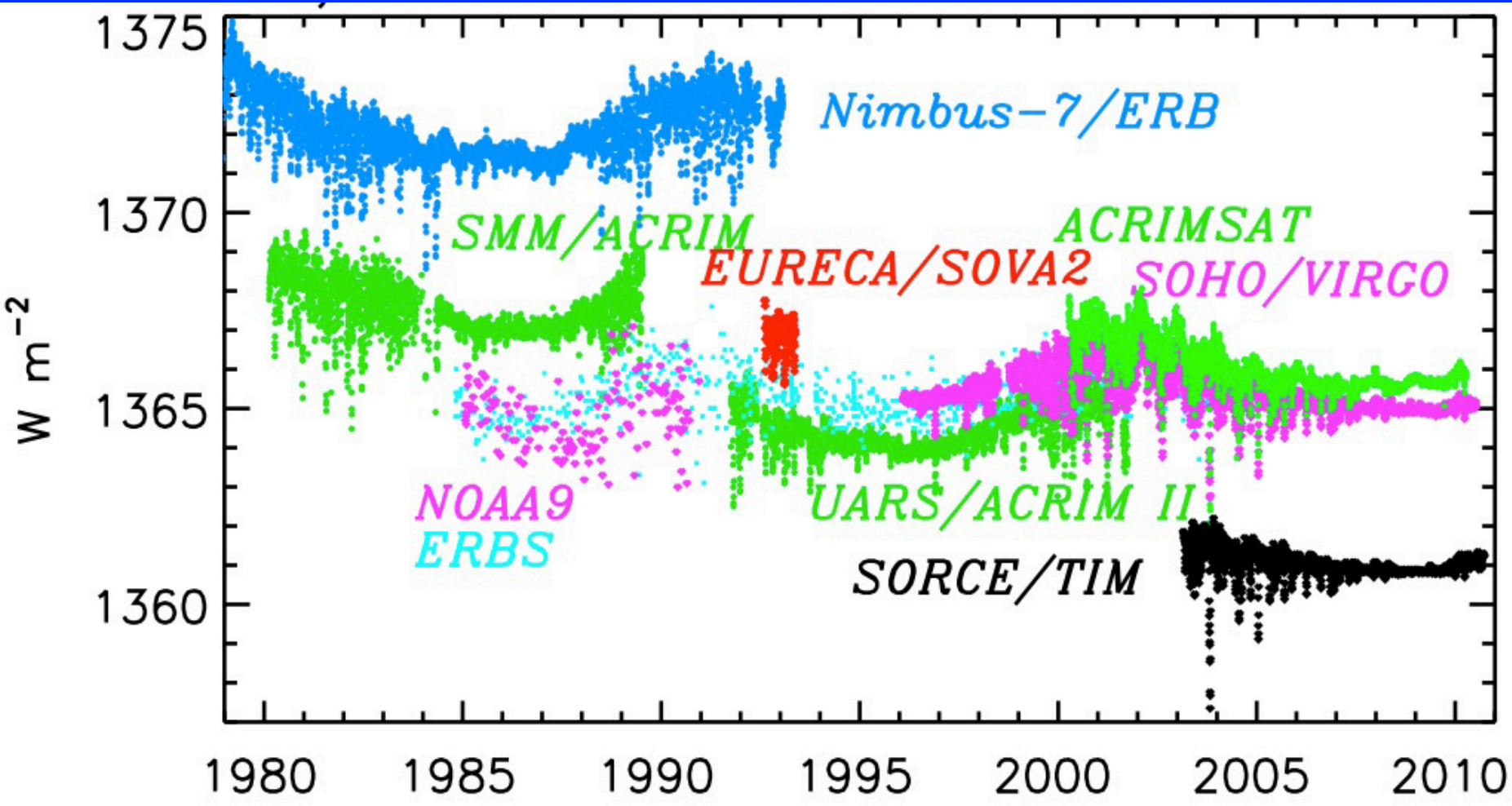
Thus beginneth a short sidebar: Sun-climate connections have been a staple for >100 yr.

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

THE

LONDON, EDINBURGH, AND DUBLIN

PHILOSOPHICAL MAGAZINE

AND

JOURNAL OF SCIENCE.

[FIFTH SERIES.]

APRIL 1896.

XXXI. *On the Influence of Carbonic Acid in the Air upon the Temperature of the Ground.* *By* Prof. SVANTE ARRHENIUS *

I. *Introduction: Observations of* Langley *on Atmospherical Absorption.*

A GREAT deal has been written on the influence of the absorption of the atmosphere upon the climate. Tyndall † in particular 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 Pouillet §; 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

* Extract from a paper presented to the Royal Swedish Academy of Sciences, 11th December, 1895. Communicated by the Author.

† 'Heat a Mode of Motion,' 2nd ed. p. 405 (Lond. 1865).

‡ *Mém. de l'Ac. R. d. Sci. de l'Inst. de France*, t. vii. 1827.

§ *Comptes rendus*, t. vii. p. 41 (1838).

"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.

Arrhenius (1896)

Motivation: Ice Ages

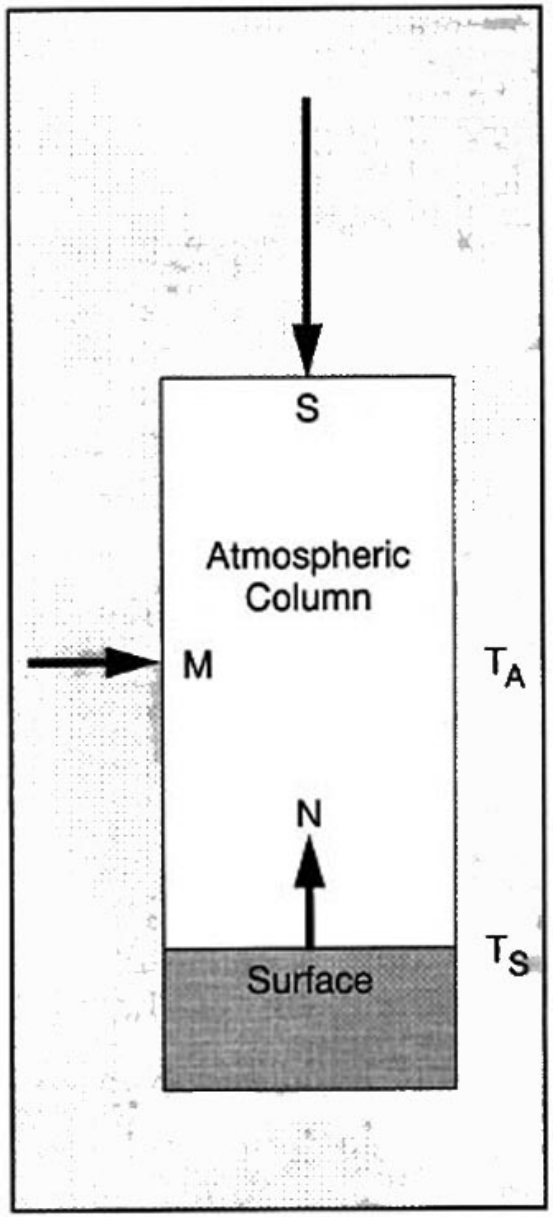
Method: pure energy balance model with 21-waveband IR radiation calculation (σT^4)

Results: change in surface temperature is

ΔT_s = 5C for 2 x CO2

$\Delta T_s \sim \log [CO2]$

Arrhenius' two energy balance equations



For a column of air we have the following expression:

$$\nu\sigma T_S^{\,4} = \nu\sigma(1-a)\left(T_S^{\,4} - T_A^{\,4}\right) + \alpha S + M \qquad \text{(I)}$$

and for the surface:

$$\nu\sigma(1-a)\left(T_S^{\,4} - T_A^{\,4}\right) =$$

$$(1-\nu)\,\sigma(1-a)\,T_S^{\,4} + (1-\alpha)(1-a)S + N \qquad \text{(II)}$$

where:
- ν is the absorption coefficient for long wave radiation
- σ Stefan Bolzmanns constant
- a albedo
- S solar radiation (1/4 of the solarconstant
- α atmospheric absorption of short wave radiation
- M atmopheric net heat transport
- N net heat exchange with the ground

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

$$T_S^{\,4} = \frac{K}{1 + (1-a)(1-\nu)} \qquad \text{(III)}$$

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

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

ε_a = atmospheric emissivity ~ 0.7 now

T_0 = surface temperature for ε_a= 0 (no greenhouse)

T_0 = 288K ===> $T - T_0 = -28K$

(Manabe 1968: - 30K)

Arrhenius was far in advance of his time

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

CO2 rising in atmosphere due to human industry. (rediscovered 1950s)

H2O could only be a feedback not a cause (forcing) of climate change.

H2O 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

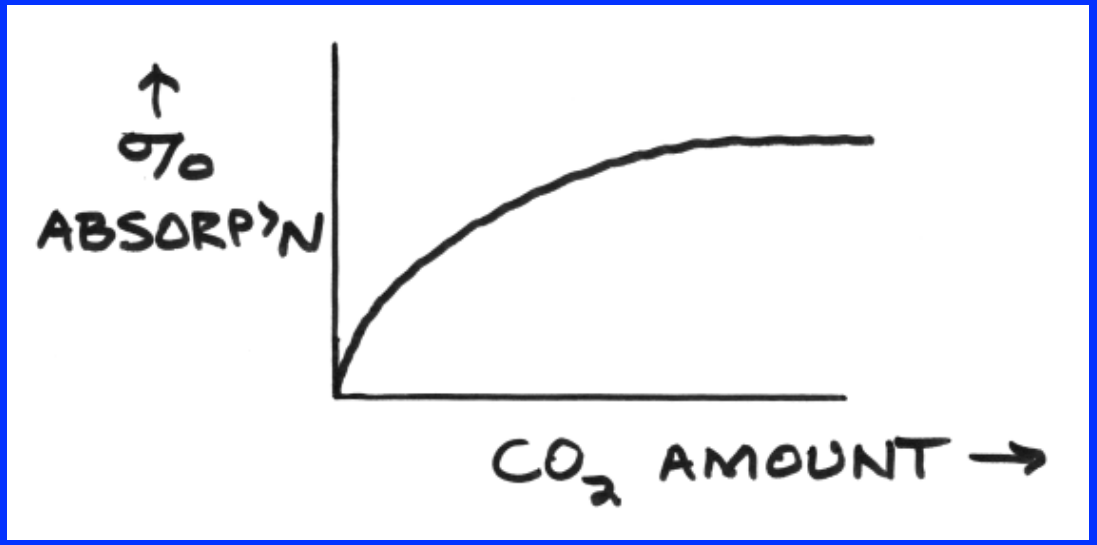
- (somewhat less than CO2 column amount in air)

Then he reduced the amount of CO2 by 1/3

The transmission changed by only 0.4%

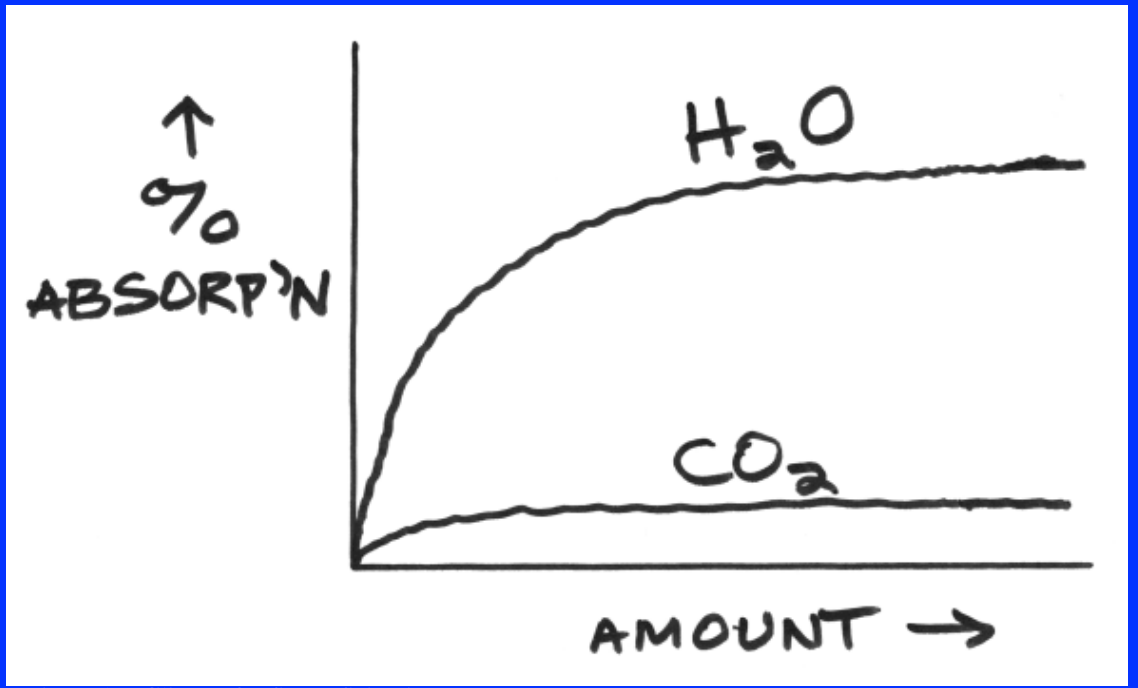
He concluded that the greenhouse effect of CO2 was already saturated.

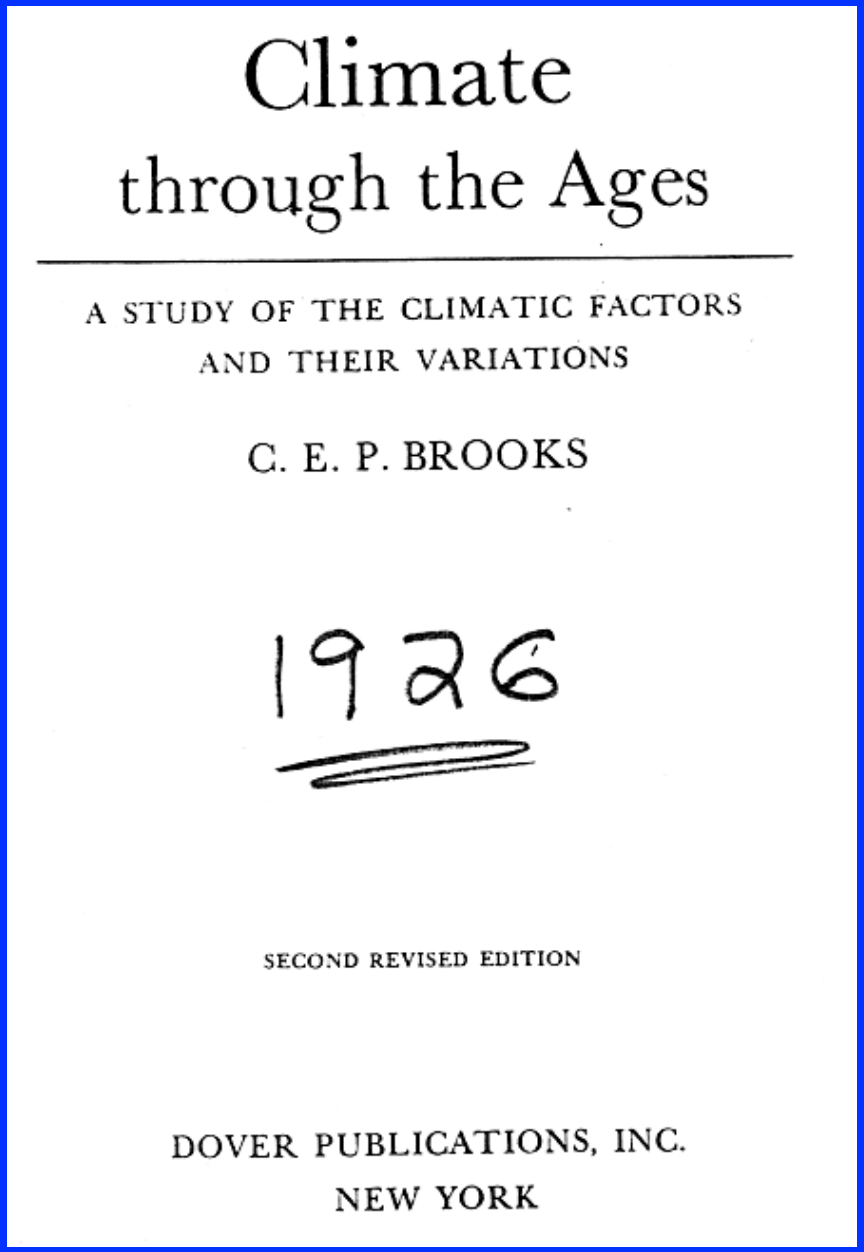
Disbelief Period #1



CO2 IR absorption bands are "saturated"

H2O absorbs in same IR spectral region





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).