# A historical approach to climate science

Early investigations to first warnings

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# The modern view

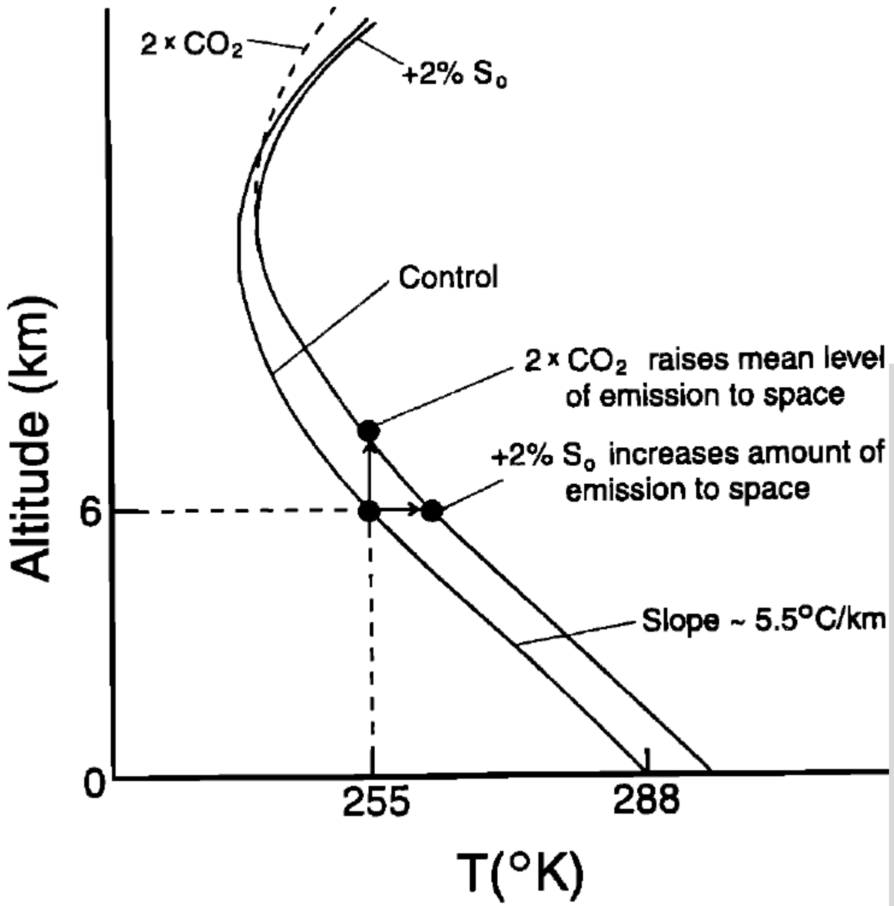


**Figure 3.** Cartoon of global mean greenhouse effect and alterations by radiative forcings. A solar irradiance increase of 2% increases the energy absorbed by the troposphere about 4.5 W/m². Doubling of atmospheric $CO_2$ decreases thermal emission to space almost the same amount after the stratospheric temperature has adjusted. In either case the tropospheric temperature must rise by about 1.2-1.3°C to restore planetary energy balance if the tropospheric lapse rate and other climate feedbacks are not allowed to change. The temperature profile is schematic and $\Delta T$ is exaggerated; the temperature minimum and the level at which the $CO_2$ effect switches from warming to cooling both occur in the 15-18 km range.

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# Radiative forcing and climate response

J. Hansen, M. Sato, and R. Ruedy

NASA Goddard Institute for Space Studies, New York

nature geoscience PROGRESS ARTICLE
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# An update on Earth's energy balance in light of the latest global observations

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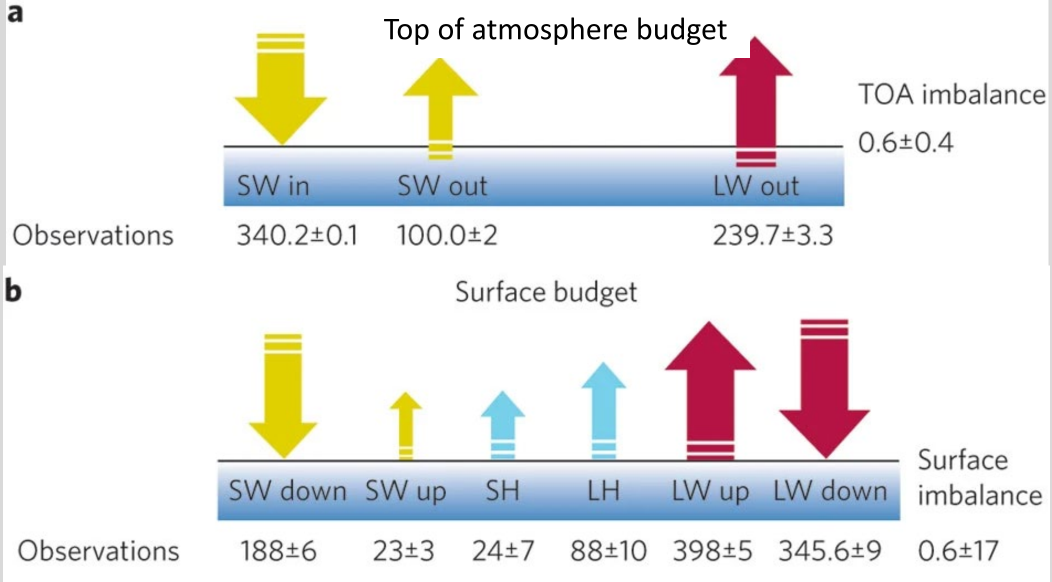
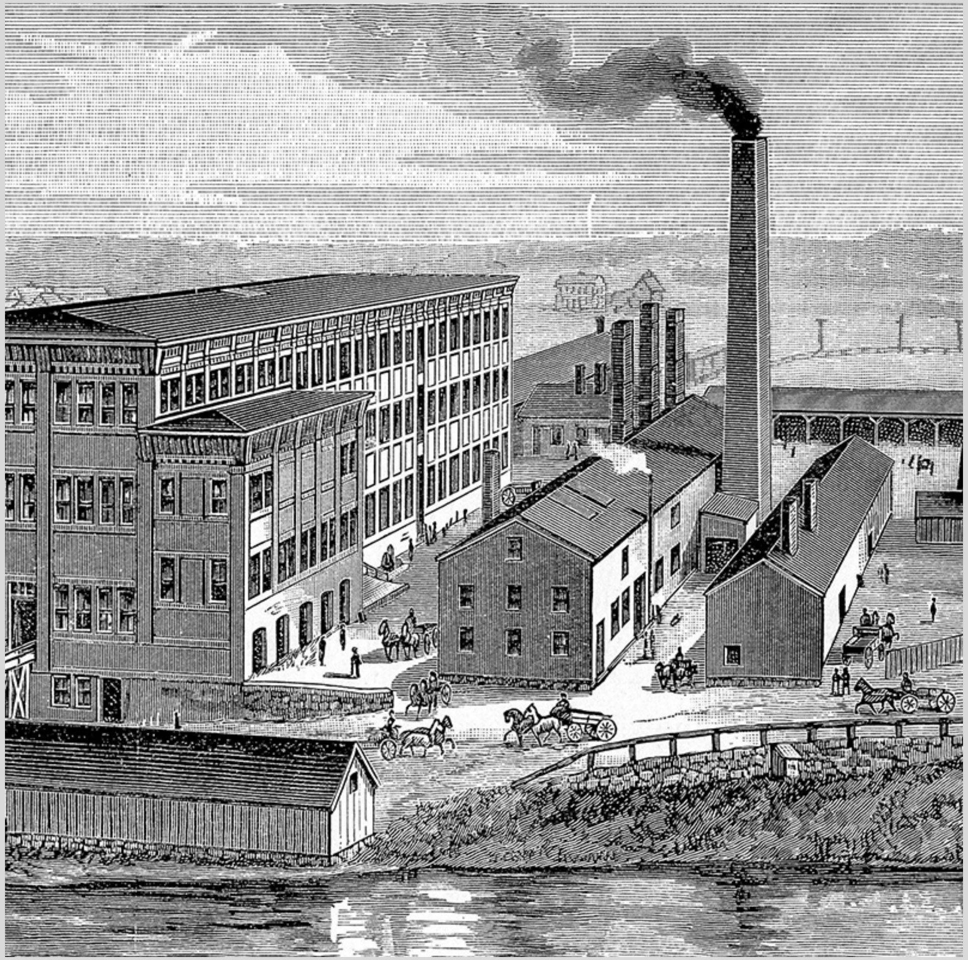


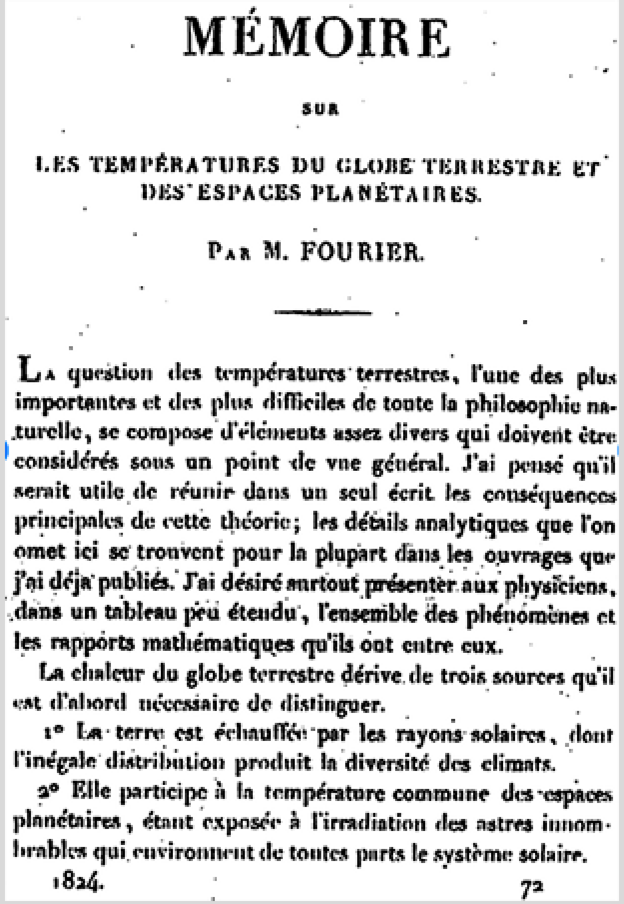
# A historical approach to climate science



1760

Since the start of the Industrial Revolution, the way people live and work has changed dramatically as manufacturing expanded. Over time, the amount of fossil fuels burned increased, which has increased the amount of carbon dioxide ($CO_2$) in the atmosphere . Before the Industrial Revolution, there was approximately 280 parts per million (ppm) of $CO_2$ in the air. Today, that amount is over 400 ppm.

## INDUSTRIAL REVOLUTION BEGINS



# MÉMOIRE

SUR

## LES TEMPÉRATURES DU GLOBE TERRESTRE ET DES ESPACES PLANÉTAIRES.

PAR M. FOURIER.

La question des températures terrestres, l'une des plus importantes et des plus difficiles de toute la philosophie naturelle, se compose d'éléments assez divers qui doivent être considérés sous un point de vue général. J'ai pensé qu'il serait utile de réunir dans un seul écrit les conséquences principales de cette théorie; les détails analytiques que l'on omet ici se trouvent pour la plupart dans les ouvrages que j'ai déjà publiés. J'ai désiré surtout présenter aux physiciens, dans un tableau peu étendu, l'ensemble des phénomènes et les rapports mathématiques qu'ils ont entre eux.

La chaleur du globe terrestre dérive de trois sources qu'il est d'abord nécessaire de distinguer.

1° La terre est échauffée par les rayons solaires, dont l'inégale distribution produit la diversité des climats.

2° Elle participe à la température commune des espaces planétaires, étant exposée à l'irradiation des astres innombrables qui environnent de toutes parts le système solaire.

1824. 72

1824

Jean-Baptiste-Joseph Fourier, a mathematician working for Napoleon, was the first to describe how Earth's atmosphere retains warmth on what would otherwise be a very cold planet.. To help explain the concept, he compared the atmosphere to the glass walls of a greenhouse.

**DESCRIBING EARTH'S ATMOSPHERE AS A GREENHOUSE**

https://scied.ucar.edu/learning-zone/how-climate-works/history-climate-science-research

## FOURIER 1824:

The earth would have only the same temperature with the heavens, were it not for two causes which are concurring to heat it. One is the internal heat which it possessed at its formation, a part of which only is dissipated through the surface; the other is the continued action of the solar rays, which penetrate the whole mass, and produce at the surface, the diversities of climate.

**EARTH HEATED PRIMARILY BY THE SUN**

The primitive heat of the globe has no longer any sensible effect upon the surface: but it may be very great as we approach the center.

**HEAT FROM EARTH'S INTERIOR HAS LITTLE INFLUENCE**

The observations heretofore collected seem to show that the temperature of different points of the same vertical line, is proportional to the depth, and that this increase of temperature, as we advance towards the center, is about one degree for every thirty or forty meters. Such a result supposes a very high internal temperature. It cannot proceed from the action of the sun's rays; and it is naturally explained by the heat which belonged to the earth at its formation.

**THE HEAT IN THE INTERIOR OF THE EARTH DOES NOT COME FROM THE SUN.**
**(LEFT OVER FROM EARTH'S FORMATION.)**

# FOURIER 1824:

The periodical effects of the solar heat, arise from the diurnal or annual variations. This order of facts is explained exactly, and in all its details, by the theory. The comparison of the results with the observations will serve to measure the conducting power of those substances of which the crust of the globe is composed.

## VARIATIONS IN SUNLIGHT EXPLAIN DAY-NIGHT TEMPERATURE DIFFERENCES AND THE SEASONS

The interposition of the air very much modifies the effects of the heat upon the surface of the globe.

## THE ATMOSPHERE MODIFIES THE EFFECTS OF THE SUN'S HEATING

The heat of the sun, coming in the form of light, possesses the property of penetrating transparent solids or liquids, and loses this property entirely, when by communication with terrestrial bodies, it is turned into heat radiating without light.

This distinction of luminous and non-luminous heat, explains the elevation of temperature caused by transparent bodies.

## TWO KINDS OF RADIATION (SHORTWAVE AND LONGWAVE)

The radiation of the most elevated strata of the atmosphere, the cold of which is very intense and almost constant, has an influence upon all the meteorological facts of our observation; it can be rendered more sensible by reflexion from the surface with concave mirrors. The presence of the clouds which intercept these rays, mitigates the cold of the nights.

## CLOUDS INTERCEPT LONGWAVE RADIATION, MITIGATING THE COLD OF NIGHTS

Fourier, 1824

# FOURIER 1824:

It is difficult to know how far the atmosphere influences the mean temperature of the globe; and in this examination we are no longer guided by a regular mathematical theory. It is to the celebrated traveller, M. de Saussure, that we are indebted for a capital experiment, which appears to throw some light on this question.

The experiment consists in exposing to the rays of the sun, a vessel covered with one or more plates of glass, very transparent, and placed at some distance one above the other. The interior of the vessel is furnished with a thick covering of black cork, proper for receiving and preserving heat. The heated air is contained in all parts, both in the interior of the vessel and in the spaces between the plates. Thermometers placed in the vessel itself and in the intervals above, mark the degree of heat in each space. This instrument was placed in the sun about noon, and the thermometer in the vessel was seen to rise to 70°, 80°, 100°, 110°, (Reaumur,) and upwards. The thermometers placed in the intervals between the glass plates indicated much lower degrees of heat, and the heat decreased from the bottom of the vessel to the highest interval.

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**EARTH'S ATMOSPHERE OPERATES LIKE A GREENHOUSE WITH SEVERAL LAYERS OF GLASS.**

**(THIS EXPLAINS WHY THE LOWER ATMOSPHERE IS HOTTER THAN THE UPPER ATMOSPHERE.)**

Fourier, 1824

# FOURIER 1824:

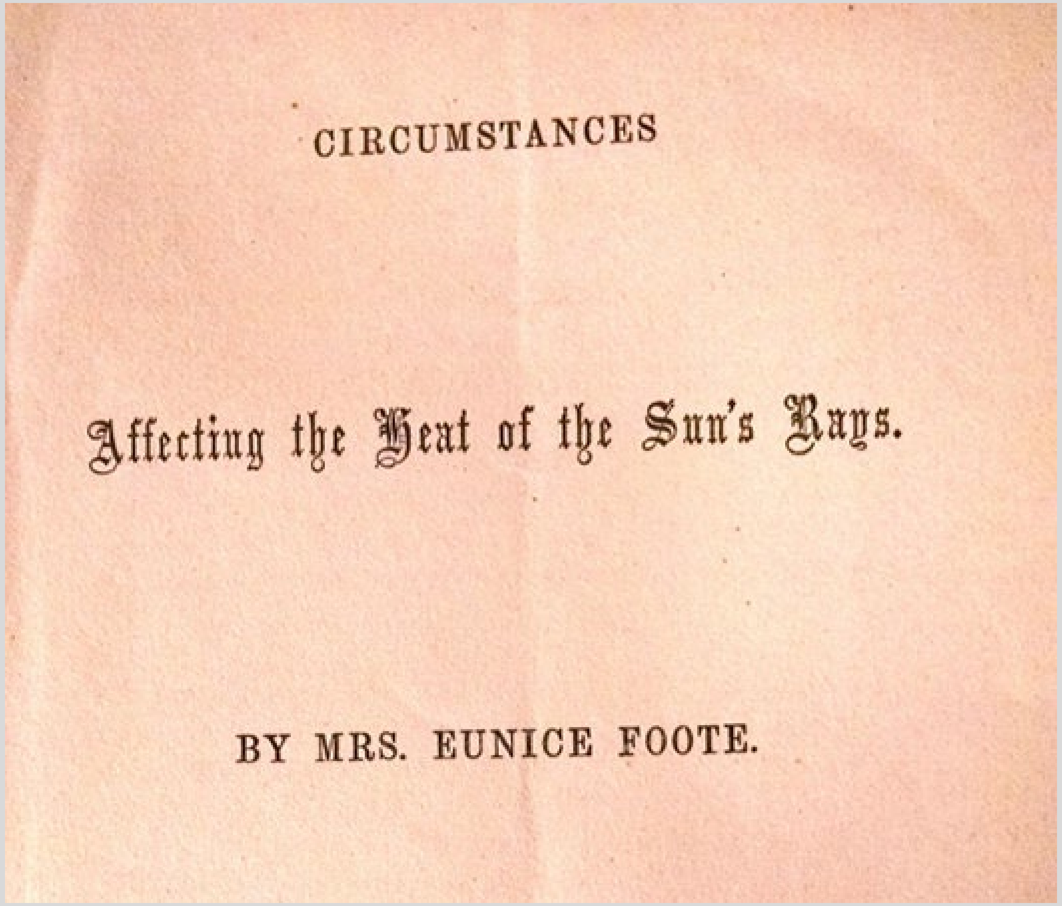
The establishment and progress of human society, and the action of natural powers, may, in extensive regions, produce remarkable changes in the state of the surface, the distribution of the waters, and the great movements of the air. Such effects, in the course of some centuries, must produce variations in the mean temperature for such places; for the analytical expressions contain coefficients which are related to the state of the surface, and have a great influence on the temperature.

**HUMAN ACTIVITIES MAY AFFECT CLIMATE**

The earth receives the rays of the sun, which penetrate its mass, and are converted into non-luminous heat:

**SUNLIGHT STRIKES THE EARTH.**
**THIS ENERGY IS CONVERTED TO LONGWAVE RADIATION.**

Fourier, 1824



CIRCUMSTANCES

Affecting the Heat of the Sun's Rays.

BY MRS. EUNICE FOOTE.

1856

Eunice Foote, American scientist, discovered that carbon dioxide and water vapor cause air to warm in sunlight. In 1856, she presented her findings at the meeting of the American Association for the Advancement of Science (AAAS).

## DISCOVERING GASES THAT TRAP HEAT

## FOOTE 1856:

### AIR ABSORBS RADIANT ENERGY



ART. XXXI.—*Circumstances affecting the Heat of the Sun's Rays*; by EUNICE FOOTE.

(Read before the American Association, August 23d, 1856.)

MY investigations have had for their object to determine the different circumstances that affect the thermal action of the rays of light that proceed from the sun.

Several results have been obtained.

First. The action increases with the density of the air, and is diminished as it becomes more rarified.

The experiments were made with an air-pump and two cylindrical receivers of the same size, about four inches in diameter and thirty in length. In each were placed two thermometers, and the air was exhausted from one and condensed in the other. After both had acquired the same temperature they were placed in the sun, side by side, and while the action of the sun's rays rose to 110° in the condensed tube, it attained only 88° in the other. I had no means at hand of measuring the degree of condensation or rarefaction.

## FOOTE 1856:

**MOIST AIR ABSORBS MORE ENERGY THAN DRY AIR**

Secondly. The action of the sun's rays was found to be greater in moist than in dry air.

In one of the receivers the air was saturated with moisture—in the other it was dried by the use of chlorid of calcium.

Both were placed in the sun as before and the result was as follows:

| Dry Air. | | Damp Air. | |
|---|---|---|---|
| In shade. | In sun. | In shade. | In sun. |
| 75 | 75 | 75 | 75 |
| 78 | 88 | 78 | 90 |
| 82 | 102 | 82 | 106 |
| 82 | 104 | 82 | 110 |
| 82 | 105 | 82 | 114 |
| 88 | 108 | 92 | 120 |

## FOOTE 1856:

**CO2 IS A STRONG ABSORBER OF RADIANT ENERGY IN THE ATMOSPHERE**

Thirdly. The highest effect of the sun's rays I have found to be in carbonic acid gas.

One of the receivers was filled with it, the other with common air, and the result was as follows:

| In Common Air. | | In Carbonic Acid Gas. | |
|---|---|---|---|
| In shade. | In sun. | In shade. | In sun. |
| 80 | 90 | 80 | 90 |
| 81 | 94 | 84 | 100 |
| 80 | 99 | 84 | 110 |
| 81 | 100 | 85 | 120 |

The receiver containing the gas became itself much heated—very sensibly more so than the other—and on being removed, it was many times as long in cooling.

An atmosphere of that gas would give to our earth a high temperature; and if as some suppose, at one period of its history the air had mixed with it a larger proportion than at present, an increased temperature from its own action as well as from increased weight must have necessarily resulted.

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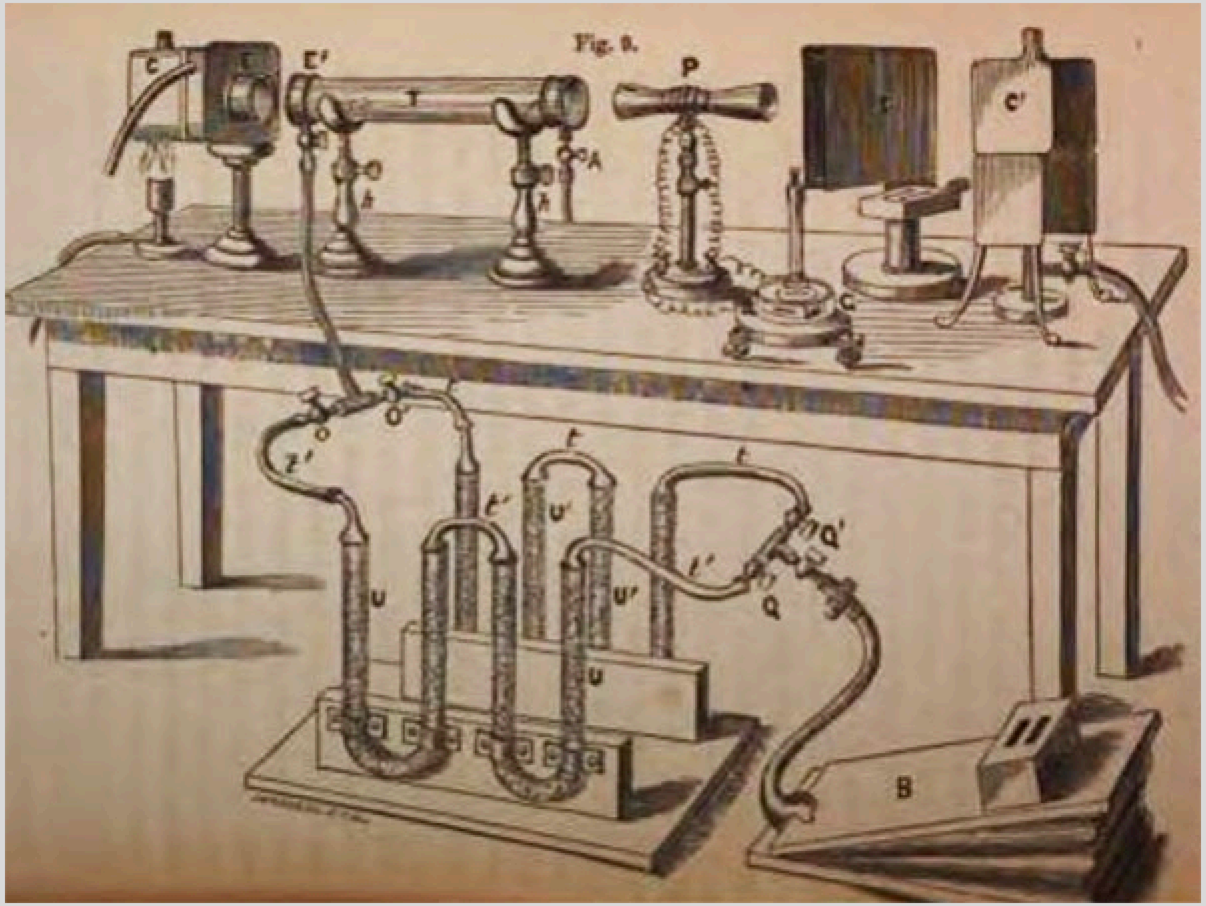



1859

John Tyndall, British physicist, tested the gases in the atmosphere to find out which are responsible for the greenhouse effect. He found that nitrogen and oxygen, which make up almost all of the atmosphere, have no ability to trap heat, but that three gases present in smaller quantities do: carbon dioxide, ozone, and water vapor. Tyndall speculated that if the amounts of these gases dropped, it would chill the Earth.

## TESTING THE HEAT-TRAPPING ABILITY OF GASES

https://scied.ucar.edu/learning-zone/how-climate-works/history-climate-science-research

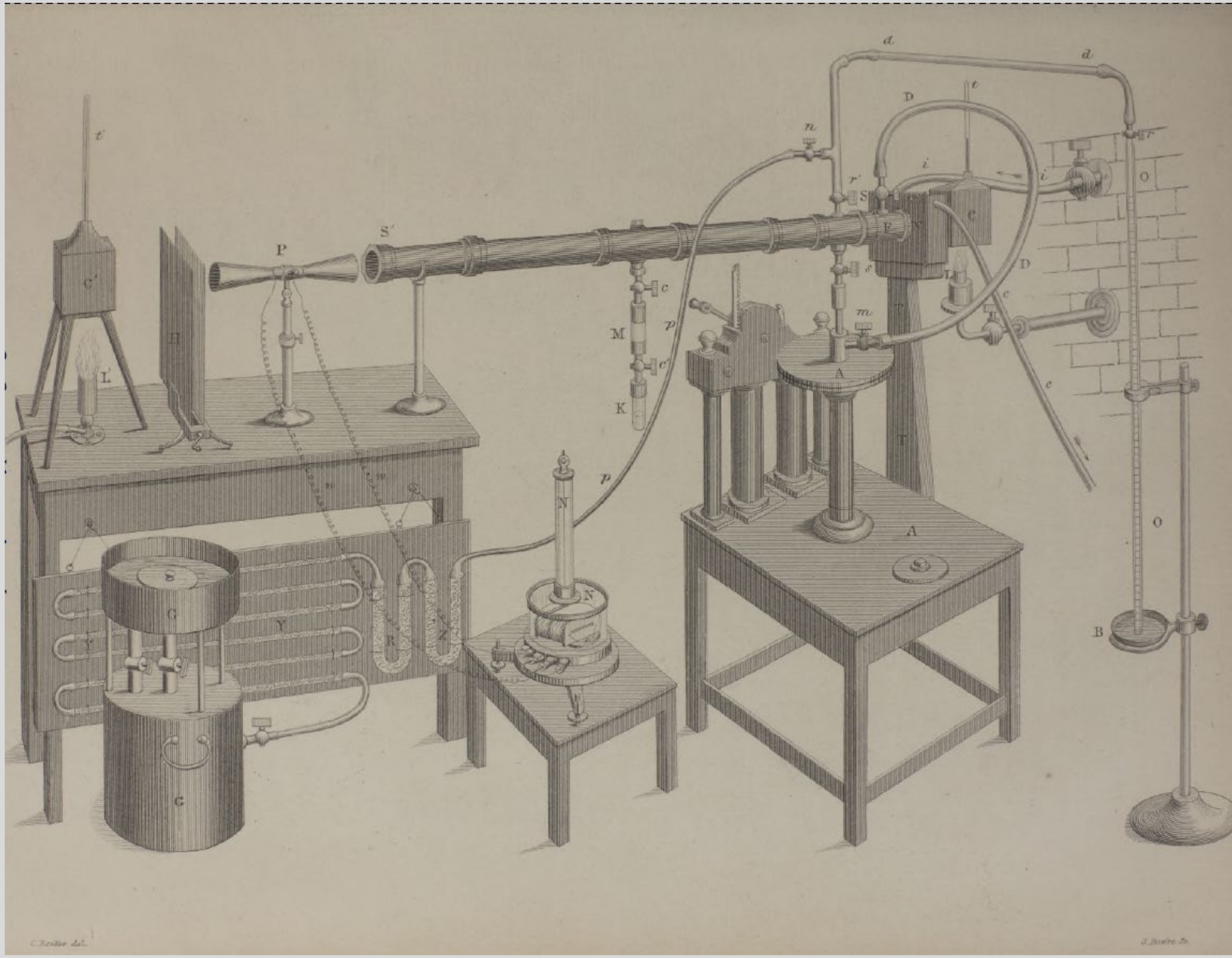
## TYNDALL 1859:

## APPARATUS TO MEASURE ABSOROPTION OF LONGWAVE RADIATION BY GASES

The entire apparatus made use of in the experiments on absorption is figured on Plate I. S S′ is the *experimental tube* composed of brass, polished within, and connected, as shown in the figure, with the air-pump, A A. At S and S′ are the plates of rock-salt which close the tube air-tight. The length from S to S′ is 4 feet. C is a cube containing boiling water, in which is immersed the thermometer *t*. The cube is of cast copper, and on one of its faces a projecting ring was cast to which a brass tube of the same diameter as S S′, and capable of being connected air-tight with the latter, was carefully soldered. The face of the cube within the ring is the radiating plate, which is coated with lampblack. Thus between the cube C and the first plate of rock-salt there is *a front chamber* F, connected with the air-pump by the flexible tube D D, and capable of being exhausted independently of S S′. To prevent the heat of conduction from reaching the plate of rock-salt S, the tube F is caused to pass through a vessel V, being soldered to the latter where it enters it and issues from it. This vessel is supplied with a continuous flow of cold water through the influx tube *i i*, which dips to the bottom of the vessel; the water escapes through the efflux tube *e e*, and the continued circulation of the cold liquid completely intercepts the heat that would otherwise reach the plate S. The cube C is heated by the gas-lamp L. P is the thermo-electric pile placed on its stand at the end of the experimental tube, and furnished with two conical reflectors, as shown in the figure. C′ is the *compensating cube*, used to neutralize by its radiation* the effect of the rays passing through S S′. The regulation of this neutralization was an operation of some delicacy; to effect it the double screen H was connected with a winch and screw arrangement, by which it could be advanced or withdrawn through extremely minute spaces. For this most useful adjunct I am indebted to the kindness of my friend Mr. Gassiot. N N is the galvanometer with perfectly astatic needles, and perfectly non-magnetic coil; it is connected with the pile P by the wires *w w*; Y Y is a system of six chloride-of-calcium tubes, each 32 inches long; R is a

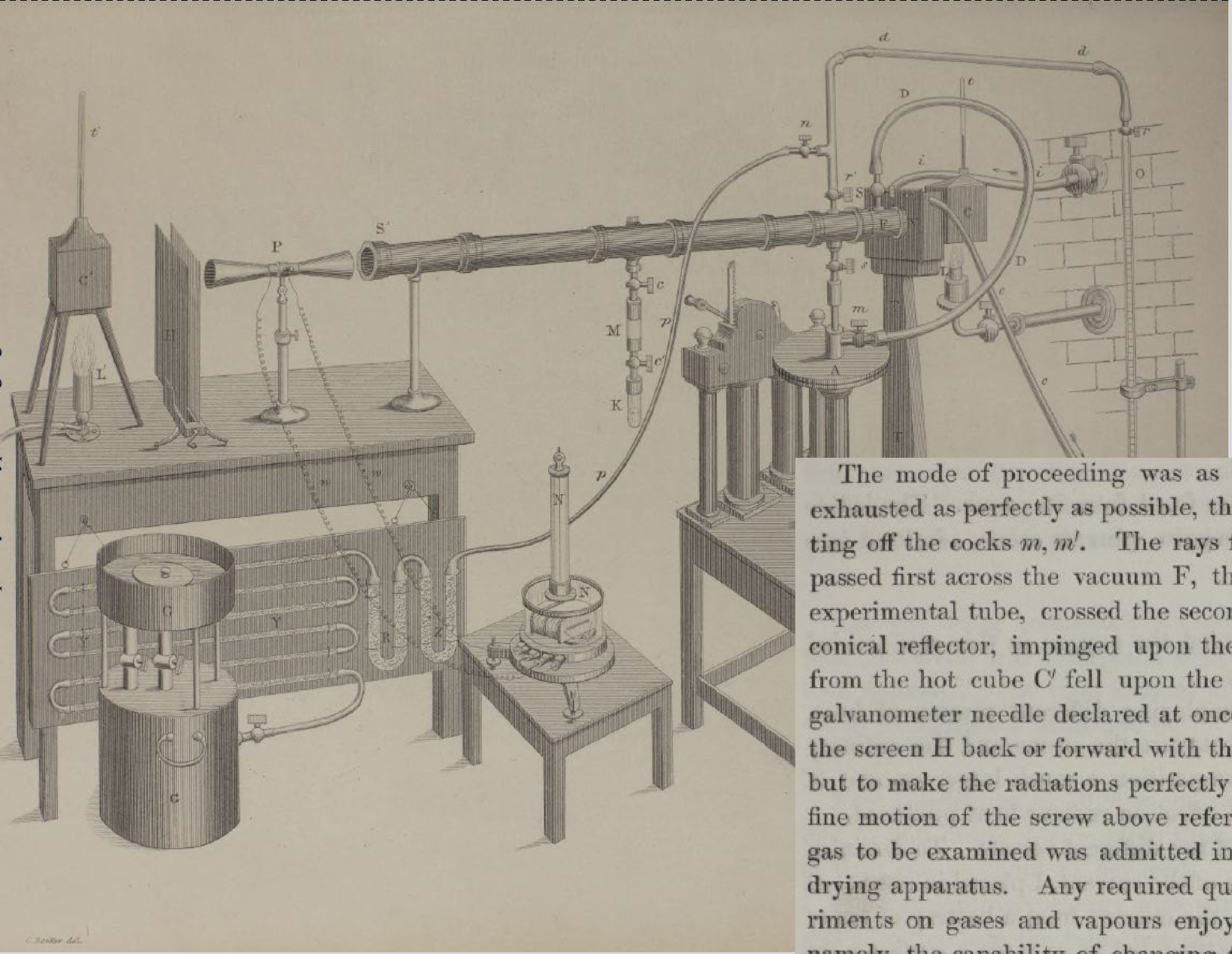
* It will be seen that in this arrangement I have abandoned the use of the differential galvanometer, and made the thermo-electric pile the differential instrument.

U-tube containing fragments of pumice-stone, moistened with strong caustic potash; and Z is a second similar tube, containing fragments of pumice-stone wetted with strong sulphuric acid. When *drying* only was aimed at, the potash tube was suppressed. When, on the contrary, as in the case of atmospheric air, both moisture and carbonic acid were to be removed, the potash tube was included. G G is a holder from which the gas to be experimented with was sent through the drying tubes, and thence through the pipe *p p* into the experimental tube S S′. The appendage at M and the arrangement at O O may for the present be disregarded; I shall refer to them particularly by and by.



# TYNDALL 1859:

# APPARATUS TO MEASURE ABSOROPTION OF LONGWAVE RADIATION BY GASES



The mode of proceeding was as follows:—The tube S S′ and the chamber F being exhausted as perfectly as possible, the connexion between them was intercepted by shutting off the cocks *m*, *m*′. The rays from the interior blackened surface of the cube C passed first across the vacuum F, then through the plate of rock-salt S, traversed the experimental tube, crossed the second plate S′, and being concentrated by the anterior conical reflector, impinged upon the adjacent face of the pile P. Meanwhile the rays from the hot cube C′ fell upon the opposite face of the pile, and the position of the galvanometer needle declared at once which source was predominant. A movement of the screen H back or forward with the hand sufficed to establish an approximate equality; but to make the radiations perfectly equal, and thus bring the needle exactly to 0°, the fine motion of the screw above referred to was necessary. The needle being at 0°, the gas to be examined was admitted into the tube; passing, in the first place, through the drying apparatus. Any required quantity of the gas may be admitted; and here experiments on gases and vapours enjoy an advantage over those with liquids and solids, namely, the capability of changing the density at pleasure. When the required quantity of gas had been admitted, the galvanometer was observed, and from the deflection of its needle the absorption was accurately determined.

## TYNDALL 1859:

## AIR CONTAINING CO2 AND WATER VAPOR ABSORBS 15 TIMES THE RADIATION ABSORBED BY AIR WITHOUT CO2 AND WATER VAPOR.

I have now to refer briefly to a point of considerable interest as regards the effect of our atmosphere on solar and terrestrial heat. In examining the separate effects of the air, carbonic acid, and aqueous vapour of the atmosphere on the 20th of last November, the following results were obtained:—

Air sent through the system of drying tubes and through the caustic potash tube produced an absorption of about

1.

Air direct from the laboratory, containing therefore its carbonic acid* and aqueous vapour, produced an absorption of

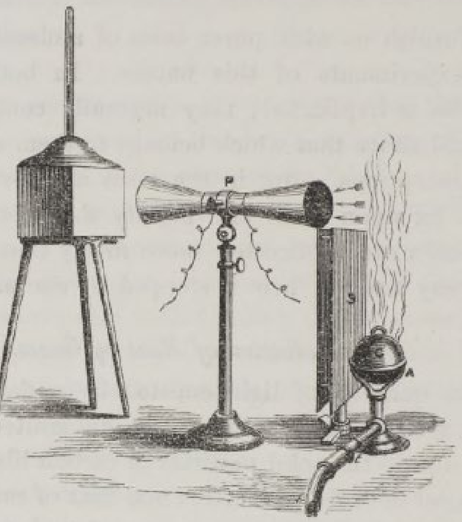
15.

Deducting the effect of the gaseous acids, it was found that the quantity of aqueous vapour diffused through the atmosphere on the day in question, produced an absorption at least equal to thirteen times that of the atmosphere itself.

**TYNDALL 1859:**

**GASES THAT ABSORB LONGWAVE RADIATION
ALSO RADIATE LONGWAVE RADIATION.**

My next care was to examine whether different gases possessed different powers of radiation, and for this purpose the following arrangement was devised. P in the woodcut



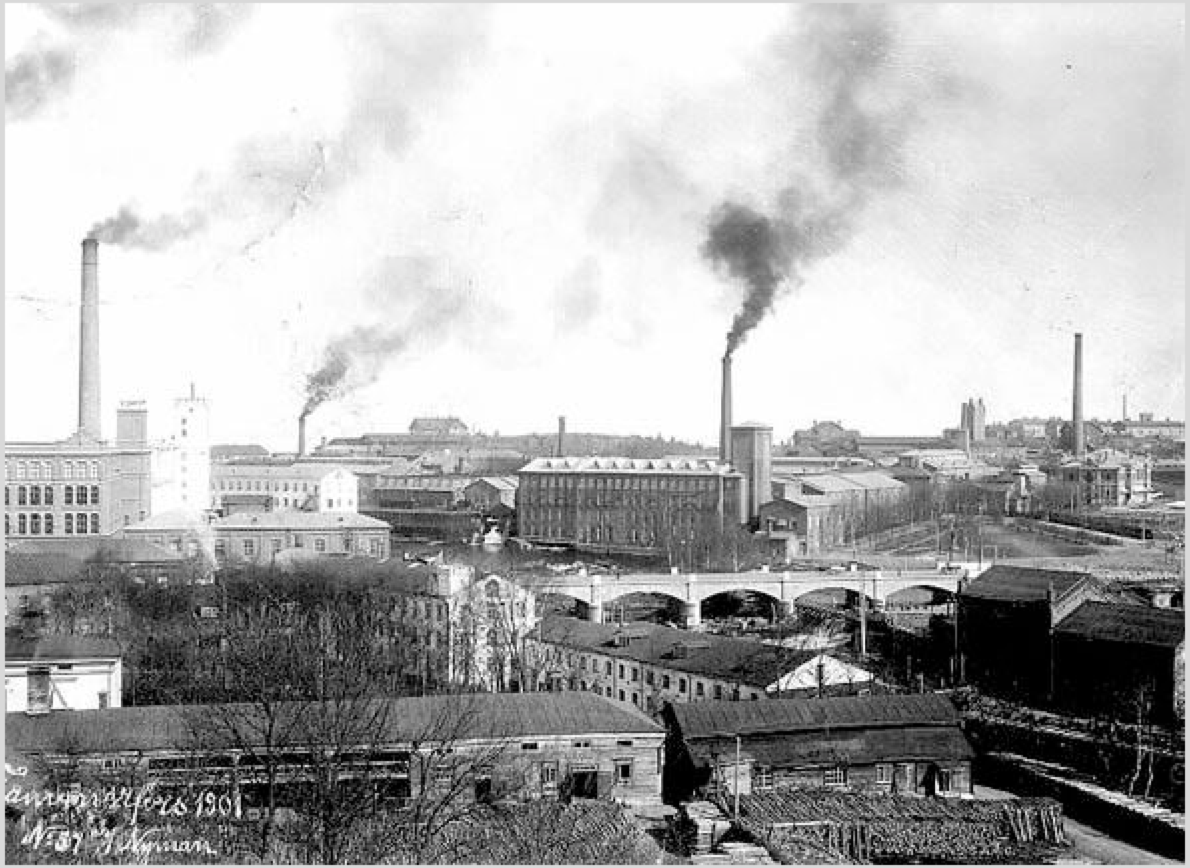
represents the thermo-electric pile with its two conical reflectors; S is a double screen of polished tin; A is an argand burner consisting of two concentric rings perforated with orifices for the escape of the gas; C is a heated copper ball; the tube *t t* leads to a gas-holder containing the gas to be examined. When the ball C is placed on the argand burner, it of course heats the air in contact with it; an ascending current is established, which acts on the pile as in the experiments last described. It was found necessary to neutralize this radiation from the heated air, and for this purpose a large Leslie's cube L, filled with water a few degrees above the temperature of the air, was allowed to act on the opposite face of the pile.

The results of the experiments are given in the following Table, the figure appended to the name of each gas marking the number of degrees through which the radiation from the latter urged the needle of the galvanometer*:—

| | |
|---|---|
| Air . . . . . . | 0° |
| Oxygen . . . . . . | 0 |
| Nitrogen . . . . . . | 0 |
| Hydrogen . . . . . . | 0 |
| Carbonic oxide . . . . | 12 |
| Carbonic acid . . . . | 18 |
| Nitrous oxide . . . . | 29 |
| Olefiant gas . . . . . | 53 |

**NITROUS OXIDE, CO2, CARBON MONOXIDE, AND ETHYLENE
ARE ABSORB LONGWAVE RADIATION,
BUT OXYGEN, NITROGEN AND HYDROGEN DO NOT.**

# CONNECTING COAL, CARBON DIOXIDE, AND CLIMATE



1896

Swedish chemist Svante Arrhenius recognized that burning coal could increase carbon dioxide and warm the climate. He estimated how much carbon dioxide the ocean could absorb. In an 1896 lecture, Arrhenius noted that it was not yet possible to calculate how fast temperature was rising. He also speculated that warming would be beneficial as people in the future "might live under a milder sky and in less barren surroundings."

## ARRHENIUS 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.

**ABSORBING GASES MODERATE DAY-NIGHT TEMPERATURE CYCLES.**

**DO THEY ALSO AFFECCT THE TEMPERATURE OF THE EARTH?**

**FOURIER SUGGESTED "YES" BECAUSE ABSORBING GASES ACT LIKE THE GLASS IN A GREENHOUSE,**
**LETTING SHORTWAVE RADIATION IN,**
**BUT IMPEDING ESCAPE OF ENERGY TO SPACE.**

## ARRHENIUS 1896:

The selective absorption of the atmosphere is, according to the researches of Tyndall, Lecher and Pernter, Röntgen, Heine, Langley, Ångström, Paschen, and others *, of a wholly different kind. It is not exerted by the chief mass of the air, but in a high degree by aqueous vapour and carbonic acid, which are present in the air in small quantities. Further, this absorption is not continuous over the whole spectrum, but nearly insensible in the light part of it, and chiefly limited to the long-waved part, where it manifests itself in very well-defined absorption-bands, which fall off rapidly on both sides †. The influence of this absorption is comparatively small on the heat from the sun, but must be of great importance in the transmission of rays from the earth. Tyndall held the opinion that the water-vapour has the greatest influence, whilst other authors, for instance Lecher and Pernter, are inclined to think that the carbonic acid plays the more important part. The researches of Paschen show that these gases are both very effective, so that probably sometimes the one, sometimes the other, may have the greater effect according to the circumstances.

**CO2 AND WATER VAPOR DO NOT PREVENT VISIBLE SUNLIGHT FROM REACHING THE GROUND.**

**CO2 AND WATER VAPOR DO PREVENT LONGWAVE RADIATION FROM ESCAPING TO SPACE.**

## ARRHENIUS 1896:

All authors agree in the view that there prevails an equilibrium in the temperature of the earth and of its atmosphere. The atmosphere must, therefore, radiate as much heat to space as it gains partly through the absorption of the sun's rays, partly through the radiation from the hotter surface of the earth and by means of ascending currents of air heated by contact with the ground. On the other hand, the earth loses just as much heat by radiation to space and to the atmosphere as it gains by absorption of the sun's rays. If

**THE EARTH IS IN ENERGY BALANCE.**

**LONGWAVE RADIATION TO SPACE**
**BALANCES**
**SHORTWAVE RADIATION FROM THE SUN.**

**ARRHENIUS 1896:**

IV. *Calculation of the Variation of Temperature that would ensue in consequence of a given Variation of the Carbonic Acid in the Air.*

We now possess all the necessary data for an estimation of the effect on the earth's temperature which would be the result of a given variation of the aërial carbonic acid.

In consequence of the variation ($t$) in the temperature, W must also undergo a variation. As the relative humidity does not vary much, unless the distribution of land and water changes (see table 8 of my original memoir), I have supposed that this quantity remains constant, and thereby determined the new value $W_1$ of W.

By means of these values, I have calculated the mean alteration of temperature that would follow if the quantity of carbonic acid varied from its present mean value (K=1) to another, viz. to K=0·67, 1·5, 2, 2·5, and 3 respectively. This calculation is made for every tenth parallel, and separately for the four seasons of the year. The variation is given in Table VII.

**LET'S ASSUME THAT RELATIVE HUMDITY REMAINS RELATIVELY CONSTANT AS EARTH'S TEMPERATURE CHANGES**

## ARRHENIUS 1896: A DOUBLING OF ATMOSPHERIC CO2 CAUSES ABOUT 5 OR 6 DEGREES CELSIUS OF WARMING



### TABLE VII.—*Variation of Temperature caused by a given Variation of Carbonic Acid.*

Carbonic Acid=0·67.

| Latitude. | Dec.–Feb. | March–May. | June–Aug. | Sept.–Nov. | Mean of the year. |
|---|---|---|---|---|---|
| 70–60 | −2·9 | −3·0 | −3·4 | −3·1 | −3·1 |
| 60–50 | −3·0 | −3·2 | −3·4 | −3·3 | −3·22 |
| 50–40 | −3·2 | −3·3 | −3·3 | −3·4 | −3·3 |
| 40–30 | −3·4 | −3·4 | −3·2 | −3·3 | −3·32 |
| 30–20 | −3·3 | −3·2 | −3·1 | −3·1 | −3·17 |
| 20–10 | −3·1 | −3·1 | −3·0 | −3·1 | −3·07 |
| 10–0 | −3·1 | −3·0 | −3·0 | −3·0 | −3·02 |
| 0–−10 | −3·0 | −3·0 | −3·1 | −3·0 | −3·02 |
| −10–−20 | −3·1 | −3·1 | −3·2 | −3·1 | −3·12 |
| −20–−30 | −3·1 | −3·2 | −3·3 | −3·2 | −3·2 |
| −30–−40 | −3·3 | −3·3 | −3·4 | −3·4 | −3·35 |
| −40–−50 | −3·4 | −3·4 | −3·3 | −3·4 | −3·37 |
| −50–−60 | −3·2 | −3·3 | — | — | — |

Carbonic Acid=1·5.

| Latitude. | Dec.–Feb. | March–May. | June–Aug. | Sept.–Nov. | Mean of the year. |
|---|---|---|---|---|---|
| 70–60 | 3·3 | 3·4 | 3·8 | 3·6 | 3·52 |
| 60–50 | 3·4 | 3·7 | 3·6 | 3·8 | 3·62 |
| 50–40 | 3·7 | 3·8 | 3·4 | 3·7 | 3·65 |
| 40–30 | 3·7 | 3·6 | 3·3 | 3·5 | 3·52 |
| 30–20 | 3·5 | 3·3 | 3·2 | 3·5 | 3·47 |
| 20–10 | 3·5 | 3·2 | 3·1 | 3·2 | 3·25 |
| 10–0 | 3·2 | 3·2 | 3·1 | 3·1 | 3·15 |
| 0–−10 | 3·1 | 3·1 | 3·2 | 3·2 | 3·15 |
| −10–−20 | 3·2 | 3·2 | 3·2 | 3·2 | 3·2 |
| −20–−30 | 3·2 | 3·2 | 3·4 | 3·3 | 3·27 |
| −30–−40 | 3·4 | 3·5 | 3·7 | 3·5 | 3·52 |
| −40–−50 | 3·6 | 3·7 | 3·8 | 3·7 | 3·7 |
| −50–−60 | 3·8 | 3·7 | — | — | — |

Carbonic Acid=2·0.

| Latitude. | Dec.–Feb. | March–May. | June–Aug. | Sept.–Nov. | Mean of the year. |
|---|---|---|---|---|---|
| 70–60 | 6·0 | 6·1 | 6·0 | 6·1 | 6·05 |
| 60–50 | 6·1 | 6·1 | 5·8 | 6·1 | 6·02 |
| 50–40 | 6·1 | 6·1 | 5·5 | 6·0 | 5·92 |
| 40–30 | 6·0 | 5·8 | 5·4 | 5·6 | 5·7 |
| 30–20 | 5·6 | 5·4 | 5·0 | 5·2 | 5·3 |
| 20–10 | 5·2 | 5·0 | 4·9 | 5·0 | 5·02 |
| 10–0 | 5·0 | 5·0 | 4·9 | 4·9 | 4·95 |
| 0–−10 | 4·9 | 4·9 | 5·0 | 5·0 | 4·95 |
| −10–−20 | 5·0 | 5·0 | 5·2 | 5·1 | 5·07 |
| −20–−30 | 5·2 | 5·3 | 5·5 | 5·4 | 5·35 |
| −30–−40 | 5·5 | 5·6 | 5·8 | 5·6 | 5·62 |
| −40–−50 | 5·8 | 6·0 | 6·0 | 6·0 | 5·95 |
| −50–−60 | 6·0 | 6·1 | — | — | — |

Carbonic Acid=2·5.

| Latitude. | Dec.–Feb. | March–May. | June–Aug. | Sept.–Nov. | Mean of the year. |
|---|---|---|---|---|---|
| 70–60 | 7·9 | 8·0 | 7·9 | 8·0 | 7·95 |
| 60–50 | 8·0 | 8·0 | 7·6 | 7·9 | 7·87 |
| 50–40 | 8·0 | 7·9 | 7·0 | 7·9 | 7·7 |
| 40–30 | 7·9 | 7·6 | 6·9 | 7·3 | 7·42 |
| 30–20 | 7·2 | 7·0 | 6·6 | 6·7 | 6·87 |
| 20–10 | 6·7 | 6·6 | 6·3 | 6·6 | 6·52 |
| 10–0 | 6·6 | 6·4 | 6·3 | 6·4 | 6·42 |
| 0–−10 | 6·4 | 6·4 | 6·6 | 6·6 | 6·5 |
| −10–−20 | 6·6 | 6·6 | 6·7 | 6·7 | 6·65 |
| −20–−30 | 6·7 | 6·8 | 7·0 | 7·0 | 6·87 |
| −30–−40 | 7·0 | 7·2 | 7·7 | 7·4 | 7·32 |
| −40–−50 | 7·7 | 7·9 | 7·9 | 7·9 | 7·85 |
| −50–−60 | 7·9 | 8·0 | — | — | — |

Carbonic Acid=3·0.

| Latitude. | Dec.–Feb. | March–May. | June–Aug. | Sept.–Nov. | Mean of the year. |
|---|---|---|---|---|---|
| 70–60 | 9·1 | 9·3 | 9·4 | 9·4 | 9·3 |
| 60–50 | 9·3 | 9·5 | 8·9 | 9·5 | 9·3 |
| 50–40 | 9·5 | 9·4 | 8·6 | 9·2 | 9·17 |
| 40–30 | 9·3 | 9·0 | 8·2 | 8·8 | 8·82 |
| 30–20 | 8·7 | 8·3 | 7·5 | 7·9 | 8·1 |
| 20–10 | 7·9 | 7·5 | 7·2 | 7·5 | 7·52 |
| 10–0 | 7·4 | 7·3 | 7·2 | 7·3 | 7·3 |
| 0–−10 | 7·3 | 7·3 | 7·4 | 7·4 | 7·35 |
| −10–−20 | 7·4 | 7·5 | 8·0 | 7·6 | 7·62 |
| −20–−30 | 7·9 | 8·1 | 8·6 | 8·3 | 8·22 |
| −30–−40 | 8·6 | 8·7 | 9·1 | 8·8 | 8·8 |
| −40–−50 | 9·1 | 9·2 | 9·4 | 9·3 | 9·25 |
| −50–−60 | 9·4 | 9·5 | — | — | — |

## ARRHENIUS 1896:

We may now inquire how great must the variation of the carbonic acid in the atmosphere be to cause a given change of the temperature. The answer may be found by interpolation in Table VII. To facilitate such an inquiry, we may make a simple observation. If the quantity of carbonic acid decreases from 1 to 0·67, the fall of temperature is nearly the same as the increase of temperature if this quantity augments to 1·5. And to get a new increase of this order of magnitude (3°·4), it will be necessary to alter the quantity of carbonic acid till it reaches a value nearly midway between 2 and 2·5.

**GLOBAL WARMING INCREASES LINEARLY WITH EACH HALVING OR DOUBLING OF ATMOSPHERIC CO2 CONTENT.**

Thus if the quantity of carbonic acid increases in geometric progression, the augmentation of the temperature will increase nearly in arithmetic progression. This rule—which naturally holds good only in the part investigated—will be useful for the following summary estimations.

**(THE EARTH WARMS IN PROPORTION TO THE LOGARITHM OF ATMOSPHERIC CO2 CONTENT.)**

**ARRHENIUS 1896:**

> One may now ask, How much must the carbonic acid vary according to our figures, in order that the temperature should attain the same values as in the Tertiary and Ice ages respectively? A simple calculation shows that the temperature in the arctic regions would rise about 8° to 9° C., if the carbonic acid increased to 2·5 or 3 times its present value. In order to get the temperature of the ice age between the 40th and 50th parallels, the carbonic acid in the air should sink to 0·62—0·55 of its present value (lowering of temperature 4°–5° C.).

**AN INCREASE OF CO2 OF 2.5 TO 3 TIMES FROM PRE-INDUSTRIAL WOULD BE ENOUGH TO MELT ICE-CAPS.**

**A DECREASE TO 0.62 TO 0.55 TIMES WOULD BE ENOUGH TO EXPLAIN ICE AGE.**

**(MODERN CALCULATIONS SUGGEST 2.5 TO 3 TIMES IS ENOUGH TO MELT MOST OF GREENLAND, BUT NOT ANTARCTICA.)**

**(ICE AGE CO2 WAS ABOUT 65% OF PRE-INDUSTRIAL CO2.)**

## ARRHENIUS 1896:

"On the supposition that the mean quantity of carbonic acid in the air reaches 0·03 vol. per cent., this number represents 0·045 per cent. by weight, or 0·342 millim. partial pressure, or 0·466 gramme of carbonic acid for every cm.$^2$ of the earth's surface. Reduced to carbon this quantity would give a layer of about 1 millim. thickness over the earth's surface.

**IF THE CARBON IN ALL OF THE CO2 IN THE ATMOSPHERE WERE IN A SOLID LAYER COVERING THE EARTH, IT WOULD ONLY BE 1 MM THICK.**

# ARRHENIUS 1896:

"The following calculation is also very instructive for the appreciation of the relation between the quantity of carbonic acid in the air and the quantities that are transformed. The world's present production of coal reaches in round numbers 500 millions of tons per annum, or 1 ton per km.$^2$ of the earth's surface. Transformed into carbonic acid, this quantity would correspond to about a thousandth part of the carbonic acid in the atmosphere.

**THE BURNING OF COAL ADDS ENOUGH CO2 TO THE ATMOSPHERE TO DOUBLE ATMOSPHERIC CO2 CONCENTRATION IN 1000 YEARS.**

## ARRHENIUS 1896:

$CO_2$ MAINLY ADDED TO THE ATMOSPHERE BY VOLCANOS.

$CO_2$ MAINLY REMOVED FROM THE ATMOSPHERE
BY SILICATE-ROCK WEATHERING
AND SUBSEQUENT CARBONATE DEPOSITION.

VARIATIONS IN VOLCANIC ACTIVITY MAY EXPLAIN
CLIMATE VARIATIONS IN THE GEOLOGIC PAST.

in the same direction.

"Carbonic acid is supplied to the atmosphere by the following processes:—(1) volcanic exhalations and geological phenomena connected therewith; (2) combustion of carbonaceous meteorites in the higher regions of the atmosphere; (3) combustion and decay of organic bodies; (4) decomposition of carbonates; (5) liberation of carbonic acid mechanically inclosed in minerals on their fracture or decomposition. The carbonic acid of the air is consumed chiefly by the following processes:—(6) formation of carbonates from silicates on weathering; and (7) the consumption of carbonic acid by vegetative processes. The ocean, too, plays an important rôle as a regulator of the quantity of carbonic acid in the air by means of the absorptive power of its water, which gives off carbonic acid as its temperature rises and absorbs it as it cools. The processes named under (4) and (5) are of little significance, so that they may be omitted. So too the processes (3) and (7), for the circulation of matter in the organic world goes on so rapidly that their variations cannot have any sensible influence. From this we must except periods in which great quantities of organisms were stored up in sedimentary formations and thus subtracted from the circulation, or in which such stored-up products were, as now, introduced anew into the circulation. The source of carbonic acid named in (2) is wholly incalculable.

"Thus the processes (1), (2), and (6) chiefly remain as balancing each other. As the enormous quantities of carbonic acid (representing a pressure of many atmospheres) that are now fixed in the limestone of the earth's crust cannot be conceived to have existed in the air but as an insignificant fraction of the whole at any one time since organic life appeared on the globe, and since therefore the consumption through weathering and formation of carbonates must have been compensated by means of continuous supply, we must regard volcanic exhalations as the chief source of carbonic acid for the atmosphere.

"But this source has not flowed regularly and uniformly. Just as single volcanoes have their periods of variation with alternating relative rest and intense activity, in the same manner the globe as a whole seems in certain geological epochs to have exhibited a more violent and general volcanic activity, whilst other epochs have been marked by a comparative quiescence of the volcanic forces. It seems therefore probable that the quantity of carbonic acid in the air has undergone nearly simultaneous variations, or at least that this factor has had an important influence.

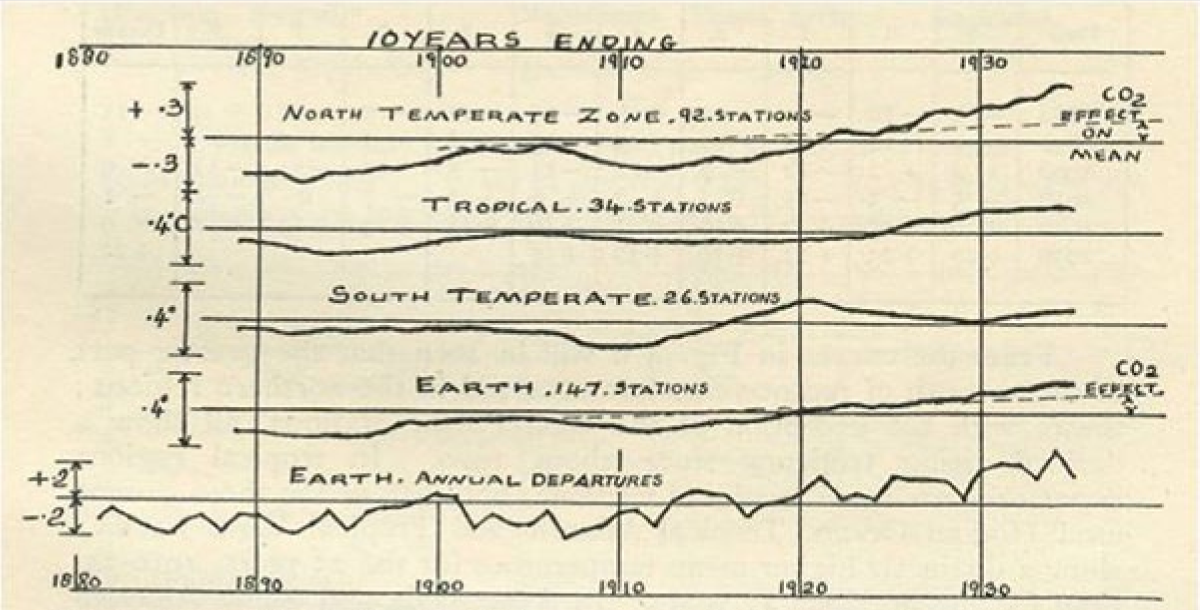



FIG. 4.—Temperature variations of the zones and of the earth. Ten-year moving departures from the mean, 1901-1930, °C.

1938

British coal engineer George Callendar compiled all carbon dioxide measurements made over the previous 100 years and found that the amount of $CO_2$ was increasing. He also found that temperatures were rising. His conclusion was that this was a good thing, that “the return of the deadly glaciers should be delayed indefinitely.”

## INCREASING CARBON DIOXIDE AND INCREASING TEMPERATURES

https://scied.ucar.edu/learning-zone/how-climate-works/history-climate-science-research

551.510.4 : 551.521.3 : 551.524.34

# THE ARTIFICIAL PRODUCTION OF CARBON DIOXIDE AND ITS INFLUENCE ON TEMPERATURE

By G. S. CALLENDAR

(Steam technologist to the British Electrical and Allied Industries Research Association.)

(Communicated by Dr. G. M. B. DOBSON, F.R.S.)

[Manuscript received May 19, 1937—read February 16, 1938.]

## SUMMARY

By fuel combustion man has added about 150,000 million tons of carbon dioxide to the air during the past half century. The author estimates from the best available data that approximately three quarters of this has remained in the atmosphere.

The radiation absorption coefficients of carbon dioxide and water vapour are used to show the effect of carbon dioxide on "sky radiation." From this the increase in mean temperature, due to the artificial production of carbon dioxide, is estimated to be at the rate of 0·003°C. per year at the present time.

The temperature observations at 200 meteorological stations are used to show that world temperatures have actually increased at an average rate of 0·005°C. per year during the past half century.

**CALLENDAR 1938:**

**INCREASE IN ATMOSPHERIC CO2 CONTENT LIKELY RESPONSIBLE FOR OBSERVED GLOBAL WARMING.**

## CALLENDAR 1938:

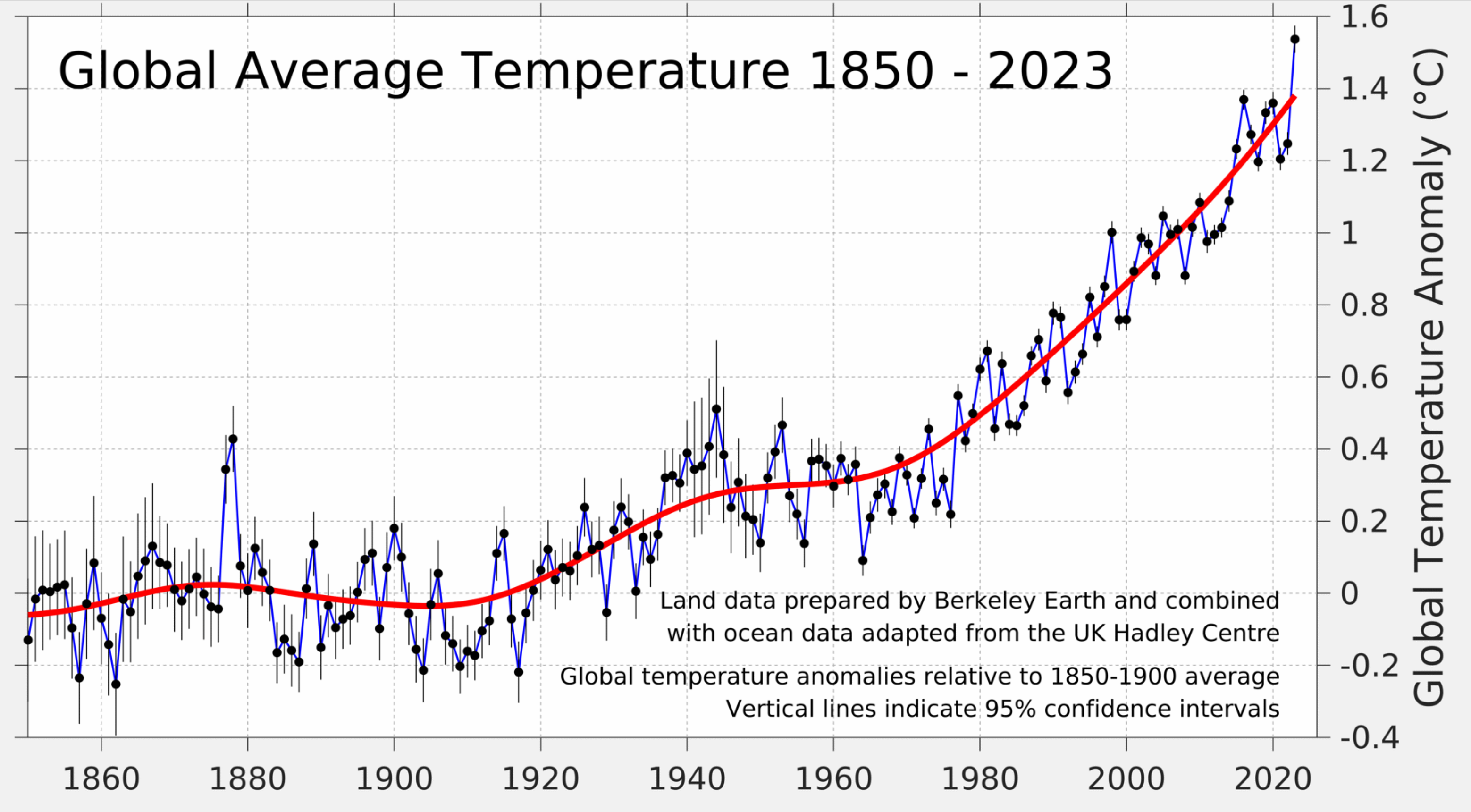
It is well known that the gas carbon dioxide has certain strong absorption bands in the infra-red region of the spectrum, and when this fact was discovered some 70 years ago it soon led to speculation on the effect which changes in the amount of the gas in the air could have on the temperature of the earth's surface. In view of the much larger quantities and absorbing power of atmospheric water vapour it was concluded that the effect of carbon dioxide was probably negligible, although certain experts, notably Svante Arrhenius and T. C. Chamberlin, dissented from this view.

**INCREASE IN ATMOSPHERIC CO2 CONTENT LIKELY RESPONSIBLE FOR OBSERVED GLOBAL WARMING.**

# CALLENDAR 1938:

From this the increase in mean temperature, due to the artificial production of carbon dioxide, is estimated to be at the rate of 0·003°C. per year at the present time.

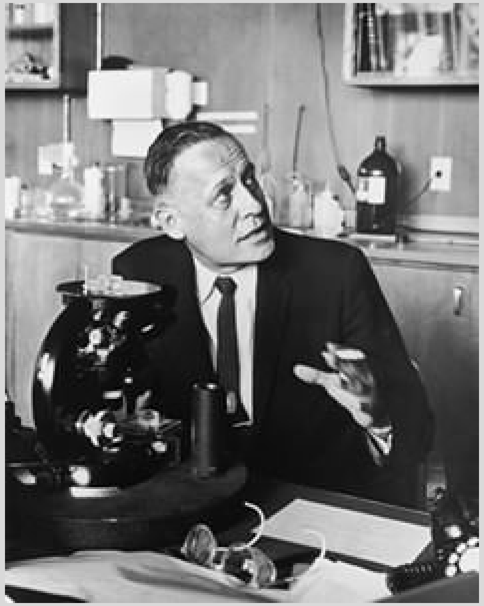
The temperature observations at 200 meteorological stations are used to show that world temperatures have actually increased at an average rate of 0·005°C. per year during the past half century.




**ACTUAL INCREAE 1888-1938 CLOSER TO 0.2 °C.**

**PROBABLY NOT STATISTICALLY SIGNIFICANT.**

https://berkeleyearth.org/global-temperature-report-for-2023/



1956

Gilbert Plass writes a review paper on “The Carbon Dioxide Theory of Climat Change”.  Concludes that “The extra CO, released into theatmosphere by industrial processes and other human activities may have caused the temperature rise” and “that this warming trend will continue, at least for several centuries.”

## THE CARBON DIOXIDE THEORY OF CLIMATE CHANGE

https://scied.ucar.edu/learning-zone/how-climate-works/history-climate-science-research

Tellus VIII (1956), 2

PLASS 1956:

# The Carbon Dioxide Theory of Climatic Change

By GILBERT N. PLASS

The Johns Hopkins University, Baltimore, Md.[1]

(Manuscript received August 9 1955)

## *Abstract*

The most recent calculations of the infra-red flux in the region of the 15 micron $CO_2$ band show that the average surface temperature of the earth increases 3.6° C if the $CO_2$ concentration in the atmosphere is doubled and decreases 3.8° C if the $CO_2$ amount is halved, provided that no other factors change which influence the radiation balance. Variations in $CO_2$ amount of this magnitude must have occurred during geological history; the resulting temperature changes were sufficiently large to influence the climate. The $CO_2$ balance is discussed. The $CO_2$ equilibrium between atmosphere and oceans is calculated with and without $CaCO_3$ equilibrium, assuming that the average temperature changes with the $CO_2$ concentration by the amount predicted by the $CO_2$ theory. When the total $CO_2$ is reduced below a critical value, it is found *that the climate continuously oscillates between* a glacial and an inter-glacial stage with a period of tens of thousands of years; there is no possible stable state for the climate. Simple explanations are provided by the $CO_2$ theory for the increased precipitation at the onset of a glacial period, the time lag of millions of years between periods of mountain building and the ensuing glaciation, and the severe glaciation at the end of the Carboniferous. The extra $CO_2$ released into the atmosphere by industrial processes and other human activities may have caused the temperature rise during the present century. In contrast with other theories of climate, the $CO_2$ theory predicts that this warming trend will continue, at least for several centuries.

**3.6 °C WARMING PER CO2 DOUBLING.**

**INDUSTRIAL PROCESSES MAY HAVE CAUSED EARTH TO WARM.**

**WARMING TREND WILL CONTINUE FOR CENTURIES.**

PLASS 1956:

c. *Time lag between periods of mountain building and glaciation*

There is considerable geological evidence that there were extensive periods of mountain building some millions of years before the last two major glacial epochs. Tremendous quantities of igneous rock are exposed to weathering by mountain building. By far the most active zone for the disintegration of rock is the zone between the surface and the level of the permanent underground water. In mountainous country this level is farther below the surface than in flat country and there is a considerably larger volume in which the active weathering of the rocks takes place. In the weathering of igneous rocks carbonates are formed, thus removing $CO_2$ from the atmosphere.

After a period of mountain building, more $CO_2$ is being taken from the atmosphere in the weathering of rock than before. This could easily change the $CO_2$ balance sufficiently so that after a period of the order of a million years, the atmospheric $CO_2$ would be reduced sufficiently to start a period of glaciation.

MOUNTAIN-BULDING INCREASES WEATHERABILITY OF SILICATE ROCKS, CAUSING CO2 TO BE REMOVED FROM THE ATMOSPHERE, COOLING THE EARTH.

d. *Influence of man's activities on climate*

At the present time the burning of fossil fuels is adding more than $6 \times 10^9$ tons per year of $CO_2$ to the atmosphere. Other activities of man such as the clearance of forests and the drainage and cultivation of land add additional amounts of $CO_2$ to the atmosphere each year. The total amount added each year from these sources is several orders of magnitude larger than any factor that contributes to the $CO_2$ balance from the inorganic world at the present time (see Table I). Therefore, this additional factor has greatly disturbed the $CO_2$ balance. If all this additional $CO_2$ remains in the atmosphere, there will be 30 per cent more $CO_2$ in the atmosphere at the end of the twentieth century than at the beginning. If no other factors change, man's activities are increasing the average temperature by 1.1° C per century. This argument was first presented by CALLENDAR (1938, 1949).

**PLASS 1956:**

**FOSSIL FUELS A MAJOR SOURCE OF CO2 RELATIVE TO THE NATURAL INORGANIC CARBON CYCLE.**

**CO2 WILL INCREASE BY 30% AND 1.1 °C WARMING BETWEEN 1900 AND 2000.**

**(ACTUAL INCREASE WAS 26% AND 0.7 °C.)**

There appear to be only two ways in which the excess $CO_2$ could be removed from the atmosphere. More $CO_2$ is used in photosynthesis when the $CO_2$ concentration increases. However, as already discussed, in a relatively short period of time increased rates of respiration and decay bring the factors from the organic world into balance once again. Except for a small initial loss, no appreciable part of the extra $CO_2$ can be used up in this manner.

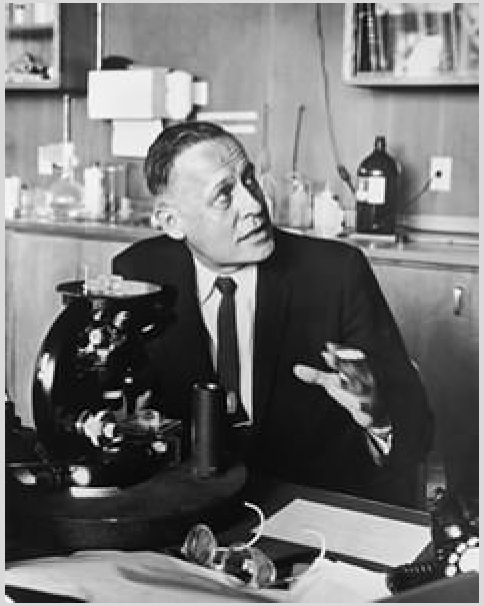
Some of the extra $CO_2$ will also be absorbed by the oceans. Because of the slow circulation of the oceans it would probably take at least 10,000 years for the atmosphere-ocean system to come to equilibrium after a change in the atmospheric $CO_2$ amount. The surface layers of the ocean start absorbing some of the extra $CO_2$ from the atmosphere as soon as the $P_{CO_2}$ is greater than the equilibrium amount. The rate at which this absorption takes place is not known accurately, but it is probably true that the surface layers can absorb only a small fraction of the extra $CO_2$ in a period of several hundred years. Thus it appears that most of the additional $CO_2$ that is released into the atmosphere will stay there for at least several centuries. Even if the oceans absorb $CO_2$ much more rapidly than has been assumed here, the accumulation of $CO_2$ in the atmosphere will become an increasingly important problem through the centuries.

**PLASS 1956:**

**CO2 REMOVED BY LAND BIOSPHERE.**

**CO2 REMOVED BY THE OCEANS.**

**OCEANS WILL LIKELY TAKE UP ONLY A SMALL FRACTION OF EXCESS ATMOSPHERIC CO2**



1957

Roger Revelle, U.S. oceanographer, and Hans Suess, Austrian-born U.S. chemist, realizing that carbon dioxide from industrial sources must be building up in the atmosphere, wrote in 1957: “Thus human beings are now carrying out a large scale geophysical experiment of a kind that could not have happened in the past nor be reproduced in the future.”

## OUR UNINTENDED EXPERIMENT

https://scied.ucar.edu/learning-zone/how-climate-works/history-climate-science-research

REVELLE 1957:

RADIOCARBON MEASUREMENTS INDICATE THAT MOST CO2 EMITTED IS GOING INTO THE OCEANS.

# Carbon Dioxide Exchange Between Atmosphere and Ocean and the Question of an Increase of Atmospheric $CO_2$ during the Past Decades

By ROGER REVELLE and HANS E. SUESS, Scripps Institution of Oceanography, University of California, La Jolla, California

(Manuscript received September 4, 1956)

CONTINUED EXPONENTIAL RISE IN EMISSIONS COULD CAUSE "SIGNIFICANT" INCREASE IN ATMOSPHERIC CONCENTRATION.

## *Abstract*

From a comparison of $C^{14}/C^{12}$ and $C^{13}/C^{12}$ ratios in wood and in marine material and from a slight decrease of the $C^{14}$ concentration in terrestrial plants over the past 50 years it can be concluded that the average lifetime of a $CO_2$ molecule in the atmosphere before it is dissolved into the sea is of the order of 10 years. This means that most of the $CO_2$ released by artificial fuel combustion since the beginning of the industrial revolution must have been absorbed by the oceans. The increase of atmospheric $CO_2$ from this cause is at present small but may become significant during future decades if industrial fuel combustion continues to rise exponentially.

## REVELLE 1957:

**20 TO 40% INCREASE IN ATMOSPHERIC CO2 CONTENT EXPECTED IN "THE COMING DECADES".**

**SHOULD ALLOW DETERMINATION OF CLIMATE EFFECTS.**

In contemplating the probably large increase in $CO_2$ production by fossil fuel combustion in coming decades we conclude that a total increase of 20 to 40 % in atmospheric $CO_2$ can be anticipated. This should certainly be adequate to allow a determination of the effects, if any, of changes in atmospheric carbon dioxide on weather and climate throughout the earth.

ACTUAL: 20% INCREASE BY 1979 AND 40% INCREASE BY 2011
FIRST "DETECTION AND ATTRIBUTION" PUBLISHED IN 1996 (29.3% INCREASE).

**REVELLE 1957:**

**SEAWATER CHEMISTRY MEANS THAT A 1% INCREASE IN INORGANIC C CONCENTRATION LEADS TO A 10% INCREASE IN CO2 PARTIAL PRESSURE.**

Because of the peculiar buffer mechanism of sea water, however, the increase in the partial $CO_2$ pressure is about 10 times higher than the increase in the total $CO_2$ concentration of sea water when $CO_2$ is added and the alkalinity remains constant (BUCH, 1933, see also HARVEY, 1955),

**CALCULATIONS SUGGEST A 3 TO 6% INCREASE IN CO2 DUE TO FOSSIL-FUEL BURNING.**

The increase in $CO_2$ in the atmosphere plus biosphere and soil due to industrial fuel combustion should therefore at present amount to 3 to 6 %, depending on the assumptions made with respect to the size of the "effective" atmospheric carbon reservoir that exchanges with the ocean.

**ACTUAL: ACTUAL INCREASE TO 1957 WAS CLOSER TO 11% BUT AT THAT POINT MORE CO2 HAD BEEN RELEASE FROM LAND-USE CHANGE THAN FOSSIL-FUEL BURNING.**

https://www.youtube.com/watch?v=EbHYcNtcW7g

https://youtu.be/EbHYcNtcW7g?t=2997s

1958

The Bell Telephone Science Hour addressed how our actions could be changing Earth's climate. "Even now, [we] may be unwittingly changing the world's climate through the waste products of [our] civilization," said the narrator. "Due to our release from factories and automobiles every year of more than six billion tons of carbon dioxide, which helps the air absorb heat from the Sun, our atmosphere seems to be getting warmer."

## CLIMATE SCIENCE ON TELEVISION

https://scied.ucar.edu/learning-zone/how-climate-works/history-climate-science-research

1958

Charles Keeling started making daily measurements of the amount of carbon dioxide in the air atop Mauna Loa in Hawaii. That first March day, he found 313 parts per million (ppm) of carbon dioxide in the air. The measurements, which are still made each day, reached 400 ppm on May 9, 2013, and continue to climb.

https://youtu.be/rEbE5fcnFVs

**DAILY MEASUREMENTS OF CARBON DIOXIDE**

https://scied.ucar.edu/learning-zone/how-climate-works/history-climate-science-research

**KEELING 1960:**

**SEASONAL CYCLE OF CO2 IN NORTHERN HEMISPHERE IS AN INDICATOR OF PHOTOSYNTHESIS AND RESPIRATION.**

# The Concentration and Isotopic Abundances of Carbon Dioxide in the Atmosphere

By CHARLES D. KEELING, Scripps Institution of Oceanography, University of California, La Jolla, California

(Manuscript received March 25, 1960)

## *Abstract*

A systematic variation with season and latitude in the concentration and isotopic abundance of atmospheric carbon dioxide has been found in the northern hemisphere. In Antarctica, however, a small but persistent increase in concentration has been found. Possible causes for these variations are discussed.

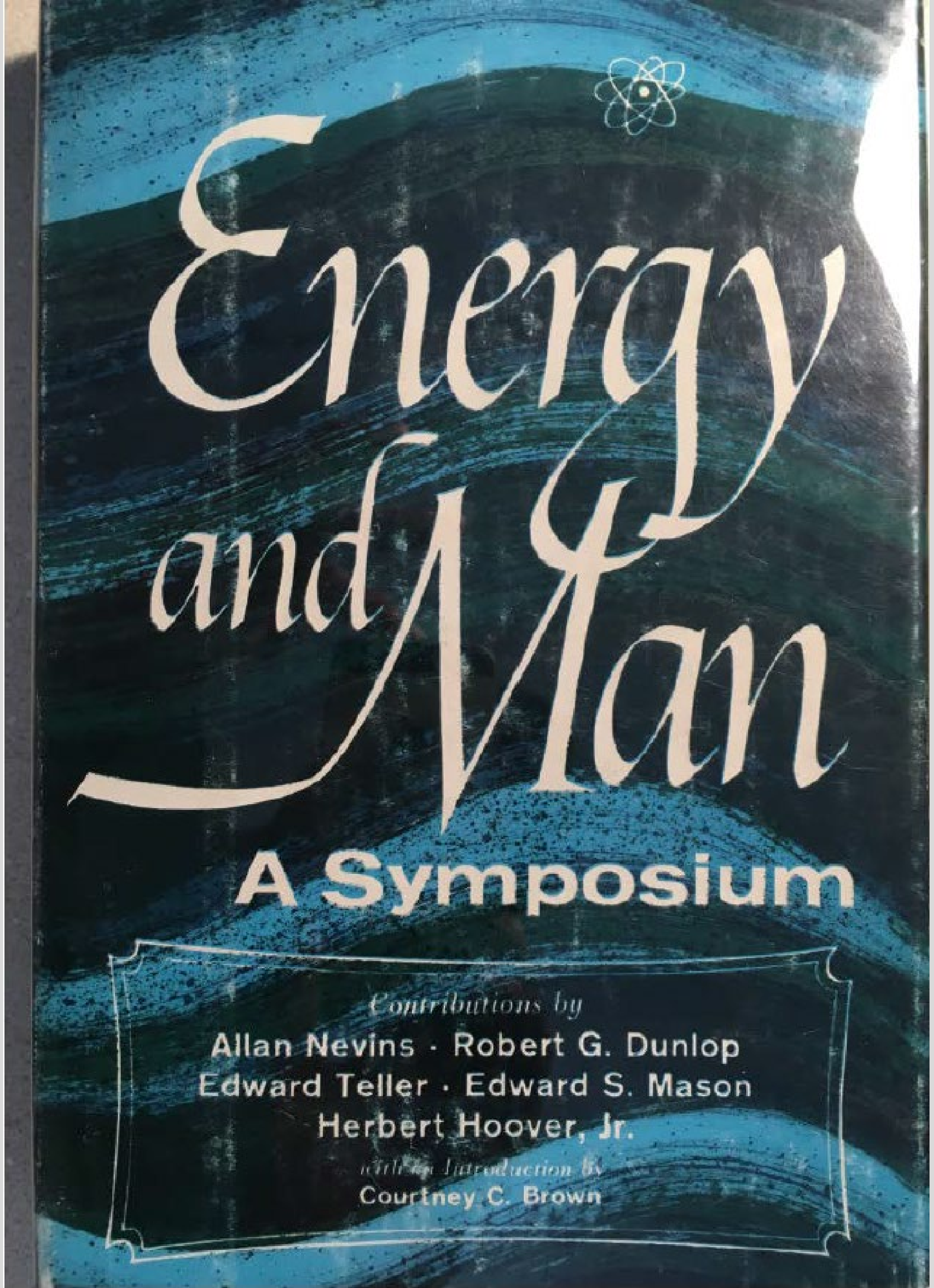
**INCREASE SEEN AT SOUTH POLE COULD BE DUE TO FOSSIL-FUEL BURNING.**

**KEELING 1960:**

**SEASONAL CYCLE OF CO2 IN NORTHERN HEMISPHERE IS AN INDICATOR OF PHOTOSYNTHESIS AND RESPIRATION.**

available in the future. At the South Pole the observed rate of increase is nearly that to be expected from the combustion of fossil fuel (1.4 p.p.m.), if no removal from the atmosphere takes place (REVELLE and SUESS, 1957). From this agreement, one might be led to conclude that the oceans have been without effect in reducing the annual increase in concentration resulting from the combustion of fossil fuel.

**RATE OF CO2 INCREASE AT SOUTH POLE INDICATES LITTLE OCEAN CO2 UPTAKE.**




## III. ENERGY PATTERNS OF THE FUTURE

by Edward Teller

## TELLER 1960:

I would like to talk to you about a more hypothetical difficulty which I think is quite probably going to turn out to be real. Whenever you burn conventional fuel, you create carbon dioxide. It has been calculated that the carbon dioxide which has been put into the atmosphere since the beginning of the industrial revolution equals approximately 10 per cent of the amount of carbon dioxide that our atmosphere contained originally.

There are modern methods by which we can find out reasonably accurately how much of this additional carbon dioxide the atmosphere actually contains today. They are the result of some excellent work at the Scripps Institute in California, and through these methods it was found that actually the carbon dioxide content of the atmosphere has increased by only 2 per cent.

**"… A MORE HYPOTHETICAL DIFFICULTY WHICH I THINK IS QUITE PROBABLY GOING TO TURN OUT TO BE REAL."**

## TELLER 1960:

If now, the rate of burning conventional fuels continues to increase by a factor of 2 each ten years, the result will be that by the end of the century there will be an increase of carbon dioxide in the atmosphere by more than 10 per cent. The carbon dioxide is invisible, it is transparent, you can't smell it, it is not dangerous to health, so why should one worry about it?

Carbon dioxide has a strange property. It transmits visible light but it absorbs the infrared radiation which is emitted from the earth. Its presence in the atmosphere causes a greenhouse effect in that it will allow the solar rays to enter, but it will to some extent impede the radiation from the earth into outer space.

The result is that the earth will continue to heat up until a balance is re-established. Then the earth will be at a higher temperature and will radiate more. It has been calculated that a temperature rise corresponding to a 10 per cent increase in carbon dioxide will be sufficient to melt the icecap and submerge New York. All the coastal cities would be covered, and since a considerable percentage of the human race lives in coastal regions, I think that this chemical contamination is more serious than most people tend to believe.

**"I THINK THIS CHEMICAL CONTAMINATION IS MORE SERIOUS THAN MOST PEOPLE TEND TO BELIEVE."**

## TELLER 1960:

## SEARCH FOR NEW FUELS TO ADDRESS CLIMATE RISK.

For this then, and for many other reasons, I will say that any new fuels we find will be welcome. I believe that of the new fuels, nuclear energy is the most promising and I will talk about nuclear energy from here on.

## PSAC 1965:

# RESTORING THE QUALITY
OF
# OUR ENVIRONMENT

*Report of The*
*Environmental Pollution Panel*
*President's Science Advisory Committee*

THE WHITE HOUSE
NOVEMBER 1965

**FIRST TIME A US PRESIDENT WAS WARNED OF CLIMATE RISK.**

PSAC 1965:

APPENDIX Y4

## Atmospheric Carbon Dioxide

ROGER REVELLE, *Chairman*

WALLACE BROECKER — C. D. KEELING
HARMON CRAIG — J. SMAGORINSKY

**FIRST TIME A US PRESIDENT WAS WARNED OF CLIMATE RISK.**

### POSSIBLE EFFECTS OF INCREASED ATMOSPHERIC CARBON DIOXIDE ON CLIMATE

One of the most recent discussions of these effects is given by Möller (1963). He considers the radiation balance at the earth's surface with an average initial temperature of 15°C (59°F), a relative humidity of 75 percent, and 50% cloudiness. We may compute from his data that with a 25 percent increase in atmospheric $CO_2$, the average temperature near the earth's surface could increase between 0.6°C and 4°C (1.1°F to 7°F), depending on the behavior of the atmospheric water vapor content. The small increase would correspond to a constant absolute

**NOW, A 25% INCREASE IS EXPECTED TO CAUSE ABOUT 1°C OF WARMING.**

# PSAC 1965:

By the year 2000 the increase in atmospheric $CO_2$ will be close to 25%. This may be sufficient to produce measurable and perhaps marked changes in climate, and will almost certainly cause significant changes in the temperature and other properties of the stratosphere. At present it is impossible to predict these effects quantitatively, but recent advances in mathematical modelling of the atmosphere, using large computers, may allow useful predictions within the next 2 or 3 years.

**CO2 MAY INCREASE BY 25% BY YEAR 2000.**

**ACTUAL INCREASE TO YEAR 2000 WAS 32%.**

The climatic changes that may be produced by the increased $CO_2$ content could be deleterious from the point of view of human beings. The possibilities of deliberately bringing about countervailing climatic changes therefore need to be thoroughly explored. A change in the radiation balance in the opposite direction to that which might result from the increase of atmospheric $CO_2$ could be produced by raising the albedo, or reflectivity, of the earth. Such a change in albedo could be brought about, for example by spreading very small reflecting particles over large oceanic areas. The particles should be sufficiently buoyant so that they will remain close to the sea surface and they should have a high reflectivity, so that even a partial covering of the surface would be adequate to produce a marked change in the amount of reflected sunlight. Rough estimates indicate that enough particles partially to cover a square mile could be produced for perhaps one hundred dollars. Thus a 1% change in reflectivity might be brought about for about 500 million dollars a year, particularly if the reflecting particles were spread in low latitudes, where the incoming radiation is concentrated. Considering the extraordinary economic and human importance of climate, costs of this magnitude do not seem excessive. An early development of the needed technology might have other uses, for example in inhibiting the formation of hurricanes in tropical oceanic areas.

According to Manabe and Strickler (1964) the absorption and reradiation of infrared by high cirrus clouds (above five miles) tends to heat the atmosphere near the earth's surface. Under some circumstances, injection of condensation or freezing nuclei will cause cirrus clouds to form at high altitudes. This potential method of bringing about climatic changes needs to be investigated as a possible tool for modifying atmospheric circulation in ways which might counteract the effects of increasing atmospheric carbon dioxide.

**PSAC 1965:**

**WARMING MIGHT BE COUNTERACTED WITH REFLECTIVE PARTICLES OR BY MODIFYING CIRRUS CLOUDS.**

**NO MENTION OF TRYING TO DECREASE EMISSIONS.**