Fizyka Procesów Klimatycznych

Historia naukowa: od CO_2 do chmur

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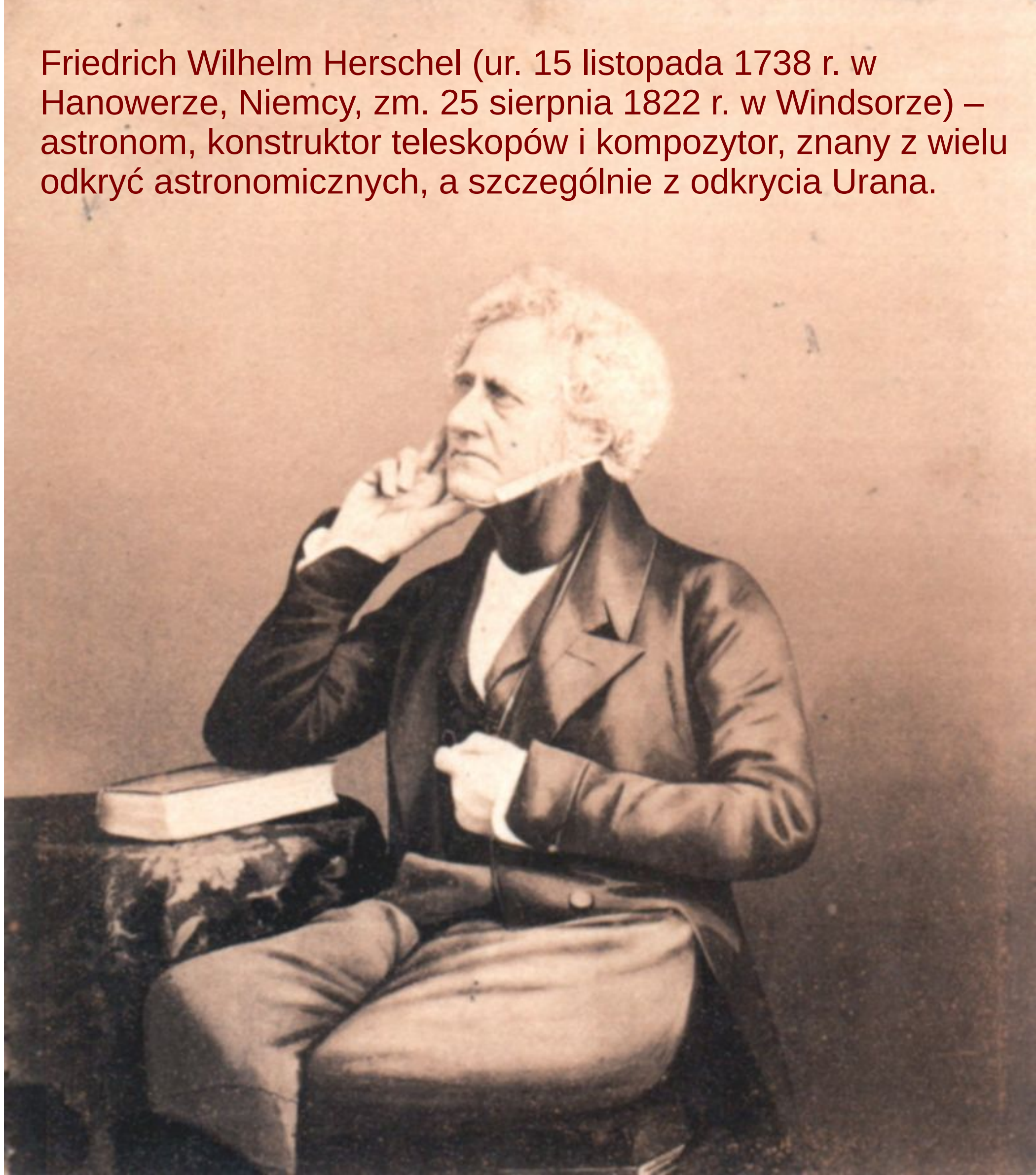
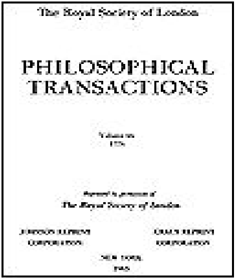
Opowieść o historii naukowej klimatu zaczniemy od brytyjskiego astronoma **Williama Herschella**, który w 1801 roku, wiedząc że wiele gwiazd zmienia jasność zadał pytanie: a jak jest ze Słońcem?

Wiedząc o zmiennej licznie plam na Słońcu, które obserwowano od czasów Galileusza skojarzył ich brak w długich okresach w 17 wieku z zapisami o cenach zbóż, które jak argumentował powinny być związane z okresami suszy.

Stąd wywiódł wniosek o wpływie Słońca na klimat.



Friedrich Wilhelm Herschel (ur. 15 listopada 1738 r. w Hanowerze, Niemcy, zm. 25 sierpnia 1822 r. w Windsorze) – astronom, konstruktor teleskopów i kompozytor, znany z wielu odkryć astronomicznych, a szczególnie z odkrycia Urana.



XIII. *Observations tending to investigate the Nature of the Sun, in order to find the Causes or Symptoms of its variable Emission of Light and Heat; with Remarks on the Use that may possibly be drawn from Solar Observations. By* William Herschel, *L. L. D. F. R. S.*

Read April 16, 1801.

On a former occasion I have shewn, that we have great reason to look upon the sun as a most magnificent habitable globe; and, from the observations which will be related in this Paper, it will now be seen, that all the arguments we have used before are not only confirmed, but that we are encouraged to go a considerable step farther, in the investigation of the physical and planetary construction of the sun. The influence of this eminent body, on the globe we inhabit, is so great, and so widely diffused, that it becomes almost a duty for us to study the operations which are carried on upon the solar surface. Since light and heat are so essential to our well-being, it must certainly be right for us to look into the source from whence they are derived, in order to see whether some material advantage may not be drawn from a thorough acquaintance with the causes from which they originate.

A similar motive engaged the Egyptians formerly to study and watch the motions of the Nile; and to construct instruments for measuring its rise with accuracy. They knew very well, that it was not in their power to add a single inch to the

Observations Tending to Investigate the Nature of the Sun, in Order to Find the Causes or Symptoms of Its Variable Emission of Light and Heat; With Remarks on the Use That May Possibly Be Drawn from Solar Observations

William Herschel

Philosophical Transactions of the Royal Society of London
Vol. 91 (1801), pp. 265-318

Około 20 lat później francuski fizyk i matematyk, **Joseph Fourier** oszacował ze temperatura powierzchni naszej planety jest wyższa niż wynikałoby z dopływu energii słonecznej i spekulował, że być może atmosfera ma własności izolacyjne, utrudniające ucieczkę ciepła w przestrzeń kosmiczną.

Zjawisko to nazwał, przez analogię do obserwowanego przez De Sausierre'a w naczyniu z wieloma szybami wzrostu temperatury w stosunku do otoczenia, efektem cieplarnianym.

Dwie podstawowe hipotezy fizyki klimatu sformułowano już na początku XIX wieku !!!

Fourier J (1827). "Mémoire Sur Les Températures Du Globe Terrestre Et Des Espaces Planétaires". Mémoires de l'Académie Royale des Sciences 7: 569–604

Jean Baptiste Joseph Fourier (ur. 21 marca 1768 w Auxerre - zm. 16 maja 1830 r. w Paryżu) – francuski matematyk i fizyk.

Dwie podstawowe hipotezy fizyki klimatu sformułowano już na początku XIX wieku !!!

MÉMOIRES

DE

L'ACADÉMIE ROYALE DES SCIENCES

DE L'INSTITUT

DE FRANCE.

TOME VII.

PARIS,

CHEZ FIRMIN DIDOT, PÈRE ET FILS, LIBRAIRES,

RUE JACOB, N° 24.

1827.

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 déja 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.

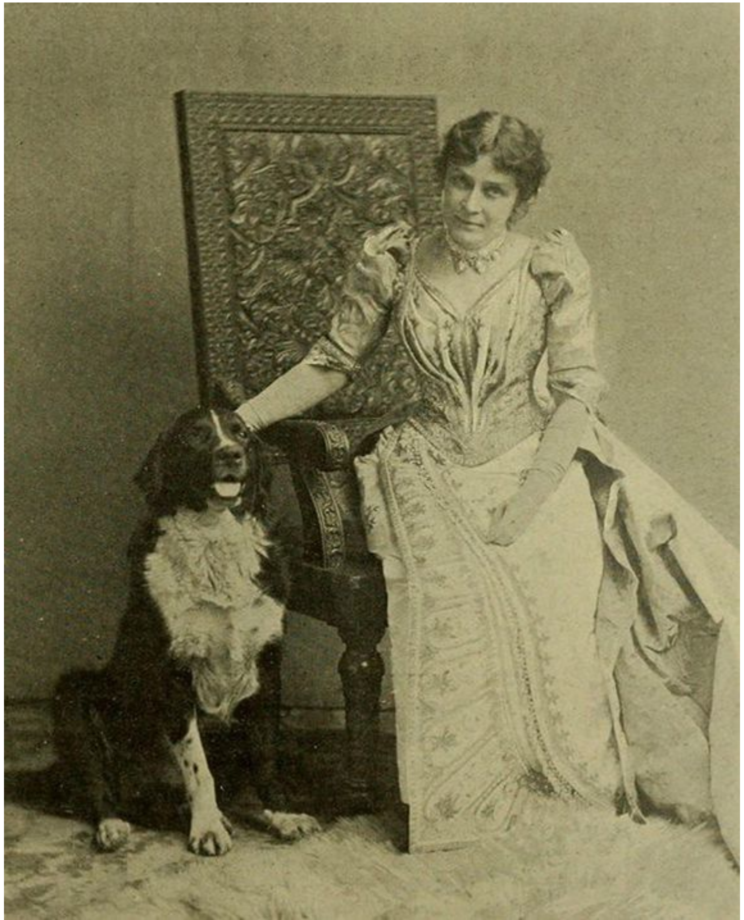
1824. 72

Fourier J (1827). "Mémoire Sur Les Températures Du Globe Terrestre Et Des Espaces Planétaires"

Eunice Newton Foote (17 lipca 1819 - 30 września 1888) była amerykańską uczoną (specjalizującą się w biologii, zwłaszcza botanice), wynalazczynią i działaczką na rzecz praw kobiet z Seneca Falls w stanie Nowy Jork.

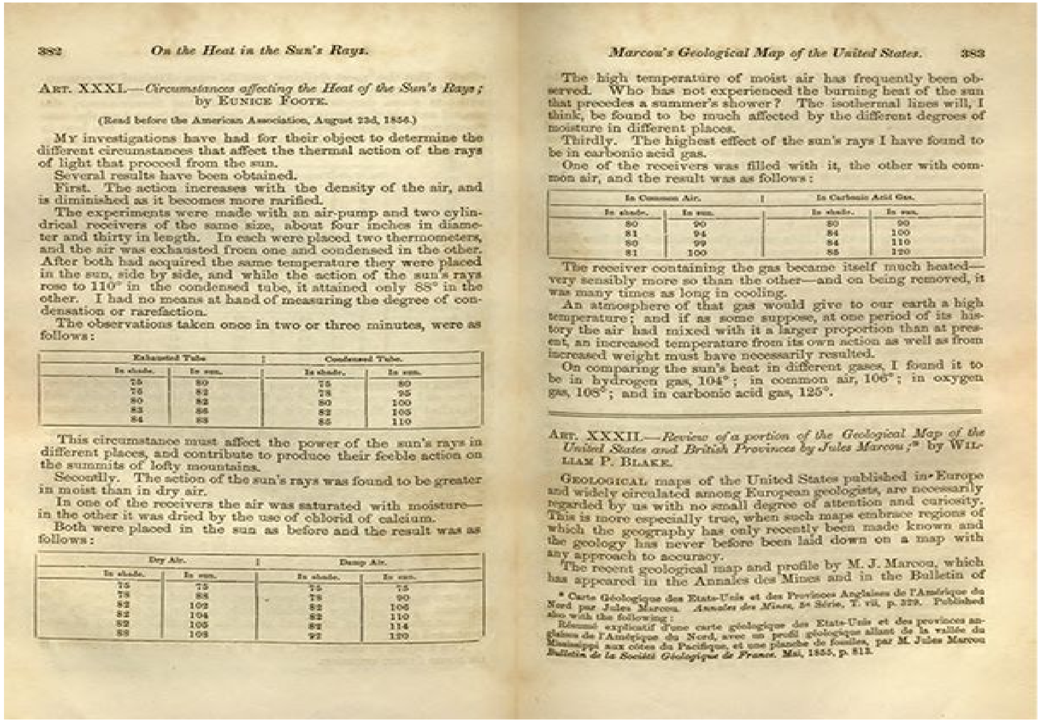
Była pierwszym naukowcem, o którym wiadomo, że eksperymentował z ocieplającym efektem światła słonecznego na różne gazy, a następnie teoretyzował, że zmiana proporcji dwutlenku węgla w atmosferze zmieni jej temperaturę. Opisała to swoim artykule
„Circumstances affecting the heat of the sun's rays”
wspomnianym na konferencji American Association for the Advancement of Science w 1856 roku.

Chociaż wydaje się, że kobiety mogły wówczas wygłaszać referaty w AAAS, profesor Joseph Henry ze Smithsonian Institution wygłosił referat, który identyfikował badania jako jej pracę.



Eunice Newton Foote (1819-1888)

„Foote's paper demonstrated the interactions of the sun's rays on different gases through a series of experiments using an air pump, four thermometers, and two glass cylinders. First, Foote placed two thermometers in each cylinder and, using the air pump, removed the air from one cylinder and condensed it in the other. Allowing both cylinders to reach the same temperature, she then placed the cylinders with their thermometers in the sun to measure temperature variance once heated and under various states of moisture. She repeated this process with hydrogen, common air, and CO2, all heated after being exposed to the sun."



382 *On the Heat in the Sun's Rays.*

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.

The observations taken once in two or three minutes, were as follows:

Exhausted Tube.		Condensed Tube.	
In shade.	In sun.	In shade.	In sun.
75	80	75	80
76	82	78	95
80	82	80	100
83	86	82	105
84	88	85	110

This circumstance must affect the power of the sun's rays in different places, and contribute to produce their feeble action on the summits of lofty mountains.

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
83	108	92	120

Marcou's Geological Map of the United States. 383

The high temperature of moist air has frequently been observed. Who has not experienced the burning heat of the sun that precedes a summer's shower? The isothermal lines will, I think, be found to be much affected by the different degrees of moisture in different places.

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.

On comparing the sun's heat in different gases, I found it to be in hydrogen gas, 104°; in common air, 106°; in oxygen gas, 108°; and in carbonic acid gas, 125°.

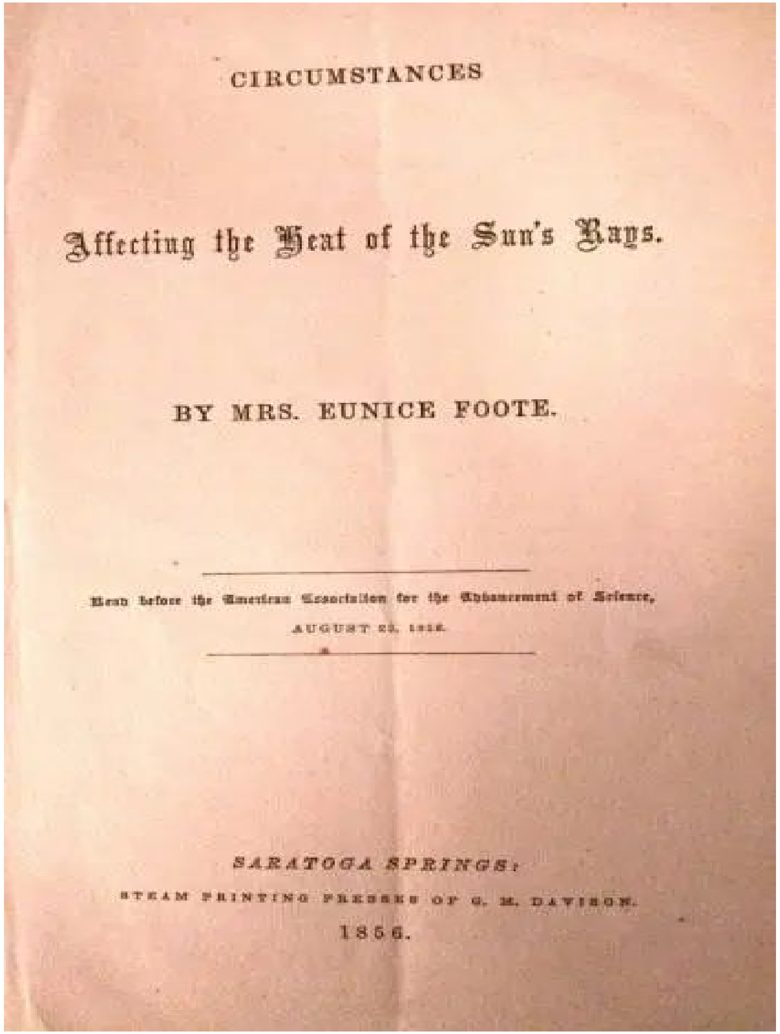
ART. XXXII.—*Review of a portion of the Geological Map of the United States and British Provinces by Jules Marcou;** by WILLIAM P. BLAKE.

GEOLOGICAL maps of the United States published in Europe and widely circulated among European geologists, are necessarily regarded by us with no small degree of attention and curiosity. This is more especially true, when such maps embrace regions of which the geography has only recently been made known and the geology has never before been laid down on a map with any approach to accuracy.

The recent geological map and profile by M. J. Marcou, which has appeared in the Annales des Mines and in the Bulletin of

* Carte Géologique des Etats-Unis et des Provinces Anglaises de l'Amérique du Nord par Jules Marcou. *Annales des Mines*, 5e Série, T. vii, p. 329. Published also with the following:

Résumé explicatif d'une carte géologique des Etats-Unis et des provinces anglaises de l'Amérique du Nord, avec un profil géologique allant de la vallée du Mississippi aux côtes du Pacifique, et une planche de fossiles, par M. Jules Marcou. *Bulletin de la Société Géologique de France*. Mai, 1855, p. 813.



CIRCUMSTANCES

Affecting the Heat of the Sun's Rays.

BY MRS. EUNICE FOOTE.

Read before the American Association for the Advancement of Science,

AUGUST 23, 1856.

SARATOGA SPRINGS:

STEAM PRINTING PRESSES OF G. M. DAVISON.

1856.

Spekulacje Fouriera o izolacyjnych własnościach gazów atmosferycznych zostały potwierdzone doświadczalnie czterdzieści lat później.

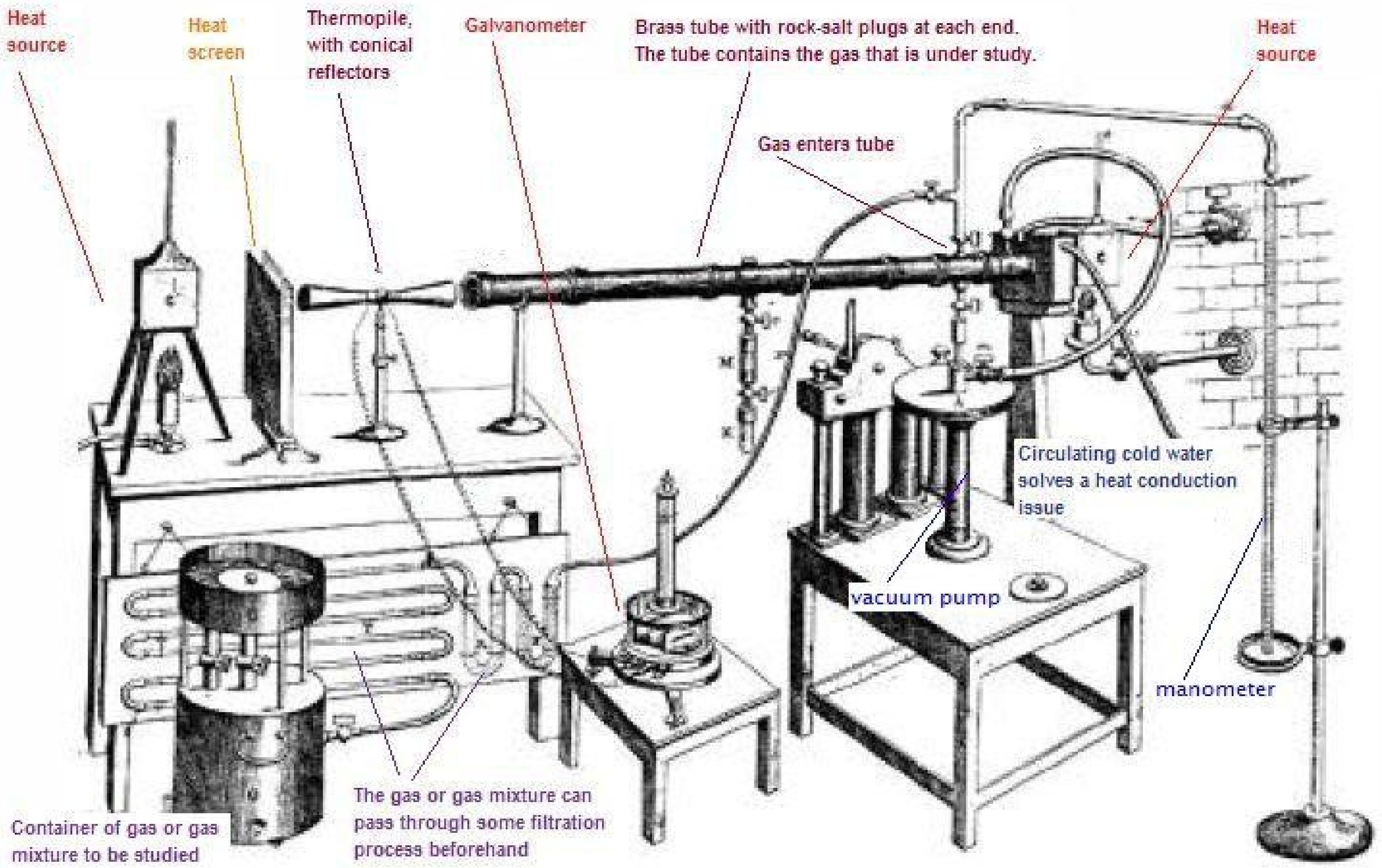
Irlandzki fizyk **John Tyndall** zmierzył w laboratorium, że para wodna oraz dwutlenek węgla (a także niektóre inne gazy) absorbują promieniowanie cieplne (podczerwone).

John Tyndall (ur. 2 sierpnia 1820 – zm. 4 grudnia 1893) – irlandzki filozof przyrody, badacz i odkrywca zjawisk fizycznych z zakresu m.in. magnetyzmu, glacjologii, chemii fizycznej i bakteriologii, członek Royal Society, alpinista: pierwszy zdobywca m.in. Weisshornu.

ON RADIATION.

Spis treści jednej z prac Tyndalla.

THE "REDE" LECTURE, DELIVERED IN THE SENATE-HOUSE, BEFORE THE UNIVERSITY OF CAMBRIDGE, ENGLAND, ON TUESDAY, MAY 16, 1865.



Ilustracja z 1861 z jednej z książek napisanych przez Johna Tyndalla pokazująca układ eksperymentalny do pomiaru absorpcji promieniowania podczerwonego przez gazy i pary.

Tyndall w roku 1860 pisał:

„De Saussure, Fourier, M. Pouillet, and Mr. Hopkins regard this interception of the terrestrial rays as exercising the most important influence on climate. . . every variation [in aqueous vapour] must produce a change of climate. Similar remarks would apply to the carbonic acid diffused through the air, while an almost inappreciable admixture of any of the hydrocarbon vapours would produce great effects on the terrestrial rays and produce corresponding changes of climate. It is not, therefore, necessary to assume alterations in the density and height of the atmosphere to account for different amounts of heat being preserved to the earth at different times; a slight change in its variable constituents would suffice for this. Such changes in fact may have produced all the mutations of climate which the researches of geologists reveal."

W wolnym tłumaczeniu brzmi to tak:

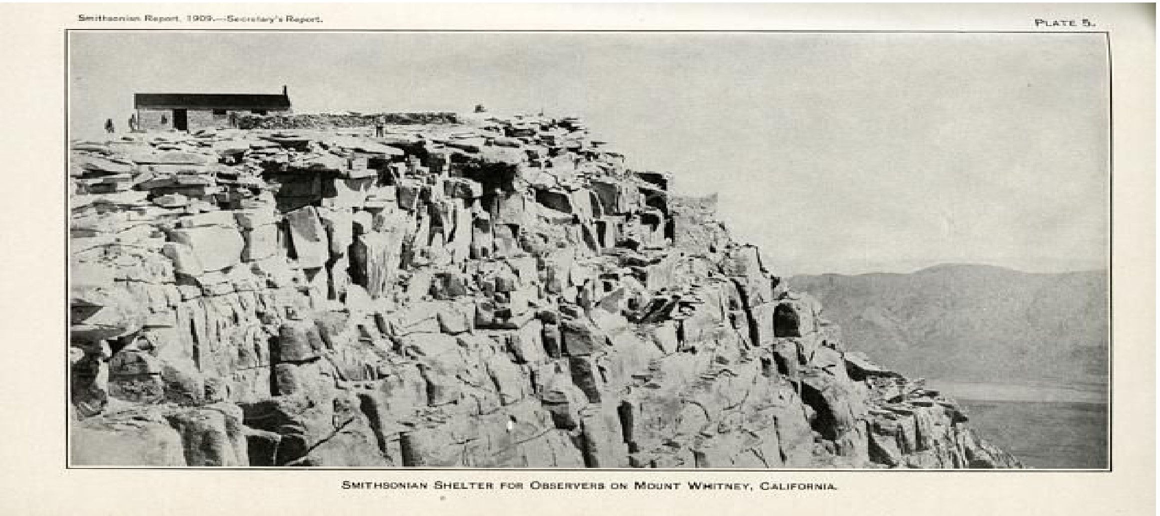
„ De Saussure, Fourier, M. Pouillet i Pan Hopkins podkreślali znaczenie pochłaniania promieniowania ziemskiego jako zjawiska najbardziej wpływającego na klimat.... każda zmiana [wody i pary wodnej] musi wywoływać zmiany klimatyczne. To samo odnosi się do dwutlenku węgla obecnego w powietrzu, albo nawet niezauważalnych domieszek węglowodorów, które mają ogromne znaczenie dla promieniowania ziemskiego i skutkują zmianami klimatu. Dlatego, dla wyjaśnienia faktu ze w różnych epokach (geologicznych) przy powierzchni Ziemi były utrzymywane różne ilości ciepła, nie trzeba zakładać istotnych zmian gęstości powietrza czy głębokości atmosfery; niewielkie zmiany w składzie powietrza zupełnie do tego wystarczają. Takie zmiany mogły powodować wszystkie zmiany klimatu które odkrywają geolodzy."

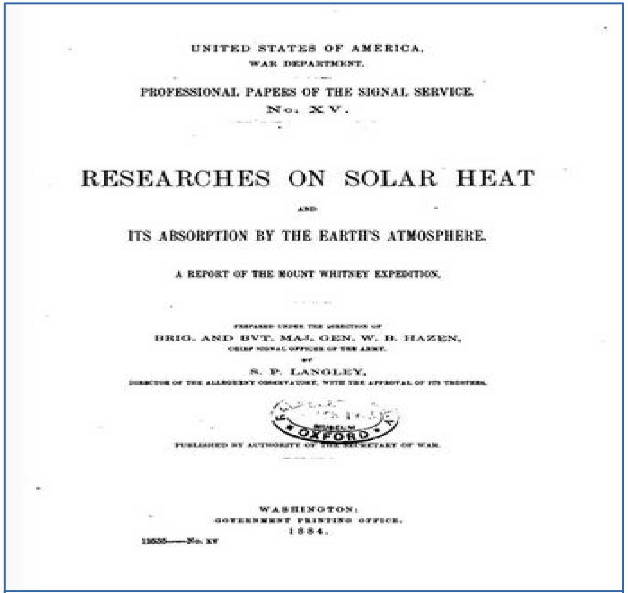
Badania tego, jak na bilans energii planety wpływa Słońce, a jak efekt cieplarniany można było wykonać tylko dzięki dzięki danym obserwacyjnym o strumieniu energii dopływającej od Słońca – tzw. „stałej słonecznej” oraz obserwacjom astronomicznym w podczerwieni.

Pionierem jednych i drugich był amerykański fizyk, i astronom **Samuel Pierpont Langley**.

Wynalazł on bolometr usprawniający pomiary energii przenoszonej przez promieniowanie słoneczne i jest autorem metody Langleya umożliwiającej określenie pochłaniania atmosfery a tym samym określenie stałej słonecznej.

Samuel Pierpont Langley (ur. 22 sierpnia 1834, zm. 27 lutego 1906, amerykański fizyk, astronom, pionier lotnictwa, założyciel Smithsonian Institution, prowadził pomiary energii docierającej do Ziemi od Słońca.





UNITED STATES OF AMERICA,
WAR DEPARTMENT.

PROFESSIONAL PAPERS OF THE SIGNAL SERVICE.
No. XV.

RESEARCHES ON SOLAR HEAT
AND
ITS ABSORPTION BY THE EARTH'S ATMOSPHERE.

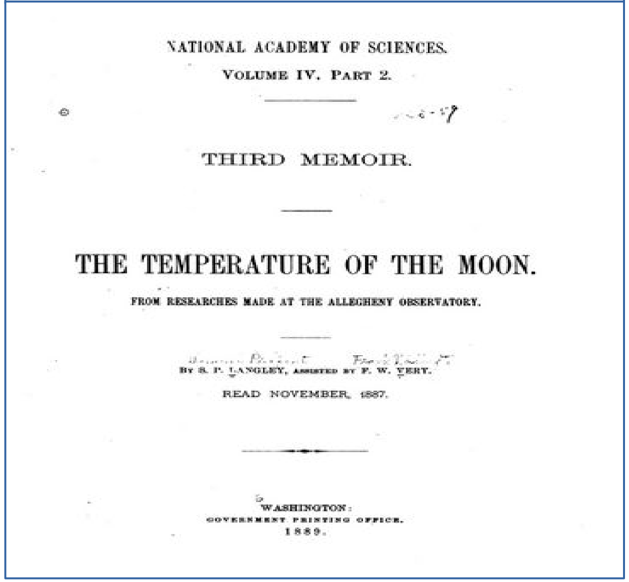
A REPORT OF THE MOUNT WHITNEY EXPEDITION.

PREPARED UNDER THE DIRECTION OF
BRIG. AND BVT. MAJ. GEN. W. B. HAZEN,
CHIEF SIGNAL OFFICER OF THE ARMY,
BY
S. P. LANGLEY,
DIRECTOR OF THE ALLEGHENY OBSERVATORY, WITH THE APPROVAL OF ITS TRUSTEES.

PUBLISHED BY AUTHORITY OF THE SECRETARY OF WAR.

WASHINGTON:
GOVERNMENT PRINTING OFFICE.
1884.

13535——No. XV



NATIONAL ACADEMY OF SCIENCES.
VOLUME IV. PART 2.

THIRD MEMOIR.

THE TEMPERATURE OF THE MOON.
FROM RESEARCHES MADE AT THE ALLEGHENY OBSERVATORY.

BY S. P. LANGLEY, ASSISTED BY F. W. VERY.
READ NOVEMBER, 1887.

WASHINGTON:
GOVERNMENT PRINTING OFFICE.
1889.

Svante Arrhenius, szwedzki chemik który działał naukowo pa przełomie XIX i XX wieku, pierwszy zrozumiał rolę dwutlenku węgla jako ważnego dla zmian klimatu gazu cieplarnianego.

Wykonał pierwsze na świecie obliczenia transferu radiacyjnego przez atmosferę. Zrobił to dla różnych szerokości geograficznych.

Svante August Arrhenius
(ur. 19 lutego 1859 w Uppsali, zm. 2 października 1927 w Sztokholmie) – szwedzki chemik i fizyk, jeden z twórców chemii fizycznej.

On the Influence of Carbonic Acid in the Air upon the Temperature of the Ground

Svante Arrhenius

Philosophical Magazine and Journal of Science
Series 5, Volume 41, April 1896, pages 237-276.

Arrhenius's paper is the first to quantify the contribution of carbon dioxide to the greenhouse effect (Sections I-IV) and to speculate about whether variations in the atmospheric concentration of carbon dioxide have contributed to long-term variations in climate (Section V). Throughout this paper, Arrhenius refers to carbon dioxide as "carbonic acid" in accordance with the convention at the time he was writing.

Contrary to some misunderstandings, Arrhenius does not explicitly suggest in this paper that the burning of fossil fuels will cause global warming, though it is clear that he is aware that fossil fuels are a potentially significant source of carbon dioxide (page 270), and he does explicitly suggest this outcome in later work.

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).

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

Latitude.	Carbonic Acid=0·67. 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	—	—	—

Latitude.	Carbonic Acid=1·5. 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	—	—	—

Latitude.	Carbonic Acid=2·0. 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	—	—	—

Latitude.	Carbonic Acid=2·5. 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	—	—	—

Latitude.	Carbonic Acid=3·0. 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	—	—	—

ADDENDUM*.

As the nebulosity is very different in different latitudes, and also different over the sea and over the continents, it is evident that the influence of a variation in the carbonic acid of the air will be somewhat different from that calculated above, where it is assumed that the nebulosity is the same over the whole globe. I have therefore estimated the nebulosity at different latitudes with the help of the chart published by Teisserenc de Bort, and calculated the following table for

Latitude.	Nebulosity.		Continent per cent.	Reduction factor.			K=0·67.		K=1·5.	
	Conti-nent.	Ocean.		Conti-nent.	Ocean.	Mean.	Conti-nent.	Ocean.	Conti-nent.	Ocean.
70–60	58·1	66·7	72·1	0·899	0·775	0·864	−2·8	−2·4	3·1	2·7
60–50	56·3	67·6	55·8	0·924	0·763	0·853	−3·0	−2·4	3·3	2·7
50–40	45·7	63·3	52·9	1·057	0·813	0·942	−3·5	−2·7	3·8	2·9
40–30	36·5	52·5	42·9	1·177	0·939	1·041	−3·9	−3·1	4·1	3·3
30–20	28·5	47·2	38·8	1·296	1·009	1·120	−4·1	−3·2	4·5	3·5
20–10	28·5	47·0	24·2	1·308	1·017	1·087	−4·1	−3·2	4·3	3·4
10–0	50·1	56·7	23·3	1·031	0·903	0·933	−3·1	−2·7	3·3	2·9
0–−10	54·8	59·7	24·2	0·97	0·867	0·892	−2·9	−2·6	3·1	2·8
−10–−20	47·8	54·0	22·5	1·056	0·932	0·96	−3·3	−2·9	3·4	3·0
−20–−30	29·6	49·6	23·3	1·279	0·979	0·972	−4·1	−3·1	4·2	3·2
−30–−40	38·9	51·0	12·5	1·152	0·958	0·982	−3·8	−3·2	4·0	3·4
−40–−50	62·0	61·1	2·5	0·86	0·837	0·838	−2·9	−2·8	3·2	3·1
−50–−60	71·0	71·5	0·9	0·749	0·719	0·719				

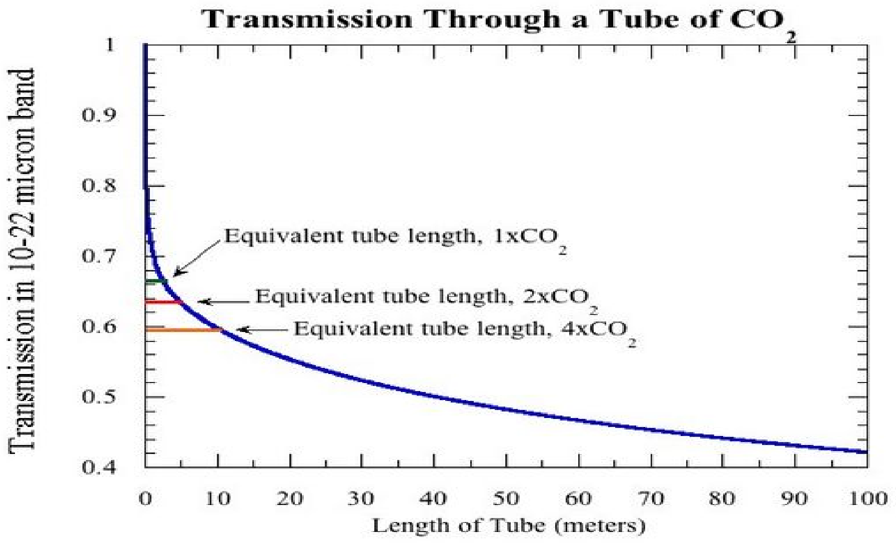
* *Cf.* p. 265.

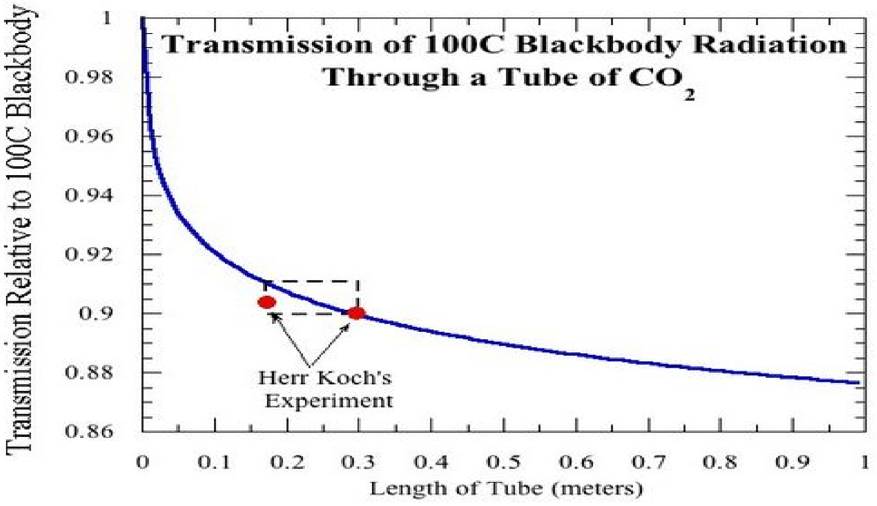
Arrhenius wyliczył też dodatkowo poprawkę na nieprzeźroczystość atmosfery (aerozole!!!!)

Wyniki obliczeń Arrheniusa skrytykował w 1900 rinny wpływowy szwedzki fizyk, **Knut Ångström**, który zinterpretował wyniki pomiarów absorpcji podczerwien w gazach cieplarnianych wykonane błędnie przez swojego asystenta (J. Kocha) i ogłosił, że przy wzroście zawartości gazów cieplarnianych w powietrzu efekt cieplarniany ulegnie wysyceniu.

Ten pogląd szybko zdobył popularność w kręgach naukowych, można o tym przeczytać np. w wydanym w 1909 roku podręczniku „Fizyka Ziemi”. Lata minęły, zanim zauważono błędy w pomiarach prowadzonych przez Kocha a błędny wynik rozpropagowany przez Ångströma stał się podstawą jednego z powszechnych “mitów klimatycznych”.

Już w 1906 r. niemiecki astrofizyk Karl Schwarzchild sformułował równanie transferu radiacyjnego, które w zmodyfikowanych wersjach jest do dziś w użyciu. Ångström nie uwzględnił emisji promieniowania przez gaz ani innych mechanizmów transportu energii (np. konwekcja – patrz równowaga radiacyjno-konwekcyjna).





Thomas C. Chamberlin w serii publikacji z ostatnich lat XIX wieku rozpropagował teorię i obliczenia Arrheniusa wśród geologów.

Jako pierwszy dowodził że atmosferyczny CO_2 jest jednym s głównych „regulatorów" temperatury powierzchni naszej planety.

Był pierwszym, który pokazał że jedyną drogą do zrozumienia procesów klimatycznych jest uwzględnienie wielu różnych procesów: nie tylko Słońca, tylko składu powietrza, ale roli oceanów, wulkanizmu, mineralogii, przemian chemicznych. Wprowadził pojęcie sprzężeń w systemie klimatycznym.

Thomas Chrowder Chamberlin, ur. 25 września 1843, zm. 15 listopada 1928, amerykański geolog, pierwszy postawią hipotezę że źródłem ciepła we wnetrzu Ziemi są procesy promieniotwórcze, propagował teorię Arrheniusa o znaczeniu CO2 w procesach klimatycznych.

An Attempt to Frame a Working Hypothesis of the Cause of Glacial Periods on an Atmospheric Basis

T. C. Chamberlin The Journal of Geology Vol. 7, No. 6 (Sep. - Oct., 1899), pp. 545-584

AN ATTEMPT TO FRAME A WORKING HYPOTHESIS OF THE CAUSE OF GLACIAL PERIODS ON AN ATMOSPHERIC BASIS[1]

THERE are hypotheses and working hypotheses. The suggestion that the last glacial period was caused by the passage of the solar system through a cold region of space may be styled a hypothesis, but scarcely a working hypothesis in the geological sense, for it does not form the groundwork or incentive of geological inquiry. An astronomer might be moved to hunt for the cold spot, but it has no inspiration for the geologist. General suggestions of a possible cause do not reach the dignity of working hypotheses until they are given concrete form, are fitted in detail to the specific phenomena, and are made the agents of calling into play effective lines of research. The construction of a concrete working hypothesis suited to stimulate and guide investigation in a wholesome manner, and to take its place in competition with other hypotheses of like working potentialities, thereby inducing a more searching scrutiny of the phenomena and a more varied application of interpretations, represents the higher limit of present reasonable aspiration. It is much too ambitious to hope for a demonstrative solution of the origin of the earth's glacial periods by first intention in the present state of knowledge.

The hypothesis here offered is not worked out into satisfactory detail at all points, but it is hoped that it is sufficiently matured to justify a preliminary statement. In forming it, which has been the work of several years, I have found, or seemed to find, the phenomena of past glaciation intimately associated with a long chain of other phenomena to which at

[1] A brief statement of the salient features of this hypothesis was given in a paper entitled A Group of Hypotheses Bearing on Climatic Changes, JOUR. GEOL., Vol. V, pp. 653–683, Oct.–Nov. 1897. For earlier history see footnotes on pp. 654 and 681 of that paper.

W I połowie XX wieku. najbardziej wytrwałym propagatorem tezy o dominującym wpływie Słońca na klimat był **Charles Greeley Abbot**, następca Langleya w Smithsonian Astrophysical Observatory.

Kontynuował on jego program pomiarów tzw. „stałej słonecznej" ilości energii którą Ziemia otrzymuje od Słońca. Na początku lat dwudziestych zauważył on że nazwa "stała" jest w tym wypadku źle użyta: energia zmienia się np. zalezie od liczby plam na Słońcu. Jego estymacje pokazywały że zmiany "stałej" mogą sięgać 1% co musi wpływać na klimat.

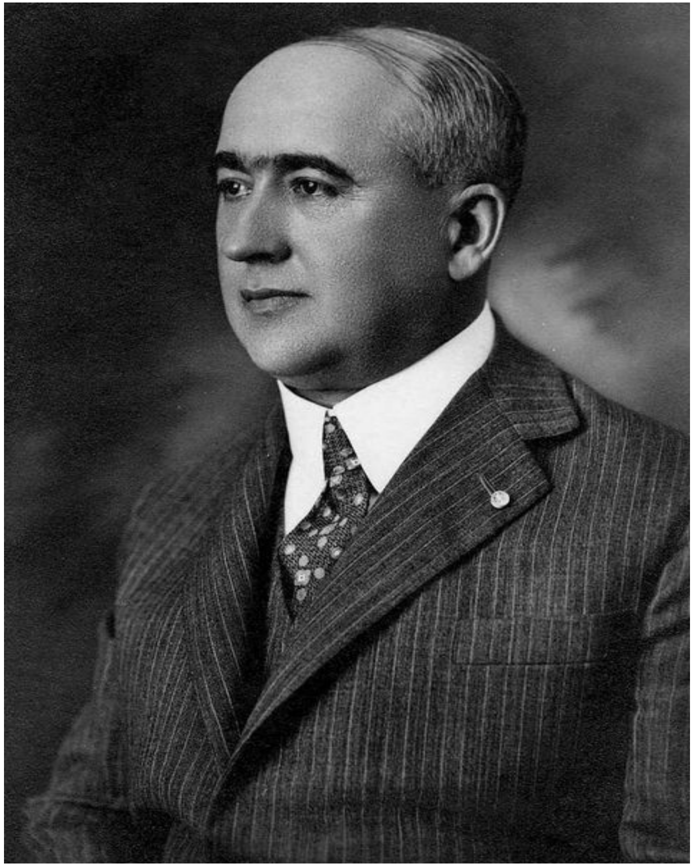
Już w 1913 Abbot dowodził że widzi w danych prosta korelację liczby plam i temperatury Ziemi (co nie było prawdą: inni pokazali ze jego wynik był przypadkowy spowodowany de facto przypadkowym zbiegiem w czasie z wybuchami wulkanów które w odpowiednim czasie chłodziły planetę). Pewny siebie Abbot dowodził że poprawa obserwacji Słońca poprawi prognozy pogody.

Abbot był sprawcą powszechnego do dziś przekonania że rola Słońca jest na tyle dominująca w klimacie że inne czynniki są drugorzędne.

Charles Greeley Abbot (ur. 31 maja 1872 w, zm. 17 grudnia 1973)/ Amerykański astrofizyk i astronom. Autor prac z zakresu aktynometrii. Specjalizował się w badaniach fizyki Słońca.

W okresie pierwszej wojny światowej serbski inżynier i matematyk, Milutin Milanković, analizując zmiany kształtu orbity i nachylenia osi Ziemi, zauważył ze zmienność w dopływie energii słonecznej spowodowana fluktuacjami kształtu orbity i nachylenia osi Ziemi jest znaczna i to ona mogła spowodować przeszłe zmiany klimatu.

Od tego momentu istniały już dwie astronomiczne hipotezy (jeszcze nie teorie – brakowało im oparcia w danych doświadczalnych) teorie klimatu

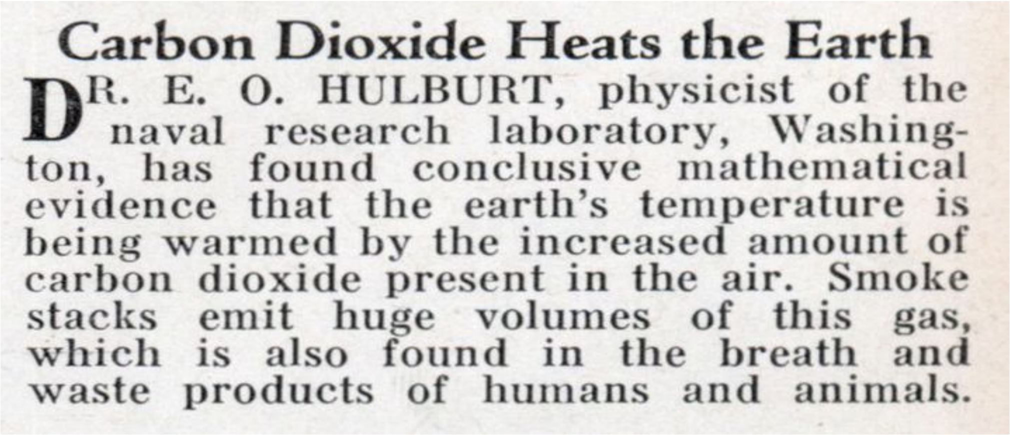


Milutin Milanković, cyrylicą: Милутин Миланковић (ur. 28 maja 1879 – zm. 12 grudnia 1958), serbski geofizyk i inżynier, jego teoria zmian orbitalnych Ziemi poświadczona dziś doświadczalnie, tłumaczy rolę dopływu energii od Słońca dla powstania/zaniku zlodowaceń.

Dwadzieścia kilka lat później, w 1931 amerykański fizyk **E.O. Hulburt** wykonał obliczenia podobne to tych jakie zrobił Arrhenius używając nowszych, znacznie dokładniejszych danych o własnościach absorpcyjnych CO_2. Wynik otrzymał nieco inny : wzrost temperatury o 4^0C przy podwojeniu koncentracji CO_2 w powietrzu.

Ta praca, opublikowana w czasopiśmie Physical Review przeszła niezauważona przez badaczy klimatu mimo działań popularyzatorskich..

E.O. Hulburt, amerykański fizyk, specjalista z zakresu optyki, i transferu radiacyjnego.



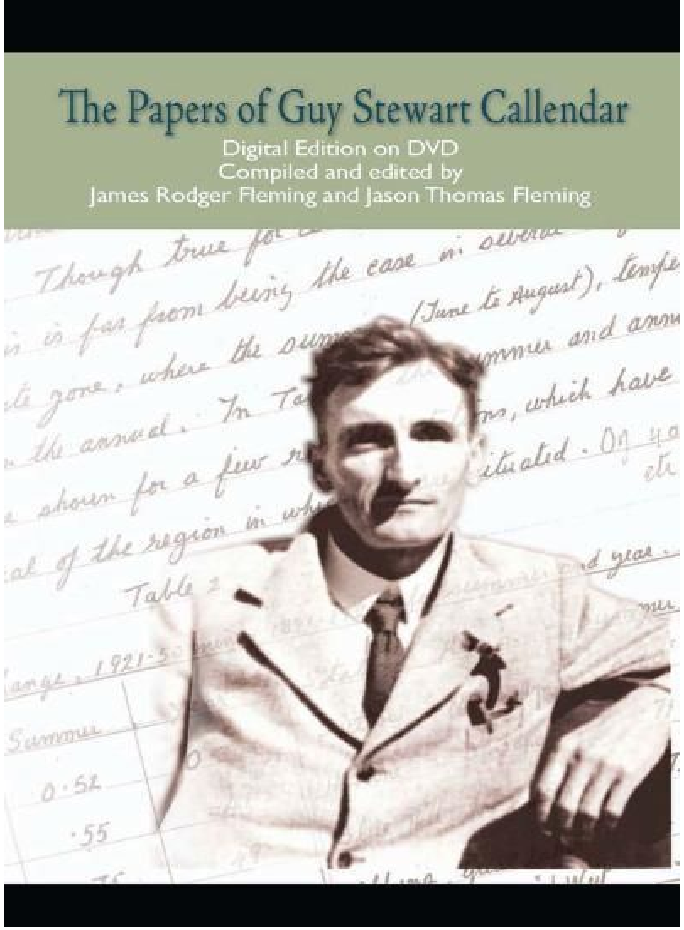
Carbon Dioxide Heats the Earth

DR. E. O. HULBURT, physicist of the naval research laboratory, Washington, has found conclusive mathematical evidence that the earth's temperature is being warmed by the increased amount of carbon dioxide present in the air. Smoke stacks emit huge volumes of this gas, which is also found in the breath and waste products of humans and animals.

Pierwszym, który powiązał eksperymentalnie wzrost koncentracji atmosferycznego CO_2 ze wzrostem temperatury był angielski inżynier który zajmował się hobbystycznie meteorologią, **G.S. Callendar**.

Analizując dane meteorologiczne od połowy XIX w. zauważył dodatni trend przebiegu temperatur w ciągu dziesięcioleci. Gdy skonfrontował aktualne (dala siebie) dane o koncentracji atmosferycznego CO_2 z danymi historycznymi, zauważył 10% wzrost. Na podstawie tych danych oszacował że klimat ociepli się o 2^0C przy podwojeniu zawartości CO_2 w powietrzu.

Efekt ten, uważał za korzystny, (podobnie jak Arrhenius).



Guy Stewart Callendar (luty 1898 - październik 1964) inżynier i wynalazca angielski wykonał pierwsze oszacowania czułości klimatu na podstawie danych empirycznych

QUARTERLY JOURNAL
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Article

The artificial production of carbon dioxide and its influence on temperature

FREE

G. S. Callendar

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Volume 64, Issue 275, pages 223–240, April 1938

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Abstract

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 a t zoo 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.

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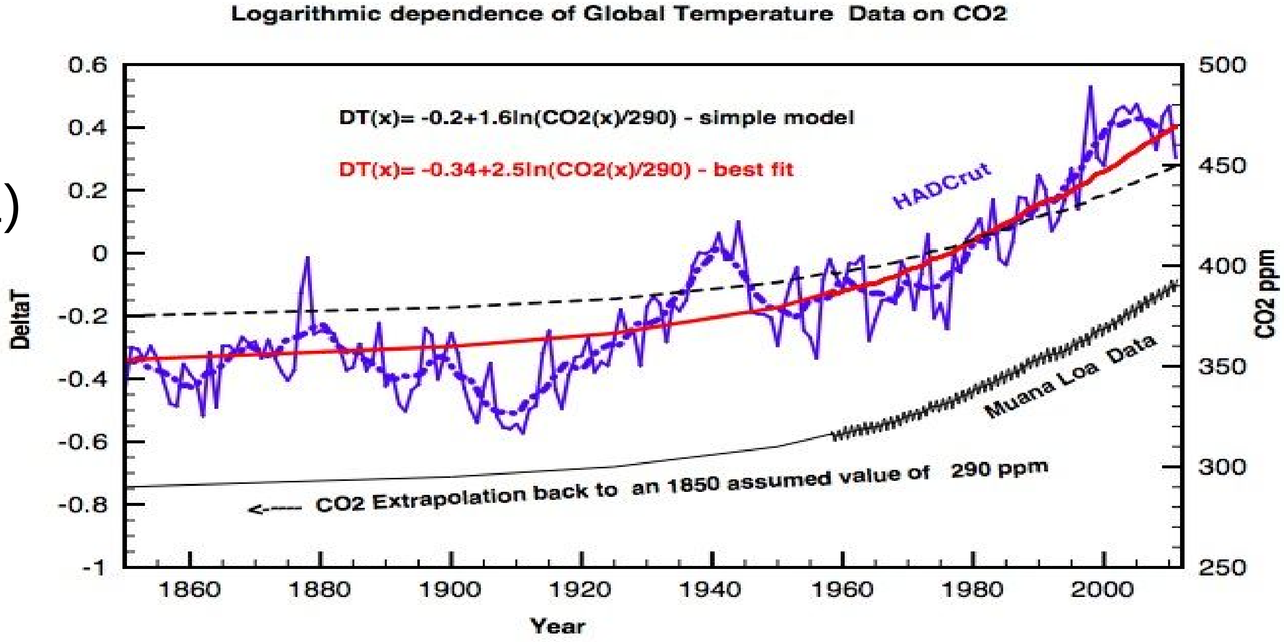
Warto podkreślić, że już pod koniec pierwszej połowy XX wieku, na długo przed „wybuchem” zainteresowania globalnym ociepleniem wyniki badań naukowych dowodziły, że tzw. „czułość klimatu” na podwojenie koncentracji CO_2 w powietrzu to od 2°C wg Callendara do 4°C wg Hulburta.

Według VI raportu IPCC (2021) równowagowa czułość klimatu to

2.5 – 4.0 °C

Najprawdopodobniej:

3°C



Pod wpływem prac Callendara zaczęto się zastanawiać jak szybko klimat może się ocieplić. Podstawowym pytaniem było jaka część emitowanego przez ludzi CO_2 rozpuszcza się w wodach oceanu a ile zostaje w atmosferze. Odpowiedź na to pytanie, podobnie jak weryfikację astronomicznych teorii zmian klimatu uzyskano, co ciekawe, dzięki rozwojowi fizyki jądrowej. Badania zawartości stałych i promieniotwórczych izotopów węgla, tlenu, berylu, wodoru w osadach, koralowcach, stalaktytach, rdzeniach lodowych, w roślinach, a także w wodzie i powietrzu pozwoliły na niezwykłe postępy w rozumieniu procesów klimatycznych.

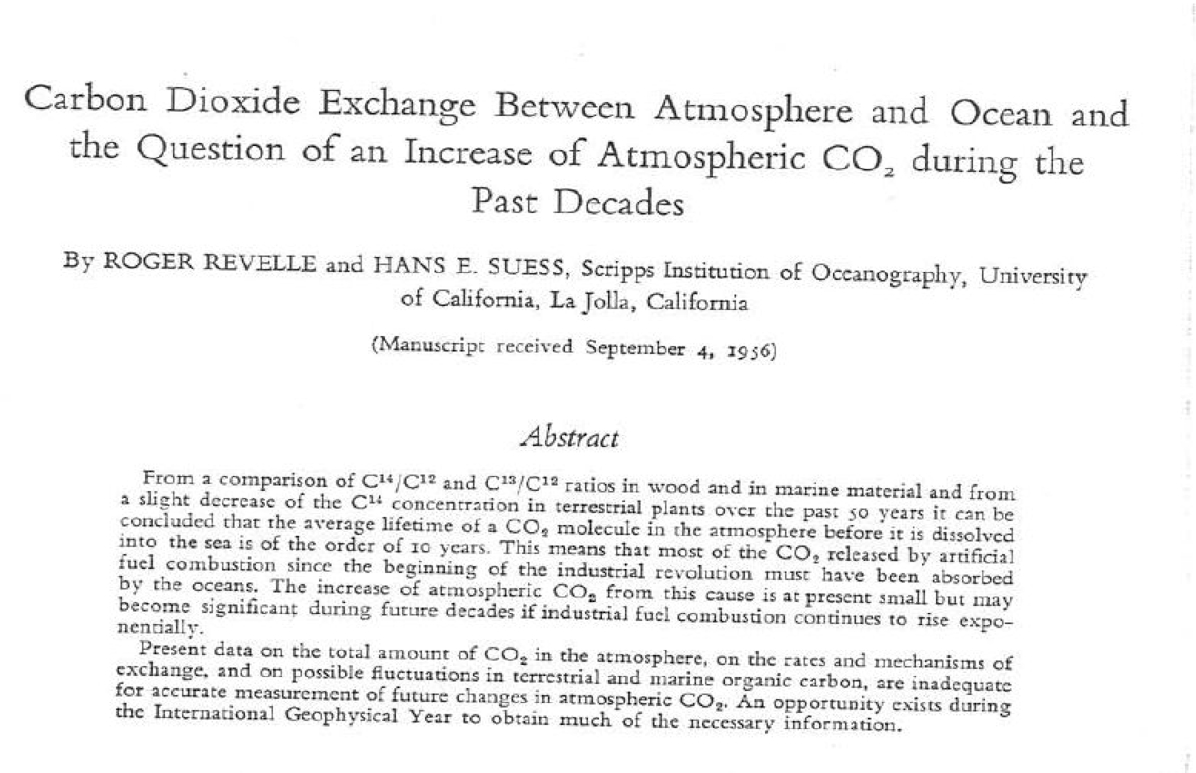
Przełomowa pracą, jeszcze niezbyt dokładnie ale jednoznacznie dokumentującą, że obserwowany wzrost zawartości CO_2 w atmosferze i oceanie jest wynikiem emisji paliw kopalnych, pozwalającą oszacować skalę tego procesu oraz tempo w jakim ten wyemitowany CO_2 rozpuszcza się w oceanie była rozprawa opublikowana w 1957 r.

Jej autorami byli oceanolog **Roger Revelle** i fizyk jądrowy **Hans Suess**, jeden z pionierów metody datowania radiowęglowego. Pochodzi z niej słynna, ale mało w Polsce znana, fraza:

„Ludzkość prowadzi teraz jedyny w swoim rodzaju eksperyment geofizyczny, który nie wydarzył się nigdy w przeszłości ani nie będzie mógł być w przyszłości powtórzony. W ciągu kilku stuleci zwracamy atmosferze i oceanowi węgiel odłożony przez naturę w skalach osadowych w procesie który trwał setki milionów lat”.

"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. Within a few centuries, we are returning to the atmosphere and oceans the concentrated organic carbon stored in sedimentary rocks over hundreds of millions of years."

Roger Randall Dougan Revelle (ur. 7 marca 1909 zm. 15 lipca 1991), amerykański oceanolog, badał tez cykl węglowy oraz emisje/pochłanianie dwutlenku węgla przez ocean.



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)

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.

Present data on the total amount of CO_2 in the atmosphere, on the rates and mechanisms of exchange, and on possible fluctuations in terrestrial and marine organic carbon, are inadequate for accurate measurement of future changes in atmospheric CO_2. An opportunity exists during the International Geophysical Year to obtain much of the necessary information.

Hans Eduard Suess (ur. 16 grudnia 1909, zm. 20 września, 1993) Austriacki chemik fizyczny i fizyk jądrowy, jeden z pionierów zastosowania fizyki jądrowej do datowania metoda radiowęglową, specjalista od badań izotopowych.

Charles David Keeling był założycielem laboratorium o na Mauna Loa.

Jego badania koncentracji CO_2 w powietrzu prowadzone na Mauna Loa, w Scripps (La Jolla, California) i na Antarktydzie tworzą zręby najważniejszych serii pomiarowych pokazujących wzrost koncentracji tego gazu wskutek emisji antropogenicznych i w ten sposób do antropogenicznego wzmocnienia efektu cieplarnianego.

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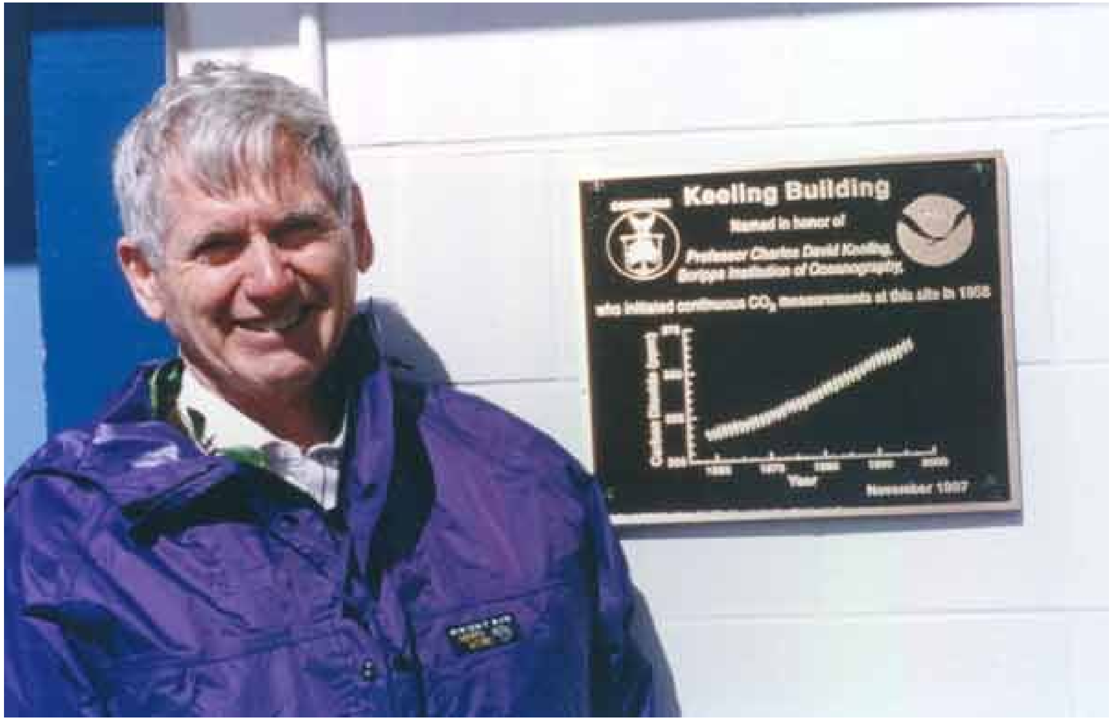
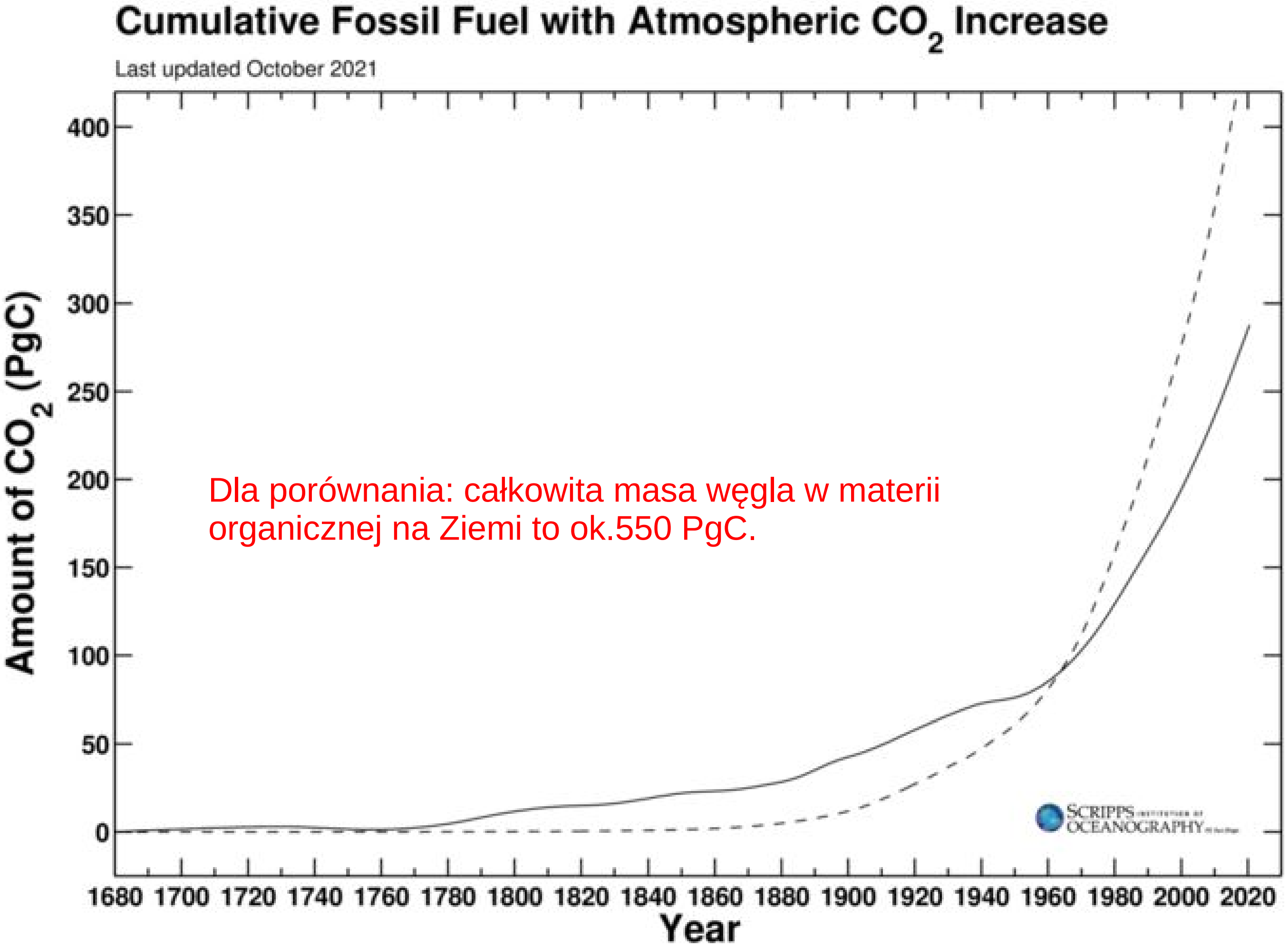
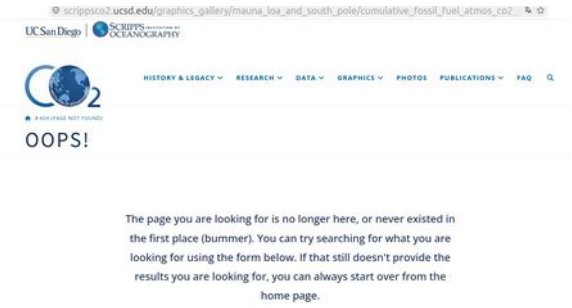


Charles David Keeling (ur. 20 kwietnia 1928, zm. 20 czerwca 2005), oceanograf i geofizyk amerykański, zapoczątkował regularne pomiary składu atmosfery w liku laboratoriach, w tym w na mauna Loa na Hawajach.



Dla porównania: całkowita masa węgla w materii organicznej na Ziemi to ok.550 PgC.



Linia ciągła: wzrost zawartości CO_2 w powietrzu (gigatony, PgC)
Linia przerywana: skumulowane emisje CO_2 ze spalania paliw kopalnych i produkcji cementu (gigatony PgC).

Gilbert Plass prowadził badania transferu radiacyjnego finansowane przez Office of Naval Research.

W latach 1954-55 uzyskał dostęp do komputera rozumiejąc że może on być efektywnie wykorzystany w obliczeniach transferu radiacyjnego.

Wykorzystując najnowsze dane doświadczalne o absorpcji CO2 w podczerwieni obliczył, że średnia temperatura powierzchni Ziemi wzrośnie o 3.6^{o}C przy podwojeniu koncentracji CO2 w powietrzu I spadnie o a 3.8^{o}C przy spadku koncentracji o połowę. Uwzględnienie efektu albedo chmur dało w obliczeniach efektywny wzrost temperatury o 2.5^{o}C przy podwojeniu CO2.

Pokazał, że absorpcja podczerwienie przez CO2 nie jest zamaskowane przez absorpcję w przez parę wodną .

Gilbert Norman Plass
(ur. 22 marca 1920, zm. 1 marca 2004)
Fizyk kanadyjski który wykonał pierwsze w pełni nowoczesne symulacje numeryczne transferu radiacyjnego w atmosferze.

The Carbon Dioxide Theory of Climatic Change

By GILBERT N. PLASS

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

(Manuscript received August 9 1955)

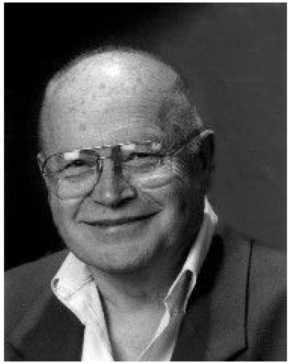
Abstract

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.

Introduction

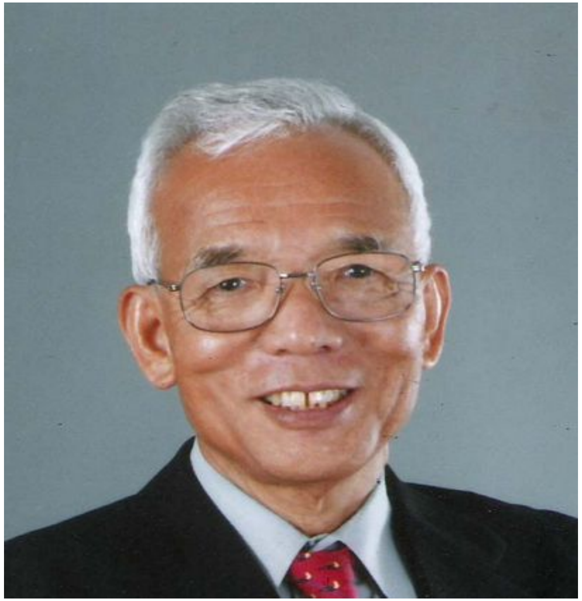
In 1861, TYNDALL wrote that "if, as the above xperiments indicated, the chief influence be xercised by the aqueous vapour, every variaon of this constituent must produce a change f climate. Similar remarks would apply to the rbonic acid diffused through the air . . . may have produced all the mutations of climate which the researches of geologists reveal. However this may be, the facts above cited remain: they constitute true causes, the *extent* alone of the operation remaining doubtful." A century of scientific work has been necessary in order to calculate with any

Norman A. Phillips, 1956.

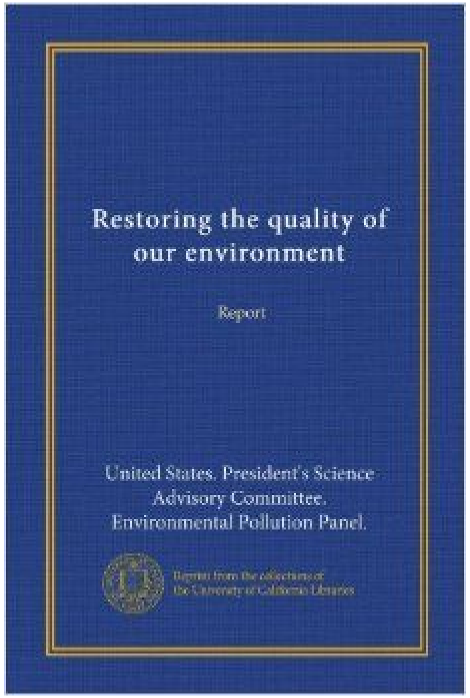


The general circulation of the atmosphere: a numerical experiment. Quarterly Journal of the Royal Meteorological Society 82 (352): 123–154.

Manabe, Syukuro and **Richard T. Wetherald**, 1967. Thermal Equilibrium of the Atmosphere with a Given Distribution of Relative Humidity. Journal of Atmospheric Science 24, 241-259.



Twórcy pierwszych nowoczesnych modeli cyrkulacji ogólnych atmosfery.



Jako pierwszy wśród przywódców państw zapoznał się z tym tematem prezydent USA Lyndon B. Johnson. Miało to miejsce już ponad pół wieku temu – w 1965 roku. Dokument „Restoring The Quality of Our Environment”
był pierwszym oficjalnym raportem, przedstawionym jakiemukolwiek rządowi na świecie, w którym opisano możliwe zagrożenia spowodowane wzrostem stężenia CO2 w atmosferze.

Napisania tej części dokumentu podjęli się uznani naukowcy, aktywnie uczestniczący w badaniach: Roger Revelle (oceanolog), Wallace Broecker (specjalista od paleoklimatologii), Charles Keeling (geochemik i fizyk atmosfery), Harmon Craig (geochemik i oceanograf) oraz Joseph Smagorisnky (meteorolog i specjalista od modelowania numerycznego).

Wallace S. Broecker, Science, Vol. 189, No. 4201 (Aug. 8, 1975), 460-463

Climatic Change: Are We on the Brink of a Pronounced Global Warming?

Abstract. *If man-made dust is unimportant as a major cause of climatic change, then a strong case can be made that the present cooling trend will, within a decade or so, give way to a pronounced warming induced by carbon dioxide. By analogy with similar events in the past, the natural climatic cooling which, since 1940, has more than compensated for the carbon dioxide effect, will soon bottom out. Once this happens, the exponential rise in the atmospheric carbon dioxide content will tend to become a significant factor and by early in the next century will have driven the mean planetary temperature beyond the limits experienced during the last 1000 years.*

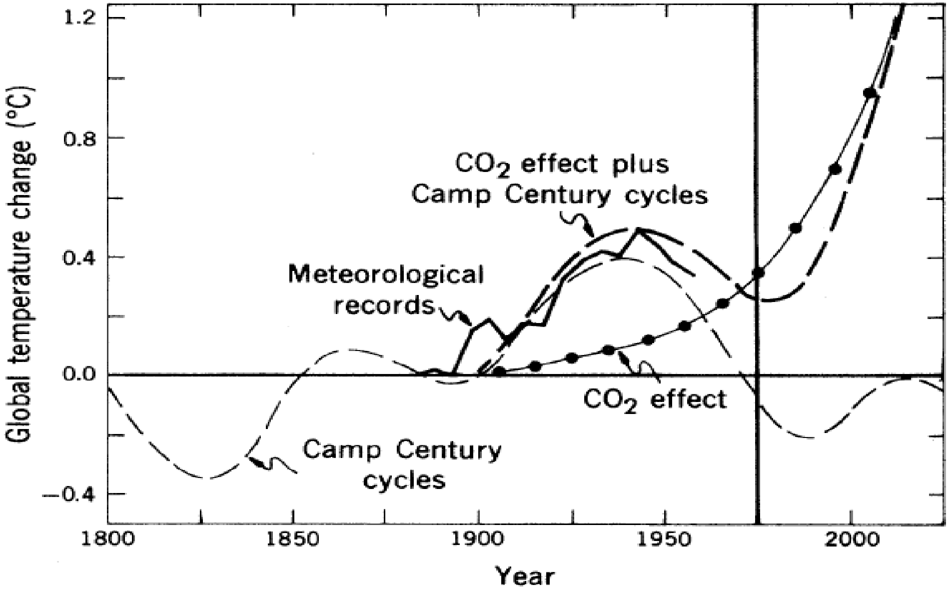
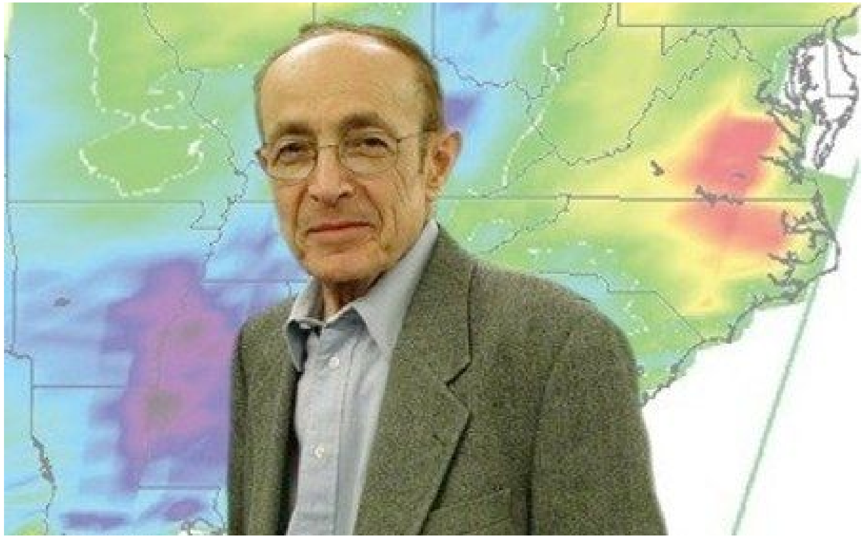


Fig. 1. Curves for the global temperature change due to chemical fuel CO_2, natural climatic cycles, and the sum of the two effects. The measured temperature anomaly for successive 5-year means from meteorological records over the last century is given for comparison.

Jule Gregory Charney (ur. 1 stycznia 1917, zm. 16 czerwca , 1981) amerykański meteorolog, pionier numerycznych prognoz pogody, twórca nowoczesnej meteorologii dynamicznej.



W 1979 **Charney** kierował "ad hoc study group on carbon dioxide and climate". Grupę tę powołała amerykańska Narodowa Rada Badań Naukowych (National Research Council).

Efektem działań grupy był 22 stronicowy raport, "**Carbon dioxide and climate: A scientific assessment**" (**"Dwutlenek węgla i klimat: przegląd stanu wiedzy"**). To pierwszy współczesny raport-przegląd stanu wiedzy na temat globalnego ocieplenia. Główny wynik: "We estimate the most probable global warming for a doubling of CO_2 to be near 3°C with a probable error of ± 1.5°C."

Carbon Dioxide and Climate:
A Scientific Assessment

Report of an Ad Hoc Study Group on Carbon Dioxide and Climate
Woods Hole, Massachusetts
July 23–27, 1979
to the
Climate Research Board
Assembly of Mathematical and Physical Sciences
National Research Council

Ad Hoc Study Group on Carbon Dioxide and Climate

Jule G. Charney, Massachusetts Institute of Technology, *Chairman*
Akio Arakawa, University of California, Los Angeles
D. James Baker, University of Washington
Bert Bolin, University of Stockholm
Robert E. Dickinson, National Center for Atmospheric Research
Richard M. Goody, Harvard University
Cecil E. Leith, National Center for Atmospheric Research
Henry M. Stommel, Woods Hole Oceanographic Institution
Carl I. Wunsch, Massachusetts Institute of Technology

Strony tytułowe raportu
Zwanego potem
„Raportem Charneya”

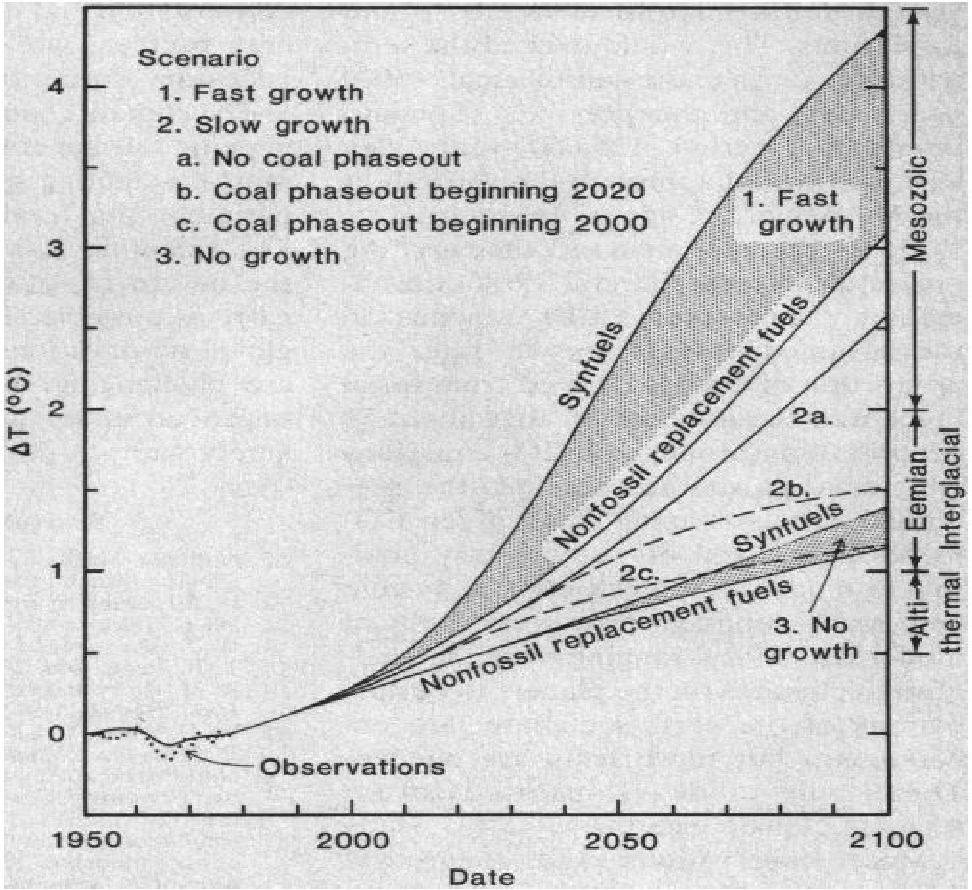
28 August 1981, Volume 213, Number 4511

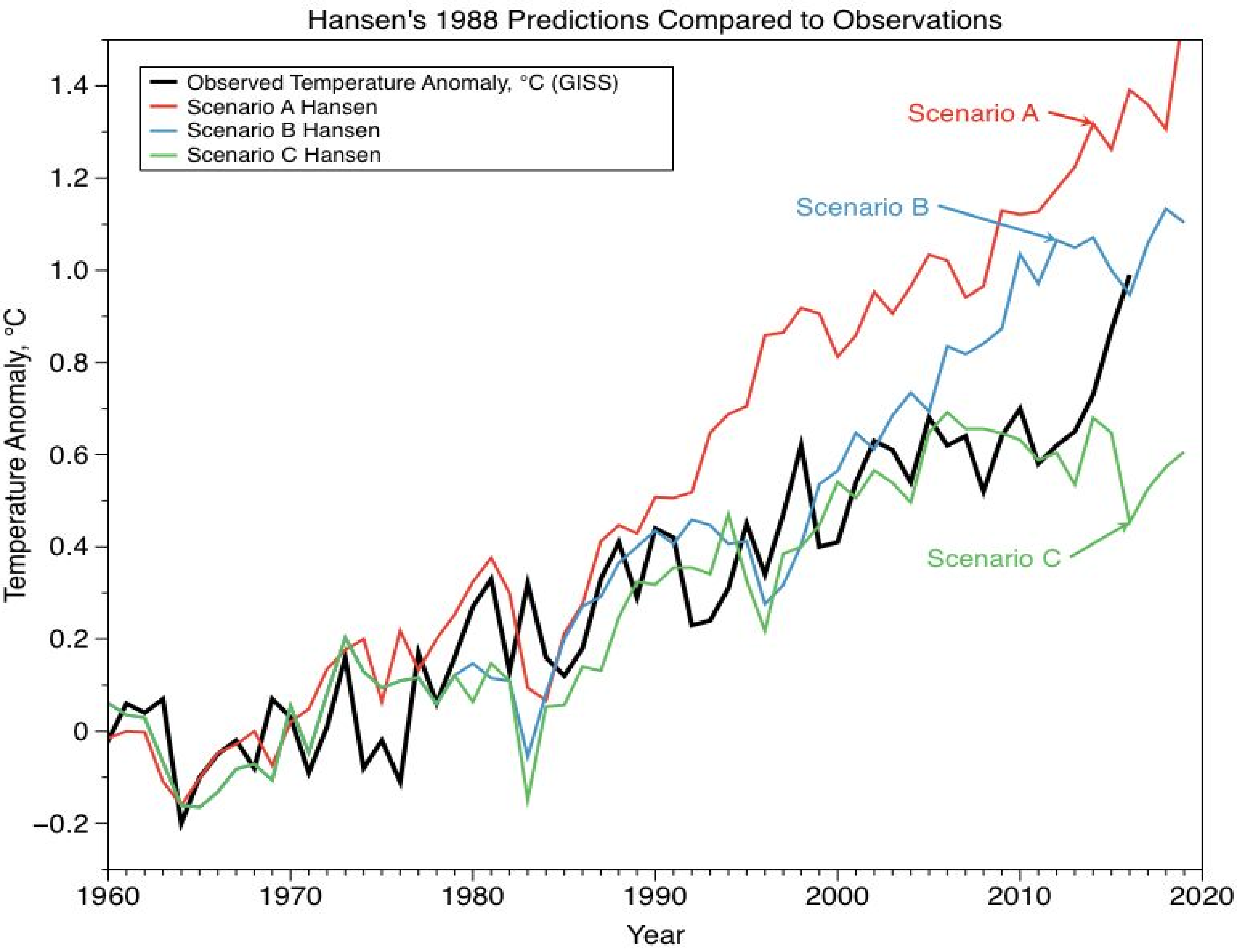
SCIENCE

Climate Impact of Increasing Atmospheric Carbon Dioxide

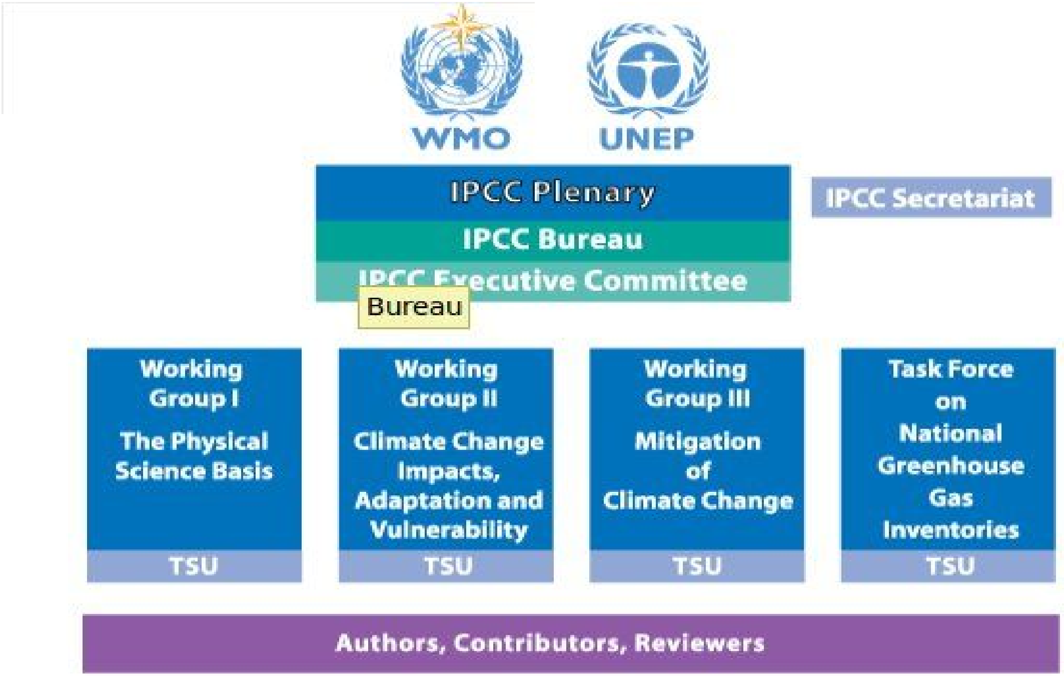
J. Hansen, D. Johnson, A. Lacis, S. Lebedeff
P. Lee, D. Rind, G. Russell

Fig. 6. Projections of global temperature. The diffusion coefficient beneath the ocean mixed layer is 1.2 cm^2 sec^{-1}, as required for best fit of the model and observations for the period 1880 to 1978. Estimated global mean warming in earlier warm periods is indicated on the right.



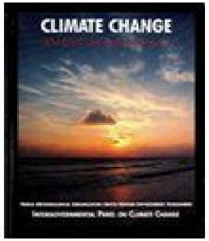

Hansen's 1988 Predictions Compared to Observations
Observed Temperature Anomaly, °C (GISS)
Scenario A Hansen
Scenario B Hansen
Scenario C Hansen
Scenario A
Scenario B
Scenario C
Temperature Anomaly, °C
Year
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0
−0.2
1960
1970
1980
1990
2000
2010
2020

The Intergovernmental Panel on Climate Change (IPCC), established in 1988
is the United Nations body for assessing the science related to climate change

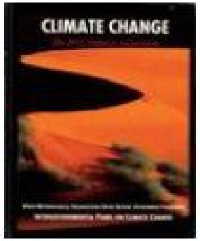


IPCC First Assessment Report 1990 (FAR)

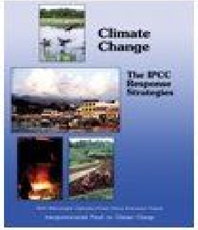
(OUT OF PRINT) *Digitized by the Digitization and Microform Unit, UNOG Library, 2010*
(Available in English only except where stated)



Working Group I:
Scientific Assessment of Climate Change
CLICK HERE



Working Group II:
Impacts Assessment of Climate Change
CLICK HERE



Working Group III:
The IPCC Response Strategies
CLICK HERE

First Assessment Report
Overview Chapter (PDF)
Also in: Chinese - French - Russian - Spanish

1.0.1 *We are certain of the following:*

- There is a natural greenhouse effect which already keeps the Earth warmer than it would otherwise be.

- Emissions resulting from human activities are substantially increasing the atmospheric concentrations of the greenhouse gases: carbon dioxide, methane, chlorofluorocarbons (CFCs) and nitrous oxide. These increases will enhance the greenhouse effect, resulting on average in an additional warming of the Earth's surface. The main greenhouse gas, water vapour, will increase in response to global warming and further enhance it.

1.0.3 *Based on current model results, we predict:*

- An average rate of increase of global mean temperature during the next century of about 0.3°C per decade (with an uncertainty range of 0.2—0.5°C per decade) assuming the IPCC Scenario A (Business-as-Usual) emissions of greenhouse gases; this is a more rapid increase than seen over the past 10,000 years. This will result in a likely increase in the global mean temperature of about 1°C above the present value by 2025 (about 2°C above that in the pre-industrial period), and 3°C above today's value before the end of the next century (about 4°C above pre-industrial). The rise will not be steady because of other factors

2. Impacts

2.0.1 The report on impacts of Working Group II is based on the work of a number of subgroups, using independent studies which have used different methodologies. Based on the existing literature, the studies have used several scenarios to assess the potential impacts of climate change. These have the features of:

i) an effective doubling of CO_2 in the atmosphere between now and 2025 to 2050;

ii) a consequent increase of global mean temperature in the range of 1.5°C to 4.5°C;

iii) an unequal global distribution of this temperature increase, namely a smaller increase of half the global mean in the tropical regions and a larger increase of twice the global mean in the polar regions;

iv) a sea-level rise of about 0.3—0.5 m by 2050 and about 1 m by 2100, together with a rise in the temperature of

SIXTH ASSESSMENT REPORT

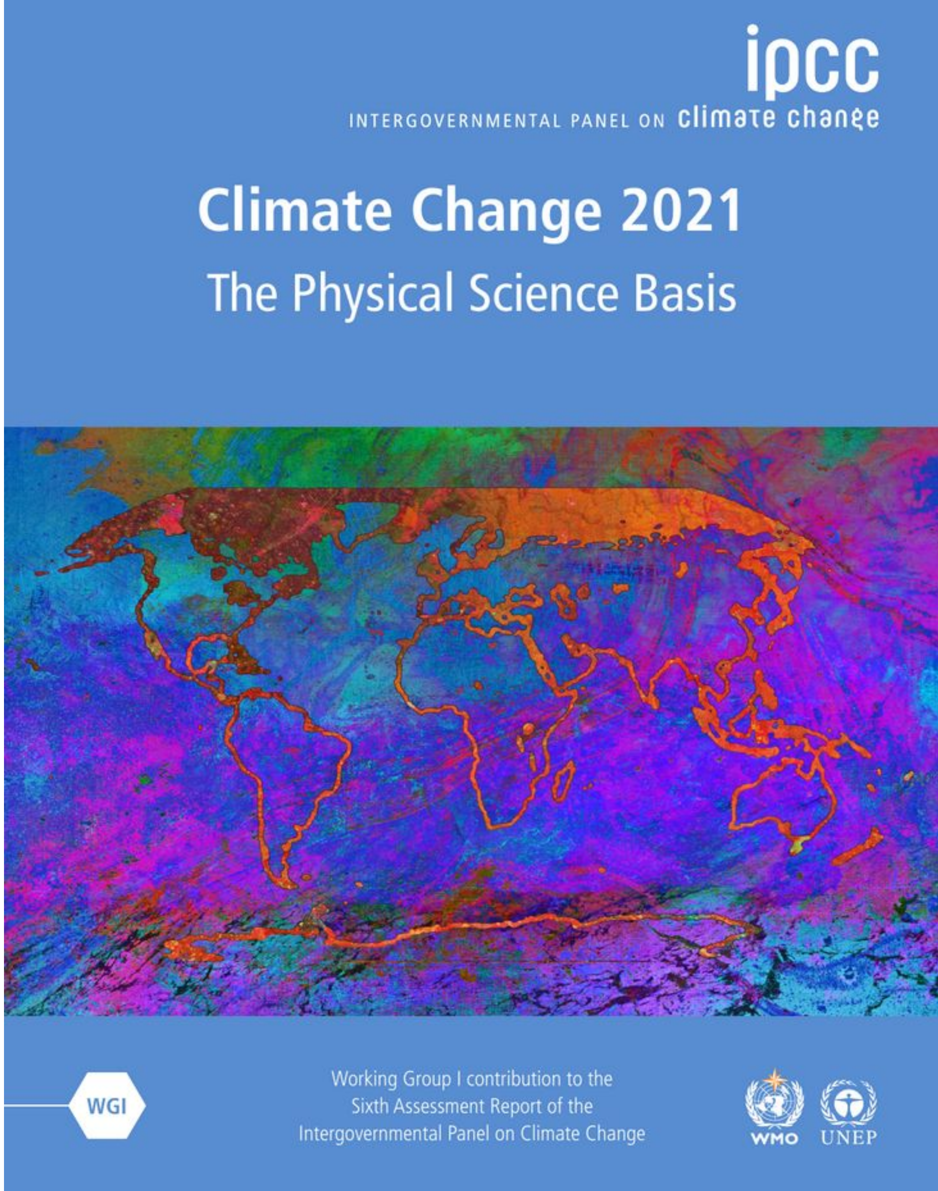
AR6 Synthesis Report: Climate Change 2022

AR6 Climate Change 2022: Impacts, Adaptation and Vulnerability

AR6 Climate Change 2022: Mitigation of Climate Change

AR6 Climate Change 2021: The Physical Science Basis

https://www.ipcc.ch/report/ar6/wg1/



Nagrodę przyznano "za przełomowy wkład w nasze zrozumienie systemów złożonych"

z tego połowę dla Syukuro Manabe i Klausa Hasselmanna

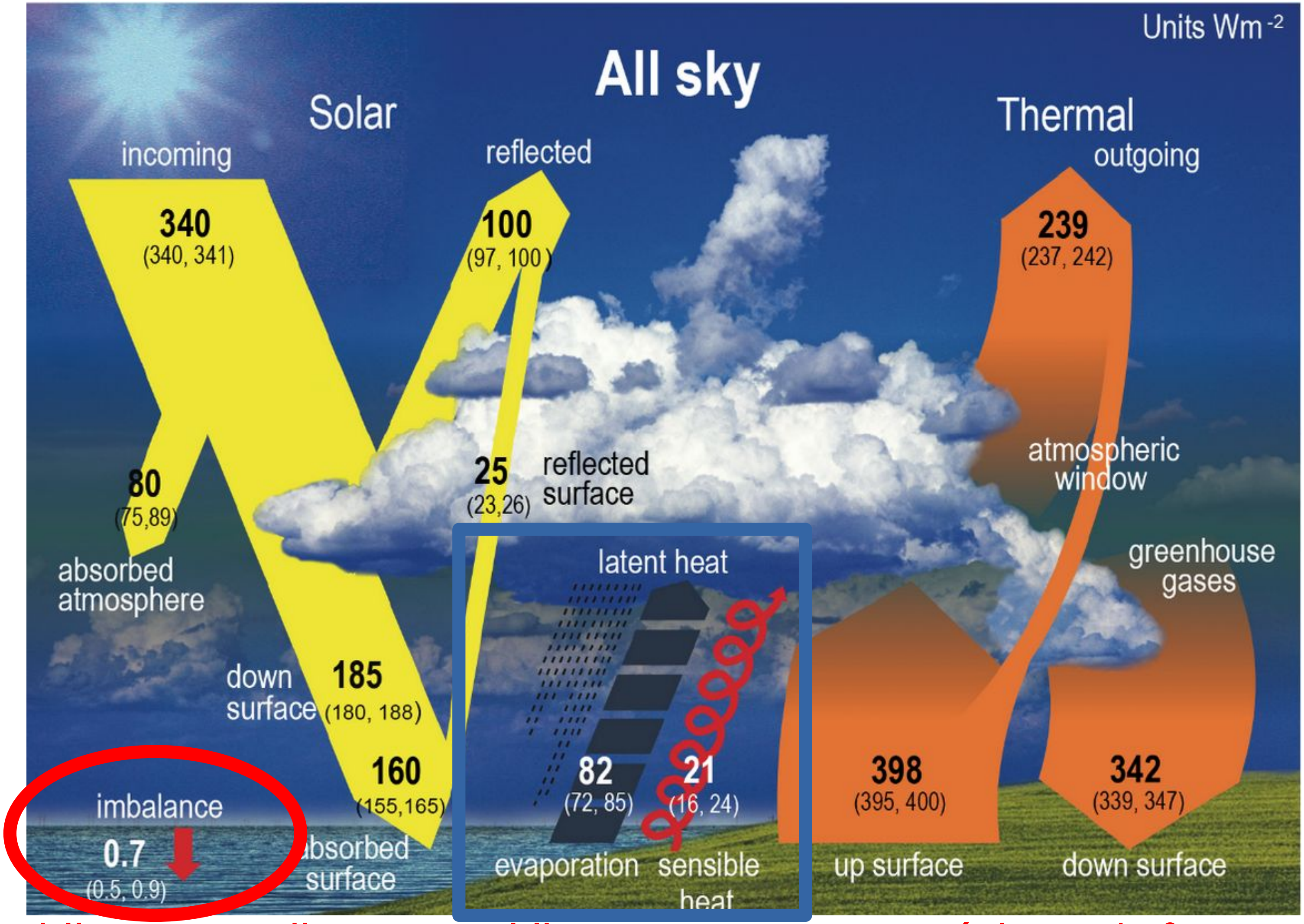
"za fizyczne modelowanie klimatu Ziemi, ilościowe określanie zmienności i wiarygodne przewidywanie globalnego ocieplenia"

oraz drugą połowę dla Giorgio Parisiego

"za odkrycie wzajemnego oddziaływania nieporządku i fluktuacji w systemach fizycznych od skali atomowej do planetarnej”.

Syukuro Manabe, urodzony 1931,
doktorat 1959, University of Tokyo

Nagroda Nobla z fizyki 2021
"za fizyczne modelowanie klimatu Ziemi, ilościowe określanie zmienności i wiarygodne przewidywanie globalnego ocieplenia"



Uśredniony bilans energii systemu klimatycznego. Wartości w W/m^2.

W nawiasach zakres niepewności i zmienności.

https://www.ipcc.ch/report/ar6/wg1/figures/chapter-7/figure-7-2/

W modelach klimatu wykorzystujemy matematyczne sformułowania praw fizyki co pozwala w sposób ilościowy symulować oddziaływania między elementami systemu klimatycznego.

$$\frac{D\mathbf{V}}{Dt} + f\mathbf{k} \times \mathbf{V} = -\nabla\Phi$$

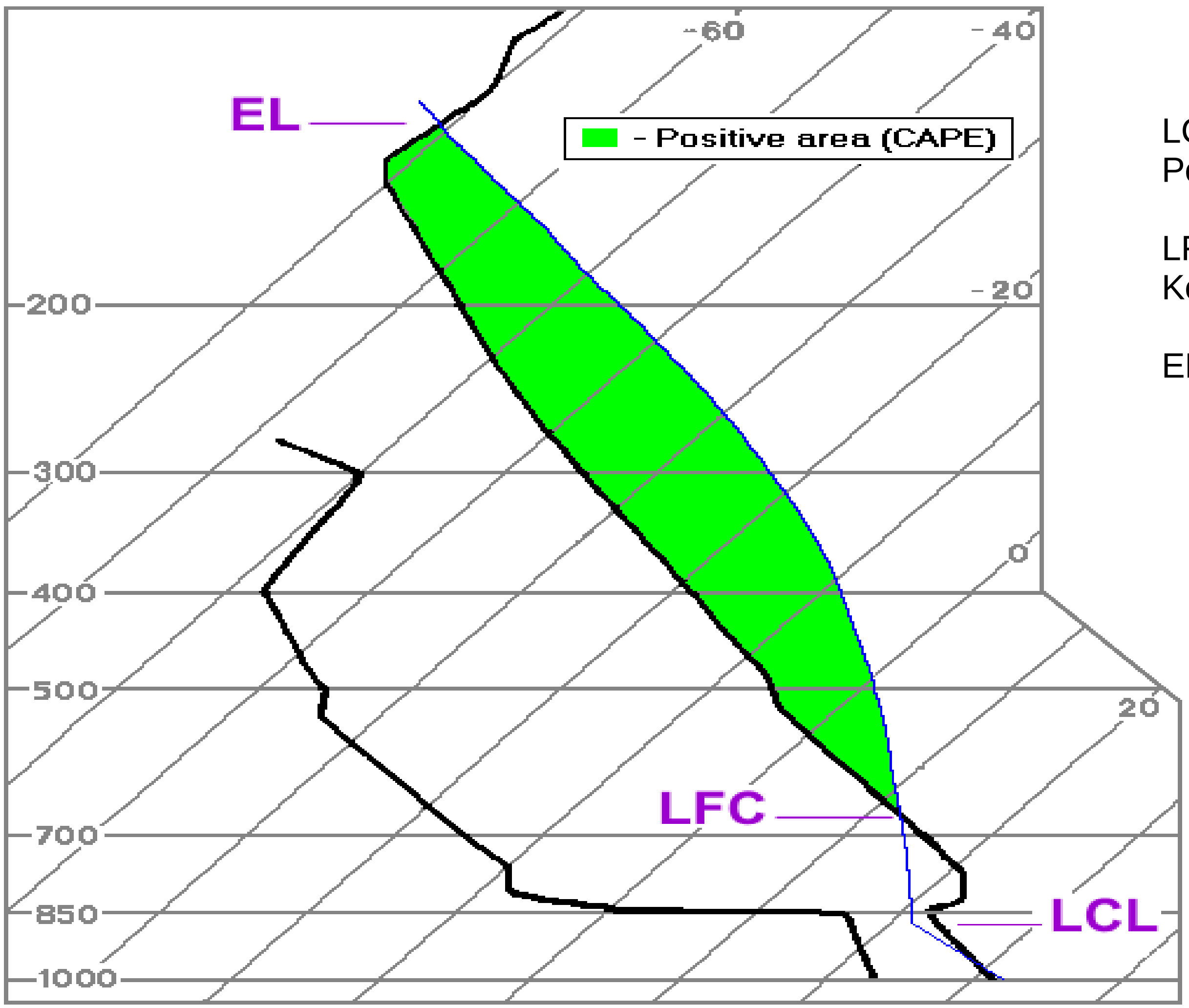
$$\frac{\partial\Phi}{\partial p} = -\alpha = -RT/p$$

$$\nabla \cdot \mathbf{V} + \frac{\partial\omega}{\partial p} = 0$$

$$\left(\frac{\partial}{\partial t} + \mathbf{V} \cdot \nabla\right) T - S_p\omega = J/c_p$$

S_p – parametr stabilności (gradient temperatury),
J – diabatyczne ogrzewanie/chłodzenie

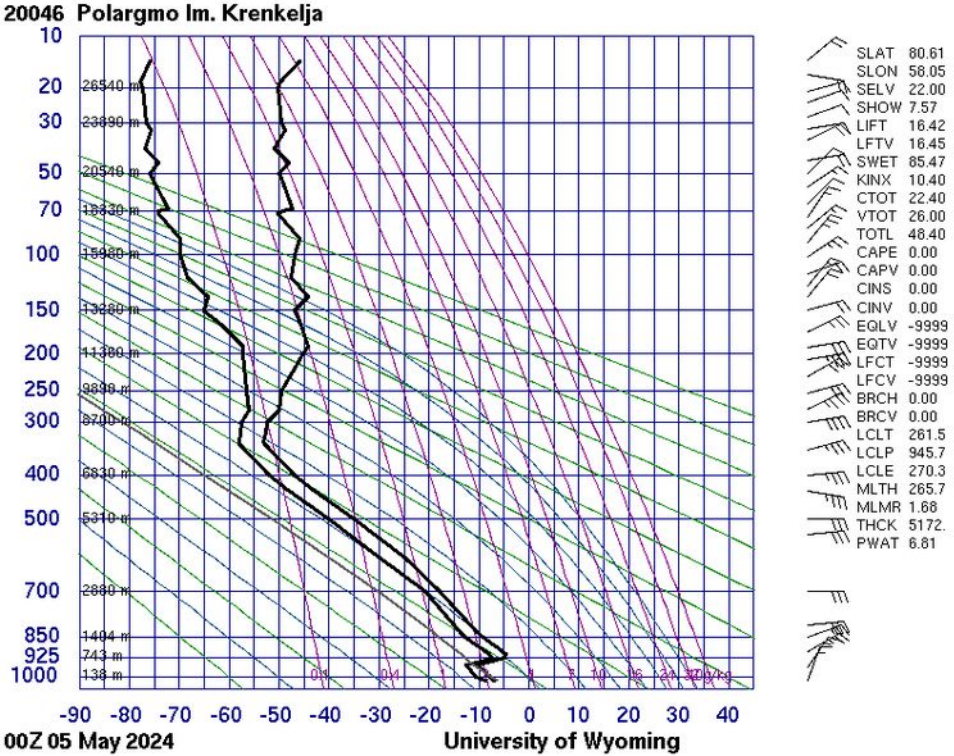
W ten sposób możemy np. badać odpowiedzi systemu klimatycznego na wymuszenia czy badać sprzężenia w systemie klimatycznym.



LCL – Lifting Condensation Level – (wymuszony) Poziom Kondensacji -PK

LFC – Level of Free Convection – Poziom Konwekcji Swobodnej

EL – Equliriblium Level – Poziom Równowagi


20046 Polargmo Im. Krenkelja
SLAT 80.61
SLON 58.05
SELV 22.00
SHOW 7.57
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LFTV 16.45
SWET 85.47
KINX 10.40
CTOT 22.40
VTOT 26.00
TOTL 48.40
CAPE 0.00
CAPV 0.00
CINS 0.00
CINV 0.00
EQLV -9999
EQTV -9999
LFCT -9999
LFCV -9999
BRCH 0.00
BRCV 0.00
LCLT 261.5
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MLTH 265.7
MLMR 1.68
THCK 5172.
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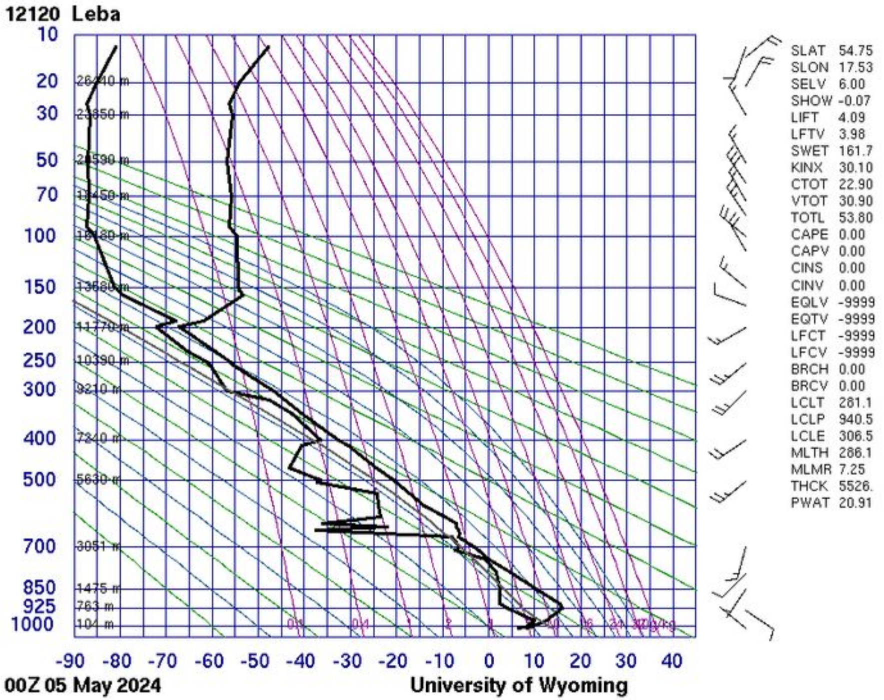
University of Wyoming


12120 Leba
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SLON 17.53
SELV 6.00
SHOW -0.07
LIFT 4.09
LFTV 3.98
SWET 161.7
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CTOT 22.90
VTOT 30.90
TOTL 53.80
CAPE 0.00
CAPV 0.00
CINS 0.00
CINV 0.00
EQLV -9999
EQTV -9999
LFCT -9999
LFCV -9999
BRCH 0.00
BRCV 0.00
LCLT 281.1
LCLP 940.5
LCLE 306.5
MLTH 286.1
MLMR 7.25
THCK 5526.
PWAT 20.91
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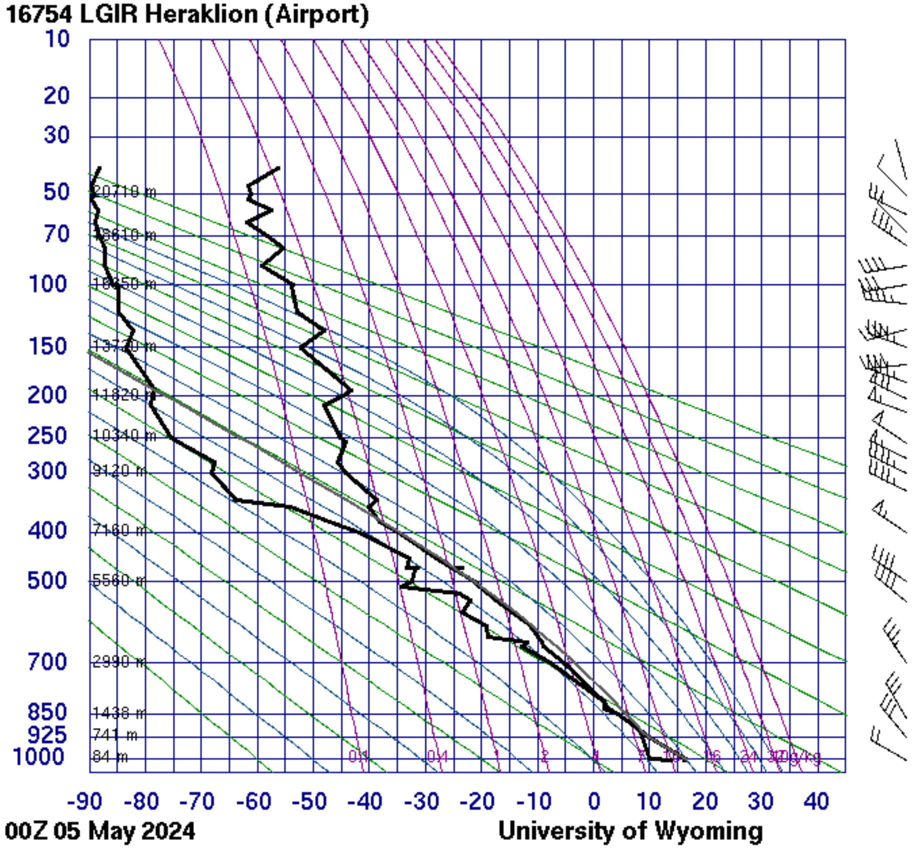
University of Wyoming


16754 LGIR Heraklion (Airport)
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20710 m
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10340 m
9120 m
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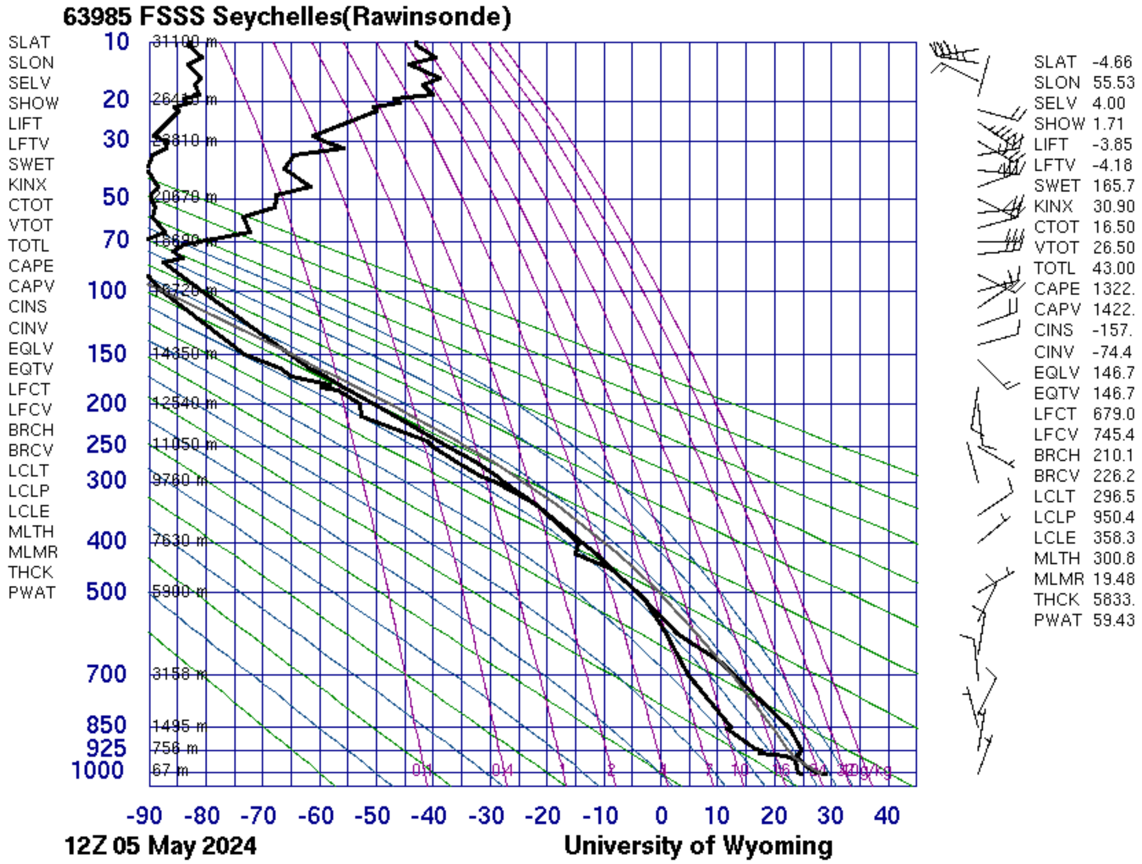
University of Wyoming


63985 FSSS Seychelles(Rawinsonde)
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14350 m
12540 m
11050 m
9760 m
7630 m
5900 m
3158 m
1495 m
756 m
67 m
-90 -80 -70 -60 -50 -40 -30 -20 -10 0 10 20 30 40
12Z 05 May 2024
University of Wyoming
SLAT -4.66
SLON 55.53
SELV 4.00
SHOW 1.71
LIFT -3.85
LFTV -4.18
SWET 165.7
KINX 30.90
CTOT 16.50
VTOT 26.50
TOTL 43.00
CAPE 1322.
CAPV 1422.
CINS -157.
CINV -74.4
EQLV 146.7
EQTV 146.7
LFCT 679.0
LFCV 745.4
BRCH 210.1
BRCV 226.2
LCLT 296.5
LCLP 950.4
LCLE 358.3
MLTH 300.8
MLMR 19.48
THCK 5833.
PWAT 59.43

Thermal Equilibrium of the Atmosphere with a Convective Adjustment

SYUKURO MANABE AND ROBERT F. STRICKLER

General Circulation Research Laboratory, U. S. Weather Bureau, Washington, D. C.
(Manuscript received 19 December 1963, in revised form 13 April 1964)

1) Rachunki równowagi radiacyjnej – na dnie i szczycie atmosfery równowagi strumieni krótko- i długofalowych.

2) Dołożenie „convective adjustment" = transportu ciepła od powierzchni w procesach konwekcyjnych.

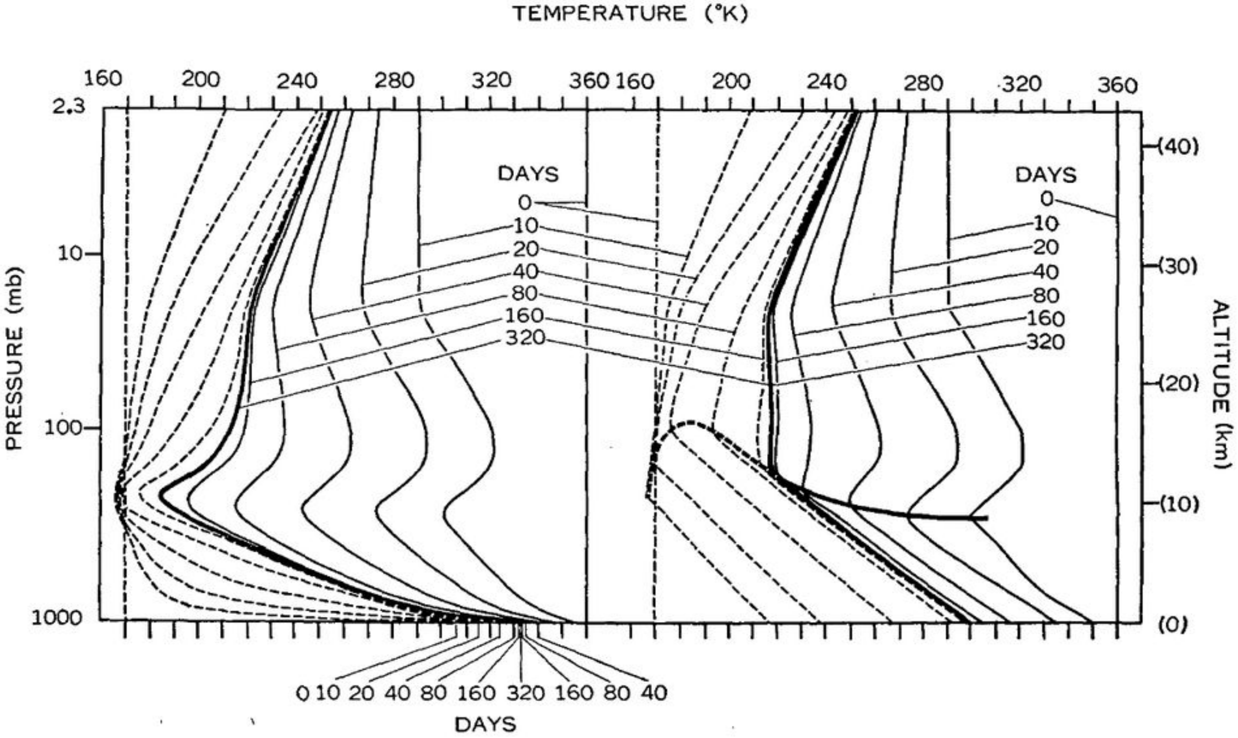


FIG. 1. The left and right hand sides of the figure, respectively, show the approach to states of pure radiative and thermal equilibrium. The solid and dashed lines show the approach from a warm and cold isothermal atmosphere.

1) Rachunki równowagi radiacyjnej – na dnie i szczycie atmosfery równowagi strumieni krótko- i długofalowych.

2) Dołożenie „convective adjustment” = transportu ciepła od powierzchni w procesach konwekcyjnych – średni gradient temperatury w troposferze 6.5K/km.

3) Dołożenie obecności chmur w modelu radiacyjnym.

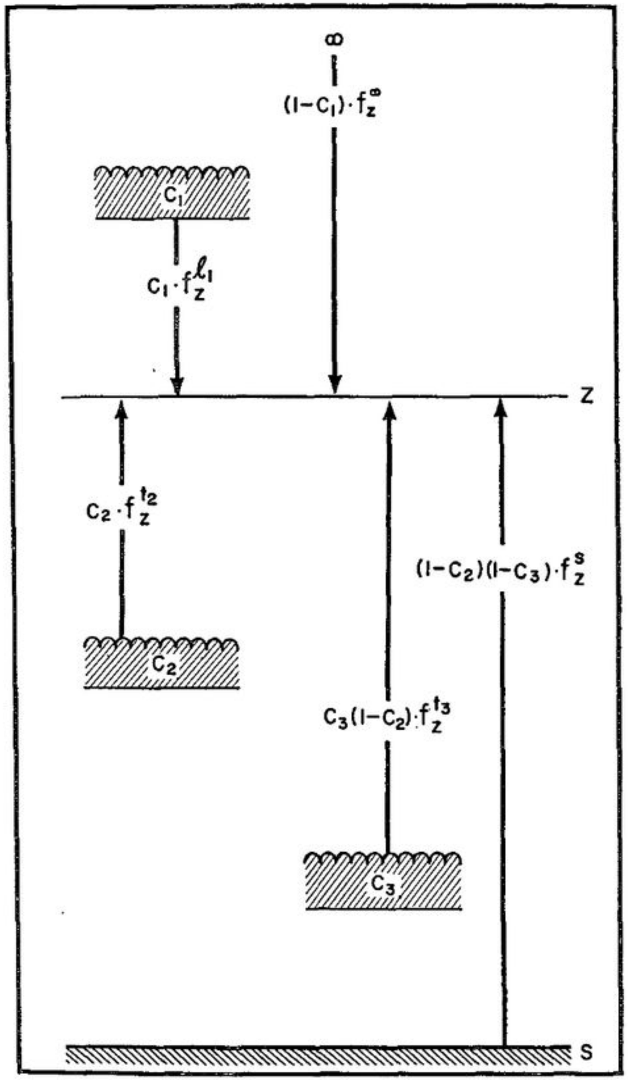


FIG. 2. Long wave radiation in an atmosphere with clouds.

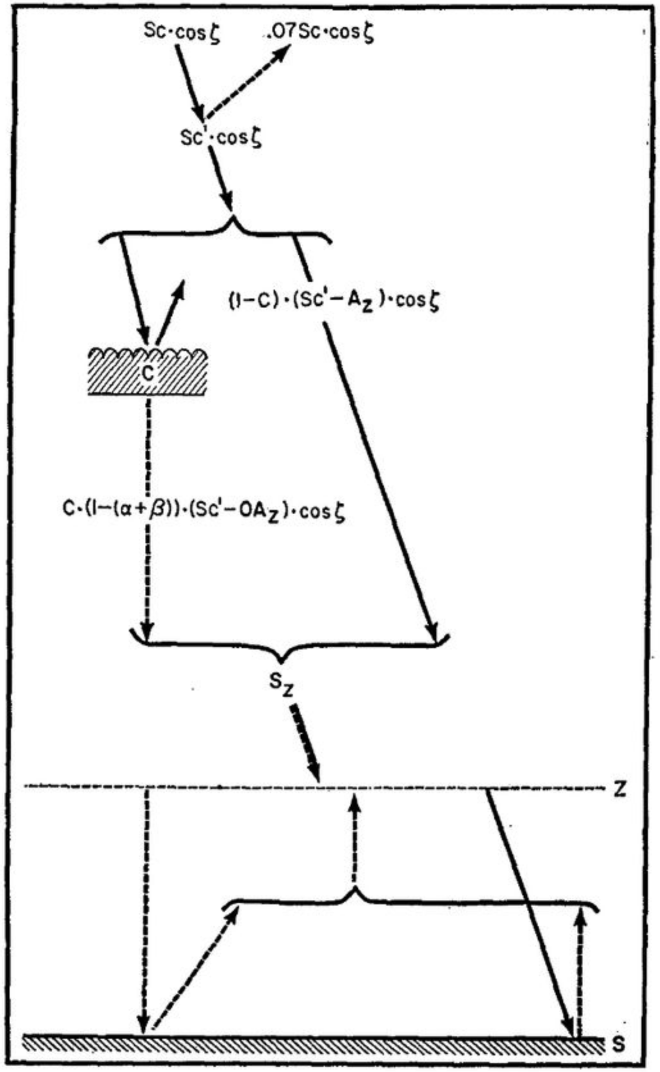


FIG. 3. Vertical distribution of the flux of solar radiation in an atmosphere with clouds.

1) Rachunki równowagi radiacyjnej – na dnie i szczycie atmosfery równowagi strumieni krótko- i długofalowych.

2) Dołożenie „convective adjustment” = transportu ciepła od powierzchni w procesach konwekcyjnych – średni gradient temperatury w troposferze 6.5K/km.

3) Dołożenie obecności chmur w modelu radiacyjnym.

4) Dołożenie rzeczywistych (obserwacyjnych) profili najważniejszych gazów cieplarnianych.

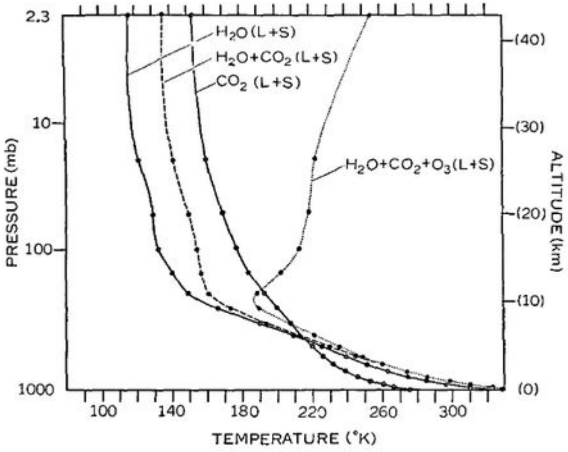


FIG. 6a. Pure radiative equilibrium for various atmospheric absorbers. The distribution of gaseous absorbers at 35N in April are used. $S_c=2$ ly min^{-1}, $\cos\bar{\zeta}=0.5$, $r=0.5$. No clouds. (L+S) means that the effects of both long wave radiation and solar radiation are included.

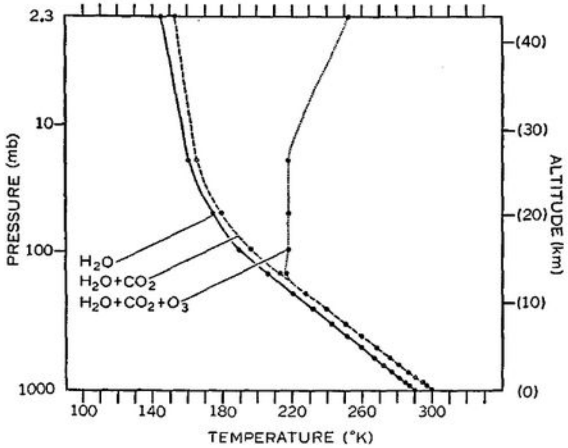


FIG. 6c. Thermal equilibrium of various atmospheres which have a critical lapse rate of 6.5 deg km^{-1}. Vertical distributions of gaseous absorbers at 35N, April, were used. $S_c=2$ ly min^{-1}, $\cos\bar{\zeta}=0.5$, $r=0.5$, no clouds.

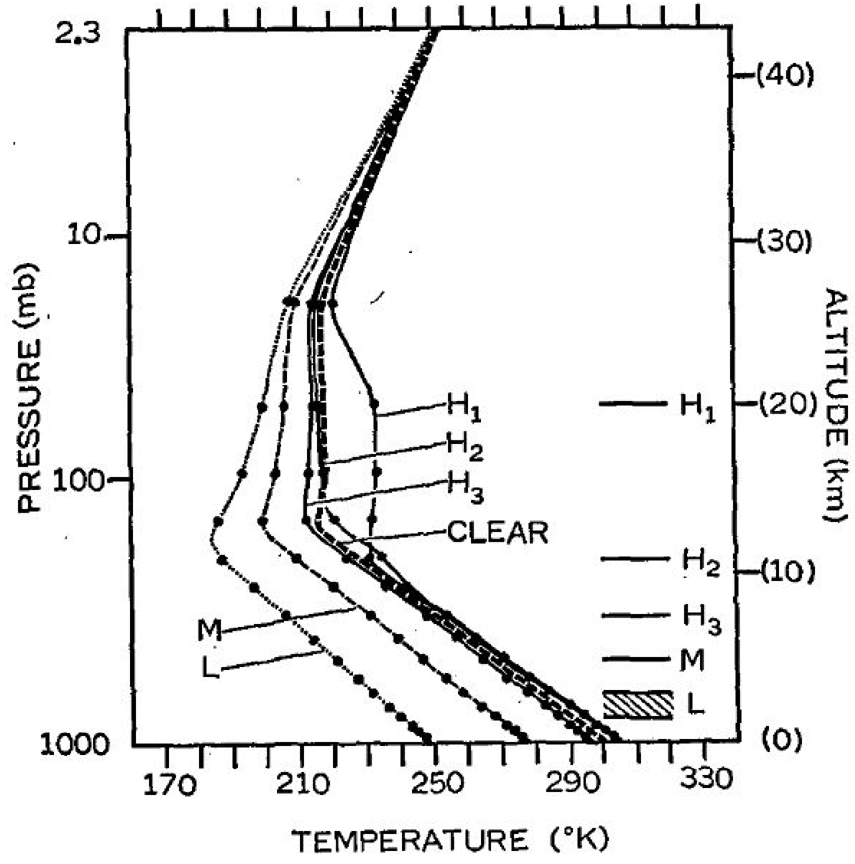


FIG. 7a. Thermal equilibrium of various atmospheres with clouds (the critical lapse rate for convective adjustment is 6.5 deg km^{-1}). On the right hand side of the figure the height of overcast clouds used for each computation is shown, H_1, H_2, and H_3 denoting high clouds, M and L denoting middle and low clouds. As a reference, the equilibrium curve of the clear atmosphere is shown by a thick dashed line.

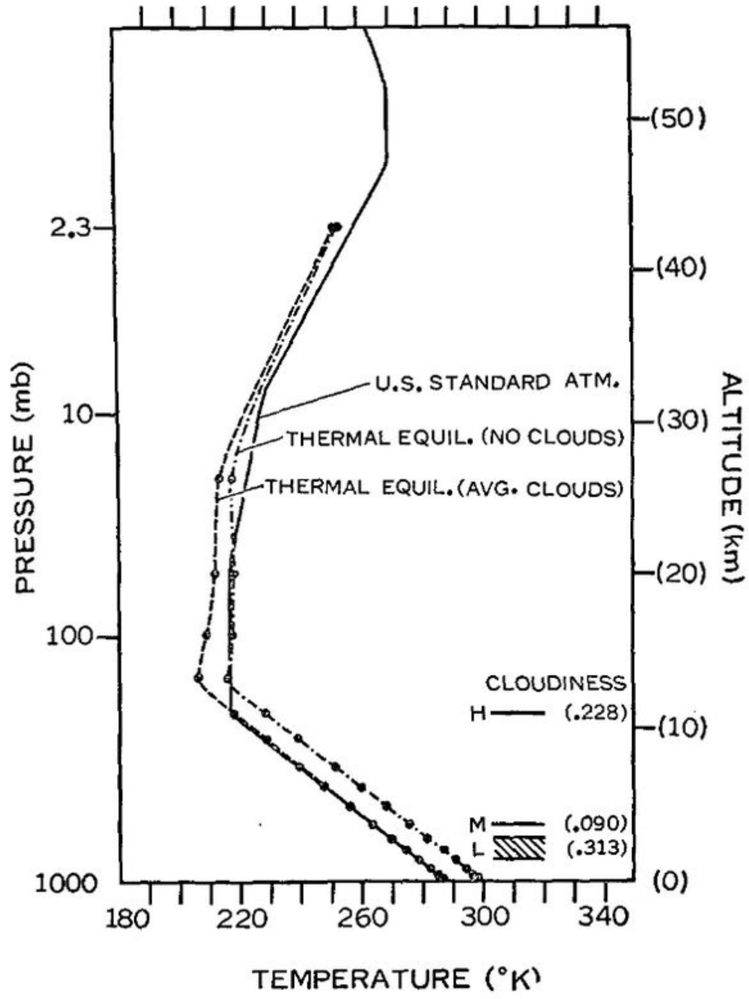


FIG. 8a. Dash-dotted and dashed lines show the thermal equilibrium of the atmosphere with and without cloudiness. The critical lapse rate for convection is 6.5 deg km^{-1}. The cloud amounts and cloud heights are shown on the right hand side. The solid line shows the U. S. Standard Atmosphere.

Thermal Equilibrium of the Atmosphere with a Given Distribution of Relative Humidity

SYUKURO MANABE AND RICHARD T. WETHERALD

Geophysical Fluid Dynamics Laboratory, ESSA, Washington, D. C.

(Manuscript received 2 November 1966)

ABSTRACT

Radiative convective equilibrium of the atmosphere with a given distribution of relative humidity is computed as the asymptotic state of an initial value problem.

The results show that it takes almost twice as long to reach the state of radiative convective equilibrinm for the atmosphere with a given distribution of relative humidity than for the atmosphere with a given distribution of absolute humidity.

Also, the surface equilibrium temperature of the former is almost twice as sensitive to change of various factors such as solar constant, CO_2 content, O_3 content, and cloudiness, than that of the latter, due to the adjustment of water vapor content to the temperature variation of the atmosphere.

According to our estimate, a doubling of the CO_2 content in the atmosphere has the effect of raising the temperature of the atmosphere (whose relative humidity is fixed) by about 2C. Our model does not have the extreme sensitivity of atmospheric temperature to changes of CO_2 content which was adduced by Möller.

TABLE 4. Equilibrium temperature of the earth's surface (°K) and the CO_2 content of the atmosphere.

	Average cloudiness		Clear	
CO_2 content (ppm)	Fixed absolute humidity	Fixed relative humidity	Fixed absolute humidity	Fixed relative humidity
150	289.80	286.11	298.75	304.40
300	291.05	288.39	300.05	307.20
600	292.38	290.75	301.41	310.12

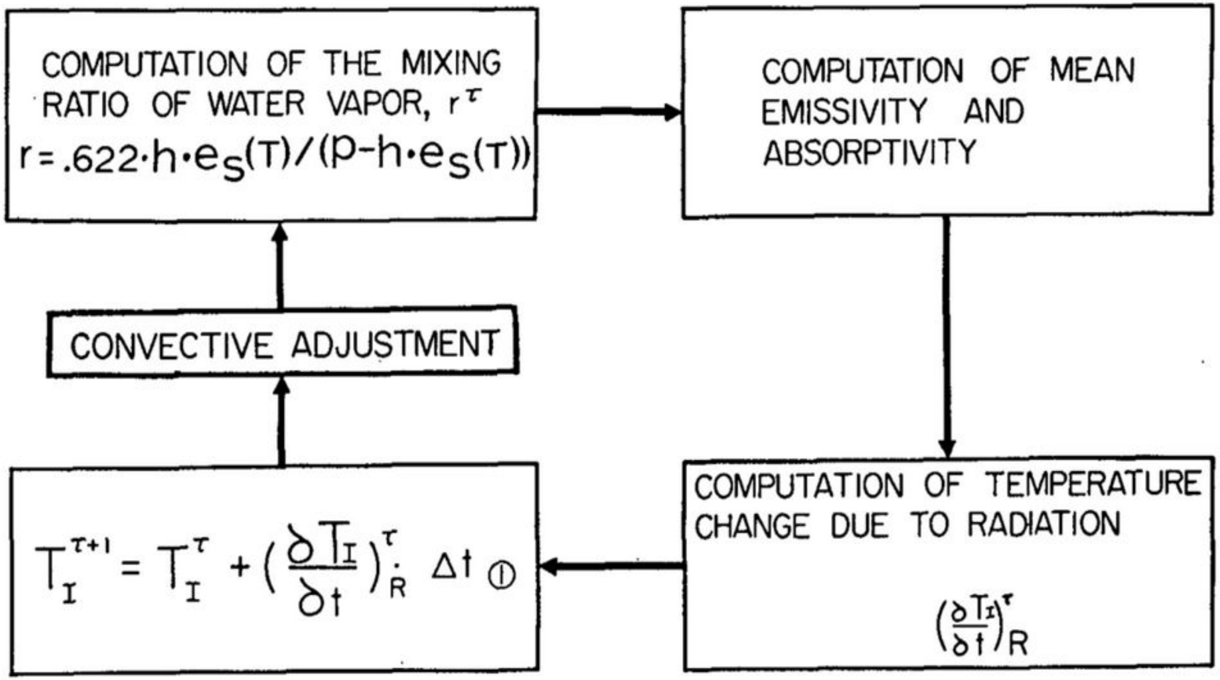


FIG. 2. Flow chart for the numerical time integration.

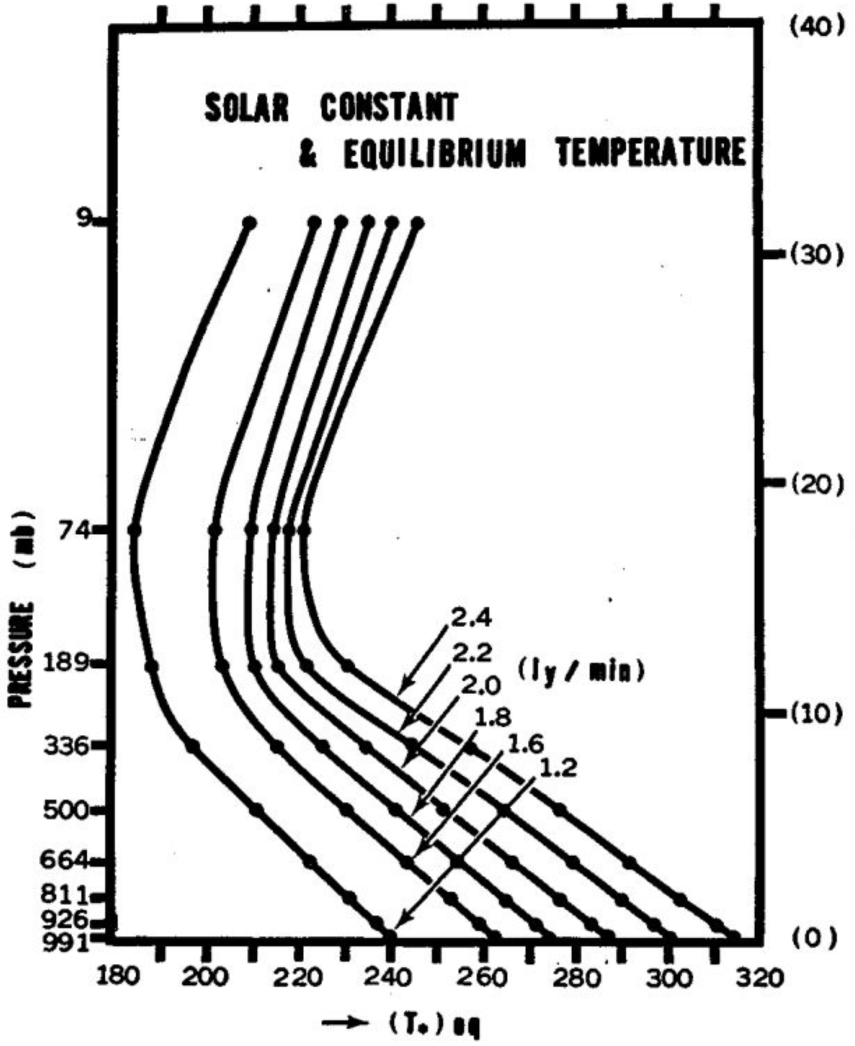


FIG. 8. Vertical distribution of radiative convective equilibrium temperature of the atmosphere with a given distribution of relative humidity for various values of the solar constant.

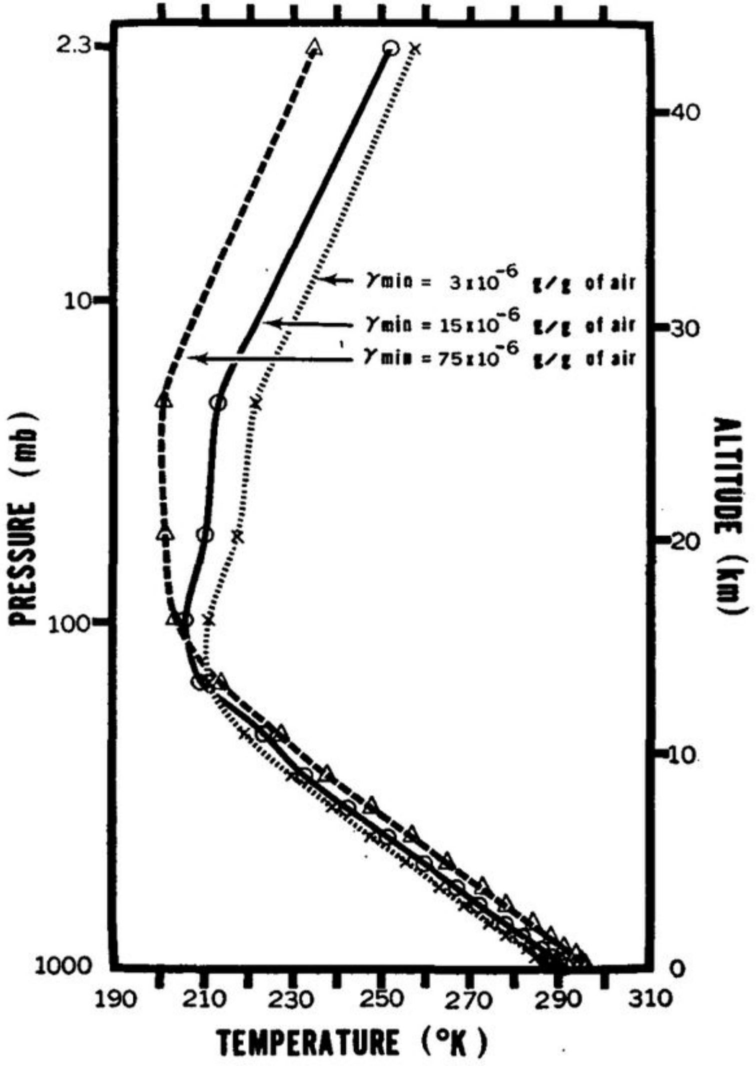
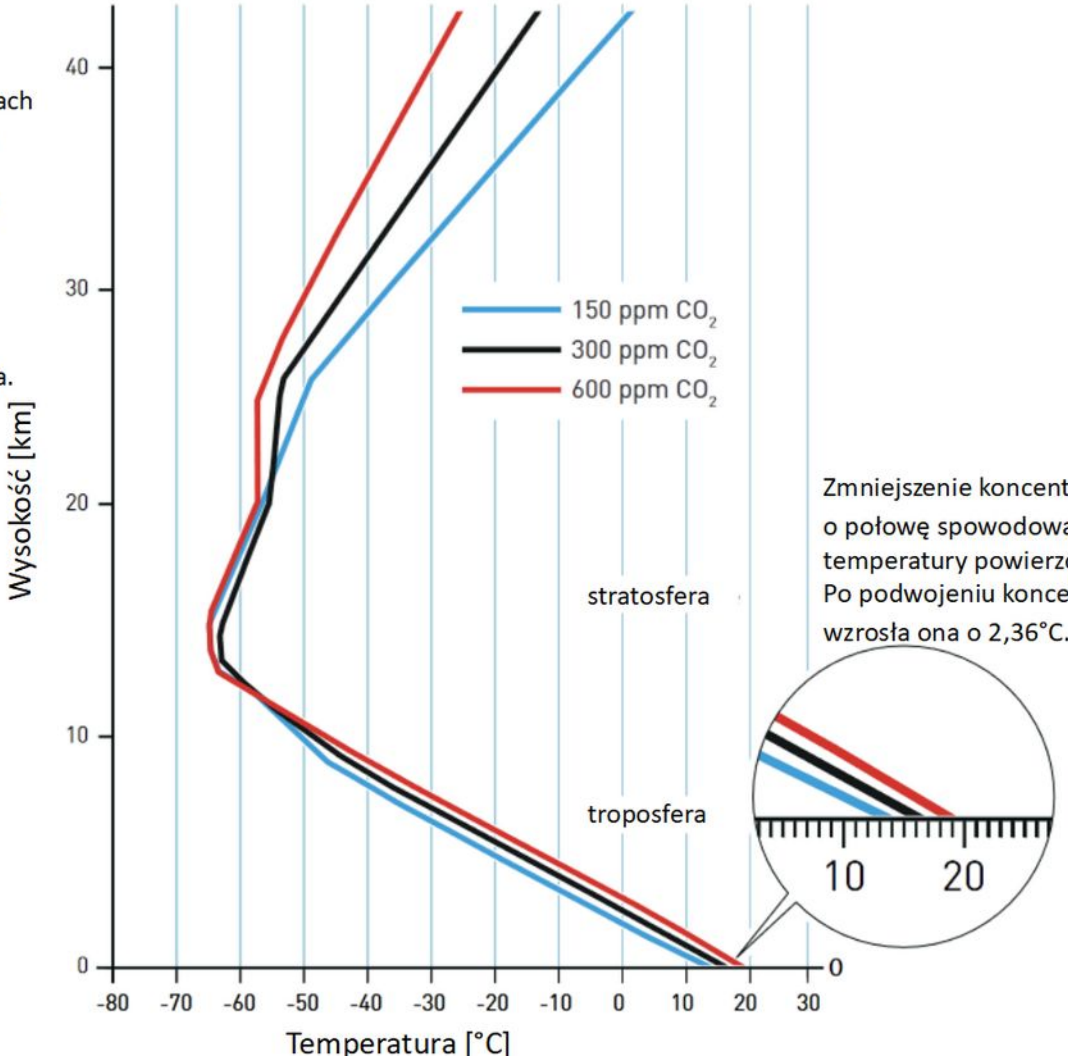


FIG. 12. Vertical distributions of radiative convective equilibrium temperature for various values of water vapor mixing ratio in the stratosphere.

Dwutlenek węgla ogrzewa atmosferę

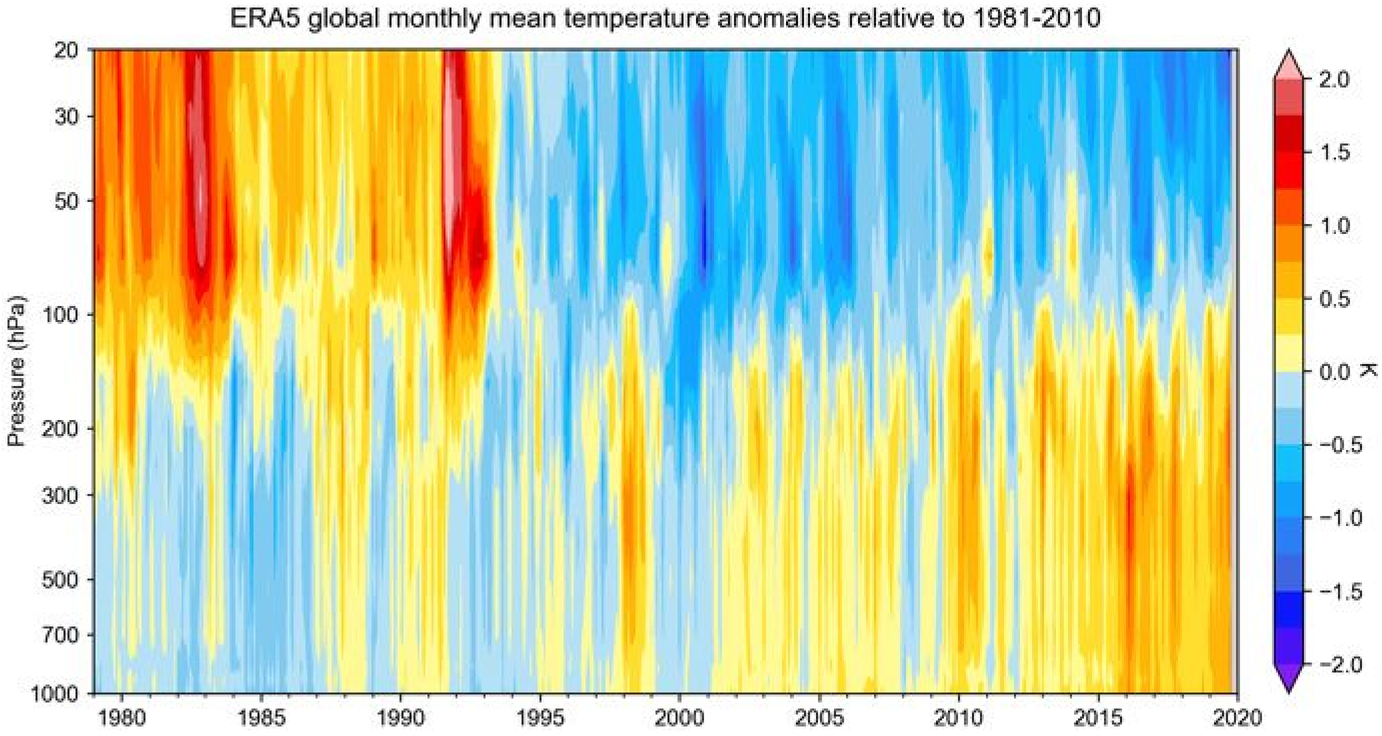
Podwyższona koncentracja CO_2 prowadzi do wzrostu temperatury w dolnych warstwach atmosfery oraz do ochłodzenia górnej atmosfery.
Manabe potwierdził, że zmiany temperatury są związane ze wzrostem koncentracji CO_2; gdyby przyczyną był wzrost aktywności słonecznej, nagrzewałaby się cała atmosfera.



Zmniejszenie koncentracji CO_2 o połowę spowodowało spadek temperatury powierzchni o 2,28°C. Po podwojeniu koncentracji CO_2 wzrosła ona o 2,36°C.

TABLE 4. Equilibrium temperature of the earth's surface (°K) and the CO_2 content of the atmosphere.

CO_2 content (ppm)	Average cloudiness: Fixed absolute humidity	Average cloudiness: Fixed relative humidity	Clear: Fixed absolute humidity	Clear: Fixed relative humidity
150	289.80	286.11	298.75	304.40
300	291.05	288.39	300.05	307.20
600	292.38	290.75	301.41	310.12



https://www.ecmwf.int/en/research/climate-reanalysis

Cloud Feedback Processes in a General Circulation Model

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(Manuscript received 6 April 1987, in final form 30 November 1987)

ABSTRACT

The influence of the cloud feedback process upon the sensitivity of climate is investigated by comparing the behavior of two versions of a climate model with predicted and prescribed cloud cover. The model used for this study is a general circulation model of the atmosphere coupled with a mixed layer model of the oceans. The sensitivity of each version of the model is inferred from the equilibrium response of the model to a doubling of the atmospheric concentration of carbon dioxide.

It is found that the cloud feedback process in the present model enhances the sensitivity of the model climate. In response to the increase of atmospheric carbon dioxide, cloudiness increases around the tropopause and is reduced in the upper troposphere, thereby raising the height of the cloud layer in the upper troposphere. This rise of the high cloud layer implies a reduction of the temperature of the cloud top and, accordingly, of the upward terrestrial radiation from the top of the model atmosphere. Thus, the heat loss from the atmosphere–earth system of the model is reduced. As the high cloud layer rises, the vertical distribution of cloudiness changes, thereby affecting the absorption of solar radiation by the model atmosphere. At most latitudes the effect of reduced cloud amount in the upper troposphere overshadows that of increased cloudiness around the tropopause, thereby lowering the global mean planetary albedo and enhancing the CO_2 induced warming.

On the other hand, the increase of low cloudiness in high latitudes raises the planetary albedo and thus decreases the CO_2 induced warming of climate. However, the contribution of this negative feedback process is much smaller than the effect of the positive feedback process involving the change of high cloud.

The model used here does not take into consideration the possible change in the optical properties of clouds due to the change of their liquid water content. In view of the extreme idealization in the formulation of the cloud feedback process in the model, this study should be regarded as a study of the mechanisms involved in this process rather than the quantitative assessment of its influence on the sensitivity of climate.

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Sensitivity of a Global Climate Model to an Increase of CO_2 Concentration in the Atmosphere

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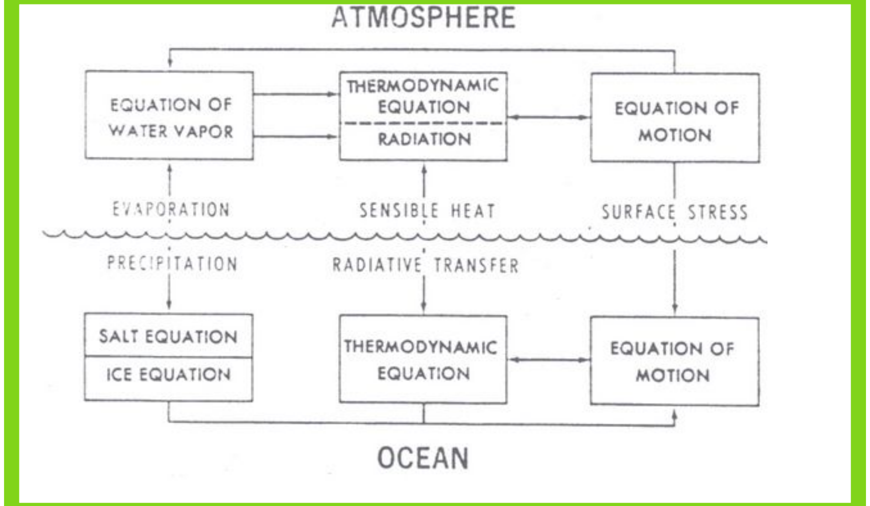
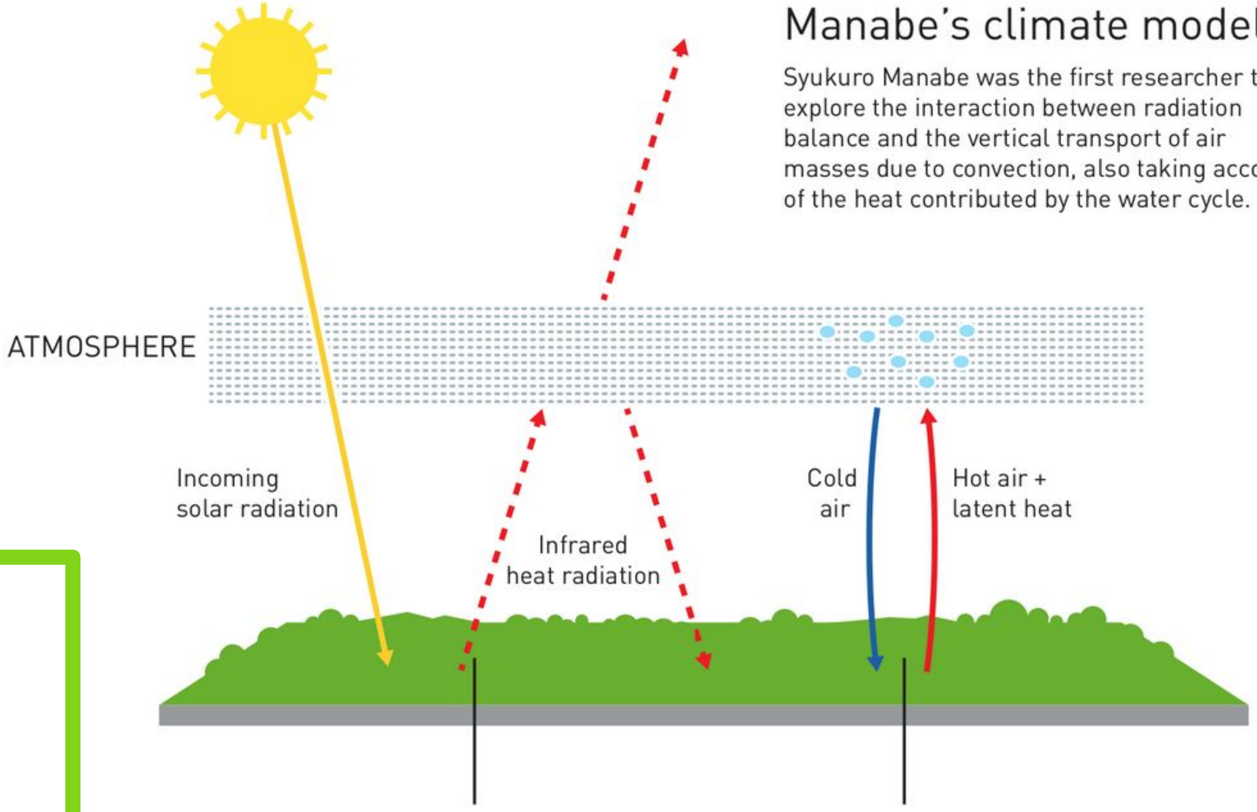
This study investigates the response of a global model of the climate to the quadrupling of the CO_2 concentration in the atmosphere. The model consists of (1) a general circulation model of the atmosphere, (2) a heat and water balance model of the continents, and (3) a simple mixed layer model of the oceans. It has a global computational domain and realistic geography. For the computation of radiative transfer, the seasonal variation of insolation is imposed at the top of the model atmosphere, and the fixed distribution of cloud cover is prescribed as a function of latitude and of height. It is found that with some exceptions, the model succeeds in reproducing the large-scale characteristics of seasonal and geographical variation of the observed atmospheric temperature. The climatic effect of a CO_2 increase is determined by comparing statistical equilibrium states of the model atmosphere with a normal concentration and with a 4 times the normal concentration of CO_2 in the air. It is found that the warming of the model atmosphere resulting from the CO_2 increase has significant seasonal and latitudinal variation. Because of the absence of an albedo feedback mechanism, the warming over the Antarctic continent is somewhat less than the warming in high latitudes of the northern hemisphere. Over the Arctic Ocean and its surroundings, the warming is much larger in winter than summer, thereby reducing the amplitude of seasonal temperature variation. It is concluded that this seasonal asymmetry in the warming results from the reduction in the coverage and thickness of the sea ice. The warming of the model atmosphere results in an enrichment of the moisture content in the air and an increase in the poleward moisture transport. The additional moisture is picked up from the tropical ocean and is brought to high latitudes where both precipitation and runoff increase throughout the year. Further, the time of rapid snowmelt and maximum runoff becomes earlier.



Manabe's climate model

Syukuro Manabe was the first researcher to explore the interaction between radiation balance and the vertical transport of air masses due to convection, also taking account of the heat contributed by the water cycle.



Infrared heat radiation from the ground is partially absorbed in the atmosphere, warming the air and the ground, while some radiates out into space.

Hot air is lighter than cold air, so it rises through convection. It also carries water vapour, which is a powerful greenhouse gas. The warmer the air, the higher the concentration of water vapour. Further up, where the atmosphere is colder, cloud drops form, releasing the latent heat stored in the water vapour.

Interaction of a Cumulus Cloud Ensemble with the Large-Scale Environment, Part I

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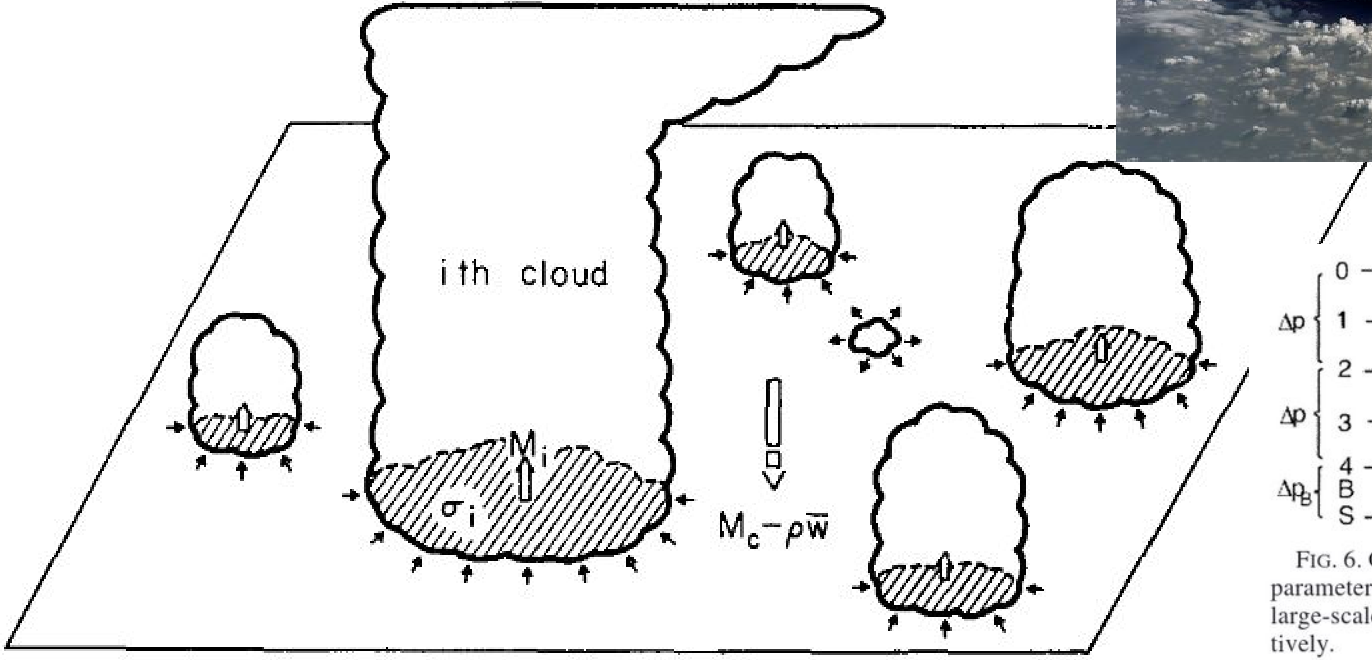
(Manuscript received 10 August 1973, in revised form 7 November 1973)

ABSTRACT

A theory of the interaction of a cumulus cloud ensemble with the large-scale environment is developed. In this theory, the large-scale environment is divided into the subcloud mixed layer and the region above. The time changes of the environment are governed by the heat and moisture budget equations for the subcloud mixed layer and for the region above, and by a prognostic equation for the depth of the mixed layer. In the environment above the mixed layer, the cumulus convection affects the temperature and moisture fields through cumulus-induced subsidence and detrainment of saturated air containing liquid water which evaporates in the environment. In the subcloud mixed layer, the cumulus convection does not act directly on the temperature and moisture fields, but it affects the depth of the mixed layer through cumulus-induced subsidence. Under these conditions, the problem of parameterization of cumulus convection reduces to the determination of the vertical distributions of the total vertical mass flux by the ensemble, the total detrainment of mass from the ensemble, and the thermodynamical properties of the detraining air.

The cumulus ensemble is spectrally divided into sub-ensembles according to the fractional entrainment rate, given by the ratio of the entrainment per unit height to the vertical mass flux in the cloud. For these sub-ensembles, the budget equations for mass, moist static energy, and total water content are obtained. The solutions of these equations give the temperature excess, the water vapor excess, and the liquid water content of each sub-ensemble, and further reduce the problem of parameterization to the determination of the mass flux distribution function, which is the sub-ensemble vertical mass flux at the top of the mixed layer.

The cloud work function, which is an integral measure of the buoyancy force in the clouds, is defined for each sub-ensemble; and, under the assumption that it is in quasi-equilibrium, an integral equation for the mass flux distribution function is derived. This equation describes how a cumulus ensemble is forced by large-scale advection, radiation, and surface turbulent fluxes, and it provides a closed parameterization of cumulus convection for use in prognostic models of large-scale atmospheric motion.



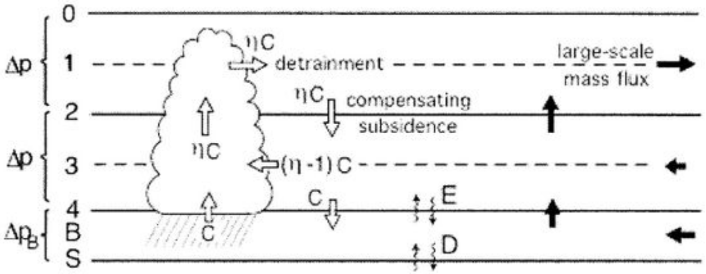


FIG. 6. One of the three cloud types considered in Arakawa's (1969) parameterization for a three-level model. Solid and open arrows show large-scale and superposed cumulus-induced mass fluxes, respectively.

FIG. 1. A unit horizontal area at some level between cloud base and the highest cloud top. The taller clouds are shown penetrating this level and entraining environmental air. A cloud which has lost buoyancy is shown detraining cloud air into the environment.

REVIEW ARTICLE

The Cumulus Parameterization Problem: Past, Present, and Future

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(Manuscript received 24 June 2003, in final form 16 January 2004)

ABSTRACT

A review of the cumulus parameterization problem is presented with an emphasis on its conceptual aspects covering the history of the underlying ideas, major problems existing at present, and possible directions and approaches for future climate models. Since its introduction in the early 1960s, there have been decades of controversies in posing the cumulus parameterization problem. In this paper, it is suggested that confusion between budget and advection considerations is primarily responsible for the controversies. It is also pointed out that the performance of parameterization schemes can be better understood if one is not bound by their authors' justifications. The current trend in posing cumulus parameterization is away from deterministic diagnostic closures, including instantaneous adjustments, toward prognostic or nondeterministic closures, including relaxed and/or triggered adjustments. A number of questions need to be answered, however, for the merit of this trend to be fully utilized.

Major practical and conceptual problems in the conventional approach of cumulus parameterization, which include artificial separations of processes and scales, are then discussed. It is rather obvious that for future climate models the scope of the problem must be drastically expanded from "cumulus parameterization" to "unified cloud parameterization," or even to "unified model physics." This is an extremely challenging task, both intellectually and computationally, and the use of multiple approaches is crucial even for a moderate success. "Cloud-resolving convective parameterization" or "superparameterization" is a promising new approach that can develop into a multiscale modeling framework (MMF). It is emphasized that the use of such a framework can unify our currently diversified modeling efforts and make verification of climate models against observations much more constructive than it is now.

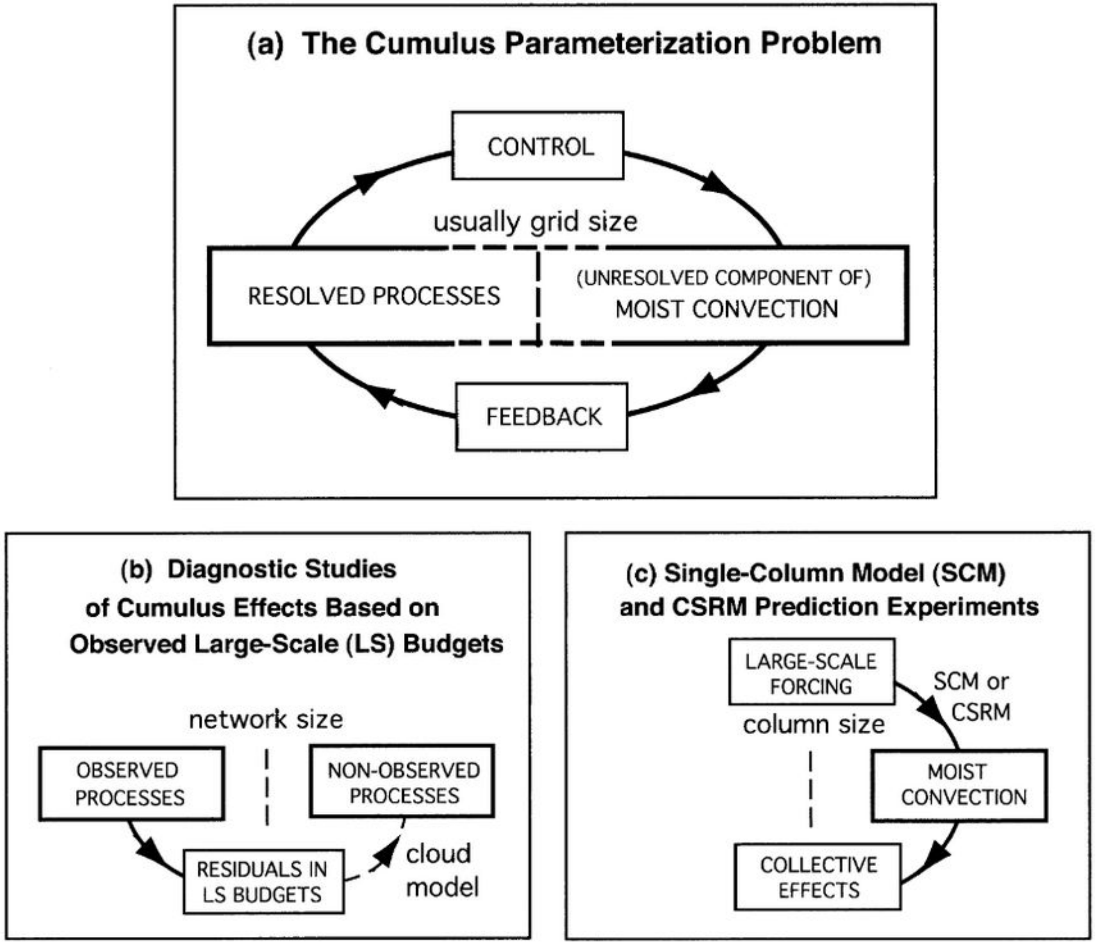

FIG. 3. (a) A schematic diagram showing interactions between resolved processes in a model and (the unresolved component of) moist convection. The formulation of the right half of the loop represents the cumulus parameterization problem. (b) A schematic diagram showing the logical structure of diagnostic studies of cumulus activity based on observed large-scale budgets. (c) Same as in (b) except for studies using SCMs or CSRMs.

Formulation structure of the mass-flux convection parameterization

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A R T I C L E   I N F O

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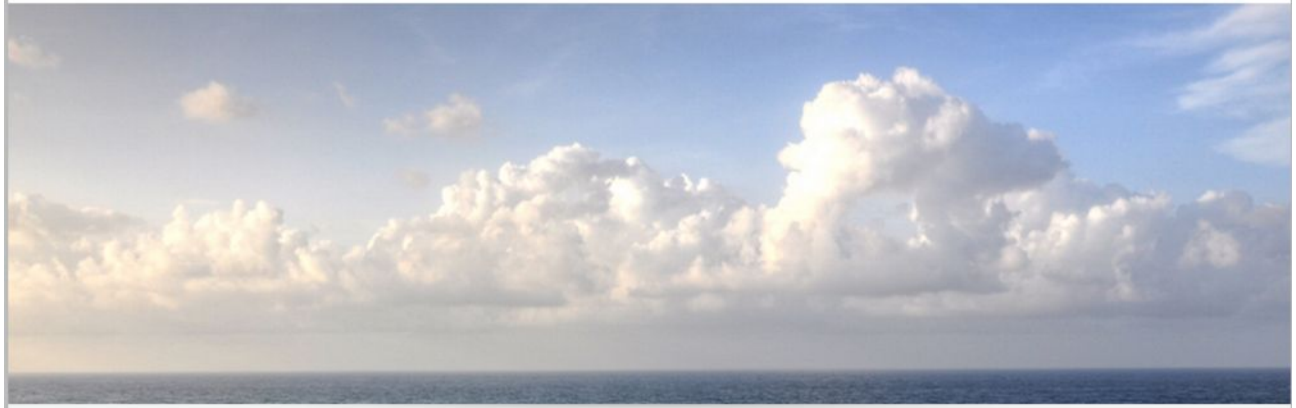
Structure of the mass-flux convection parameterization formulation is re-examined. Many of the equations associated with this formulation are derived in systematic manner with various intermediate steps explicitly presented. The nonhydrostatic anelastic model (NAM) is taken as a starting point of all the derivations.

Segmentally constant approximation (SCA) is a basic geometrical constraint imposed on a full system (e.g., NAM) as a first step for deriving the mass-flux formulation. The standard mass-flux convection parameterization, as originally formulated by Ooyama, Fraedrich, Arakawa and Schubert, is re-derived under the two additional hypotheses concerning entrainment–detrainment and environment, and an asymptotic limit of vanishing areas occupied by convection.

A model derived at each step of the deduction constitutes a stand-alone subgrid-scale representation by itself, leading to a hierarchy of subgrid-scale schemes. A backward tracing of this deduction process provides paths for generalizing mass-flux convection parameterization. Issues of the high-resolution limit for parameterization are also understood as those of relaxing various traditional constraints. The generalization presented herein can include various other subgrid-scale processes under a mass-flux framework.



RCEMIP: Radiative-Convective Equilibrium Model Intercomparison Project

RCEMIP-II

We are excited to move towards a Phase II of RCEMIP, which will involve simulations with a prescribed analytic SST boundary condition. For more info check out: RCEMIP Simulations and the RCEMIP-II protocol paper. **Registration for participating in Phase II is now open!**

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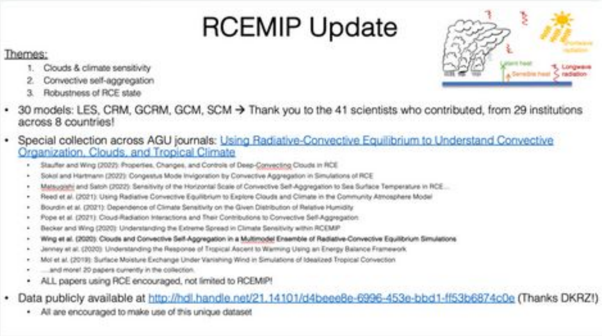
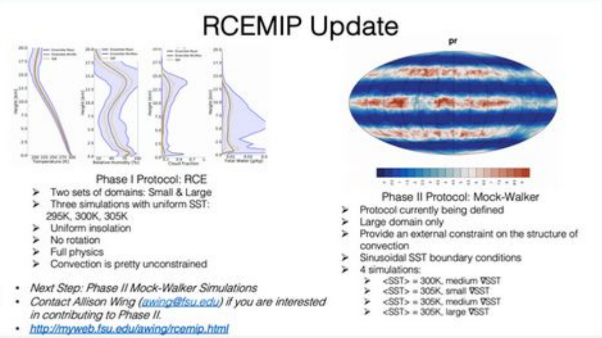
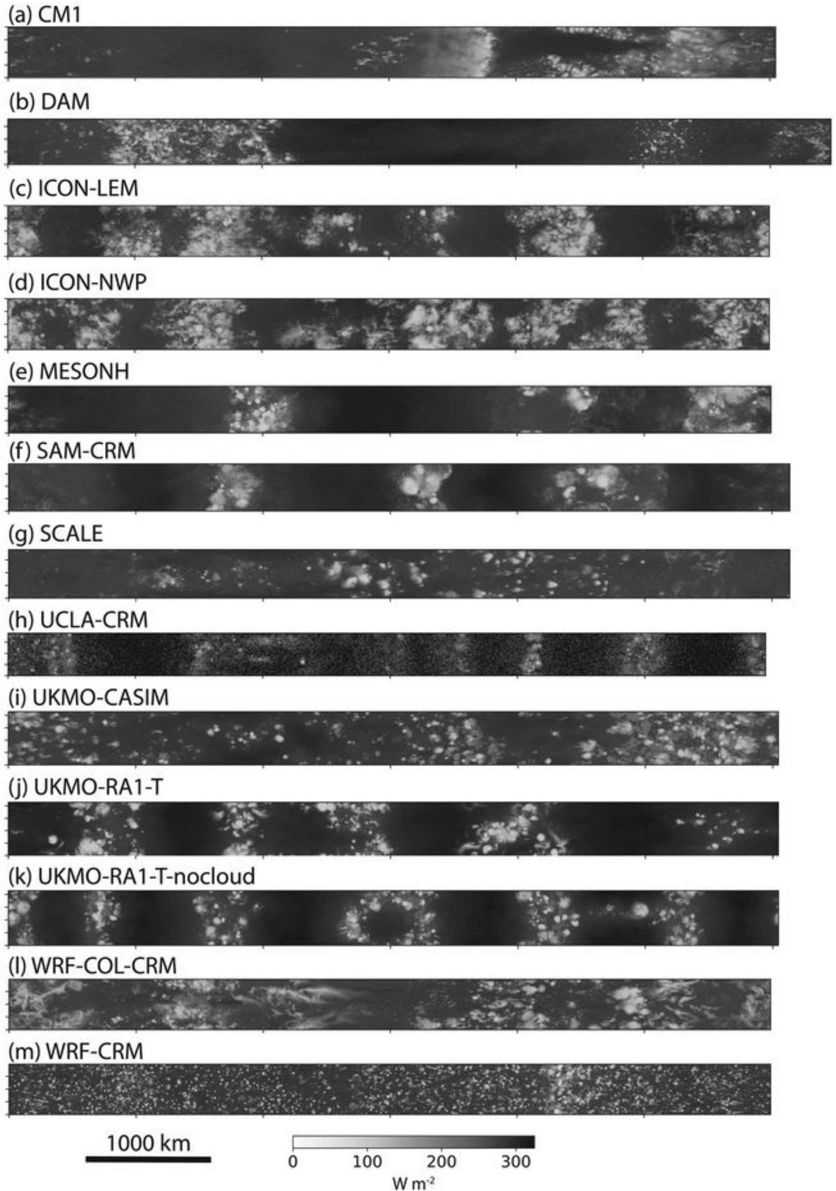




Clouds and Convective Self-Aggregation in a Multimodel Ensemble of Radiative-Convective Equilibrium Simulations.

Hourly averaged outgoing longwave radiation (W m^{-2}) at Day 80 of the RCE_large300 simulation for all cloud-resolving models. Each panel displays a different model and the size of each panel represents the domain size, which varies slightly across models.



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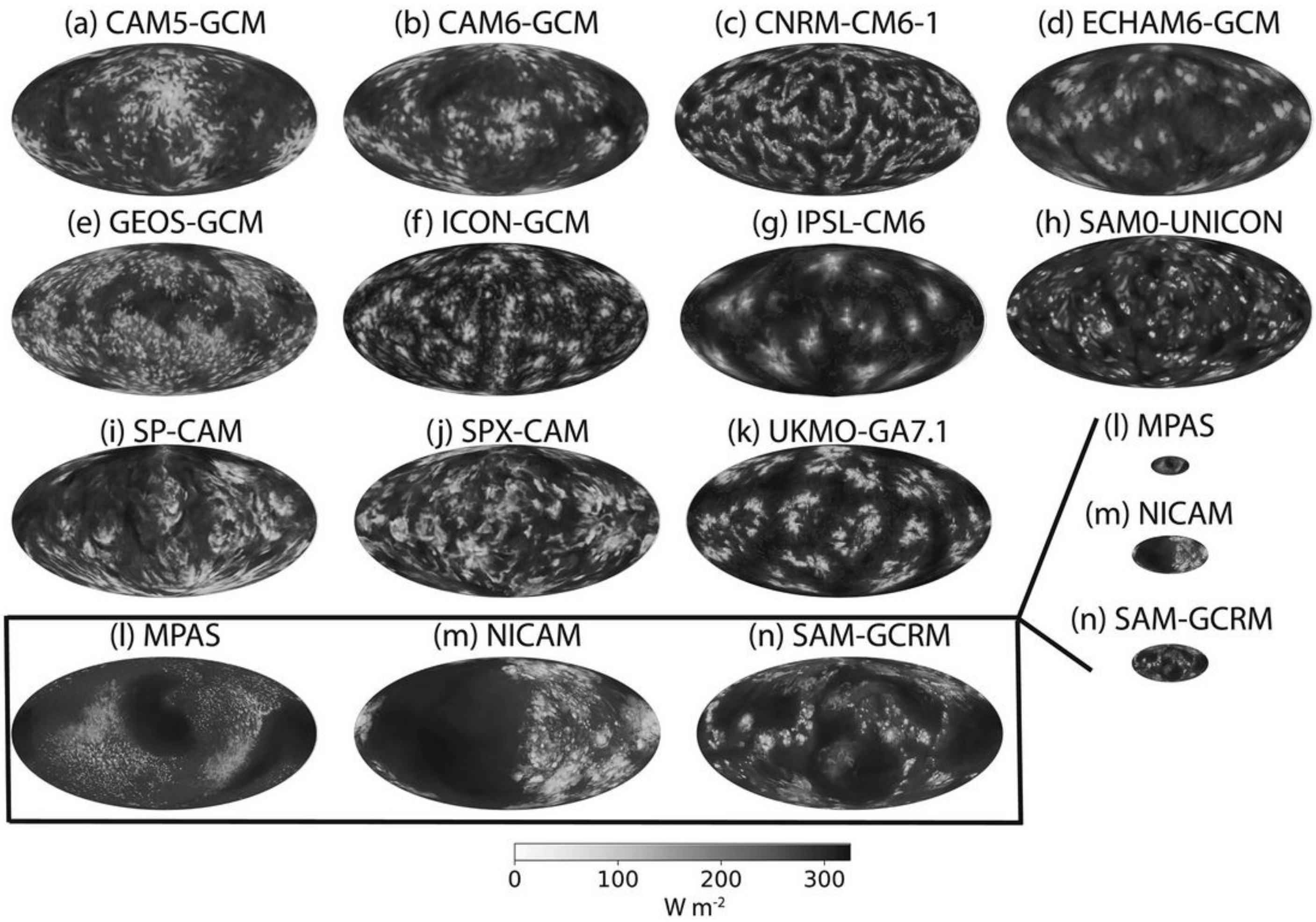
Clouds and Convective Self-Aggregation in a Multimodel Ensemble of Radiative-Convective Equilibrium Simulations

Hourly averaged outgoing longwave radiation (W m^{-2}) at Day 80 of the RCE_large300 simulation for all global models (except for IPSL-CM6, which reported daily averaged output). All models shown are GCMs with parameterized convection (panels a–k) except MPAS, NICAM, and SAM (panels l–n), which are global cloud-resolving models that employ reduced Earth radius of RE/8, RE/4, and RE/4, respectively, and are shown to scale and, in the box, zoomed in.



In summary, despite some robust behaviors, there is substantial disagreement across the RCEMIP ensemble in representations of cloudiness, self-aggregation, and climate sensitivity. Some readers may find this discouraging or surprising (perhaps hoping that models with explicit convection might have agreed better), while some readers may have anticipated that the many degrees of freedom in how models may achieve RCE would result in divergent behavior.

Indeed, because RCE is relatively unconstrained, with convection left free to evolve as long as energy balance is still met, it is a tough test for models. We argue that this is a benefit of RCE, rather than a weakness. The divergent behavior in RCEMIP reveals the true sensitivities to representations of convection, microphysics, turbulence, and dynamical cores, sensitivities that might be masked in other comparisons by constraints imposed by large-scale circulations. Furthermore, the **RCEMIP results show that the wide range of equilibrated states is not due to differences in the basic configuration such as SST, CRM grid spacing, insolation, or initialization**, as there is a large spread despite constraining these factors to be the same. **Instead, the different responses must be due to differences in model physics and/or numerics.**

Ale… Może stan stacjonarny nie istnieje?

Mamy wymuszanie w cyklu dobowym i rocznym, zmienne cyrkulacje atmosferyczne transportujące masy powietrza o różnej stabilności…