Global warming - physicist's perspective - 04

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Time-line (milestones)
(after http://www.aip.org/history/climate/timeline.htm and other sources)

1801 – Herschel hypothesizes on the effects of variablee solar emission om climate

1824 - Fourier calculates that the Earth would be far colder if it lacked an atmosphere and introduces term „greenhouse effect”

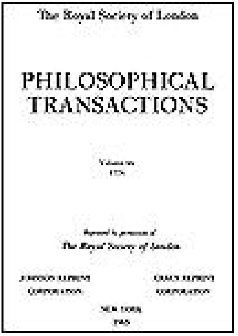
1859 - Tyndall discovers that some gases absorb infrared radiation. He suggests that changes in the concentration of the gases could bring climate change.

1896 - Arrhenius publishes first calculation of global warming from increased concentrations of CO2.

1897 - Chamberlin produces a model for global carbon exchange including feedbacks.

1930s: Global warming trend since late 19th century reported.
Milankovitch proposes orbital changes as the cause of ice ages.
Hulburt publishes calculations of warming from increased concentrations of CO2.

1938 - Callendar argues that CO2 greenhouse global warming is underway, reviving interest in the problem.


The Royal Society of London

PHILOSOPHICAL TRANSACTIONS

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

Two basic climate mechanisms were known in the beginning of XIX century !!!

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.

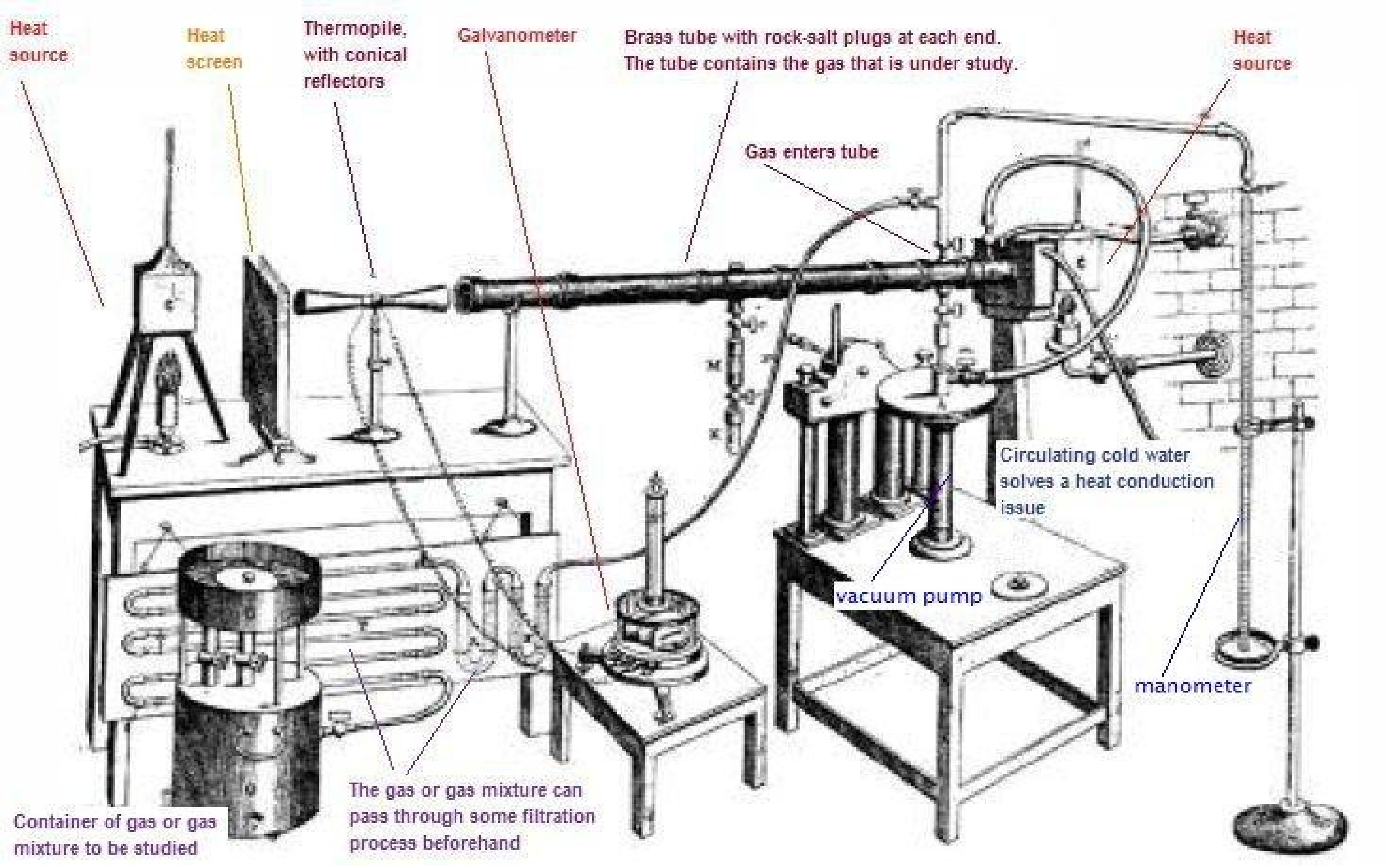
La chaleur du globe terrestre dérive de trois sources qu'il est d'abord nécessaire de distinguer.

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". Mémoires de l'Académie Royale des Sciences 7: 569–604



1861, Tyndall's apparatus measuring properties of greenhouse gases.

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

* *Cf.* p. 265.

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

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

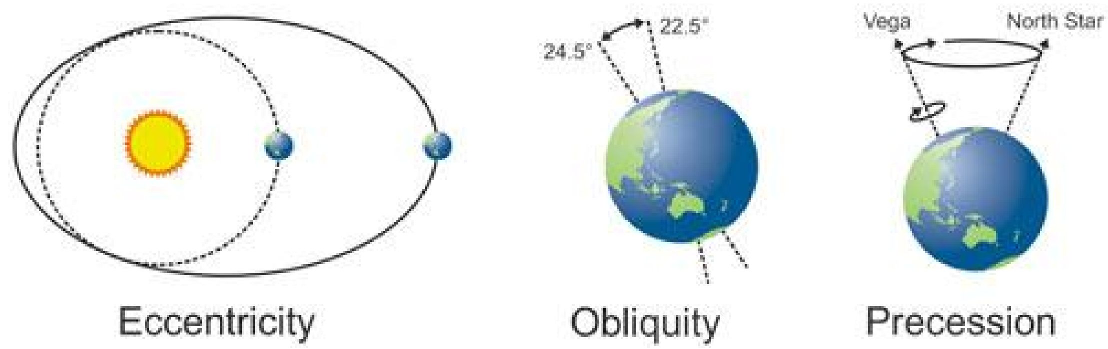
AN ATTEMPT TO FRAME A WORKING HYPOTHESIS OF THE CAUSE OF GLACIAL PERIODS ON AN ATMOSPHERIC BASIS[1]

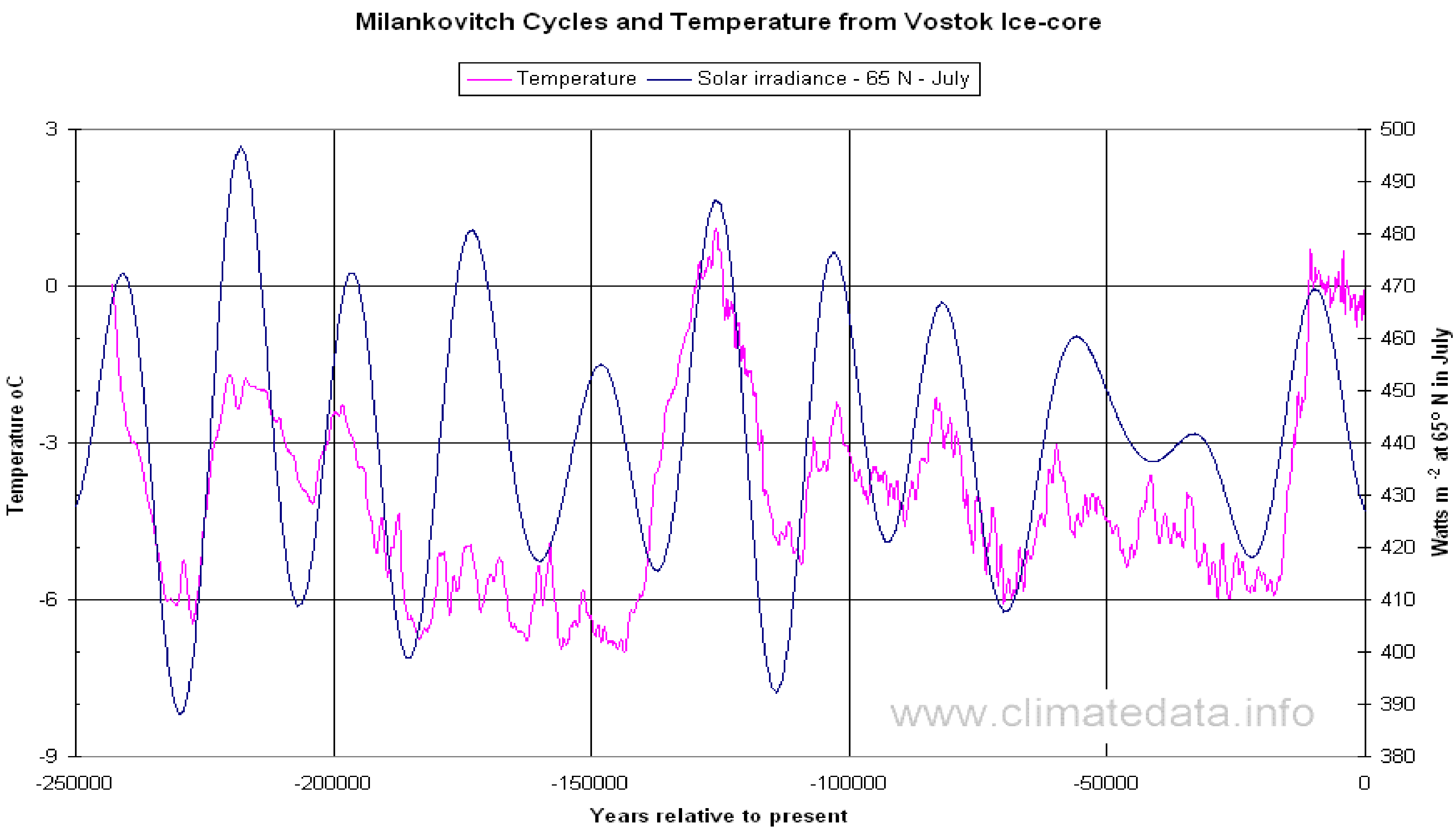
THERE are hypotheses and working hypotheses. The suggestion that the last glacial period was caused by the passage of the solar system through a cold region of space may be styled a hypothesis, but scarcely a working hypothesis in the geological sense, for it does not form the groundwork or incentive 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.

Milankovitch Cycles





QUARTERLY JOURNAL OF THE ROYAL METEOROLOGICAL SOCIETY

RMetS Royal Meteorological Society

Article

The artificial production of carbon dioxide and its influence on temperature

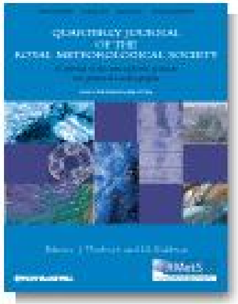
FREE

G. S. Callendar

Article first published online: 10 SEP 2007

DOI: 10.1002/qj.49706427503

Issue



Quarterly Journal of the Royal Meteorological Society

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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1956 - Phillips produces a computer model of the global atmosphere, Plass calculates again that radiation balance depends on CO_2 concentration

1957 - Revelle and Suess demonstrate that only a fraction (about ½) of CO_2 produced by humans absorbed by the oceans.

1960 - Keeling detects an annual rise of CO_2 in the atmosphere.

1965 - Lorenz points out the chaotic nature of climate system and the possibility of sudden shifts.

1966 - Emiliani's analysis of deep-sea cores and Broecker's analysis of corals show that the timing of ice ages was set by small orbital shifts.

1979 - US National Academy of Sciences report finds that doubling CO_2 will bring 1.5-4.5°C global warming.

1990 - First IPCC report says world has been warming and future warming seems likely.

1991 - Mt. Pinatubo explodes; Hansen predicts cooling pattern, verifying (by 1995) computer models of aerosol effects.

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.

(Tellus, 9, 1957, 18–27)

"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."

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

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.*

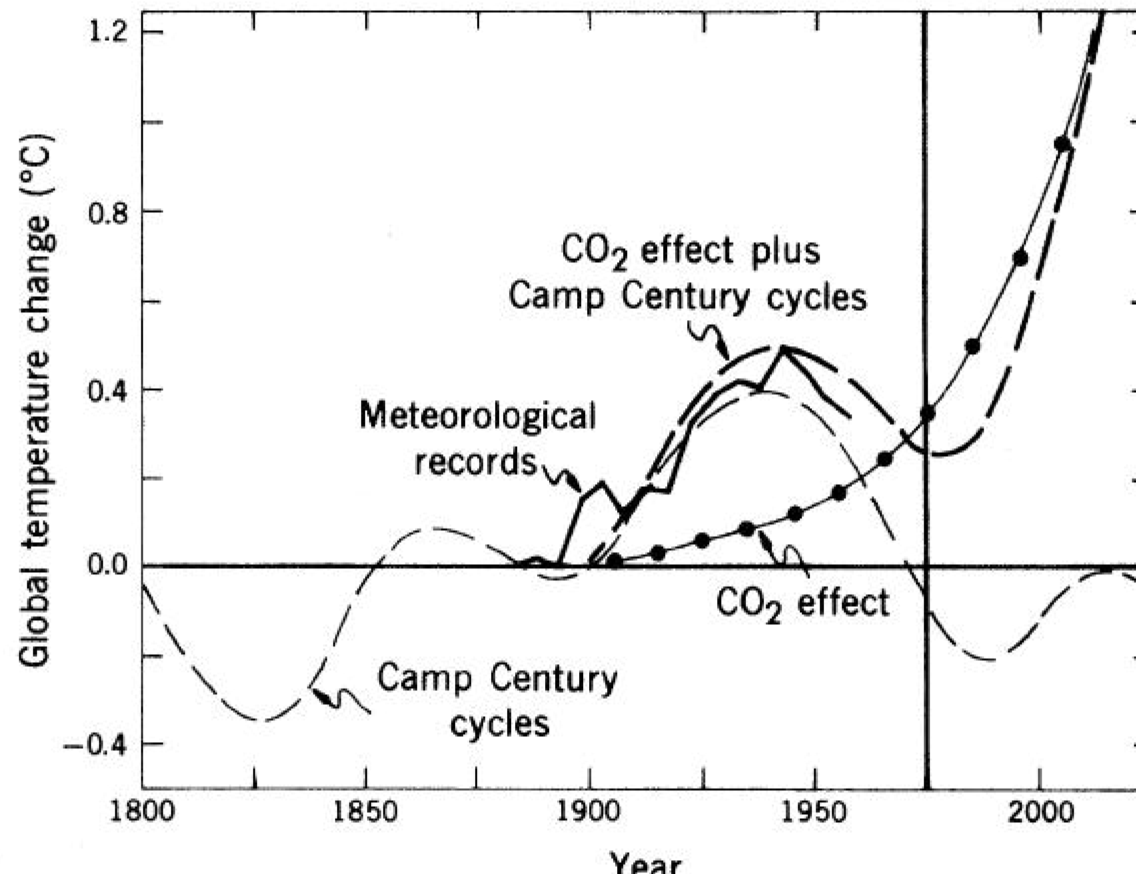


Fig. 1. Curves for the global temperature change due to chemical fuel CO_2, natural climatic cycles, and the sum of the two effects. The measured temperature anomaly for successive 5-year means from meteorological records over the last century is given for comparison.

Carbon Dioxide and Climate: A Scientific Assessment

Report of an Ad Hoc Study Group on Carbon Dioxide ar
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

We have examined the principal attempts to simulate the effects of increased atmospheric CO_2 on climate. In doing so, we have limited our considerations to the direct climatic effects of steadily rising atmospheric concentrations of CO_2 and have assumed a rate of CO_2 increase that would lead to a doubling of airborne concentrations by some time in the first half of the twenty-first century. [redacted]

When it is assumed that the CO_2 content of the atmosphere is doubled and statistical thermal equilibrium is achieved, the more realistic of the modeling efforts predict a global surface warming of between 2°C and 3.5°C, with greater increases at high latitudes. This range reflects both uncertainties in physical understanding and inaccuracies arising from the need to reduce the mathematical problem to one that can be handled by even the fastest available electronic computers. It is significant, however, that none of the model calculations predicts negligible warming.

The primary effect of an increase of CO_2 is to cause more absorption of thermal radiation from the earth's surface and thus to increase the air temperature in the troposphere. A strong positive feedback mechanism is the accompanying increase of moisture, which is an even more powerful absorber of terrestrial radiation. We have examined with care all known negative feedback mechanisms, such as increase in low or middle cloud amount, and have concluded that the oversimplifications and inaccuracies in the models are not likely to have vitiated the principal conclusion that there will be appreciable warming. The known negative feedback mechanisms can reduce the warming, but they do not appear to be so strong as the positive moisture feedback. 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. Our estimate is based primarily on our review of a series of calculations with three-dimensional models of the global atmospheric circulation, which is summarized in Chapter 4. We have also reviewed simpler models that appear to contain the main physical factors.

To summarize, we have tried but have been unable to find any overlooked or underestimated physical effects that could reduce the currently estimated global warmings due to a doubling of atmospheric CO_2 to negligible proportions or reverse them altogether. However, we believe it quite possible that the capacity of the intermediate waters of the oceans to absorb heat could delay the estimated warming by several decades. It appears that the warming will eventually occur, and the associated regional climatic changes so important to the assessment of socioeconomic consequences may well be significant, but unfortunately the latter cannot yet be adequately projected.

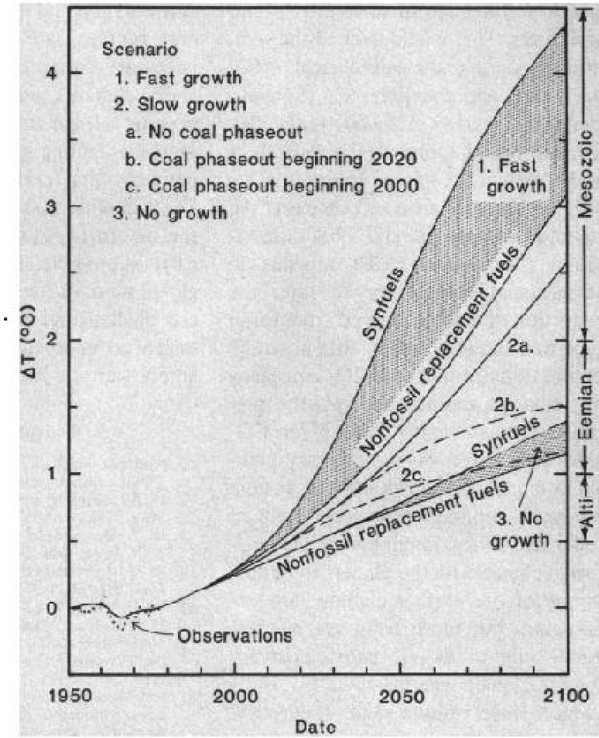
28 August 1981, Volume 213, Number 4511

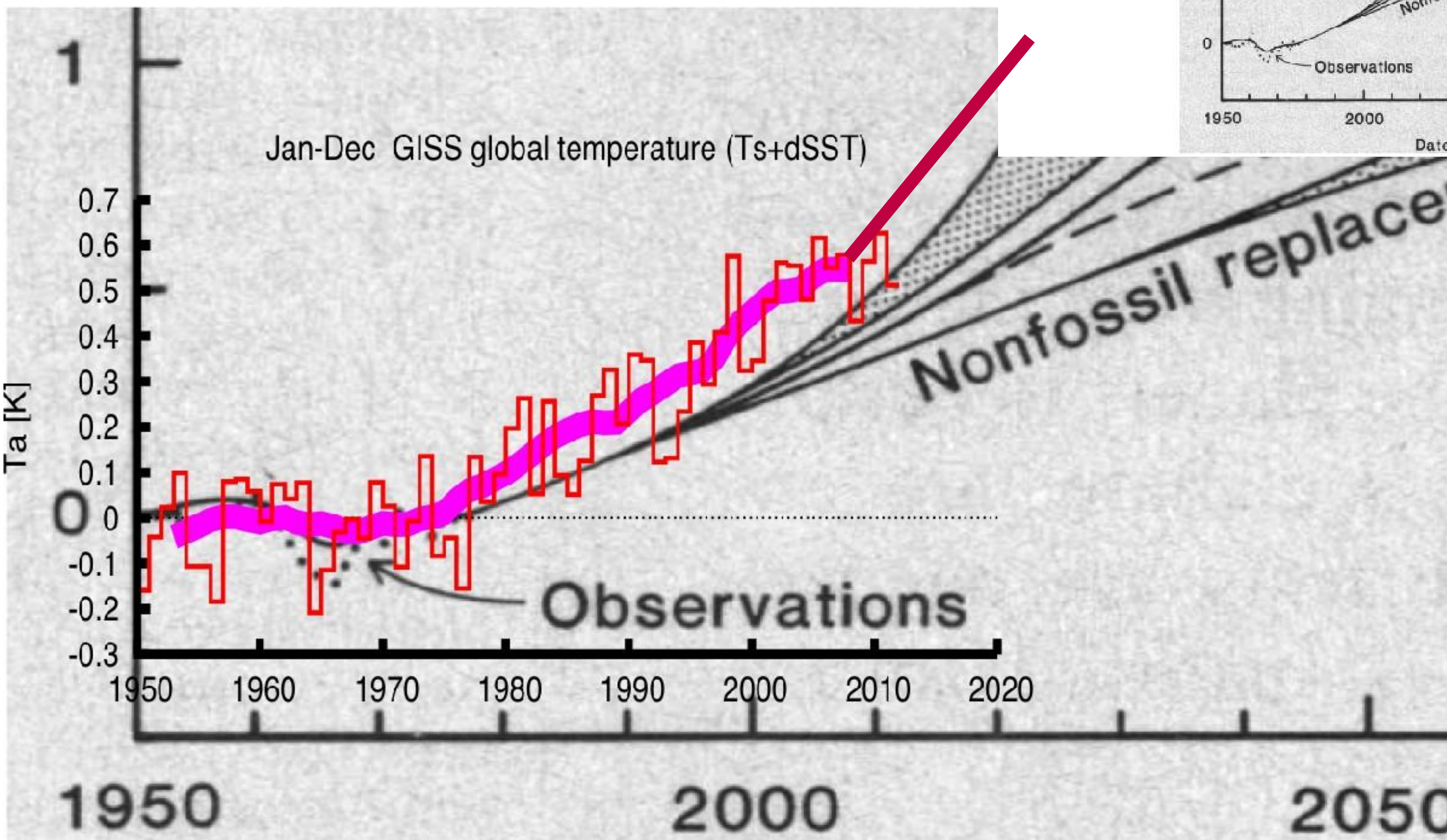
SCIENCE

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.





The Nobel Prize in Physics 2021

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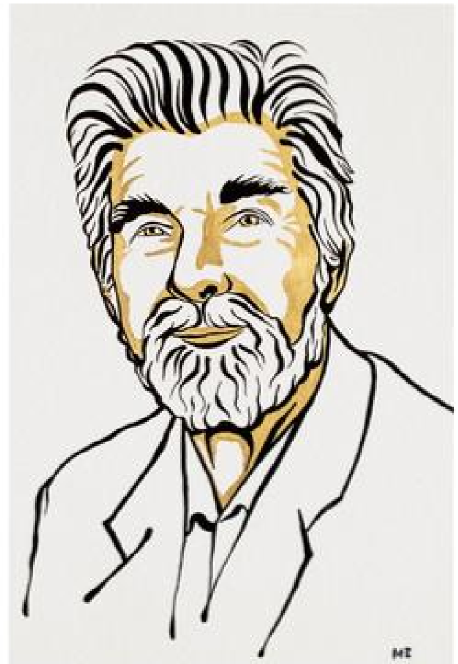
Syukuro Manabe

Prize share: 1/4



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Klaus Hasselmann

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Giorgio Parisi

Prize share: 1/2

The Nobel Prize in Physics 2021 was awarded "for groundbreaking contributions to our understanding of complex systems" with one half jointly to Syukuro Manabe and Klaus Hasselmann "for the physical modelling of Earth's climate, quantifying variability and reliably predicting global warming" and the other half to Giorgio Parisi "for the discovery of the interplay of disorder and fluctuations in physical systems from atomic to planetary scales."

Thermal Equilibrium of the Atmosphere with a Convective Adjustment

Syukuro Manabe ND 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)

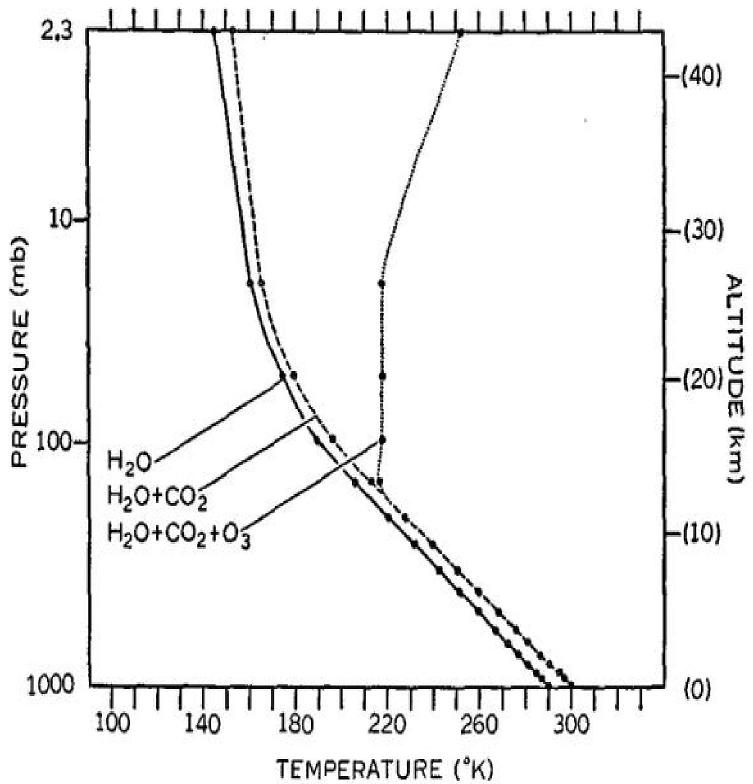

Fig. 6c. Thermal equilibrium of various atmospheres which have a critical lapse rate of 6.5 deg km^{-1}. Vertical distributions of gaseous absorbers at 35N, April, were used. $S_c=2$ ly min^{-1}, $\cos\bar{\zeta}=0.5$, $r=0.5$, no clouds.

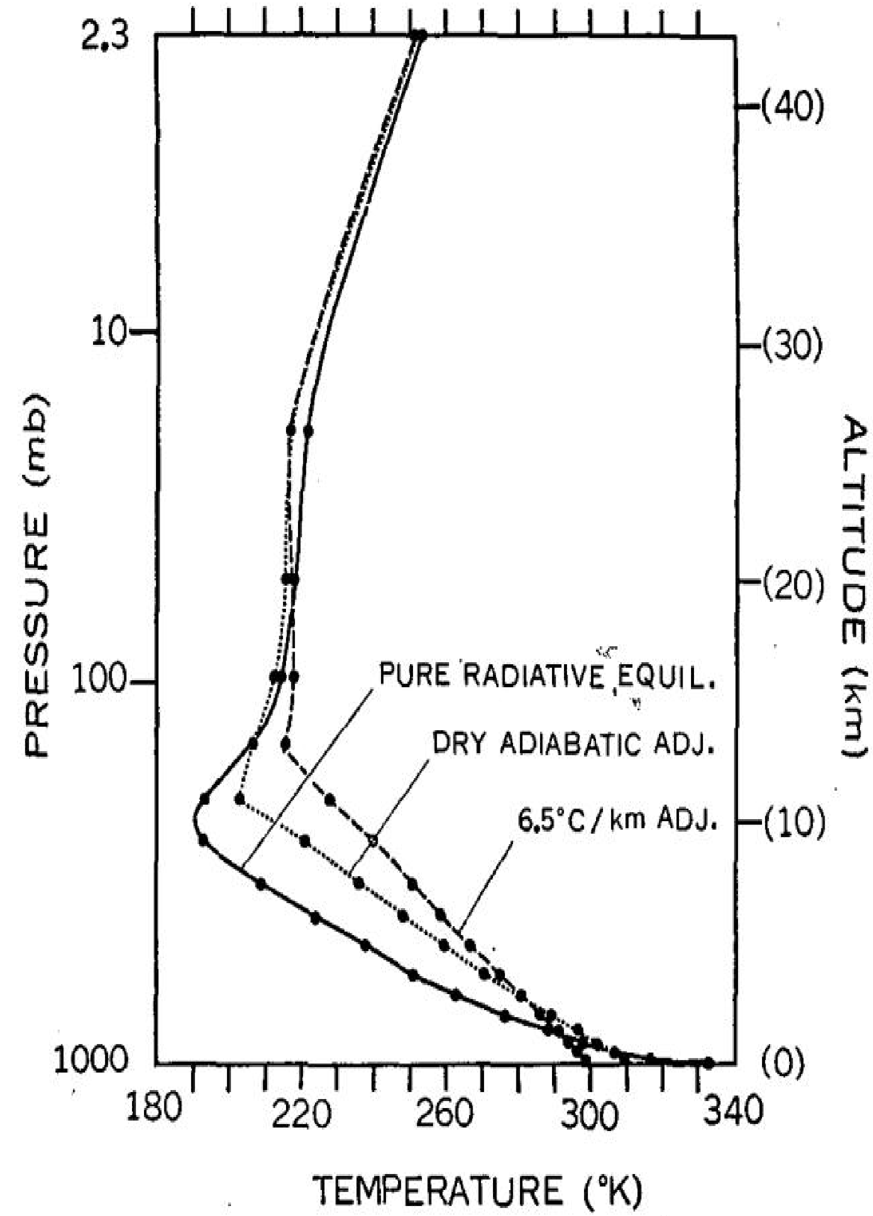

Fig. 4. The dashed, dotted, and solid lines show the thermal equilibrium with a critical lapse rate of 6.5 deg km^{-1}, a dry-adiabatic critical lapse rate (10 deg km^{-1}), and pure radiative equilibrium.

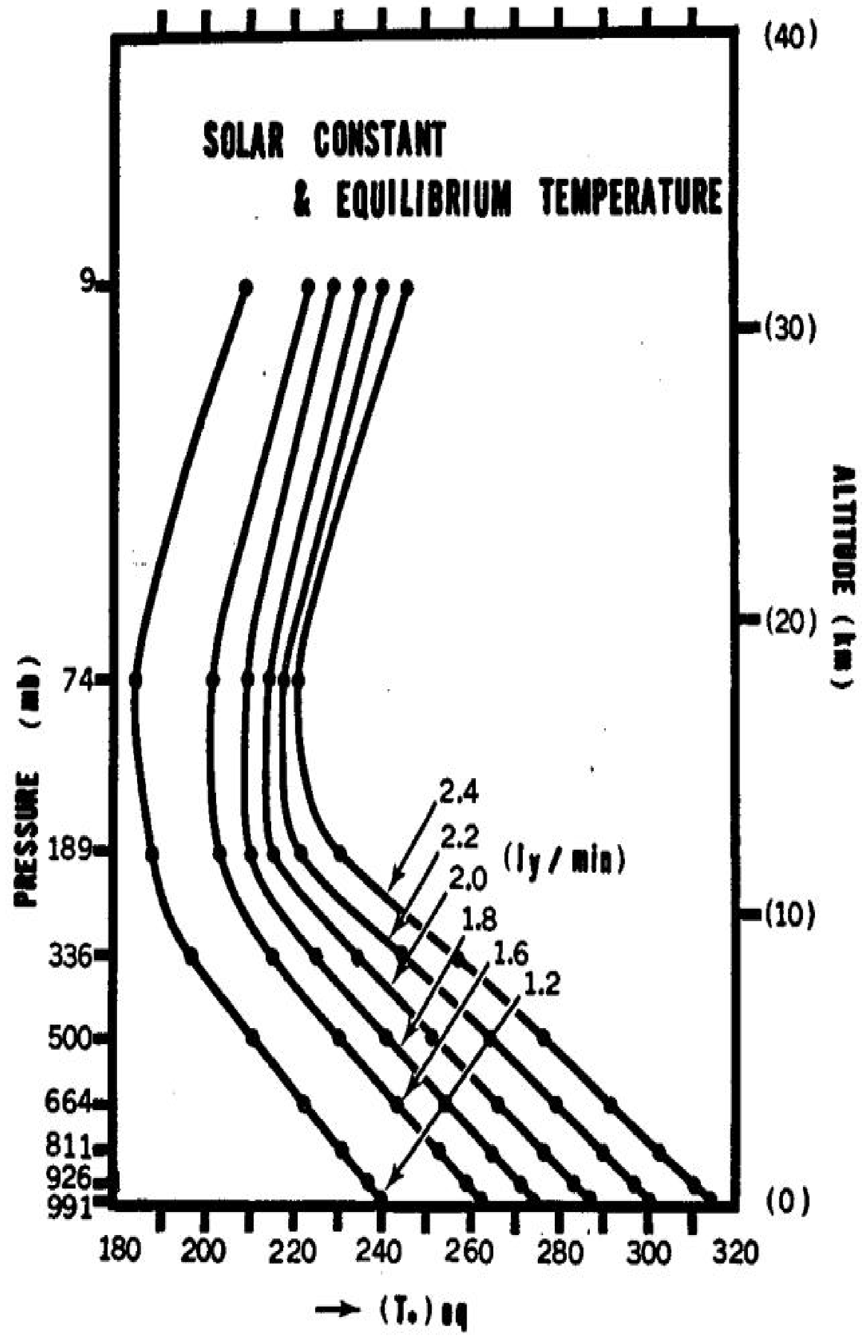

FIG. 8. Vertical distribution of radiative convective equilibrium temperature of the atmosphere with a given distribution of relative humidity for various values of the solar constant.

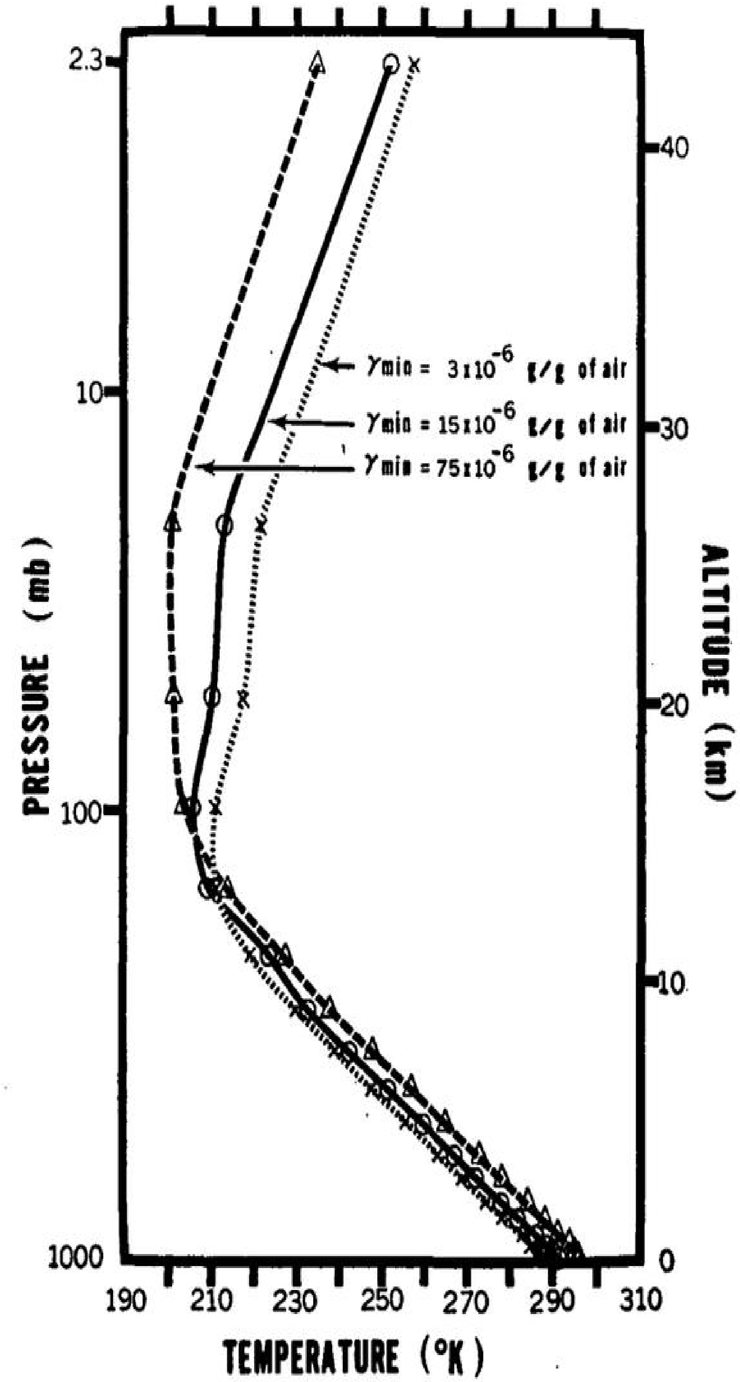

FIG. 12. Vertical distributions of radiative convective equilibrium temperature for various values of water vapor mixing ratio in the stratosphere.

Stochastic climate models

Part I. Theory

By K. HASSELMANN, *Max-Planck-Institut für Meteorologie, Hamburg, FRG*

(Manuscript received January 19; in final form April 5, 1976)

ABSTRACT

A stochastic model of climate variability is considered in which slow changes of climate are explained as the integral response to continuous random excitation by short period "weather" disturbances. The coupled ocean–atmosphere–cryosphere–land system is divided into a rapidly varying "weather" system (essentially the atmosphere) and a slowly responding "climate" system (the ocean, cryosphere, land vegetation, etc.). In the usual Statistical Dynamical Model (SDM) only the average transport effects of the rapidly varying weather components are parameterised in the climate system. The resultant prognostic equations are deterministic, and climate variability can normally arise only through variable external conditions. The essential feature of stochastic climate models is that the non-averaged "weather" components are also retained. They appear formally as random forcing terms. The climate system, acting as an integrator of this short-period excitation, exhibits the same random-walk response characteristics as large particles interacting with an ensemble of much smaller particles in the analogous Brownian motion problem. The model predicts "red" variance spectra, in qualitative agreement with observations. The evolution of the climate probability distribution is described by a Fokker-Planck equation, in which the effect of the random weather excitation is represented by diffusion terms. Without stabilising feedback, the model predicts a continuous increase in climate variability, in analogy with the continuous, unbounded dispersion of particles in Brownian motion (or in a homogeneous turbulent fluid). Stabilising feedback yields a statistically stationary climate probability distribution. Feedback also results in a finite degree of climate predictability, but for a stationary climate the predictability is limited to maximal skill parameters of order 0.5.

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Stochastic resonance in climatic change

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GIORGIO PARISI, *I.N.F.N., Laboratori Nazionali di Frascati, Frascati, Roma, Italy*,
ALFONSO SUTERA, *The Center for the Environment and Man, Hartford, Connecticut 06120, U.S.A.*
and ANGELO VULPIANI, *Istituto di Fisica "G. Marconi", Università di Roma, Italy*

(Manuscript received November 12, 1980; in final form March 13, 1981)

ABSTRACT

An amplification of random perturbations by the interaction of non-linearities internal to the climatic system with external, orbital forcing is found. This stochastic resonance is investigated in a highly simplified, zero-dimensional climate model. It is conceivable that this new type of resonance might play a role in explaining the 10^5 year peak in the power spectra of paleoclimatic records.

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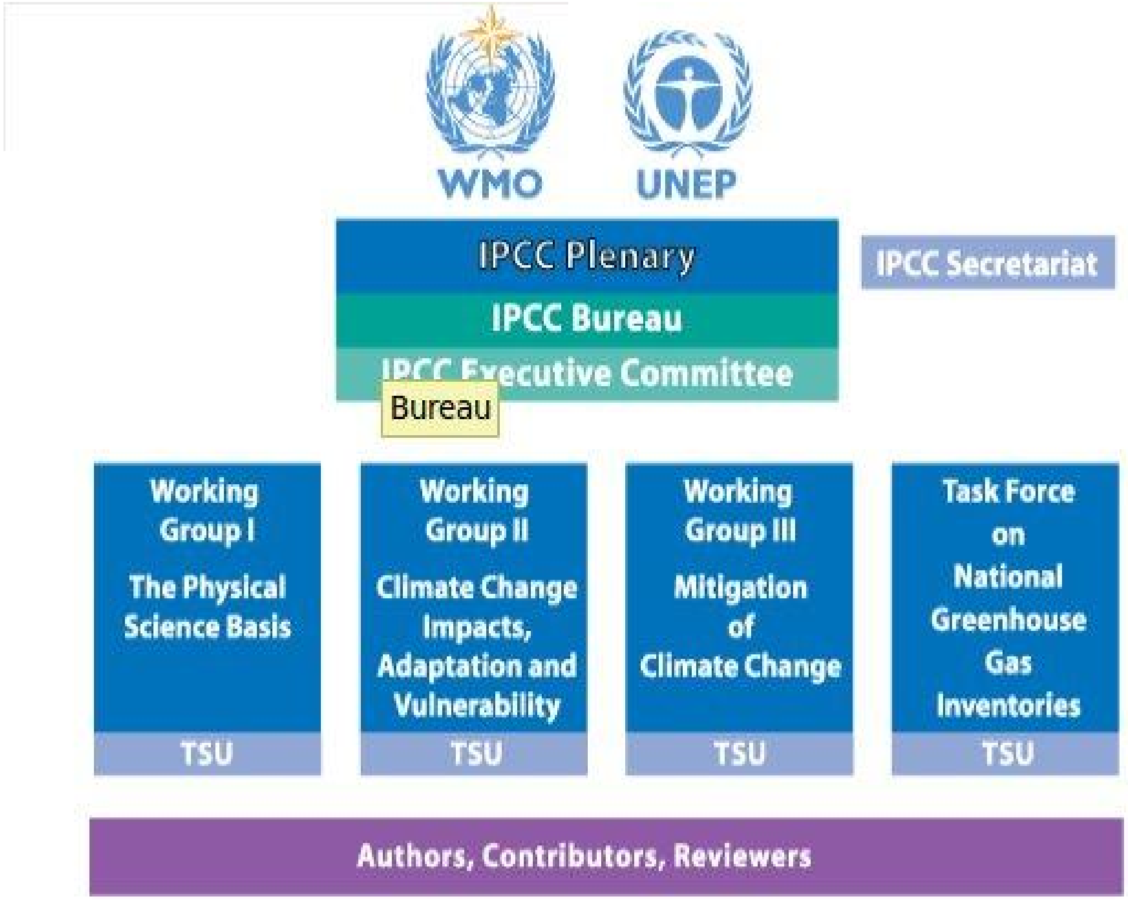
5. Conclusions

Our results point to the possibility of explaining large amplitude, long-term alternations of temperature by means of a co-operation between external periodic forcing due to orbital variations and an internal stochastic mechanism. The external periodic forcing alone is unable to reproduce the major peak in the observed quaternary climate records. The internal stochastic forcing alone does not reproduce it either. The combination of the two effects, however, produces what we may call a stochastic resonance, which amplifies the small external forcing: a small change in the external forcing induces a large change in the probability of jumping between two observable climates. This new mechanism could be useful in our understanding of long-term climatic change. At any rate, it seems to warrant further investigation.

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



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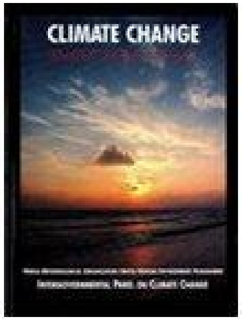

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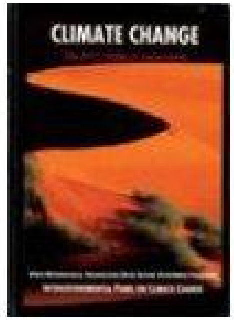

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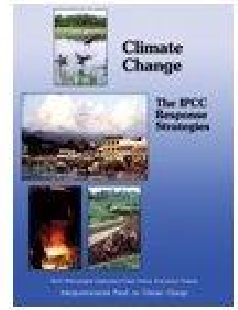

Working Group III:
The IPCC Response Strategies
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First Assessment Report
Overview Chapter (PDF)
Also in: Chinese - French - Russian - Spanish

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

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

1992 Supplementary Reports

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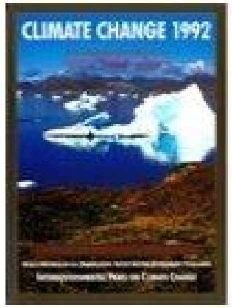

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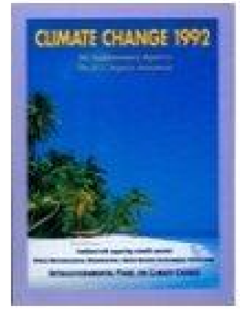

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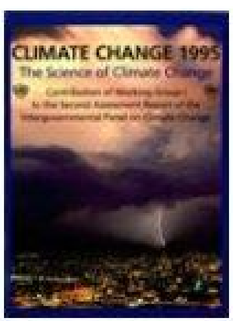

Working Group I:
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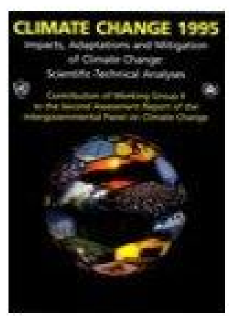

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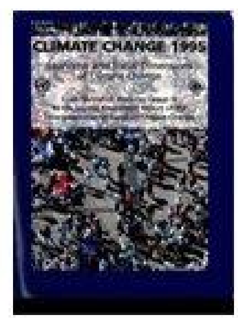

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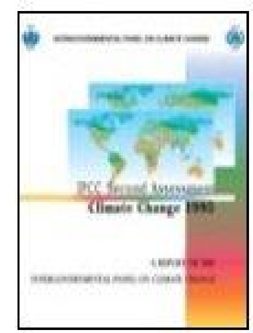

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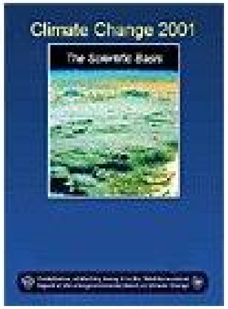
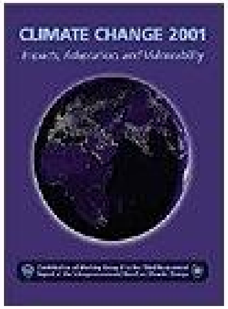
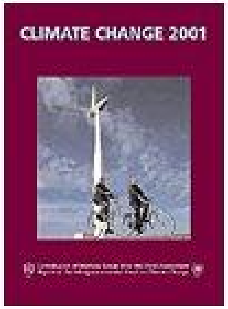


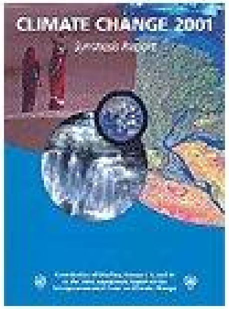
Working Group I:
The Scientific Basis



Working Group II:
Impacts, Adaptation and Vulnerability



Working Group III:
Mitigation



Synthesis Report

WG1 - Summary for Policymakers

The Third Assessment Report of Working Group I of the Intergovernmental Panel on Climate Change (IPCC) builds upon past assessments and incorporates new results from the past five years of research on climate change[1]. Many hundreds of scientists[2] from many countries participated in its preparation and review.

This Summary for Policymakers (SPM), which was approved by IPCC member governments in Shanghai in January 2001[3], describes the current state of understanding of the climate system and provides estimates of its projected future evolution and their uncertainties. Further details can be found in the underlying report, and the appended Source Information provides cross references to the report's chapters.

An increasing body of observations gives a collective picture of a warming world and other changes in the climate system.

Since the release of the Second Assessment Report (SAR[4]), additional data from new studies of current and palaeoclimates, improved analysis of data sets, more rigorous evaluation of their quality, and comparisons among data from different sources have led to greater understanding of climate change.

The global average surface temperature has increased over the 20th century by about 0.6°C.

- The global average surface temperature (the average of near surface air temperature over land, and sea surface temperature) has increased since 1861. Over the 20th century the increase has been 0.6 ± 0.2°C[5], [6] (Figure 1a). This value is about 0.15°C larger than that estimated by the SAR for the period up to 1994, owing to the relatively high temperatures of the additional years (1995 to 2000) and improved methods of processing the data. These numbers take into account various adjustments, including urban heat island effects. The record shows a great deal of variability; for example, most of the warming occurred during the 20th century, during two periods, 1910 to 1945 and 1976 to 2000.
- Globally, it is very likely[7] that the 1990s was the warmest decade and 1998 the warmest year in the instrumental record, since 1861 (see Figure 1a).
- New analyses of proxy data for the Northern Hemisphere indicate that the increase in temperature in the 20th century is likely[7] to have been the largest of any century during the past 1,000 years. It is also likely[7] that, in the Northern Hemisphere, the 1990s was the warmest decade and 1998 the warmest year (Figure 1b). Because less data are available, less is known about annual averages prior to 1,000 years before present and for conditions prevailing in most of the Southern Hemisphere prior to 1861.
- On average, between 1950 and 1993, night-time daily minimum air temperatures over land increased by about 0.2°C per decade. This is about twice the rate of increase in daytime daily maximum air temperatures (0.1°C per decade). This has lengthened the freeze-free season in many mid- and high latitude regions. The increase in sea surface temperature over this period is about half that of the mean land surface air temperature.

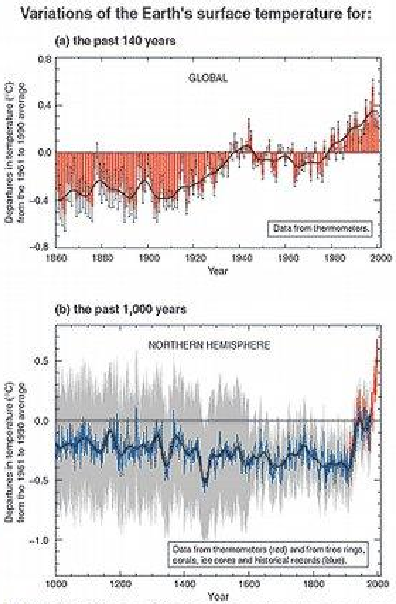
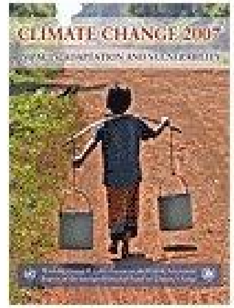


Figure 1: *Variations of the Earth's surface temperature over the last 140 years and the last millennium.*

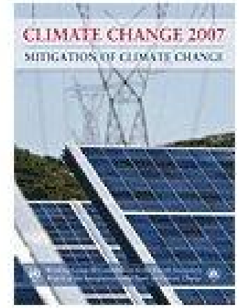
(a) The Earth's surface temperature is shown year by year (red bars) and approximately decade by decade (black line, a filtered annual curve suppressing fluctuations below near decadal

IPCC Fourth Assessment Report: Climate Change 2007 (AR4)

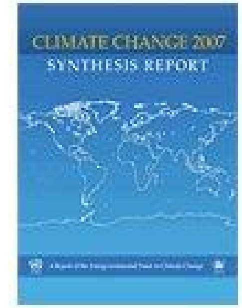
Working Group I Report
"The Physical Science Basis"



Working Group II Report
"Impacts, Adaptation and Vulnerability"



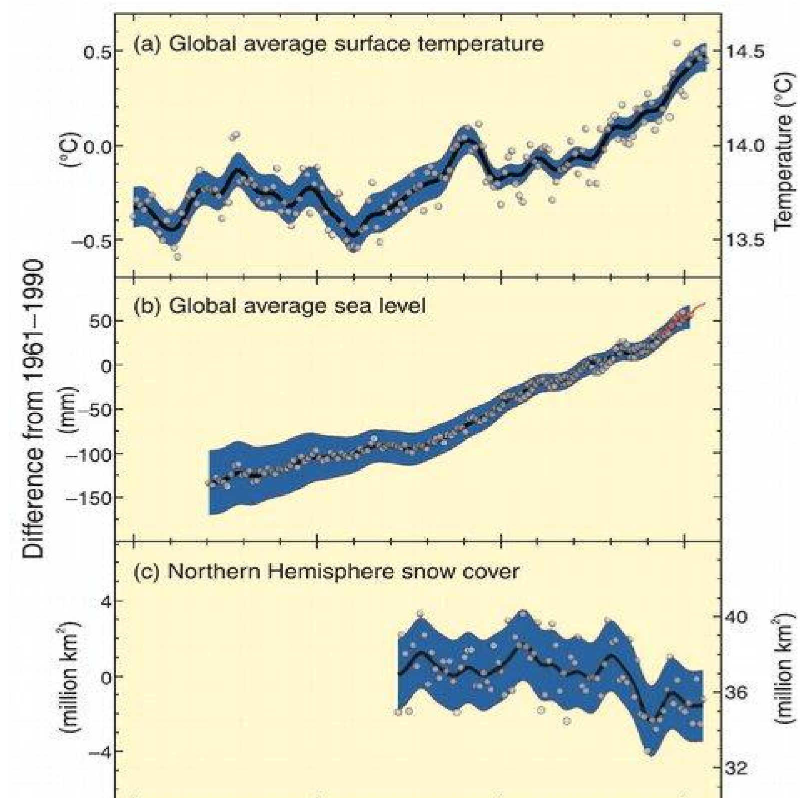
Working Group III Report
"Mitigation of Climate Change"



The AR4 Synthesis Report

1. Observed changes in climate and their effects

Warming of the climate system is unequivocal, as is now evident from observations of increases in global average air and ocean temperatures, widespread melting of snow and ice and rising global average sea level (Figure SPM.1). *{1.1}*



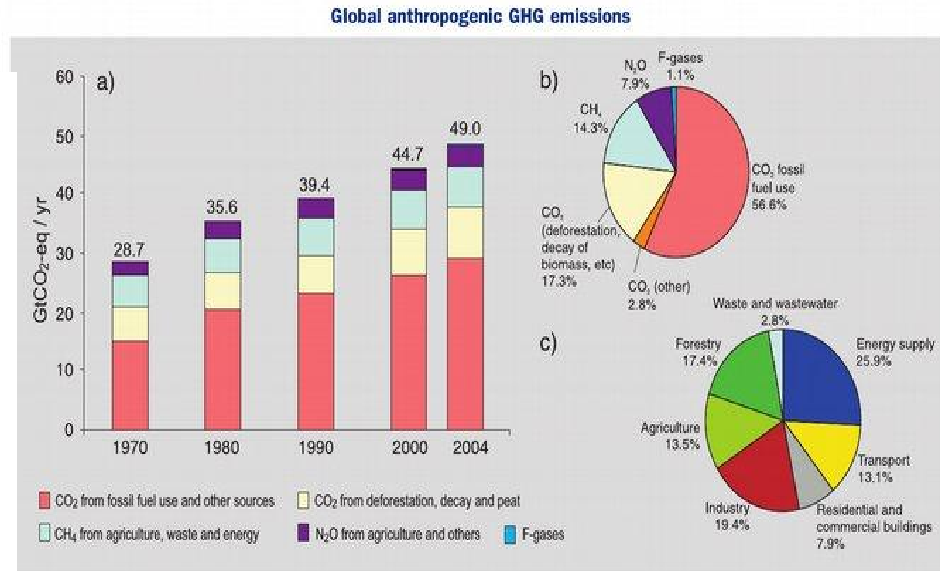
2. Causes of change

Changes in atmospheric concentrations of greenhouse gases (GHGs) and aerosols, land cover and solar radiation alter the energy balance of the climate system. *{2.2}*

Global GHG emissions due to human activities have grown since pre-industrial times, with an increase of 70% between 1970 and 2004 (Figure SPM.3).[5] *{2.1}*

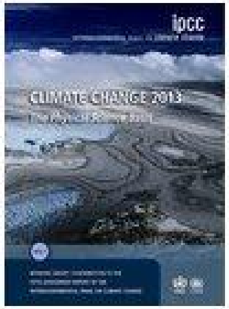
Carbon dioxide (CO_2) is the most important anthropogenic GHG. Its annual emissions grew by about 80% between 1970 and 2004. The long-term trend of declining CO_2 emissions per unit of energy supplied reversed after 2000. *{2.1}*

Global atmospheric concentrations of CO_2, methane (CH_4) and nitrous oxide (N_2O) have increased markedly as a result of human activities since 1750 and now far exceed pre-industrial values determined from ice cores spanning many thousands of years. *{2.2}*

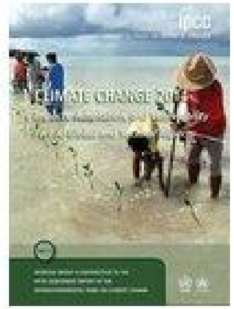


ure SPM.3. (a) Global annual emissions of anthropogenic GHGs from 1970 to 2004.[5] (b) Share of different anthropogenic GHGs in total issions in 2004 in terms of carbon dioxide equivalents (CO_2-eq). (c) Share of different sectors in total anthropogenic GHG emissions in 2004 erms of CO_2-eq. (Forestry includes deforestation.) {Figure 2.1}

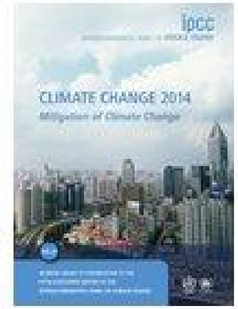
IPCC Fifth Assessment Report



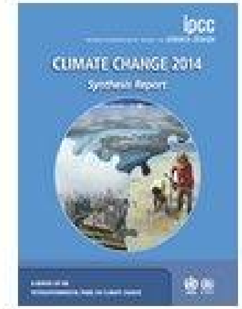
Working Group I Report
"Climate Change 2013: The Physical Science Basis"



Working Group II Report
"Climate Change 2014: Impacts, Adaptation, and



Working Group III Report
"Climate Change 2014: Mitigation of Climate Change"



"Climate Change 2014: Synthesis Report"

SPM 1. Observed Changes and their Causes

Human influence on the climate system is clear, and recent anthropogenic emissions of greenhouse gases are the highest in history. Recent climate changes have had widespread impacts on human and natural systems. *{1}*

SPM 1.1 Observed changes in the climate system

Warming of the climate system is unequivocal, and since the 1950s, many of the observed changes are unprecedented over decades to millennia. The atmosphere and ocean have warmed, the amounts of snow and ice have diminished, and sea level has risen. *{1.1}*

SIXTH ASSESSMENT REPORT

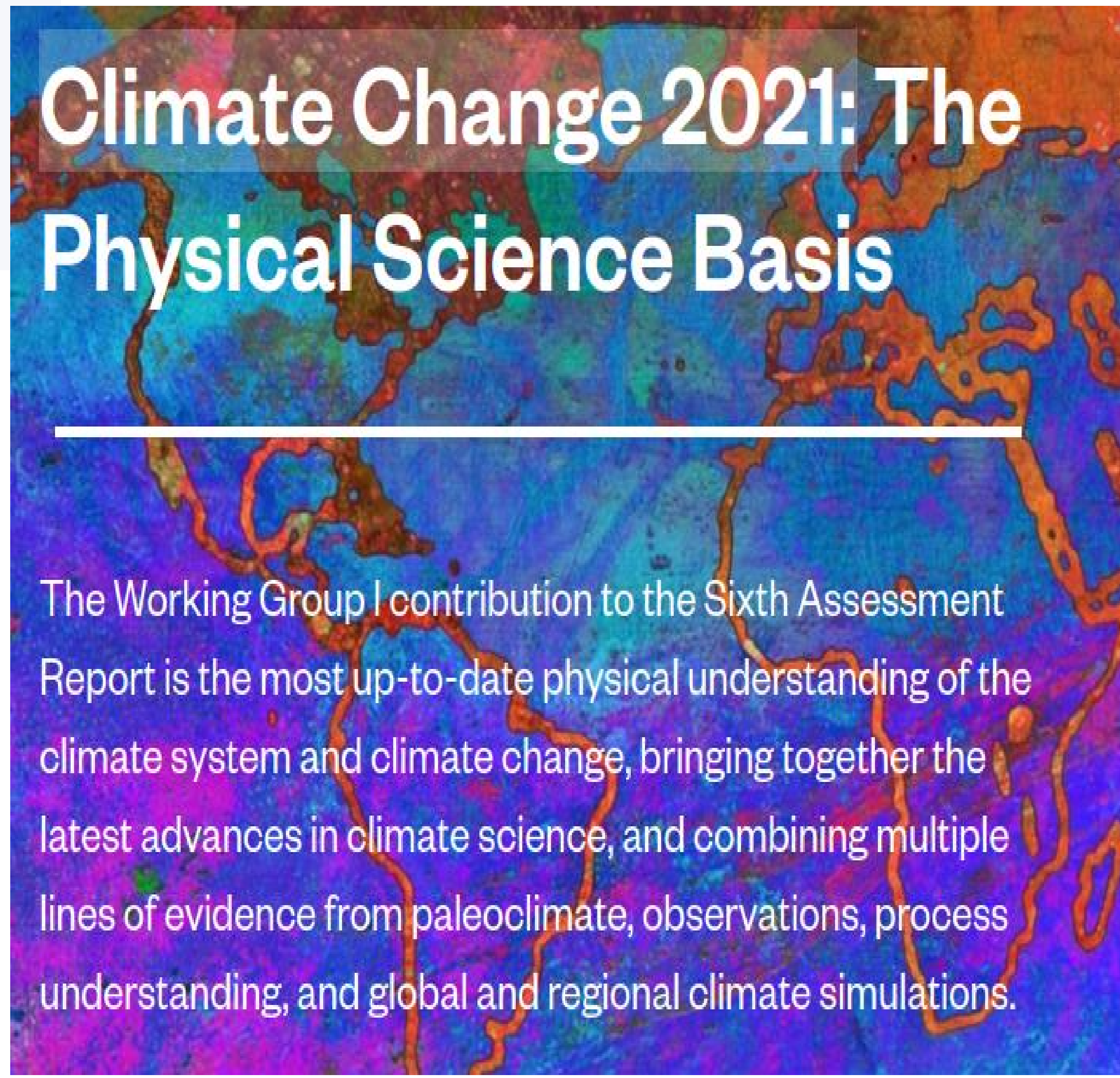
AR6 Synthesis Report: Climate Change 2022

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/



A. The Current State of the Climate

A.1 It is unequivocal that human influence has warmed the atmosphere, ocean and land. Widespread and rapid changes in the atmosphere, ocean, cryosphere and biosphere have occurred.

A.2 The scale of recent changes across the climate system as a whole and the present state of many aspects of the climate system are unprecedented over many centuries to many thousands of years.

B. Possible Climate Futures

B.1 Global surface temperature will continue to increase until at least the mid-century under all emissions scenarios considered. Global warming of 1.5°C and 2°C will be exceeded during the 21st century unless deep reductions in carbon dioxide (CO_2) and other greenhouse gas emissions occur in the coming decades.

B.2 Many changes in the climate system become larger in direct relation to increasing global warming. They include increases in the frequency and intensity of hot extremes, marine heatwaves, and heavy precipitation, agricultural and ecological droughts in some regions, and proportion of intense tropical cyclones, as well as reductions in Arctic sea ice, snow cover and permafrost.

C. Climate Information for Risk Assessment and Regional Adaptation

C.1 Natural drivers and internal variability will modulate human-caused changes, especially at regional scales and in the near term, with little effect on centennial global warming. These modulations are important to consider in planning for the full range of possible changes.

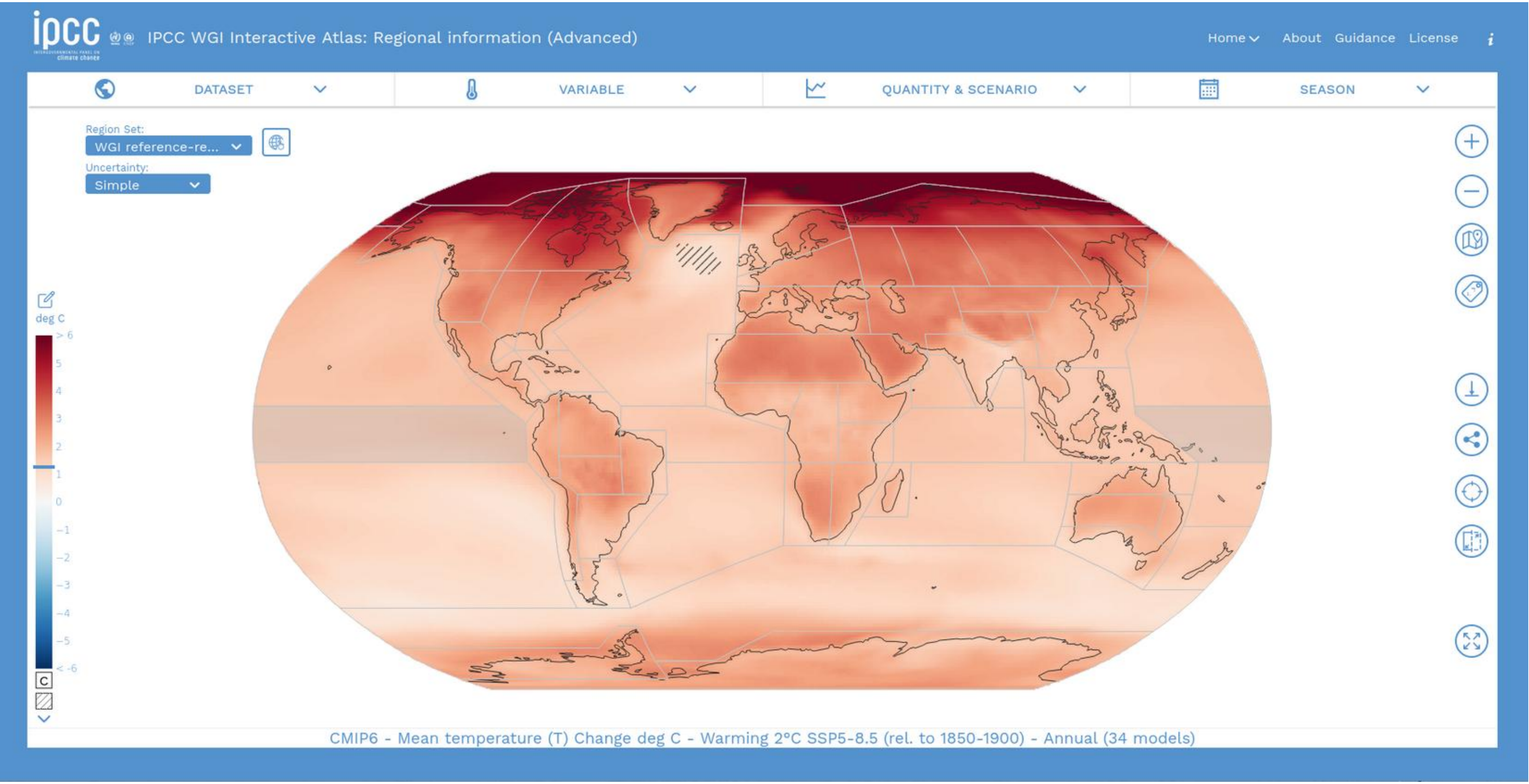
C.2 With further global warming, every region is projected to increasingly experience concurrent and multiple changes in climatic impact-drivers. Changes in several climatic impact-drivers would be more widespread at 2°C compared to 1.5°C global warming and even more widespread and/or pronounced for higher warming levels.

C.3 Low-likelihood outcomes, such as ice sheet collapse, abrupt ocean circulation changes, some compound extreme events and warming substantially larger than the assessed *very likely* range of future warming cannot be ruled out and are part of risk assessment.

D. Limiting Future Climate Change

D.1 From a physical science perspective, limiting human-induced global warming to a specific level requires limiting cumulative CO_2 emissions, reaching at least net zero CO_2 emissions, along with strong reductions in other greenhouse gas emissions. Strong, rapid and sustained reductions in CH_4 emissions would also limit the warming effect resulting from declining aerosol pollution and would improve air quality.

https://interactive-atlas.ipcc.ch

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Climate Data Online
Climate Data Online (CDO) provides free access to NCDC's archive of global historical weather and climate data in addition to station history information. These data include quality controlled daily, monthly, seasonal, and yearly measurements of temperature, precipitation, wind, and degree days as well as radar data and 30-year Climate Normals. Customers can also order most of these data as certified hard copies for legal use.
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Mapping Tool »
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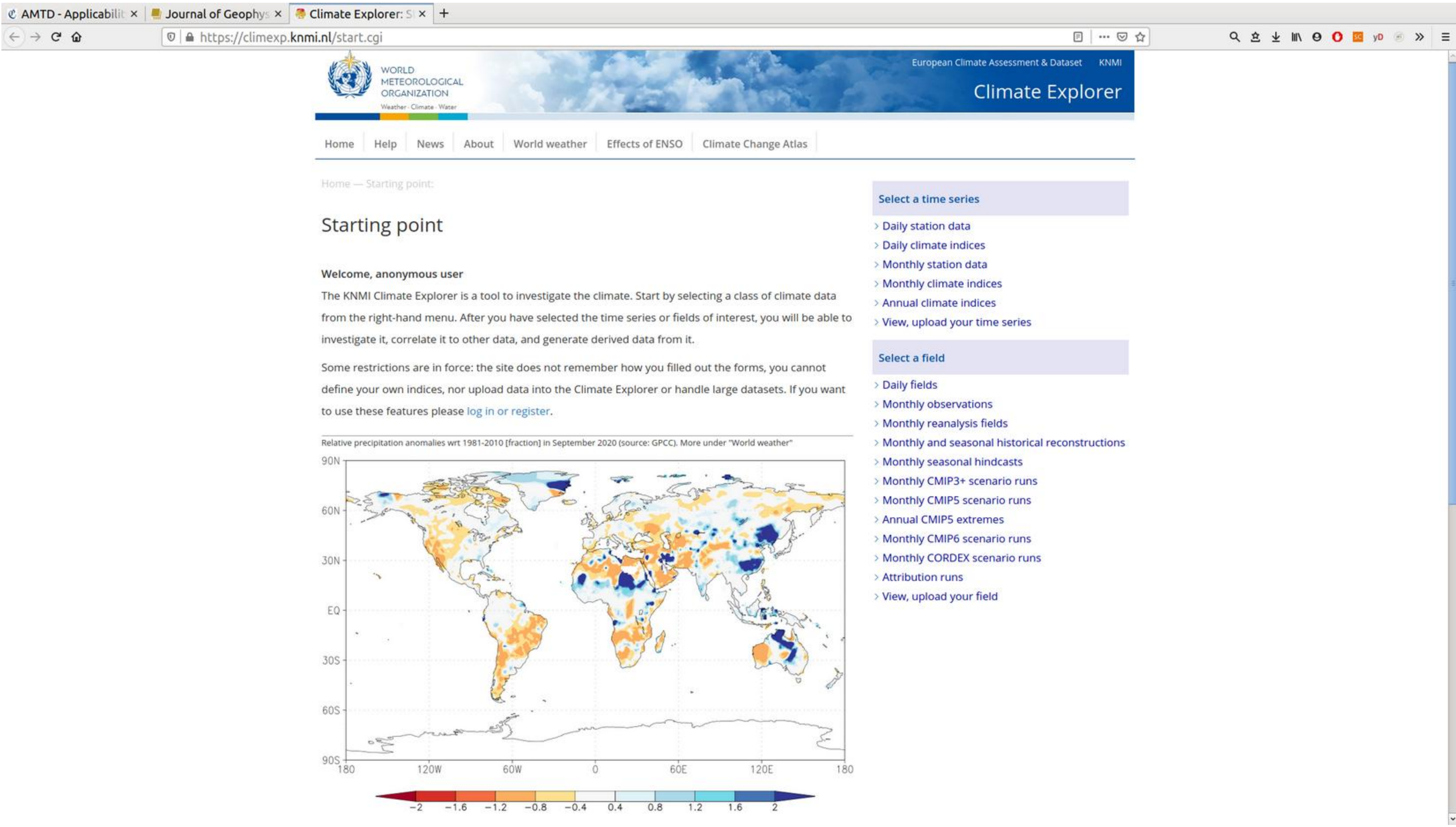
Access past weather and climate data using a collection of specialized tools.
Data Tools »
https://www.ncdc.noaa.gov/cdo-web/datatools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Climate Explorer: S
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Weather · Climate · Water
European Climate Assessment & Dataset
KNMI
Climate Explorer
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Help
News
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World weather
Effects of ENSO
Climate Change Atlas
Home — Starting point:
Starting point
Welcome, anonymous user
The KNMI Climate Explorer is a tool to investigate the climate. Start by selecting a class of climate data from the right-hand menu. After you have selected the time series or fields of interest, you will be able to investigate it, correlate it to other data, and generate derived data from it.
Some restrictions are in force: the site does not remember how you filled out the forms, you cannot define your own indices, nor upload data into the Climate Explorer or handle large datasets. If you want to use these features please log in or register.
Relative precipitation anomalies wrt 1981-2010 [fraction] in September 2020 (source: GPCC). More under "World weather"
90N
60N
30N
EQ
30S
60S
90S
180
120W
60W
0
60E
120E
180
−2
−1.6
−1.2
−0.8
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0.4
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1.6
2
Select a time series
Daily station data
Daily climate indices
Monthly station data
Monthly climate indices
Annual climate indices
View, upload your time series
Select a field
Daily fields
Monthly observations
Monthly reanalysis fields
Monthly and seasonal historical reconstructions
Monthly seasonal hindcasts
Monthly CMIP3+ scenario runs
Monthly CMIP5 scenario runs
Annual CMIP5 extremes
Monthly CMIP6 scenario runs
Monthly CORDEX scenario runs
Attribution runs
View, upload your field

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https://www.ncdc.noaa.gov/data-access/paleoclimatology-data 133%

NOAA NATIONAL CENTERS FOR ENVIRONMENTAL INFORMATION
NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION

Formerly the National Climatic Data Center (NCDC)... more about NCEI »

Home | Climate Information | Data Access | Customer Support | Contact | About | Search

Home > Data Access > Paleoclimatology Data

- Quick Links
- Land-Based Station
- Satellite
- Radar
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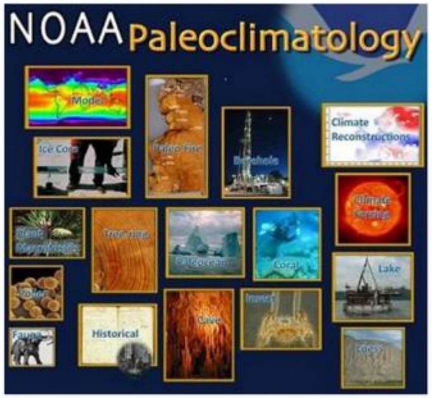
  - About the Program
- Severe Weather
- Blended & Global

Paleoclimatology Data

Paleoclimatology data are derived from natural sources such as tree rings, ice cores, corals, and ocean and lake sediments. These proxy climate data extend the archive of weather and climate information hundreds to millions of years. The data include geophysical or biological measurement time series and some reconstructed climate variables such as temperature and precipitation.

NCEI provides the paleoclimatology data and information scientists need to understand natural climate variability and future climate change. We also operate the World Data Service for Paleoclimatology, which archives and distributes data contributed by scientists around the world.



Paleoclimatology data are derived from a wide variety of natural sources such as tree rings, ice cores, corals, and ocean and lake sediments.

- Paleoclimatology Datasets
  Access paleoclimatology datasets by proxy data type
- Paleoclimatology Data Search
  Search all paleoclimatology datasets and analyses available from NCEI and the World Data Service for Paleoclimatology
- Paleoclimatology Projects
  Access paleoclimatology research datasets and research projects
- Paleoclimatology Perspectives
  View in-depth presentations on climate change topics
- Contribute Paleoclimatology Data
  Preserve your paleoclimatology data and make it available to others without restriction

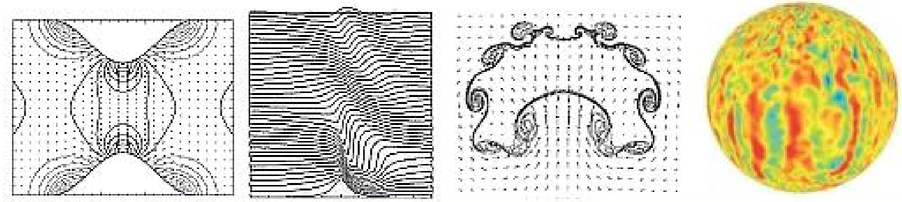
CAM-EULAG: A non-hydrostatic atmospheric climate model with grid stretching

Babatunde J. Abiodun, William J. Gutowski, Abayomi A. Abatan, Joseph M. Prusa
Acta Geophysica
01/2011; 59(6):1158-1167.
DOI:10.2478/s11600-011-0032-2

ABSTRACT This study evaluates the capability of a non-hydrostatic global climate model with grid stretching (CEU) that uses NCAR Community Atmospheric Model (CAM) physics and EULAG dynamics.

Eulag

Research Model for Geophysical Flows



Upcoming Events

Past Events

What is New in Eulag?

Public Notice

FRONTIERS IN COMPUTATIONAL PHYSICS

MODELING THE EARTH SYSTEM

16-20 Dec. 2012

Boulder, CO, USA

EULAG is a numerical solver for all-scale geophysical flows. The underlying anelastic equations are either solved in an EULerian (flux form), or a LAGrangian (advective form) framework.

EULAG model is an ideal tool to perform numerical experiments in a virtual laboratory with time-dependent adaptive meshes and within complex, and even time-dependent model geometries. These abilities are due to the unique model design that combines the nonoscillatory forward-in-time (NFT) numerical algorithms and a robust elliptic solver with generalized coordinates. The code is written as a research tool with numerous options controlling the numerical accuracy and to allow for a wide range of numerical sensitivity tests. These capabilities give the researcher confidence in the numerical solutions of his/her problem. The formulation of the model equations allow for various derivatives of the code including codes for stellar atmospheres, ocean currents, sand dune propagation or biomechanical flows. EULAG is a fully parallelized code and is easily portable between different platforms.

All the model developments and details of the numerical algorithms are documented in a number of peer reviewed papers by Piotr Smolarkiewicz and his colleagues. The EULAG modeling system is developed and supported by the Cloud Systems Group in the Mesoscale and Microscale Meteorology Division, NCAR.

Example: QBO analogue simulation

Current announcements:

4th International EULAG Workshop on Forward-in-time Differencing for Earth-System Models, 20-24 October 2014 in Mainz, Germany
(see also first announcement in PDF)

Past events:

3rd International EULAG Workshop held 25th -28th June 2012 in Loughborough UK.

2nd EULAG Model Users' Workshop took place in Sopot, Poland, 13-16 September 2010.

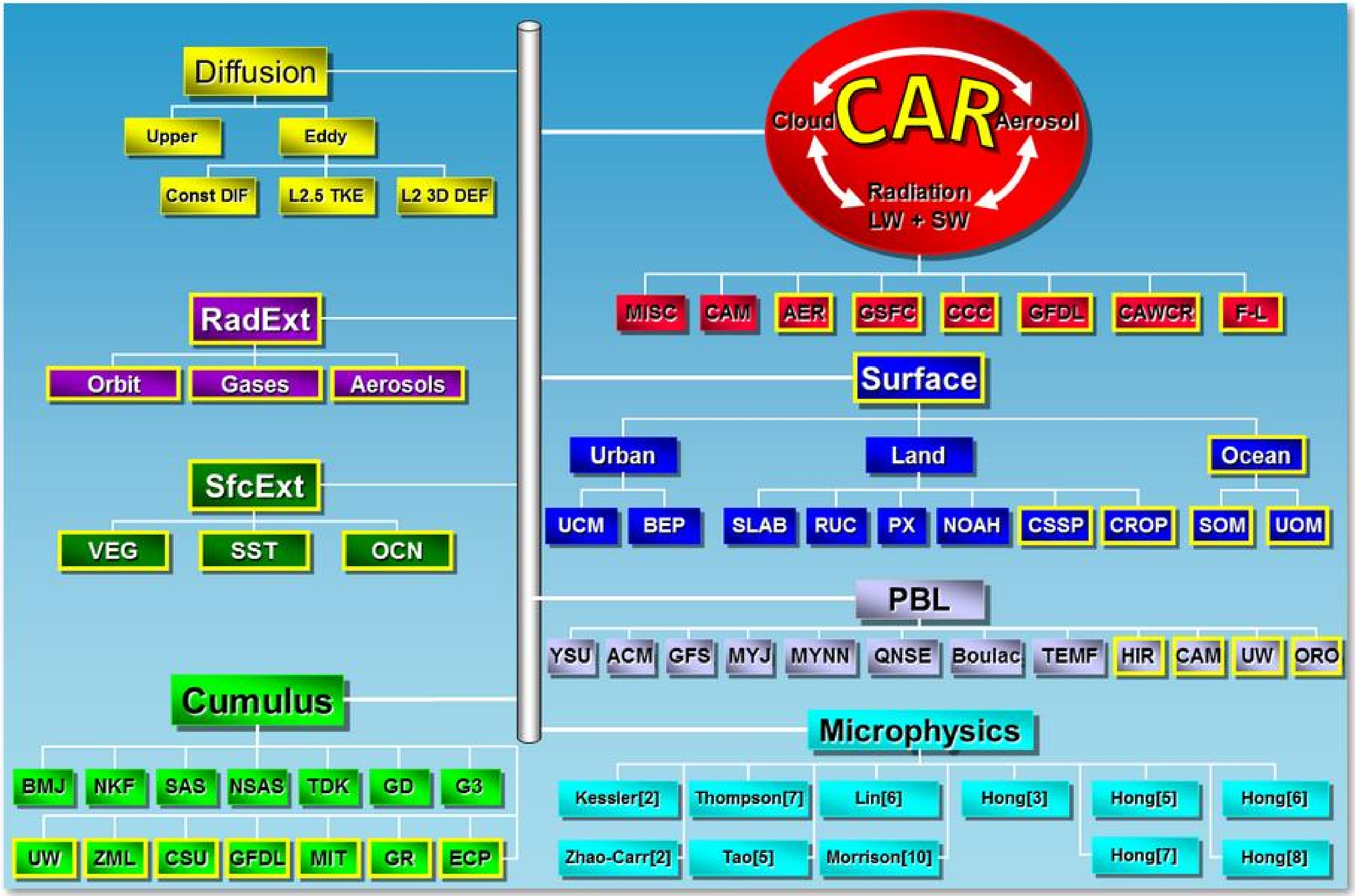
1st EULAG Model Users' Workshop was held in Bad T�lz, Germany 6-10 October 2008. The workshop offered tutorials covering essential physical, mathematical and numerical aspects of EULAG and provided a forum to exchange information and ideas among EULAG users.

Special issues:

The special issue of the **Acta Geophysica**: **Special volume 59 (6), 2011: Modeling Atmospheric Circulations with Sound-Proof Equations** The papers collected in the present volume of Acta Geophysica address the capability of sound-proof equations to model all-scale atmospheric circulations. Technical topics covered in this special issue range from theoretical numerical analysis, model design, and massively-parallel programming to simulation of cloud processes, regional weather and global atmospheric circulations.

CWRF

Climate - Weather Research and Forecasting Model



- CWRF is a Climate extension of the Weather Research and Forecasting model (WRF):
  - Inherits all WRF functionalities for NWP while enhancing the capability to predict climate, thus has unified applications for both weather forecast and climate prediction.
- CWRF incorporates a grand ensemble of alternative physics schemes:
  - Contains more than 10^{24} of alternative physics configurations representing interactions between surface

News:

- CWRF test data available for download
- CWRF website goes live
- CWRF V3.1.1 ready to release

Links:

- CAR: Cloud-Aerosol-Radiation Ensemble Modeling System
- WRF: The Weather Research and Forecasting Model
- ESSIC/UMD

NCAR

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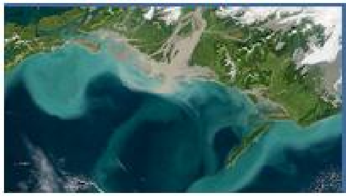
19TH ANNUAL CESM WORKSHOP

16 - 19 June 2014

CESM EXPERIMENTS

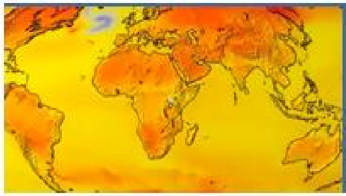


CESM Experiments

CMIP5 Output

IPCC Experiments

CESM RELEASES



CESM Supported Releases

CESM Scientifically Validated Configurations

CESM Legacy Models

ANNOUNCEMENTS & EVENTS

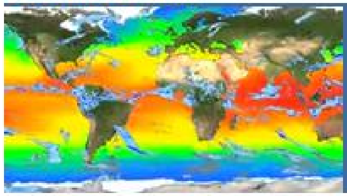
19th Annual CESM Workshop, 16-19 June 2014, Breckenridge, CO

CESM Tutorial, 11-15 August 2014, Boulder, CO

CESM GOVERNANCE

CESM PROJECTS

CESM SUPPORT



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Software update

ANNOUNCEMENTS:
EdGCM 4.0 beta is now available for Mac OS X Lion (10.7) and Mountain Lion (10.8) read more…
EdGCM 3.2 users: Windows 7 and Mac OS X 10.6 (Snow Leopard) updates are still available read more…

EdGCM provides a research-grade Global Climate Model (GCM) with a user-friendly interface that can be run on a desktop computer. For the first time, students can explore the subject of climate change in the same way that actual research scientists do. In the process of using EdGCM, students will become knowledgeable about a topic that will surely affect their lives, and we will better prepare the next generation of scientists who will grapple with a myriad of complex climate issues.

Our goal is to improve the quality of teaching and learning of climate-change science through broader access to GCMs, and to provide appropriate technology and materials to help educators use these models effectively. With research-quality resources in place, linking classrooms to actual research projects is not only possible, but can also be beneficial to the education and research communities alike.

Read more…

CMIP Phase 6 (CMIP6)

Overview CMIP6 Experimental Design and Organization

The overview paper on the CMIP6 experimental design and organization has now been published in GMD (Eyring et al., 2016). This CMIP6 overview paper presents the background and rationale for the new structure of CMIP, provides a detailed description of the CMIP Diagnostic, Evaluation and Characterization of Klima (DECK) experiments and CMIP6 historical simulations, and includes a brief introduction to the 23 CMIP6-Endorsed MIPs.

A brief summary can be found in the following overview presentation (CMIP6FinalDesign_GMD_180329.pdf) and below. After a long and wide community consultation, a new and more federated structure has been put in place. It consists of three major elements:

1. a handful of common experiments, the DECK (Diagnostic, Evaluation and Characterization of Klima) and CMIP historical simulations (1850 – near-present) that will maintain continuity and help document basic characteristics of models across different phases of CMIP,
2. common standards, coordination, infrastructure and documentation that will facilitate the distribution of model outputs and the characterization of the model ensemble, and
3. an ensemble of CMIP-Endorsed Model Intercomparison Projects (MIPs) that will be specific to a particular phase of CMIP (now CMIP6) and that will build on the DECK and CMIP historical simulations to address a large range of specific questions and fill the scientific gaps of the previous CMIP phases.

WGCM

- Overview
- Members
- Meetings
- Publications
- CMIP
  - A Short Introduction (Video)
  - CMIP Panel
  - CMIP3
  - CMIP5
  - CMIP6
- Catalogue of MIPs
  - CMIP6-Endorsed MIPs
  - Other active MIPs
  - Former MIPs
- Sessions

Modelling Overview

CMIP6 - Coupled Model Intercomparison Project Phase 6

Overview:

The WCRP Working Group on Coupled Modelling (WGCM) oversees the Coupled Model Intercomparison Project, which is now in its 6th phase. Background information about CMIP and its phases can be found on WGCM website as well as on the PCMDI-hosted pages. An introductory overview of CMIP6 is also provided by the WGCM.

Practical information for those interested in participating in CMIP6 is provided in three guides, tailored to different groups:

1. Modelers carrying out CMIP6 simulations,
2. Data managers responsible for data node operations, and
3. Data users analyzing and making use of CMIP6 model output

Model output Access:

- First see the Data Users Guide
- **Summary table** of currently available data
- The complete archive of CMIP6 output is accessible from any one of the following portals:
  - USA, PCMDI/LLNL (California) - https://esgf-node.llnl.gov/projects/cmip6/
  - France, IPSL - https://esgf-node.ipsl.upmc.fr/projects/cmip6-ipsl/
  - Germany, DKRZ - https://esgf-data.dkrz.de/projects/cmip6-dkrz/
  - UK, CEDA - https://esgf-index1.ceda.ac.uk/projects/cmip6-ceda/

CMIP6 Endorsed MIPs:

- WCRP Endorsed (Model Intercomparison Project) MIPs overview page
- CMIP6 Ocean Model Intercomparison Project (OMIP) overview page

Additional information for CMIP6:

- CMIP6 license and terms of use

CMIP6 Modeling Groups (click on flags to reveal identity)

Almost everything important is just a mouse click away, open, ready for criticism!