Co wnieśli do nauki tegoroczni nobliści z fizyki?

Szymon Malinowski

Wydział Fizyki Uniwersytetu Warszawskiego

UNIWERSYTET
WARSZAWSKI

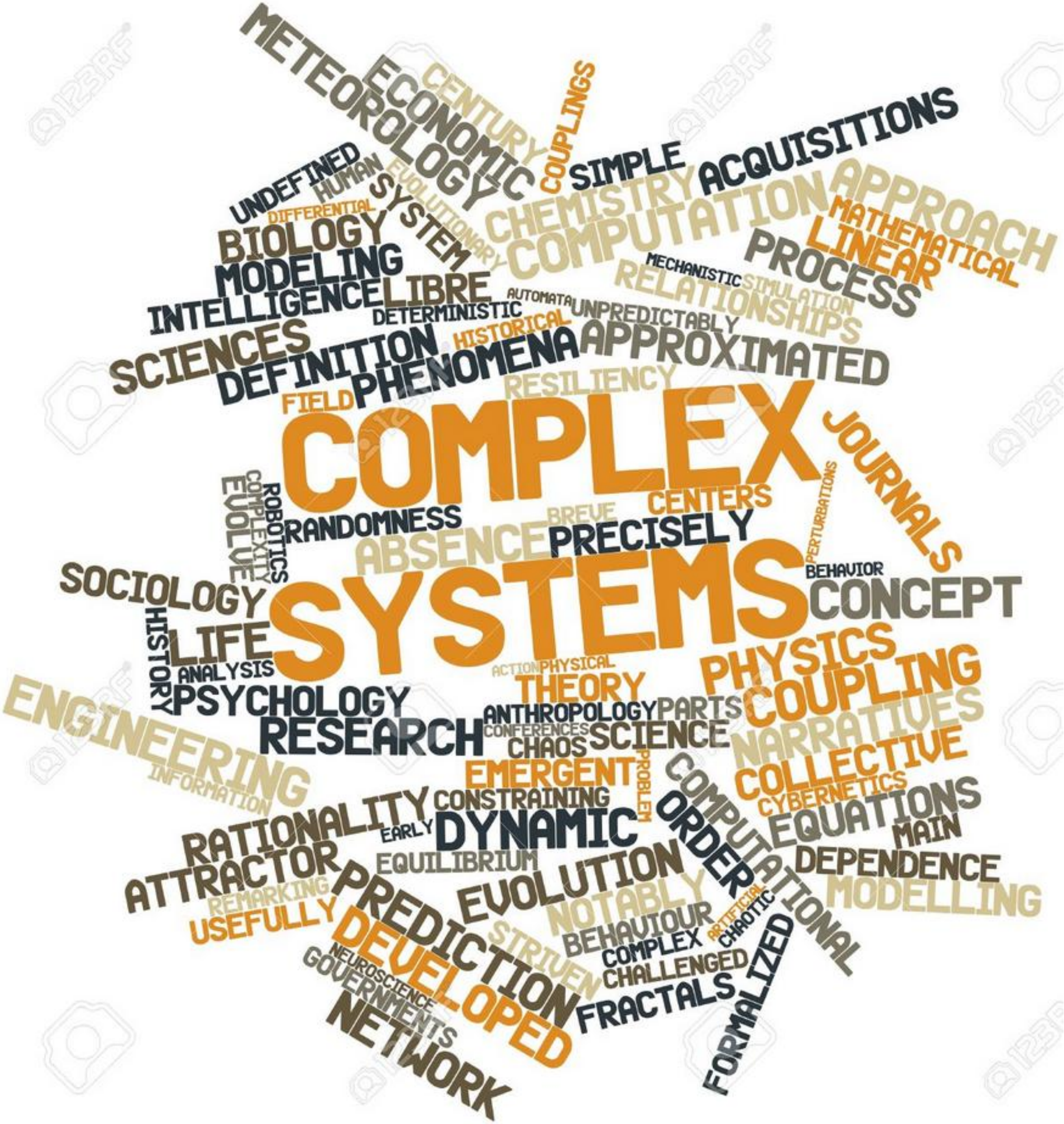
Nagrodę przyznano
"za przełomowy wkład w nasze zrozumienie systemów złożonych"

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”.



COMPLEX
SYSTEMS
METEOROLOGY
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CENTURY
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SIMPLE
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BIOLOGY
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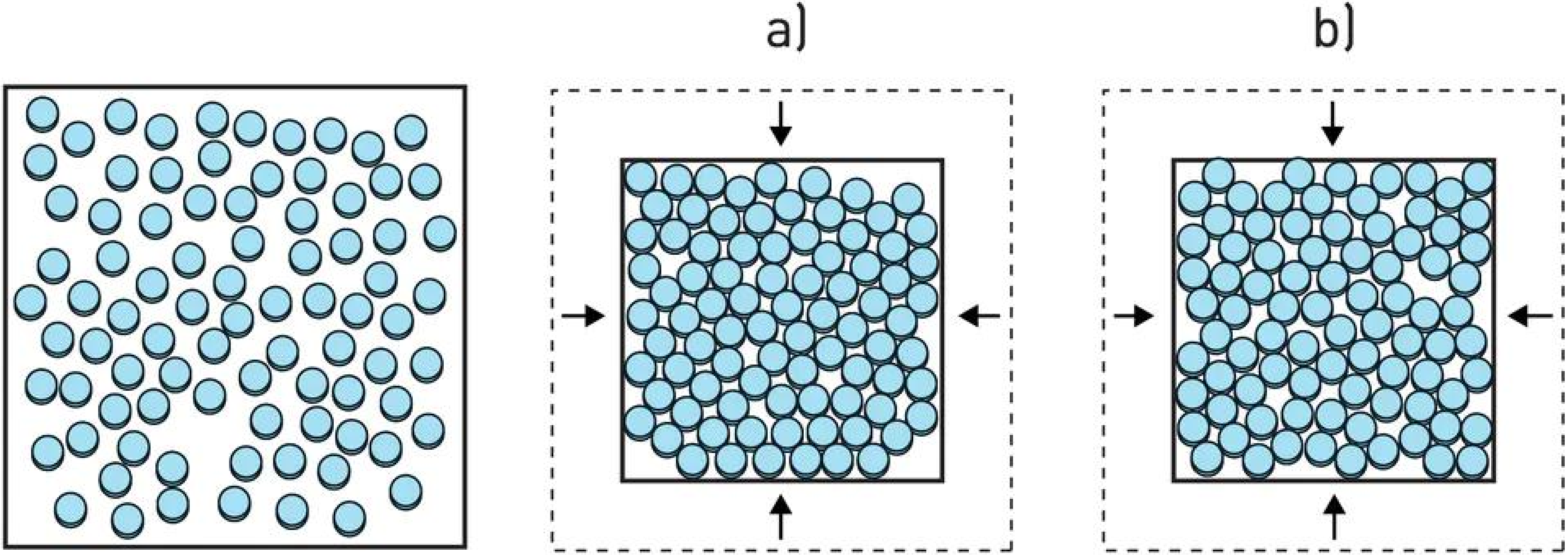
CHALLENGED
FORMALIZED
FRACTALS
NETWORK

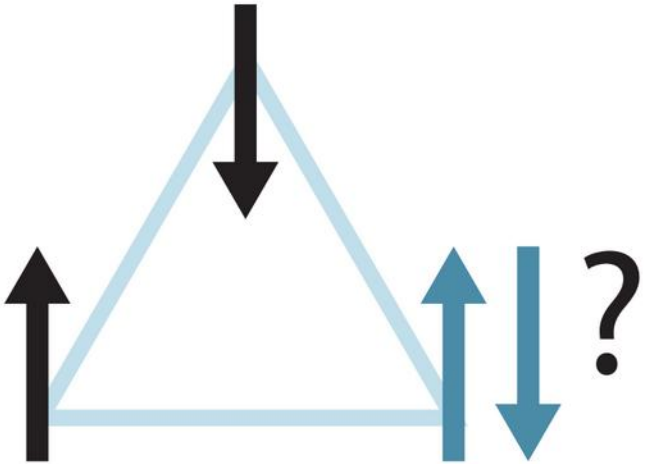
Giorgio Parisi, urodzony 1948,
doktorat 1970,
Università degli Studi di Roma "La Sapienza"

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

Mathematics for complex disordered systems

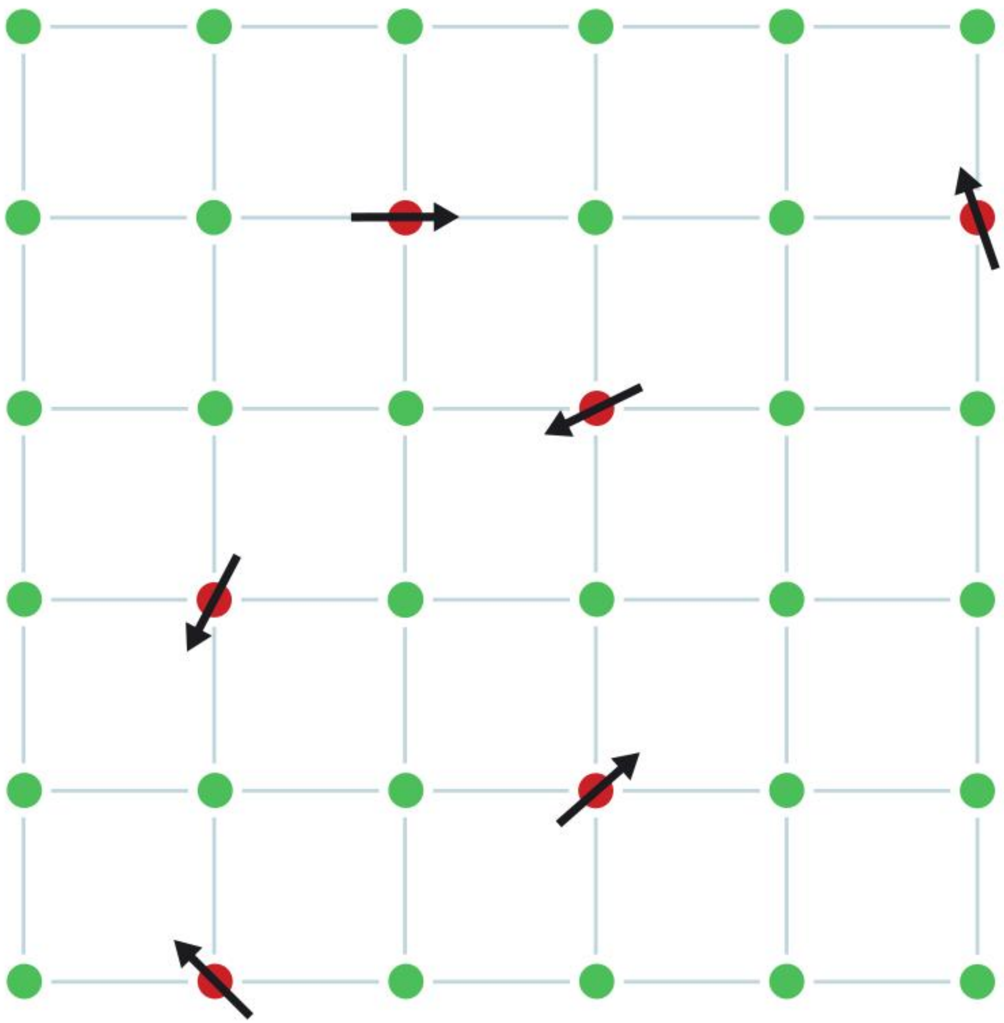
Every time many identical discs are squeezed together, a new irregular pattern is formed despite them being squeezed in exactly the same way. What governs the result? Giorgio Parisi discovered a hidden structure in such complex disordered systems, which these discs represent, and found a way of describing them mathematically.





Frustration

When one spin points upward and the other downward, the third one cannot satisfy them both at the same time, because neighbouring spins want to point in different directions. How do the spins find an optimal orientation? Giorgio Parisi is a master at answering these questions for many different materials and phenomena.



Spin glass

A spin glass is a metal alloy where iron atoms, for example, are randomly mixed into a grid of copper atoms. Each iron atom behaves like a small magnet, or spin, which is affected by the other magnets around it. However, in a spin glass they are frustrated and have difficulty choosing which direction to point. Using his studies of spin glass, Parisi developed a theory of disordered and random phenomena that covers many other complex systems.

🔴 Iron

🟢 Copper

On the multifractal nature of fully developed turbulence and chaotic systems

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Angelo Vulpiani‡

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‡ Università di Roma 'La Sapienza', Dipartimento di Fisica, and GNSM-CNR unità di Roma, P.le Aldo Moro 2, 00100, Roma, Italy
§ Università di Roma II, 'Tor Vergata', Dipartimento di Fisica, 00173, Roma and Laboratori Nazionali INFN, Frascati, Italy

Received 1 June 1984

Abstract. It is generally argued that the energy dissipation of three-dimensional turbulent flow is concentrated on a set with non-integer Hausdorff dimension. Recently, in order to explain experimental data, it has been proposed that this set does not possess a global dilatation invariance: it can be considered to be a multifractal set. In this paper we review the concept of multifractal sets in both turbulent flows and dynamical systems using a generalisation of the β-model.

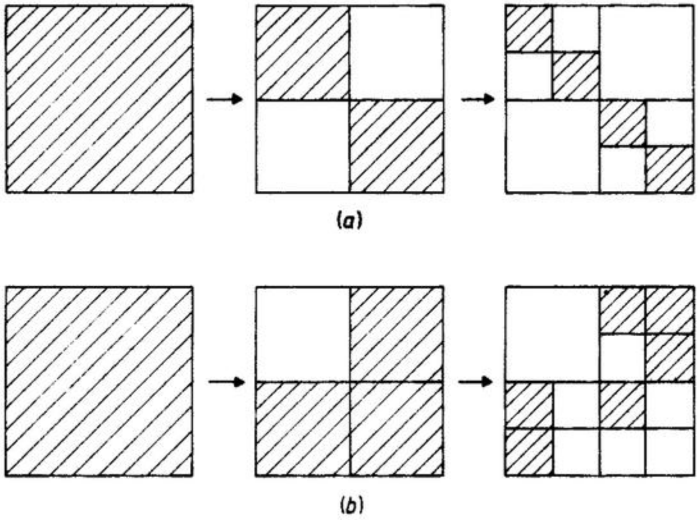

Figure 2. (a) Schematic view of the β-model and (b) compared with the random β-model. The shaded areas are the zones active during the fragmentation process.

Tellus (1982) *34*, 10–16

Stochastic resonance in climatic change

By ROBERTO BENZI, *Istituto di Fisica dell'Atmosfera, C.N.R., Piazza Luigi Sturzo 31, 00144, Roma, Italy,*
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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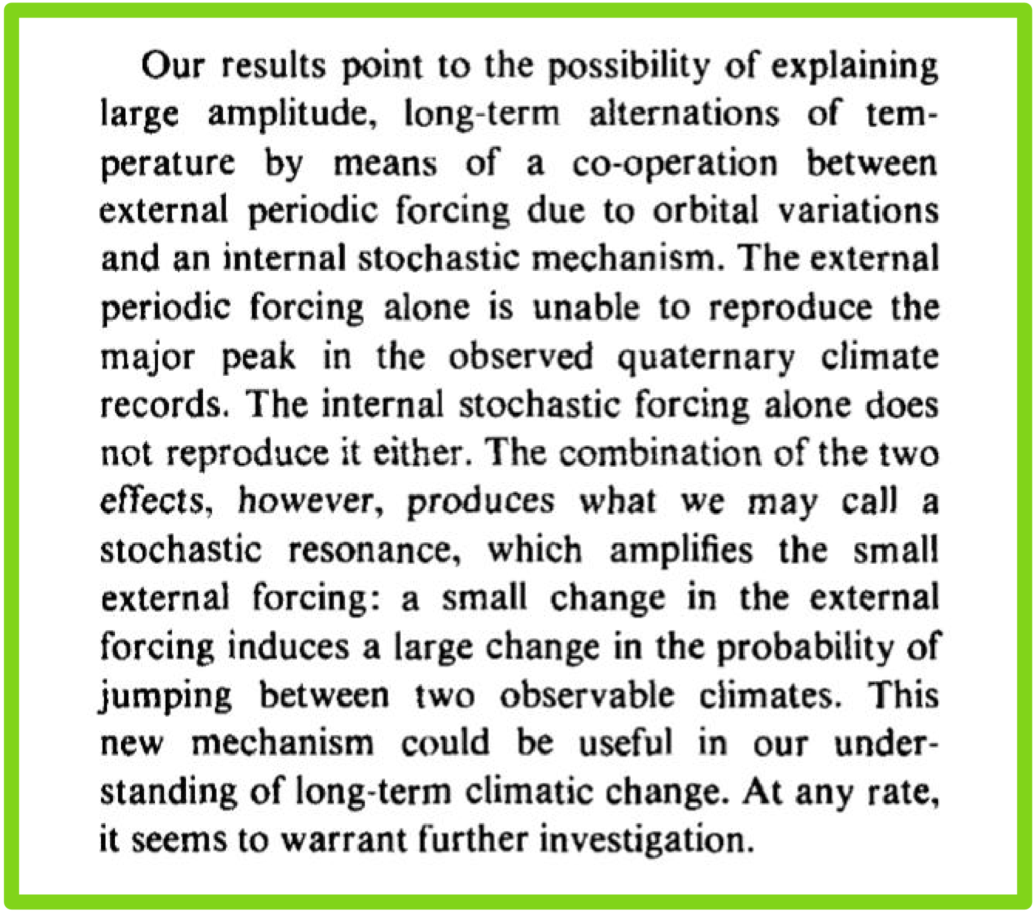
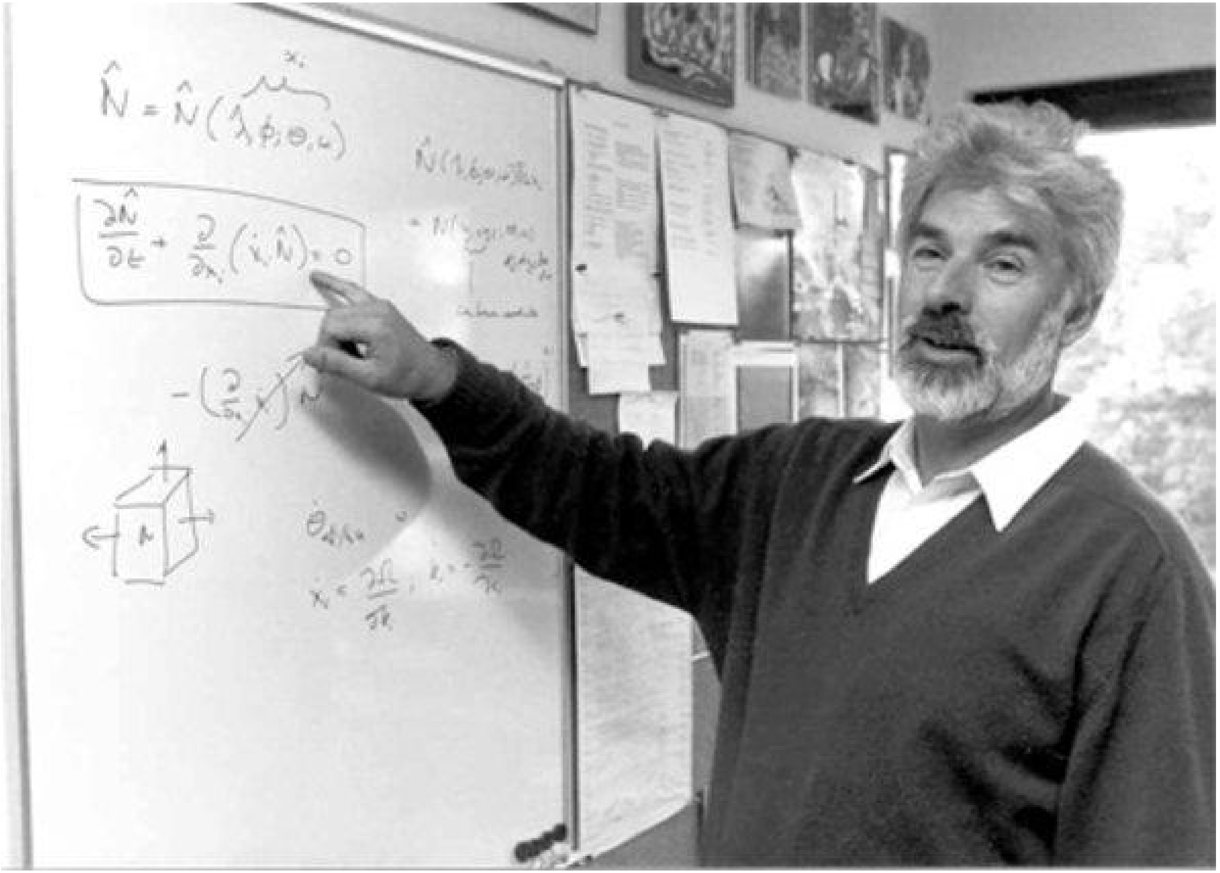
5. Conclusions

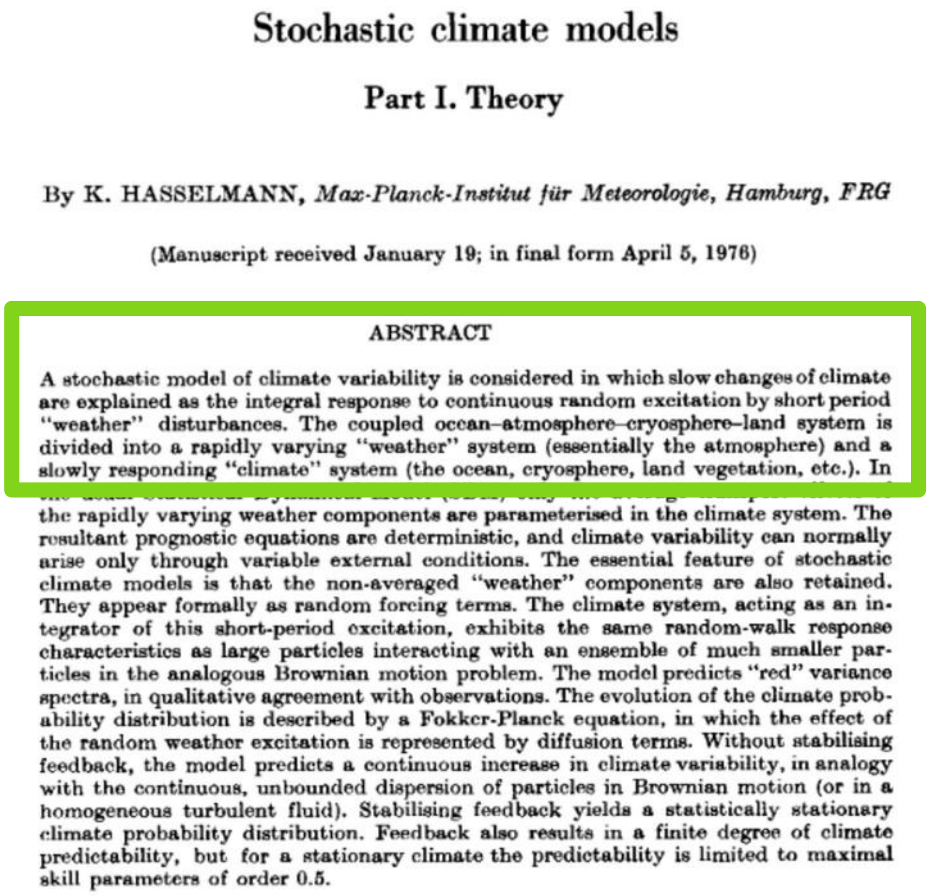


Our results point to the possibility of explaining large amplitude, long-term alternations of temperature by means of a co-operation between external periodic forcing due to orbital variations and an internal stochastic mechanism. The external periodic forcing alone is unable to reproduce the major peak 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.



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

Klaus Hasselmann, urodzony 1931,
doktorat 1957, Universität Göttingen



Stochastic climate models

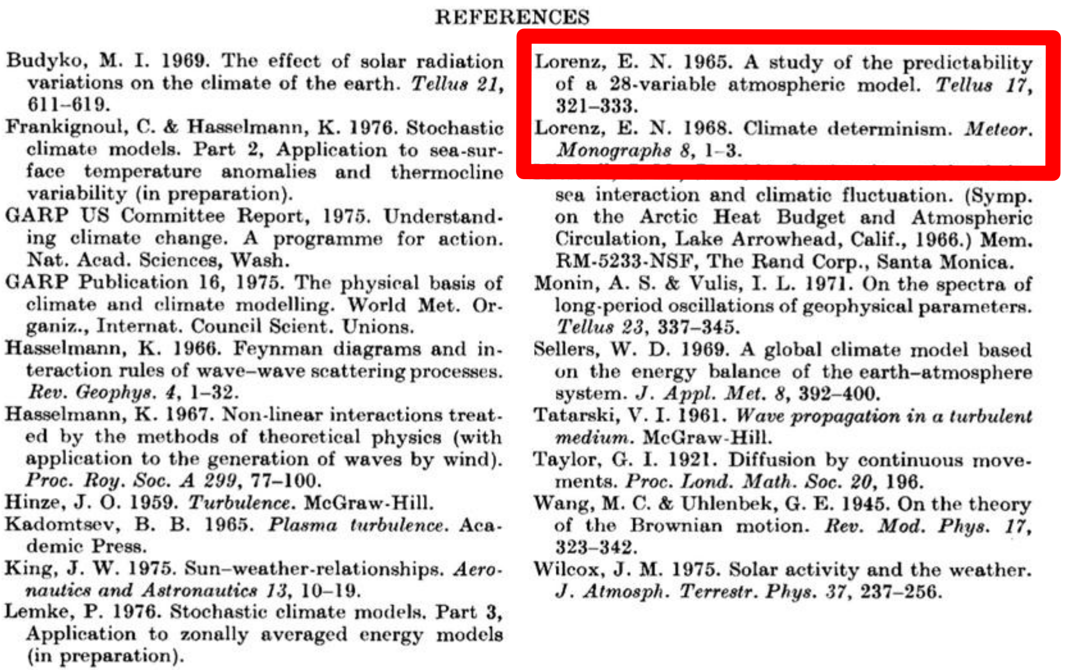
Part I. Theory

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 [illegible] 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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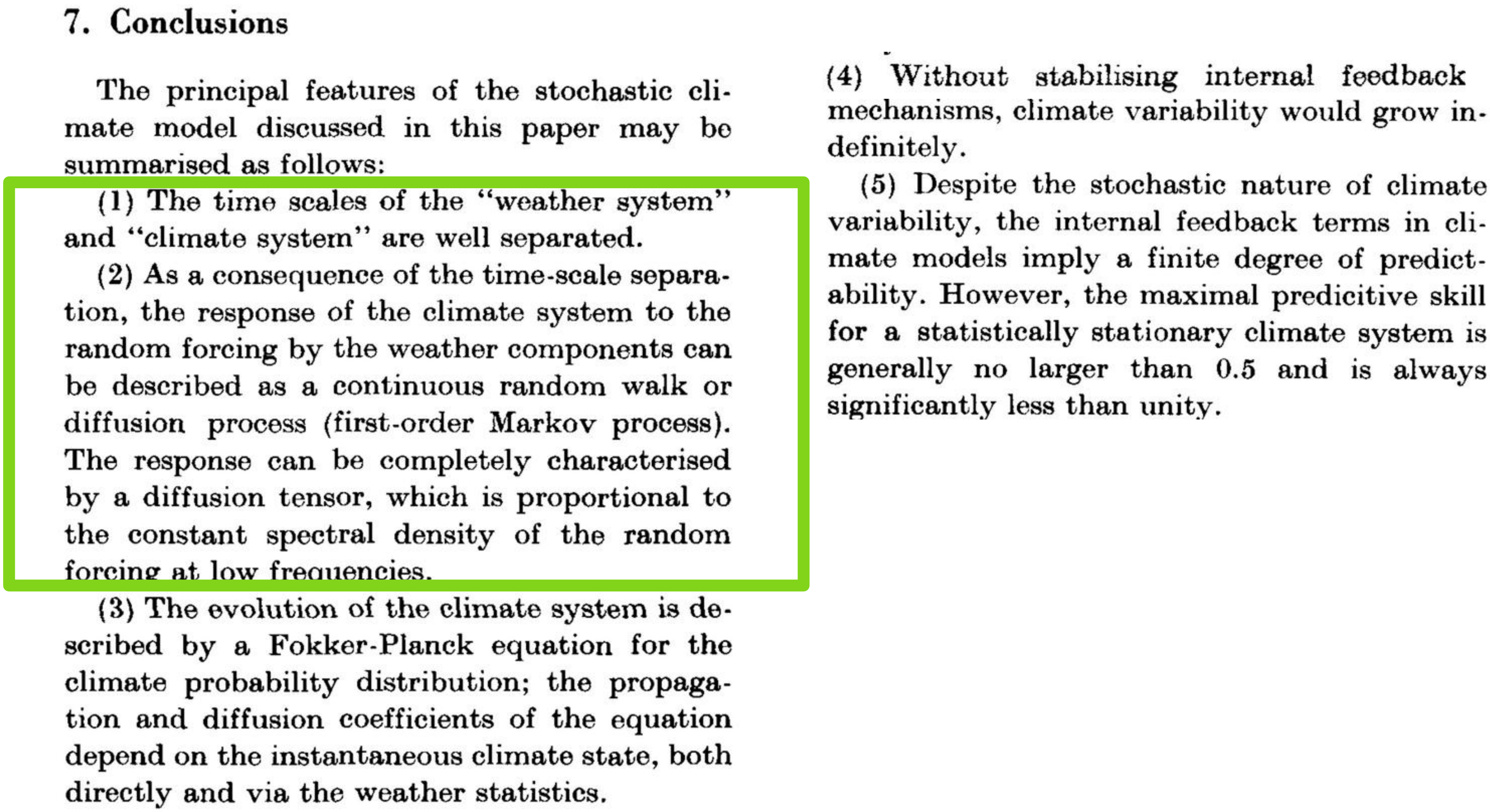


7. Conclusions

The principal features of the stochastic climate model discussed in this paper may be summarised as follows:

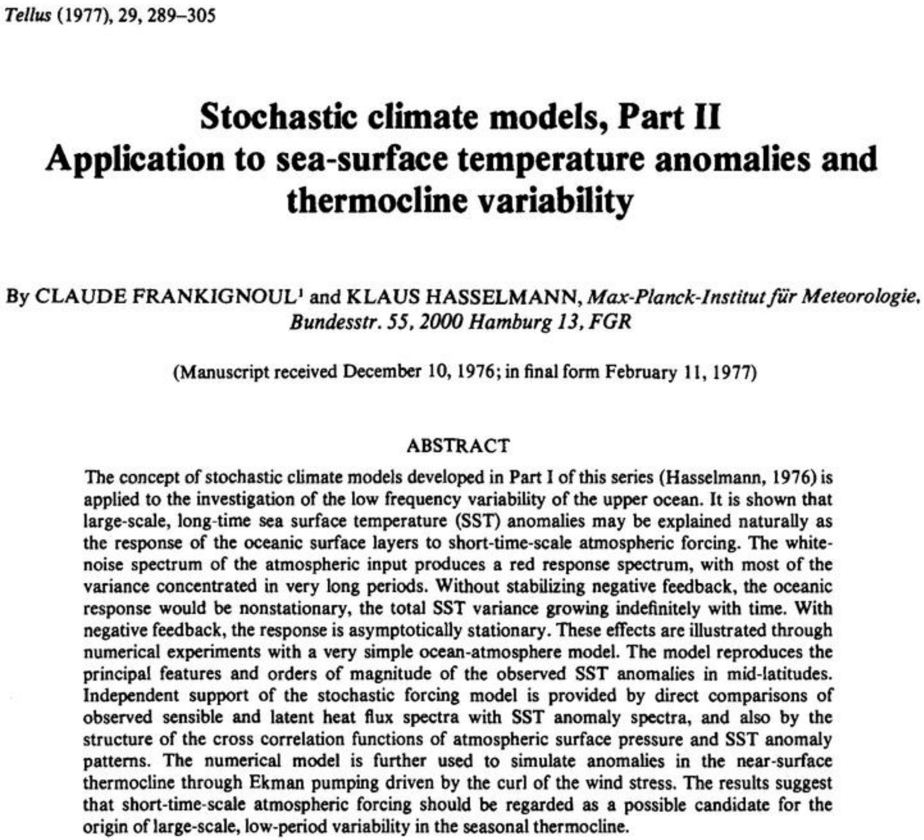
(1) The time scales of the "weather system" and "climate system" are well separated.

(2) As a consequence of the time-scale separation, the response of the climate system to the random forcing by the weather components can be described as a continuous random walk or diffusion process (first-order Markov process). The response can be completely characterised by a diffusion tensor, which is proportional to the constant spectral density of the random forcing at low frequencies.

(3) The evolution of the climate system is described by a Fokker-Planck equation for the climate probability distribution; the propagation and diffusion coefficients of the equation depend on the instantaneous climate state, both directly and via the weather statistics.

(4) Without stabilising internal feedback mechanisms, climate variability would grow indefinitely.

(5) Despite the stochastic nature of climate variability, the internal feedback terms in climate models imply a finite degree of predictability. However, the maximal predicitive skill for a statistically stationary climate system is generally no larger than 0.5 and is always significantly less than unity.



Tellus (1977), 29, 289–305

Stochastic climate models, Part II
Application to sea-surface temperature anomalies and thermocline variability

By CLAUDE FRANKIGNOUL[1] and KLAUS HASSELMANN, *Max-Planck-Institut für Meteorologie, Bundesstr. 55, 2000 Hamburg 13, FGR*

(Manuscript received December 10, 1976; in final form February 11, 1977)

ABSTRACT

The concept of stochastic climate models developed in Part I of this series (Hasselmann, 1976) is applied to the investigation of the low frequency variability of the upper ocean. It is shown that large-scale, long-time sea surface temperature (SST) anomalies may be explained naturally as the response of the oceanic surface layers to short-time-scale atmospheric forcing. The white-noise spectrum of the atmospheric input produces a red response spectrum, with most of the variance concentrated in very long periods. Without stabilizing negative feedback, the oceanic response would be nonstationary, the total SST variance growing indefinitely with time. With negative feedback, the response is asymptotically stationary. These effects are illustrated through numerical experiments with a very simple ocean-atmosphere model. The model reproduces the principal features and orders of magnitude of the observed SST anomalies in mid-latitudes. Independent support of the stochastic forcing model is provided by direct comparisons of observed sensible and latent heat flux spectra with SST anomaly spectra, and also by the structure of the cross correlation functions of atmospheric surface pressure and SST anomaly patterns. The numerical model is further used to simulate anomalies in the near-surface thermocline through Ekman pumping driven by the curl of the wind stress. The results suggest that short-time-scale atmospheric forcing should be regarded as a possible candidate for the origin of large-scale, low-period variability in the seasonal thermocline.

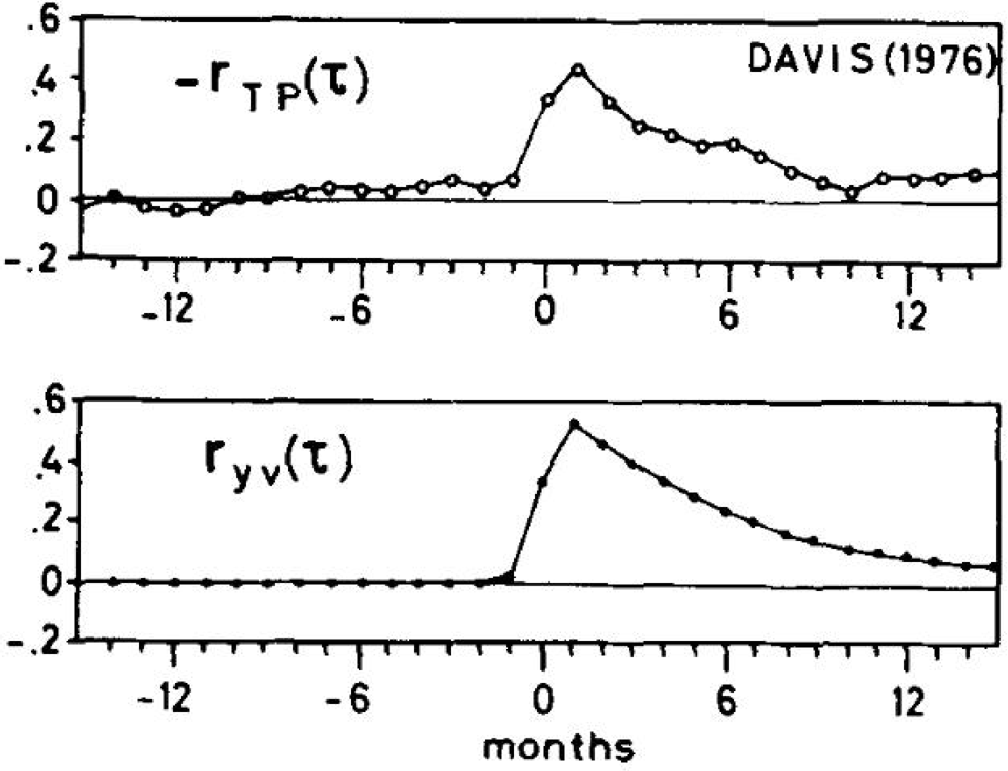
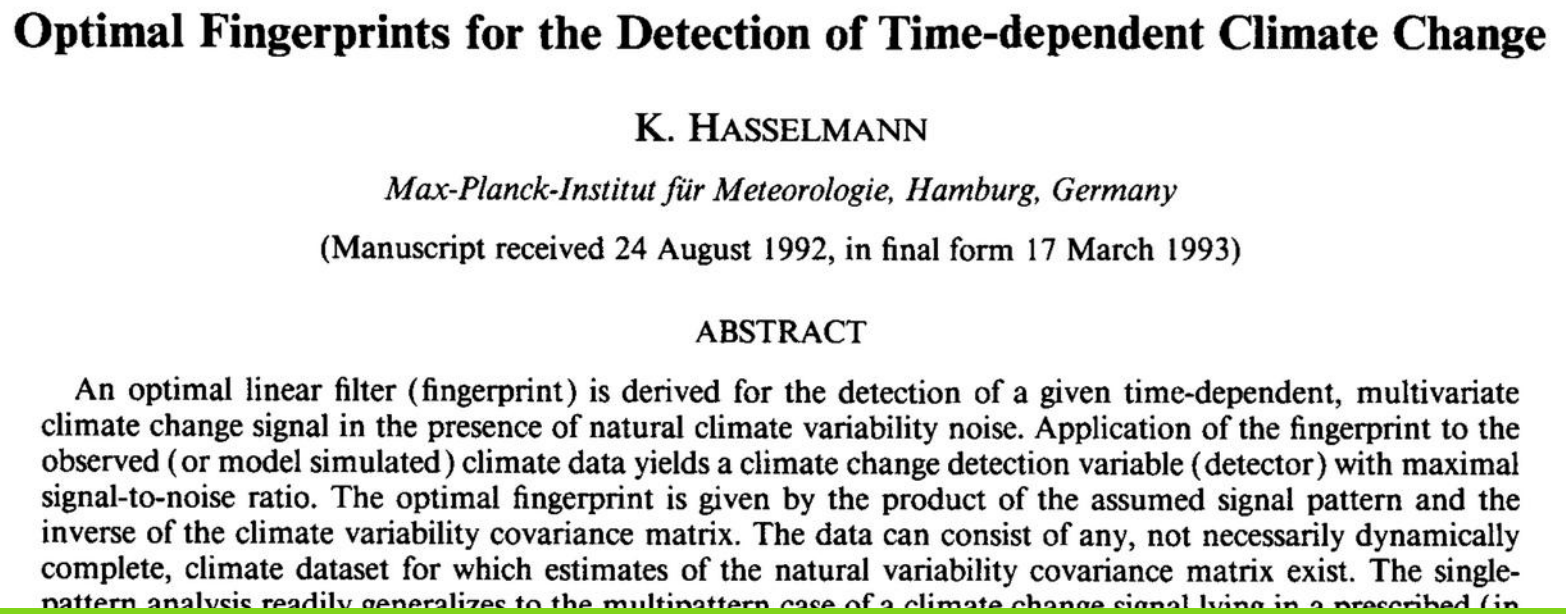


Fig. 9. Upper panel: observed correlation between the amplitude of the dominant mode of SST and sea level pressure (after Davis, 1976). *Lower panel:* theoretical correlation estimated from monthly averaged data for $\nu = (8.5\ \text{day})^{-1}$, $\lambda = (6\ \text{month})^{-1}$ (see appendix).



Optimal Fingerprints for the Detection of Time-dependent Climate Change

K. HASSELMANN

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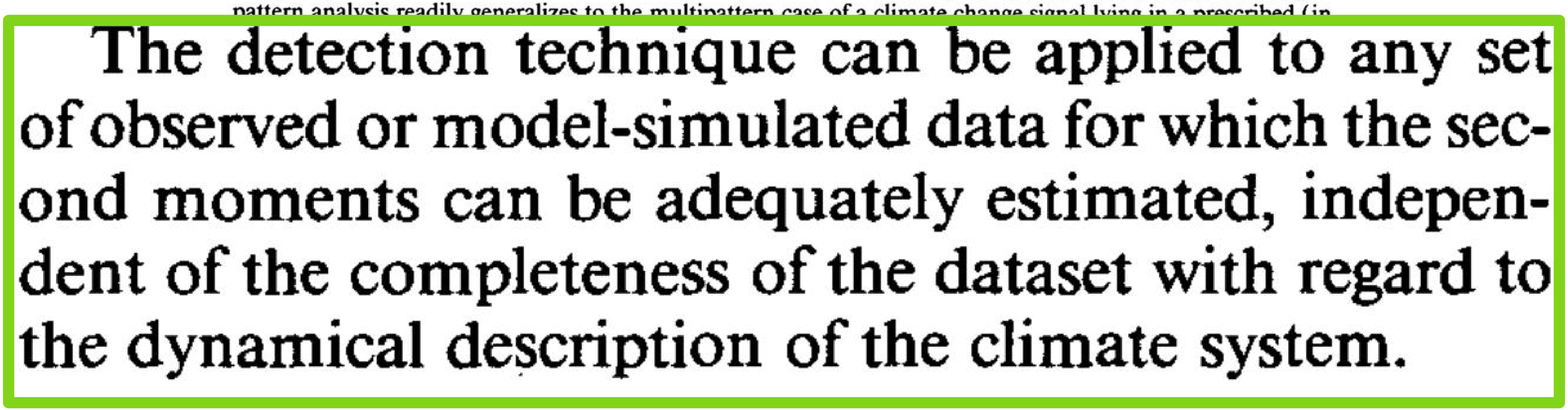
(Manuscript received 24 August 1992, in final form 17 March 1993)

ABSTRACT

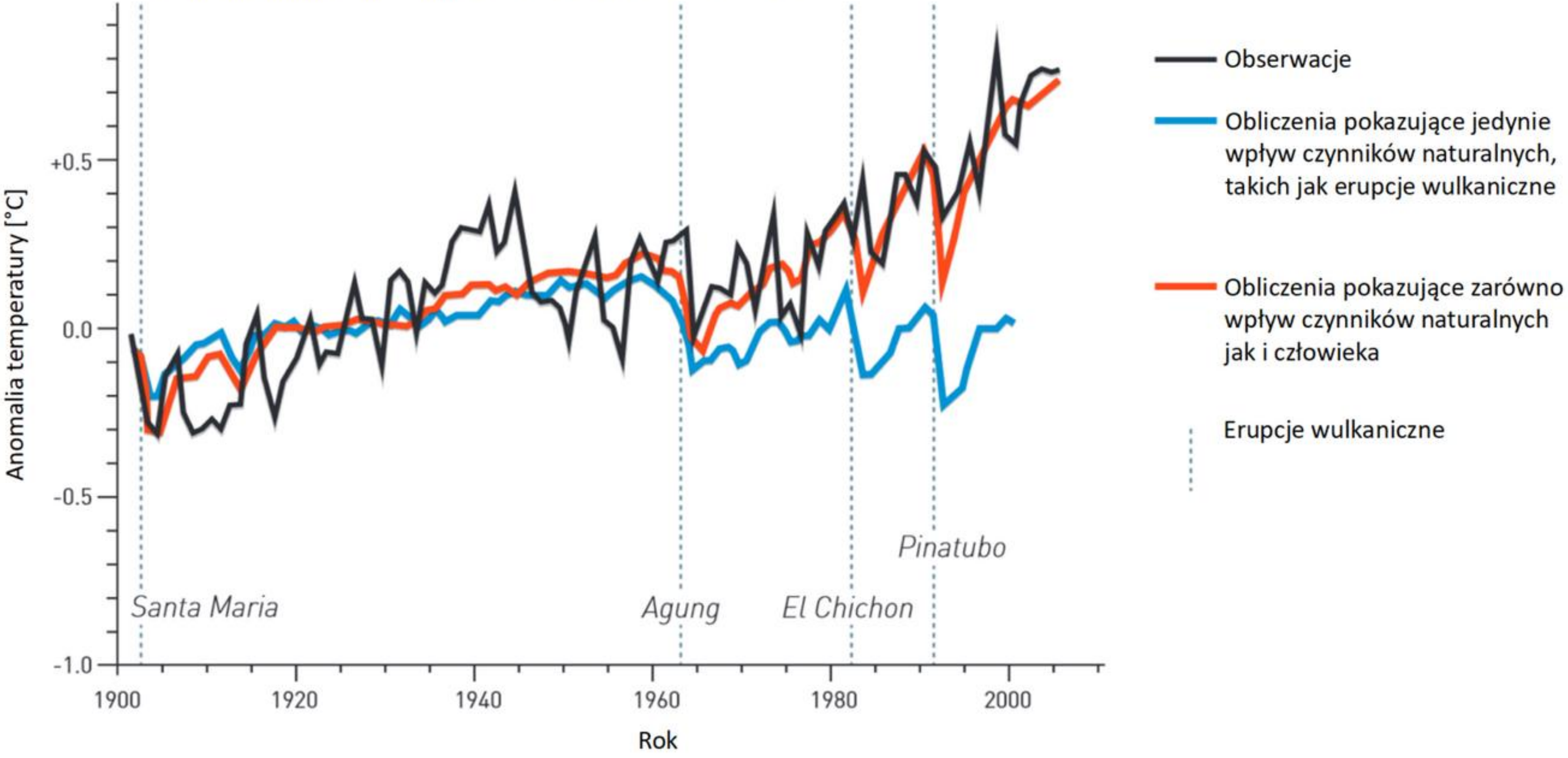
An optimal linear filter (fingerprint) is derived for the detection of a given time-dependent, multivariate climate change signal in the presence of natural climate variability noise. Application of the fingerprint to the observed (or model simulated) climate data yields a climate change detection variable (detector) with maximal signal-to-noise ratio. The optimal fingerprint is given by the product of the assumed signal pattern and the inverse of the climate variability covariance matrix. The data can consist of any, not necessarily dynamically complete, climate dataset for which estimates of the natural variability covariance matrix exist. The single-pattern analysis readily generalizes to the multipattern case of a climate change signal lying in a prescribed (in

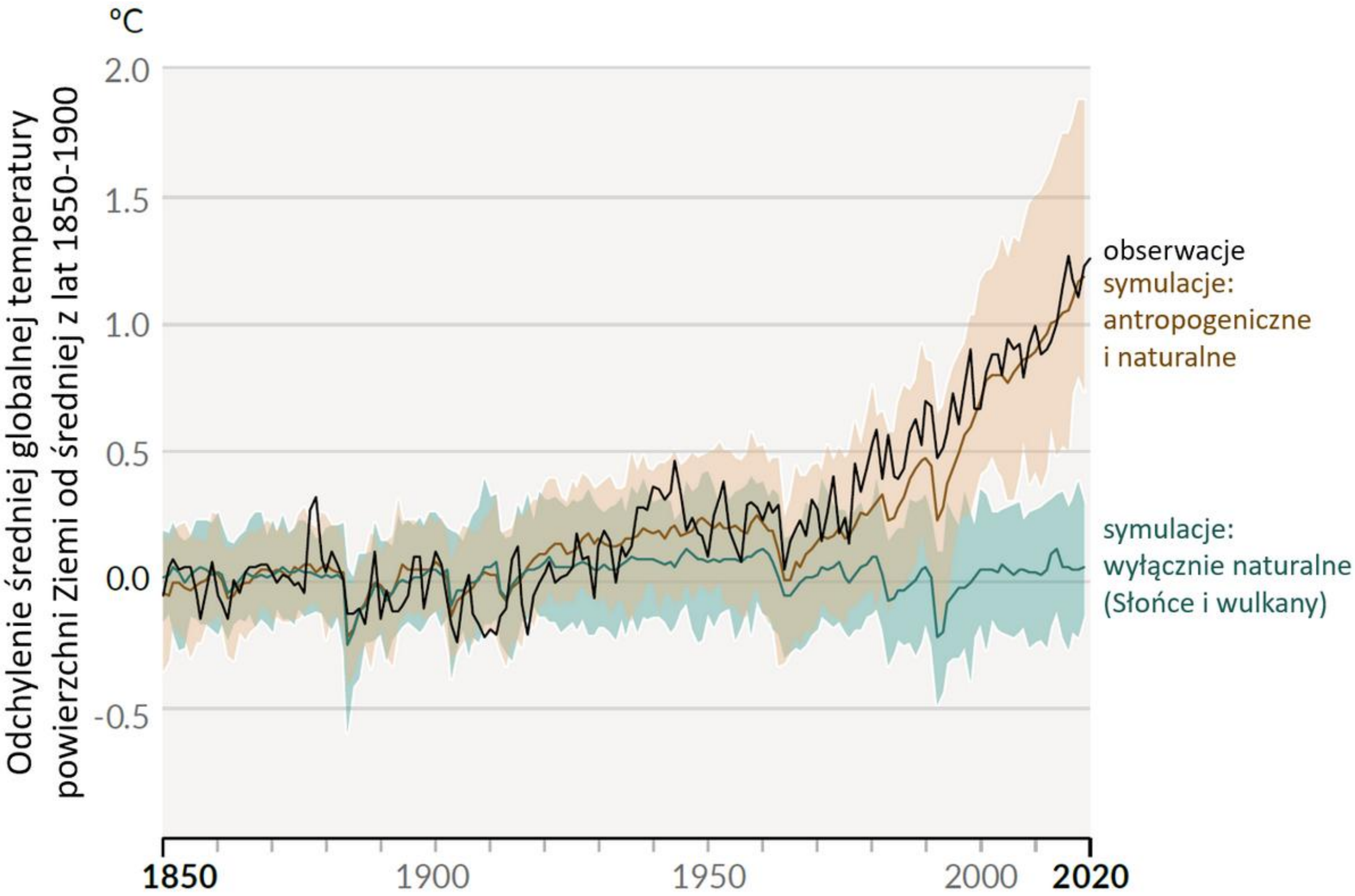


The detection technique can be applied to any set of observed or model-simulated data for which the second moments can be adequately estimated, independent of the completeness of the dataset with regard to the dynamical description of the climate system.

Identyfikacja przyczyn zmiany klimatu

Klaus Hasselmann opracował metody rozróżniania wpływu
czynników naturalnych i antropogenicznych na ocieplenie atmosfery.
Porównanie zmian średniej temperatury względem lat 1901-1950 [°C].

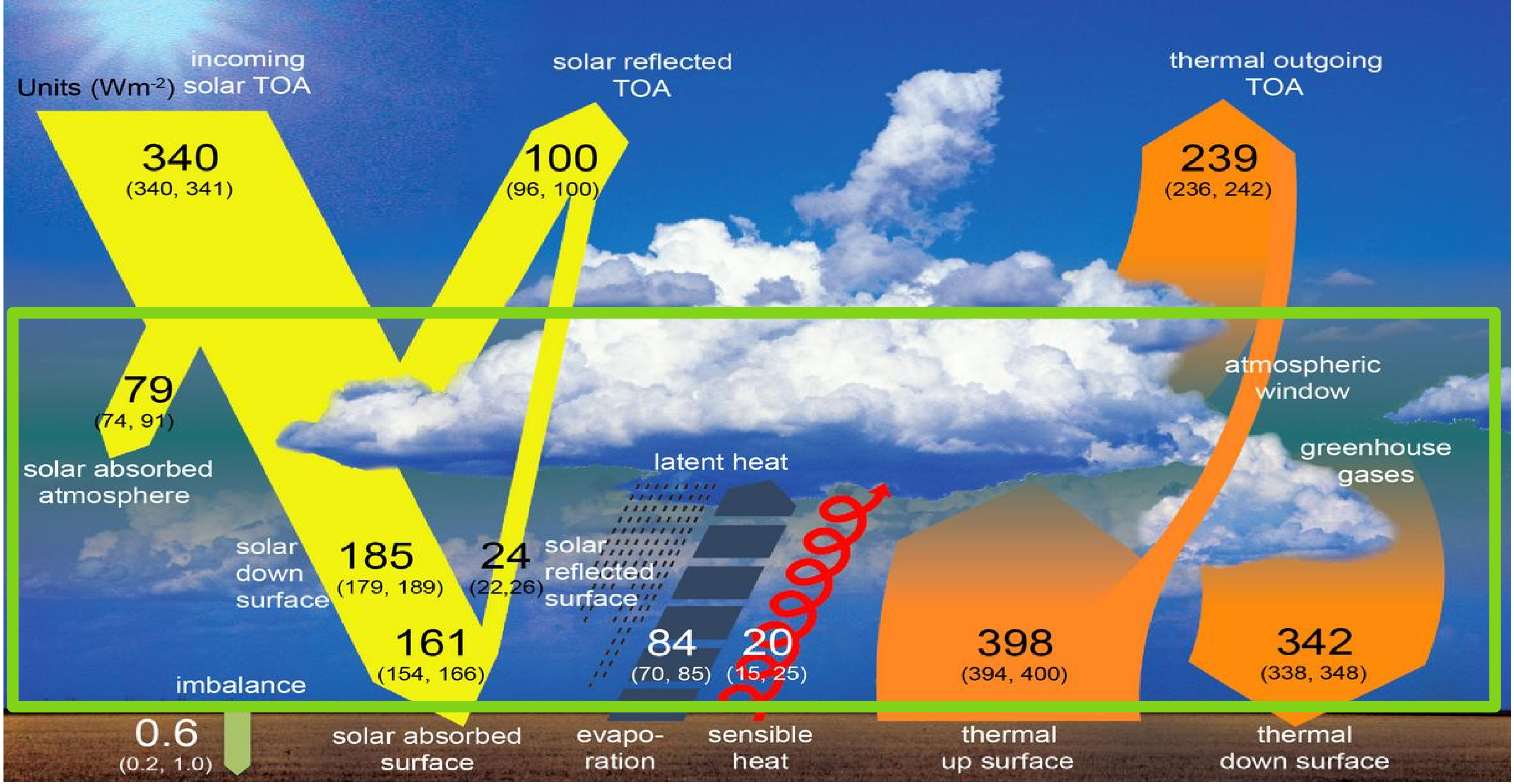




Zmiany średniej globalnej temperatury powierzchni Ziemi (średnie dekadowe). Linia czarna – obserwacje, linia beżowa – symulacje z uwzględnieniem zarówno czynników antropogenicznych jak i naturalnych, linia szaroniebieska – symulacje z uwzględnieniem jedynie czynników naturalnych.

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

"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/ar5/wg1/

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)

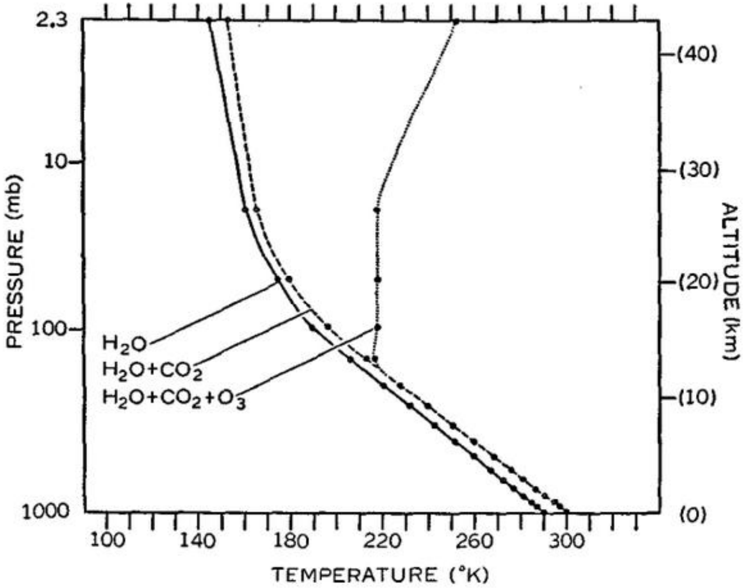


FIG. 6c. Thermal equilibrium of various atmospheres which have a critical lapse rate of 6.5 deg km^{-1}. Vertical distributions of gaseous absorbers at 35N, April, were used. $S_c=2$ ly min^{-1}, $\cos\bar{\zeta}=0.5$, $r=0.5$, no clouds.

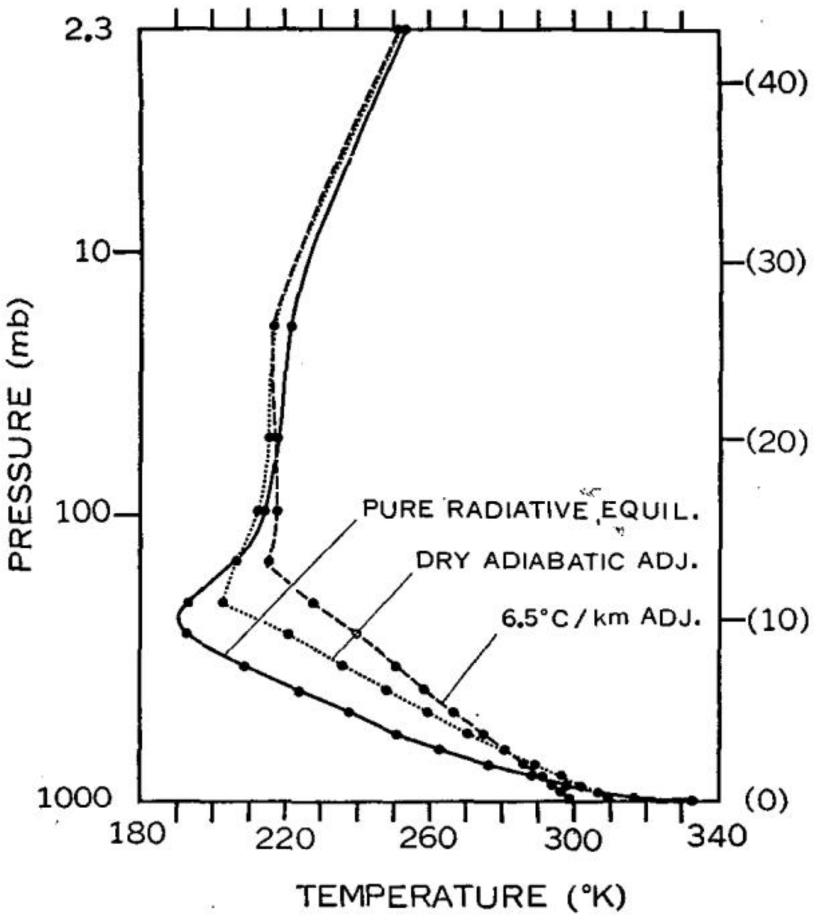
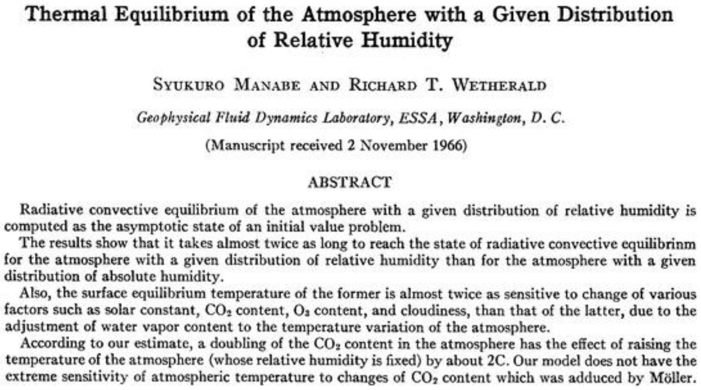


FIG. 4. The dashed, dotted, and solid lines show the thermal equilibrium with a critical lapse rate of 6.5 deg km^{-1}, a dry-adiabatic critical lapse rate (10 deg km^{-1}), and pure radiative equilibrium.



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.

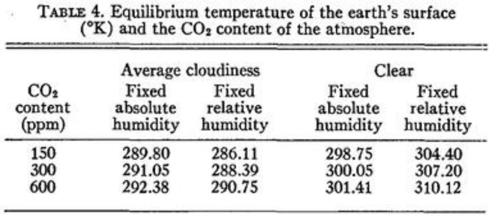


TABLE 4. Equilibrium temperature of the earth's surface (°K) and the CO_2 content of the atmosphere.

	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

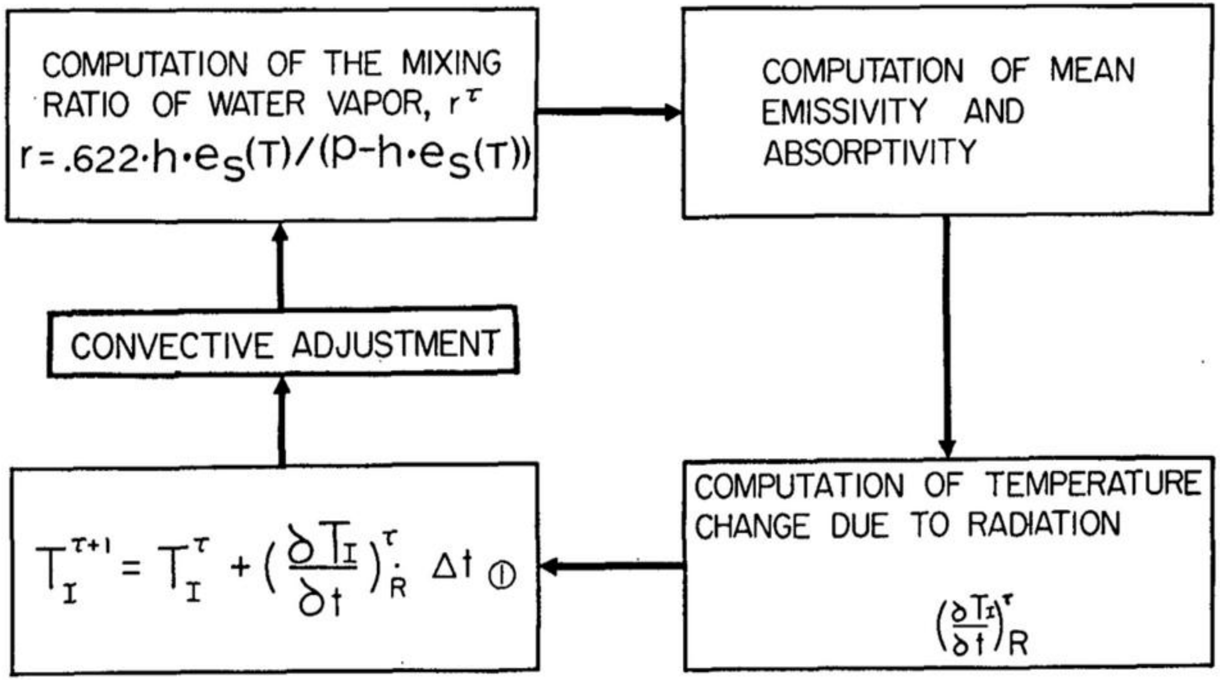


FIG. 2. Flow chart for the numerical time integration.

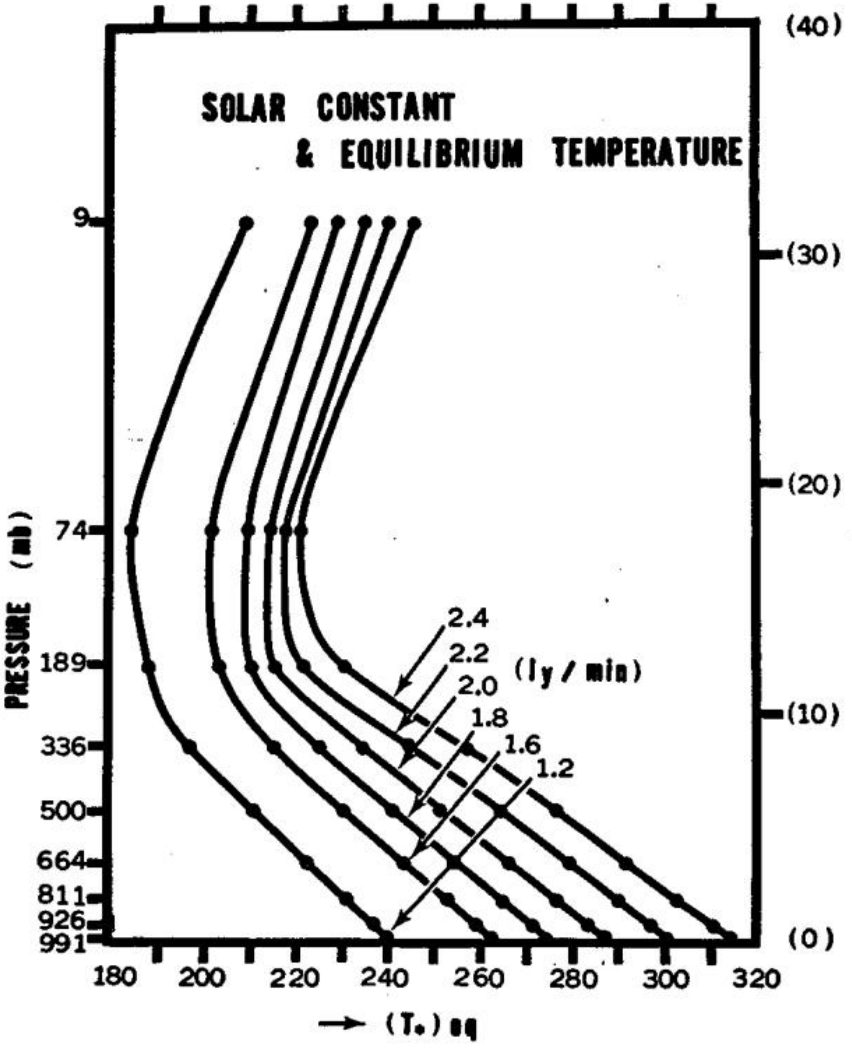


FIG. 8. Vertical distribution of radiative convective equilibrium temperature of the atmosphere with a given distribution of relative humidity for various values of the solar constant.

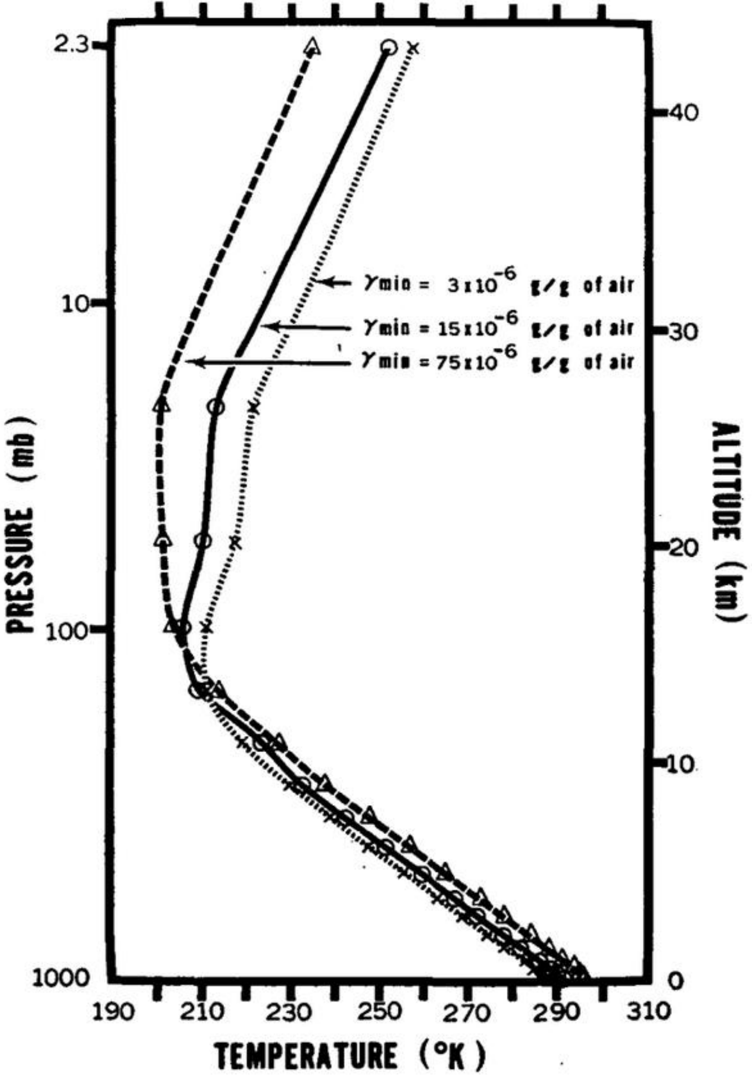
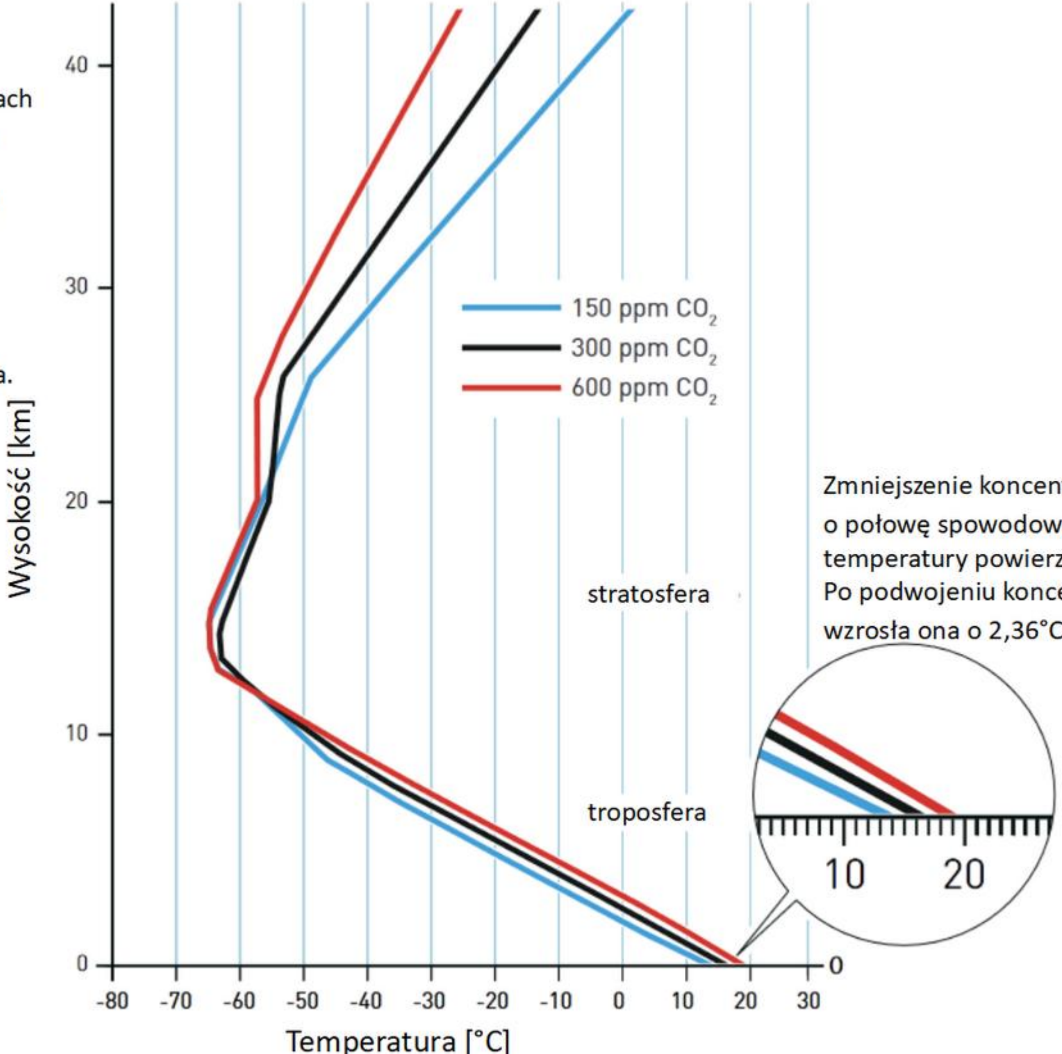


FIG. 12. Vertical distributions of radiative convective equilibrium temperature for various values of water vapor mixing ratio in the stratosphere.

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.

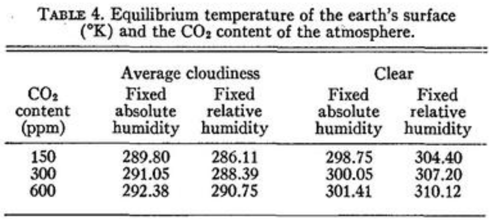
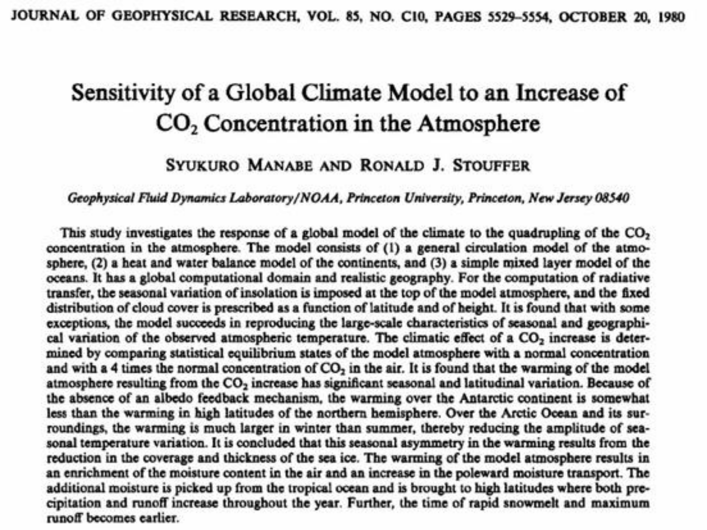


TABLE 4. Equilibrium temperature of the earth's surface (°K) and the CO_2 content of the atmosphere.

CO_2 content (ppm)	Average cloudiness		Clear	
	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



JOURNAL OF GEOPHYSICAL RESEARCH, VOL. 85, NO. C10, PAGES 5529–5554, OCTOBER 20, 1980

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

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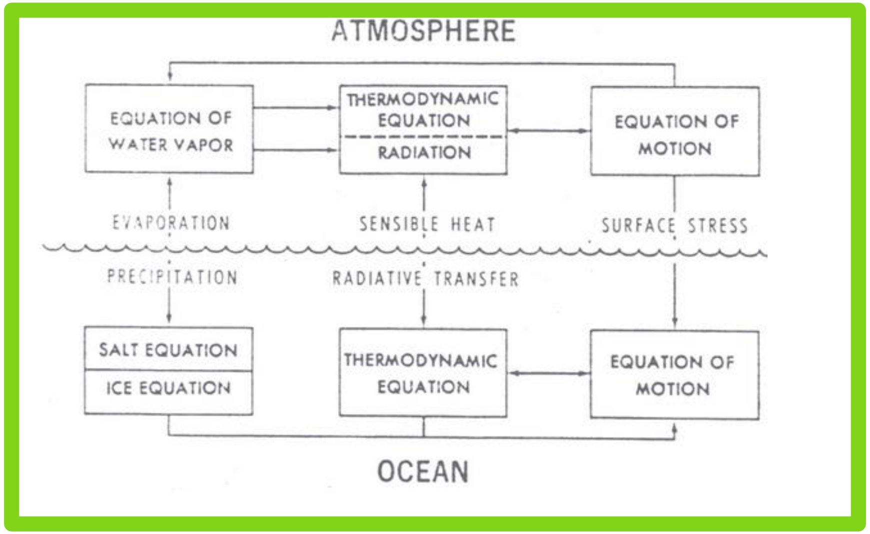
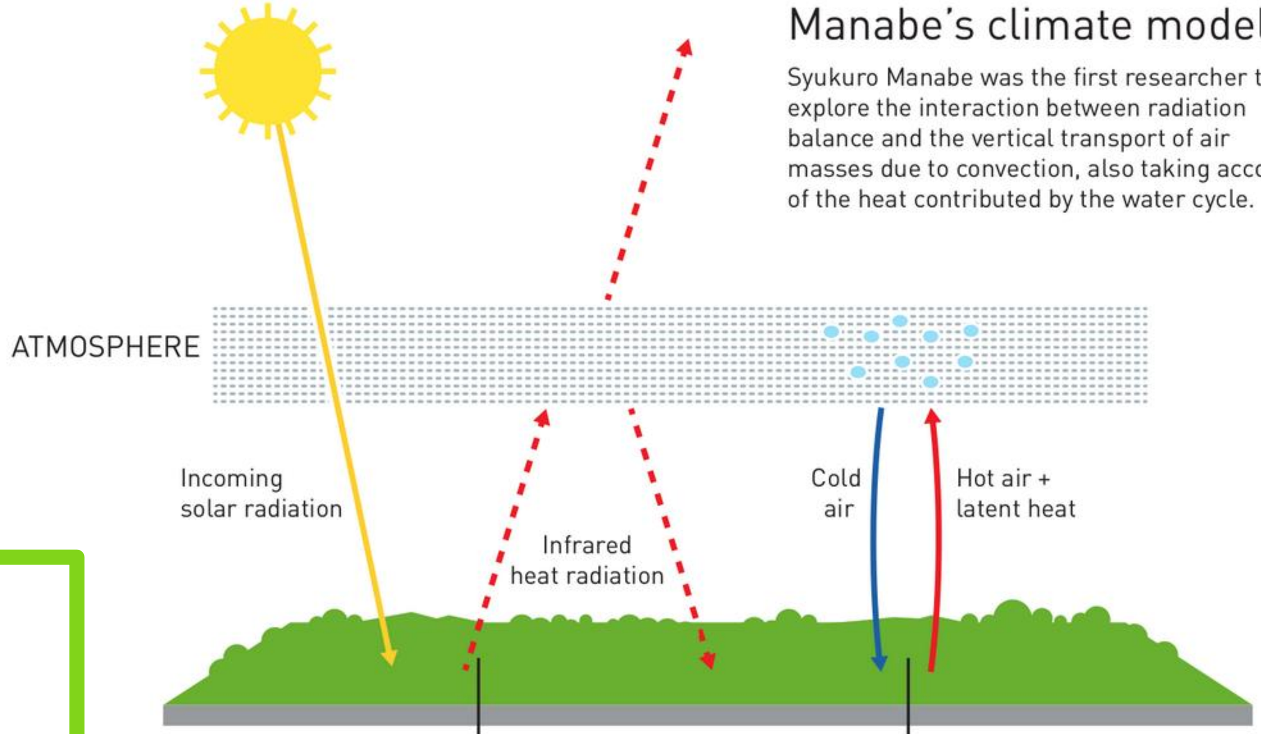
This study investigates the response of a global model of the climate to the quadrupling of the CO_2 concentration in the atmosphere. The model consists of (1) a general circulation model of the atmosphere, (2) a heat and water balance model of the continents, and (3) a simple mixed layer model of the 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.



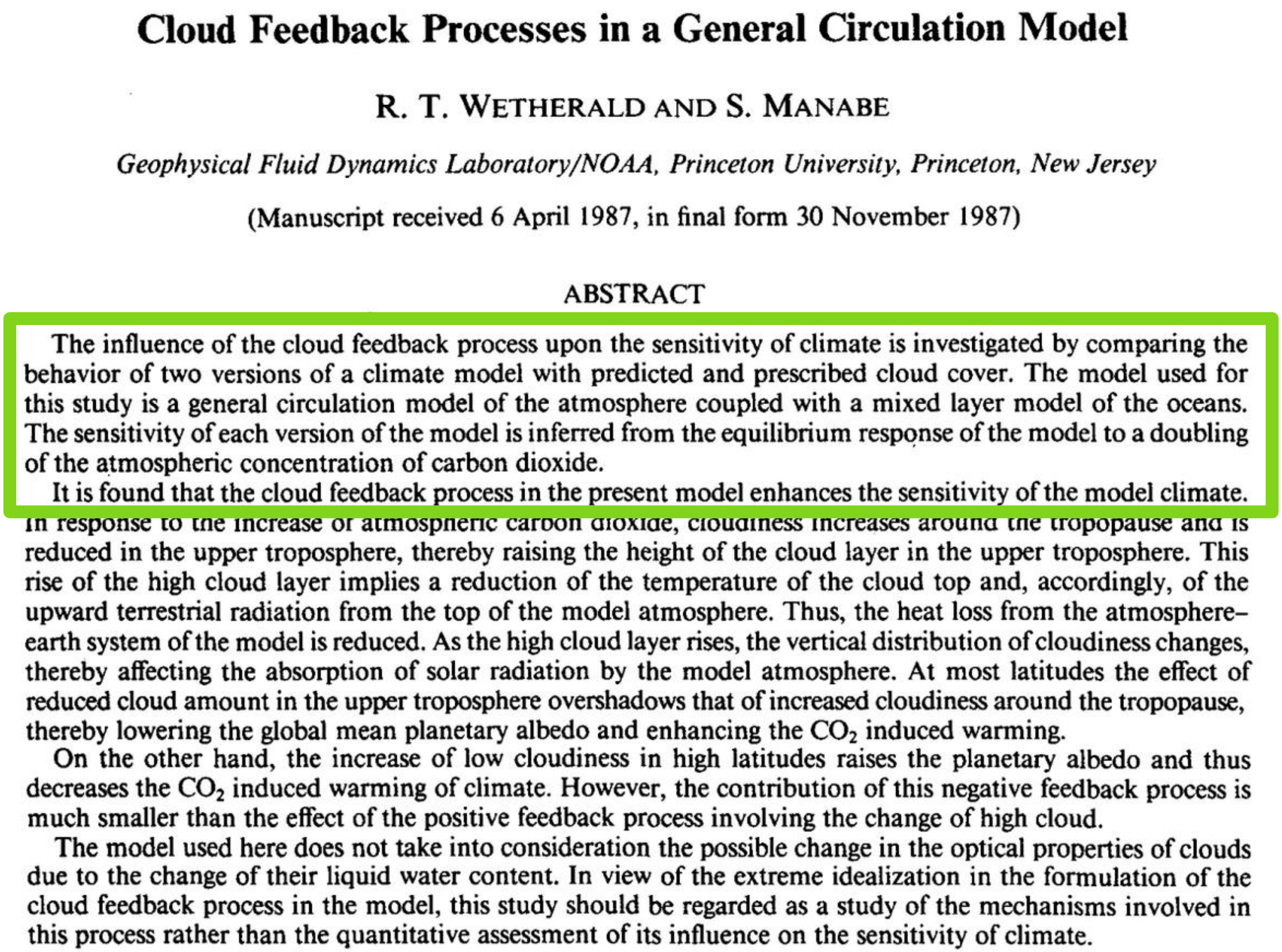
Manabe's climate model

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.



Cloud Feedback Processes in a General Circulation Model

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

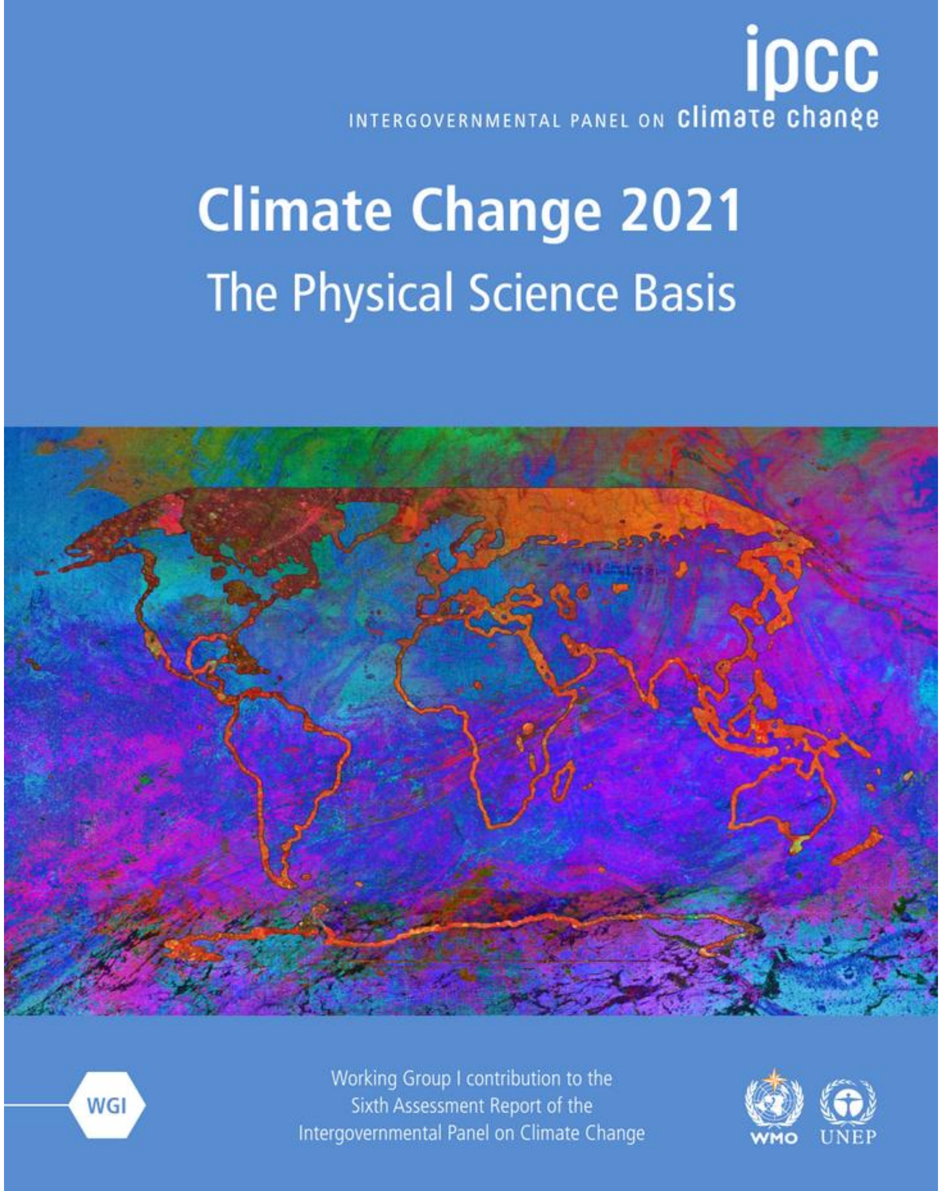
ABSTRACT

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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Climate Change 2021

The Physical Science Basis

WGI

Working Group I contribution to the
Sixth Assessment Report of the
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