Pós-Graduação
Programas em Energia (PPGE) e Ciência Ambiental (PROCAM)

Mudanças Climáticas e Redução de Emissões

PCA5019

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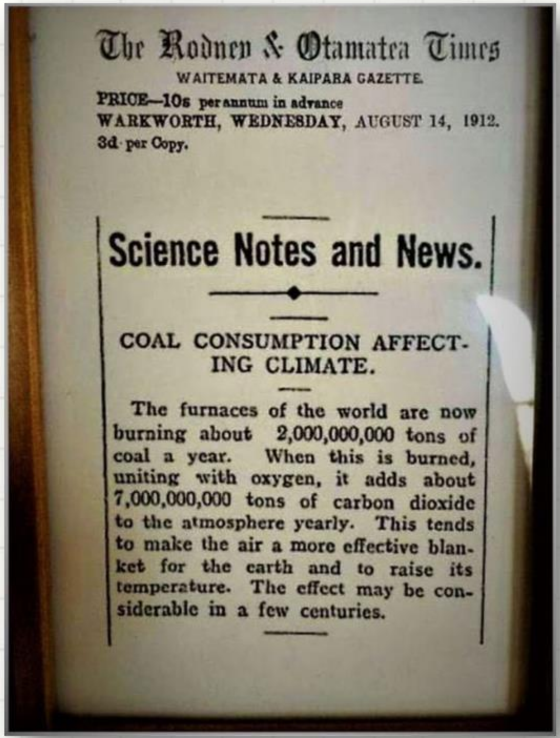
Em 1896, a primeira previsão climática: Svante Arrhenius

Arrhenius quantificou em 1896 as mudanças na temperatura da superfície (aprox. 5 C) que deveriam ocorrer se dobrássemos a concentração de CO_2, baseado nos conceito do efeito "glass bowl" introduzido em 1824 por Joseph Fourier.



The Rodney & Otamatea Times
WAITEMATA & KAIPARA GAZETTE.
PRICE—10s per annum in advance
WARKWORTH, WEDNESDAY, AUGUST 14, 1912.
3d per Copy.

Science Notes and News.

COAL CONSUMPTION AFFECTING CLIMATE.

The furnaces of the world are now burning about 2,000,000,000 tons of coal a year. When this is burned, uniting with oxygen, it adds about 7,000,000,000 tons of carbon dioxide to the atmosphere yearly. This tends to make the air a more effective blanket for the earth and to raise its temperature. The effect may be considerable in a few centuries.

Matéria de jornal de 1912!

Pós-Graduação
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Voltando no tempo ...

A.......

Inverno é questão crucial para Carter

de dólares.
A instabilidade do clima vem sendo prevista periodicamente com teorias que variam desde o derretimento das calotas polares e um novo dilúvio, até a entrada da terra em uma nova era glacial. Recentemente começaram a ser

Jornal O Estado de S.Paulo - 06 2 1977

Cafeicultor é contra plantar em SP e PR

Bolsa de NY altera o mercado a termo

Ele faz esta afirmação baseado em conclusões de climatologistas e biólogos norte-americanos e europeus, segundo os quais, "a terra está entrando em nova fase glacial, com redução das áreas de clima quente e intensificação do frio nas áreas de clima temperado".

Jornal O Estado de S.Paulo - 24 5 1977

Mudanças Climáticas...produção desde o início do século passado

TITLE-ABS-KEY ("Climate change") AND DOCTYPE (ar OR re)

Pós-Graduação
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PROCAMUSP

USP

Considerações gerais sobre a natureza das mudanças climáticas

WEATHER AND GLACIATION[1]

BY CHESTER A. REEDS

(Read before Section E of the American Association for the Advancement of Science, December 27, 1928)

CONTENTS

INTRODUCTION

Weather as it affects glaciation is a subject which has been under observation during the past century. Remnants of the last glaciation still exist in Greenland, Antarctica, and on some of the islands of the polar regions and in the high mountain fastenesses of the temperate and tropical zones. Weather conditions are modifying these ice-masses; in fact, the variability of the weather causes glaciers to grow at certain times and wane during other periods. The changes that are going on today are apparently similar to those that took place during past ages.

There is a distinction between weather and climate. Climate is the average of normal conditions of the atmosphere, while weather constitutes the variations from the normal. Weather changes are of a day-to-day occurrence. When averaged for the year and for longer periods, they yield differences which make the weather of one year vary from that of another, as well as for groups of years.

During the last decade a few meteorologists have correlated weather changes with variations in solar radiation. This correlation has been

[1] Manuscript received by the Secretary of the Society, December 21, 1929. (597)

WEATHER AND GLACIATION
BY CHESTER A. REEDS

1929

During the last decade a few meteorologists have correlated weather changes with variations in solar radiation. This correlation has been specially emphasized by H. H. Clayton in his volume, ''World Weather,'' 1923. The correlation of changes in glaciation with solar radiation variations has been mentioned by various scientists, but it has not been discussed in the light of recent developments.

Durante a última década, alguns meteorologistas correlacionaram as mudanças climáticas com as variações na radiação solar. Essa correlação foi especialmente enfatizada por HH Clayton em seu volume 'World Weather', 1923. A correlação de mudanças na glaciação com variações da radiação solar foi mencionada por vários cientistas, mas não foi discutida à luz de desenvolvimentos recentes.

Considerações gerais sobre a natureza das mudanças climáticas

RECENT EVIDENCE ABOUT THE NATURE OF CLIMATE CHANGES AND ITS IMPLICATIONS*

I. I. Schell
Department of Geology, Tufts University, Medford, Mass.

Introduction

The solution of the problem of climate changes would be greatly aided by a better understanding of the nature of these changes, both during the earlier history of the earth as well as during the recent past which can be examined in greater detail. Although much remains to be accomplished before the true nature of these changes can be ascertained, the lengthening meteorological record, together with the other records from land and sea, makes it possible to probe deeper into the nature of these changes and into the validity of the different explanations that have been offered for them.

In seeking an explanation for a change in climate it was logical to consider that, since without the heat received from the sun the earth would be a cold body, this heat may have been "considerably diminished during glacial epochs" (Hitchcock, 1891). This very simple explanation of a change in climate poses a dilemma, as may be seen from the following quotation ". . . such a variation would be most effective in the low latitudes, but it is there that the climatic changes have been the smallest" (Brooks, 1950).

In explaining a climate change, such as, for example, an ice age, it becomes necessary, therefore, to reconcile the seeming paradox of a steeper equator-to-pole temperature gradient, increased circulation, evaporation, and precipitation with a decreased solar output that, because of the sphericity of the earth, seemingly calls for a greater decrease in temperature in the low than in the high latitudes and hence a less steep gradient, decreased circulation, evaporation, and precipitation.

In addition to a reconciliation between a greater decrease in temperature in the higher than in the lower latitudes and a decreased solar output, the explanation here offered must also account for (1) a change in climate that, although essentially global, is not simultaneous in all areas; (2) a more gradual onset of a cold period than of a mild period; (3) the long mild period preceding the Pleistocene and the transition to this epoch without, if possible, relying on extensive changes in the physical make-up of the globe; and (4) the smaller changes in climate or a climatic change.

As my first aim is to reconcile a decreased solar output with a greater lowering in temperature at the pole than at the equator, this point will be treated first.

A Reconciliation of a Greater Lowering of Temperature at the Pole than at the Equator with a Decrease in Solar Output

I shall try to show that while a slight increase in temperature gradient and in circulation will develop with a simple increase in solar output, a very much

* Tufts University Meteorological Studies No. 2.
The work described in this article was prepared with support from the National Science Foundation, Washington, D.C.

1961

Recent Evidence About the Nature of Climate Changes and its Implications

Schell, I.I.
1961 - Annals of the New York Academy of Sciences
95(1), pp. 251-270

As discussões centravam-se especialmente nas condições para uma nova era glacial.

Considerações gerais sobre a natureza das mudanças climáticas

551.583:551.521 (268)

(Department of Meteorology, McGill University, Montreal)

Climate Change over the Polar Ocean. I

The Radiation Budget[1]

By

E. Vowinckel and Svenn Orvig

With 1 Figure

(Received May 20, 1966)

Summary. Climatic change results from changes in the terms of the energy equation. The present study consists of an analysis of possible changes in the radiative terms of the Polar Ocean energy budget.

The absorbed global radiation at the surface depends mainly on clouds and surface albedo. These factors are discussed, and the absorbed global radiation is presented for various extreme surface and atmospheric conditions.

The short wave radiation absorbed in the atmosphere is next discussed. It is apparent that variations in the atmospheric short wave absorption are of rather small importance for climatic change.

There is greater possibility of variations in long wave radiation than of solar radiation. Theoretical polar atmospheres are discussed, with the consequent changes in the radiation balance. The conclusion appears that the atmosphere is at present adjusted in the best possible way for the conservation of energy.

Long wave fluxes have been calculated for the condition of an open Polar Ocean in winter and for a Polar Ocean completely frozen throughout the year.

It is concluded that, for *cloudless conditions*, there is little possibility for a change in the long wave balance in summer; the long wave balance would become much more negative in winter; the development of a winter balance less negative than the present seems unlikely. Changes in surface conditions are much more important than changes in the atmosphere, for the long wave radiation budget.

[1] The research reported in this paper was sponsored in part by the Natick Laboratories, U. S. Army Materiel Command, under contract No. DA 19-129 AMC-490 (N).

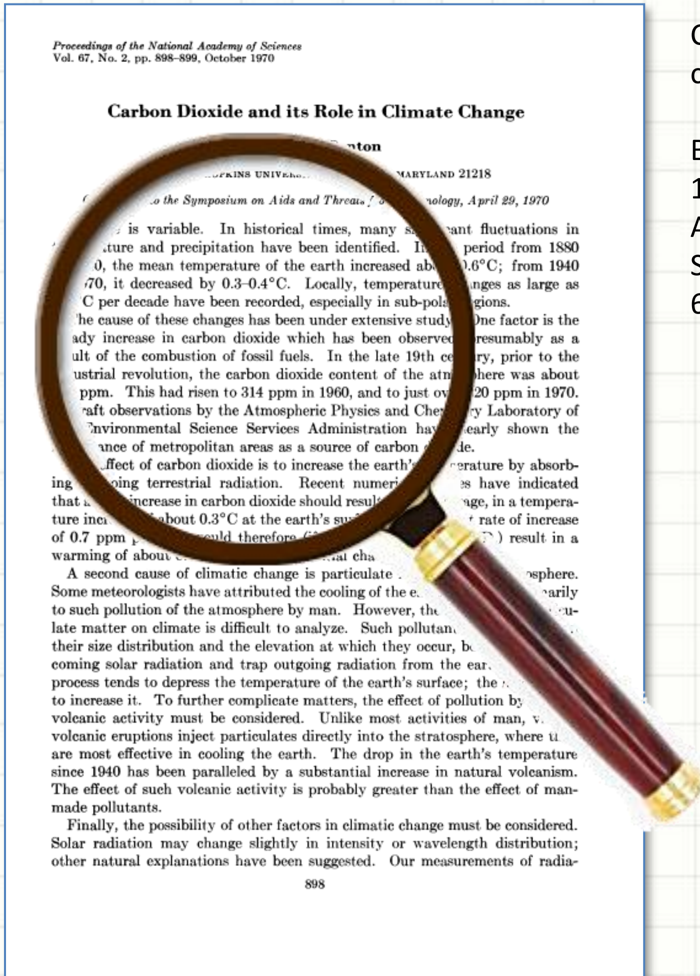
1967

Climate change over the Polar Ocean. I - The radiation budget

Vowinckel, E., Orvig, S.
1967 - Archiv für Meteorologie, Geophysik und Bioklimatologie Serie B 15(1-2), pp. 1-23

As discussões também concentravam-se em aspectos físicos naturais, sem a interferência antrópica.

Trabalhos primordiais...reconhecendo a existência do problema



Proceedings of the National Academy of Sciences
Vol. 67, No. 2, pp. 898–899, October 1970

Carbon Dioxide and its Role in Climate Change

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...o the Symposium on Aids and Threats ... ...ology, April 29, 1970

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Finally, the possibility of other factors in climatic change must be considered. Solar radiation may change slightly in intensity or wavelength distribution; other natural explanations have been suggested. Our measurements of radia-

898

Carbon dioxide and its role in climate change.

Benton, G.S.
1970 - Proceedings of the National Academy of Sciences of the United States of America
67(2), pp. 898-899

1970

Até que, em 1970, o papel do CO_2 passa a ser discutido.

Trabalhos primordiais...reconhecendo a existência do problema

Proceedings of the National Academy of Sciences
Vol. 67, No. 2, pp. 898–899, October 1970

Carbon Dioxide and its Role in Climate Change

George S. Benton

THE JOHNS HOPKINS UNIVERSITY, BALTIMORE, MARYLAND 21218

Contributed to the Symposium on Aids and Threats from Technology, April 29, 1970

Climate is variable. In historical times, many significant fluctuations in temperature and precipitation have been identified. In the period from 1880 to 1940, the mean temperature of the earth increased about 0.6°C; from 1940 to 1970, it decreased by 0.3–0.4°C. Locally, temperature changes as large as 3–4°C per decade have been recorded, especially in sub-polar regions.

The cause of these changes has been under extensive study. One factor is the steady increase in carbon dioxide which has been observed, presumably as a result of the combustion of fossil fuels. In the late 19th century, prior to the industrial revolution, the carbon dioxide content of the atmosphere was about 290 ppm. This had risen to 314 ppm in 1960, and to just over 320 ppm in 1970. Aircraft observations by the Atmospheric Physics and Chemistry Laboratory of the Environmental Science Services Administration have clearly shown the importance of metropolitan areas as a source of carbon dioxide.

The effect of carbon dioxide is to increase the earth's temperature by absorbing outgoing terrestrial radiation. Recent numerical studies have indicated that a 10% increase in carbon dioxide should result, on the average, in a temperature increase of about 0.3°C at the earth's surface. The present rate of increase of 0.7 ppm per year would therefore (if extrapolated to 2000 A.D.) result in a warming of about 0.6°C—a very substantial change.

A second cause of climatic change is particulate loading of the atmosphere. Some meteorologists have attributed the cooling of the earth since 1940 primarily to such pollution of the atmosphere by man. However, the net effect of particulate matter on climate is difficult to analyze. Such pollutants, depending upon their size distribution and the elevation at which they occur, both intercept incoming solar radiation and trap outgoing radiation from the earth. The first process tends to depress the temperature of the earth's surface; the latter tends to increase it. To further complicate matters, the effect of pollution by natural volcanic activity must be considered. Unlike most activities of man, violent volcanic eruptions inject particulates directly into the stratosphere, where they are most effective in cooling the earth. The drop in the earth's temperature since 1940 has been paralleled by a substantial increase in natural volcanism. The effect of such volcanic activity is probably greater than the effect of man-made pollutants.

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A causa dessas mudanças está sendo estudada extensivamente. Um fator é o aumento constante do dióxido de carbono que foi observado, presumivelmente como resultado da combustão de combustíveis fósseis. No final do século 19, antes da revolução industrial, o conteúdo de dióxido de carbono na atmosfera era de cerca de 290 ppm. Isso aumentou para 314 ppm em 1960 e para pouco mais de 320 ppm em 1970.

Trabalhos primordiais...modelagem

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O efeito do dióxido de carbono é aumentar a temperatura da Terra absorvendo a radiação terrestre que antes seria lançada ao espaço. Estudos numéricos recentes indicaram que um aumento de 10% no dióxido de carbono deve resultar, em média, em um aumento de temperatura de cerca de 0,3OC na superfície da Terra.
A presente taxa de aumento de 0,7 ppm por ano, portanto (se extrapolada para 2000 d.C.) resultaria em um aquecimento de cerca de 0,60 °C - uma mudança muito substancial.

1971

In the past decade, scientists have become increasingly concerned with man's pollution of the atmosphere and his inadvertent ability to effect change in climate at macro scales. The nature of such change is not yet known, but in this article, the premise that continued atmospheric pollution will promote higher air temperatures and ultimately coastal flooding through melting of all solid water forms, is accepted as inevitable. The author speculates on the probability of such an event and cartographically analyzes the possible extent of change in continental shapes and sizes, as well as the impact of world inundation on population densities and distributions. Projecting to 2050 A.D. as the earliest possible date for the maximization of this occurrence, it is expected that the expanding oceans will have reduced continental surfaces by approximately 17%, and roughly 19% of the population of the mid-21st century will have been

Global climate change and the impact of a maximum sea level on coastal settlement
Kopec, R.J.

Na década passada, os cientistas se preocuparam cada vez mais com a poluição da atmosfera causada pelo homem e sua capacidade provocar mudanças no clima em macro escalas.

A natureza de tal mudança ainda não é conhecida, mas neste artigo a premissa tida como inevitável é de que a poluição atmosférica continuada provocará temperaturas mais altas do ar e levará à ocorrência de inundações costeiras pelo derretimento de todas as formas de água sólida é aceita como inevitável.

O autor especula sobre a probabilidade de tal evento e analisa cartograficamente a possível extensão da mudança de formas e tamanhos continentais, bem como o impacto da inundação, em escala mundial, nas densidades e distribuições populacionais.

Projetando-se para o ano de 2050, espera-se que os oceanos em expansão reduzam as superfícies continentais em aproximadamente 17% e que aproximadamente 19% da população de meados do século XXI tenha sido realocada .

Trabalhos primordiais...reconhecendo a existência do problema

1973

This paper reviews some of the major findings, conclusions, and recommendations of the Study of Man's Impact on Climate (SMIC). This study was conducted in Stockholm during the summer of 1971 under the sponsorship of the Massachusetts Institute of Technology and was hosted by the Royal Swedish Academy of Sciences and the Royal Swedish Academy of Engineering Sciences. Thirty scientists from fourteen countries devoted 3 weeks of concentrated effort to develop a consensus concerning the present and future scale of man's activities that may affect the global temperature and heat balance and to determine whether such effects may become large enough to cause climate changes for the whole earth or for large regions. The principal conclusions of the study was that man may indeed be affecting local, regional, and global climate through a large number of varied activities. The gaps in present knowledge were identified and recommendations on how to fill these gaps were developed.

International Journal of Environmental Studies
Volume 4, Issue 1-4, 1 January 1973,
Pages 283-289
Climatic effects of man's activities
Matthewst, W.H.

Trabalhos primordiais...reconhecendo a existência do problema

1973

Abstract

Rates of consumption of fossil fuels have increased steadily since the beginning of the industrialization of the world. Amounts are tabulated, and based on estimated carbon content of each fuel type, the amount of carbon dioxide resulting from combustion processes is calculated. These inputs to the atmosphere are compared with the observed values which show annual increases. Observations at Mauna Loa, Hawaii, and other locations indicate that over 50 percent of the carbon dioxide resulting from fossil fuel burning has remained in the atmosphere. Atmospheric carbon dioxide is not yet present in quantities to cause great alarm, but continued heavy dependence on fossil fuels will raise carbon dioxide levels such that observable climate changes could result within the next several decades.

Global Prediction Of CO_2 From Fossil Fuels and Possible Changes in the World`s Climate.

Rotty, R.M.
1973 - ASME Pap
(73 -Pwr-11)

Trabalhos primordiais...reconhecendo a existência do problema

C. F. Baes, Jr., H. E. Goeller, J. S. Olson, and R. M. Rotty

Carbon Dioxide and Climate: The Uncontrolled Experiment

Possibly severe consequences of growing CO_2 releases from fossil fuels require a much better understanding of the carbon cycle, climate change, and the resulting impacts on the atmosphere

According to Revelle and Suess (1957), "Human beings are now carrying out a large-scale geophysical experiment of a kind that could not have happened in the past nor be repeated in the future. Within a few centuries we are returning to the atmosphere and oceans the concentrated organic carbon stored in the sedimentary rocks over hundreds of millions of years. This experiment, if adequately documented, may yield a far-reaching insight into the processes determining weather and climate." Thus well said is the need to *observe* vigilantly the consequences of man's consumption of fossil fuels—coal, oil, and natural gas—and the concomitant return of vast amounts of carbon to the atmosphere in the form of carbon dioxide.

Left unstated, however, is perhaps the greater need to *anticipate* the consequences of this process well enough in advance to keep them within acceptable limits. The urgency stems from the uncontrolled manner in which the "experiment" is being conducted. The release of fossil carbon as CO_2 has been increasing at an exponential rate since the beginning of the industrial revolution about 100 years ago (Fig. 1). As a result the concentration of CO_2 in the atmosphere, which thus far has grown only about 12%, may double in the next 60 years or so. The effects may well become visible suddenly and, because of the great momentum developed by the machinery that produces man's energy, could grow out of control before remedial actions become effective.

The principal effect of an increased concentration of CO_2 in the atmosphere should be a warming (Schneider 1975). While CO_2 is transparent to the incoming solar radiation, it absorbs a portion of the infrared radiation returned to space by the Earth. This "greenhouse effect" has given the words themselves a rather specialized meaning. The amount of warming produced by a given increase is, as we shall see, still quite uncertain, involving as it does all the complexities of the world climate. Yet the impacts of increased atomspheric CO_2 on man's environment could be large indeed, rendering this a problem in impact assessment of unprecedented scope and difficulty.

This matter has been considered extensively in the current literature by climatologists (e.g. Mitchell 1972, 1975; Schneider 1975), geochemists (e.g. Broecker 1975; Keeling, in press), and biologists (e.g. Reiners et al. 1973), but not often in all its important aspects. In the present article we shall attempt to consider these and especially the important uncertainties that presently limit the reliability of impact assessment. Effective remedial actions, if and when they become necessary, quite obviously cannot be expected unless and until their need can be foretold with a reliability that will match the considerable costs of their implementation.

The growth of atmospheric CO_2

Since the beginning of accurate and regular measurements in 1958, the concentration of CO_2 in the atmosphere has shown an accelerating increase upon which is superimposed annual fluctuations from photosynthesis and other seasonal effects (Fig. 2). The current average value is about 330 ppm, compared to estimated preindustrial values between 290 and 300 ppm (Callendar 1958). The measurements in Figure 2 were taken at Mauna Loa Observatory (3,400 m elevation) in Hawaii and were corrected for any temporary disturbances from local sources. Measurements at Point Barrow, Alaska, from aircraft over Sweden, and at the South Pole all show quite clearly the same secular increase (Machta et al. 1976).

The excess of the annual average concentration over the preindustrial value has grown about 4% per year (lower curve in Fig. 3). Over the same period the cumulative amount of CO_2 produced by the burning of fossil carbon (upper curve in Fig. 3) has been about twice as great as the atmospheric increase and has shown a similar rate of growth. (Except for brief interruptions during the two

C. F. Baes, H. E. Goeller, and J. S. Olson are, respectively, members of the Chemistry Division, the Program Planning and Analysis Office, and the Environmental Sciences Division of Oak Ridge National Laboratory. R. M. Rotty is a member of the Institute for Energy Analysis, Oak Ridge Associated Universities. The paper is an adaption of a report entitled "The Global Carbon Dioxide Problem" (U.S. Energy Research and Development Report ORNL-5194). The research was sponsored by the Energy Research and Development Administration under contract with Union Carbide Corporation. During the course of this review, the authors have benefited greatly from discussions with a number of individuals; they wish especially to thank W. Broecker, of the Lamont-Doherty Geological Observatory; V. Ramanathen, of the National Center for Atmospheric Research; L. Machta, Director of the Air Resources Laboratories, NOAA; J. M. Mitchell, of the Environmental Data Service, NOAA; S. Manabe, of the Geophysical Fluid Dynamics Laboratory, NOAA; and G. Marland, Oak Ridge Associated Universities. Address: Oak Ridge National Laboratory, or, for R. M. Rotty, Oak Ridge Associated Universities, Oak Ridge, TN 37830.

Carbon dioxide and climate: the uncontrolled experiment

Baes Jr., C.F., Goeller, H.E., Olson, J.S., Rotty, R.M.
1977 - American Scientist
65(3), pp. 310-320

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Trabalhos primordiais...modelagem

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According to Revelle and Suess (1957), "Human beings are now carrying out a large-scale geophysical experiment of a kind that could not have happened in the past nor be repeated in the future. Within a few centuries we are returning to the atmosphere and oceans the concentrated organic carbon stored in the sedimentary rocks over hundreds of millions of years. This experiment, if adequately documented, may yield a far-reaching insight into the processes determining weather and climate." Thus well said is the need to *observe* vigilantly the consequences of man's consumption of fossil fuels—coal, oil, and natural gas—and the concomitant return of vast amounts of carbon to the atmosphere in the form of carbon dioxide.

Left unstated, however, is perhaps the greater need to *anticipate* the consequences of this process well enough in advance to keep them within acceptable limits. The urgency stems from the uncontrolled manner in which the "experiment" is being conducted. The release of fossil carbon as CO_2 has been increasing at an exponential rate since the beginning of the industrial revolution about 100 years ago (Fig. 1). As a result the concentration of CO_2 in the atmosphere, which thus far has grown only about 12%, may double in the next 60 years or so. The effects may well become visible suddenly and, because of the great momentum developed by the machinery that produces man's energy, could grow out of control before remedial actions become effective.

The principal effect of an increased concentration of CO_2 in the atmosphere should be a warming (Schneider 1975). While CO_2 is transparent to the incoming solar radiation, it absorbs a portion of the infrared radiation returned to space by the Earth. This "greenhouse effect" has given the words themselves a rather specialized meaning. The amount of warming produced by a given increase is, as we shall see, still quite uncertain, involving as it does all the complexities of the world climate. Yet the impacts of increased atomspheric CO_2 on man's environment could be large indeed, rendering this a problem in impact assessment of unprecedented scope and difficulty.

This matter has been considered extensively in the current literature by climatologists (e.g. Mitchell 1972, 1975; Schneider 1975), geochemists (e.g. Broecker 1975; Keeling, in press), and biologists (e.g. Reiners et al. 1973), but not often in all its important aspects. In the present article we shall attempt to consider these and especially the important uncertainties that presently limit the reliability of impact assessment. Effective remedial actions, if and when they become necessary, quite obviously cannot be expected unless and until their need can be foretold with a reliability that will match the considerable costs of their implementation.

The growth of atmospheric CO_2

Since the beginning of accurate and regular measurements in 1958, the concentration of CO_2 in the atmosphere has shown an accelerating increase upon which is superimposed annual fluctuations from photosynthesis and other seasonal effects (Fig. 2). The current average value is about 330 ppm, compared to estimated preindustrial values between 290 and 300 ppm (Callendar 1958). The measurements in Figure 2 were taken at Mauna Loa Observatory (3,400 m elevation) in Hawaii and were corrected for any temporary disturbances from local sources. Measurements at Point Barrow, Alaska, from aircraft over Sweden, and at the South Pole all show quite clearly the same secular increase (Machta et al. 1976).

The excess of the annual average concentration over the preindustrial value has grown about 4% per year (lower curve in Fig. 3). Over the same period the cumulative amount of CO_2 produced by the burning of fossil carbon (upper curve in Fig. 3) has been about twice as great as the atmospheric increase and has shown a similar rate of growth. (Except for brief interruptions during the two

C. F. Baes, H. E. Goeller, and J. S. Olson are, respectively, members of the Chemistry Division, the Program Planning and Analysis Office, and the Environmental Sciences Division of Oak Ridge National Laboratory. R. M. Rotty is a member of the Institute for Energy Analysis, Oak Ridge Associated Universities.
The paper is an adaption of a report entitled "The Global Carbon Dioxide Problem" (U.S. Energy Research and Development Report ORNL-5194). The research was sponsored by the Energy Research and Development Administration under contract with Union Carbide Corporation. During the course of this review, the authors have benefited greatly from discussions with a number of individuals; they wish especially to thank W. Broecker, of the Lamont-Doherty Geological Observatory; V. Ramanathen, of the National Center for Atmospheric Research; L. Machta, Director of the Air Resources Laboratories, NOAA; J. M. Mitchell, of the Environmental Data Service, NOAA; S. Manabe, of the Geophysical Fluid Dynamics Laboratory, NOAA; and G. Marland, Oak Ridge Associated Universities.
Address: Oak Ridge National Laboratory, or, for R. M. Rotty, Oak Ridge Associated Universities, Oak Ridge, TN 37830.

The impact on climate to be expected from a particular stimulus has been deduced from models developed over the last several decades, from simple one-dimensional radiation-balance models of the Earth's atmosphere to quite complicated so-called general circulation models that include the circulation of the atmosphere in three dimensions. Such models indicate an increase in temperature with increased CO_2 and suggest that the temperature response is approximately logarithmic, i.e. each doubling in the concentration of CO_2 produces about the same increase in the average temperature of the troposphere. The more sophisticated models predict, moreover, that the temperature change is much greater at high latitudes. The amount of the average increase in temperature per doubling

Carbon dioxide and climate: the uncontrolled experiment

Baes Jr., C.F., Goeller, H.E., Olson, J.S., Rotty, R.M.
1977 - American Scientist
65(3), pp. 310-320

Trabalhos primordiais...modelagem

1977

HOW LONG IS COAL'S FUTURE?*

RALPH M. ROTTY and ALVIN M. WEINBERG
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Abstract. Nearly all scenarios for future U.S. energy supply systems show heavy dependence on coal. The magnitude depends on assumptions as to reliance on nuclear fission, degree of electrification, and rate of GNP growth, and ranges from 700 million tons to 2300 million tons per year. However, potential climate change resulting from increasing atmospheric carbon dioxide concentrations may prevent coal from playing a major role. The carbon in the carbon dioxide produced from fossil fuels each year is about 1/10 the net primary production by terrestrial plants, but the fossil fuel production has been growing exponentially at 4.3% per year. Observed atmospheric CO_2 concentrations have increased from 315 ppm in 1958 to 330 ppm in 1974 – in 1900, before much fossil fuel was burned, it was about 290–295 ppm. Slightly over one-half the CO_2 released from fossil fuels is accounted for by the increase observed in the atmosphere; at present growth rates the quantities are doubling every 15–18 years. Atmospheric models suggest a global warming of about 2 K if the concentration were to rise to two times its pre-1900 value – enough to change the global climate in major (but largely unknown) ways. With the current rate of increase in fossil fuel use, the atmospheric concentration should reach these levels by about 2030. A shift to coal as a replacement for oil and gas gives more carbon dioxide per unit of energy; thus if energy growth continues with a concurrent shift toward coal, high concentrations can be reached somewhat earlier. Even projections with very heavy reliance on non-fossil energy (Neihaus) after 2000 show atmospheric carbon dioxide concentrations reaching 475 ppm.

How long is coal's future?
Rotty, R.M., Weinberg, A.M.
1977 - **Climatic Change**
1(1), pp. 45-57

Editorial da "Climate Change"...políticas públicas

1977

EDITORIAL FOR THE FIRST ISSUE OF CLIMATIC CHANGE

Climatic Change is a new journal designed to provide a means of exchange among researchers from a variety of disciplines who are working on problems related to climatic variations. *Climatic Change* will give authors an opportunity to communicate the essence of their studies both to researchers in other climate-related disciplines and to interested non-disciplinarians, who might be unable to follow the details of new results published in highly technical journals. The intention of this exchange will be to stimulate interdisciplinary interest that will lead to new research possibilities and will help to define and sharpen issues that have a climatic component – issues that could also relate ultimately to public policy questions.

Researchers from any discipline – meteorology, anthropology, medicine, agricultural science, economics, ecology, etc. – are invited to submit articles about work related to any aspect of climatic change that would be of interest to specialists in at least two disciplines. *Articles should be written at a level that is professional though not specialized.*

The other important objectives of *Climatic Change* are perhaps less directly related to issues of climatic variations, but are, nonetheless, of considerable importance to the general progress of interdisciplinary research. One such objective is to define and maintain

Editorial for the first issue of climatic change
Schneider, S.H.
1977 - Climatic Change
1(1), pp. 3-4

Trabalhos primordiais...geoengenharia

1977

ON GEOENGINEERING AND THE CO_2 PROBLEM

CESARE MARCHETTI
International Institute for Applied Systems Analysis, Laxenburg, Austria

Abstract. The problem of CO_2 control in the atmosphere is tackled by proposing a kind of 'fuel cycle' for fossil fuels where CO_2 is partially or totally collected at certain transformation points and properly disposed of.

CO_2 is disposed of by injection into suitable sinking thermohaline currents that carry and spread it into the deep ocean that has a very large equilibrium capacity.

The Mediterranean undercurrent entering the Atlantic at Gibraltar has been identified as one such current; it would have sufficient capacity to deal with all CO_2 produced in Europe even in the year 2100.

1. Introduction

The problem of climatological effects of CO_2 has recently attracted much attention, but the related question of how much fossil fuel we can still burn without burning our fingers is yet open. It may turn out that burning fossils 'à gogo' will have no really important consequences at least for our generation; yet reports on the subject, following the spirit of the time perhaps, tend to be more and more pessimistic [1, 2].

The first order effects are thought to be caused by the intense absorption bands of this gas in the infrared window of the atmosphere, i.e. in the region between approximately 8μ and 12μ. Calculations show that the isotropic scattering and absorption-re-emission of infrared radiation by CO_2 molecules in the atmosphere reduce the diffusiveness of infrared radiation, consequently producing a so-called greenhouse effect (greenhouses do in fact operate on different principles).

As water is competing with CO_2 in the same window, the effect will be larger where water concentration is lowest; this is so in the anticyclonic areas over the deserts, for example, and especially over the poles where due to the very low temperatures the water content is at a minimum. This can produce a second order effect, namely a decreased horizontal lapse rate between the poles and the equator, which would directly influence the circulation cells and the precipitation regime.

A third order effect may come from the increased photosynthetic rate of plants for which atmospheric CO_2 tends to be a limiting factor [3, 4]. This increase may induce a higher level of plant coverage, thus tendentially decreasing the earth's albedo and consequently working in much the same way as the greenhouse effect but with a concentrated influence upon temperate zones and tropical savannas.

An increase in temperature in the polar regions would bring about a similar positive feedback as it would induce a reduction in the snow cover and floating ice coverage, thus reducing the albedo and increasing the energy input.

These effects have been analyzed mainly at the level of total energy balance [1] with

Climatic Change 1 (1977) 59–68.

On **geoengineering** and the CO2 problem
Marchetti, C.
1977 - Climatic Change
1(1), pp. 59-68

Geoengenharia

3. CO_2 Transportation

CO_2 can be easily compressed to a liquid of 60–70 atm at room temperature. This liquid has a low viscosity and pumps like water. It can be transported in pipelines that are essentially the same as those for methane.

The high pressures needed to carry CO_2 in a liquid form, even if it is moderately chilled, make the use of normal oil tankers improbable. But the problem has not been examined in detail and simple tricks may be discovered to do that. Solid CO_2, for example, can be piled on barges.

For the sake of the discussion I will assume that only liquid CO_2 is carried overland in pipelines. I am also confident that the cost of transporting it anywhere will finally be lower than the cost of 'forward' fuel transportation which could be taken as a reference.

4. CO_2 Disposal

This could be done in the form of a permanent underground storage, e.g. by using exhausted gas fields. This possible storage of liquid CO_2 at pressure lower than 100 atm guarantees a large storage capacity than for the original methane, although the solubility of CO_2 in water and the solubilization of carbonate rocks do not guarantee a similar

Trabalhos primordiais...reconhecendo a existência do problema

1978

ATMOSPHERIC CARBON DIOXIDE

Possible Consequences of Future Fossil Fuel Use*

Ralph M. ROTTY

*Institute for Energy Analysis, Oak Ridge Associated Universities, Oak Ridge, TN 37830, U.S.A.***

Accurate and regular measurements of the concentration of CO_2 in the atmosphere during the past 20 years show an accelerating increase. Although clearing of tropical forests has released large amounts of carbon to the atmosphere, evidence is strong that a major contributor is the combustion of fossil fuels. Future energy demands
exploitation of fossil fuels, and projections show tha
fuel alternatives, the atmospheric concentration will d
require serious attention:
- The developing countries will require vastly incre
develop suitable (inexpensive) non-fossil energy so
demand are required.
- The distribution of carbon released from fossil fu
among the reservoirs of the carbon cycle must be be
- Uncertainties regarding the effect of the increased c
global climate must be reduced.
- Possible political and social responses to a substant
to more fully understand all of the implication of in

1. Introduction

The release of carbon as CO_2 as a
increasing at an exponential rate for more
continues, the concentration of CO_2 in the atmosphere may be doubled in the next 60 years or so. The effects on global climate may well become apparent suddenly, and because of the great momentum developed by the machinery that produces man's energy, could grow out of control before remedial actions become effective.

Because the amount of carbon contained in easily accessible fossil fuels is so vast, there is great temptation to use these resources as a source of energy

*This paper was originally prepared for and at the request of the Committee on Health and Ecological Effects of Increased Coal Utilization, a national advisory committee mandated by the United States National Energy Plan submitted to Congress by President Carter in 1977.

**Operated by the U.S. Department of Energy under contract number EY-65-C-05-0033. The work on which this paper is based was supported by DOE Assistant Secretary for Environment.

As these reserves are used, an increase in concentration of CO_2 in the atmosphere will surely result; and because CO_2 absorbs a portion of the infrared radiation emitted by the Earth, it is generally believed that a warmer global climate will result. Although the amount of warming produced by a given increase is uncertain, the impact of increased atmospheric CO_2 on man's environment could be quite large. The potential CO_2 problem may present a challenge of unprecedented scope and difficulty.

Atmospheric carbon dioxide. Possible consequences of future fossil fuel use
Rotty, R.M.
1978 - Resources and Energy
1(3), pp. 231-249

Trabalhos primordiais...abordagem interdisciplinar

1981

SOCIETAL RESPONSE TO CO_2-INDUCED CLIMATE CHANGE: OPPORTUNITIES FOR RESEARCH

RICHARD A. WARRICK
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and
WILLIAM E. RIEBSAME
Climate and Society Research Group, Center for Technology, Environment and Development, Clark University, Worcester, MA 01610, U.S.A.

Abstract. How might a climate change, induced by increased CO_2 in the atmosphere, affect societies? What is the range of existing and potential mechanisms for societal response? And how might research contribute to a reduction of the adverse impact (or enhancement of the unique opportunities) of a climate change by providing greater understanding of the processes involved in climate and society interaction? This paper reflects an initial effort to shed light on these questions. It offers first a framework for identifying key issues in climate-society interaction; eight major questions are suggested by the framework. A discussion of each major question is then presented with the purpose of reviewing the current state of knowledge, identifying the gaps in understanding, and offering opportunities for research to fill those gaps. In all, twenty-two research needs are outlined and are summarized at the conclusion of the paper. The perspective is interdisciplinary, but the review draws heavily from the geographic literature, reflecting the disciplinary bias of the autho

0. Climate and Society Relationships

Initially, we would like to comment on recent
As the need for, and interest in, climate impac
last several years, a flurry of research activi
oftentimes rely upon a rather simple concept
would like to term 'neo-environmental deter
conceptual model which depicts a one-way
environment, if you will) and human activit
of society can be traced to the classical Greeks, a resurgence of intellectual environmental determinism was strongly evident in the first decades of the 20th century. Ellsworth Huntington, a geographer, was noteworthy as the spokeperson for this view, as reflected in his *Civilization and Climate* (1915). This view assumes that climate is the independent variable whose explanatory power is pervasive in understanding social structure, settlement patterns, and human behavior. The arguments led easily into racial or cultural stereotyping (the tropical climate fosters lazy, unmotivated peoples, and the midlatitude regimes promote vigorous, industrious humans), and finally to explanations of the differences in the global patterns of economic development we see today. These views fell out of intellectual favor as being too simplistic and mechanistic, and largely disappeared (at least in their overt form) for many decades. With the recent concern over CO_2 and other

Climatic Change 3 (1981) 387–428. 0165–0009/81/0034–0387$04.20.

Second, because of the complexity and holistic character of the CO_2 issue, disciplinary research foci have only limited application. Interdisciplinary communication and research are central to progress in understanding climate-society interaction in general and CO_2-induced climate change in particular. The research opportunities suggested herein reflect this view.

Societal response to CO2 -induced climate change:
Opportunities for research
Warrick, R.A., Riebsame, W.E.
1981-Climatic Change
3(4), pp. 387-428

Pós-Graduação
Programas em Energia (PPGE) e Ciência Ambiental (PROCAM)

IEE USP

PROCAMUSP

USP

Trabalhos primordiais...impactos econômicos

1982

ECONOMIC IMPACT ANALYSIS AND CLIMATE CHANGE:
A CONCEPTUAL INTRODUCTION

V. KERRY SMITH*
Dept. of Economics, University of North Carolina at Chapel Hill, N.C. 27514, U.S.A.

1. Introduction

analysis in estimating the economic consequences of climate change. It will be argued that there is a variety of special features of climate change that require substantial amendments to, or indeed complete replacement of, these traditional methodologies. Unfortunately, the 'social science machinery' necessary to address these problems is simply not available at the present time. That is, we do not have two important ingredients to making progress with these questions: (1) a sufficient community of social scientists with knowledge of climatic system to appreciate the problems of economic impact analyses for climate change; and (2) an accumulated set of research information directed toward evaluating the implications of climate for economic activities and social structures. As a consequence, in considering the prospects for the development of a capacity to perform economic impact analyses of changes or variations in climate we must address both issues purely associated with economic methodology and those of an institutional nature pertaining to the development of a social science research community in this area. The primary focus of this paper is on the methodological issues.

Climatic Change 4 (1982) 5–22. 0165–0009/82/0041–0005$01.80.

Chama a atenção para a necessidade de cientistas que possam analisar os impactos econômicos e sobre a importância de pesquisas sobre o tema.

Economic impact analysis and climate change: A conceptual introduction
Smith, V.K.
1982-Climatic Change
4(1), pp. 5-22

Trabalhos primordiais...captura de carbono

1995

**GLOBAL FOREST SYSTEMS:
AN UNCERTAIN RESPONSE TO ATMOSPHERIC POLLUTANTS
AND GLOBAL CLIMATE CHANGE?**

ROBERT K. DIXON[1] AND JOE WISNIEWSKI[2]

[1]U.S. Support for Country Studies to Address Climate Change, PO-63, 1000 Independence Avenue, SW, Washington, DC 20585 USA, [2]Wisniewski and Associates, Inc., 6862 McLean Province Circle, Falls Church, VA 22043 USA

Abstract. Forest systems cover more than 4.1 x 10^9 ha of the Earth's land area. The future response and feedbacks of forest systems to atmospheric pollutants and projected climate change may be significant. Boreal, temperate and tropical forest systems play a prominent role in carbon (C), nitrogen (N) and sulfur (S) biogeochemical cycles at regional and global scales. The timing and magnitude of future changes in forest systems will depend on environmental factors such as a changing global climate, an accumulation of CO_2 in the atmosphere, and increase global mineralization of nutrients such as N and S. The interactive effects of all these factors on the world's forest regions are complex and not intuitively obvious and are likely to differ among geographic regions. Although the potential effects of some atmospheric pollutants on forest systems have been observed or simulated, large uncertainty exists in our ability to project future forest distribution, composition and productivity under transient or nontransient global climate change scenarios. The potential to manage and adapt forests to future global environmental conditions varies widely among nations. Mitigation practices, such as liming or fertilization to ameliorate excess NO_x or SO_x or forest management to sequester CO_2 are now being applied in selected nations worldwide.

Key words: carbon, nitrogen, sulfur, biogeochemistry, mitigation, global change

1. Introduction

Globally, forests cover 4.1 x 10^9 ha of the Earth's land surface with approximately 13% of the forests protected by governments and less than 10% actively managed (Sharma, 1992). The largest area of forests (42%) is in low latitudes, where more than half are in tropical America. Mid-latitude forest make up approximately 25% of the global total. Russia has the largest area of forests, approximately 21% of the global forest area. Brazil is next with approximately 10% of the total. Forest systems play a prominent role in global carbon (C), nitrogen (N) and sulfur (S) cycles, as well as response and feedbacks to atmospheric pollutants and global climate change. Given our current understanding of atmospheric pollutants, global change, and global biogeochemical cycles, the prospect for managing forest systems to mitigate or ameliorate adverse impacts are promising.

Forest systems are concomitantly influenced by changes in atmospheric chemistry, land use and global climate (Melillo, 1995; Dixon *et al.*, 1994; Skelly and Innes, 1994). Recent analyses suggest that current atmospheric CO_2 increases could lead to global warming of between 0.2^0 and 0.3^0 per decade in the next century (IPCC, 1995). Shifts in the area distribution and productivity of forest systems are predicted in response to global climate change (Smith *et al.*, 1993). Changes in atmospheric chemistry, such as observed increases in CO_2 (Keeling and Wharf, 1994) and N compounds (Melillo, 1995)

Water, Air and Soil Pollution **85**: 101–110, 1995.

Global forest systems: An uncertain response to atmospheric pollutants and global climate change?
Dixon, R.K., Wisniewski, J.
1995 - Water, Air, & Soil Pollution
85(1), pp. 101-110

Trabalhos primordiais...modelagem

2000

letters to nature

Acceleration of global warming due to carbon-cycle feedbacks in a coupled climate model

Peter M. Cox*, Richard A. Betts*, Chris D. Jones*, Steven A. Spall* & Ian J. Totterdell†

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† Southampton Oceanography Centre, European Way, Southampton SO14 3ZH, UK

Here we present results from a fully coupled, three-dimensional carbon–climate model, indicating that carbon-cycle feedbacks could significantly accelerate climate change over the twenty-first century. We find that under a 'business as usual' scenario, the terrestrial biosphere acts as an overall carbon sink until about 2050, but turns into a source thereafter. By 2100, the ocean uptake rate of 5 Gt C yr^{-1} is balanced by the terrestrial carbon source, and atmospheric CO_2 concentrations are 250 p.p.m.v. higher in our fully coupled simulation than in uncoupled carbon models[2], resulting in a global-mean warming of 5.5 K, as compared to 4 K without the carbon-cycle feedback.

Descobrimos que, em um cenário "business as usual", a biosfera terrestre atua como um sumidouro global de carbono até cerca de 2050, mas se transforma em uma fonte a partir de então.

Acceleration of global warming due to carbon-cycle feedbacks in a coupled climate model
Cox, P.M., Betts, R.A., Jones, C.D., Spall, S.A., Totterdell, I.J.
2000 - Nature
408(6809), pp. 184-187

IEE USP

Pós-Graduação

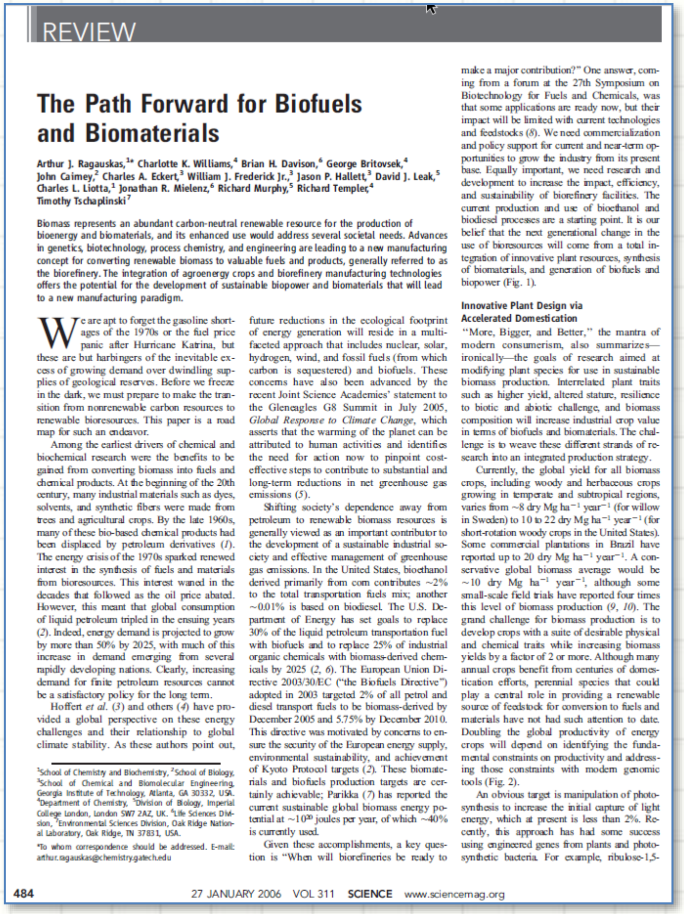
Programas em Energia (PPGE) e Ciência Ambiental (PROCAM)

PROCAMUSP

USP

Trabalhos primordiais...busca por soluções/alternativas

2006



REVIEW

The Path Forward for Biofuels and Biomaterials

Arthur J. Ragauskas,[1*] Charlotte K. Williams,[4] Brian H. Davison,[6] George Britovsek,[4] John Cairney,[2] Charles A. Eckert,[3] William J. Frederick Jr.,[3] Jason P. Hallett,[3] David J. Leak,[5] Charles L. Liotta,[1] Jonathan R. Mielenz,[6] Richard Murphy,[5] Richard Templer,[4] Timothy Tschaplinski[7]

Biomass represents an abundant carbon-neutral renewable resource for the production of bioenergy and biomaterials, and its enhanced use would address several societal needs. Advances in genetics, biotechnology, process chemistry, and engineering are leading to a new manufacturing concept for converting renewable biomass to valuable fuels and products, generally referred to as the biorefinery. The integration of agroenergy crops and biorefinery manufacturing technologies offers the potential for the development of sustainable biopower and biomaterials that will lead to a new manufacturing paradigm.

484 27 JANUARY 2006 VOL 311 SCIENCE www.sciencemag.org

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REPORTS

Ethanol Can Contribute to Energy and Environmental Goals

Alexander E. Farrell,[1*] Richard J. Plevin,[1] Brian T. Turner,[1,2] Andrew D. Jones,[1] Michael O'Hare,[2] Daniel M. Kammen[1,2,3]

To study the potential effects of increased biofuel use, we evaluated six representative analyses of fuel ethanol. Studies that reported negative net energy incorrectly ignored coproducts and used some obsolete data. All studies indicated that current corn ethanol technologies are much less petroleum-intensive than gasoline but have greenhouse gas emissions similar to those of gasoline. However, many important environmental effects of biofuel production are poorly understood. New metrics that measure specific resource inputs are developed, but further research into environmental metrics is needed. Nonetheless, it is already clear that large-scale use of ethanol for fuel will almost certainly require cellulosic technology.

506 27 JANUARY 2006 VOL 311 SCIENCE www.sciencemag.org

The path forward for biofuels and biomaterials
Ragauskas, A.J., Williams, C.K., Davison, B.H., (...), Templer, R., Tschaplinski, T.
2006 - Science
311(5760), pp. 484-489

Ethanol can contribute to energy and environmental goals
Farrell, A.E., Plevin, R.J., Turner, B.T., (...), O'Hare, M., Kammen, D.M.
2006-Science
311(5760), pp. 506-508

Trabalhos atuais...captura de carbono

2011

A Large and Persistent Carbon Sink in the World's Forests

Yude Pan,[1]* Richard A. Birdsey,[1] Jingyun Fang,[2,3] Richard Houghton,[4] Pekka E. Kauppi,[5] Werner A. Kurz,[6] Oliver L. Phillips,[7] Anatoly Shvidenko,[8] Simon L. Lewis,[7] Josep G. Canadell,[9] Philippe Ciais,[10] Robert B. Jackson,[11] Stephen W. Pacala,[12] A. David McGuire,[13] Shilong Piao,[2] Aapo Rautiainen,[5] Stephen Sitch,[7] Daniel Hayes[14]

The terrestrial carbon sink has been large in recent decades, but its size and location remain uncertain. Using forest inventory data and long-term ecosystem carbon studies, we estimate a total forest sink of 2.4 ± 0.4 petagrams of carbon per year (Pg C year^{-1}) globally for 1990 to 2007. We also estimate a source of 1.3 ± 0.7 Pg C year^{-1} from tropical land-use change, consisting of a gross tropical deforestation emission of 2.9 ± 0.5 Pg C year^{-1} partially compensated by a carbon sink in tropical forest regrowth of 1.6 ± 0.5 Pg C year^{-1}. Together, the fluxes comprise a net global forest sink of 1.1 ± 0.8 Pg C year^{-1}, with tropical estimates having the largest uncertainties. Our total forest sink estimate is equivalent in magnitude to the terrestrial sink deduced from fossil fuel emissions and land-use change sources minus ocean and atmospheric sinks.

Forests have an important role in the global carbon cycle and are valued globally for the services they provide to society. International negotiations to limit greenhouse gases require an understanding of the current and potential future role of forest C emissions and sequestration in both managed and unmanaged forests. Estimates by the Intergovernmental Panel on Climate Change (IPCC) show that the net uptake by terrestrial ecosystems ranges from less than 1.0 to as much as 2.6 Pg C year^{-1} for the 1990s (*1*). More recent global C analyses have estimated a terrestrial C sink in the range of 2.0 to 3.4 Pg C year^{-1} on the basis of atmospheric CO_2 observations and inverse modeling, as well as land observations (*2*–*4*). Because of this uncertainty and the possible change in magnitude over time, constraining these estimates is critically important to support future climate mitigation actions.

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A large and persistent carbon sink in the world's forests
Pan, Y., Birdsey, R.A., Fang, J., (...), Sitch, S., Hayes, D.
2011 - Science
333(6045), pp. 988-993

Trabalhos atuais...impactos

2018

REVIEW SUMMARY

OCEANS

Declining oxygen in the global ocean and coastal waters

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BACKGROUND: Oxygen concentrations in both the open ocean and coastal waters have been declining since at least the middle of the 20th century. This oxygen loss, or deoxygenation, is one of the most important changes occurring in an ocean increasingly modified by human activities that have raised temperatures, CO_2 levels, and nutrient inputs and have altered the abundances and distributions of marine species. Oxygen is fundamental to biological and biogeochemical processes in the ocean. Its decline can cause major changes in ocean productivity, biodiversity, and biogeochemical cycles. Analyses of direct measurements at sites around the world indicate that oxygen-minimum zones in the open ocean have expanded by several million square kilometers and that hundreds of coastal sites now have oxygen concentrations low enough to limit the distribution and abundance of animal populations and alter the cycling of important nutrients.

ADVANCES: In the open ocean, global warming, which is primarily caused by increased greenhouse gas emissions, is considered the primary cause of ongoing deoxygenation. Numerical models project further oxygen declines during the 21st century, even with ambitious emission reductions. Rising global temperatures decrease oxygen solubility in water, increase the rate of oxygen consumption via respiration, and are predicted to reduce the introduction of oxygen from the atmosphere and surface waters into the ocean interior by increasing stratification and weakening ocean overturning circulation.

In estuaries and other coastal systems strongly influenced by their watershed, oxygen declines have been caused by increased loadings of nutrients (nitrogen and phosphorus) and organic matter, primarily from agriculture; sewage; and the combustion of fossil fuels. In many regions, further increases in nitrogen discharges to coastal waters are projected as human populations and agricultural production rise. Climate change exacerbates oxygen decline in coastal systems through similar mechanisms as those in the open ocean, as well as by increasing nutrient delivery from watersheds that will experience increased precipitation.

Expansion of low-oxygen zones can increase production of N_2O, a potent greenhouse gas; reduce eukaryote biodiversity; alter the structure of food webs; and negatively affect food security and livelihoods. Both acidification and increasing temperature are mechanistically linked with the process of deoxygenation and combine with low-oxygen conditions to affect biogeochemical, physiological, and ecological processes. However, an important paradox to consider in predicting large-scale effects of future deoxygenation is that high levels of productivity in nutrient-enriched coastal systems and upwelling areas associated with oxygen-minimum zones also support some of the world's most prolific fisheries.

OUTLOOK: Major advances have been made toward understanding patterns, drivers, and consequences of ocean deoxygenation, but there is a need to improve predictions at large spatial and temporal scales important to ecosystem services provided by the ocean. Improved numerical models of oceanographic processes that control oxygen depletion and the large-scale influence of altered biogeochemical cycles are needed to better predict the magnitude and spatial patterns of deoxygenation in the open ocean, as well as feedbacks to climate. Developing and verifying the next generation of these models will require increased in situ observations and improved mechanistic understanding on a variety of scales. Models useful for managing nutrient loads can simulate oxygen loss in coastal waters with some skill, but their ability to project future oxygen loss is often hampered by insufficient data and climate model projections on drivers at appropriate temporal and spatial scales. Predicting deoxygenation-induced changes in ecosystem services and human welfare requires scaling effects that are measured on individual organisms to populations, food webs, and fisheries stocks; considering combined effects of deoxygenation and other ocean stressors; and placing an increased research emphasis on developing nations. Reducing the impacts of other stressors may provide some protection to species negatively affected by low-oxygen conditions. Ultimately, though, limiting deoxygenation and its negative effects will necessitate a substantial global decrease in greenhouse gas emissions, as well as reductions in nutrient discharges to coastal waters. ■

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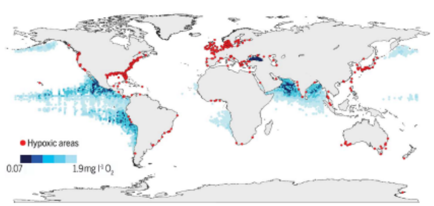

Low and declining oxygen levels in the open ocean and coastal waters affect processes ranging from biogeochemistry to food security. The global map indicates coastal sites where anthropogenic nutrients have exacerbated or caused O_2 declines to <2 mg liter^{-1} (<63 μmol liter^{-1}) (red dots), as well as ocean oxygen-minimum zones at 300 m of depth (blue shaded regions). [Map created from data provided by R. Diaz, updated by members of the GO_2NE network, and downloaded from the World Ocean Atlas 2009].

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