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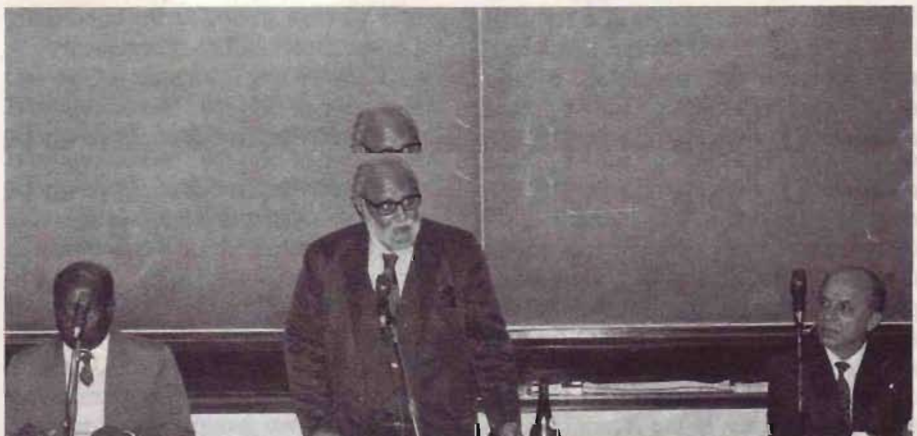
Round Table Conference on Scientific Brain Drain in the Third World and in Central and Eastern Europe

The Round Table Conference on Scientific Brain Drain in the Third World and in Central and Eastern Europe was held on 25-26 March at the International Centre for Theoretical Physics in Trieste. Prof. Abdus Salam, Director of the ICTP, inaugurated the two-day Round Table Conference in which he had invited thirty personalities from the Third World, Central and Eastern Europe and international organizations to discuss the scientific brain drain to the developed world. The speakers overviewed the problems of brain drain in Science & Technology and put forward some important recommendations on how to stop the brain drain from the developing countries to the developed countries.

Prof. Abdus Salam, in his introductory speech said, "People are the ultimate source and beneficiary of all human activities. It has been estimated that human potential, capital, particularly in the developed world, represent more than half of the wealth of nations. This is intangible wealth, created through investments in education, health, various social aims, as compared to tangible wealth which includes means of production like machines, tools, raw materials etc. Science & Technology has been the highest, most pronounced achievement of human creation and the source of all the wealth, including the most modern, tangible ones, because the most efficient machines, tools etc. incorporate more and more Science & Technology (as a human creation). That is why all societies interested in progress devote the utmost attention to human capital, scientists and technologists in particular."



Professor Abdus Salam Director, International Centre for Theoretical Physics, inaugurated the Round Table Conference on Scientific Brain Drain the the Third World and Central and Eastern Europe on 25th March, 1991, in the Main Lecture Hall of the ICTP. Prof. D. Ekong is on the left and Prof. A. Hamoui on the right.

Increasing internationalization, globalization and interdependence have been the prominent features of the world of today, quickly affecting all aspects of human activities. This is demonstrated by increased trade in goods and services, movement of capital, Science & Technology (both directly or as incorporated in goods and services) and especially in the circulation of people — migrations, temporary international contacts, tourists and, unfortunately, as refugees.

Checking the brain drain to the "reversed transfer of technology" from the poor nations to the more advanced ones, the recent emigration waves from Mediterranean and developing countries as well as from Central and Eastern Europe to the West has called for the attention of governments in the West. In particular, the re-organization of science academies and universities in Eastern Europe after 1989 is such that a large number of active scientists will no longer be employed by their former organizations and forced to either leave their country or leave their profession.

The brain drain is a serious problem, especially in the Third World countries, not merely because of better attractions elsewhere, but also of bureaucratic and administrative control, lack of high-quality facilities, absence of peer appraisal and of social respect. There is a small percentage of GNP allocated for Science & Technology and R&D in the Third World countries, and the amount allocated for R&D per scientists and engineers is much less than in the West.

The South Commission has demanded increases in the allocation of GNP for R&D to 1% on average (much more in some countries) i.e., a little more than doubling the current allocation. In the case of scientists and more than doubling the current allocation. In the case of scientists and engineers the request is higher. Both components of the recommendation are interconnected, meaning a substantial push for S&T in the South. At the same time, this may serve not only as an anti-brain-drain action but may also contribute in some cases to the reversal of that trend, even to the return of some scientists from abroad.

Prof. Salam suggested a few remedies that should be taken as anti-brain-drain.

1. Like the one pioneered by the Associateship Scheme of the ICTP here in Trieste.
2. TWAS has a number of schemes designed to encourage scientists from the South to pursue research in their own countries.
3. Another scheme is TOKTEN, devised by UNDP.
4. The privately-run Foundation for Science, organised by expatriate scientists could greatly help their home countries. Even without the Foundation for Science, individual scientists could help their own countries.
5. Finally, another instrument can be the creation of a commonwealth of science on a regional or subregional basis.

He strongly pointed out that nobody has the right, under the pretext of national interest, to keep scientists at home without giving them conditions for optimum scientific achievements.


A glimpse of the audience.

Dr. D. Ekong (Secretary General, Association of African Universities) and Dr. O. Moretto (President, Academy of Association of African Universities) and Dr. O. Moretto (President, Academy of Sciences, Argentina) stressed the problem of brain drain in Science & Technology in Latin America. Latin America is composed of 19 countries, including Cuba and Dominican Republic and excluding the Caribbean. Possibly one could divide Latin American countries in two groups — one is more advanced in S&T like Argentina, Brazil and Mexico, and another is least advanced countries such as Bolivia, Paraguay and some Central American countries. The brain drain of Latin America is as serious as in the Third World. Argentina devotes a little over 0.5% of its GNP to research and development.

Prof. A. Papić (former member of the South Commission), Prof. A. Hamoui (Kuwait University, Kuwait) and Dr. V. Kuzminov (Director, UNESCO-ROSTE, Venice) read out the overview of the South, North, Central and East European brain drain in Science & Technology.

In the morning session of March 26, the case studies of the Third World analyzed the situation of scientific brain drain in various selected countries like Bangladesh, Sri Lanka, Morocco, focusing on the origin and amplitude of the phenomenon, and its effect on the scientific and economic impoverishment of these countries. Prof. J.N. Islam (Bangladesh) and Prof. V.K. Samaranayake (Sri Lanka) delivered their papers to overview the scientific brain drain in S&T of these countries.

One session was dedicated to the presentation of various modalities to counteract the scientific brain drain. presentation of various modalities to counteract the scientific brain drain. Prof. L. Bertocchi, (Deputy Director ICTP), Prof. M.H.A. Hassan (Executive Secretary, Third World Academy of Sciences) and Dr. B. Jerman Blazic (Institute Jozef Stefan, Yugoslavia) were the speakers of this session and presented their papers.

After each presentation, there was ample time for open discussion. Ideas and proposals were debated in the last session which had been scheduled for drawing the conclusions of the conference and setting up recommendations for the follow-up.

The recommendations are:

a. Measures should be taken by the governments in the South to stop the migration of highly-qualified scientists and technologists to the developed world by improving their working conditions and involving them fully in national development programmes. Governments should have full confidence in their own scientists and technologists who in several cases have demonstrated better abilities than many of the foreign scientific and technical expertise hired as consultants.

b. To counteract this brain drain, building of appropriate institutions in the South needs to be vigorously pursued at all levels of scientific education, training and research. This will require rebuilding the scientific infrastructure in schools and universities and ensuring the availability of equipment and scientific literature.

c. The establishment of world-class research and training institutions in the South in critical areas, such as food security, energy supply, tropical diseases, soil erosion, deforestation and desertification, are vital to the survival and credibility of the developing nations.

d. In addition, an international effort is needed to establish high-level research and training centres in key areas of frontier science and high technology such as molecular biology, biotechnology, informatics and new materials.

e. A major effort should be made to fully mobilize competent research and training institutions within the South to train scientists from other countries with poorer facilities. To further facilitate the development of human resources, a massive regional scholarship programme should be sponsored by governments of the South and donor agencies to enable sponsored by governments of the South and donor agencies to enable students to pursue training in institutions in the South with adequate facilities and infrastructure.

f. There is an urgent need to identify and nurture young talented students with exceptional scientific ability. To facilitate this, institutes for talent searching and development need to be established in the South. Such institutes can organize regional programmes like school olympiads to identify and encourage talented students. It can also sponsor a system of élite schools and colleges as well as specialized courses in basic sciences to nurture gifted students to develop their talent.

g. Measures should be taken by governments to promote strong linkages between research institutions, industry and agriculture with the aim of involving scientists and technologists in the major production sectors of the country.

ICTP Dirac Medals

The 1990 Dirac Medals of the International Centre for Theoretical Physics (ICTP), Trieste (Italy), have been awarded to Prof. Ludwig Dmitriyevich Faddeev (Steklov Mathematical Institute, Leningrad, USSR) and Sidney Richard Coleman (Harvard University, Cambridge, Massachusetts, USA).

Ludwig Dmitriyevich Faddeev is honoured for researches in the area of quantum field theory and mathematical physics. His name is well known in theoretical physics in connection with the Three Body System (Faddeev's equation). He made decisive contributions to the quantization of the Yang-Mills and gravitational field. The Faddeev-Popov covariant prescription of quantization of non-Abelian gauge theories discovered in 1966-67 has many essential applications including quantum effects in the Glashow-Salam-Weinberg model of electroweak interactions and in quantum chromodynamics. Faddeev is a disciple of Dirac's ideas in theoretical physics. His studies are related with the evolution of the Dirac Hamiltonian interpretation in the inverse scattering method (1971) and with exact integrable systems, as well as with quantum theory of solitons (1975). He also clarified the group-theoretical origin of anomalies in the context of cocycles (1984). His works stimulated the wide-spread the context of cocycles (1984). His works stimulated the wide-spread application of solitons in relativistic quantum field theory. Faddeev's contributions to the quantum inverse scattering method and 4-matrix theory initiated the development of this direction which is now known as the Quantum Group Approach. His scientific work significantly contributed to the broad extent of geometrical and algebraic ideas in modern theoretical and mathematical physics.

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Life of Prof. Faddeev

Prof. Ludwig Dmitriyevich Faddeev was born in Leningrad on March 23, 1934. He graduated from Leningrad State University in 1956. He received his Ph.D. in 1956 and degree of doctor of sciences in 1963 at Steklov Mathematical Institute of the USSR Academy of Sciences. Prof. Faddeev permanently works at Leningrad Department of Steklov Mathematical Institute. He started as a Research Associate (1960), Senior Research Associate (1964), then became leader of the Laboratory of Mathematical Methods of Physics (1974) and Deputy Director for the Leningrad Department of Steklov Institute in 1976. He was appointed as Professor at the Department of Mathematical and Mathematical Physics in 1967. Ludwig D. Faddeev is a member of the USSR Academy of Sciences (1976), Member of the American Academy of Science and Art at Boston (1979), President of the International Union of Mathematics (1986), Honorary Member of the Academy of Science of Poland (1987), Doctor Honoris Causa of Universities at Nankai and Buenos Aires (1987 and 1988), Foreign Member of the Academy of Science and Literature of Finland (1988). He has published more than 150 scientific articles and five books. He is a member of the editorial board of several international journals. Honours bestowed include: USSR State Prize (1971) and Danny Heinemann Prize on Mathematical Physics (1975).

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Dirac Medal Award Ceremony

On Tuesday, 23rd April 1991, Professor Ludwig D. Faddeev (Steklov Mathematical Institute, Leningrad, USSR) received the 1990 Dirac Medal which had been awarded to him last year. The other 1990 Dirac Medal will be presented to Prof. Sidney Richard Coleman (Harvard University, Cambridge, Massachusetts, USA) during Coleman (Harvard University, Cambridge, Massachusetts, USA) during the 1991 Summer School in High Energy Physics and Cosmology. These two Medals are awarded every year on 8th August, birthday of P.A.M. Dirac.

Professor Abdus Salam, Director of ICTP, was not there to preside over the ceremony, as he was travelling abroad for urgent work. Prof. Stig Lundqvist, Chairman of the Scientific Council of the ICTP, chaired the function. He paid a tribute to the memory of Dirac. As a student he had found Dirac's book on quantum mechanics very difficult to understand. He discovered that this book contained the seeds for topological methods in quantum field theory, for magnetic monopoles and also for the quantum Hall effect — topic closer to

Professor Ludwig D. Faddeev receiving the Dirac Medal from Prof. L. Bertocchi, Deputy Director, ICTP.

his own research field. Early papers of Dirac were seminal to the path integral method. Prof. Lundqvist introduced him as the man who has bridged mathematics and theoretical physics in a most fruitful way and also as a very helpful colleague in the international work.

Prof. L. Bertocchi, Deputy Director of the ICTP, had the pleasant occasion of presenting the golden medal and a cheque of US$5,000, on behalf of Professor Abdus Salam, to Prof. Faddeev. Prof. Faddeev introduced the subject of his lecture "Dirac's Generalized Dynamics and Gauge Field Theory". He felt himself as a disciple of Dirac. He decided to work on the quantization of gauge fields since he finished his research on the quantum three-body problem, the results of which had brought him in the limelight of theoretical physics towards the end of theoretical physics towards the end of the fifties. Quantum field theory which had produced a successful theory of quantum electrodynamics, failed when it was extended to particles other than the electron.

Many theoreticians had abandoned it and turned to different approaches like the S-matrix theory, encouraged by W. Heisenberg, or to dispersion relations. Only a few obstinately persevered in this direction. These included Dirac himself and Gell-Mann. Faddeev was not influenced by the Yang-Mills theory which was not related to physical activities, but he was struck by a statement of Hermann Weyl: "Electrodynamics is a geometrical theory in the charged space". Another element which encouraged him to work on gauge field theory was a book by A. Lichnerowicz on the theory of global conversion and holonomy discovered eventually in a bookshop in Leningrad. His research with the geometrical approach absorbed his energy for many years and it took twenty square metres of a blackboard filled with Lagrangians and other formulas and fifty minutes to summarize it to the audience.

The Dirac Medal lecture will be published in the next ICTP newsletter.

Dr. Khursheed Awarded Salam Prize

Courtesy of
Higher Education News,
February 1991.

Dr. Khursheed Hassan, Professor of Physics, Quaid-i-Azam University, Islamabad, was awarded the Salam Prize for the year 1990, for his research on "Magnetic Properties of Superconductors at High Temperatures". The award-giving ceremony which was organized by the University Grant Commission and Salam Prize Committee, was held at Islamabad College for Girls, F-6/2, on December 23, 1990.

Dr. Khursheed Hassan's research could help produce fast computers and fast railway trains with the use of magnetic properties. Loss of electricity in transmission could also be saved by utilisation of high research.

Dr. Khursheed Hassan is the fourth from Quaid-i-Azam University to receive the Salam Prize which is given in rotation to people who make exceptional contribution in the field of Mathematics, Physics, Chemistry or Biology.

Dr. Khursheed Hassan, who was awarded a cash prize of $1000, opined that one could work wonder even in bad conditions, with determination and a strong sense of commitment.

Symposium on Geometry and Physics, Edinburgh

A Symposium on Geometry and Physics was held in Edinburgh, UK, from 19 to 28 March, 1991. This conference was the first scientific activity of the International Centre for Mathematical Sciences which was set up in Edinburgh with the co-operation of the ICTP, for the benefit of mathematical scientists throughout the world. The aims of this venture will be very similar to those of the Trieste centre.

International Prize "Primo Rovis" 1991

On the occasion of its tenth anniversary, the Trieste International Foundation for Scientific Progress and Freedom has instituted a prize to be awarded to a candidate who has notably contributed to the diffusion of scientific culture: a contribution according to the aims of the didactic activities and cultural services which the Laboratorio dell'Immaginario Scientifico has been carrying out according to the National Programme for the diffusion of scientific Programme for the diffusion of scientific culture and information.

Over the last few years, the problem of scientific communication has attracted the interest of the whole world, and in particular Europe and Italy. Nowadays, the need for the diffusion of science and history of science is deeply felt, not only by the scientific community.

The Trieste International Foundation for Scientific Progress and Freedom, presided over by the Nobel Laureate Professor Abdus Salam, Director of the International Centre for Theoretical Physics (ICTP), has instituted an international prize on the occasion of its tenth anniversary. The Prize is meant for scientists who have effectively worked on this very important and topical cultural activity, whether in Italy or abroad.

The Prize, instituted out of the generosity of businessman Primo Rovis and worth US$ 20,000 per year, is a token of the role which Trieste is playing in Italy and Europe in the field of scientific culture.

The Prize Committee, presided over by Prof. Salam and composed of representatives of international repute from local universities and research institutions, has awarded the Prize to Prof. Richard Langton Gregory with the following citation: *"Founder of "The Exploratory" in Bristol (UK); international promoter of the development of interactive didactics in scientific museums; First President of the European Consortium of Science Industry and Technology Exhibitions; scientist, epistemological writer, promoter of new concepts in scientific museology".*

The presentation ceremony took place on 19 March, 1991, at the Laboratorio dell'Immaginario Scientifico, within the framework of the "National Week of Scientific Culture". Many personalities from the political, economic, cultural and scientific sectors were attending.

After this first edition, the Foundation intends to disseminate the announcement of the Prize to all scientific institutions and museums both in Italy and abroad, so as to receive information on the work of scientists and/or qualified managers in the selected scientific field, and to draw the attention of these institutions and museums on the initiatives taken up by the City of Trieste through the Primo Rovis Prize.

The Greenhouse Effect and Global Warming

Prof. Sir John Mason, guest scientist of the Third World Academy of Sciences (TWAS) and Royal Society Lectureship Programme, presented a paper on the greenhouse effect and global warming at the Adriatico Lecture Hall on Thursday 18 April, 1991. This lecture described how increasing levels of carbon dioxide and other 'greenhouse' gases, such as methane and CFCs, are likely to affect the global climate over the next 50-100 years. The estimates are based on the predictions of the largest computer models of the world's climate which are presently not in sufficient agreement to provide governments with firm scientific guidance for remedial action.

Research in the next ten years will therefore concentrate on improving the complex physics of these models which involve both the oceans and the atmosphere. A pre-requisite will be a greatly improved supply of world-wide observations to feed and validate the models, and to detect any actual climatic changes that may be attributed to the greenhouse effect.

Sir John Mason was Professor of cloud physics and a colleague of Professor Abdus Salam at Imperial College in the 1960's. In 1965 he became Director-General of the UK Meteorological Office and retired from there in 1983. During that period he was also Senior vice-President and Treasurer of the Royal Society for ten years.

Since retirement, he has been very busy — he says has four half time jobs. He is Chancellor of the University of Manchester Institute of Science and Technology, as well as Director of the Anglo-Scandinavian research programme on acid rain which involves some 300 scientists from 30 research institutions in a six-year major study, now almost completed. He is Chairman of the Co-ordinating Council for Marine Science and Technology charged with producing a national strategy for all activities in this field ranging from oceanography, fisheries, North Sea oil and gas, marine biology. He was Chairman of the International Committee for planning the World Climate Reserch Programme for six years. His latest job is Scientific Adviser to the new Global Environment Research Centre at Imperial College, London.

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The Greenhouse Effect and Global Warming

Sir John Mason

Lecture presented at the Royal Society on November 5th, 1990.

Summary

Atmospheric concentrations of greenhouse gases such as water vapour, carbon dioxide and methane affect the radiative heat balance and surface temperature of the Earth. On present trends, increases in carbon dioxide and the other greenhouse gases are together likely to approximate to a doubling of the present concentration of carbon dioxide by the year 2060. The effects of such a perturbation on the global climate are estimated using large, complex computer models designed to simulate the present climate and its natural variations, and to predict future changes, whether natural or man-made. Current best estimates, based on coupled atmosphere-ocean models, indicate that a doubling of carbon dioxide would produce an average global surface temperature rise of 2.5°C and a rise in sea level of 50 cm.

However, the model predictions are sensitive to rather small changes in the properties of clouds and their influence on radiation, so that the treatment of

Sir John Mason, guest scientist of TWAS and Royal Society Lectureship Programme, presented a paper at the Adriatico Guest House Lecture Hall on 18th April, 1991.

these and other feedback mechanisms will have to be improved in order to reduce the uncertainties of current predictions and provide firmer scientific guidance for remedial action.

The oceans will almost certainly reduce and delay any global warming because of their large capacity to absorb heat and about half of the carbon dioxide emitted into the atmosphere. This may largely explain why it is not yet possible to detect a clear signal that can be confidently ascribed to greenhouse warming rather than to natural climate fluctuations.

1. Introduction

The greenhouse gases, especially water vapour and carbon dioxide, play a crucial role in regulating the temperature of the Earth and its atmosphere. In the absence of these gases, the average surface temperature would be -19°C instead of the present value of +15°C, and the Earth would be a frozen, lifeless planet. There is now concern that atmospheric temperatures will rise further, due to the steadily increasing concentration of carbon dioxide resulting largely from the burning of fossil fuels. The concentration is now 27% higher than that which prevailed before the industrial revolution, and is increasing at 0.5% p.a. It is expected to reach double the 1860 value during the second half of the next century. Recently we have become aware that other strongly absorbing gases, notably methane, nitrous oxide, ozone and chlorofluorocarbons (CFCs) are adding to the greenhouse warming and may, by the middle of the next century, contribute about half as much again as the increase in carbon dioxide.

Higher temperatures will be accompanied by changes in other climate Higher temperatures will be accompanied by changes in other climate parameters such as precipitation, cloudiness, soil moisture and snow cover and may, eventually, result in significant expansion of the oceans and melting of the mountain glaciers, and hence a rise in sea level.

Although the climate changes and their economic and their social effects are likely to vary seasonally, and geographically from region to region, and even from country to country, the overall problem of man-induced climatic change is a global one, whose thorough study is beyond the resources of any one country. It follows that national research programmes should be planned largely as contributions to international projects, such as the World Climate Research Programme and the World Ocean Circulation Experiment, described by Mason et al. (1987).

2. The global budget of carbon dioxide

In order to estimate more accurately the future concentration of atmospheric carbon dioxide, it will be necessary to study and understand in more detail the complete carbon cycle. The problem is that partition of the added man-made carbon dioxide between the atmosphere, oceans and biosphere, involves difficult estimates of small differences between large two-way fluxes between enormous reservoirs (...).

The total atmospheric reservoir of carbon dioxide is equivalent to 743 GtC (gigatonnes of carbon: 1 gigatonne = 10^9 = 1 billion tonnes) which is much smaller than 1760 GtC for the terrestrial biosphere, of which about 560 GtC is stored in trees and plants, and is tiny compared with the 39,000 GtC in the oceans. The atmospheric concentration is therefore susceptible to rather small changes in the fluxes between these reservoirs. The current rate of emission of carbon dioxide from the burning of fossil fuels is 5.4 GtC/yr, whilst the net emissions due to deforestation and changes in land use are estimated at 1.6 GtC/yr. These are small compared with the fluxes exchanged between the atmosphere and the Earth's surface, which exceed 200 GtC/yr. The atmosphere retains about 3.4 GtC/y (almost 50% of the emissions) leaving 3 GtC/yr to be taken up by the oceans. The net fixation of carbon dioxide by photosynthesis, largely by phyto-plankton growing in the top 100 m or so of ocean is about 100 GtC/yr, about the same as for the terrestrial biosphere. Most of this is released by respiration the same as for the terrestrial biosphere. Most of this is released by respiration and returns to the atmosphere, but some is dissolved in the ocean and some is converted into inorganic carbon in the skeletons and faeces of zooplankton and falls to the ocean floor.

Models of the ocean uptake suggest that it can accept about 1.8 GtC/yr, so that there is an apparent imbalance of about 1.6 GtC/yr. This is a measure of the uncertainty in current understanding of the global budget of atmospheric carbon dioxide. Either there are some as yet unidentified mechanisms for removing carbon dioxide from the atmosphere, or the amount of carbon dioxide released by tropical deforestation has been greatly over-estimated, and/or our quantitative knowledge of the known mechanisms is unsatisfactory. Nevertheless relatively minor adjustments in the world ocean circulation and chemistry are likely to affect significantly the amount of carbon dioxide added each year to the atmosphere, even if emissions are stabilized. In particular, ocean warming is likely to decrease the net uptake of carbon dioxide by sea water. Until this problem is resolved, predictions of the proportion of future emissions of carbon dioxide retained in the atmosphere will be subject to considerable uncertainty. However, an even larger uncertainty lies in the future global rate of increase of combustion of fossil fuels and wood, for which estimates range from less than 2% per annum to double this figure.

3. Carbon dioxide in the atmosphere

Analysis of air bubbles trapped in the deep interiors of glaciers reveals that the atmospheric concentration of carbon dioxide in the last Ice Age was about 210 ppmv. The value at the beginning of the industrial revolution is estimated at 275 ppm and to have increased by 15% over the following 100 years to reach 316 ppm in 1960. Since accurate and continuous measurements were started in 1958, the concentration has risen at an ever-increasing rate which is currently very nearly 0.5% p.a. The present concentration of 354 ppm is 27% above the 1860 value. If the concentration were to continue to increase at the present rate (0.5% p.a.), it would double its pre-industrial value by 2080, and double its present value by 2130 A.D. However, it is likely that the increase will continue to accelerate, particularly if the world's population continues to increase at the current rate, and may reach double the present value, continues to increase at the current rate, and may reach double the present value, i.e.700 ppm, in 80-130 years, depending on the future rate of burning fossil fuels and wood and the extent to which carbon dioxide is taken up and stored in the oceans and by trees and vegetation through photosynthesis.

4. The effect of carbon dioxide and water vapour on the radiation budget of the atmosphere

(...) Of the short-wave solar radiation incident on the top of the atmosphere (a global annual average of 340 W/m^2) about 17% is reflected back to space by clouds, 8% is back-scattered by the air, and 6% reflected by the Earth's surface, to give a planetary albedo of 31%.

About 19% is absorbed by water vapour, ozone and dust and about 4% by clouds as the radiation passes through the atmosphere, so only 46% is absorbed at the surface. This is transferred to the atmosphere as infra-red radiation (a net 15 units where 100 units represents the incoming solar radiation), as sensible heat (7 units), leaving 24 units to evaporate water which later condenses to form clouds and a global annual average rainfall of 104 cm.

Considering now the balance of the long-wave radiation (...), of the 115 units (390 W/m^2) emitted by the Earth's surface, only 9 are transmitted through the atmospheric window to space, the other 106 being absorbed by the atmosphere, mainly by water vapour, carbon dioxide and ozone. This absorption of the up-welling long-wave radiation, plus that from the incoming solar radiation (19 units), plus the sensible heat flux (7 units), total 132 units to which must be added a net contribution of (24 + 4 - 20 = 8) units from clouds. Of this total heat input of 140 units, the atmosphere emits 40 to space and 100 (340 W/m^2) to the surface, the net long-wave radiative flux from the surface to the atmosphere being only 15 units. The net absorption of infra-red radiation by the greenhouse gases is the difference between the 115 units of outgoing radiation from the Earth's surface and the 69 units emitted at the top of the atmosphere, i.e. 46 units or 154W/m^2.

In the absence of absorbing greenhouse gases (mainly water vapour and carbon dioxide), the equilibrium black-body surface temperature, T_e, of the planet, assuming it to have an albedo of $\alpha = 0.31$, is given by the equation

equation

$$4\pi a^2 \cdot \sigma T_e - \pi a^2 S(1\text{-}\alpha)$$

or

$$T_e = \left[\frac{S(1-\alpha)}{4\sigma}\right]^{\frac{1}{4}} = 254°K$$

where σ is Stefan's constant, S the solar constant and a the radius of the planet.

The intensity of the emitted radiation would be only 236 W/m 2 compared with the actual value of 390 W/m^2, which again implies that the combined contribution of the greenhouse gases is 154 W/m^2. About 100 W/m^2 are calculated to come from water vapour and about 50 W/m^2 from carbon dioxide.

Both water vapour and carbon dioxide absorb infra-red over a range of wavelengths, and the relatively high concentrations of these two gases ensure that many of the spectral lines are saturated, and any increase in absorption from an increase in their concentration is limited to the wings of the absorption lines. Thus, while the present concentration of carbon dioxide (354 ppmv) produces a downward atmospheric flux of 50 W/m^2, a near doubling to 600 ppmv would increase the flux by only 3 W/m^2 and raise the surface temperature by only 0.9°K in the absence of feedback effects due to water vapour, clouds, ice, etc. The quantitative impact of the various feedback mechanisms in the global climate system can be estimated only from the results of large, complex models described in Section 7.

However, a simple calculation for a climate system in thermal equilibrium indicates that the concomitant increase in water vapour would amplify the temperature rise due to carbon dioxide by a factor of 1.6 to 1.4°K. On the same basis, the enhancement of carbon dioxide since 1860 should have produced a warming of about 0.5°K.

5. The role of the other greenhouse gases

Although water vapour and carbon dioxide are the main cause of the greenhouse effect, any gas that absorbs in the infra-red will help to reduce the loss of terrestrial radiation to outer space. However, absorbtion by water vapour and carbon dioxide is so strong that other gases will contribute little unless they absorb at wavelengths, mainly from 8 microns to 12 microns (the atmospheric 'window'), where absorption by carbon dioxide and water is weak.

absorption by carbon dioxide and water is weak.

The most important of the trace gases which contribute significantly to the trapping of terrestrial radiation, despite their small concentrations, are methane, nitrous oxide and the chlorofluorocarbons, especially CCl_3F (F11) and CCl_2F_2 (F12). Methane concentrations are only about 0.5% of those of carbon dioxide, but are 21 times as effective molecule for molecule as carbon dioxide as an absorber of terrestrial radiation. CFCs are only one-millionth as abundant as carbon dioxide but 14,000 times more effective.

Methane, currently at 1750 ppbv, is increasing at about 1% annually, and is expected to double in about 70 years. Various sources of methane have been identified but not quantified. These include emissions from ruminants, rice paddies, waste disposal sites and oil recovery operations. Doubling methane would have about 15% of the warming effect of doubling carbon dioxide.

Nitrous oxide, currently at 300 ppbv, is increasing at 0.25% per annum for largely unknown reasons. It is formed primarily as a product of bacterial denitrification but also in combustion processes. It is likely to increase by about 20% by 2060, contributing in the meantime about 4% to the total greenhouse warming.

Table 1 shows the present concentrations of CFCs in the atmosphere and their contributions to global warming to be about 0.2 W/m^2 or 12%. The trace gases combined now contribute about half as much again as carbon dioxide to greenhouse warming.

Even if CFC emissions are reduced, the concentrations may continue to rise because F11 and F12 have atmospheric lifetimes of 80 and 140 years, respectively. If the Montreal Agreement to reduce emissions to 80% of 1986 levels from 1993, and to 50% from 1998, is fully implemented, CFCs are likely to contribute almost 10% to greenhouse warming in 2060.

A simple radiative calculation with no feedbacks would suggest that those greenhouse gases together, should have

no feedbacks would suggest that those greenhouse gases together, should have

produced a global warming of 0.7°K relative to 1765, but enhanced to 1.1°K by the concomitant increase in water vapour. A corresponding calculation of the present warming relative to 1900 gives 0.85°K, very close to the best estimate obtained from advanced models

TABLE 1. - GLOBAL WARMING BY GREENHOUSE GASES IN 1990 RELATIVE TO 1765.

	CO_2	CH_4	N_2O	CFC_{11}	CFC_{12}	$HCFC_{22}$
Concentrations (1765)	279	790	285	0	0	0
Concentration (1990)	354	1720	310	280	480	320
	ppm	ppb	ppb	ppt	ppt	ppt
Increased heat flux	1.5	0.42	0.10	0.06	0.14	0.08
$\Sigma = 2.30\ W/m^2$						
% contributions	66	18	4		12	

of 0.9°K. However, this agreement is probably fortuitous as the simple calculations ignore all feedbacks except that due to water vapour.

6. Is greenhouse warming apparent in the observations?

The above estimate that the climate should have warmed by almost 1°K since 1900 prompts one to examine the observed average global temperature record which (...) indicates a rise of about 0.5°K over the last 90 years. However, it is unlikely that this can be attributed to the greenhouse effect for the following reasons:

- 0.3°K of the 0.5°K rise occurred between 1900 and 1940 when carbon dioxide was increasing at only 0.1% per annum, compared with the current rate of 0.5%.
- there was a small fall in temperature between 1940 and the mid 1960s, widely claimed by the media and some scientists in the 1970s to herald a new Ice Age!
- despite the rather sharp rise during the last decade in average global air temperatures, this has not occurred in high latitudes, nor has there been any significant decrease in the ice cover, although all the models predict greatest greenhouse warming in the Arctic.

The timing of the fluctuations in the temperature record, and the fact that greenhouse warming is likely to be delayed for some decades because of the thermal inertia of the oceans (...) strongly suggest that these are natural climatic fluctuations.

If we assume that this is indeed the case, we may use a coupled atmosphere-ocean model to estimate how long it will take for a greenhouse signal of, say, 0.5°K to be detectable. The only published account (Manabe et al. 1990) 0.5°K to be detectable. The only published account (Manabe et al. 1990) of a coupled atmosphere-deep ocean model, in which carbon dioxide is allowed to increase at 1% per annum compound and so double in 70 years, predicts an average global temperature rise of 2-3°K, a rise of 0.5°K occurring after 20 years.

7. Model simulations and predictions of climate change

7.1 Introduction

Changes in global and regional climates due to greenhouse gases will be small, slow and difficult to detect above natural fluctuations during the next 10 to 20 years. It will therefore be necessary to rely heavily on model predictions of changes in temperature and rainfall, ice cover, etc. Indeed, in the absence of any direct evidence, concern over the greenhouse effect is based almost entirely on model predictions, which unfortunately vary so widely that they do not yet provide a sufficiently firm basis for government action.

Climate models, ranging from simple one-dimensional energy-balance models to enormously complex, three-dimensional global models requiring vast computing power, have been developed during the last 20 years, the most advanced at three centres in the USA, and at the UK Meteorological Office.

Until recently, effort was concentrated on developing models (that evolved from weather prediction models) of the global atmosphere coupled to the oceans and cryosphere (sea and land ice) only through prescribing and up-dating surface parameters such as temperature and albedo, from observations. However, realistic predictions of long-term changes in climate, natural or man-made, must involve the atmosphere, oceans, cryosphere and, eventually, the biosphere, treated as a single, strongly coupled and interactive system. The oceans play a major, stabilizing role in global climate because of their inertia and heat storage capacity. Moreover, they transport nearly as much heat between the equator and the poles as does the atmosphere. The oceans absorb about half of the carbon dioxide emitted by fossil fuels and will hence delay warming of the atmosphere. The oceans also absorb and transport a good deal of the associated additional heat flux from the atmosphere.

The Meteorological Office has developed perhaps the most advanced model of the global atmosphere coupled developed perhaps the most advanced model of the global atmosphere coupled to simple models of the ocean, land and sea ice, and has used these to study the effects of nearly doubling the present level of carbon dioxide to 600 ppmv.

7.2 The atmospheric model

The physico-mathematical models of the atmosphere are based on the physical and dynamical laws that govern the birth, growth, decay and movement of the main weather systems that can be resolved by the model. In other words, the models must properly represent the relevant or significant scales of motion and their non-linear reactions, but smooth out all the smaller scale motions that cannot be adequately observed or represented individually, while allowing for their overall contribution to transport and energy conservation processes by representing their statistically averaged properties in terms of larger-scale parameters that can be measured. The parameterization of these sub-grid scale processes is one of the most difficult and uncertain features of weather and climate models, and occupies a good deal of the present research effort.

The models incorporate the principles of conservation of mass, momentum, energy and water in all its phases, the Newtonian (Navier-Stokes) equations of motion applied to a parcel of air, the laws of thermodynamics and radiative transfer, and the equation of state of humid air. Parameters specified in advance include the size, rotation, geography and topography of the Earth, the incoming solar radiation and its diurnal and seasonal variations, the radiative and heat conductive properties of the land surface according to the nature of the soil, soil moisture, vegetation and snow or ice cover, all of which are computed every 5 days.

The atmosphere is divided into 11 concentric shells (11 levels) between the surface and 20 mb (approx 30 km) with 3 levels in the surface boundary layer (lowest km) to allow calculation of the surface fluxes of heat, moisture and momentum. There are also 3 levels in the soil to calculate the heat flux through the soil and hence the land surface temperature. The variables are calculated on a spherical grid with mesh 2.5 degrees latitude x 3.75 degrees longitude with some 30,000 points at each level, or about 350,000 points in all.

The main physical processes represented in the model are:
transfer of heat by:
represented in the model are:
transfer of heat by:

- – solar and terrestrial (infra-red) radiation, including absorption by the greenhouse gases water vapour, carbon dioxide, ozone and methane;
  – scattering and absorption by clouds;
  – reflection/absorption at the Earth's surface by soil, vegetation, snow, land and sea ice and by the oceans;
- shallow and deep convection;
- conduction at the Earth's surface;

the hydrological cycle:

- evaporation of moisture from land and water surfaces, condensation in the atmosphere to form clouds, rain and snow (precipitation), calculation of run-off and soil moisture;
- transport of heat, moisture and

momentum in the lowest atmospheric layers (atmospheric boundary layer) by small-scale turbulent motions;

- the frictional drag on the atmosphere exerted by mountains, the land surface, breaking gravity waves in the atmosphere, and by waves on the ocean surface.

Starting from initial values derived from observations on a particular day, the governing finite-difference equations are integrated in time-steps of 20 minutes to give new values of the following parameters at all the relevant grid points, which are then averaged to give monthly mean values over total integration times of years or decades.

The most important computed variables are:

E-W and N-S components of the wind,
Vertical motion,
Air temperature and humidity,
Heights of the 11 specified pressure surfaces,
Short-and long-wave radiation fluxes,
Cloud amount, height and liquid-water content,
Precipitation - rain/snow,
Atmospheric pressure at Earth's surface,
Land surface temperature,
Soil moisture content,
Snow cover and depth,
Sea-ice cover and depth,
Ice-surface temperature,
Sea-surface temperature.

The atmospheric model is coupled to a simple shallow well mixed ocean layer only 50 m deep, which transports heat horizontally and vertically and allows computations of the fluxes of heat, moisture and momentum between the ocean surface and the atmosphere. An energy-balance sea-ice model allows the areal cover, snowdepth and ice thickness to be calculated every 5 days and the areal cover, snowdepth and ice thickness to be calculated every 5 days and the albedo to decrease gradually as the ice melts and recedes. The surface temperature of the sea-ice is calculated from the heat balance equation at every model time step.

A 24 hour integration for the whole system involves about 10^{12} numerical operations, so that a complete annual cycle takes about 10 hours on the most powerful supercomputer, the CRAY YMP.

Such models have been remarkably successful in simulating the main features of the present global climate — the distribution of temperature, rainfall, winds, etc. — and their seasonal and regional variations. They do, however, contain some systematic errors (different in different models) and will require continued development and improvement in order to provide accurate simulations/predictions of the fractionally small but, nevertheless, potentially very important changes that may result from natural or man-made perturbations.

7.3 Model simulations for the doubling of carbon dioxide

The changes in global temperatures and precipitation to be expected from a near doubling of carbon dioxide to 600 ppm, as predicted by the Meteorological Office model before the recent changes in the treatment of clouds are described below (...). These changes, achieved when the climate system represented by the model has come into equilibrium with the enhanced atmospheric carbon dioxide, are the highest predicted by any of the advanced models. A detailed account is given by Wilson and Mitchell (1987). Although recent modifications to the cloud parameterisation scheme have produced smaller changes, these 'upper' estimates are presented here because they bring out more clearly the geographical and seasonal patterns of the changes which are not greatly altered in the newer simulations.

The global average temperature is increased by 5.2°K, accompanied by a 15% increase in both global precipitation and evaporation of water from the surface. Comparable results from other advanced models are shown in Table 2. The enhanced radiative heating of the surface due to increases in carbon dioxide and water vapour causes increased evaporation (which restricts the temperature rise), and produces a more intense globally-averaged hydrological cycle. Enhanced carbon dioxide causes increased emission of long-wave radiation from the top of the atmosphere to space and, consequently, a cooling of the stratosphere (...).

The zonally-averaged (along latitude bands) warming is generally most pronounced in high latitudes near the surface in winter because of several amplifying factors. Firstly, greenhouse warming reduces the highly reflecting snow and ice cover and leads to greater absorption of heat, which accelerates the retreat of the ice. Secondly, in high latitudes in winter, there is a shallow layer of cold, dense air near the surface (an inversion), which traps the increased radiative heating, whereas in the tropics and sub-tropics this is mixed through the whole depth of the atmosphere by deep convection, to produce a smaller warming. Thirdly, the warmer, moister atmosphere transports more latent energy upwards and polewards from the tropics, releasing additional latent heat by condensation in the middle and upper troposphere on the way. These positive feed-back effects, together, result in winter polar surface temperatures being increased by 12°K, compared with only 4°K in the tropics.

The simulated changes in

TABLE 2. – GLOBAL MEAN CHANGES CAUSED BY DOUBLING CO_2 AS PREDICTED BY VARIOUS MODELS UNDER EQUILIBRIUM CONDITIONS WITH DIFFERENT CLOUD SCHEMES.

All models consist of a global atmosphere with 9 to 11 levels and a shallow mixed-layer ocean with prescribed heat transport.

Model *Cloud* *Radiative properties* *Temperature* *Precipitation*

Model	*Cloud representation*	*Radiative properties of clouds*	*Temperature rise °K*	*Precipitation increase %*
UKMO (1)	Empirical-linked relative humidity. All-water clouds.	Fixed	5.2	15
UKMO (2)	Computed liquid water and ice content.	Fixed	3.2	8
UKMO (3)	"	Variable-function of water and ice content.	1.9	3
GFDL	Empirical-linked to relative humidity.	Fixed	4.0	8
GISS	"	Fixed	4.8	13
CCC	"	Variable	3.5	4

UKMO: UK Met Office.
GFDL: Geophysical Fluid Dynamics Laboratory, Princeton.
GISS: Goddard Institute of Space Studies.
CCC: Canadian Climate Centre, Toronto.

temperature also vary considerably with longitude and season. Greenhouse warming is greatest over sea-ice in winter, smallest over sea-ice in summer. In summer, sea-ice in the Arctic is maintained at constant temperature by melting. Greenhouse warming either produces more melting with no change of temperature, or melts sea ice completely to expose an oceanic mixed layer which warms only slowly because of its large thermal inertia. The additional heat stored in the mixed layer is released in autumn and winter, delaying the onset of freezing and leading to thinner sea ice through which heat from the ocean can diffuse more rapidly and enhance surface warming in winter. There is also considerable variation in the predicted greenhouse warming within individual continents. In regions where the soil becomes drier, evaporation may be restricted, leading to increased warming, and vice-versa.

The increase in atmospheric moisture accompanying the warming due to enhanced carbon dioxide would lead one to expect increased precipitation, especially in regions where the low-level winds converge to produce rising motions, notably in the extra-tropical depression belts and along the inter-tropical convergence zone. This is confirmed (...) by an increase in the summer monsoon rains over SE Asia. There is also a general increase in precipitation in high latitudes, especially in winter, consistent with increased transport of moisture from low latitudes. (There are) large areas of slightly decreased rainfall, especially in the sub-tropics in DJF and over Eurasia in the northern summer. These large-scale latitudinal and seasonal changes are broadly reproduced in the various models, but they show considerable differences in their predictions on the regional and small scales. Models of higher resolution and improved physics will be required to resolve these differences. This is important because global or zonal averages are of little use in assessing the effects of greenhouse warming on agriculture, forestry, energy consumption, water supply etc.

7.4 Sensitivity of models

It is important to note that the model results are quite sensitive to the representation of the many interacting physical processes, in particular, to the simulation of clouds and their influence on the incoming solar and outgoing terrestrial radiation, to the fluxes of heat and moisture between the oceans and the atmosphere, to the positive feedback between changes in ice cover and ocean or atmosphere temperature, and to changes between melting snow-cover and soil moisture.

This sensitivity of the model simulations, and the differences or inefficiencies of the various models in treating these physical processes, are largely responsible for the rather wide range of predicted changes of climatic parameters due to prescribed increases of carbon dioxide shown in Table 2.

Climate models are particularly sensitive to the parameterization of clouds, which may affect the computed equilibrium greenhouse warming by a factor of more than two. Important factors are the coverage, height and type of cloud; their optical thickness, reflectivity, absorptivity and emissivity, which are determined by the concentration and size of the droplets and ice particles. Depending on these factors, clouds can generate a feedback effect that is either positive or negative. Thus a relative increase in high cloud, which has a relatively low albedo and emits less radiation, tends to warm the atmosphere, whereas a relative increase in low cloud, with its higher albedo and larger emission of radiation to space, will have a cooling effect. Overall, clouds have a net cooling effect on the planet of about 15W/m^2 so that, on a simplistic view, doubling of carbon dioxide could be completely offset by a 20% increase in the present cloud distribution, but by a smaller percentage increase if this were mainly low cloud.

The recent introduction of a more realistic representation of clouds and their radiative properties in the Meteorological Office model has led to a marked reduction in the predicted warming due to enhanced carbon dioxide. For the model simulations described in the last section, the cloud cover was calculated from an empirical formula on the basis of the prevailing relative humidity, but the liquid-water content of the cloud and its detailed radiative properties were not computed.

The new version of the model calculates the liquid water content of the cloud as the difference between that formed by condensation in air cooled by vertical ascent and that released as precipitation. Also ice crystals are introduced above the -15°C level in concentrations which increase with introduced above the -15°C level in concentrations which increase with decreasing temperature. Furthermore, the different radiative properties of the water droplets and ice crystals are taken into account. These changes result in an atmosphere with doubled carbon dioxide producing an increase in low and medium-level cloud cover at middle latitudes, and a reduction in the global average greenhouse warming from 5.2°K to only 1.9°K (Mitchell et al. 1989). The end result is to change the Meteorological Office predictions from being the highest to the lowest of those shown in Table 2.

Other important feedback effects result from the melting and retreat of the ice and snow cover induced by greenhouse warming. As the highly

Sir John Mason presented a paper on the "Greenhouse effect and global warming" at the Adriatico Lecture Hall on Thursday 18th April, 1991.

reflecting sea ice retreats and is replaced by more strongly absorbing sea water, the latter is warmed, causes further melting of ice, and so enhances the greenhouse warming. The greenhouse warming also accelerates the melting and retreat of the snow cover at middle and high latitudes in the Spring. The newly exposed soil is then subject to greater warming and evaporation and the soil moisture is reduced.

The model simulations suggest that the combined effect of these various feedback mechanisms is to enhance the magnitude of the warming that would arise from the purely radiative effects of the greenhouse gases, including water vapour, by a factor of between 1.5 and 3.5, depending on the particular model used, and imply values for the global average warming for nearly doubling carbon dioxide to 600 ppmv of between 2°K and 5°K. By the time carbon dioxide reaches this concentration, the other greenhouse gases will have increased these figures by at least 50%, even if the Montreal Agreement is carried out.

Irrespective of the actual magnitudes of the climate changes predicted by the various models, it is important to realise that they involve only very small percentage changes in the normal radiative fluxes — much smaller than the errors in either measurements or calculations of these fluxes. We therefore have to rely on the assumption that systematic errors will be the same in the 'perturbed' and normal (control) models, and so disappear in the differences which may be attributed to the greenhouse effect.

Furthermore, these greenhouse 'signals' are comparable in magnitude with the inter-annual variations that occur both in the models and the real with the inter-annual variations that occur both in the models and the real atmosphere, so it is necessary to assess whether they are significant relative to the natural noise. Such statistical tests are made as a routine in the Meteorological Office model, the results described in Section 7 (...) being significant at the 90% confidence level.

7.5 Limitations and future model development

We have already intimated that current models contain some important deficiencies leading to uncertainty in the prediction of greenhouse effects which should therefore be taken as only broad indications of likely changes, giving little weight at this stage to the actual magnitudes, and even less to their significance on regional and smaller scales. The hope is that continued development of the different models will cause their predictions to converge, narrow the range of uncertainty, and thereby provide more reliable guidance for remedial action.

Improvements are likely to come mainly from better representation of the physical processes and greater spatial resolution. The former will require more intensive study of the processes in the real atmosphere using highly-instrumented research aircraft, radars, lasers, etc. Higher resolution, doubling of which increases the amount of computation at least 8-fold, requires greater computing power than is currently available. One therefore has to choose, or effect a compromise, between the need for high resolution and more detailed physics leading to greater accuracy on the one hand, and the need for long model runs to study inter-annual and longer-term variations in climate on the other.

These longer-term changes, on time-scales of decades to centuries, will be largely determined by the oceans, not only in the surface layers, but at depth. It is therefore necessary to develop fully 3-dimensional models of the global ocean circulation which are coupled to, and driven by, the winds of the atmospheric model. Such models are being developed in the USA and the Meteorological Office with encouraging success and should be ready to utilise data on sea-surface temperature, surface winds and wind stress, and circulations in the surface layers of the ocean, from the new oceanographic satellites in the early 1990s and beyond. However, as yet very few long-term integrations have been made with these fully-coupled models, which will require even more been made with these fully-coupled models, which will require even more computing power, especially if it proves necessary to resolve the ocean 'weather' systems such as gyres, eddies and fronts that are an order of magnitude smaller in linear dimension than their atmospheric counterparts.

The improvement of climate models will also depend on an adequate supply of observations from all parts of the climatic system, not least the atmosphere. These are required for input to, and initialization of, the models, for their validation, and for the detection and monitoring of climate changes in the climate system itself. Provision of these observations is one of the main functions of the World Climate Research Programme and the World Ocean Circulation Experiment, which were described by Mason (1987).

8. Time-dependent simulations of greenhouse warming — delaying effects of the oceans

Virtually all the model calculations on greenhouse warming to date have assumed that both the normal climate system (control model), and the system perturbed by enhanced levels of greenhouse gases, are in equilibrium at all stages. The carbon dioxide is doubled in one step and the model climate system is allowed to come into equilibrium with the new concentration. In the real world this will never be the case because the trace gases are increasing gradually with time and the response of the total climate system depends upon a variety of physical and bio-geochemical processes acting on widely different time scales. The atmosphere, together with the sea ice, the upper layers of the ocean, and the land-surface hydrology, respond quite rapidly and reach a quasi-equilibrium in the model after a few annual cycles. On the other hand, the deep ocean circulation and the land-based ice sheets respond much more slowly on time scales of hundreds of years, and so will constantly lag behind the response of the atmosphere.

The large thermal capacity of the oceans and their ability to store and transport some of the additional heat flux from the trace gases will delay the greenhouse warming but also ensure that temperatures will continue to rise long after any reduction in emissions takes place. This is probably the main reason why there is, as yet, no convincing observational evidence of temperature rises due to the gases accumulated so far.

The delaying effect of the oceans will rises due to the gases accumulated so far.
The delaying effect of the oceans will be determined by the net additional heat flux at the ocean surface produced by the greenhouse gases, and the effective heat capacity of the ocean, which is determined by the penetration of the heat below the surface. Initially the warming will involve only the well-mixed, stably stratified, 'warm water shell' down to a mean depth of 100 m or so and, even after 20 years, may involve only the top 500 m, as indicated by the observed penetration of tritium ejected into the atmosphere during the 1950s series of thermo-nuclear explosions.

The actual changes in climatic parameters for a given increase in greenhouse gas concentrations are therefore likely to be smaller than those predicted by the 'equilibrium' models, and to be delayed. More realistic estimates of the magnitude and timing of the greenhouse effects will require the concentrations of the gases to increase gradually at current or predicted rates, in a model which couples the atmosphere to a global deep ocean. Only a very few model simulations of this type have been published. The results of one experiment by Manabe et al. (1990), in which the carbon dioxide was increased at 1% per annum compound to double in 70 years, (...) plotting the increase in surface air temperatures over the globe, averaged over one annual cycle. The globally averaged value of 2.3°K is much lower than that obtained by all other advanced models, except the latest Meteorological Office version mentioned in Section 7. The reduced warming is especially marked in the Southern Hemisphere, which shows little enhanced warming in the Antarctic compared with that in the Arctic. This is explained by the vertical ocean circulation in the southern oceans, which produces a deep down-welling of water around 65 deg South that carries much of the additional greenhouse flux of heat from the surface to great depths (...) where it is stored for many decades. This very interesting result should be treated with caution, because this is only the first experiment with a model that, like all coupled ocean-atmosphere models, has considerable difficulty in reproducing the correct fluxes of heat and moisture at the interface. However, it points to the moderating and delaying effect of the oceans on greenhouse warming of the atmosphere. According to this simulation, a temperature rise of 0.5°K would occur after 20 years.

When, during the next century, the greenhouse gases will reach
wnen, aurıng tne next century, tne greenhouse gases will reach
concentrations at which they will produce significant climate changes, will depend also on the rates of exchange of the gases between the atmosphere and the oceans, the fraction retained in the atmosphere, the take-up, storage and release of carbon dioxide by phytoplankton, forests and other vegetation, all involving biological processes that will have to be incorporated into global climate models at a suitable stage. The first requirement is to obtain high-quality observational data, which is one of the objectives of the International Geosphere Biosphere Programme. The National Biogeochemical Ocean Fluxes Study, which is part of the International Joint Global Ocean Fluxes Study, and which will form a strong interface with the World Climate Research Programme, is an important first step along this road. However, by far the most important factor in determining the future levels of atmospheric carbon dioxide and other greenhouse gases, and hence the timing of significant climate changes, will be the future rates of emissions, scenarios for which differ so widely that estimates of the time likely to elapse before the carbon dioxide reaches double the present day concentration range from 80 to 130 years.

Predicted rises in average global temperature for a number of emission scenarios published in the IPCC Report, Houghton et al. (1990) are shown in Table 3. These are computed from a simplified atmosphere-ocean model calibrated against the GDFL global circulation model described above, to give a 2.5°K rise when in equilibrium with a doubled carbon dioxide concentration.

9. Sea-level rise

A potentially important consequence of greenhouse warming is the melting of sea-ice and ice sheets on land, only the latter resulting in a rise in sea level. The sea-level will also rise as the ocean waters expand in response to the additional warming. Estimates of these consequences involve large uncertainties because of lack of observations and of understanding of the mass balance and dynamics of glaciers and ice sheets. Moreover, there is considerable uncertainty in the predicted increases in surface temperature due to greenhouse warming.

Glaciers and small ice caps are very small in volume compared with the major ice sheets, but are liable to melt much more rapidly. Their melting is calculated to have contributed about 40% to the total sea-level rise of some 10 cm over the last hundred years (see Table 4).

The mass balance of the great Antarctic ice sheet, and of the Greenland ice sheet with only one-tenth the volume, are determined by the difference between accumulated snowfall on the one hand, and melting and calving on the other. In Antarctica, observations suggest that accumulation is very nearly balanced by calving of slabs of ice on the ice shelves with little melting taking place because of the very low air temperature. In Greenland, accumulation is balanced about equally by melting and calving. In neither case is there any direct evidence that the ice sheets are far from equilibrium, so that together they are unlikely to have contributed more than 20% to sea-level rise over the last century.

The remaining 40% of this rise is

TABLE 3.– FUTURE PREDICTIONS OF CO_2 CONCENTRATIONS, RISES IN GLOBAL TEMPERATURE AND SEA LEVEL FOR VARIOUS EMISSION SCENARIOS

(A) BUSINESS-AS-USUAL, HIGH EMISSION SCENARIO
CO2 emissions continue to increase linearly with time adding 2% of 1990 values each year. Montreal Agreement 75% implemented CH_4 and N_2O continue to increase at 1990 rates

AD	1990	2030	2060	2100
CO_2 concentration	354	470	590	850
CO_2 concentration	354	470	590	850
ΔT (°K)	0	1.1	2.0	3.25
Sea-level rise (cm)		18	38	65

(B) ALL EMISSIONS KEPT CONSTANT AT 1990 RATES

CO_2 concentration	354	420	465	520
ΔT (°K)	0	0.72	1.1	1.6
Sea-level rise (cm)	0	15	27	42

(C) 2% P.A. (COMPOUND) REDUCTION IN ALL EMISSIONS FROM 1990

CO_2 concentration	354	388	395	390
ΔT (°K)	0	0.4	0.4	0.3
Sea-level rise (cm)	0	11	18	21

(D) 2% P.A. INCREASE IN ALL GAS EMISSIONS 1990-2010, THEREAFTER A 2% P.A. DECREASE

CO_2 concentration	354	436	458	464
ΔT (°K)	0	0.93	1.10	1.0
Sea-level rise (cm)	0	17	28	34

attributed to thermal expansion of sea water. Since this is very sensitive to temperature, being six times greater at 25°C than at 0°C, the rise in sea-level depends very much on the depth to which the warming penetrates and therefore the mass of water which expands. This can, in principle, be determined from a fully coupled atmosphere-ocean model, but no such long-period calculations have yet been made. Calculations based on a simple one-dimensional model and quoted in the IPCC Report (1990), indicate that thermal expansion has contributed 2-6 cm, with a best estimate of 4 cm, to a total estimated rise of 10.5 cm (Table 4).

If atmospheric and surface temperatures increase due to greenhouse warming, thermal expansion of the oceans and melting glaciers are likely to continue to make the largest contributions to sea-level rise, as shown in Table 5, where the best estimates of contributions for a temperature rise of 1.1°K by 2030 are 10 and 7 cm, respectively, to a total rise of 18 cm. If by 2060 AD the global warming increases to 2.0°K, the corresponding sea-level rise is estimated to be 38 cm; by 2100 AD it may rise by 65 cm in response to a temperature increase of 3.25°K. Estimates for lower emission scenarios leading to slower temperature increases are given in Table 3.

All these estimates of sea-level rise, which are probably uncertain by a factor of two, are much less than exaggerated claims based on the assumption that the western Antarctic ice sheet will largely disintegrate and melt. Most glaciologists discount such a scenario, rendered even more unlikely by the recent model climate simulations which are described in Section 8. which recent model climate simulations which are described in Section 8, which produce very little greenhouse warming in Antarctica.

TABLE 4. ESTIMATED CONTRIBUTIONS TO SEA-LEVEL RISE (IN CM) OVER LAST 100 YEARS.

	Low	Best estimate	High
Thermal expansion	2	4	6
Mountain glaciers	1.5	4	7
Greenland Ice Sheet	1	2.5	4
Antarctic Ice Sheet	-5	0	5
Total	-0.5	10.5	22
Observed	10	15	20

From IPCC Report, p. 274.

TABLE 5. ESTIMATES OF CONTRIBUTIONS TO SEA-LEVEL RISE (IN CM) FROM 1990-2030 ACCORDING TO BUSINESS-AS-USUAL SCENARIO IN TABLE 3.

	Low	Best estimate	High
Thermal expansion	6.8	10.1	14.9
Mountain glaciers	2.3	7.0	10.3
Greenland	0.5	1.8	3.7
Antarctica	-0.8	-0.6	0
Total	8.8	18.3	28.9

From IPCC Report, p. 276.

10. In conclusion

It is virtually certain that the troposphere is warming very slowly in response to the continually increasing concentrations of carbon dioxide and other 'greenhouse' gases, but the signal is as yet too small to detect above the large natural climate variations, partly because it is being delayed by the thermal inertia of the oceans. Predictions of the magnitude and timing of the greenhouse warming, and of the concomitant changes in rain-fall and other climate parameters come entirely from physico-mathematical models of the global climate system. Unfortunately, the differences between the various model predictions, which are very sensitive to how clouds and their interaction with the radiation fields are represented, are too large to provide firm guidance for major policy decisions. Continued improvement in model resolution and model physics should cause the predictions to converge and thereby narrow the range of uncertainty. This will require several years of model development, especially in respect of the oceans; much faster computers; and, above all. an adeauate suoolv of global oceans; much faster computers; and, above all, an adequate supply of global observations from both the atmosphere and the oceans, to feed and validate the models, and to monitor the actual changes in climate that may eventually become evident.

In the meantime, although the current best estimates of global warming are not so alarming as to warrant major strategic changes in energy, agriculture, etc., industrialized countries should take all reasonable and practical steps to restrain or reduce energy consumption, utilize all fuels more efficiently, and explore economically promising alternatives to fossil fuels. The decision of the government to restrict UK emissions of carbon dioxide by 2005 to current levels, and to reduce emissions of CFCs in line with the Montreal Agreement, are realistic first steps.

In addition, we should develop, without delay, adaptive strategies in agriculture, forestry, coastal defences, water supplies and so on, to make the economy less vulnerable to climate changes when they occur. It would appear that we have a breathing space of some 50 years but this may prove too optimistic; in any case, it is none too long.

IOI Training Programme on the Management and Conservation of Marine Resources in the Mediterranean

The International Ocean Institute (IOI) is convening an international training programme on the Management and Conservation of Marine Resources in the Mediterranean for officials from governments and universities in the Mediterranean Region at the Third World Academy of Sciences and the International Centre for Theoretical Physics in Trieste, Italy, between 29 April and 24 May, 1991.

The training programme will be conducted in cooperation with the Trieste-based Third World Academy of Sciences, International Centre for Theoretical Physics and International Centre for Earth and Environmental Sciences, the Italian Ministry of Foreign Affairs and the Italian Commission for Nuclear and Alternative Energy (ENEA). Also cooperating with the IOI in this programme are the UNEP Coordinating Unit for the Mediterranean Action Plan (Athena) and the UNESCO Commission for Qatar.
(Athena) and the UNESCO Commission for Qatar.

The training programme is the second in a series of three such courses. The first was convened in Malta in the autumn of 1989. The 1991 programme is highly interdisciplinary and addresses cooperation and sustainable development of Mediterranean marine resources. The course aims at exposing decision-makers to the broad range of marine uses and the impact on the environment, the role of science and technology, the legal and policy framework of ocean development and management, regional cooperation and major socio-economic issues facing the region today.

The course will be attended by up to twenty participants from Algeria, Cyprus, Egypt, Italy, Libya, Malta, Morocco, Spain, Tunisia, Turkey and

Yugoslavia. The course director is Dr. Anton Vratusa, Honorary President of the International Centre for Public Enterprises in Developing Countries, Ljubljana, Yugoslavia. The course faculty is also international and drawn mainly from the region.

The IOI is an international non-governmental organisation registered in the Netherlands and with headquarters in Malta since 1972. It has been organising global and regional training programmes in marine resources management for government officials from developing countries in North America, Europe, the Caribbean, Indian Ocean, South Pacific and Mediterranean since 1980. The Class C training programme in Trieste is the thirty-second such course.

Post-Doc Position at University of Oklahoma

A postdoctoral position in HEP theory is expected to be available September 1, 1991 in the HEP goup at OU. In addition to carrying out interactive research with other group members, this position carries the administrative responsibility of planning and running TV-satellite communications, e.g. seminars, between groups involved in SSC related research and development. The initial appointment will be for one year with possible continuations for up to a total of three.

Applicants are requested to send a vita and the names (with e-mail addresses) of three references promptly to R. Kantowski, Department of Physics and Astronomy, 440 West Brooks, University of Oklahoma, Norman, OK 73019. Fax or e-mail is preferred,
University of Oklahoma, Norman, OK 73019. Fax or e-mail is preferred,
Fax (405)325-7557,
e-mail kantowski@uokniels,
@phyast.nhn.uoknor.edu,
or
UOKHEP::

NSERC Women's Faculty Awards in Physics at Carleton University and University of Ottawa

The Ottawa-Carleton Institute for Physics invites applications from women who wish to be nominated for the NSERC women's faculty awards in Physics, to be held either at Carleton University or the University of Ottawa. Research at the University of Ottawa is principally in theoretical and experimental aspects of condensed matter physics, including surface physics, polymer physics, magnetism, superlattices and superconductors. There is also interest in nuclear physics, neural networks and non-linear systems. At Carleton the medical physics program includes work in radiation dosimetry, X-ray and ultrasound imaging, and hyperthermia. Work in experimental high energy physics concentrates on the OPAL detector, at LEP, and the Sudbury Neutrino Observatory (SNO). The theoretical program is mainly concerned with phenomenological aspects of the Standard model and extensions to it.

The NSERC awards will be supplemented by the university to provide a salary equal to that of a conventional faculty position. Assistance towards travel expenses will be offered. Appointment will be initially for three years, with renewal for a further two providing satisfactory progress is made. It is possible that the position will become a tenure track one at an early stage. The teaching load will be kept small in order to maximise the time for research.

Applications should include a curriculum vitae, a list of publications and the names of three referees. Applications should be received by August 30th, 1991 for appointment in July 1992, although the latter date is flexible. This position is restricted to Canadian citizens or permanent residents of Canada.

Applicants should contact the appropriate person below:
Dr. Richard Hodgson
Department of Physics,
University of Ottawa,
Ottawa, Ont. K1N 6N5
University of Ottawa,
Ottawa, Ont. K1N 6N5
(613-564-3356)
or
Dr. Peter Watson
Department of Physics
Carleton University,
Ottawa, Ont. K1S 5B6
(613-788-4326)

Visits to ICTP

Japanese Ministry of Foreign Affairs

Mr. H. Kato and Mr. Watanabe from the Nuclear Energy Division of the Japanese Ministry of Foreign Affairs, responsible for budget preparations in their Division, had a meeting with the Deputy Director of ICTP on 12 April, to discuss matters of administration, research related to technical co-operation and official development assistance.

High-School Students

Students from the Scientific High School "Galileo Galilei", Trento (Italy) and from the Vocational Training Institute from Tirano (Sondrio, Italy), were shown the ICTP facilities on 18 and 23 April, respectively.

Conferences and Lectures

• Dr. Bonaventure Loo, Visiting Mathematician, was invited to give a talk at the University of Durham on Monday, 18 March 1991. The title of his paper was "Superminimal surfaces in S^4".

• Prof. M.P. Tosi, in charge of the Condensed Matter Research Group, was invited to the 11th General Conference of the Condensed Matter Division of the European Physical Society to deliver the paper "Stability of local structure for polyvalent metal ions in molten salts". The Conference was held from 8 to 11 April in Exeter, UK.

• Dr. M.-S. Lubuma, post-doctoral student at the Mathematics Section, presented the talk "Error Estimates in the Projective Solution of Radon's Equation" at the conference "Approximation Theory, Spline Functions and Applications" organized by the NATO-Advanced Study Institute in Maratea, Italy, from 29 April to 9 May 1991.

Activities at ICTP March-April 1991

Title: WORKSHOP ON MATHEMATICAL PHYSICS AND GEOMETRY, 4 – 15 March.

Organizers: Professors X. Gomez Mont (Centro de Investigación en Matemáticas, Guanajuato, Mexico, and Universidad Nacional Autónoma de Mexico) and M.S. Narasimhan (Tata Institute of Fundamental Research, Bombay, India).

Lectures: Topology of compact simply connected smooth 4-manifolds. Moduli space of connections. Linear superalgebra and supermanifolds. 4-manifolds and gauge theory.

Supergravity. A local index theorem for families of D-operators on punctured Riemann surfaces and a new Kähler metric on their moduli space. Jones-Witten invariant for flows on 3-manifolds. Symmetry wider than supersymmetry. Gravitational instantons and monopoles in a Kaluza-Klein model with scalar fields. The geometry of spaces of conformal structures. Compactifications of the space of stable bundles. Geometric superalgebra and the Dirac equation. Eigenvalues and Eigenspaces of Dirac and Casimir operators over noncompact symmetric spaces. Connections and curvatures on complex Riemannian manifolds. Morse theory, classifying spaces and Floer homology. Variations of Hodge structure and Higgs bundles. Algebraic geometry of instantons. On the topology of 4-manifolds. Conformal field theory and vector bundles on variable Riemann surfaces. Algebraic geometry, Fay's identity and correlation functions. Differential equations on supermanifolds and $R^{1/1}$-actions. Determinant line bundles and the holomorphic factorization in 2 dimensional field theory. Does a spherically symmetric space time admit five isometries? 2+1 dimensional topological field theory and algebraic geometry. Some problems in linear and nonlinear analysis on noncompact manifolds. Monads, connections and compactifications. Consistent approach to supermanifolds modelled over finite dimensional exterior algebras. A remark on the quantization of electric charge from Dirac monopoles. Geometric quantization of the momentum mapping associated with coupled harmonic oscillators.

The Workshop was attended by 101
The Workshop was attended by 101 lecturers and participants (77 from developing countries).

Title: ICS-ICTP-WMO INTERNATIONAL TECHNICAL CONFERENCE ON LONG-RANGE WEATHER FORECASTING RESEARCH, 8 – 12 April.

Organizers: Professors K. Miyakoda (Chairman of the International Organizing Committee; Princeton University, USA) and G. Furlan (University of Trieste and ICTP), in co-operation with the International Centre for Science and High Technology (ICS, Trieste, Italy) and the World Meteorological Organization (WMO, Geneva, Switzerland).

Lectures: Climatological variation of 30-60 day oscillation around East Asia during Northern Summer. A study on climate predictability: theoretical aspects. Transient Eddies and forecast skill in low frequencies. Sensitivity of mesoscale predictions to standard errors in upper air data. The droughts of Northeast Brazil: from diagnostics to prediction. Issue of tropical long-range forecast: status and development of new forecasts. Regularities in the chaotic atmospheric dynamics. Predictability of El Niño onset, Kenyan droughts and floods. Numerical study for formation mechanism of short anomalous climate change. The WMO sponsored intercomparison of sea surface temperature data sets for long-range forecasting. Stratospheric oscillations and long-range prediction of Indian weather. One month forecast of wet and dry spell of the monsoon. Energetic interactions between El Niño and African droughts. The choice of an observed climatology to verify extended range forecasts. The influence of El Niño/Southern Oscillation (ENSO) on the Ethiopian seasonal rainfall. Techniques of operational long-range forecasts at the UK Meteorological Office. Practical extended-range dynamical forecasting at UKMO. Linear instability analysis and its application to ensemble forecasting. Improvement of long-range predictions by combination of model forecasts. Prediction of tropical Pacific SST with coupled ocean-atmosphere models. Design of experimental seasonal forecasts using an air-sea model. Monitoring and probabilistic forecasting of short-term climate variations. Predictability and physical factors influencing Sahel rainfall variation. Variability and
temporal prediction of summer monsoon
temporal prediction of summer monsoon rainfall over India, China, and Sri Lanka. Seasonal mesoscale circulations and LRF in East Africa. Seasonal predictions with the COLA GCM. Seasonal simulations with ECMWF NWP model. The feasibility of seasonal NWP from decadal simulations. Prediction of forecast skill. On the use of the sufficiency relation to evaluate climate forecast. Seasonal predictability of East African rainfall from SST anomalies and Southern oscillation signal. Long-range forecasting of the onset and cessation of rainfall in the Nigerian Sahel. The onset of the 1982/83 Summer monsoon over Southern Africa: a diagnostic study. A numerical study of the impact of SST in the warm pool of Western Pacific on the East Asia Winter monsoon. Temporal variability of the structure and phase propagation of the Madden-Julian oscillation in tropical convection. Nature of Madden-Julian oscillations over Indian monsoon regions. Variations of 30-60 day oscillation during 1982 El Niño. Empirical prediction of NE Brazil (North Nordeste). Tropical cyclone activity over the Western North Pacific from El Niño to La Niña. Status and prospects of long-range forecasting at the Hungarian meteorological service. Detailing of the monthly forecasting by the statistical orientation of a deterministic model. Establishment of the method of long-range forecast for the first severe cold period in Winter in the North of Viet Nam. Typifying the evolution in the meteorological parameter by using the analogy method. Skill characteristics of US long-range forecasts. Economic loss by precipitation. Value of long-range forecasts to commercial users in the UK. Relating climatological information to the value of long-range weather forecasts.

The Conference was attended by 97 lecturers and participants (43 from developing countries).

Title: SPRING SCHOOL AND WORKSHOP ON STRING THEORY AND QUANTUM GRAVITY, 15 – 26 April.

Organizers: Professors J.A. Harvey (Enrico Fermi Institute, University of Chicago, USA), R. Iengo (International School for Advanced Studies, SISSA, Trieste, Italy), H. Verlinde (Princeton University, USA) and Drs. K.S. Narain and S. Randjbar-
Daemi (ICTP)
Daemi (ICTP).

Lectures: *(School)* Introduction to topological and conformal field theory. Introduction to matrix model and Liouville theory. Some properties of non-critical strings. Instantons and solitons in heterotic string theory. Introduction to W algebras. String theory in 2-dimensions. Integrable models. Liouville theory and its recent developments.

(Workshop) Target space duality symmetries and effective actions of string theory. Geometric structures in effective superstring Lagrangians. Duality invariant effective action for supersymmetries. Equivariant topological Sigma models and topological open strings. New

parafermion SU(2) coset and N=2 superconformal field theory. Transition from critical to non-critical string at high temperatures. Correlation functions in compactified C=1 quantum gravity. On a multiorbit geometrical action for the integrable system. The quantum group symmetry of conformal field theories. Large gauge transformation and special Virasoro orbits. The origin of the string equation. Quantization of SL(2,R) Chern-Simons topological theory. String propagation in a black hole geometry. Classical 3-d gravity with N particles. Currents and anomalies in the topological Yang-Mills theory. Double scaling limit in the O(N) vector model. Multicritical complex matrix models and nonperturbative 2-d quantum gravity. O(N) vector model and nonperturbative particle theory. 1-d conformal field theories. Nonperturbative super-symmetry anomaly in supersymmetric QCD. Singular vectors in Virasoro representations. Schwinger-Dyson eqs. for 2-matrix model and W_3 algebra. Quantum Hamiltonian reduction and N=2 coset model. Nonlinear realizations of classical W_3 symmetry. O(N) vector model in the double scaling limit.

The Spring School and Workshop were attended by 161 lecturers and participants (57 from developing countries).

Title: COURSE ON "OCEANOGRAPHY OF SEMI-ENCLOSED SEAS", 15 April – 4 May.

Organizers: Dr. L. Cavaleri (Istituto Dinamica Grandi Masse, Venice, Italy), Sir Alan Cook (Selwyn College, Cambridge, UK), Dr. M. Gacic (Institute of Oceanography and Fisheries, Split, Yugoslavia), Dr. F. Stravisi (University of Trieste, Italy) and Dr. E. Accerboni (Osservatorio Geofisico Sperimentale, Trieste, Italy, in collaboration with the International Centre for Science (ICS, Trieste, Italy) and with the co-sponsorship of the Direzione Generale per la Cooperazione allo Sviluppo (Ministry of Foreign Affairs, Rome, Italy).

Lectures: Geophysical fluid dynamics. Tides. Long waves along coasts and over continental shelves. Long waves in the Gulf of California. The general circulation in the Gulf of California. Pressure and wind forcing. The use of satellite data. Analysis of oceanographic time series. Marine chemistry. Thermohaline forcing and heat fluxes. Oceanographic instruments. Shallow sea modelling. Chaos in oceanography. Surface gravity waves. Oceanography from space. Marine biology. Historical oceanography. Marine geology. Ecological models.

Poster Sessions: Frequency dependence of the reflection coefficient for compressional plane waves at the seabed. Acoustic measurements in Argentinian continental shelf and continental slope. Surface mixed layer temperature and layer depth in water off the Argentinian coast. Shallow-water waves on a rotating ocean due to oscillatory surface stresses. Hydrodynamics and sediment flux in the Gulf of Guinea. Dynamical studies on the Yellow Sea. Windows techniques for climate trend analysis. Paleoenvironment of the continental margin of Egypt: interstitial water study. Typifying the evolution in the meteorological parameters by using the analogy method. Light attenuation in the Adriatic Sea.

College, Cambridge, UK), Dr. M. Gacic

Presentations by Participants: The index of refraction for compressional plane waves in ocean bottoms of the Voigt's type and causality. Environmental processes and beach changes: observation on the West coast of Cross River estuary. Ocean dynamics and the stability of the Nigerian coastline: a case study of Victoria Island. Wind wave modelling in the N. Aegean Sea. Summer stratification effects on the wind-currents in the Northern Adriatic. Damping of the Adriatic seiches. Time series analysis of Adriatic data: package and a few examples. Numerical modelling in the environmental research of Xiamen Bay. Circulation and hydrography of the Sea of Marmara. Subinertial variations along the coast of the Gulf of Mexico. Sea level variations along the coast of the Gulf of Mexico. Sea level variations along the Bulgarian Black Sea coast: analysis and modelling of storm surges. Winter circulation in the Northpatagonic gulfs: COX/CIMA model. Large-scale circulation in the bay of Bengal during the Southwest monsoon. Dilution characteristics of the water of the Bay of Bengal. Weather and climate of the ocean: the Atlantic and Indian oceans. Intrathermocline lenses in the Atlantic Ocean originated from intermediate Mediterranean Sea water.

Round Tables: The Adriatic Sea. The Mediterranean Sea. The Gulf of California.

The Course was attended by 97 lecturers and participants (63 from developing countries).

International Centre for Theoretical Physics
of IAEA and UNESCO
Strada Costiera, 11
P.O. Box 586
34136 Trieste
Italy

Telephone: (40) 22401
Cable: CENTRATOM
Telex: 460392 ICTP I
Telefax: (40) 224163
E-mail: POSTOFFICE@ICTP.TRIESTE.IT
Bitnet: POSTOFF@ITSICTP
Decnet: VXICP1::POSTOFFICE
or 40124::POSTOFFICE
PPSDN: 022224110125

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