Induced Critical Conditions in the Atmosphere

Europhysics Study Conference, Torino, 27-30 September 1989

The Europhysics Study Conference "Induced Critical Conditions in the Atmosphere" was held at the Institute for Scientific Interchange, Villa Gualino, Torino, from 27-30 September 1989. It was the second in a series of meetings organized by the EPS Action Committee for Physics and Society dealing with scientific problems having a strong social relevance. It was preceded by the "Nuclear Winter" workshop in Geneva in October 1986, and followed by the WE-Hereaus Stiftung / EPS Seminar entitled "Balances in the Atmosphere and the Energy Problem", held in Bad Honnef, FRG, on 5-7 February 1990.

Perhaps the most terrible of the climatic conditions that could be induced by human activity is the so-called nuclear winter, a dramatic chilling of the planet resulting from a substantial nuclear exchange. More mundane but nevertheless vitally important changes that are taking place include depletion of the ozone layer, the greenhouse effect, the increase in the sea level, and local metereological effects. The conference summarized what is known about these conditions, the essential problems and research needs.

The Nuclear Winter

Nuclear winter synthesizes the global effects of nuclear war following a massive injection of smoke and dust into the atmosphere. Understanding has progressed considerably since the "discovery" of the problem in 1982 and the Geneva workshop in 1986. Data derived from experiments and from observations of the effects of natural fires generally support previous models.

Changes to estimates of the worldwide quantities of some flammable materials have been reported recently. However, the effect of these revisions has been compensated for by an improved evaluation of scavenging processes. Studies of smoke plumes from fires show a very low immediate scavenging effect implying a removal efficiency of about one-half the early estimates. Observations have also confirmed that large clouds of smoke from fires in the USSR, China and the USA reduced diurnal ground temperatures by several degrees.

The reliability of computer models used to forecast climatic impact has improved considerably. In particular, some three-dimensional general circulation models have been enhanced by introducing the radiative properties of smoke, dynamic coupling between the heating and transport of smoke, the influence of heat storage and transport in soils, and the variation of diurnal temperatures. The results of the latest simulations strengthen earlier predictions.

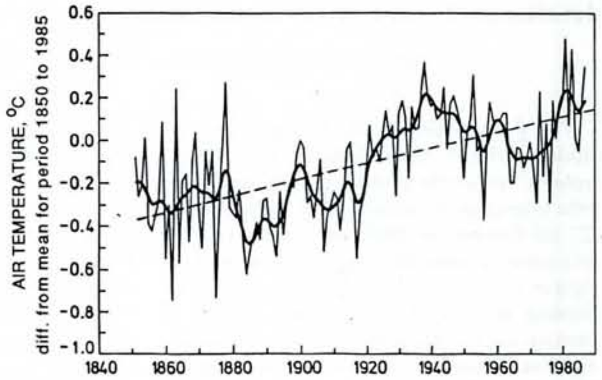

Fig. 3 - Annual air temperature fluctuation in the northern hemisphere. The thick continuous line represents the data after a 10 year low-pass filtering and the linear trend is shown by the dashed line. The autocorrelation coefficient of the unfiltered annual data is 0.48. The temperatures are deviations from the average for the period 1951-1970.

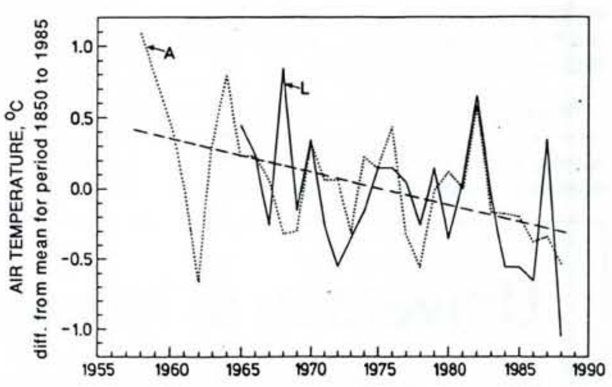

Fig. 4 – Annual variation of the temperature of the stratosphere averaged over the northern hemisphere. The dotted line (A) is for the layer between 16 and 24 km in height during 1958-1988; curve L is for the period 1965-1988 at a height of 24 km. The linear trend (dashed line) corresponds to curve A; it has an autocorrelation coefficient of 0.42.

The physical features that should be anticipated during a nuclear winter are now well established. They include severe decreases in temperatures at the centres of continents to temperatures around about 0°C and below, a rapid worldwide spreading of darkness and cold, and a perturbation of the general climate lasting at least one year.

An effect that has been highlighted by the latest simulations invokes the motive for the research that led to the discovery of the nuclear winter. This is a pronounced depletion of the ozone layer caused by the injection of oxides of nitrogen into the atmosphere, combined with severe heating of the lower stratosphere. Simulations indicate a depletion of up to 50 per cent lasting several years.

Depletion of the Ozone Layer

The ozone content of the stratosphere has been decreasing for many years owing to the injection of halogenated molecules into the atmosphere, especially the two million tons of chlorinated fluorocarbons (CFC's) which are released each year. Depletion cycles seasonally, coming to a maximum over Antarctica in the springtime. Local, less pronounced, maxima have been observed in Arctic regions. The peculiar topography of Antarctica (land surrounded by sea) with its characteristic pattern of air circulation stabilizes meteorological conditions favouring depletion.

The chemistry of the ozone cycle is intricate and needs clarification. The temperature of the stratosphere plays an important though controversial role. Higher temperatures speed up chemical reactions but also shorten the lifetimes of catalysts. The greenhouse effect (see below) leading to higher temperatures in the troposphere (and lower temperatures in the stratosphere) therefore influences the ozone layer.

Simulations of the dynamics of the ozone layer are able to reproduce its general features but not the measured ozone concentrations (*e.g.*, the doubling in size of the "hole" over Antarctica observed in 1989 was not predicted). It has also emerged that the atmosphere's ozone content is far from equilibrium. The relaxation time of the system is on the order of several decades (Fig. 1) so measures to limit the release of CFC's will only begin to produce significant changes after many years. Moreover, the predicted 3% decrease in the equilibrium concentration of ozone in the stratosphere (Fig. 1), while appearing insignificant may in fact lead to significantly increased exposure to solar radiation with important biological effects.

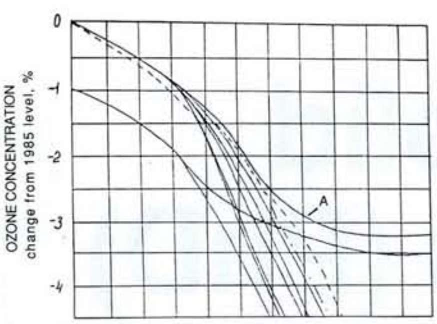

Fig. 1 – Results of simulations of the evolution of the ozone concentration in the stratosphere. The upper curve (A) gives the change (in per cent) relative to the 1985 level assuming that the injection of CFC's and their equivalents is stabilized at the 1985 level.

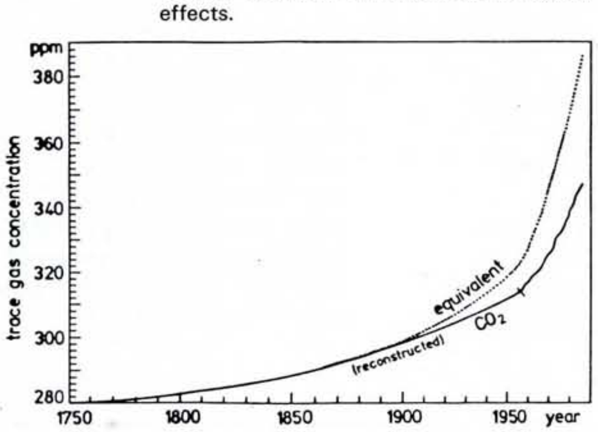

Fig. 2 – Measured and reconstructed contents of "greenhouse" gases in the atmosphere over the past two centuries. The dotted line is for the combined gases expressed as the CO_2 equivalent.

The Greenhouse Effect

Carbon dioxide

The amount of carbon dioxide in the atmosphere has been steadily increasing for more than two centuries (Fig. 2). The phenomenon is fully supported by up-to-date measurements of the composition of the atmosphere, and by analyses of air trapped in ice samples.

Carbon dioxide is a "greenhouse gas" because it absorbs infrared radiation at the wavelengths of thermal emission from the ground. Other gases with this property include water vapour, methane, nitrous oxide, tropospheric ozone and CFC's. The total quantity of these gases may be expressed in CO_2 equivalents (dotted line in Fig. 2). The increasing contents of CO_2 and its equivalents clearly correlate with increased human activity. The annual emission of CO_2 in 1986 due to combustion was about 2×10^{10} tonnes. About half of this enormous quantity remains in the atmosphere to give an annual increase of 0.4 per cent, coinciding with the measured value.

While these global numbers may be used for general estimates, many details of the carbon cycle need deeper investigation so as to assess more accurately the roles of various components of the system, such as the oceans, carbon containing rocks and the biosphere.

Global warming

Statistical analyses of the average air temperature at the earth's surface shown in Fig. 3 indicate an increase of about 0.5° C over the last 100 years. Data for the temperature of the stratosphere (Fig. 4) during the last 30 years show on the other hand, a *decreasing* temperature.

The simultaneous increase of the CO_2 content of the atmosphere (Fig. 2) and the mean surface temperature (Fig. 3) immediately suggests a correlation. This is supported by reconstructions of the history of the planet over the last 160 millennia based on data from air trapped in Antarctic ice.

Some simulations of the dependence of Earth's temperature on the CO_2 content of the atmosphere fit the historic data fairly well. But doubts remain owing to the same difficulties as those encountered in meteorological forecasting models. The best models predict that the surface temperature will increase by a further 2.7–5°C by the year 2030.

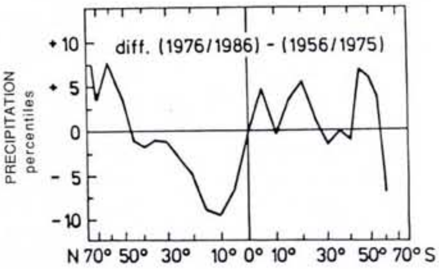

Fig. 5 – The difference between the amounts of rain falling at various latitudes during 1956 to 1975 and 1976 to 1986. The data are normalised and given in percentiles.

The models can be improved by taking into account the non-equilibrium nature of the atmosphere. The large thermal inertia of the oceans hinders heating of the atmosphere and the latest results show that it takes 20 years to reach equilibrium. An increase of another 0.5°C should be expected within this time, even if the atmospheric CO_2 content is stabilized its present level.

Rainfall patterns and the sea level

Meteorological data (Fig. 5) indicate a trend towards dry subtropical climates in the northern hemisphere, and to an increase in rainfall at latitudes above 50°C North.

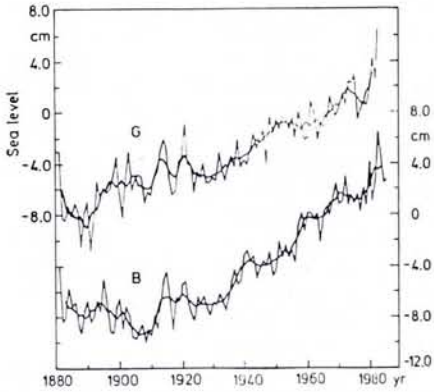

Fig. 6 – Two independent assessments of the sea level rise over the past 100 years. The continuous thick lines are for 10 year filtered data.

Reconstructions (Fig. 6) of the sea level show that it has risen by 150 mm over last 50 years. Changes in the rainfall pattern and increases in the sea level seem to correlate with the greenhouse effect. Assuming there is a correlation, and by using it in simulations one can make a rather unreliable estimate of the increase in the sea level by the year 2030: it is 0.7 to 1.7 meters.

Conclusions

The present state of knowledge allows a general forecast of the global effects to be expected soon. It is able to point out some of the most relevant phenomena. Many details as well as some fundamental mechanisms remain unclear and poorly defined so time scales are unreliable. Much work is necessary in connection with the chemistry of the atmosphere and computer modelling. In any case, the greenhouse effect is the most significant problem that is now altering our climate. Based on current trends its effect is expected to emerge unequivocally above the background noise in 10-15 years, the foreseeable consequences at which point seem to be extremely important.

A. Tartaglia, *Politechnico di Torino*