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Foreword

This study was triggered by recent publications in various periodicals, all indicating that an issue is newly coming up in the field of greenhouse science, viz. increased frequency in the near future of extreme climate events. Such threatening consequences of the greenhouse gas levels, still rising due to the passivity of the international community to take measures for lowering the emission of these gases, probably could more easily yield a consensus, at least in the industrialized world, that such measures have to be taken. The alternative will lead to a climate change where "any impact of a greenhouse warming on extreme climatic events will for many decades be far larger than the greenhouse effect itself" (Fred Pearce, New Scientist, 6 January, 1990, p. 31).

Policy-Relevant Short-Term Consequences of Anthropogenic Greenhouse Disturbance

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Uncertainties in Climate Change

The serious drought of 1988 in the USA nationally caused a negative economic impact in that year of about 1%, especially due to the effects on agriculture. It is known that also several power plants were in serious shortage of cooling water. Much more negative effects can easily be listed. Some scientists stated that the year 1988, which was not only dry but also exceptionally warm, could be related to the greenhouse disturbance [1]. Similar statements were made about the 1986 drought in the USA [2]. There is controversy among scientists and among policy makers concerning the statistical significance of a relation between the anthropogenic greenhouse disturbance and the climate indicators like the temperature of the Earth's atmosphere, the levels of the seas, and the retreat of glaciers [3]. There is also consensus about large uncertainties in climate change.

Some people (amongst them recognized scientists like Budyko, an USSR climatologist) regard the anthropogenic greenhouse disturbance to be highly beneficial. According to Budyko, after a transition period of about a decade from now, a new climate period will commence, similar to the Pliocene, described as a "CO_2 Paradise" [4]. In this choir of optimistic futurology singers one may also hear the gay Gaia voices which bring forward the holistic idea of the Earth being an organism with versatile mechanisms to counteract threats to its life and the organisms living in symbiosis with it [5]. Badly enough, also scientists have been blamed of drawing conclusions concerning anthropogenic global warming from statistical analyses of global and regional temperature/time series whereas there was insufficient statistical significance [3].

An excellent overview of the climate uncertainties and their impact on policy development is given in Robert M. White's paper to the Intergovernmental Panel on Climate Change IPCC in its meeting in Geneva, May 1989 [6].

Altogether, these scientific uncertainties and lapses which are difficult to transform into reliable policy arguments, and the rumors about not-negative consequences of increasing levels of greenhouse gases have influenced international policy making negatively. The fact that the inadvertent greenhouse experiment is a unique one and that it will show its serious consequences only on a very long term (beyond the usual policy maker's time horizon) have already made the economy and technology oriented politicians hesitating to effectively respond to the greenhouse problem.

Mankind is dealing with a unique problem of consequences of the anthropogenic greenhouse disturbance as these are prospected nowadays. These consequences have never occurred in historical periods, they are of a global scale and when the global warming becomes observable it's too late for actions to eliminate the emission sources (anthropogenic greenhouse gases have very long atmospheric life times). Additionally, there exists the above described credibility problem of scientists with conflicting views. Meanwhile the levels of radiatively active gases increase, even higher increase rates are forecasted, and the resulting radiative forcing of the earth's atmosphere will be enhanced. The usefulness and reliability of computed temperature increases is already and will become even more questionable. Let us, therefore, consider other consequences of the radiative forcing of the atmosphere which probably are more appealing to policy makers.

Shorter-Term Consequences of Greenhouse Disturbance

It is worthwhile to consider other than the usual long-term consequences of the greenhouse disturbance which are of a different nature and duration. Important shorter-term consequences than the uncertain average global warming of a few degrees some time in the next century, may also result from the radiative forcing by anthropogenic greenhouse gases. In fact, the temperature increases calculated usually, are mainly functional in comparing the various global circulation models which contain gross simplifications in simulating the processes in the Earth's climate system (therefore, the radiative forcing is probably a more relevant output for comparison). Indications of shorter-term consequences can be inferred from global circulation modelling, from climate records, and from natural forcing of the Earth's radiation balance, like by volcanic eruptions. These three topics will be dealt with below.

Greenhouse Disturbance by Volcanic Eruptions and its Climate Changes

The greenhouse disturbance by man-made emissions is an inadvertent experiment. It will be too late to stop it when observations of its serious consequences are significant. However, the uncertainty about these consequences hampers any action. Since we cannot (and should not) do such a climate experiment, one may look for a similar experiment and its short-term consequences performed by Nature itself. Such natural events exist, viz. loading of the stratosphere with large amounts of aerosol by vigorous eruptions of volcanoes. Some climatologists speculate that also the impact of a huge asteroid or comet may have led to high dust levels (0.01–0.1 $g.cm^{-2}$ atmospheric loading) resulting in important changes in climate and extinction of ecosystems e.g. at the Cretaceous-Tertiary boundary [7]. However, such events are very rare (fortunately) which makes their analyses difficult and conclusions not useful for our purpose. On the contrary, the more frequent well-documented volcanic eruptions that took place in the previous century and their resulting stratospheric aerosol loading have been the subject of a great number of climatological investigations.

Radiative forcing by volcanic eruptions is mainly due to the sulphuric acid aerosol cloud which is formed in the stratosphere after some weeks by photochemical oxidation of SO_2 injected by the eruption [8]. A recent investigation of the effects of explosive volcanism on the Earth's surface temperature by Bradley [9] deals with about 50 eruptions in the previous one-and-a-half centuries. From an extensive analysis he concludes that major eruptions are followed by temperature depressions. The surface cooling of continents averages about 0.4 K, lasting for approximately one year. Well-known examples are 1816, the year-without-a-summer, following the Tambora eruption of 1815 which affected the climate in North America, Europe, and China [10], the Krakatoa eruption of 1883, and the major eruption of the Agung in 1963, lowering the surface temperature in the tropics about 0.5 K [11]. The tropospheric lowering is the result of absorption and reflection of solar radiation by the aerosol cloud formed higher up in the stratosphere. Examples of climate indicators which have shown to have a significant relation to major volcanic eruptions are ice records in the Hudson Strait and Bay as of mid 18th century [12] and tree-ring data from North America since the end of the 17th century [13]. A first conclusion from this is that volcanic eruptions may compensate for the warming of the troposphere due to increased levels of greenhouse gases, thereby hiding the greenhouse effect temporarily. However, another climate effect of stratospheric volcanic clouds has to be considered which is likely to yield more convincing evidence of a potential serious climate change due to radiative forcing from any cause. Meant are short-term severe climate events due to large-scale atmosphere/ocean coupling like El Niño (see below) and severe monsoons about which investigations have shown that they can often be related to the larger volcanic eruptions.

Studies by Handler [14] and Parker [15] have shown that increased levels of stratospheric aerosol correlate well with so-called El Niño events (see below) and with monsoon precipitation intensity which largely have an identical meteorological origin, both being significant parts of a large global climate pattern. The analysis by Handler agrees with the global climate model of Kutzbach and Guetter [16]. El Niño is a Pacific large-scale warm-water current flowing to the north-west coast of South America, influencing global climate when very powerful. Irregularly, El Niño was catastrophic, in particular the one of 1982–83 which resulted in a serious Australian/Indonesian drought, severe flooding in South America, and many disasters elsewhere in the world [17], damages being estimated at almost US$ 3.5 billion.

The heart of the El Niño matter lies in heat accumulating over several years in the western Pacific. The strong positive radiative forcing of the resulting increased water vapour levels [18] may further speed up the climatic fly-wheel before it converts itself more or less explosively into an El Niño. Handler [14], in his analysis of the possible association of stratospheric aerosols of volcanic origin and El Niño type events (some 30 cases since 1869), has been able to show with a high level of significance that cooling or heating of the sea surface depends on the latitude of the aerosol (fig. 1). In case of a low latitude eruption this is followed by several seasons of heating

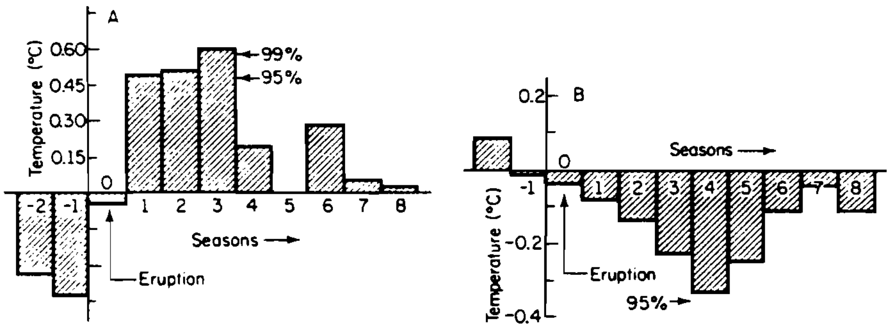

Figure 1: A. Composite sea surface temperature anomaly for twelve low latitude (tropical) stratospheric aerosols from two seasons before the eruption season to eight seasons after the eruption season. B. Composite sea surface temperature anomaly for twenty high latitude (extratropical) stratospheric aerosols as in A [14].

of the sea surface in the region 0°–10° S and 90°–180° W which is the El Niño's heart. The opposite occurs in case of a high latitude volcanic eruption. In order to apply this information to the radiative forcing by greenhouse gases which are almost homogeneously distributed over the globe, one needs to take into account that the pattern of warming nevertheless is uneven. In connection with the simultaneous continuous variation of sea surface temperature, pressure, wind, rainfall, etc. over large regions, this means that an influence on the strength of El Niño (either positively or negatively) will change the strength of large-scale climate events elsewhere. Hence, any greenhouse disturbance will increase the frequency of disastrous weather conditions. This is underlying some climatologist's observations that the January/February hurricanes and heavy storms are possibly the first signs of global climate change [19].

Recently, investigations of temperature records of the past 100 years have revealed that the global temperature variations in that time period can be explained largely by the combination of influences of El Niño and five larger volcanic eruptions [20]. Handler's conclusion of the relation between stratospheric aerosols being of volcanic origin, and El Niño events makes it plausible to assume a cause/effect relationship between the major El Chichón eruption of April 1982 and the disastrous El Niño of 1982–83. Also his observation of the relation between "the long-term secular behavior of Indian monsoon precipitation" and "the frequency of low-latitude volcanic eruptions" [14] supports a causal relationship between (even short-lasting) radiative forcing like from stratospheric aerosol and large-scale temporary climate changes like monsoon precipitation and El Niños [21]. Pearce, considering the shallowness of the mixing layer in the equatorial Pacific, expects the influence there of the anthropogenic greenhouse disturbance on El Niño to be "early and sharp" [22].

Increased Frequencies of Extreme Climate Events

In a study on warmer-climate induced changes in forest and vegetation disturbance, Overpeck [23] summarizes his literature findings concerning the higher frequency of various sorts of "disturbance weather" (summer/autumn drought and various kinds of thunderstorm):

- decreasing temperature variability on all time scales leading to longer periods of consecutive hot days during growing seasons;
- greater precipitation variability;
- increased precipitation at the warmer low- and mid-latitudes;
- strengthening of tropical storms and hurricanes.

Literature references are: [24], [25], [26]. Rind et al, using their GISS general circulation model (GCM), found that climate warming generally lowers latitudinal temperature contrasts and atmospheric eddy energy and increases precipitation variability due to the higher water content of the atmosphere. The unavoidable simplifications in the large GCMs like GISS, however, lower the credibility of these conclusions. Nevertheless, the shorter-term consequences on climate variability of global warming like floodings, extended periods of drought and forest fires likely are an inherently better basis for decision making than the longer-term ones like sea level rise. Rind's conclusions have similar weight as Emanuel's who estimated that global warming will increase hurricane intensity by about one-and-a-half [27].

A completely different approach toward estimating the effect of radiative forcing by greenhouse gases on climate variability was followed by Lough et al. [28]. They compared the climate in Europe in the periods of 1934–53 and 1901–1920, being the warmest and the coolest 20-year periods of this century, respectively. The temperature difference is about 0.4 K. Some of the results of this method of historical analogue are that the anthropogenic greenhouse disturbance leads to:

- greater frequency of severe winters,
- warmer springs, summers, and autumns,
- drier springs and summers, wetter autumns and winters.

To a large extent, the modelling results of Rind [24] and Emanuel [27] fit the picture of Lough's analysis which in view of prospected global temperature increase (ca. $0.05\ K.y^{-1}$) gives an illustration of the coming one or two decades.

Waggoner analyzed an extensive precipitation data set [29] and came to the same conclusion concerning precipitation (see fig. 2). A more general analysis of the effect of global warming on the occurrence of extreme events was carried out by Wigley [30]. His conclusions are that

- a small trend in the mean of event frequencies markedly reduces the return period of extreme events and strongly increases the risk,
- "The warm extremes that have occurred by chance over the past 300 years are likely to be compressed into the next 40 years, with new record highs almost guaranteed, and accelerated record-breaking as global warming continues into the twenty-first century. Thus, if current greenhouse projections are valid, events which we now consider to be most unusual are likely to become commonplace well before the middle of next century".

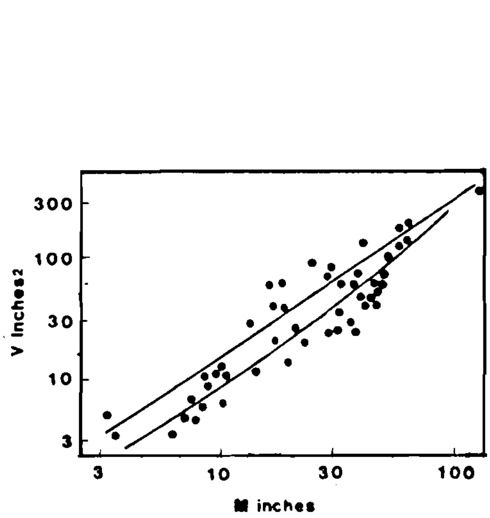

Figure 2: The variances, V, and means, M of 55 frequency distributions of annual precipitation. The coordinates are logarithmic. The upper line represents estimates of monthly precipitation. The lower, curved line represents Conrad's equation. The regression fitted to the annual precipitation lies between the two lines on the graph. V is in inches^2, M is in inches [29].

Discussion and Conclusions

Uncertainties in the risks from short-term effects of the anthropogenic greenhouse disturbance, though smaller, are not essentially different from those of the long-term effects which are considered usually. However, the interest of climatologists in the former consequences is much smaller than in the latter. This is unfortunate because the much larger uncertainties inherent in the long-term scenario studies make these less attractive for policy makers for use as a basis for abatement policies of greenhouse gases. Therefore, the risks of those short-term extreme events are of interest. From the above given overview of various climate effects (which were investigated in climatological studies of stratospheric clouds of volcanic origin and in some studies using general circulation models, or in 20th-century climate records), one may conclude that radiative forcing equivalent to a few 0.1 K affects regional temperatures and pressure differently (even with different signs) thereby causing increased occurrence of extreme climate events like hurricanes, floodings, and extended periods of severe drought and cold winters. The hurricanes hitting Western Europe in late January and early February 1990 clearly show the risks involved in increases of such occurrences: more than 100 casualties and enormous damages to properties. Also the above mentioned droughts of 1986 and 1988 were economic disasters and probably also affected nature seriously. On the basis of a three-century record, the 1986 drought in the USA was labelled as "a very rare event with a probable recurrence interval of at least 287 years [2]. Monsoons of extreme strength are catastrophes in the economically vulnerable tropical developing countries.

In summary one may conclude that

- small changes in the mean of a climate event (e.g. temperature rise or precipitation change) lead to an enhanced frequency of the extreme climate event with the same sign. E.g. a somewhat dryer climate shows a strongly enhanced frequency of severe droughts and severe floodings return more frequently in a somewhat wetter climate (the latter implies also higher risks, in strength and frequency, of hurricanes);

- the radiative forcing by anthropogenic greenhouse gases results in an average global temperature rise of 3 ± 1.5 K which varies in time and space. The prospected global temperature increase in the coming decade due to anthropogenic greenhouse disturbance (which amounts to about 0.05 K.y^{-1} [31]) is in the range of temperature increases of 0.5 K used in the recent climate variability studies and in the studies related to volcanic eruptions. Winters might be more severe and summers warmer; the polar regions become warmed stronger than the lower latitudes. This causes increased occurrence of extreme climate conditions analogously to the climate effects of large volcanic eruptions (though the volcanic stratospheric aerosol lasts only a few seasons);

- it is much more difficult for policy makers to base their decision on information from the extremely complicated climate models and from temperature records. These results are of insufficient certainty, they concern climate changes and consequences which take place beyond the time horizon relevant for policy makers and, more over, these consequences (sea level rise, etc.) are not recorded in history;
- the insight into the short-term effects of climate change is of primary importance for policy makers because of the day-to-day experience of mankind of such extreme climate events;
- keeping record of the various extreme climate events and analyzing the frequency changes in view of the anthropogenic greenhouse disturbance is urgently needed;
- additionally, general circulation models might be modified in order to yield information about the variability of climate events as it will be influenced by anthropogenic greenhouse disturbance.

It is essential to get almost all nations, beginning with the industrialized, started towards taking effective measures that will clearly generate a lowering of greenhouse gas emissions in the coming decade. Otherwise too many nations will be waiting, giving priority to other, mostly national, urgent problems (to begin with the Third World and followed by the Centrally Planned Economies). The above given overview of consequences of anthropogenic greenhouse disturbance other than the usual global warming, may give rise to a common value easier to handle for policy makers. A major part of research on global climate change might focus on the relationship between radiative forcing by greenhouse gases and short-term extreme climate events.

It is recommended that

- modelling activities be focussed partially on development of new models (or modification of existing ones) which relate emission sources and the shorter-term consequences of extreme climate events;
- empirical relations be derived concerning the frequency of occurrence of extreme climate events, especially hurricanes, severe winters, extended periods of drought and floodings. Attention must be given to the time and location dependence of such events.

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