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# Some remarks on the scientific problems related to the greenhouse gas issue

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RESUMEN

**Algunos problemas fundamentales relacionados con el enfoque actual que se le está dando al tema del cambio climático global desde el punto de vista de modelado y de observación se discuten. El autor ofrece su opinión personal y sugiere que se debe tener precaución en términos de un esfuerzo único (muy concentrado) de entender el problema a través de la experimentación numérica basada en los modelos de circulación general (GCM). Al mismo tiempo aconseja otros enfoques, por ejemplo, estadísticos y otros estudios de fenómenos atmosféricos, aparte de la temperatura para buscar evidencias de cambio climático. En particular enfatiza la necesidad de encontrar, por razones políticas, y tan pronto como sea posible, una señal clara de que el efecto de invernadero se incrementa y de que éste tiene un impacto sobre la circulación general de la atmósfera.**

ABSTRACT

**Some of the fundamental problems related to the current approach to global climate change from modelling and observational stand points are discussed. The author offers his personal opinion and suggests caution in terms of an all out effort to understand the problem through numerical modelling based on GCMs models. At the same time he advises other approaches i.e. statistical and other studies of atmospheric phenomena different from temperature in seeking evidences of climate change. He emphazises in particular the need to find, for political reasons and as soon as possible, a clear signal that the greenhouse gas affect is being enhanced and that this has an impact on the general circulation of the atmosphere.**

## Recent development of the greenhouse gas issue

The fact that the Earth's temperature is related to the amount of $CO_2$ in the atmosphere was pointed out as early as 1861 by the British physicist Tyndall and that the amount of carbon dioxide in the atmosphere could be a basic reason for climate change on Earth, was first discussed by Arrhenius (1896).

Various short-lived attempts were made during the first half of the 20th century to observe the current $CO_2$ in the atmosphere. However, it would not be until the 1950's that serious monitoring of $CO_2$ would start with the establishment of the Mauna Loa Observatory on Hawaii in connection with the International Geophysical Year. Continuous reliable records of the carbon dioxide in the atmosphere hence exist since the year 1958. During the 1960's these data were used primarily for studying long-range transport in the atmosphere under various meteorological conditions.

By the end of the 1960's it became clear from the Mauna Loa records that the amount of carbon dioxide in the atmosphere was steadily increasing presumably due to man's burning of fossil fuel. Hence when the UN Conference on the Human Environment was convened in

Stockholm in 1972, one of the global environmental problems mentioned as a potential threat was a climatic change due to an enhanced greenhouse effect caused by a continued increase of atmospheric $CO_2$. In the year 1972, the concentration of $CO_2$ had risen from 315 ppm in 1958 to around 322, i.e. by about 0.5 ppm per year.

By about the same time, the first attempts had been made to develop simple models which could be used to simulate the future global climate due to an enhanced greenhouse effect (Manabe and Wetherald, 1967, 1974).

Since 1974 when WMO/ICSU formulated the physical basis for its GARP climate programme (WMO, 1974), the general circulation modelling approach has been dominating research on climate and climate change. Hence it has also came to dominate studies and research about the impact of an enhanced greenhouse effect.

In 1980 WMO, UNEP and ICSU presented a first international scientific assessment of the greenhouse gas problem based upon modelling attempts and other research made in the 1970's. It was concluded (WMO, 1981) that the results from simple radiative, convective equilibrium models which had been applied during the early 1970's had shown that a doubling of $CO_2$ in the atmosphere could lead to an average warming of the globe by 1.5 to 2.3°C. The early simulation attempts that had been made with general circulation models (GCM) (1975-1980) had resulted in an average likely warming of 2.0 to 3.5° for a doubling of $CO_2$ in the atmosphere. It should be noted that the difference between the results of the two modelling approaches is not very great and well within the uncertainty of both approaches.

In adhering to an informal international agreement that assessment of the greenhouse gas issue should be undertaken every five years, WMO/UNEP/ICSU supported from 1982 a more elaborate exercise to find out the actual knowledge about the scientific aspects of the greenhouse gas issue. This assessment was undertaken by the International Meteorological Institute (IMI) in Stockholm, Sweden, under the leadership of Prof. B. Bolin and in co-operation with a number of well-known scientists from around the world involved in studies of the greenhouse effect and the carbon dioxide cycle.

The results of this first in-depth assessment of the problem was reported to an international meeting of scientific experts organized by WMO/UNEP/ICSU in Villach in 1985. The assessment showed that further studies with the general circulation models, carried out during the 1980's by various groups of scientists, had confirmed that a doubling of carbon dioxide in the atmosphere would likely lead to a global warming of the Earth by an annual average of 1.5 to 4.5°C, i.e. a somewhat higher figure than obtained in the first assessment of 1980 (Bolin *et al.*, 1986).

Another important result was that there exist in the atmosphere other greenhouse gases than $CO_2$ which are increasing due to human activities and which will have to be taken into account in order to arrive at a complete picture. If we assume that their amount continues to increase together with that of the $CO_2$, the additive effect of all greenhouse gases will lead, as early as in 2030, to a warming equivalent to that due to a doubling of the pre-industrial amount of $CO_2$ in the atmosphere. This is several decades earlier than the time estimated for a doubling of the amount of $CO_2$ with "business as usual". The most important of these additional greenhouse gases to be considered are methane, nitrous oxide, tropospheric ozone and chlorofluorocarbons (IPCC, 1990).

An important conclusion in the IMI assessment of 1985 was that, although most data records show a clear increase in the global mean temperature over the last 5-10 years, it is inacceptable to relate this increase definitely to an enhanced greenhouse effect because of the great natural variability inherent in the Earth's climate system.

The meeting in Villach (WMO/UNEP/ICSU, 1985) agreed that the most important problems to tackle in order to further improve the scientific understanding of the issue were:

i. to improve the GCMs by coupling them with models of the ocean circulation, both at the surface and at lower levels,

ii. to improve parameterization in the GCMs of land surface and fresh water phenomena,

iii. to include in the GCMs the feedbacks from cloudiness and cryosphere,

iv. to develop models or other methods to find out the impact of an enhanced greenhouse effect at the regional scale.

v. to analyse in more depth the different contributions to the greenhouse effect of various greenhouse gases,

vi. to improve our understanding of the biosphere and the oceans as sources and sinks for atmospheric carbon dioxide. This was deemed essential to understand more completely the carbon cycle and in particular the contribution of deforestation to the airborne fraction of $CO_2$.

In addition to calling upon scientists to tackle the above problems, the meeting realized that if an increase of 2 to 3°C of the Earth's mean temperature could take only 40 to 50 years, it was an urgent matter to bring this possibility before the world's politicians. As a follow-up to the Villach meeting in 1985, another conference was organized in Villach in 1987 to consider the socio-economic impact to the world of a warming of the above-mentioned order of magnitude. These consequences were further discussed with a selection of politicians in Bellagio late in 1987 and it was concluded that it was time to bring the issue up to the political level of consideration. (WMO/UNEP/ICSU, 1989).

For this purpose, WMO and UNEP in 1988 jointly established the Intergovernmental Panel on Climate Change (IPCC) which undertook a third assessment of the greenhouse gas issue which was reported to the IPCC in late 1990 (IPCC, 1990). The report by IPCC on its assessment included three parts:

i. a new scientific assessment of the greenhouse gas issue,

ii. an assessment of the potential impact of an enhanced greenhouse effect,

iii. the consideration of the political options to limit or to adapt to an enhanced greenhouse effect.

The process of an assessment of the scientific situation by IPCC brought together about 300 scientists to contribute in one way or another to a very thorough analysis of the present understanding of the greenhouse gas issue. The following were the most important further results of the new scientific assessment:

i. a detailed analysis of the estimated contribution of the different greenhouse gases to an enhanced greenhouse effect. In particular, the importance of the differences in their residence time in the atmosphere was realized and emphasized,

ii. new results of simulation with a GCM including improved feedbacks from cloudiness considering the opposite effects of high and low clouds (Mitchell, 1989).

The improved feedback effects from clouds resulted in slightly lower values for the expected increase of temperature by the year 2030, best guess given as + 2.5°C but no change in the range presented in 1985 (1.5-4.5°C),

iii. the presentation of new temperature records showing continued increase in the mean temperature of the world (Jones, 1988). However, it was still concluded that it is not yet possible to conclude that this increase is related to an enhanced greenhouse effect,

iv. interesting but preliminary results regarding the likely impacts on climate of an enhanced greenhouse effect in three selected regions of the globe,

v. new estimates of the likely sea-level rise and impact on ecosystems of an enhanced greenhouse effect.

In spite of the above-mentioned considerable efforts to analyse our knowledge of the greenhouse effect and its likely future enhancement, there is still not unanimous agreement among scientists about how great the risk is for a future change of the Earth's climate. Indeed there are experts who do not accept that there is any clear risk for such a change.

## Analysis of selected scientific problems

In order to present some personal views on this subject, I should like to take the following approach to an analysis of the present situation. We shall start with presenting a list of those questions which have been most often raised by the sceptics and continue to discuss each one of these questions from my personal point of view.

Through analysing various articles published in the last few years (i.a., Lindzen 1990; White, 1990; Trefil, 1990), the following list of questions, uncertainties and concerns presented by scientists sceptical to the IPCC conclusions has been selected for further discussion (not in order of priority):

- there is a need to improve our knowledge about the sources and the sinks of the carbon cycle so that we shall be able to understand why the airborne fraction of $CO_2$ emitted into the atmosphere is about 50% and how this fraction may change in the future. The rôle of the oceans is particularly critical in this respect. Until we have this information, speculations about the future level of $CO_2$ in the atmosphere are futil,
- a special problem that needs consideration in this context is the contribution of deforestation to the airborne fraction of atmospheric carbon dioxide,
- why is the established increase in annual global mean temperature since the start of industrialization only about 0.5°C when it can be theoretically calculated that the amount of greenhouse gases emitted since this time should have caused an increase of 0.5-2.0°C due to the enhanced greenhouse effect?,
- the calculated increase of 0.5°C in global mean temperature since 1880 cannot be considered certain because there exist several factors which could have influenced the data record available. Problems stemming from inhomogeneity of records and influence of urbanization have been mentioned. Lack of data over the oceans contribute to difficulties to obtain a proper value for the global mean temperature,

- how can we explain that the main increase of global temperature since 1880 took place in the early half of the 20th century, i.e. before the strong emittance of greenhouse gases started around 1950? From 1950 to 1975 global temperature declined rather than increased,
- how to explain that data so far indicate cooling in the Arctic when at the same time models show that increase of temperature due to an enhanced greenhouse effect should be at a maximum in high latitudes?,
- are the physical processes involved with the greenhouse effect taken correctly into account in the general circulation models? A basic problem is how the increase in water vapour should be brought into the picture as an additional greenhouse gas when warming from other gases takes place? In present major models all feedbacks from water are considered to be positive. A more thorough analysis may show that some of the feedbacks are negative and hence may reduce the warming process. The feedbacks from various kinds of clouds are closely related and add further complications to the feedbacks from water vapour.

More general topics which according to more general agreement need further consideration in the near future and which will be discussed below are the following,

- from a political point of view, the transient period* is most critical. It is therefore necessary to study this period in various regions in more detail than has hitherto been done,
- how should a research programme be designed in order to reach, as soon as possible, understanding about what is going on at present in the atmosphere due to the enhanced greenhouse effect?,
- how should a technique be developed to study the impact of an enhanced greenhouse effect on climate in different regions of the world.

## The airborne fraction

The first point on the above list is obviously fundamental and most scientists would agree to the need to clarify in more detail the carbon cycle. It is disturbing that at present we cannot obtain a balance in the overall carbon budget. It is not yet known how about half of the $CO_2$ emitted into the atmosphere disappears and is being absorbed (Bolin *et al.*, 1986). Even more disturbing is the fact that without this understanding, we shall not be able to make any predictions about future possible changes in the airborne fraction of carbon dioxide which at the moment is about 50%. This, of course, is essential for predicting future levels of $CO_2$ and consequently also for forecasting when that amount will double or reach any other special level.

It is obvious that a better understanding of the rôle of the oceans as a sink for atmospheric $CO_2$ is basic for solving the above problem. The research needed for better understanding of the ocean circulation and its rôle in the carbon cycle is a long-term undertaking which involves large cost which can only be provided by national or international authorities. The WMO/ICSU World Climate Research Programme has launched several programmes to achieve this research

* Not very well defined, but often referred to as the next thirty to fourty years (2030), i.e. the period until it is expected that the additive effect of the greenhouse gases will be equivalent to the effect of a doubling of $CO_2$ in the atmosphere. Equilibrium is theoretically expected to be reached about ten to twenty years after the doubling effect is reached (2050).

goal but it is not expected that useful results will emerge in less than 5 to 10 years (WMO, 1988). In the meantime, we have to be somewhat cautious in making strong statements on matters where the future of the airborne fraction of $CO_2$ is crucial. A typical example of such a problem is the contribution of deforestation to the greenhouse gas issue.

### Contribution of deforestation to the airborne fraction

According to the latest estimates, about 75% of the annual net addition of carbon gases to the atmosphere comes from fossil fuel combustion mostly in developed countries. Clearing of tropical forests then contributes 20-25% of the net annual release of carbon (IPCC, 1990).

However, there is great uncertainty and much arguing going on about the above figures for the contribution of deforestation to the carbon in the atmosphere. Indeed, uncertainty about the amount of clearing (deforestation) going on in the tropics has lead to a heated debate between developed and developing countries regarding the latter's contribution to the carbon dioxide in the atmosphere.

There can be no doubt that there is an urgent need for further studies of the current rate of deforestation in the tropics in order to settle this dispute and in order to make clear how much a reduction in the rate of increase of carbon dioxide in the atmosphere would be achieved by abatement of deforestation in the tropics. The fundamental question about biota on land and in the ocean acting as a source or a sink for carbon in the atmosphere is not solved and has to be studied in detail.

### Trends in global mean temperature since 1880

Available sets of data to determine global temperature trend have two fundamental weaknesses:

i. data from climatological stations on continents are often biased due to their location, in particular when they are situated under strong influence of urbanization or other anthropogenic factors. In many areas stations have often been moved and the available data records therefore are in many cases not satisfactory as to homogeneity,

ii. stations on the oceans are limited to locations on islands, the data from which are difficult to compare with observations from ships or with sea-surface temperature. In order to obtain a homogeneous data set for the globe, various data from the oceans have to be made compatible with data from the continents.

Although the above problems with available data are serious, there is no doubt that competent climatologists having had to deal with these and similar problems for many decades in many other contexts, have developed statistical methods to cope with most of them. In other words, if the available set of data from continents and oceans are treated with all the methods developed by climatologists to harmonize series of data, it should be possible to arrive at a global data set that would give a reasonable answer to how the mean temperature for the globe has behaved during the past century. It is my conviction that, for instance, the thorough efforts which have been made by the group working at the Climate Center at the University of East Anglia, have produced a set of temperature data for the globe where the weaknesses mentioned above have been eliminated or at least been brought down to a minimum (Jones, 1988; Jones *et al.*, 1989). To argue in this context that no significant change of temperature has been possible to establish for the last decades over the American continent is quite irrelevant as we are only concerned with global means in connection with the detection of an enhanced greenhouse effect.

However, even if we are satisfied that well scrutinized and balanced data sets for the whole globe are now available and can be relied upon to provide a reasonably true picture of the fluctuations of the mean temperature over the last century, there are other problems with the trends provided.

Looking at the trend since 1880 we must ask why the total increase since 1880 in global mean temperature is at the lower limit of the increase that has been theoretically estimated to take place with the enhancement of the greenhouse effect that we expect to have taken place. There are various suggestions put forward to account for this. It has been argued for instance that increases in the amount of aerosols in the atmosphere triggered by higher frequencies of volcanic eruptions could have counter-balanced the warming during periods of lowering temperatures (Hansen and Lebedeff, 1987). Obviously there could exist several to us unknown reasons why the warming has kept at the lower end of the anticipated range but the following problem with the trend since 1880 is even more difficult to explain. The total increase of global mean temperature since 1880 is around 0.6°C as calculated with the best available data sets but most of this increase took place from 1910 to 1950 when the emission of $CO_2$ into the atmosphere was reasonably small and increasing only slowly. Even more peculiar is that according to the available data the warming which started around 1915, stagnated and changed into a cooling about 1950 when the emissions of $CO_2$ started to increase rapidly. Not surprisingly a similar hypothesis about fluctuations in the aerosol content of the atmosphere –as presented for the overall low global warming since 1880– is used as explanation for this peculiar behaviour of the global temperature trend since the beginning of this century. However, until we have further proof of the existence of a counter-balancing impact of the amount of aerosols in the atmosphere, the whole record from 1880 to about 1975 should not be used as a basis for any statement about an ongoing enhancement of the greenhouse effect.

It should be added here that there are clear indications of a continuous warming of the whole globe in average since about 1975, but the period since then is too short to be used for a definite statement about an impact of anthropogenic effects on climate because the natural variability of climate could account for this increase. Nevertheless, a statistical treatment of this period in comparison with the overall record since 1880 is very soon becoming appropriate in order to establish the statistical significance of the recent warming trend.

Because of the weaknesses and contradictions involved with available data on global surface temperature, there are good reasons to increase research activities on trends and fluctuations of other parameters of the world climate system that may be less biased than temperature but at the same time reflect a global warming. Flohn *et al.* (1990) recently reported the results of studies of changes in the moisture transport from low to high latitudes and its relation with the general circulation over the last 40 years. He concludes that this transport has increased significantly as would be expected with an enhanced greenhouse effect.

It is not my intention to claim that this study by Flohn provides proof of an ongoing warming of the globe but it is my conviction that further studies of changes of the general circulation of the atmosphere and related parameters over the last decades would be of significant help to understand if there are changes of processes going on in the atmosphere which could be due to an enhanced greenhouse effect.

## The distribution of the warming over the globe

All of the GCM models used to simulate future global climates with an enhanced greenhouse effect show stronger impact of the effect on temperature in high latitudes than in low. In fact some of them indicate with a doubling of $CO_2$ a temperature increase of as much as 8-10°C for the winter months in the subarctic regions of the Northern Hemisphere while the warming in the tropics would be of the order of 1 to 2°C only (IPCC, 1990).

This is as yet non confirmed result of the GCM model simulations. It is true –and has been used as an argument for the model results– that the warming of the Northern Hemisphere that took place in the beginning of this century (1915-1950) also started and became stronger in high than in low latitudes. However, it is also clear that the forcing factor for the warming at that time most likely was a different physical factor than the increase of the amount of greenhouse gases in the atmosphere. It is not yet known which forcing factor caused this warming but it seems more likely that it was a natural cause –perhaps as indicated above coupled with fluctuations in the frequency of volcanic eruptions. If the forcing factor to the warming of the Northern Hemisphere in the early part of this century was totally different from the one expected to occur due to the enhanced greenhouse effect, the argument that warming was stronger in high than in low latitudes in the first case looses its relevance for the second case.

Hence it seems necessary to clarify in more detail the physical processes involved with the regional temperature increase due to an enhanced greenhouse effect. Recent studies of the processes involved with the ENSO and El Niño phenomena indicate that the tropics, in particular in the Pacific ocean, represent a very sensitive part of the globe where the impact of factors significant for a global change of climates are particularly strong (Ramanathan and Collins, 1991). This may imply that the tropics is a region where the processes involved with an enhanced greenhouse effect are much stronger than earlier thought. Of course, it does not follow from this reasoning that the temperature increase will be stronger in the tropics than in high latitudes. However, there is no doubt that the changes of the physical processes caused by an enhanced greenhouse effect and their feedbacks in various climatic regions of the globe must be known in more detail than is now the case before we can forecast the regional change of temperature. As indicated earlier, important parameters to be studied in these processes are the creation and impact of various types of clouds and the latitudinal moisture transport (Ramanathan and Collins, 1991, and Flohn *et al.*, 1990). It is quite possible that our lack of knowledge of the impact of an enhanced greenhouse effect on regional temperature is reflected in the fact that the North Atlantic region shows a cooling rather than a warming over the last few decades. However, it is too early to have any definite opinion on that matter. It is important indeed that we accept the fact that due to gradual changes in the general circulation some regions of the globe may show cooling rather than warming, particularly during the transient period. For obvious reasons one should therefore avoid the expression "global warming" for the consequences of an enhanced greenhouse effect.

## Modelling problems

One fundamental problem is relevant to all attempts that have been made so far to simulate the future climate with the help of models. The results that emerge are surprisingly similar, either a very simple type of model or a complicated GCM model is used. One must ask oneself whether this may be due to the fact that all models applied are so similarly dominated by a few factors that the simulated results become the same, independently of the taking into account of less important paramenters and of the size of the model. Another possibility is, of course, that the similarity of the results reflect a real characteristic of the climate system –in that case one may conclude that it is not worthwhile to develop bigger and more complicated models.

The above-mentioned need to study in more detail the physical processes involved with the greenhouse effect is crucial also for the modelling approach because improved parameterization is required of several factors in the models which are not sufficiently well known. To continue to change various parameters in the models by a trial and error approach or to change the mathematical methods seem not to render any further improvement in results.

Let us therefore repeat some of the parameters that need to be better understood. First of all, the impact of the increase of latent heat in the atmosphere with the warming must be better parameterized in the models. This feedback is well known and has been taken into account in most modern models. However, it is not clear whether this always has been done in the proper way taking radiation theory into account. It has been argued for instance that the additional warming from increased moisture content in the atmosphere has an upper limit which considerably reduces the impact of water vapour as a greenhouse gas compared with the results so far obtained when this feedback has been taken into account (Adem and Garduño, 1991; Garduño and Adem, 1992).

It is possible that the additional moisture becoming available in the atmosphere with a warming from an enhanced greenhouse effect will result in an increased amount of clouds where low and upper clouds will have different effects. It is necessary to continue ongoing efforts to include the feedback from different kinds of clouds in available models. The earlier mentioned recent study of the thermostatic impact of cirrus clouds created during El Niño's in the Pacific (Ramanathan and Collins, 1991) is a typical example of the complications which must be taken into account.

A general conclusion to be drawn from the above discussion is that a complete concentration on the modelling approach for studies of the greenhouse effect is not justified until we know better how to parameterize the many of the physical processes involved. The important results from the simulations about a future climate through the modelling approach that has been carried out should not be underestimated, they have told us that the risks for a future climate change are. However, in order to be able to become more convincing in our predictions to policy makers it is necessary to improve our models by:

**a.** further intensifying research on the physical processes involved with the greenhouse effect in order to improve parameterization of feedback from clouds, moisture content, soil moisture, evapotranspiration, vegetation and the cryosphere;

**b.** coupling of the gradually improved atmospheric models with realistic ocean models built upon better understanding of the physical and circulation processes in the ocean,

**c.** further research to detect as soon as possible whether changes are taking place in the general circulation which may be due to an enhanced greenhouse effect and which will cause changes of climate.

## General approaches

Another field of research which is of fundamental importance for the political decisions about climatic change is to get to understand the regional consequences of a globally enhanced greenhouse effect. In the first place, it is necessary to find out the future climate in different regions, i.e. how temperature, precipitation and evaporation will change in any special region and secondly, which consequences to ecosystems and human activities these changes will have. Only when it will be possible to predict these consequences with some reasonable degree of confidence in any country, will it be possible to convince governments about the need for action.

Finally, a word of caution about the near future. It is essential that we make a special research effort to tackle the problem of the *regional* impact of an enhanced greenhouse effect *during the transient period** of the next 20 to 30 years. To existing governments the next decades are much more important than what will happen during the equilibrium period after 50 years. It is therefore of great significance that research be devoted to the changes that may occur in the next 10 to 20 years in different regions of the globe. This period is likely to show up in increased frequencies of extreme events such as droughts, floods, tropical cyclones, tornadoes, etc. With unprecedented changes of the general circulation due to the gradually increasing impact of the greenhouse effect, some regions are likely, during the transient period, to become colder rather than warmer a fact that if not clearly explained by the scientists involved, could come as a complete surprise to decision and policy makers. We can already see that the acceptance of the idea that an enhanced greenhouse effect is working is much more difficult to achieve in areas where a cooling is at present taking place.

It is clearly most important to clarify to decision makers that a large amount of research remains to be carried out before we know in detail about the impact on climate of an enhanced greenhouse effect around the globe. However, it is for political reasons also necessary that research to detect as soon as possible the climatic consequences of the enhanced greenhouse effect be given precedence to all other research activities.

In order to increase the research activities to find the signal of a climatic change due to the enhanced greenhouse effect, it is essential that all kinds of methods classical or modern are being applied. The present concentration on modelling the general circulation for simulation of an equilibrium stage will not help us to analyse the ongoing processes in the atmosphere unless a completely new approach to modelling such processes in themselves is taken. In addition, the statistical approach to climatic change seems to be completely forgotten. Analysis of frequencies and variability using records from the last 40 years, including those for the upper air, could be extremely helpful to understand ongoing processes or at least to get an idea about which general circulation processes are the most important to study. The following proposed list of research topics give an idea of the type of studies that I have in mind for trying to find the signal of an ongoing change of climate. I am, of course, aware of the fact that many of these research items are already being tackled in one way or another. The list is basically presented to indicate the type of research that need to be enhanced in parallel with the ongoing modelling approach.

Proposed research projects for finding the signal of a world-wide climatic change:

1. Further theoretical studies of the radiation processes involved with enhanced greenhouse effect.
2. Modelling changes of the general circulation due to the above changes in the radiation processes.
3. Seasonal and regional frequencies and amounts of various types of clouds.
4. Seasonal frequencies, location and duration of blocking situations in the mid-latitudes since 1950.
5. Trends in annual mean temperature around the Arctic but south of the drifting sea ice, which will keep summer temperature unchanged (roughly along the polar circle).
6. Trends in seasonal and regional frequencies of tropical cyclones, typhoons and hurricanes.

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* see footnote on page 5

7. Trends in standard deviations of mean temperatures around the globe – 1950-1990.
8. Trends in mean maximum temperatures in the tropics, subtropics and temperate latitudes.
9. Trends in amount of evapotranspiration in semi-arid regions since 1950.
10. Trends in precipitation amounts in temperate latitudes since 1950.
11. Trends in frequencies of droughts in key areas around the globe.
12. Secular changes in frequencies of key parameters related with the El Niño phenomenon.

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