INCREASED CARBON DIOXIDE CONCENTRATIONS AND CLIMATE: THE EQUILIBRIUM RESPONSE

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1. Introduction

Unlike some other pollutants introduced into the atmosphere by Man, carbon dioxide is naturally occurring and non-toxic. The direct effect of increased concentrations may be beneficial notably because it will tend to increase the rate of photosynthesis in plants. On the other hand, there may be deleterious effects through its influence on climate but this is still unproven and we cannot be certain whether, on a global scale, it will on the whole be harmful or beneficial. Taking an extreme view, it has been suggested that the induced climatic warming might be sufficient to cause surging and melting of glaciers and lead to the inundation of vast tracts of coastal land surface, with serious consequences for all mankind (see also Oerlemans this volume). A more general view seems to be that while some areas of the globe might experience a significant deterioration of the climate, in many parts the changes will be either beneficial or difficult to distinguish within the natural variability (see also Kellogg this volume). A third view is possible; that because of limitations in their formulations, models tend to exaggerate the effect on climate, and that consequently, no significant change will be observed. The strategy which should be adopted for research on carbon dioxide depends on which view is correct.

Clearly, within the area of carbon dioxide research as a whole, investigation of the influence of increased concentrations on global and regional climates is central and crucial, for its results are required to guide the effort put into other areas, particularly prediction of concentrations in future de-

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cades. The problem of determining the effect of increased carbon dioxide on climate is difficult, the more so because there are some essential aspects of the physical basis of climate that are not well understood, and which it is the purpose of the World Climate Research Programme to elucidate during the next one or two decades. Estimates which can be made now of the climatic change caused by increased carbon dioxide are necessarily preliminary and tentative, and may be substantially altered as a result of an increase in our understanding of climatologically significant processes.

Most investigations on carbon dioxide and climate have been concerned with the 'equilibrium response' of the climatic system to a specified increase in the atmospheric concentration of the gas. An 'equilibrium climate' for a given atmospheric concentration is attained in a time integration of a model after all the systematic trends in the climate system, which are likely to be present initially, have disappeared. The 'equilibrium response' is the difference between equilibrium climates with increased and with present day carbon dioxide concentrations. As it does not correspond to a feasible carbon dioxide scenario, the 'equilibrium response' is strictly not a prediction. However, it presents the meteorologist with a relatively well-posed problem whose solution can provide guidance on the mechanisms by which carbon dioxide affects the climate, and, in the present state of understanding, this is the most significant aspect of the problem that needs to be worked on. In this chapter, we review the results of experiments aimed at establishing the 'equilibrium response'.

In the following section, the effect of carbon dioxide concentrations on climate is considered in a general way in order to indicate how the problem has to be approached. There follows a consideration of, first, radiative-convective, and then general circulation model results. For the latter, we concentrate on results produced by two groups: the Geophysical Fluid Dynamics Laboratory (GFDL, Princeton) and Meteorological Office (Bracknell) groups. The fifth section is concerned with the statistical problem of determining which changes in general circulation integrations are 'significant', and, finally, an attempt is made to assess the present position and to indicate what is required to improve our assessment of the carbon dioxide impact on climate.

2. The methodology for determining the climatic effect of increased CO_2

In the natural atmosphere, three gases are active radiatively in the infrared; namely - water vapour, carbon dioxide and