Scenarios of climate change in the Australian region due to the enhanced greenhouse effect

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Summary. Future climate change due to the enhancement of the greenhouse effect has the potential to substantially affect agriculture in Australia. To assess these impacts, scenarios of climate change on the regional scale are required. Outlined here are the current CSIRO scenarios of temperature and precipitation change by the year 2030, which are based on the latest relevant global climate model results. Due to much uncertainty in the science, these scenarios encompass a broad range of future climate changes. Implications of these changes for agriculture are briefly discussed.

Introduction

Due primarily to anthropogenic emissions of greenhouse gases (most notably carbon dioxide and methane), concentrations of these gases are increasing in the earth's atmosphere, and will continue to increase well into the next century. These gases absorb long-wave (heat) radiation emitted by the earth's surface, and thus, through increasing in concentration, will lead to a climatic warming. The rate of this warming depends on rates of increase of greenhouse gas concentrations, and the sensitivity of the climate system to this increase. There is much uncertainty with both of these factors, and consequently in estimates of future global warming. Nevertheless, some warming is expected, and with it other changes in weather patterns, such as regional increases and decreases in rainfall and changes in the frequency and/or severity of extreme weather events such as drought and flood conditions. The direct effects of increasing CO_2 on plants must also be considered.

Clearly such changes are of potential importance to agriculture, but to assess what the impacts might be requires estimates of climate change at the regional scale. The main tools used in climate change research, general circulation models (GCMs), do not, currently, provide reliable detailed regional predictions of climate change. Of the many shortcomings of GCMs, low horizontal resolution and the need to parameterise small scale processes such as precipitation are probably most significant at the regional scale. This means a very careful approach to regional climate change assessment is needed. Our approach is to: (a) analyse the control run (I xCO_2) of the available GCM greenhouse experiments to identify those models which simulate current regional climate acceptably well, and (b) analyse the enhanced greenhouse (2xCO_2) results of the acceptable models, placing most confidence on simulated features common to a number of models. This approach leads only to the development of a plausible range of scenarios of regional climate change for use in impact studies. Single and precise predictions are not yet possible.

GCM data used

The GCM experiments we have examined have been conducted with the the 9-level CSIRO model (CSIRO9), the Bureau of Meteorology Research Centre model, the United Kingdom Meteorological Office high resolution model, the Geophysical Fluid Dynamics Laboratory high resolution model, and the Canadian Climate Centre model. All use a simple mixed layer ocean without explicit ocean currents, but with a heat flux correction which implicitly allows for them. The experiments were run to equilibrium for 1xCO2 and 2xCO2 conditions. The global warming simulated by these models ranges from 2.1-4.8?C - similar to the range of uncertainty in climate sensitivity of 1.5-4.5?C adopted by the Intergovernmental Panel on Climate Change (IPCC) (1).

The variables chosen for assessing the GCM results were those of key importance in impact studies: mean sea level pressure, surface air temperature (or the nearest equivalent) and precipitation. On a global scale, we found that all five models simulated under current conditions the main features of the observed latitudinal distribution of these variables. The broadscale climatic features of the Australian region were also simulated by each model. For example, the models simulated the seasonal migration in the latitude of the subtropical high pressure belt (from over southern Australia in winter to south of the continent in summer), and the development of a monsoonal low pressure area over northern Australian in summer. In rainfall, the models successfully simulate the dominance of summer rainfall across northern Australia and winter rainfall across southern Australia, and the drier climate of central and western areas of the continent and the wetter climate of southern, northern and eastern coastal areas. Although the broadscale patterns were well simulated, there were some errors in the magnitude of key features, and at a finer scale, the simulations had many deficiencies. We concluded that the 2xCO_2 results of all five experiments should be given equal weight in assessing possible regional climate change. This contrasts with an earlier regional intercomparison study we conducted (2), where some older GCMs were rejected as having unacceptably poor control simulations.

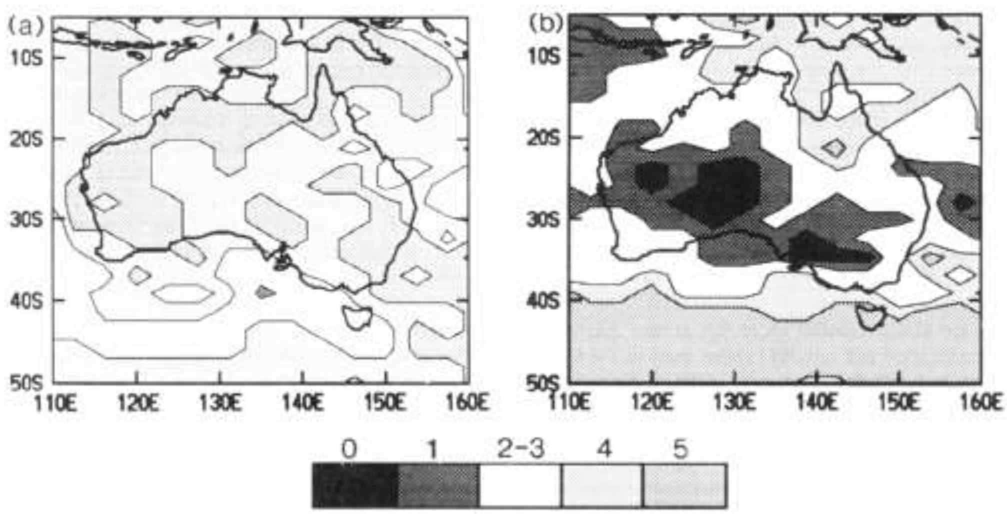

Figure 1. Number of GCMs (maximum of five) showing an increase in rainfall under enhanced greenhouse conditions: (a) summer half-year (Nov.-Apr.), (b) winter half-year (May-Oct.).

Simulated regional climate change

The results from the GCMs are used to prepare scenarios of the spatial pattern of temperature and rainfall change in the Australian region. To obtain these, the 2xCO2 results are re-expressed as the pattern of temperature change, or percentage rainfall change, per degree of global warming. For each grid point (on an interpolated common grid), the simulated changes were then ranked from the highest to the lowest. Seasonal maps of the rank 2 and rank 4 changes (the 80th and 20th percentiles) were then examined. These maps were taken to represent the range of regional temperature and rainfall change per degree of global warming indicated by the five models.

For temperature, the ratio of local warming to global warming was around 0.3-1.0 in northern coastal areas of Australia. It was a little greater in southern coastal areas (0.8-1.2), and encompassed a large range in inland Australia (0.5-1.4).

For rainfall, the models simulate areas of increase and decrease, with considerable agreement between models as to their location. Figure 1 shows the regional distribution of the number of models showing an increase in rainfall for the summer and winter half years. In summer, at least four of the five models indicate rainfall increases across nearly all of Australia, and in many regions all five show increases. In winter, all models show increases south of around 40?S, and at least four of the five models show decreases over inland southern areas of Australia. Between these zones (southern and south-eastern coastal Australia) the models disagree on the sign of the rainfall change. Based on the spatial patterns presented in the figure and the 20 and 80 percentile maps for rainfall changes, the simulated response of Australian rainfall per degree of global warming can be determined.

Scenarios of climate change in the Australian region for particular times in the future can then be constructed by multiplying the regional response scenarios by scenarios of global warming. For this purpose, we have used the recent transient global warming scenarios of Wigley and Raper (3). The range of warming represented by these scenarios takes into account uncertainty in the sensitivity of global climate to greenhouse gas forcing (global equilibrium warming of I.5-4.5?C for a doubling of CO2, see (1)) and uncertainty in future emissions of greenhouse gases. Using this approach, the temperature scenarios for the year 2030 give increases of 0-1.5?C in northern coastal areas, 0.5-2.0?C in southern coastal areas and 0.5-2.5?C inland. For precipitation, the scenarios are 0-20% increase in summer half-year rainfall at locations throughout the continent, and winter half-year rainfall decreases of 0-10% in southern inland areas, increases or decreases of 0-10% in southern and southeastern coastal areas and increases of 0-10% south of 40?S. These rainfall values were obtained by linearly scaling model-simulated regional percentage rainfall change per degree of global warming by the 2030 global warming values. In the broad range of model results reported by IPCC (I), global rainfall and temperature changes are approximately linearly related. More detail of these scenarios are in a document obtainable from CSIRO (4).

The simulated rainfall increases across Australia in summer appear to be due to increases in rainfall intensity (rain per rainday) rather than in the number of raindays. This result has emerged from analysis of the daily rainfall output of CSIRO9 (5) and the UKMO model (J.Gregory. pers.comm.). Data were not available to test this for other models. The model results show increases in rainfall intensity to occur in most regions throughout the globe, even extending into some regions and seasons of simulated decrease in total rainfall. The significant implication of this is a simulated increase in the frequency of occurrence of heavy rainfall events and substantial reductions in their return period. This result is also supported by theoretical considerations and by the results of the earlier CSIRO4 model (6). Such a change, were it to occur with global warming, may be very significant because of its implications for increased flooding. However, an important point must be noted with regard to these results. In the GCM, individual rainfall events can be no smaller in spatial extent than a model grid square (around 500 km by 500 km in the present generation of GCMs), whereas in the real world they can be very much smaller. This important mismatch of scales means that the rainfall intensity changes simulated by current GCMs are not applicable to the real world in quantitative terms, and are indicative only.

These regional climate change scenarios have many shortcomings. They are based on equilibrium climate simulations and hence assume that the transient regional response is proportional to the equilibrium regional response. As the GCMs used do not simulate the El Nino - Southern Oscillation phenomenon (ENSO) (7), the scenarios do not encompass climate changes that may ensue from changes in ENSO behaviour. Possible changes in tropical cyclone behaviour are also not included. Also, the horizontal resolution of the GCMs used is not high enough to resolve many topographical features of regional climatic importance.

Discussion

Such changes in climatic means and in the frequency of climatic extremes have the potential to significantly affect agriculture (8). For example, any decreases in rainfall, as is considered possible for southern Australia, would increase drought potential and affect the viability of many crops. The effect of any increases in summer rainfall is unclear, as the balance between this and the expected increase in evaporation is uncertain (5). Changes in temperature will be important, particularly the increase in the frequency of very hot days, and the decrease in the frequency of frosty days implied by a general warming. The latter may restrict the regions suitable for horticultural crops requiring winter chilling (9), but allow southward expansion of subtropical crops. Important indirect impacts would include changes in the occurrence of pests and diseases (10) and availability of the water for irrigation and changes in soil erosion. The direct effects on plant growth of increased atmospheric CO2 must also be allowed for. For example work by Wang *et al. (1* I) has shown that although potential yield is decreased due to faster maturation at higher temperature in some cultivars, this is more than offset by CO2 enhancement of productivity in other, longer season, cultivars. Finally, as agriculture is a source of greenhouse gases, changes in agricultural practices may play a role in any future national effort to reduce such emissions.

The uncertainty in the current climate change scenarios means that impacts such as those discussed above cannot be accurately assessed. However, significant impacts on agriculture are very likely. This underscores the need for impact studies to explore the sensitivity of the system under consideration for a range of possible futures. The Climate Impact Group welcomes consultation by those planning to use the CSIRO scenarios in agricultural impact studies, and would be happy to collaborate in such studies.

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