Uncertainties in Ecological and Hydrological Impacts of Doubled-CO_2 Climate Change

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Abstract

The identification of "dangerous" levels of climate change is made more difficult by the uncertainties in the representation of physical and biological processes in climate models and impacts models. For example, the regional climatic, ecological and hydrological responses to a given increase in greenhouse gas concentrations may be highly sensitive to the specific values assigned to physical parameters which are poorly constrained by observations. The Hadley Centre climate model is being used to explore the implications of these uncertainties for projections of changes in vegetation growth (net primary productivity, NPP) and water availability (surface and sub-surface runoff) in response to a doubling of CO2, as a result of both climate change and the direct effects of increased CO2 on plant physiology, transpiration and runoff. Uncertainties in both of these processes combine to generate large uncertainties in the overall responses of both NPP and runoff to doubling CO_2 in many regions.

Background

Complex climate models with detailed representation of the atmosphere, ocean and land surface are the only tools that can independently predict changes in climate averages and extremes over the planet. The predictions of future climate from these models are being used increasingly to estimate ecological and socio-economic impacts, and to plan adaptive responses. They are also used to evaluate the effect of various mitigation options, such as stabilisation of atmospheric concentrations of greenhouse gases.

All predictions of future climate change contain uncertainties. These are due to unknown future greenhouse gas emissions, uncertainties in the models used to simulate climate change, and because of natural variability. The ability to quantify the uncertainties in model predictions will enable us to estimate the relative likelihood of different predicted values within the range of uncertainty, and allow the results to be used in quantitative risk assessment methods.

Some of the largest of the uncertainties stem from the climate models themselves; different models give quite different predictions because they represent aspects of the climate system (such as clouds) in different ways. The Hadley Centre has recently developed a method to quantify this climate model uncertainty. This employs many versions of a climate model, each of which uses different, but plausible, representations of climate processes. The model versions are used to predict future changes, with each different version of the model producing a different predicted future climate.

The impacts of climate change can be predicted from the results of complex climate model simulations and, like predictions of temperature and rainfall, they are also subject to uncertainty. In particular, in the case of ecosystem impacts, the extent to which photosynthesis will be enhanced by the fertilization effect of increased CO_2 is not clear. Moreover, the extraction and evaporation of water from the soil into the atmosphere via plants (transpiration) depends on the opening of plant stomatal apertures which is generally observed to decrease under higher CO_2 – this could imply wetter soils and increased runoff as a direct consequence of the CO_2 independently of any radiatively-forced climate change. However, the extent of this effect on transpiration is also uncertain.

Using an ensemble of climate model simulations including sub-models of vegetation of hydrology, we have varied the values of key model parameters influencing both climatic processes and the direct effects of CO_2 on photosynthesis and transpiration. We have then estimated uncertainty ranges for predicted future changes in plant productivity and water availability for a scenario of doubled atmospheric CO_2 concentrations.

Net Primary Productivity

The indicator of plant productivity used here is the net primary productivity (NPP), a measure of how much carbon plants can store. It is controlled by the concentration of CO_2 in the atmosphere, temperature, rainfall, and the availability of nutrients, and hence will change in the future. The Figure below (upper panel) shows the changes in plant productivity predicted by the average of the models. As a global average, there is an increase of around 10%. The region with the largest decrease is north-eastern South America. The sizeable uncertainty range in the predictions of plant productivity is influenced by the potentially competing effects of CO_2 fertilization and climate change – as well as regional climates varyng acocrind to uncertainties in the atmospheric model parameters, the direct responses to doubling CO_2 are included in some model version but not in others.

Water availability

Runoff provides a measure of the availability of water in a given region. Changes in runoff predicted by the Hadley Centre climate model are shown in the Figure below, and are affected by both changes in precipitation and also evaporation (which depends on temperatures) and transpiration (which additionally depends on plant stomatal responses to CO_2, which are included in some model versions but not others). The global average increase in runoff, estimated from the average of the ensemble of models (upper panel), is around 12%. As in the case of plant productivity, the uncertainty in the predicted change in runoff (lower panel) tends to be larger than the average predicted change at most locations.

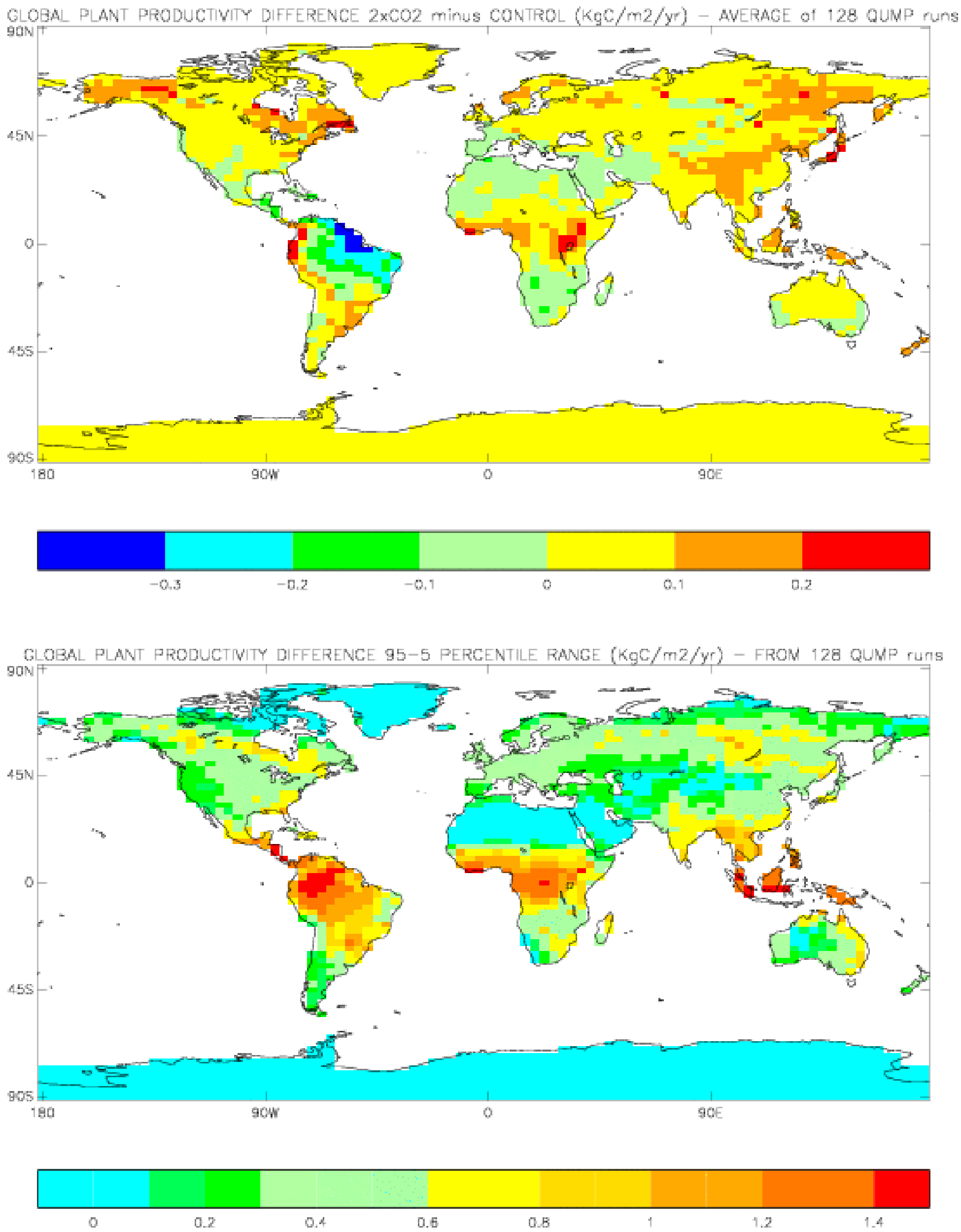

Figure 1. Top: Mean changes in net primary productivity (NPP, kg C /m^2/year) from 128 GCM simulations perturbing key physical parameters, including plant stomatal responses to CO_2. Bottom: Variations in changes in NPP in the 128 model versions: 5 to 95 percentile range

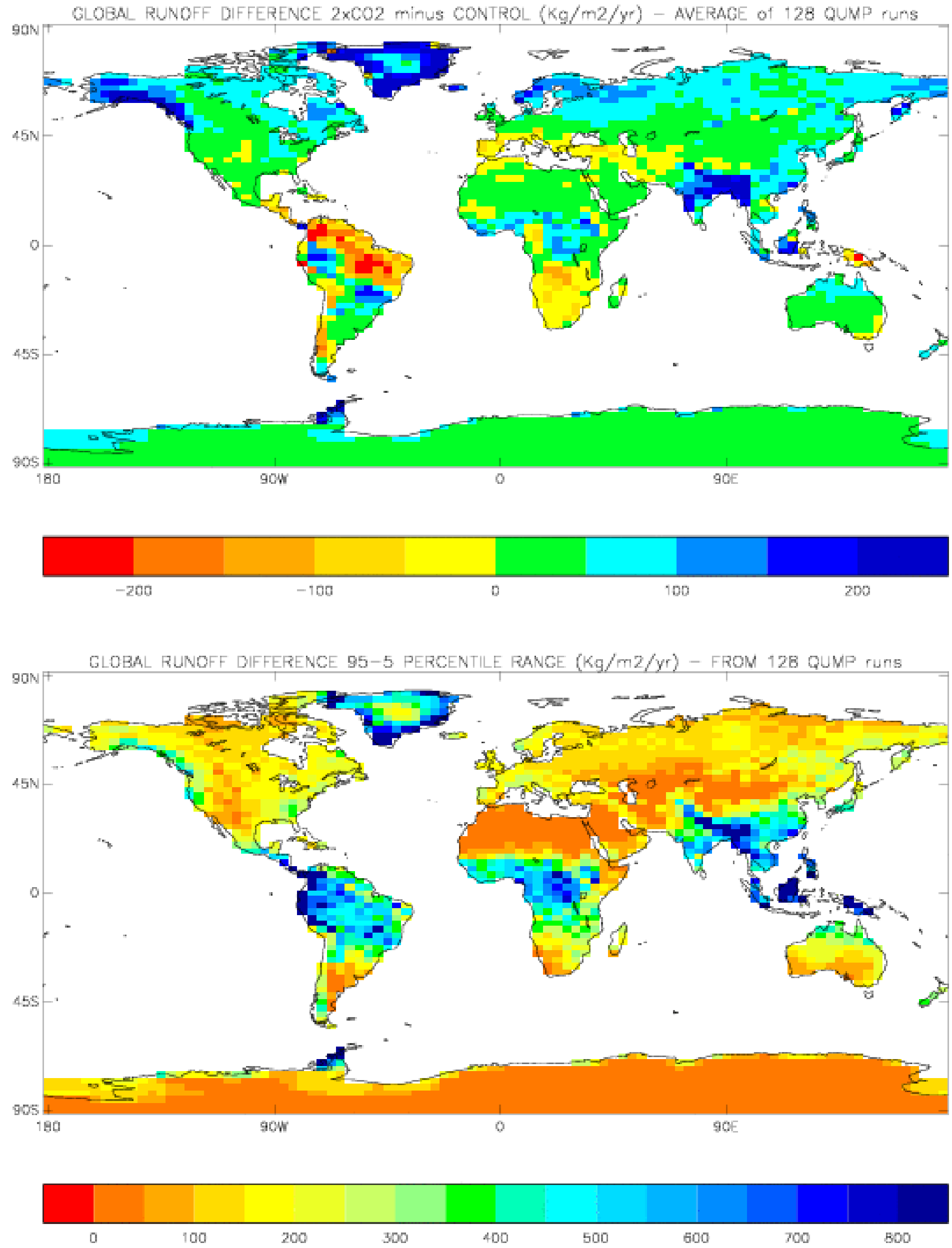

Figure 2. Top: Mean changes in runoff (kg/m^2/year) from 128 GCM simulations perturbing key physical parameters, including plant stomatal responses to CO_2. Bottom: Variations in changes in runoff in the 128 model versions: 5 to 95 percentile range