MIS31-17 Room:511 Time:May 2 14:45-15:00

Emission scenario dependency of pattern scaling and linear additivity of climate forcing-response relationship

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Human activities are changing the climate, and the consequent impacts on humans and ecosystems are becoming increasingly serious. It has been recognised that adapting to and mitigating anthropogenic climate change is a matter of immediate concern for the world. To inform adaptation and mitigation policies, it is essential to assess the impact of climatic changes under a wide range of scenarios for the stabilization of emissions of greenhouse gases (GHGs) and anthropogenic aerosols (sulfate, black carbon, and organic carbon aerosols). Impact assessments are based on climate change projections from coupled atmosphere-ocean general circulation models (GCMs). Therefore, uncertainties in climate projection propagate to impact assessments and affect subsequent policy decisions for adaptation and mitigation.

Due to the large computational costs of GCMs, only a limited number of emissions scenarios can be made for GCM simulations. To overcome this difficulty and obtain climate scenarios under a wide range of emissions scenarios, the so-called pattern scaling method is often used. By multiplying climate change patterns per 1K of global warming from an AOGCM (called a scaling pattern) by the global mean warming projections from a simple climate model, this method provides projections of precipitation, as well as other variables, at global and regional scales under many emission scenarios. Although the pattern scaling method is widely used, applicability of pattern scaling has been evaluated by only a few studies, and further investigations are clearly warranted.

The basic assumption of pattern scaling method is that scaling patterns are independent on the emission scenarios. Here I show a robust emission-scenario dependency (ESD) in scaling patterns of annual mean precipitation; smaller global precipitation sensitivities occur in higher GHG and aerosol emission scenarios in all the CMIP3 GCM. Different aerosol emissions lead to this ESD. The ESD of precipitation pattern potentially propagates into considerable biases in water resource assessments via pattern scaling.

It is possible to scale climate response patterns to individual forcing agents to obtain climate scenarios. This 'separated pattern' approach is useful to overcome the influences of the ESD. However, this approach requires care in its use. An important assumption of the separated pattern is that individual climate responses to individual forcing agents can be linearly added to obtain the total climate response to the sum of the forcing agents. We explored whether linear additivity holds in 5-year mean temperature/precipitation responses to various combinations of forcing agents in the 20th century and in a future-emissions scenario at global and continental scales. We used MIROC3 GCM, which includes the first and second indirect effects of aerosols. The forcing factors considered were well-mixed greenhouse gases, the direct and indirect effects of sulphate and carbon aerosols, ozone, land-use changes, solar irradiance and volcanic aerosols (the latter three factors were specified only in the 20th-century runs). By performing and analysing an enormous matrix of forcing runs, we concluded that linear additivity holds in temperature responses for all of the combinations of forcing agents at the global and continental scales, but it breaks down for precipitation responses in certain cases of future projections.

Keywords: Climate scenario, pattern scaling, impact assessment