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Pattern scaling approach for generating regional projections of future extreme events associated with tropical cyclones

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The assessment of a wide range of greenhouse-gas-emission scenarios in climate change studies employs a simple climate model and pattern scaling based on ensemble projections with complex climate models for a few representative scenarios. The simple climate model deals with the global mean surface temperature as a prediction variable, and the pattern scaling specifies the spatial distributions of different climate variables with prescribed spatial patterns that do not depend on specific scenarios and time points. Although mean temperature and precipitation are typical variables specified by pattern scaling, the present study applies the concept of pattern scaling to extreme events, which are essential for assessing the impact of climate change. An example shown here is a scheme to assess changes in the minimum sea-level pressure and precipitation extreme of the most intense class of tropical cyclones that make landfall in Japan.

This scheme is based on the theory of potential intensity of tropical cyclones and general precipitation extremes. Although real tropical cyclones do not necessarily attain their potential intensities because of various environmental restrictions, the annual cycle of the lower limit of observed minimum sea-level pressures is well represented by climatological potential intensity. An extremely strong tropical cyclone with high societal impact forms only occasionally, within large fluctuations of natural climate variability, regardless of background warming. It is generally difficult to assess relatively small background changes in the intensity of such a rare event by observation statistics or numerical climate projections. The scheme overcomes this difficulty by focusing on large-scale thermodynamic conditions alone, with no consideration of the dynamic conditions that dominantly control the frequency of tropical cyclones. The thermodynamic conditions are scaled with global mean surface temperature anomalies by referring to results (patterns) of ensemble climate model experiments, and reflected in changes in the potential intensity of a target tropical cyclone. Then, the formulation of precipitation extreme incorporates the dynamic effect associated with the intensification of the target tropical cyclone by scaling the vertical structure of the base updraft with that potential intensity change, in addition to thermodynamic change in the amount of water vapor.

Figure 1 shows the assessment results for three different scenarios. The scheme formulates changes in the pressure drop and precipitation extreme of a target tropical cyclone as a function of global mean surface temperature anomaly. The temperature anomaly is calculated using a simple climate model, which has been developed separately, for 3000 cases for each scenario, taking the uncertainty of climate sensitivity into consideration. The computation load of the scheme is negligible, which enables the assessment of many scenarios with different conditions. The scheme also incorporates another uncertainty, not shown here, associated with the amplification of the upper-air temperature anomaly in the troposphere, which greatly affects the minimum sea-level pressure. Thus, the combination of a simple climate model and pattern scaling handles different types of uncertainties in a distinctive way, which is one of the advantages of this approach.

Figure 1: Probabilistic analysis of a target tropical cyclone for three different scenarios labeled RCP2.6, RCP4.5, and Z650. (a), (b): Secular change in the atmospheric multigas concentration and reference global-mean surface temperature anomaly, (c)-(e): Probability density function of the temperature anomaly, increase in pressure drop, and increase in precipitation extreme in 2081-2100 relative to 1981-2000.

Keywords: tropical cyclone, potential intensity, precipitation extreme, pattern scaling, simple climate model, emission scenario

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