International Max Planck Research School on Earth System Modelling

Warming up the atmosphere's heat engine: atmospheric energetics with higher greenhouse gas concentrations

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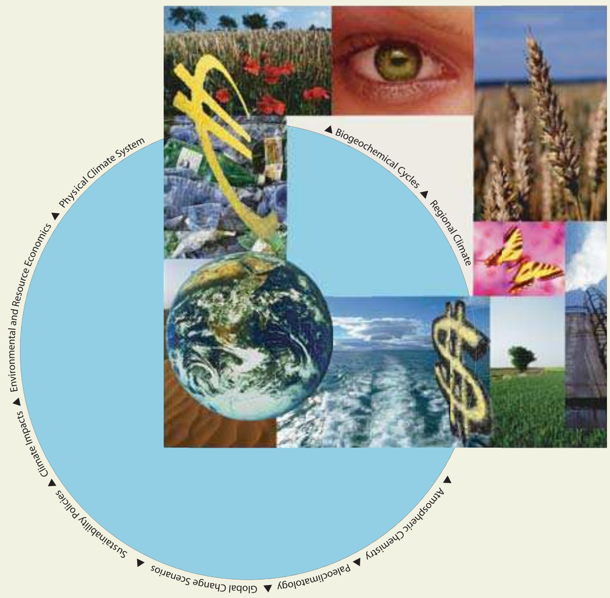

Abstract

Although an increase in greenhouse gas concentrations warms the troposphere, it is unclear if this changes the atmospheric energetics, i.e., the generation of available potential energy, its conversion into kinetic energy, and its further dissipation. The Lorenz Energy Cycle describes these energy processes and concisely summarizes the atmosphere's behavior as a heat engine from which other properties may be inferred. In order to study the response of the atmospheric energetics to an increase in greenhouse gas concentrations, we evaluate changes in the Lorenz Energy Cycle due to increased atmospheric CO_2 in the coupled atmosphere-ocean ECHAM5/MPI-OM model.

Globally, doubling of CO_2 results in a 4% to 7% weakening of the Lorenz Energy Cycle, since less available potential energy is converted into kinetic energy per unit of time, indicating a reduction in energetic activity. This global weakening is the result of two opposite responses: a strengthening in the upper troposphere and a weakening in the lower and middle troposphere. The latter dominates the globally-integrated response. These two responses result from the simulated $2xCO_2$ warming pattern that consists of a strong warming in the tropical upper-troposphere and in the high-latitudes near the surface. By performing additional experiments in which these two features of the $2xCO_2$ warming pattern are simulated separately, we find that the strengthening (a 4% increase) of the energetic activity is a consequence of the high-latitude surface warming, whereas the weakening (a 10% decrease) is a consequence of the tropical upper-tropospheric warming. Furthermore, both responses are accompanied by corresponding changes in baroclinicity—the main process responsible for the conversion of available potential energy into kinetic energy—as well as in extratropical storm activity, as measured by the global reservoir of eddy kinetic energy.

We show that the dominant aspect of the warming pattern that alters the global atmospheric energetics is not its horizontal temperature distribution but its mean static stability. This stands in contrast to the expectations based on Held (1993), which consider only effects of changes in the horizontal temperature distribution. We expand these expectations by pointing out that changes in the temperature stratification are more important. The response of static stability is the driving mechanism for changes in the atmospheric energetics, as well as in baroclinic activity from a global point of view. This means that the tropical upper-tropospheric warming, which increases mean static stability, causes a weakening in the energetic activity, whereas the high-latitude surface warming, which decreases mean static stability, causes a strengthening in the energetic activity. The combined response to a CO_2 doubling is dominated by the tropical upper-tropospheric warming effect, which explains the overall weakening in energetic activity. In terms of the reservoir of eddy kinetic energy, the two opposite responses—6% decrease due to the tropical upper-tropospheric warming and 5% increase due to the high-latitude surface warming—nearly cancel each other in the $2xCO_2$ case. This may explain the current lack of consensus regarding global changes in extratropical storm activity in a warmer climate.