Geophysical Research Abstracts
Vol. 17, EGU2015-10493, 2015
EGU General Assembly 2015

Comparing convective heat fluxes derived from thermodynamics to a radiative-convective model and GCMs

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The convective transport of heat and moisture plays a key role in the climate system, but the transport is typically parameterized in models. Here, we aim at the simplest possible physical representation and treat convective heat fluxes as the result of a heat engine. We combine the well-known Carnot limit of this heat engine with the energy balances of the surface-atmosphere system that describe how the temperature difference is affected by convective heat transport, yielding a maximum power limit of convection. This results in a simple analytic expression for convective strength that depends primarily on surface solar absorption.

We compare this expression with an idealized grey atmosphere radiative-convective (RC) model as well as Global Circulation Model (GCM) simulations at the grid scale. We find that our simple expression as well as the RC model can explain much of the geographic variation of the GCM output, resulting in strong linear correlations among the three approaches. The RC model, however, shows a lower bias than our simple expression. We identify the use of the prescribed convective adjustment in RC-like models as the reason for the lower bias. The strength of our model lies in its ability to capture the geographic variation of convective strength with a parameter-free expression. On the other hand, the comparison with the RC model indicates a method for improving the formulation of radiative transfer in our simple approach. We also find that the latent heat fluxes compare very well among the approaches, as well as their sensitivity to surface warming. What our comparison suggests is that the strength of convection and their sensitivity in the climatic mean can be estimated relatively robustly by rather simple approaches.