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Means and trends in surface radiation budgets: GCM simulations, observations, impacts

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Substantial uncertainty still exists regarding the temporal and spatial distribution of surface radiative fluxes, and its representation in General Circulation Models (GCMs). To constrain these uncertainties, we use direct observations at the surface from the Global Energy Balance Archive (GEBA) and Baseline Surface Radiation Network (BSRN) located at ETH Zurich. These data are used to systematically assess the performance of a total of 36 GCMs with respect to their surface radiative fluxes. These models represent almost two decades of model development, from the atmospheric model intercomparison projects AMIP I and AMIP II to the state-of-the art models participating in the 4th Assessment Report of the Intergovernmental Panel on Climate Change (IPCC-AR4). Results show that models tend to overestimate the solar irradiance at the surface, due to a lack of shortwave absorption in the atmosphere. The excessive surface insolation is also found under cloud-free conditions in many models, while improvements are found in some of the latest models with higher atmospheric absorption.

Large discrepancies exist also in the longwave downward radiation in the GCMs, both under all sky and clear sky conditions. A comparison with available observations suggests that GCMs tend to underestimate this flux. The downward longwave flux at the surface is also a particularly interesting component in the context of climate change, as it is most directly affected by changes in atmospheric greenhouse gases. GCMs predict the downward longwave flux to undergo the largest changes of all energy and radiation balance components, and observed changes at the BSRN sites are in line with the model predictions.

Recent evidence suggests that also the amount of solar radiation reaching the earth sur-

face is not stable over time but exhibits significant decadal variations. These variations, in addition to the changes in longwave radiation induced by alterations in greenhouse gases, cause changes in radiative forcings which may significantly affect surface climate. Observations from GEBA and BSRN suggest that surface solar radiation, after decades of dimming, reversed into a brightening since the mid 1980s at widespread locations. These changes are in line with a recovery of atmospheric transparency, possibly related to reduced aerosol loadings due to air pollution control and the breakdown of industry in formerly Communist countries. Current GCMs typically do not represent aerosol effects with a degree of sophistication to capture these effects. Here we use a special version of the Max Planck Institute for Meteorology GCM (ECHAM5-HAM), which includes aerosol effects in much more detail than in most other GCMs, Due to the improved treatment of aerosol effects, the model is able to reproduce the observed trend reversal under cloud-free conditions realistically.

The transition towards more sunlight at the earth's surface since the late 1980s after decades of decline may significantly affected surface climate. From the 1960s to the 1980s, the dimming may have been large enough to counterbalance the greenhouse-induced increase in downward longwave radiation, so that the available energy at the surface was rather decreasing than increasing. Further, land surface temperatures increased only marginally from the 1960s to the 1980s. Since the mid 1980s, the solar dimming was no longer there to mask the increasing greenhouse effect, so that the greenhouse effect became fully apparent during the 1990s. This is reflected, e.g., in much stronger temperature increase during the 1990s compared to earlier decades, no further decrease in daily temperature range, an intensified global hydrological cycle, as well as a substantial retreat of mountain glaciers, which was suppressed during the prior decades of dimming.

Recent related references:

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