Radiative Forcing by Long-Lived Greenhouse Gases: Calculations with the AER Models

Contributors

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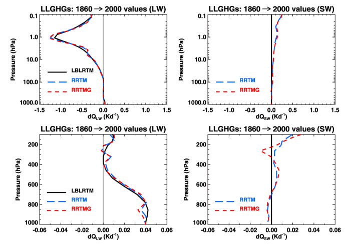

Heating rate profile differences from increasing the concentrations of CO2, CH4, N2O, CFC-11 and CFC-12 from 1860 to 2000 values using the standard mid-latitude summer profile for the (left) longwave and (right) shortwave from (top) the surface to 0.1 hPa and (bottom) the troposphere as calculated by the AER radiation models.

Research Highlight

A primary component of recent climate change is the radiative forcing caused by the increasing amounts of the radiatively active greenhouse gases in the atmosphere. Between 1750 and 2005, the radiative forcing at the top of the atmosphere due to increases in carbon dioxide, methane, nitrous oxide, and halocarbons has totaled over +2.6 W m-2. This forcing represents roughly one percent of the shortwave energy absorbed by the climate system and the longwave energy emitted by the Earth at the top of the atmosphere in a typical year, and the sign of the forcing indicates that the climate system is presently absorbing more energy than it releases. Accurate representation of these radiative processes in climate models is clearly essential to enhancing our ability to understand and to predict global climate change. The recent Radiative Transfer Model Intercomparison Project (RTMIP) examined the radiative forcing calculated by several coupled atmosphere-ocean general circulation models (GCMs) that contributed to the Intergovernmental Panel on Climate Change Fourth Assessment Report and by several reference line-by-line radiative transfer models (LBLRTMs). This research reproduces the RTMIP forcing calculations with the Atmospheric Environmental Research, Inc. (AER) longwave and shortwave radiative transfer models that have been developed with ARM support. This is motivated by the wide use of the LBLRTM within the community and in particular by the increasing application of the correlated k-distribution broadband rapid radiative transfer model (RRTM) to climate and weather forecasting GCMs (RRTMG). Descriptions of these radiation models and the source code are available at rtweb.aer.com.

Radiative forcing calculations with LBLRTM, Code for High-resolution Accelerated Radiative Transfer and Scattering (CHARTS), RRTM, and RRTMG follow the eight clear sky cases defined by RTMIP, in which only the concentrations of the long-lived greenhouse gases (carbon dioxide, methane, nitrous oxide, CFC-11 and CFC-12) are varied. Several changes in molecular amounts of these gases have been examined including the difference in their values from 1860 to 2000 and the effect of doubling carbon dioxide. Temperature, water vapor, and ozone are specified by the standard mid-latitude summer profile, and the calculations extend over forty vertical layers from the surface to a height of 0.01 hPa. Neither clouds nor aerosols are considered in the calculations. At the surface, 200 hPa, and the top of the atmosphere, the longwave net flux radiative forcing calculated by LBLRTM in each case is within 0.06 W m-2 of the mean of the RTMIP line-by-line model results. Similar longwave forcing calculations with RRTM and RRTMG are within 0.25 W m-2 of the line-by-line result except for the case in which methane and nitrous oxide were increased from zero to their 1860 concentration. The smallest differences between the AER broadband and line-by-line forcing calculations are at the surface. In the shortwave, the radiative forcing calculated by CHARTS is within 0.05 W m-2 of the mean RTMIP line-by-line result in most cases. The RRTM and RRTMG shortwave forcing is within 0.10 W m-2 of CHARTS at the top of the atmosphere, within 0.16 W m-2 of CHARTS at 200 hPa, and within 0.38 W m-2 at the surface. By contrast, the mean RTMIP shortwave forcing calculations of various GCM radiative transfer models differ by up to 1.0 W m-2 from the mean RTMIP line-by-line calculation. In some cases, this is partly caused by the absence of methane and nitrous oxide in the GCM shortwave models examined during RTMIP. In terms of heating rate, RRTM and RRTMG very closely reproduce the profile of longwave heating rate forcing changes calculated by LBLRTM from the surface to 0.1 hPa. The largest forcing differences of about ten percent occur at and just below the stratospheric peak in longwave cooling.

In summary, LBLRTM and CHARTS calculate radiative forcing that is in close agreement with the line-by-line models studied in RTMIP, and in most cases RRTM and RRTMG calculate forcing that is in better agreement with the line-by-line results than the mean of the GCM radiation models examined by RTMIP. In general, RRTM and RRTMG calculate longwave net flux forcing that is within a range of –0.20 to 0.23 W m-2 of LBLRTM, and more than half of the results are within 0.10 W m-2. In the shortwave, RRTM and RRTMG generally calculate shortwave forcing within a range of –0.16 to 0.38 W m-2 of CHARTS at the three vertical levels examined. Results for the case, in which methane and nitrous oxide are increased from zero to their 1860 values, are outside these ranges, and the cause for this is being investigated. Finally, the surface was identified during RTMIP as the level at which GCM radiation models require particular improvement in radiative forcing. This study shows that RRTM and RRTMG perform especially well at the surface relative to line-by-line calculations in the longwave with improved radiative forcing also seen in the shortwave.

Additional References:

Collins, WD, et al. 2006. "Radiative forcing by well-mixed greenhouse gases: Estimates from climate models in the Intergovernmental Panel on Climate Change (IPCC) Fourth Assessment Report (AR4)." Journal of Geophysical Research 111, D14317, doi:10.1029/2005JD006713.

Reference(s)

Iacono, MJ, JS Delamere, EJ Mlawer, MW Shephard, SA Clough, and WD Collins. 2008. "Radiative forcing by long-lived greenhouse gases: Calculations with the AER radiative transfer models." Journal of Geophysical Research 113, D13103, doi:10.1029/2008JD009944.

Working Group(s)

Radiative Processes