Impact of an Improved Longwave Radiative Transfer Model on the NCAR Community Climate Model

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Introduction

The effect of introducing a new longwave (LW) radiation parameterization, rapid radiative transfer model (RRTM), on the energy budget and thermodynamic properties of the National Center for Atmospheric Research (NCAR) Community Climate Model (CCM3) is described. RRTM is a rapid and accurate, correlated-k, radiative transfer model (Mlawer et al. 1997) developed for the Atmospheric Radiation Measurement (ARM) Program to address the ARM objective of improving radiation models in global climate models. Among the important features of RRTM are its connection to radiation measurements through comparison to the extensively validated line-by-line radiative transfer model (LBLRTM) (Clough et al. 1992; Clough and Iacono 1995), and its use of the improved and validated CKD water vapor continuum model (Clough et al. 1989). RRTM is accurate to within 1 W m^{-2} of LBLRTM, which itself is validated against ARM measurements.

Single-Column Comparisons

The improved continuum absorption in RRTM relative to the CCM3 longwave model (CCM3_LW) is primarily due to the inclusion of the foreign continuum in the important water rotation band (200 cm^{-1} to 600 cm^{-1}), though there are differences in other spectral regions. This produces enhanced LW absorption relative to the older continuum in CCM3_LW. In the mid-latitude summer (MLS) atmosphere, this additional absorption occurs in the middle to upper troposphere. Figure 1 shows the upward, downward, and net (up-down) longwave fluxes and the cooling rate computed with CCM3_LW on the left. The RRTM-CCM3_LW differences are on the right. Outgoing longwave radiation (OLR) is reduced by 5 W m^{-2} to 6 W m^{-2}. Downward flux is increased by as much as 14 W m^{-2} in the mid-troposphere, with smaller changes near the surface where greater opacity reduces the effect. Cooling rate is significantly impacted, with an increase of 0.4 K d^{-1} in the upper troposphere and a reduction of similar magnitude in the lower troposphere.

In the drier sub-arctic winter (SAW) atmosphere, a large enhancement of downward longwave flux of 14 W m^{-2} extends to the surface. Profiles with high water amounts, such as MLS, are nearly opaque to water vapor near the surface and the enhanced continuum absorption provided by RRTM has only a small additional effect there. In the drier SAW atmosphere, the CKD continuum enhances absorption between water vapor lines and greatly increases downward flux to the surface. For SAW, cooling rate is increased throughout the troposphere except near the surface.

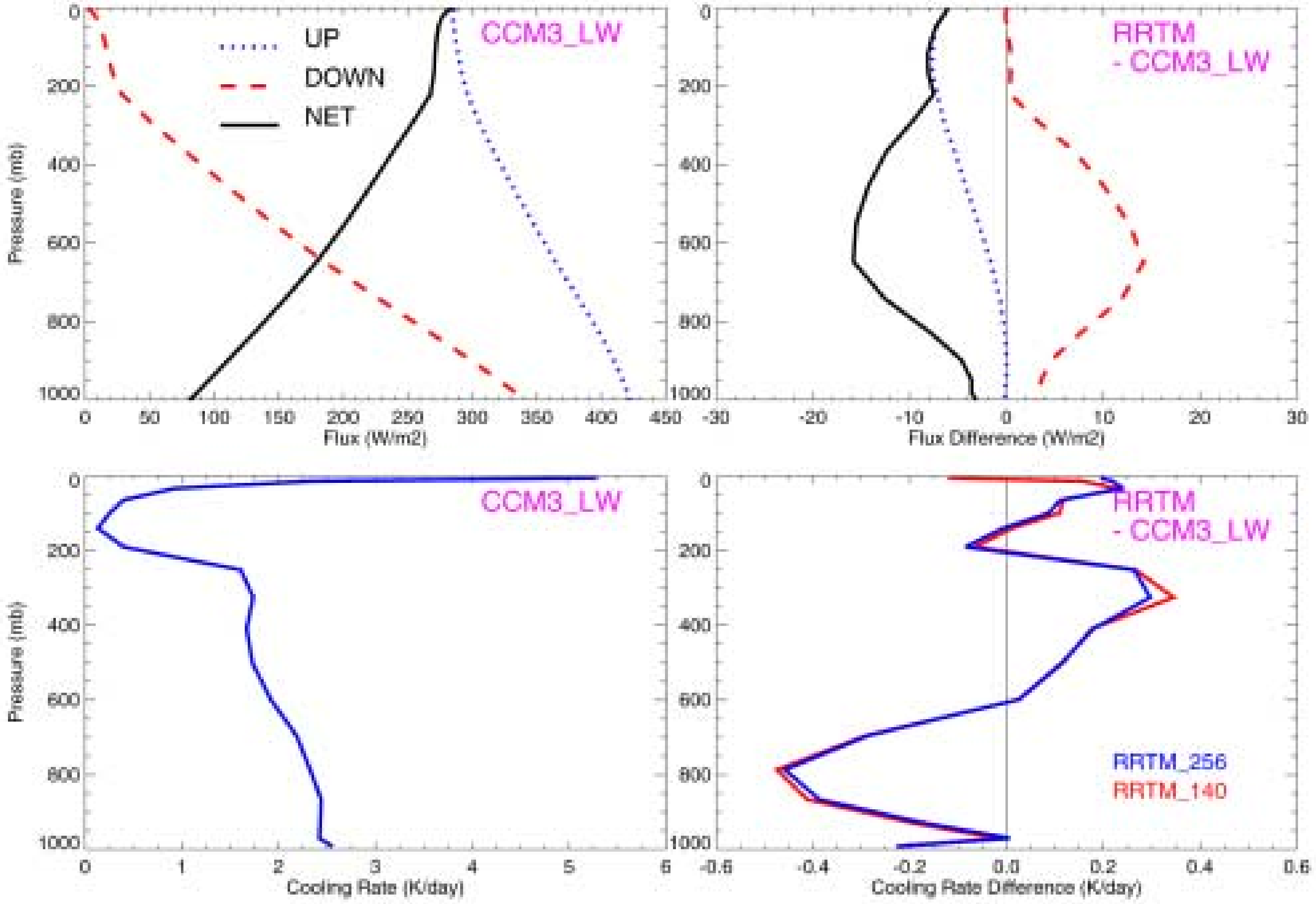

Figure 1. Mid-latitude summer, clear sky LW up, down, and net fluxes and cooling rate for CCM3 (left) and the RRTM-CCM3_LW flux and cooling rate differences (right).

GCM Simulations

Comparisons between RRTM and CCM3_LW have been performed for two 10-year CCM3 simulations with observed, monthly varying sea surface temperatures for the period 1979-1988 (following the protocol of Phase II of the Atmospheric Model Intercomparison Project [AMIP]) using each LW model. Earlier work analyzed the impact of RRTM on 5-year CCM3 simulations using climatological sea surface temperatures (Iacono et al. 2000). RRTM produces a significant enhancement of LW absorption largely due to its more physical and spectrally extensive water vapor continuum model relative to the older CCM3 water continuum treatment, and this is examined in the context of climate simulations.

Flux Impacts

The effect of RRTM on the annual average, CCM3 top of the atmosphere and surface longwave fluxes is shown in Figure 2 for 1987. Clear-sky OLR is reduced by about 5 W m^{-2} in the global average and by as much as 12 W m^{-2} in the tropics, while total sky OLR is reduced by 3 W m^{-2} with larger regional changes in the low and middle latitudes. At the surface, net flux is reduced by 10 W m^{-2} to 20 W m^{-2} at high latitudes and other dry or elevated areas. These changes are of the correct sign and magnitude to account for the documented biases in clear-sky longwave fluxes in CCM3 (Kiehl et al. 1998). The net flux change is largely due to an enhancement of downward surface flux toward the surface. This, in turn, warms the surface to produce smaller increases in upward flux from the surface. Note the regional differences in the surface flux changes between 1987 and 1988. This is likely a result of changes in sea surface temperature forcing between the El Niño conditions in 1987 and the La Niña conditions in 1988.

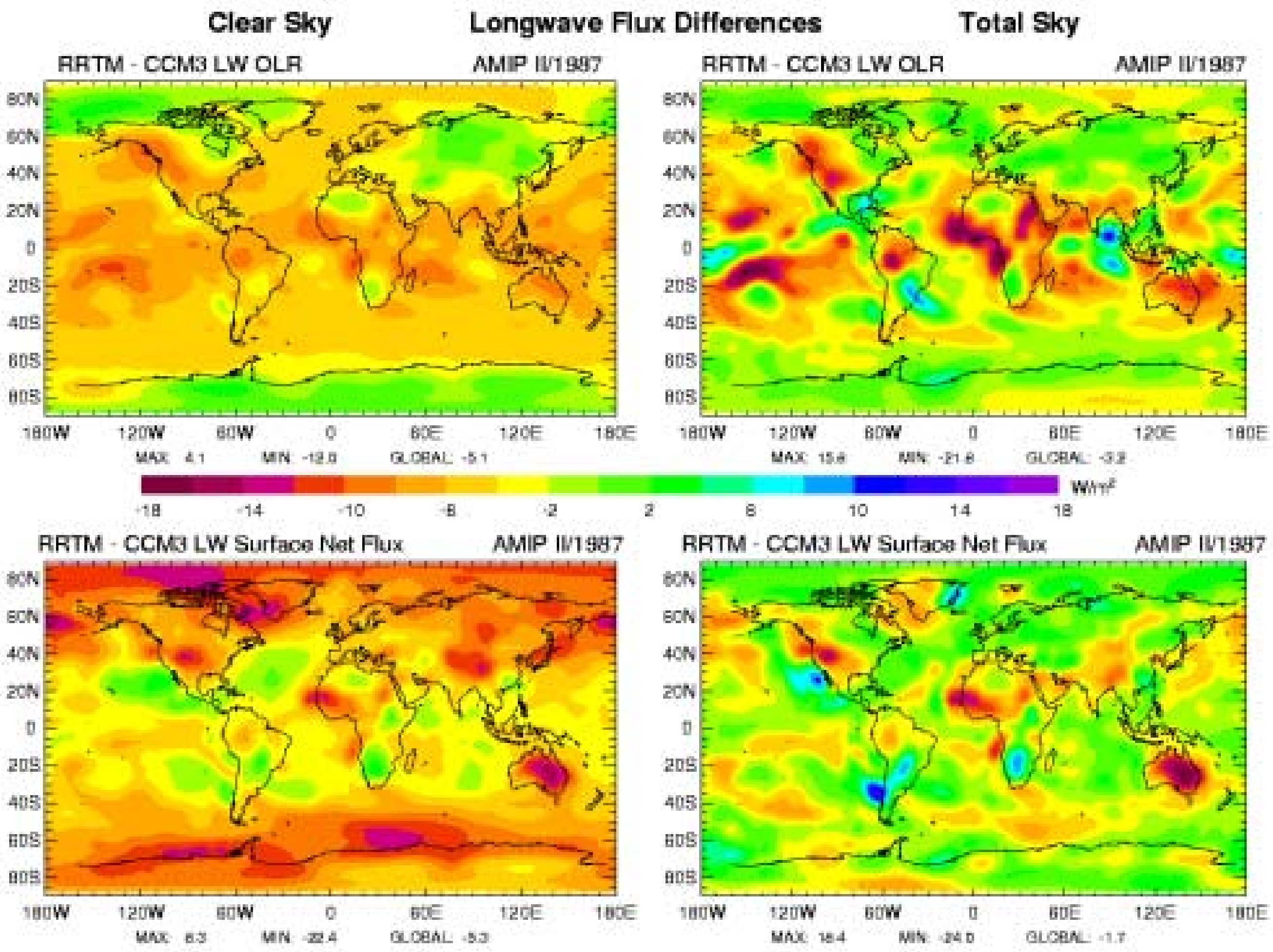

Figure 2. Annual mean, longwave flux differences (RRTM-CCM3_LW) between two CCM3 AMIP simulations running different LW models for (a) clear-sky OLR, (b) total-sky OLR, (c) clear-sky surface net flux, and (d) total-sky surface net flux for 1987.

Temperature Impacts

The enhancement of downward flux to the surface contributes to increasing surface and lower tropospheric temperatures, especially at high latitudes, by 2 K to 4 K. This is shown in Figure 3 for both zonal average and surface temperature differences for 1987 and 1988. CCM3 is known to have cold temperature biases near the surface in polar areas (Briegleb and Bromwich 1998). In the upper troposphere, temperature is reduced by about 1 K, which adds to the CCM3 cold bias there. Note that the surface temperature differences also vary by region (e.g., North America) between 1987 and 1988.

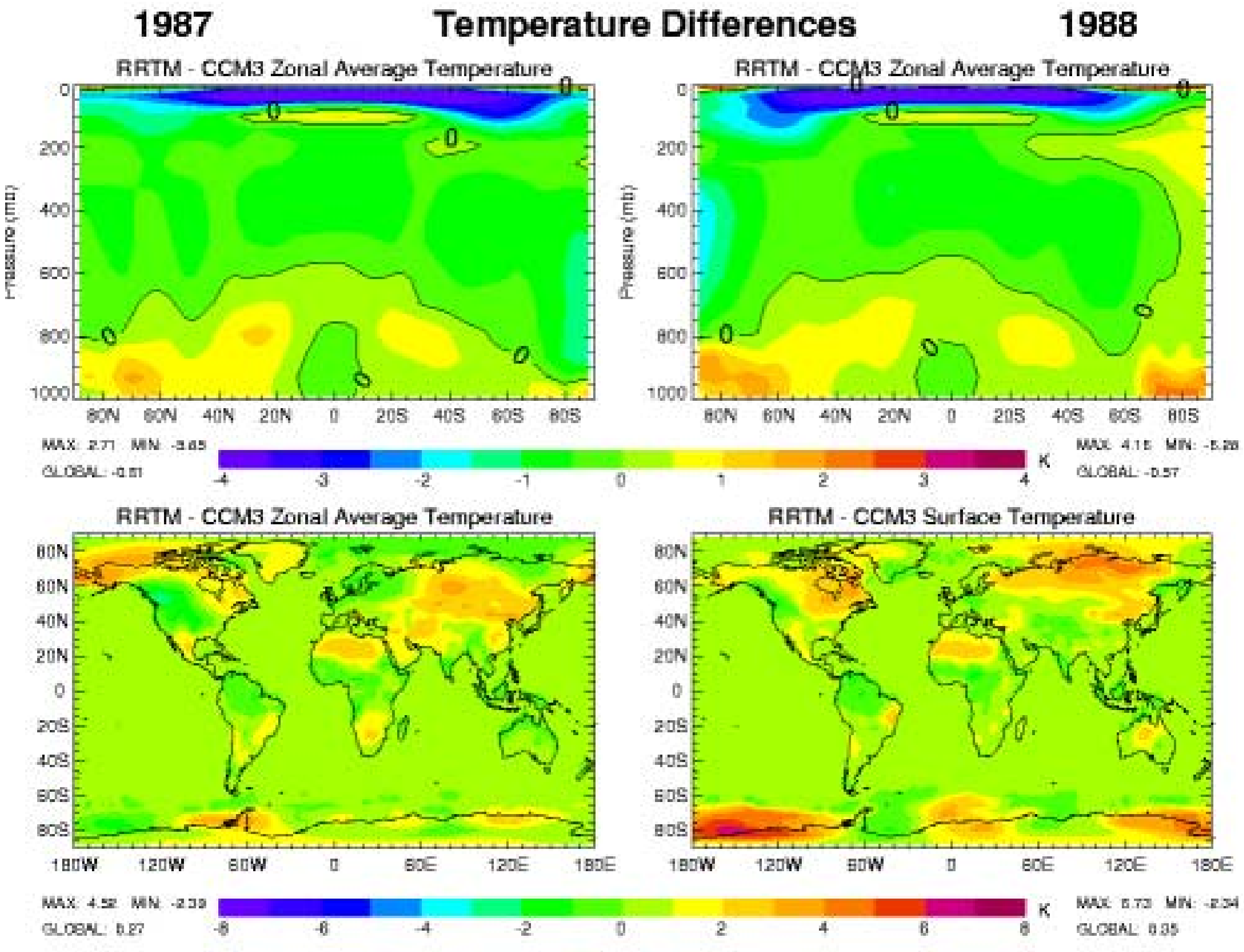

Figure 3. Annual mean temperature differences (RRTM-CCM3_LW) between two CCM3 AMIP simulations of zonal average temperature for (a) 1987, and (b) 1988, and surface temperature for (c) 1987, and (d) 1988.

Cloud and Moisture Impacts

Changes to the temperature structure effect the CCM3 hydrological cycle. There is a significant decrease in moisture in the tropics and mid-latitudes near 700 mb (top panels of Figure 4) that is present in all seasons. Slight increases in moisture occur near the surface. Total column precipitable water (bottom panels of Figure 4) and percent changes in specific humidity at 400 mb and 700 mb (not shown) show large regional variations due to replacing the CCM3 LW model with RRTM. Note that percent changes in moisture of 30% to 40% or more are produced in the upper troposphere. Cloud fraction is increased for high clouds at most latitudes, and it is decreased slightly in the mid-troposphere.

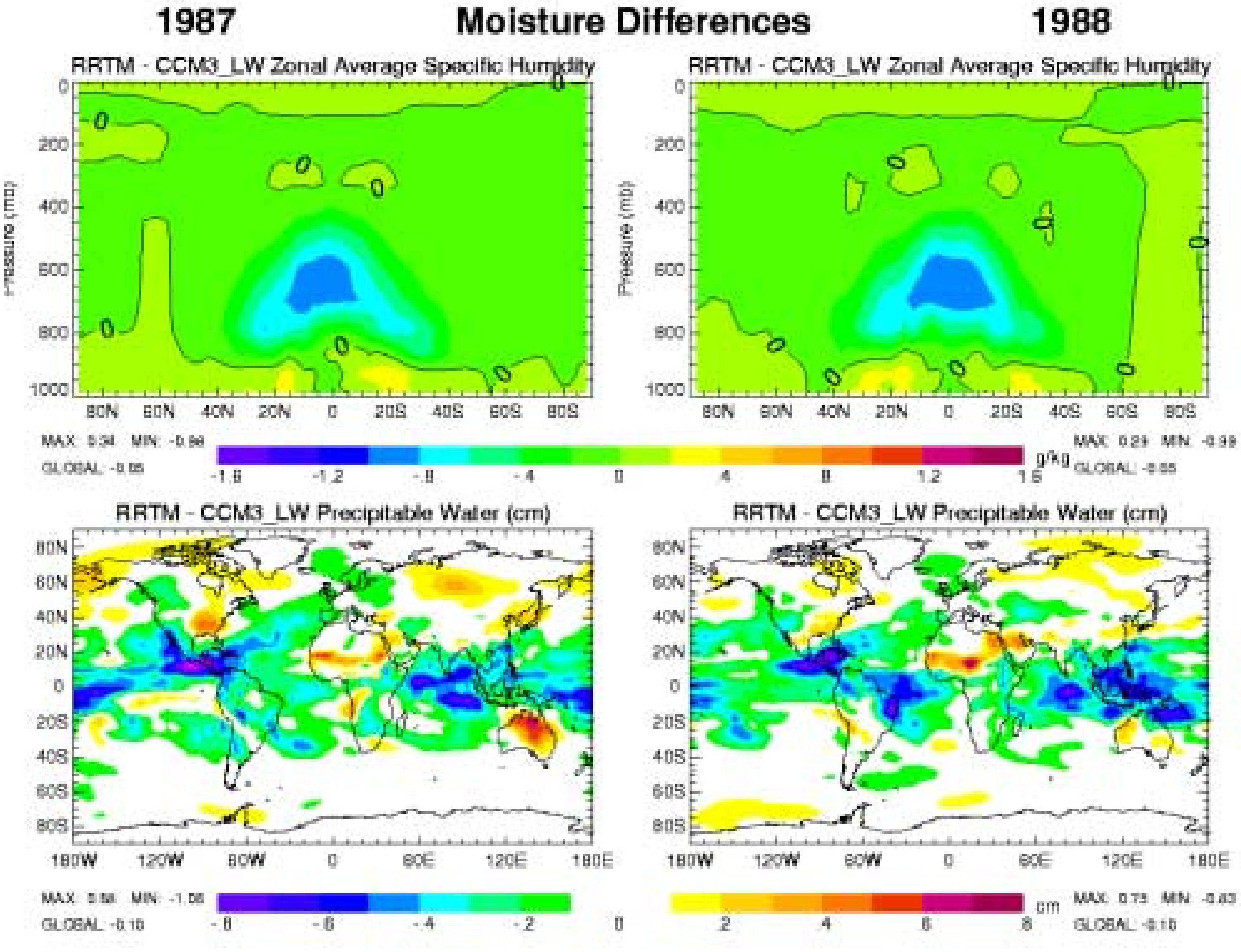

Figure 4. Annual mean moisture differences (RRTM-CCM3_LW) between two CCM3 AMIP simulations of zonal average specific humidity for (a) 1987, and (b) 1988, and precipitable water for (c) 1987, and (d) 1988.

Summary

The impact of introducing an improved, LW radiative transfer model, RRTM, into the NCAR climate model, CCM3, has been described. Stronger water vapor continuum absorption reduces outgoing LW radiation and enhances downward surface flux in dry areas, where it also enhances surface temperature by 2 K to 4 K. Changes in atmospheric temperature result in dynamical feedbacks that modify moisture and cloud cover. It is a significant result of this work that an accurate radiative transfer model with a validated water vapor continuum (both products of ARM research) can significantly impact the dynamical properties of general circulation models that use older continuum methods.

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