1. PI and Co-I Names and Affiliations

Principal Investigator: Michael J. Iacono, Atmospheric and Environmental Research, Inc.

Co-Principal Investigator: Shepard A. Clough, Atmospheric and Environmental Research, Inc.

2. Title of Research Grant

Title: "Improved Shortwave Radiation Modeling and Longwave Cloud Treatment for Climate Models"

Grant No.: DE-FG02-92ER61549

Start Date: March 15, 2000

3. Scientific Goal(s) of Research Grant

Our research addresses the DOE and ARM objective of implementing improved radiative transfer methods in general circulation models (GCMs). The rapid radiative transfer models, RRTM_LW and RRTM_SW, developed and validated under separate ARM support, are utilized as the vehicles for evaluating improved radiative parameterizations in GCMs. An objective of this approach is to capitalize on the connection between the two rapid models developed for use in GCMs and the ARM spectral radiance measurements used to validate the detailed algorithms. This ensures that the spectral signatures associated with various atmospheric physical processes are accurately represented in the GCM through the validated rapid model. We have found that RRTM_LW can have a significant impact on the top of the atmosphere energy balance, surface flux, and temperature in a GCM due to its enhanced accuracy and its more physically based water vapor continuum model. The principal goals for the next phase of our ARM research are: (1) the examination of more sophisticated longwave cloud absorption and cloud overlap techniques for RRTM; (2) the implementation of RRTM_SW to GCMs to establish the impact of improved shortwave radiative transfer for both molecular absorption and multiple scattering of clouds and aerosols in GCMs; and (3) the study of the impact of improved radiation modeling for the Single Column Modeling (SCM) exercises.

4. **Accomplishments**

A) RRTM_SW has been prepared for clear sky and aerosol absorption applying the model DISORT for radiative transfer.

B) Single column comparisons for standard atmospheric profiles between RRTM_SW and the NCAR CCM3 shortwave model show differences of 10-15 W m^{-2} in downwelling surface flux in high water atmospheres. Significant differences are also seen relative to the ECMWF SW model.

C) A maximum-random cloud overlap method has been developed for RRTM_LW and has been tested within the NCAR CCM3 climate model and the ECMWF weather forecast model.

5. **Progress and accomplishments during last twelve months (or from beginning of the current effort whichever is shorter).**

We have developed a maximum-random (MR) cloud overlap approach for the longwave version of RRTM to address our effort to improve the longwave treatment of clouds in GCMs. The RRTM MR cloud overlap method uses a two-layer memory approach in which the cloud fractions from two adjacent layers are utilized in the computation of radiance within a cloud layer. Maximum overlap is applied within all blocks of adjacent cloudy layers, while random overlap is applied among blocks of cloudy layers that have at least one clear layer between them. A single-season simulation in the NCAR CCM3 with RRTM_LW using the MR overlap method shows the significant impact (10-30 W m^{-2}) of this assumption relative to random cloud overlap, especially in regions where clouds are strongly vertically correlated. A more extensive GCM test of the cloud overlap method will be conducted when an experiment can be performed that applies a consistent overlap approach in both LW and SW.

The shortwave version of RRTM is currently being adapted for use in general circulation models to address our effort to apply an improved SW radiation model to GCMs. RRTM_SW has been prepared for clear sky and aerosol absorption applying the model DISORT for radiative transfer. Cloud absorption (and eventually MR cloud overlap) will be added to the model's capability. Performance enhancements will be devised (as was done for RRTM_LW) to optimize its computational speed for use in GCMs while preserving as much of its accuracy as possible. For this purpose, it may be necessary to replace DISORT with a two-stream radiative transfer approach. Spectral measurements from both the RSS and ASTI instruments at the ARM Southern Great Plains CART site have been utilized to validate the line-by-line model, LBLRTM, that provides the absorption coefficient data needed for RRTM_SW.

Single column, clear sky comparisons have been performed between RRTM_SW and the NCAR Community Climate Model, CCM3, that show differences of 10-15 W m^{-2} in downwelling surface flux

in high water atmospheres at low zenith angles. RRTM_SW produces somewhat more clear sky absorption than the CCM3 SW model that reduces the downward surface fluxes. Significant differences are also seen between RRTM_SW and the ECMWF SW model, and we will collaborate with J.-J. Morcrette at ECMWF to address this issue. This illustrates the important need for improved clear sky shortwave radiative transfer in GCMs in addition to the established deficiencies in shortwave cloud absorption. Note that our continued collaboration with ECMWF has resulted in that organization adopting RRTM_LW as part of its operation weather forecast model and as part of its Integrated Forecast System model that will be used to produce their new 40-year (ERA-40) Reanalysis.

6. **As appropriate, attach one or so electronic figures with paragraph discussions**

   NONE

7. **List all *refereed* publications either submitted or published during the *current* grant FY that acknowledge DOE ARM support.**

   Iacono, M. J., E. J. Mlawer, S. A. Clough, and J.-J. Morcrette, Impact of an improved longwave radiation model, RRTM, on the energy budget and thermodynamic properties of the NCAR community climate model, CCM3, *J. Geophys. Res.*, **105**, 14,873-14,890, 2000.

8. **List all published (either paper or web-based) extended abstracts in the current FY that acknowledge DOE ARM support.**

   Two extended abstracts, which are based on posters presented at the March 2000 ARM Science Team Meeting, are in progress.

   A) Iacono, M. J., E. J. Mlawer, and S. A. Clough, Impact of an improved longwave radiative transfer model, RRTM, on the NCAR Community Climate Model, CCM3, Presented at the Tenth Atmospheric Radiation Measurement (ARM) Science Team Meeting, San Antonio, Texas, March 13-17, 2000.

   B) Iacono, M. J., E. J. Mlawer, and S. A. Clough, Application of a maximum-random cloud overlap method for RRTM to general circulation models, Presented at the Tenth Atmospheric Radiation Measurement (ARM) Science Team Meeting, San Antonio, Texas, March 13-17, 2000.

9. **Please update us on the status of submitted referred publications from the previous FY progress report**.

   One paper published in *J. Geophys. Res.*, see (7).