

Technical Report to the U. S. Department of Energy

**ICRCCM Phase II:
Verification and Calibration of
Radiation Codes in Climate Models**

for the Period 1 May through 31 December 1990

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Introduction

Following the finding by the InterComparison of Radiation Codes used in Climate Models (ICRCCM) of large differences among fluxes predicted by sophisticated radiation models that could not be sorted out because of the lack of a set of accurate atmospheric spectral radiation data measured simultaneously with the important radiative properties of the atmosphere, our team of scientists proposed to remedy the situation by carrying out a comprehensive program of measurement and analysis called SPECTRE (Spectral Radiance Experiment). SPECTRE will establish an absolute standard against which to compare models, and will aim to remove the 'hidden variables' (unknown humidities, aerosols, etc.) which radiation modelers have invoked to excuse disagreements with observation. The data to be collected during SPECTRE will form the test bed for the second phase of ICRCCM, namely verification and calibration of radiation codes used in climate models. This should lead to more accurate radiation models for use in parameterizing climate models, which in turn play a key role in the prediction of trace-gas greenhouse effects.

This report summarizes the activities of our group during the project's first year to meet our stated objectives. The report is divided into sections on SPECTRE and ICRCCM activities. The section on SPECTRE summarizes the steps we've taken to prepare for the field experiment scheduled for November 1991, whereas the section on ICRCCM summarizes the progress made in ICRCCM during the past year.

SPECTRE Activities

The overall plans for SPECTRE are proceeding as outlined in the original proposal. The site for the experiment will be located at the Coffeyville, KS airport and the logistical arrangements for our participation is being coordinated with the NASA FIRE Project Office. The activities in preparation for SPECTRE are most easily summarized according

to the participating groups at the University of Maryland, Denver University, the University of Wisconsin, and NASA Greenbelt. These are discussed in turn below.

University of Maryland

This group, led by Professor Ellingson, has been primarily involved with coordinating the activities of the various groups supported through the University of Maryland, insuring the acquisition of data from a tethered sonde system, and performing sensitivity analyses of model calculation as an aide to the interpretation of the radiance observations and their comparisons with observations. The analyses have focussed on the sensitivity of the vertically downwelling radiance calculations at the surface to possible errors in the measurement of the radiatively important variables for clear-sky conditions (i.e., temperature, H₂O, O₃, CO₂, N₂O, CH₄ and Freons). Since we are particularly concerned with improving our understanding of the water vapor continuum, the study has concentrated on the semi-transparent portion of the spectrum from 700 to 1220 cm⁻¹ (about 8 to 14 μm). The results reported here are based on calculations with the line-by-line code FASCODE2 using meteorological data from the AFGL mid-latitude summer profile. The analysis has concentrated on averages over 1 cm⁻¹ intervals, although larger intervals will be investigated before the experiment.

The calculations show that the maximum random (rms) error in the spectral radiance is about 1.5% per Kelvin temperature error and about 0.8% per percent relative humidity error. In general, the effects of systematic errors are larger than the random errors by about a factor of 2. Nevertheless, the results show that with the expected 5% humidity and 0.5 K temperature errors, the errors in the calculations should be kept below about 8% in the regions of relatively strong lines and below about 5% in weakly absorbing regions. These should allow much more stringent tests of the parameterizations of the H₂O continuum than heretofore possible.

Our original proposal anticipated the purchase of a tethered sonde system for obtaining temperature, water vapor and ozone profiles in the lowest few hundred meters where the remote sensing techniques are blind. However, we have located a group at NASA Wallops that has considerable experience with such a tethered sonde and is willing to participate in SPECTRE. Therefore, we are requesting permission from DOE (in a separate action) to use the tethered sonde equipment funds for a subcontract to the Wallops group.

Denver University

This group, led by Professor David Murcray, has supplied the following progress report.

The major objective of our participation in SPECTRE is to obtain atmospheric emission spectra and solar absorption spectra under conditions where the atmospheric physical parameters are well measured. The major thrust will be to obtain data during FIRE-CIRRUS in November and December 1991. For the data to be of maximum use in the comparison of radiation codes the absolute accuracy of the experimental data should be as high as possible. The system which we will use to obtain the atmospheric emission data will be an improved version of a system which we installed at the South Pole in December 1989. The system has been operating for the past year with minimum operator interaction. Selected spectra obtained during the Austral winter indicate that the system was operating properly even when the air temperature was as low as -60°C . In order to determine the absolute accuracy of the spectral data we have compared the observed spectra with spectra calculated using our radiation code. These comparisons indicate that calculations agree with the experimental data in the CO_2 regions to within the accuracy of the temperature data. These comparisons, however, have been made for a very limited data set. The data recorded during the year are being brought from the Pole and will be available after the first of the year. The comparisons will be continued on these data sets.

The basic emission instrument for SPECTRE was purchased and it was delivered to us in September. Modifications to the instrument have begun. The solar spectral data will be obtained with our balloon-borne solar spectrometer system. This system employs an interferometer to obtain very high resolution spectral data. Interferometers are routinely used for obtaining spectra data, however, there is a great deal of mathematical manipulation required to convert interferograms to spectra. This gives rise to the question of the accuracy of the various computer programs used to process the interferogram to spectra. In order to determine the accuracy of the software developed by various interferometer manufacturers we are currently engaged in a comparison of very high resolution solar spectra obtained using instrumentation and software supplied by BOMEM with spectra obtained with BRUKE hardware and software. Initial comparisons indicate both systems give comparable results with any differences being very small. This study is continuing and will be extended to include data obtained under a variety of conditions.

University of Wisconsin

Professor William Smith has supplied the following progress report for the Wisconsin group.

The role of the University of Wisconsin (UW) in the DOE program "ICRCCM Phase II: Verification and Calibration of Radiation Codes in Climate Models" is to provide highly accurate measurements of downwelling thermal spectra, and retrievals of state parameters and cloud properties, as well as, spectroscopic analyses from the observations. The UW effort is divided into three major task areas: (1) Development and testing of a FTIR Spectrometer, (2) Participation in the Spectral Radiance Experiment (SPECTRE) field program, and (3) Data analysis. With the exception of our participation in the November SPECTRE planning meeting at the site in Coffeyville, Kansas, all of the efforts during the first eight months of the program have been directed at the FTIR spectrometer development.

Our approach to spectrometer development makes full use of the complementarity of this effort and the UW instrument development for the DOE Atmospheric Radiation Measurement (ARM) program. When the UW participation in SPECTRE was first proposed, it was not clear whether a new uplooking instrument would be ready in time for the 1991 field experiment or whether the High-resolution Interferometer Sounder (HIS) aircraft instrument would be used. Since then, because a prototype of the new instrument has been assembled and tested, and because of our participation in the ARM program, we plan to have a reasonably mature new instrument ready for SPECTRE.

The availability of a new high-performance uplooking instrument for SPECTRE will allow us to make non-interfering uplooking and downlooking high spectral resolution observations in conjunction with FIRE. The HIS aircraft instrument will be flown on the NASA ER2, which will conduct frequent flights over the SPECTRE site. These unique coincident observations are expected to provide important new insights into the spectroscopic and radiative properties of the atmosphere.

Specific accomplishments to date include system design and procurement efforts, tests of an improved approach to calibration, tests of the prototype blackbody temperature control and monitoring subsystem, and software development.

The overall system design has been established, using our current "Baby HIS" prototype instrument as a guide. The system components include a commercially available spectrometer, calibration reference sources and a scene switching mirror, a control and monitoring subsystem, and a data acquisition and analysis subsystem. The system for SPECTRE will also include an uplooking video camera for cloud monitoring.

Procurement of a spectrometer from BOMEM, Inc., Quebec, Canada has been initiated. Many options for both hardware and software have been evaluated and a purchase order has been placed. (Between this program and the ARM program, two

instruments with somewhat different capabilities will be obtained in the next several months. Procurement procedures for the second instrument are currently being initiated. The first completed system will be tested and prepared for SPECTRE.)

Testing of our new calibration approach involved intercomparing sky spectra calibrated using one hot and one ambient blackbody reference source with those calibrated in our usual way using one ambient and one reference at liquid nitrogen temperature. The purpose of the new approach is to eliminate the need for a liquid-nitrogen-temperature reference, which requires frequent refills and which can introduce errors in humid environments. The main anticipated problem with the hot/ambient calibration is dealing with detector non-linearity. The outcome of the testing to date is that this effect is not large and can probably be accounted for accurately.

Prototype blackbody temperature control and monitoring subsystem testing was recently completed. The purpose of these tests is to evaluate the performance of the system for identifying areas needing improvement and for comparing with the performance of alternative designs. The subsystem makes use of two high emissivity cavity sources, originally constructed for the calibration of the UW Small-probe Net Flux Radiometer for the Pioneer Venus Multiprobe mission. The temperature servo system uses a single wire wound sensor/heater unit and temperatures are monitored with two thermistors in each cavity. The analog thermistor data is digitized by an A/D board on the IBM AT data acquisition computer bus. The tests results show the performance of the current subsystem to be adequate.

However, design changes to make computer control of the subsystem more flexible and to improve the computer interface are being evaluated. Finally, significant progress has been made in the software development for both calibration and display of the data products. This software development is crucial for thorough testing of the instrument performance and for quality control of the final data products.

We are well on our way to making sure that a radiometrically accurate FTIR spectrometer, data system, and software from the UW are ready for the SPECTRE field experiment next November.

NASA Goddard

Dr. Warren Wiscombe leads this group, and he has secured group funding from NASA for participation in FIRE. The instrumentation from this group includes the Raman Lidar for water vapor profiling (led by Dr. J. Melfi), a high resolution spectrometer and a calibration facility (the latter two led by Dr. J. Kunde). The assembly of the necessary components of each system is well underway, and they are expected to be field tested during the summer of 1991.

Coordinated Team Activities

Wiscombe and Ellingson have had frequent contact to coordinate the activities of the various groups. Furthermore, most of the team met at the FIRE Science Team Meeting in November 1990 to discuss various approaches and to specify the best locations for the experiment. Wiscombe and Ellingson are now preparing an operations plan based upon the scientific goals and the logistical needs of the various groups.

ICRCCM Activities

ICRCCM continues to be a working group of the International Radiation Commission (IRC) and World Climate Research Program and Professors Ellingson and Fouquart (Univ. Lille, France) have been designated as co-Chairs of the group. Following recommendations of the 1988 Paris Workshop and the 1989 meeting of the IRC, Ellingson and Fouquart made a call for a new set of calculations in January 1990. These calculations are directed at (1) understanding the differences in model treatments of trace gases and (2) determining differences between model calculated heating rates (the previous calculations concentrated on fluxes at the boundaries). The trace gas calculations are being coordinated with Dr. Wei-Chung Wang of SUNY Albany as part of the activity of the Ozone

Commission. We are in the process of acquiring the results from the various ICRCM participants, and we expect to present some results of the calculations at a workshop to be held at the IUGG meeting in Vienna in August 1991.

In addition, Ellingson completed his analysis of the original ICRCM calculations during the past year as part of this grant, and the results are contained in two papers contained in a special volume of the *Journal of Geophysical Research* scheduled for publication in January 1991. The results are summarized in the attached abstracts.

Summary

Overall, the project is proceeding much as had been anticipated in the original proposal. The most significant accomplishments to date include the completion of the analysis of the original ICRCM calculations, the completion of the initial sensitivity analysis of the radiation calculations for the effects of uncertainties in the measurement of water vapor and temperature and the acquisition and testing of the inexpensive spectrometers for use in the field experiment. The sensitivity analysis and the spectrometer tests give us much more confidence that the field experiment will yield the quality of data necessary to make a significant tests of and improvements to radiative transfer models used in climate studies.

THE INTERCOMPARISON OF RADIATION CODES USED IN CLIMATE MODELS: LONG WAVE RESULTS

R. G. Ellingson
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Stephen Fels

An international program of intercomparison of radiation codes used in climate models has been initiated because of the central role of radiative processes in many proposed climate change mechanisms. During the past 6 years, results of calculations from such radiation codes have been compared with each other, with results from the most detailed radiation models (line-by-line models) and with observations from within the atmosphere. Line-by-line model results tend to agree with each other to within 1%; however, the intercomparison shows a spread of 10-20% in the calculations of radiation budget components by the less detailed climate model codes. The spread among the results is even larger (30-40%) for the sensitivities of the codes to changes in radiatively important variables, such as carbon dioxide and water vapor. The analysis of the model calculations shows that the outliers to many of the clear-sky calculations appear to be related to those models that have not tested the techniques used to perform the integration over altitude. When those outliers are removed, the agreement between narrow band models and the line-by-line models is about $\pm 2\%$ for fluxes at the atmospheric boundaries, about $\pm 5\%$ for the flux divergence for the troposphere, and to about $\pm 5\%$ for the change of the net flux at the tropopause as CO_2 doubles. However, this good agreement does not extend to the majority of the models currently used in climate models. The lack of highly accurate flux observations from within the atmosphere has made it necessary to rely on line-by-line model results for evaluating model accuracy. As the inter-comparison project has proceeded, the number of models agreeing more closely with the line-by-line results has increased as the understanding of the various parameterizations has improved and as coding errors have been discovered. The most recent results indicate that several climate model techniques are in the marginal range of (relative) accuracy for lognwave flux calculations for many climate programs. However, not all such models will give such accuracy. It is recommended that a code not be accepted to provide such accuracy until it has made comparisons to the line-by-line results of this study. The data necessary to make such comparisons are included herein. However, uncertainties in the physics of line wings and in the proper treatment of the water vapor continuum make it impossible for the line-by-line models to provide an absolute reference for evaluating less detailed model calculations. A dedicated field measurement program is recommended for the purpose of obtaining accurate spectral radiance rather than integrated fluxes as a basis for evaluating model performance.

THE INTERCOMPARISON OF RADIATION CODES IN CLIMATE MODELS (ICRCCM): AN OVERVIEW

R. G. Ellingson
Y. Fouquart

The recognition of the central role of radiative processes in many proposed climate change mechanisms and the perception of possibly significant uncertainties in the estimates of these fundamental processes led the Joint Scientific Committee of the World Climate Research Programme and the International Radiation Commission of the International Association of Meteorology and Atmospheric Physics to initiate the international Intercomparison of Radiation Codes in Climate Models (ICRCCM). The results from model calculations with specified clear-and-cloudy conditions show that many radiation algorithms may have unidentifiable but large errors which may significantly affect the conclusions of the studies in which they are used. This is true for climate modeling but may also be the case for other applications such as the estimation of radiation fluxes at the surface from satellite observations.

As the study has progressed over a four year period, there has been a narrowing of results as errors were found in some codes and as the understanding of many modeling problems increased. Many of the results, particularly for clear-sky conditions, indicate that we are close to the range of (relative) accuracy for calculating flux quantities necessary for many climate programs. However, not all models will give such accuracy. It is recommended that the ICRCCM test cases be used to test radiation algorithms prior to their application to climate related problems.

The participants feel that the rather large discrepancies revealed during ICRCCM cannot be decisively resolved by further calculation. Therefore the group recommends the organization of a program to simultaneously measure spectral radiance at high spectral resolution along with the atmospheric data necessary to calculate radiances.

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