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Progress Report No. 1

A Research Program
on
Radiative Transfer Model Development
in Support of the ARM Program

A research program funded by the

Office of Energy Research

Grant No. DE-FG02-90ER61064

For the period

15 September 1990 - 14 September 1991

Submitted by

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1. Significant Research Accomplishment:

A new algorithm for the implementation of the adding doubling method for multiple scattering in the context of FASCODE line-by-line calculations has been developed. The method involves the precalculation of the doubling result for the transmittance and reflectance at selected values of the molecular optical depth. The transmittance and reflectance values for optical depths associated with the molecular line-by-line calculation are then obtained by performing interpolations on the precalculated results. The precalculated values are valid over a spectral domain for which the scattering properties may be taken as constant. Since the spectral variation of the scattering is slow compared with that for the molecular absorption, this method enables the computation of multiple scattering results by performing interpolations of precalculated results for a large spectral range of molecular optical depths. The method has some similarity in concept to the k-distribution method for radiative transfer. The implementation of this method will provide accurate line-by-line results in the presence of multiple scattering with greatly accelerated performance for application to the high resolution longwave and shortwave ARM spectral measurements.

2. Progress for the reporting period

2.1 Line-by-line multiple scattering code

The main research effort at AER on this project has been focussed on the development of a rapid line-by-line multiple scattering code for availability to ARM in the September 1991 time frame. The first phase of the effort has been to consider the many approaches that have been developed to treat the multiple scattering problem. One of the important decisions that had to be resolved was the choice of line-by-line code. The two candidate codes that we considered were GENLN and FASCODE. There is a major conceptual difference between the two codes. GENLN performs the complete radiative transfer calculation through the inhomogeneous atmosphere at sequential wavenumber values. FASCODE performs the spectral radiative transfer calculations a layer at a time and then obtains the final result by appropriately combining layer results.

FASCODE takes maximum advantage of spectral correlations but suffers the penalty of requiring significant IO. After a rather extensive analysis of the multiple scattering problem and discussions with colleagues, it has become apparent that for the spectral radiances at a given altitude, as desired for the ARM site application, the adding doubling method has significant advantages. The method has been extensively tested and is well accepted in the radiation community. In particular, the implementation of the method in the context of FASCODE offers attractive computational advantages as described in the previous section on significant accomplishments. It is on this basis that we are proceeding with the implementation of the method in FASCODE. The utilization of FASCODE offers other advantages in the present application: our familiarity with the code, its accelerated performance, its extensive validation and its incorporation of the full GL capabilities including LOWTRAN aerosol models and the effects of radiative transfer due to heavy molecules, eg the CFC's.

The adding doubling multiple scattering algorithms are currently in the process of being implemented in new FASCODE layer merging routines. The computational effort required to perform line-by-line multiple scattering calculations over extended spectral regimes is extremely large, so that particular effort is being placed on coding issues. The coding is being developed to be as optimal as possible for the target computer, assumed to be a CRAY. Critical FASCODE routines are being restructured to facilitate vectorization. As soon as the code becomes operational, the possibilities of using more than one processor to further accelerate the computations will be studied. An initial investigation with two processors has already been initiated. Of particular interest in our coding effort will be the possibility of the utilization of asynchronous reading and writing. The multiple scattering program will require a significant amount of IO and if it can be arranged to continue the computations during the IO transfers, the potential of speeding up the throughput is large. UNICOS does not currently support asynchronous read/writes in FORTRAN so that we will have to explore other programming levels if this feature is to be implemented. We have used this capability on CYBER computers with excellent results.

Our initial effort will be to develop the radiative transfer code for the long wave region. The radiative transfer calculation is somewhat simpler for this case in that

the azimuthal angle does not have to be handled as a separate variable. Our goal is to develop a code in which the number of streams is arbitrary, the limit being set by the computational resource. We expect that four streams will be adequate for most longwave calculations and that as many as eight or sixteen may be required for the shortwave region. Our goal is to have an operational code that will handle at least 32 streams on the target computer. As a consequence of discussions at the November ARM meeting, we are keeping open the possibility of handling polarization in the multiple scattering calculations.

2.2 Screen driven user interface for FASCODE

To facilitate the utilization of the FASCODE radiative transfer model in the ARM program and to address difficulties encountered by some users in implementing the code, a screen driven user interface is being developed. The interface is being written in C and will be compatible with all systems supporting X-windows. The initial 'look and feel' has been decided upon using Sun Open Look windowing tools. We are about to implement the first phase of the actual X-window development using the SUN 'dev-guide' software. This activity is being pursued at a low level of effort since it is not central to our research goals, but it is our expectation that a model which includes the most often accessed FASCODE options will be available in Sept 1991. The full implementation would then become available in the subsequent year. The interface as currently conceived, provides an input file for subsequent execution of the FASCODE program.

2.3 Rapid Radiative Transfer Model

This part of the research effort is focussed at Pennsylvania State University. The initial effort has centered on the familiarization of the new graduate student with (i) atmospheric radiative transfer techniques in general, particularly those needed in this research project, (ii) the computer system at Penn. State, and (iii) the delta-2-stream radiative transfer code that will be used on this project, Toon

et al. A preliminary assessment has been given to incorporating a 4-stream technique for the rapid model. In general, the errors in a 4-stream radiative transfer technique are of the order of 1-2%, particularly if a "delta" approach is utilized. If a means can be found for rapid solution of the 4-stream matrix a very attractive rapid model will be available for multiple scattering calculations in the inhomogeneous atmosphere.

Over the remainder of this contract year we intend to

- a) carry out model comparisons of the delta-2-stream with ICRCM model atmospheres and results.
- b) assess the feasibility of the 4-stream approach and if feasible develop a working version for evaluation
- c) evaluate various absorption coefficient techniques within the context of the delta-2-stream model.

3. Support of Measurements

Our main focus in this area has been with respect to two issues: (i) measurement of the water vapor continuum and (ii) the parameterization of cloud optical properties for input to the radiative transfer calculations. With respect to the water vapor continuum, we have had discussions with Gerry Stokes and several PI's on the possibility of making horizontal path measurements of the continuum at the CART sites using the spectral radiative measuring systems available at the sites. The path would be characterized using the applicable equipment available for the nadir measurements. This approach has the virtue of obtaining a measurement over a realistic temperature regime which is difficult to attain in the laboratory.

The continuum is also required for the more strongly absorbing regions (in band continuum). These measurements are amenable to measurement in the laboratory since shorter paths are required. Discussions are proceeding with Prasad Varanasi with respect to this issue. This continuum is particularly important for heating rates in the upper tropopause.

4. Code Maintenance and Availability

A problem that has arisen and remains unresolved relates to the archiving and maintaining of code. At present we are supplying codes to a number of ARM science team members which has necessitated the porting of code to their environment. Operating in this fashion, it is difficult given our interests and our resources, to provide a proper structure for maintaining the codes. It had been anticipated that ARM would provide a repository site for code archival but given the extent of current demands, that evidently is not feasible. We are exploring the possibility of providing this capability at AER for AER developed code. ARM Science team members would be able to access a designated ftp account. Although our present thought is that this would include only code developed at AER, a broader context could be considered. The main requirement for AER is that sufficient disk space be available on the special ftp account and that there not be an adverse impact on the AER network.

In addition to AER, LBLRTM has been implemented at Florida State University (cray-ymf), Pacific Northwest Laboratories (Convex and Cray), the Pennsylvania State University (cray-ymf), the Jet Propulsion Laboratory (cray-ymf) and at the U. of Maryland (RISC based workstation). The versions implemented at these sites have some differences dependent on the time of implementation. As of June 1992 these codes will be available with SCCS revision numbers and the code will be maintained consistent with that archiving system. The X-window interface has been implemented and is operational at Penn. State U.

5. Travel

Shepard A. Clough participated in the ARM meeting in Las Vegas in November 1990, as a member of the radiative modeling team. Mr. Clough also attended the ARM Science Team Meeting in New Orleans at the American Meteorological Society meeting in January 1991.

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