RADIATION CODES FOR CLIMATE MODELS : RESULTS OF INTERCOMPARISONS STUDY AND SENSITIVITY OF GCMs

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1. INTRODUCTION

The importance of radiative energy fluxes in the climate system need not be underscored since radiation constitutes the primary energy source and the ultimate energy sink for the whole atmospheric circulation. The sensitivity of climate to radiation processes can be expressed in quantitative terms by noting that net energy fluxes of 1 to 10 Watts/m^2, which would yield substantial climatic effects, are only a small residual of the overall radiative energy transfers which amount to several hudred Watts/m^2. It is therefore essential that, in climate simulations with general circulation models, errors in computation of the planetary radiation budget be avoided, especially in order to prevent spurious indications of climatic trends.

Assuming that the parameters describing the state of the atmosphere and the boundaries (clouds distribution surface spectral properties temperature, water vapor, ozone, aerosols etc...) are known with the desired accuracy, it is possible, in principle to write an equation which describes the transfer of energy through absorption, emission and scattering. The physical mechanisms involved in radiative transfer are generally well known and provided that the spectral optical properties of gases, particles and boundaries are known, the radiation field could be computed to any degree of accuracy if there were no restriction in computational time.

Apart from errors which can rise from an unsufficient knowledge of the state of the atmosphere, the main source of possible errors for one dimensional computations of radiative transfer in a vertical air column lies in the limited accuracy of the available physical data on the spectral properties of absorbers and scatterers. Absorption by molecules is well understood, however the accuracy with which spectral line intensities and line shapes are known, may lead to significant errors in particular spectral intervals. Since band intensities are much more accurate, the impact of the above mentioned unaccuracies on the frequency integrated radiation fluxes can be expected to remain small; however they can still have a significant impact on the absorption properties of the various continua, particularly that of water vapor in the 8-12 µm infrared window.

The spectral properties of clouds, dust and aerosols are a major problem. Theoretically, the spectral properties of individual liquid water droplets (scattering and extinction cross-sections) are well-known, however there are indications that the shortwave absorption by actual clouds is larger than predicted by Mie theory and liquid water refractive index (Reynolds et al., 1975, Stephens et al., 1978).Whether or not that can be attributed to aerosols, drop size distributions or clouds inhomogeneities is still a subject of concern and indeed other authors obtained a good agreement between observations and theory (Schmetz et al., 1980, Bonnel et al., 1983, Slingo et al., 1982).

For ice clouds a complicating factor is the multiplicity of ice crystal shapes. Recent theoretical work on the scattering of radiation by ice crystals (Wendling et al,1979) has shown significant differences in cloud optical properties depending on crystal type.

Aerosols have spectral optical properties which depend on their shape, dimension and refractive index. Humidity effects on aerosol properties are also important (see WCP 55,1983). The accuracy of one dimensional computations of radiation transfer is limited by the accuracy with which optical properties of aerosols and clouds are presented.

Practically, the full interaction between molecular absorption and scattering is an important complicating factor in the solar near IR range. Accurate methods of resolution of the Radiative Transfer Equations in a Scattering Medium are available for the plane-parallel case (see Lenoble, 1977),however in the presence of molecular absorption they only apply on a monochromatic basis; the amount of computational time needed for line by line calculations associated with multiple scattering calculations in the shortwave range (which includes thousands of spectral lines) is prohibitive, even for one dimensionnal radiation calculations. Approximate methods(exponential sum fitting and distributions of photon optical paths) are available; they allow a considerable saving of computational time, however their accuracy needs to be tested, at least on the basis of selected small spectral intervals.

Highly accurate methods such as for example "line by line" models cannot be used in climate models as they are far too time consuming and we are faced to the problem of finding the best compromise between computational efficiency and accuracy, that means that a high level of approximation is necessary. Keeping in mind the recommendations reported in Physical Basis of Climate and Climate Modelling (GARP,1975), that is: partial derivatives of the radiation better than 10 % and preferably 3 %, equator to pole radiation gradient to 10 %, preferably 3 %, systematic errors less than about 0.05 C/day over a scale height and random errors less than 0.3 to 0.5 C per day per one kilometer layer; one thus has to evaluate the impact of the different simplifying assumptions or parameterizations,and verify the radiation code with reference to a more sophisticated one and wherever possible against observations.

Errors may also arise from the rather coarse vertical resolution of the climate model defining the atmospheric profiles or from the simplifying assumptions or parameterizations utilized in the radiation code itself. Usual simplifications are

(1) use of band models to parameterize the molecular absorption: the number of spectral intervals involved varies from model to model , many GCMs make use of a single spectral interval in the longwave this is called the "emissivity method" .

(2) parameterization of pressure and temperature effects on the molecular absorption (Curtis-Godson approximation, scaling approximation).

(3) fast algorithms for multiple scattering calculations (Delta-Eddington, Two Streams...etc) or specification of cloud reflectance, transmittance and absorption.

In practice, the accuracy with which fluxes and heating rates are computed by such simplified radiation codes is difficult to verify because of lack of appropriate observational data. Only the outgoing radiative flux can, in principle, be verified against satellite measurements, but there exists no suitable measuring technique to determine heating rates or radiation flux divergence in the atmosphere for grid scale areas. However, the accuracy of radiation codes used in climate models can be assessed (particularly for "clear sky" conditions) by comparison with comprehensive calculations of radiative transfers in one dimension.There is therefore much to be learnt by comparing radiation codes used in climate models with an accurately calculated "standard" where possible, and with the results of other radiation codes.

The IAMAP Radiation Commission, jointly with WMO (CAS), supports an intercomparison programme for radiation codes used in climate models (ICRCCM). The ICRCCM programme deals with the following topics

1 - radiative transfer applied to individual gases and combination of gases for both shortwave and longwave;

2 - cloud and radiation interactions in radiative codes;

3 - radiative and dynamic response within GCMs.

    3a - static : statistical intercomparison of radiation code response to variations in atmospheric parameters

    3b - interactive : tests of the sensitivity of GCMs to difference in Radiation Codes.

2. INTERCOMPARISON OF RADIATION CODES IN THE STAND ALONE MODE

The first step was the intercomparison of calculations of longwave fluxes performed by 39 different radiation codes for a set of 37 selected clear atmospheric models. The results of this first phase (WCP 93 , 1984)are presented in this section, while section 3 deals with the impact of systematic differences in the radiative codes on the response of a climate model.

Among the radiation codes were 4 line by line models (LMD, GLAS, GISS and GFDL), 16 Narrow Band Models with a spectral resolution better than 100 cm^{-1} and 12 GCM type radiation codes.

2.1 Line by line models

The set of calculations included the radiatively important gases individually as well as all gases present simultaneously. The temperature and humidity profiles were those of the McClatchey' Mid Latitude Summer Model. An example of the results is presented in Table 1.

The agreement between line by line calculations was extremely good for the pure CO_2 atmosphere (fluxes at the surface, at top of atmosphere and at the tropopause agreed to within 1 Wm^{-2}). However it should be noted that all models used very similar physical assumptions and spectral data.

For the pure water vapor atmosphere, the problem is complicated because the absorption spectrum of water vapor includes not only the lines of the rotation and vibration-rotation bands, but also a very strong continuum whose physical origin is unclear. While the effect of the continuum is of great importance, the manner in which it is calculated is very much the same in line-by-line and narrow band models. Hence, the line-by-line calculations can only serve as a reference for calculations for the H_2O lines without the continuum. Unfortunately, the results of such calculations depend on the shape assumed for the line wings. Experiments indicate that lines cannot be Lorentzian far (20-40 cm^{-1}) from their line centers, since in that case the atmospheric "window" at 10 μm would be more opaque than observed. The line shape in the far wings is not known precisely, which introduces uncertainty to the water vapor calculations in spectral regions where the contribution from the line wings is significant. Tests of the effect of varying the line shape so

Table 1 : Line by line flux calculations (Wm^{-2})

	F down surface				F up top			
	LMD	GISS	GFDL	GLAS	LMD	GISS	GFDL	GLAS
CO_2 only 300 ppm	76.38	75.36	75.38		383.52	384.33	384.54	
			(0-2200 cm^{-1})					
			↙	↘				
H_2O lines only	267.29		267.29	265.24	329.51		333.91	334.42
	↑							
	(100-2600 cm^{-1})		→	263.25				334.61
O_3 only 9.6+14 μbands	4.99*	6.37	6.07	5.92	411.56	411.70	409.82	412.06
9.6 μ band only	4.41	4.79	4.43	4.40				
CO_2 +O_3		adjusted to		(0 - 2600 cm^{-1})				
+ H_2O (no continuum)	302.80		303.46		293.69		294.42	
CO_2 + O_3 + H_2O (with continuum) + CH_4 + N_2O			(100 - 2600 cm^{-1})					
300ppm CO_2)	341.8			341.3 (330ppm CO_2)	284.0			283.3

* LMD calculations includes only partly the 14 μm band

that it is sub-Lorentzian in the far wings were carried out by the GFDL group for several cutoff factors;they indicated that the uncertainty in the downward flux at the surface in line-by-line calculations due to uncertainty in line shape is on the order of a few W/m^2.

This uncertainty in the line shape is the main reason for the differences which can be seen in Table 1 for the pure H_2O lines case: the GFDL and GLAS models have very similar line cutoffs and the downward fluxes at the surface agree to within 2 Wm^{-2} .Calculations by the GLAS group show that the inclusion of the continuum from 400 to 700 cm^{-1} increases the downward flux at the surface by 15 W/m^2.

If we consider the remaining results of Table 1, the agreement is quite satisfactory, within 1 % for all gases present simultaneously. For the case of CO_2 + H_2O (no continuum) + O_3 it is also possible to compare the cooling rates (Fig. 1). There are discrepancies of up to 0.3 K/day in the troposphere, which is somewhat puzzling in light of the good agreement of the fluxes. The cause of this discrepancy is presently under investigation.

In general, it is seen that the line-by-line models are in reasonable agreement with each other. The calculated flux components (net flux at tropopause and top of atmosphere,and downward flux at surface) usually agree to within a few W/m^2, which is less than a 2 % difference. However it must be noted that all models use very similar spectral data. In addition the uncertainties in the H_2O line shape cause the fluxes to be more uncertain for water vapor (up to 5 Wm^{-2} for the flux at top of atmosphere) although the agreement is very good when the same line shape

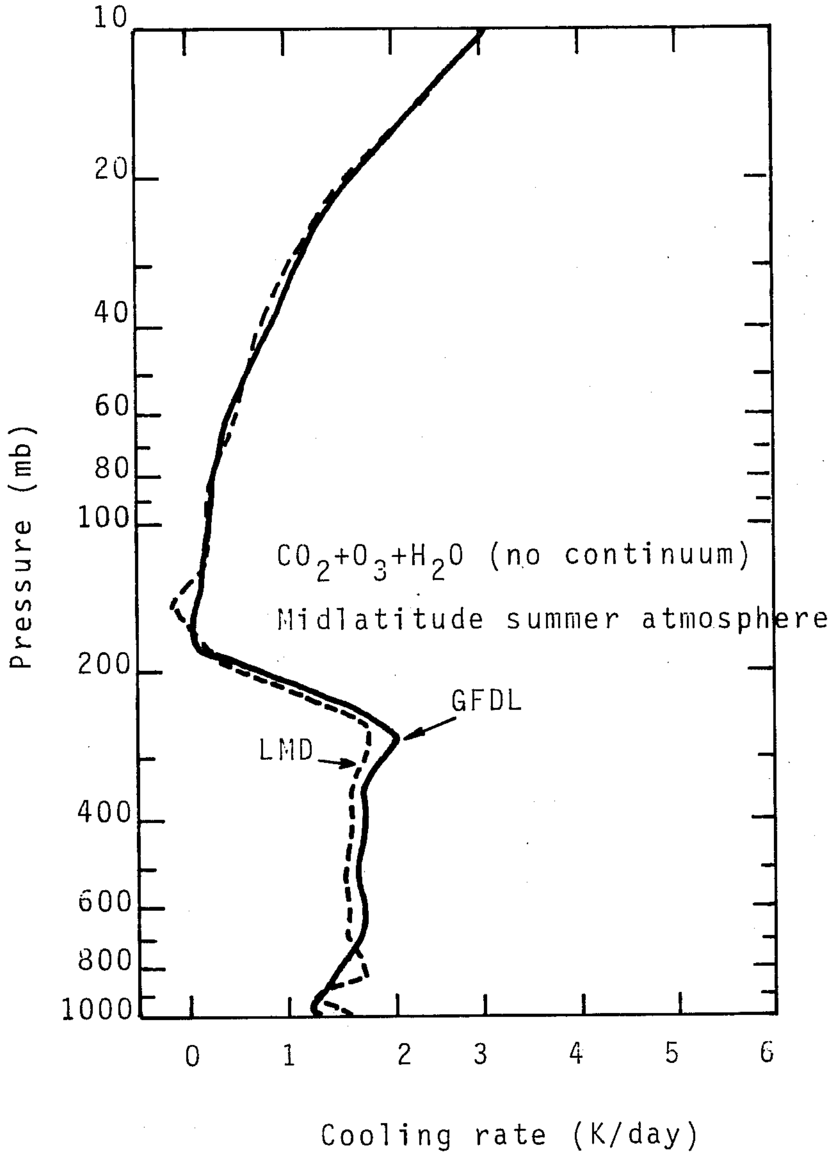

Figure 1 - Line-by-line model calculations of cooling rates for the midlatitude summer atmosphere : CO_2 + O_3 + H_2O (no continuum).

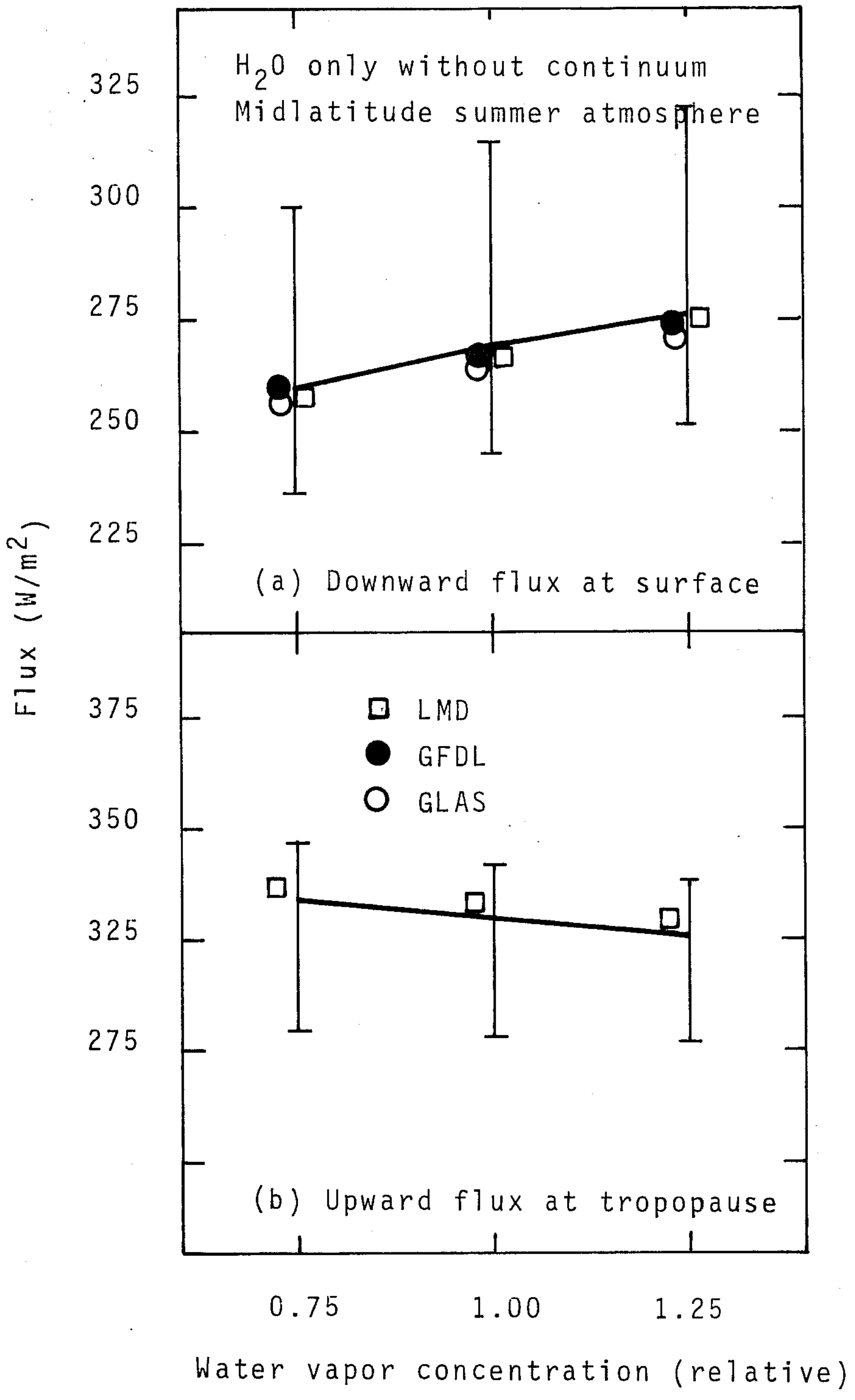

Figure 2 - Averages and ranges of 9 narrow band model calculations for (a) downward flux at the surface and (b) the upward flux at the tropopause. The calculations are for H_2O alone with no continuum and midlatitude summer conditions. The average is noted by the horizontal lines and the vertical lines denotes the range. Line-by-line model results are indicated by the symbols.

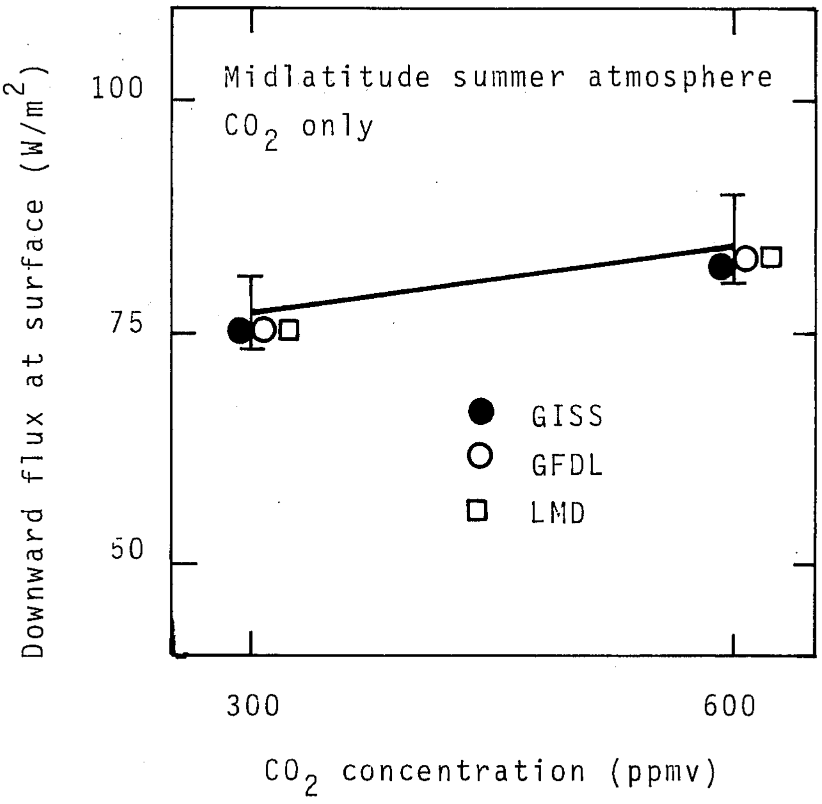

Figure 3 - Averages and ranges of the downward flux at the surface calculated by 9 narrow band models for CO_2 alone. Line-by-line model results are indicated by the symbols.

assumptions are made. The e-type continuum, the p-type continuum, and the temperature dependence of H_2O line widths are still the source of significant errors in all calculations.

The intermediate results of the line by line calculations have been made available for future work,these are

a. Frequency integrated fluxes at the surface, tropopause, and top of the atmosphere.
b. Frequency integrated cooling rates.
c. Narrow-band (5 or 10 cm^{-1}) fluxes and cooling rates.
d. Narrow-band transmission matrices.

2.2 Narrow band models (NBM)

The results from 9 NBMs (defined as using a spectral resolution better than 100 cm^{-1}) were used to calculate the mean and range of the flux quantities.The results for calculations with H_2O only without the continuum, and CO_2 only are shown in Figures 2 and 3, respectively. In each case the vertical line indicates the range of results for the 9 NBMs, and a line connects the mean values for each range, thereby indicating approximately how the mean value varies as the amount of absorbing gas is varied. The largest differences between the calculations occurred for the H_2O calculations. The range of the downward flux at the surface for the midlatitude summer conditions amounts to 26 % of the flux value. When CO_2 is considered alone, the range of the downward flux at the surface is 8 % of the mean. When the combined effects of H_2O, CO_2 and O_3 are considered, the range is 6 % of the mean.

In addition to the relatively large range of flux values, the model results show different responses as the gas concentrations change. For example, the range of the change in the net flux at the tropopause, for midlatitude summer conditions and CO_2 alone, amounts to approximately 20 % of the average change (for doubling CO_2). Approximately one-fourth of this range may be attributed to the neglect of the 10 µm band of CO_2 by some models. Comparing results for atmospheric profiles at other latitudes and seasons shows that the range of discrepancy increases with increasing atmospheric temperature.

An unanticipated results was the large range in sensitivities of the downward flux at the surface to increases in H_2O. These differences have potentially major consequences for climate models because of the strong water vapor feedback effect that accompanies changes in surface temperature resulting from climate perturbations.

Because the physics of the gaseous portion of the longwave radiation problem is believed to be well known, the observed differences are distressingly large. Further investigations have been performed since this first intercomparison; preliminary tests to estimate the signs and magnitudes of the variations in model fluxes due to possible assumptions indicate that the major discrepancies are likely due to:

1. The choice of widths of the spectral intervals.
2. Different treatments of the H_2O continuum.
3. Errors in calculating the temperature dependence of spectral lines, particularly for CO_2.
4. Inaccuracies in the numerical techniques used for the integration over altitude.
5. Different sources of spectral line data.

6. Differences in the way band parameters are derived from the spectral data.

Beginning with a high spectral resolution NBM, Morcrette (1984) sequentially implemented different simplifications in his model. The list of changes is given in Table 2 along with their effect on atmospheric absorption. The change in absorption applies to the single simplification indicated, but the model at each stage includes all of the changes higher on the list.

The main lesson from Table 2 is that the impact of simplifications on atmospheric absorption can vary in sign and magnitude. Consequently,compensating errors might lead to results which do not differ greatly from the much more detailed model.However,one does not feel very confident in methods which give the right result for the wrong reason.

2.3 Wide band and General Circulation Model

The wide-band models and the longwave radiation algorithms used in general circulation models are designed to achieve high computational efficiency. Computational efficiency is normally achieved by either parameterizing or approximating certain aspects of the radiative transfer calculation.

One of the issues to be evaluated in the comparison of wide-band and GCM model algorithm results is whether the approaches used to achieve computational efficiency affect model accuracy and sensitivity in any

Table 2 - Impact of simplifying assumptions on the results of a longwave radiation narrow band model (Morcrette, 1984).

Simplification	Impact on atmospheric absorption	Change in atmospheric absorption (W/m^2) Subarctic winter atmosphere	Tropical atmosphere
N layers 40 10	decrease	-4.0	-5.0
L = 8 L = 2[1]	decrease	-0.5	-1.5
G2 G25[2]	decrease	-0.8	-4.0
T,q T, q[3]	increase	+4.0	+5.0
Voigt Lorentz lines	decrease	-2.5	-4.5
strong line regime	increase	+6.0	+7.0
neglects N_2O, CH_4	decrease	-4.5	-5.0
CO_2 15 μm, O_3 9.6 μm[4]	decrease	-2.0	-5.0
Reduce no spect. intervals	increase	Depends on initial width of spectral intervals	

1 - Decreasing the order of the numerical quadrature used for vertical integration.
2 - 2-points Gauss quadrature for nearby layers, trapezoidal rule for distant layers.
3 - Using averaged values within layers.
4- Limiting CO_2 to 500-800 cm^{-1} and O_3 to 970-1110 cm^{-1}.

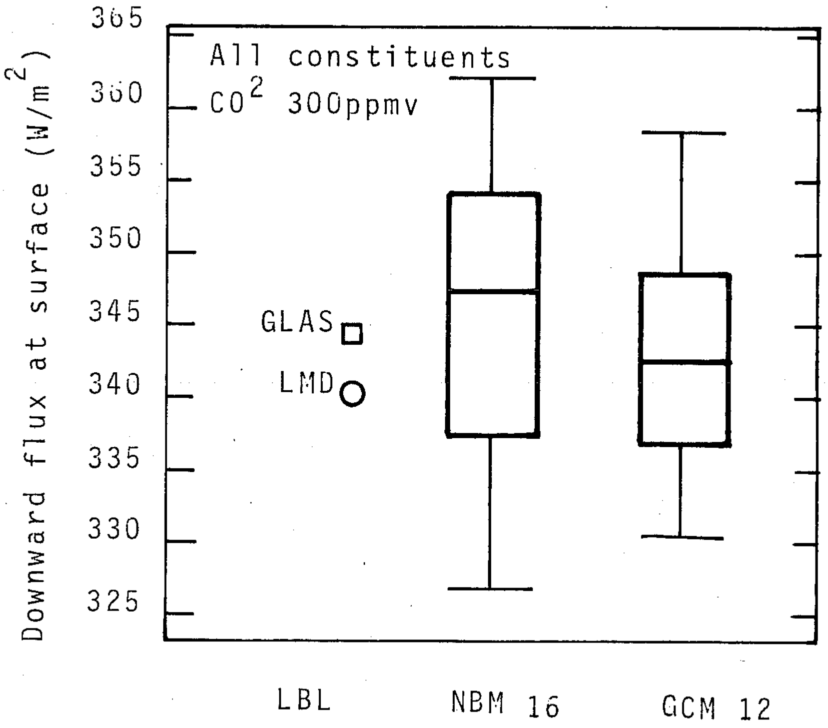

Figure 4 - Line-by-line, narrow band model, and GCM calculations of the downward flux at the surface for the midlatitude summer profile with all constituents included. The number of model results in each set is given. See text for meaning of rectangles.

significant way. In order to make this determination, the wide-band and GCM model results (hereafter simply referred to as GCM models) were compared as a group with the group of narrow-band model results.

Figure 4 shows the comparison for the downward flux at the surface calculated for the midlatitude summer profile with all gases included. This figure shows the range and percentile distribution of values for the narrow-band models and GCM models. The "box plots" in Figure 4 divide the distribution into four parts, each containing a quarter of the population (Chambers et al., 1983). The bottom and top of the rectangle denote the 25th and 75th percentile flux values. The horizontal line within the rectangle represents the median value or the 50th percentile. The median is portrayed rather than the mean because the value of the median is insensitive to outlying data points. The vertical line segments extending upward and downward from the rectangle terminate at the 100th and the zero-th percentile, respectively, and thus indicate the range of the data.

The narrow-band and GCM model results show quite similar distributions of values for the downward flux at the surface. The GCM model results have a smaller overall range and there is a narrower distribution between the 25th and 75th percentile values. The median value of the downward flux for the GCM models is about 5 W/m^2 less than that of the narrow-band models, which is a difference of slightly more than 1%.

Similar results were obtained as for the sensitivity of the radiative fluxes to a doubling of CO_2 a changing the water vapor concentration: in summary, there is no systematic difference between the GCM and narrow-band model results. Although there are differences between the two sets of results for certain flux components and changes in fluxes, these differences are not significant enough to warrant maintaining separate groupings of GCM and narrow-band model results. The reason for the general similarity between the two groups is probably due to the fact that the GCM and wide-band models have been validated against narrow-band or line-by-line model results.Approaches to computational efficiency that do not provide acceptable accuracy are either discarded or corrected. Consequently, it is not appropriate to assume that a radiation transfer algorithm is less accurate just because it is very efficient computationally.

3. SENSITIVITY OF CLIMATE MODELS TO RADIATION CODES

A similar exercise is underway for the SW and for the cloudy cases; here again the objective being to estimate the range of uncertainty of the methods of calculation of the radiation transfer – the spectral radiative properties of the clouds and aerosols being fixed, as well as the solar spectra. However, beyond the uncertainties linked to any particular well-established simplification of the radiation transfer (see above for the longwave case), there exists some implicit tuning in their practical application in GCMs: the choice of the spectral band limits, the choice of an averaging procedure for optical or spectroscopic properties inside these bands, the choice of particle size distributions for off-line Mie calculations and the mathematical fitting of transmission functions and of their temperature/pressure dependncy all involve some arbitrarity. And even the simplified solutions of the radiative transfer equation are so complex that it is almost impossible to find which part of the difference with more sophisticated solutions is due to the simplification per se or to an inadequate "tuning", not to speak about compensating errors ! Furthermore the radiative computation part of climate models gets an input affected by so much uncertainty on some model-diagnosed and/or arbitrarily-fixed quantities that the removal of some simplifications can hardly be considered as an improvement of the results, when compared with the output errors associated with unavoidable biases in the input; this is especially true of course for clouds and aerosols.

The central question of radiative fluxes computations is therefore, for a given computing power and a given amount of memory strorage, to find the most appropriate approximations. Up to now this search has usually been conducted with the guidance of a mixture of personal feeling, trial and error results and past experience. The strategy has the consequence that no consensus has yet been reached and, more alarming, that none seems in view for the coming years.On the contrary,and, even if some degree of agreement on the methods simplification is wishable, there will never be a complete one, since the choice of the algorithms and their tuning are largeley influenced by the nature of the problem for which the climate model is designed: obviously the priorities of gaseous and cloud/aerosol treatments will be different if one wishes to study either the CO_2 increase effects or the albedo-desertification feed-back loop.

The first steps of the ICRRCM study corresponds to a "static" point of view, allowing for an estimate of the systematic differences between radiation schemes. However, this approach is not sufficient as it does not provide any insight on the influence of these systematic differences on the GCM results. To reach this goal the "interactive" or "dynamic" point of view must be taken, i.e. results from integrations of the same GCM including the different radiation schemes must be analysed. The results of such a study (Morcrette and Geleyn, 1985 hereafter referred as MG) are presented in this section.

MG ran the operationnal ECMWF model for three 10 days forecast (21-31 January 1979) corresponding to the first special observation period of FGGE) with three different radiation codes: (i) the original ECMWF code (Geleyn and Holingsworth, 1979, hereafter referred as ECL), (ii) the scheme developed by the University of Koln (Hense et al, 1982), (iii) the scheme developed by the University of Lille for the GCM of the Laboratoire de Météorologie Dynamique (Fouquart et Bonnel, 1980 ; Morcrette and Fouquart, 1985 ; hereafter LI). For sake of clarity, in the following, the comparison is restricted to EC and LI.

In addition to different parameterizations of the molecular absorption, the main differences between these radiation schemes are (i) no e-type continuum absorption with the EC scheme, (ii) in the longwave, emissivity type method for the Lille scheme and two-streams method associated with a path length method for EC, (iii) maximum cloud overlapping assumption for EC, and random overlap for LI.

3.1 Initial radiation fields

As both radiation schemes use the same diagnosed cloudiness, comparisons of the radiative fields at the first step integration shows intrinsic differences between the schemes. Concerning the latitudinal distribution of solar heating and IR cooling, MG noticed the overall agreement between the two fields, however the solar heating rates in the troposphere averaged 0.25 K/day more for EC than for LI; an important difference appeared in the IR cooling of the lower troposphere; due to the absence of e-type H_2O water vapor absorption the tropical lower layers were cooled significantly less (0.5 K/day) with the EC scheme. The net radiative heating presented differences varying from 0.25 to 1 K/day below 850 mb with the LI scheme giving the largest cooling tendancy. In addition the latitudinal distributions of the radiation heatings differed significantly, the LI scheme giving a steeper slope (larger decreases of cooling with latitude). These features result in different vertical stabilities and possible differences in the variation of the tropopause height with latitude.

MG also presented maps of the covariance between heating rates and temperature or cloud cover at the initial step. These covariances are related to the generation (positive covariances) or dissipation (negative covariances) of available potential energy (APE). Indeed, temperatures fluctuations lead to negative covariances because warmer parts of the atmosphere have a stronger emission whereas moisture and clouds fluctuations have an opposite effect, at least in certain parts of the atmosphere, since clouds generally indicate warm air and their relative radiative effect is a warming within and below and a strong cooling localized at cloud top. Generation of APE (positive covariances) should take place in the lower atmosphere and dissipation (negative covariance) in the higher regions; the dissipation should be strong in the baroclinically active regions and the generation strong in the tropics.

From this point of view, the comparison of the covariances between temperature and radiative heating rates as given by the two schemes gave an insight into some properties of the radiation codes, in particular the EC scheme exhibited a much larger extension of the positive covariances to high latitudes; MG attributed this difference to a deficiency of the EC scheme. For small optical thicknesses the EC scheme significantly overestimated the absorption yielding too large cooling rates at high altitudes and leading to a sort of greenhouse effect for the layers underneath, which explains the observed large dissipation of APE around 400 mb poleward of 30°N and the generation of APE in the lower layers.

The radiative fields at the top of the atmosphere derived from satellite observations constitute at present the only available data againts which model calculations can be checked on a planetary scale. However the radiative fields either calculated or observed depend on so many parameters and include so many uncertainties, that such comparisons do not provide information on the reasons for discrepancies or even agreements. Nevertheless, if we consider the initial step of the integration, a comparison between the calculated radiative fields may still give hints as to the ability of the radiation codes to properly simulate the large scale atmospheric features such as the pole-equator gradient or the land ocean contrast.

In the present case, two main features were appearent: (i) poleward of 50°N and over the cloudy areas of the equatorial zone the LI scheme gave a higher albedo than did the EC scheme; (ii) land-ocean contrasts were lacking or even reversed on the map of the outgoing longwave radiation for the EC scheme. The first point was attributed to a deficient parameterization of the Rayleigh scattering and of the effective solar zenith angle assumed below clouds of small optical thicknesses in the LI scheme; the second point was attributed to the screening effect of the higher tropospheric layers which overestimate the emission of the layers above the mean cloud top, then decreasing the contrast between clear and cloudy areas.

The radiative-dynamical interactions have a relatively long time scale, thus the 10 days period of integration is probably too small to get a complete feedback interaction. However MG stated that this period was long enough to show the direct impact of the different radiation schemes on the evolution of the radiative fields through the evolution of the controlling parameters such as cloudiness, temperature and humidity.

During the 10 days of integration the globally averaged outgoing longwave fluxes remained very stable for both schemes (from 243.8 to 242.4 Wm^2 for EC, from 246.7 to 246.8 Wm^{-2} for LI), whereas the fluxes derived from AVHRR observations decreased slightly from 240.4 to 239.8 Wm^{-2}. The calculated albedoes decreased much more subtantially (from 0.37 to 0.31 for LI, from 0.32 to 0.29 for EC) whereas observations gave almost no variation, around 0.30. As already noted the LI scheme gave much too large albedo values, thus leading to a net deficit in the radiation budget (-24 Wm^{-2} at the initial step, compared to -5 Wm^{-2} for EC and + 4.5 Wm^{-2} from observations, in agreement with what could be expected from the annual cycle). This corresponds to an important radiative forcing to which the model has adapted. The way the model did so was mainly through the variation of the SW cloud optical properties which are interactives in both schemes. Indeed for both schemes the planetary temperature decreased during the integration (from 265.5 to 264.9 for EC, from 265.5 to 263.5 for LI); the cloud cover also decreased (from 0.58 to 0.47 over oceans, from 0.61 to 0.57 over land) but this decrease was independant of the radiation scheme. Indeed with the diagnostic relationship giving the cloud cover and liquid water paths (LWPs) of the clouds, the cloud cover is linked to the relative humidity whereas the LWPs are linked to the saturation mixing ratio, thus the strong temperature decrease observed with the LI scheme leads to smaller LWPs.

From the radiative point of view, the clouds are mainly black in the IR so that the variation of the LWPs do not effect too much the longwave radiation fields; this is quite different in the SW where the decrease in LWPs leadsto smaller albedoes.

The time evolution of the globally averaged solar heating and IR cooling illustrated the tuning of the original radiation code of the ECMWF model as both quantities kept steady values along the period of integration. However this stability, when account is done for the temperature and cloudiness decreases, gives another hint into the deficiency abready noted for the ECL scheme (overestimation of the absorption at short pathlengths) and more importantly it shows that the temperature decrease of the model does not originate solely from the radiative calculations and suggests that other heating processes are involved in the cooling of the model.

MG also compared calculated and observed ten-day means of the radiation fields at top of the atmosphere, this method is of common use among the modellers to validate their parameterizations. Their results lead to a questioning of this method, mainly for two reasons:
(i) the time averaging of the radiation fields lead to differences which are much smaller than those observed at the initial step
(ii) due to the various compensating mechanisms (temperature decrease, global redistribution of cloudiness etc..) the radiation fields have adapted themselves to the different internal forcings of the model during the integration.

MG noted that consequently, comparisons between time-averaged computed and observed radiative fields are not guaranteed to provide an exact measure of the tested schemes. As observations from satellites will still remain for a long time the best way to monitor the atmosphere and to derive parameters that can be directly compared with GCM's outputs, emphasis must be put on obtaining measurements with finer time, space and spectral scales from the next generation of satellites. Another alternative is to use the large-scale fields of temperature, pressure, humidity and winds analysed by the forecast models together with the cloud and radiation parameters derived from the existing satellite system. Large-scale fields can be taken as inputs for GCM-type cloud generation and radiation schemes, and the computed cloudiness and consequent radiation fields are compared with the satellite measurements (Bonnel et al., 1983).

4. SUMMARY AND CONCLUSION

This paper presented the first results of the ICRCCM study which dealt with the clear sky longwave calculations.Even though the basis of the radiative transfer computations is well established,the results of the intercomparison exhibited considerable dicrepancies between individual radiative codes.Considering climate sensitivities studies, the observed large discrepancies in the responses of the radiative codes to water vapor or CO_2 changes were particularly striking.By comparison,the results of the line by line models showed a very satisfying agreement,however it must be noted that these models are mostly based on the same spectral data;in addition, there remain considerable uncertainties as to the various water vapor continua or the spectral line shape far from the center.The second part of this paper illustrates the impact on the operational ECMWF model of such systematic differences in the radiation codes: despite relatively large original differences in the radiation fields, compensating mechanisms lead to similar trends over the 10 days integrations. This result might be due to the hiding effect of the deficiencies in the hydrological cycle. More research is needed, particularly on a longer integration time basis, to evaluate the sensitivity of the climate models to radiative forcings.

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