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RADIATION

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INTRODUCTION

This note describes the scientific aspects of the representation of radiative processes in the Unified forecast/climate Model (UM). The longwave scheme is based on that described by Slingo and Wilderspin (1986) and the shortwave on that previously used in the climate model (Slingo, 1985), extended to include the spectral division and interactive cloud optical properties of Slingo (1989).

The uneven distribution of solar heating is the ultimate driving force of the general circulation and the original source of essentially all the atmosphere's available potential energy and kinetic energy. Radiative processes are responsible for the existence and nature of the troposphere and stratosphere. Assessing the effects of environmental changes, whether natural or man-made, requires the representation of the effects of such things as changes in humidity and cloud due to changes in circulation. Even on forecast timescales there may be important interactions between radiation and the large-scale flow, and it is clearly more satisfactory to forecast quantities such as surface temperature from radiation calculations consistent with the rest of the forecast than allowing for radiative effects indirectly through statistical relations. And of course experiments to assess the effects of, say, increasing CO_2 , require accurate radiation schemes to incorporate its effects quite apart from interactive radiative effects in the simulations.

For meteorological purposes, radiation can be divided into two parts, shortwave and longwave, treated by separate schemes. This is possible because there is very little overlap in terms of wavelength between sunlight (shortwave) and terrestrial heat radiation (longwave). In each part, the net flux F is calculated at the layer boundaries and the heating rate of layer k is then given by;

$$\frac{\partial T_k}{\partial t} = \frac{g}{C_p} \frac{\Delta F}{\Delta p} = \frac{g}{C_p} \frac{(F_{k+1/2} - F_{k-1/2})}{(p_{k+1/2} - p_{k-1/2})} \quad (1.1)$$

At the surface a net radiative flux is produced rather than a heating rate, for use by the surface calculations (Unified Model Documentation Paper (UMDP) 24). (Note: for radiation, "flux" means an energy flux, i.e. the amount of energy crossing a certain plane - for radiation, a horizontal one - per unit time, and so has SI units Wm^{-2}. "Net" fluxes in this paper will always refer to net downward fluxes, i.e. the total flux downward minus the total flux upward.)

Three radiatively-active gases (water vapour, ozone and carbon dioxide) are considered in calculating the radiative heating rates. The water vapour mass mixing ratio is of course a basic model variable, but amounts of the other two gases are prescribed in the standard use of the model. Ozone mixing ratios are prescribed in the standard model, from monthly climatological estimates (Appendix 4) but it is intended that in some middle-atmosphere applications they will be calculated interactively or assimilated (UMDP 30) or both. Ozone data need not be specified for the lower model levels: the values for the lowest level where it is specified are used. The mass mixing ratio of carbon dioxide is constant throughout the atmosphere at a value set by the user: the standard value is 4.9×10^{-4} corresponding to 320 parts per million by volume (ppmv).

The other physical inputs required are temperatures at each model layer centre, pressures at each layer centre and boundary, cloud quantities (base, top, fractional cover, and condensed water path for each cloud), land/sea indicator, sea-ice fraction and the flux-to-heating-rate conversion factor (1.1). These are all standard model quantities except that the condensed water path CWP for layer cloud is obtained from the cloud condensed water content:

$$CWP = \rho\, q_C \Delta z \quad (1.2)$$

while that for convective cloud is specially calculated by the convection scheme (UMDP 27). The shortwave calculations also need the solar zenith angle, surface albedo and the effective radius r_e of each cloud's drop-size distribution. As well as the atmospheric heating rates and surface fluxes, various diagnostics are available (UMDP P23).

The computational expense of full radiation calculations is rather more than any other physical process, but fortunately they do not suffer from the stability problems which restrict the timesteps for most of theothers. Thus both radiation schemes can be used with a timestep of order three hours, much longer than for other atmospheric processes.

A very important part of the radiation schemes is their interaction with the clouds predicted by other parts of the model (UMDP 29, 27). Cloud variations of course affect surface temperature even on the shortest timescales, but they may also influence the circulation on periods of days to weeks, by altering horizontal temperature gradients and atmospheric stability. Also, fractionally small changes in cloud distribution and cloud forcing - their effect on planetary albedo, and the cloud "greenhouse" effect - can be large compared with external forcing such as changes in "greenhouse" gases, so that cloud change could provide major feedbacks on the latter.

The schemes allow for a single convective tower and a number of layer clouds. A cloud is assumed to occupy a whole η layer or number of layers with its top and base at layer boundaries, since current cloud parametrizations cannot provide physically based information on the vertical distribution of clouds on a finer resolution than the model's. No cloud can extend into the top model layer, where the temperature of its top would be undefined. Only one layer cloud may exist in any one layer, but the convective cloud may extend through layers containing layer cloud: the layer cloud fraction given by the large-scale cloud scheme (UMDP 29) is then interpreted as the fractional cover in the part of the gridbox outside the convective cloud. As usual in large-scale models, all clouds are assumed homogeneous and plane-parallel, and edge effects are neglected.

Though the concept of "cloud amount" is often convenient, it is not physically well-defined. Almost any air contains some particulate matter, and even to measure "cloud amount" one must apply a physically arbitrary threshold at an arbitrary resolution, and from an arbitrary viewing angle (Rossow et al, 1985). The amounts used in GCMs, and the corresponding uniform cloud optical properties, are tuned quantities. They can only approximate the complex variations of optical depth and condensed water path over the area in reality corresponding to a grid-box in the model. There is thus not even any logical necessity for the cloud distribution to be the same for the shortwave and longwave schemes.

The usual assumption in those large-scale models which allow fractional cloud cover is that clouds in different layers overlap randomly. An alternative assumption (Geleyn and Hollingsworth, 1979) is that clouds overlap maximally when they are in adjacent layers or when there is cloud extending through all the layers between them, and randomly if there is a cloud-free layer between them. This is physically more plausible, and an observationally based study of part of the North Atlantic in winter (Tian and Curry, 1989) concluded that it is realistic (with exceptions that do not apply to our purposes). Both assumptions are available in the longwave scheme, but *only random overlap in the shortwave.* (With random overlap, when more than one layer cloud exists in the layers through which the convective cloud extends, they overlap randomly in the space outside the convective cloud.)

The effects of atmospheric aerosol other than cloud are omitted.

The remainder of this paper describes the radiation schemes in detail. First the longwave calculations are described. As with most of the "physics", there is a natural plug-compatible unit, corresponding to UM logical component P232. The calculation of the interaction of shortwave radiation with the atmosphere, however, has the unique feature that it can be entirely omitted for many points on non-meteorological grounds (where the sun is down). The preliminary calculations that determine this, and also find the solar zenith angle, are described first, and then the calculation of surface albedo, which is also treated separately. These together constitute UM logical component P233, and the routines obey the full plug-compatibility rules despite the need to know the geographical position of a point to find the incoming insolation there. After the plug-compatible scheme for the interaction of shortwave radiation with the atmosphere and surface, UM logical component P234, has been described, the final section documents the extra calculations that have to be done at sea points to allow for leads. Appendices document the derivation and contents of the look-up tables of gaseous transmissivity and the ozone climatology. (See also UMDP P23, for diagnostics available.)

LONGWAVE RADIATION

Longwave radiation is absorbed and emitted by atmospheric gases, clouds and the earth's surface. The use of the Planck or black-body flux is fundamental to the calculation of its effects. This is a function of frequency and temperature only, which can be defined as the flux that would exist inside an enclosure in total thermal equilibrium, assuming only basic thermodynamics and Planck's Law (that electromagnetic radiation comes in quanta whose energy is proportional to their frequency). Two of its well-known properties are that its spectral integral increases as the fourth power of temperature, and that at higher temperatures its peak shifts towards higher frequencies (so that sunlight is at higher frequencies than terrestrial heat radiation). Up to around 70 km (5 Pa) in the earth's atmosphere, one can assume "local thermodynamic equilibrium", i.e. matter absorbs and emits at each wavelength a fraction of the Planck flux which depends on how readily it interacts with radiation of the corresponding energy. If the atmosphere had no significant interaction with longwave wavelengths, then longwave radiation would simply be a matter of the surface radiating direct to space. Conversely, if the atmosphere were a perfect absorber and emitter ("black"), the net longwave flux would be zero except at a temperature discontinuity. The complexities and importance of longwave processes in the atmosphere are due to its lying between these extremes.

The main constituents of the atmosphere, nitrogen and oxygen, are diatomic and symmetric. Because of this, there are few wavelengths at which they interact effectively with electromagnetic radiation, and the associated energies are generally large compared with those of photons found in the Planck flux for terrestrial or (mostly) even solar-surface temperatures. Their effects on atmospheric radiation are therefore negligible for our purposes, and we need often only consider the three most abundant triatomic trace constituents, water (H_2O) in its three phases, ozone (O_3) and carbon dioxide (CO_2). Other "greenhouse" gases which may make a significant contribution to anthropogenic warming, though climate change experiments often represent their effects by an equivalent CO_2 change, are included in one version of the UM LW scheme: methane (CH_4), nitrous oxide (N_2O), and two of the chlorofluorocarbons, trichlorofluoromethane $(CFC1_3, "CFC11")$ and dichlorodifluoromethane $(CF_2C1_2, "CFC12")$.

The use of CO_2 as a proxy for other minor gases in GCMs has been a widespread practice which saved computing time and reduced complexity; but as models have become more accurate in their simulations, the effects of using explicit parametrizations of minor gases instead of proxy CO_2 are no longer negligible. There is now some evidence that the inclusion of some minor trace gases in GCMs may lead to a change in the model climate (Wang et al. 1992).

Each gas has its own distribution and its own longwave spectrum, different from those of other gases. For example, the main CO_2 band at 15 microns is quite strongly overlapped with water vapour and is largely saturated for paths through the whole atmosphere, whereas the absorption characteristics of the CFC11 band at 9.3 microns are completely different, because the integrated band strength is much greater than that of the CO_2 band, it is in the water vapour window and the concentration of CFC11 is very low. The relative positions of gases on the Planck spectrum also affects the amount of radiation which each can absorb. These differences may cause large differences in radiative effects of gases: for example CO_2 tends to cool the stratosphere, whereas CFC11 and CFC12 tend to warm it.

The explicit parametrization of minor gases is most important for climate change applications of the Unified Model. Although the four most important minor gases - Nitrous Oxide (N_2O), Methane (CH_4), CFC11 and CFC12 only account for a few percent of the current radiative forcing, the increases in their concentrations caused 37% of the change in radiative forcing between 1980 and 1989 (compared with 55% for CO_2)

The 1C version of the Longwave code includes explicit parametrizations of the minor trace gases N_2O, CH_4, CFC11 and CFC12.

Spectral intervals

The wavelength-dependence of the absorption and emission by the radiatively-active gases is enormously complex because they have many vibrational and rotational energy transitions which are excited by longwave radiation. Thus there are tens of thousands of spectral lines, grouped into a much smaller number of bands. For water vapour, continuum absorption, which changes only slowly with frequency, is also important. Thus a longwave scheme requires a judicious division of the spectrum, to represent these bands and the main regions of overlap between the contributions from the various gases as accurately as possible at minimal computational expense.

Seven spectral divisions, grouped into six bands, are used in the original division of the LW, which is still standard in climate mode, as shown by the circled numbers 1-6 in Figure 1 (Slingo and Wilderspin, 1986). The first interval (wave numbers$0-40000\ m^{-1}$) treats the far-infrared rotation band of water vapour and the second ($40000-56000\ m^{-1}$) deals with the overlap between the weaker line absorption around the $20\mu m$ window and absorption by the water vapour continuum. (Water vapour continuum and line absorption have to be treated separately because their pathlengths scale differently, as described below.) The third interval ($40000-56000\ m^{-1}$) represents the triple overlap between water vapour line and continuum absorption and the well-known $15\mu m$ band of CO_2. The fourth ($90000-110000\ m^{-1}$) and fifth ($80000-90000\ m^{-1}$ plus $110000-120000\ m^{-1}$) bands cover the contributions in the $10\mu m$ atmospheric window from weak water vapour lines, the water vapour continuum and, in the former case, the $9.6\mu m$ 9.6 æm band of ozone, important in the stratosphere. (The weak $10\mu m$ CO_2 band is ignored, although in principle it could easily interval represents the $6.3\mu m$ vibration/rotation band of water vapour ($120000\ m^{-1}$ upwards).

An alternative treatment of the LW effects of the major trace gases similar to the scheme used at ECMWF (Morcrette et al., 1986) is available and is standard in global forecast mode. Again, it uses 6 bands, but now covering 9 spectral intervals - also illustrated in Fig 1. The divisions are at 35000, 50000, 80000, 97000, 111000, 125000, 145000 and 188000 m^{-1}. Again, water vapour absorbs in all 6 bands, with foreign and self broadened continuum terms in 4, and ozone in 1, but now CO_2 is included in 3, though it is treated identically in bands 3 and 4 (the water vapour window).

Version 1C of the Longwave code (including minor trace gases) has a 9 band spectral structure (see Fig. 1). The bands are as follows:
(N.B. H_2OF and H_2OS refer to the foreign-broadened and self-broadened parts of the water vapour continuum spectrum respectively. H_2OL refers to the water vapour line spectrum)

Band 1	10 - 400 cm^{-1}	: H_2OF, H_2OL
2	400 - 550	: H_2OS, H_2OF, H_2OL
3	550 - 800	: H_2OS, H_2OF, H_2OL, CO_2, O_3, N_2O
4	800 - 880	: H_2OS, H_2OF, H_2OL, CFC11
5	880 - 990	: H_2OS, H_2OL, CO_2, CFC12
6	990 - 1120	: H_2OS, H_2OL, CO_2, O_3, CFC11, CFC12
7	1120 - 1200	: H_2OS, H_2OL, N_2O, CFC12
8	1200 - 1500	: H_2OS, H_2OF, H_2OL, N_2O, CH_4
9	1500 - 2000	: H_2OL

Radiative transfer equation (clear-sky conditions)

The contributions to the longwave flux are calculated separately for each spectral band. Within each band, the equations for the downward and upward longwave fluxes respectively at pressure p can be written:

$$F^{\downarrow}(p) = B(o)\epsilon\ (o,p) - \int_{p}^{0} a(p',p)\ \frac{dB(p')}{dp'}\ dp' \quad (2.1.1)$$

$$F^{\uparrow}(p) = B(ps) + \int_{p_s}^{p} a(p',p)\ \frac{dB(p')}{dp'}\ dp' \quad (2.1.2)$$

where B(p) is the black-body flux for the temperature of the air at pressure p, p_S is surface pressure, ϵ **(0, p)** is the emissivity of the atmosphere from space up to pressure p ,and $a(p',p)$is the absorptivity from the dummy pressure $p'$to p. For monochromatic radiation ϵ and a are identical (Kirchoff's Law) but when they are spectrally averaged ϵ is weighted by $B$and a by dB/dT (see also Appendix 1).

This formulation assumes that the air close to the surface is at the same temperature as the surface itself, which is a reasonable approximation for this purpose, and that the surface acts as a black-body so that the downward flux at the ground is completely absorbed and re-emitted.

To calculate heating rates only the net longwave flux is needed. Combining (2.1.1) and (2.1.2) and integrating by parts, this is:

$$F^N\uparrow(p) = B(p_s)Tr(p_s,p) + \int_{p_s}^{0} B(p') \frac{dTr(p,p')}{dp'} dp' \quad (2.1.3)$$

where Tr is a transmissivity defined by

$$Tr(p_s,p) = 1 - \epsilon\,(p_s,p) \quad (2.1.4)$$

Since B is a function of T which is carried at layer centres, Tr is a function of absorber pathlengths which are carried for whole layers, and F is needed at layer boundaries, a natural discretization of (2.1.4) is:

$$F(J+\frac{1}{2}) = B(\frac{1}{2})Tr(J+\frac{1}{2},\frac{1}{2}) \qquad +\sum_{K=1}^{N} B(k) \{Tr(J+\frac{1}{2},k+\frac{1}{2}) - Tr(J+\frac{1}{2},k-\frac{1}{2}$$

(2.1.5)

where the numbering is by model η layer, so that $J+\frac{1}{2}$ is a layer boundary and $\frac{1}{2}$ is the surface.

This re-arranges to:

$$[B(\frac{1}{2}) - B(1)]\ Tr(J+\frac{1}{2},\frac{1}{2}) + \sum_{K=2}^{N} Tr(J+\frac{1}{2},k-\frac{1}{2})\ [B(k-1) - B(k)]$$

$$+ Tr(J+\frac{1}{2},N+\frac{1}{2})\ B(N) \quad (2.1.6)$$

which is of the computationally convenient form:

$$\sum_{K=1}^{N+1} Tr(J+\frac{1}{2},k-\frac{1}{2})\ FDB(k) \quad (2.1.7)$$

allowing the O(N) FDB to be precalculated and stored while the O(N^2) Tr can be calculated once for each pair of layers and the contributions to the net fluxes at both layers added in.

However, this formulation is not satisfactory. One must take more accurate account of the influence of the air immediately adjacent to the layer boundary where the flux is being found. The adjacent layers in (2.1.7) give a contribution:

$$Tr(J+\frac{1}{2},J+\frac{1}{2})\,(B(J) - B(J+1)) \equiv B(J) - B(J+1) \quad (2.1.8)$$

This is not very local, cannot be interpreted in terms of upward and downward fluxes, and can be shown by increasing the resolution to give a significant over-estimate of the net upward flux in the mid-troposphere. It is replaced by:

$$Tr(J+\frac{1}{2},J+\frac{1}{4})\,(B(J) - B(J+\frac{1}{2})) + Tr(J+\frac{1}{2},J+\frac{3}{4})\,(B(J+\frac{1}{2}) - B(J+1))$$

(2.1.9)

which does not have these faults. This correction is formally only second-order (2.1.5 and 2.1.7 themselves are only accurate to first order), but it is important because, however thin the layers, there are always some wavelengths at which they are optically thick (Wu, 1980). It needs a Planck flux, and therefore temperature, at layer boundaries (as do the cloud terms discussed below). The vertical interpolation of temperature is as described in UMDP S1.

The terms which contribute to the upward and downward clear-sky fluxes at any level are illustrated on the left hand side of Figure 2. The notation is explained by the small diagram on the bottom right.

The black-body fluxes are calculated from polynomial fits to the flux in each band as a function of temperature (Table 1). For the standard bands these are cubics, obtained by numerical integration of the Planck function using 100 m^{-1} spectral resolution for 5 K intervals from 180 K to 320 K. (Program held by UM librarian.) For the "ECMWF-like" code, the fits are quintic, and the input temperature is normalized by dividing by 250 K and subtracting 1.

Gaseous absorption - standard code

Purely monochromatic absorption (i.e. just one single wavelength considered) is very simple - the emissivity is an exponential function of the scaled pathlength (see below) of the absorber. However, the spectral averaging converts this into an integral over exponential functions with varying absorption coefficient. This is often approximated as the sum of exponentials, but on many computers this is computationally inefficient. The standard UM uses look-up tables.

The pathlength of a radiatively active gas is defined as the mass per unit area. If the same mass or number of molecules always gave the same absorption, then this would be the direct input to the transmissivity calculations. However, absorption lines are broadened by collisions with other molecules (Lorenz broadening), and by molecular motions (Doppler broadening). These processes make the amount of line absorption depend on pressure and temperature respectively, to an extent dependent on the strength of the lines (since the stronger a line, the further from its centre the changes in absorption occur). "Scaled pathlengths" are usually used to represent these effects in models with this sort of spectral resolution, though strictly a single scaling cannot be appropriate for all wavelengths.

Mixing ratios are assumed constant through each model layer. This convenient approximation is not of course very realistic for water vapour. When the calculation is across full model levels it will have only a minor effect on the pressure scaling. The water vapour amounts input to the quarter-layer Tr in (2.1.7) will be more sensitive to this assumption, but as Tr is roughly logarithmically dependent on absorber amount, it is still not very important.

Taking the scaled pathlength to be partly proportional to p^{α} and partly to be independent of pressure, the scaled absorber pathlength for layer k is:

$$m_k \left(\frac{p_{k-1/2}^{1+\alpha} - p_{k+1/2}^{1+\alpha}}{(1+\alpha)\, g\, p_0^{\alpha}} + D\,(p_{k-1/2} - p_{k+1/2}) \right) \quad (2.3.1)$$

where m_K is the mass mixing ratio and p_0 is the standard pressure 101325 Pa. α is 0.9 for water vapour and carbon dioxide, and 0.4 for ozone. D, which crudely represents the effects of Doppler broadening and non-strong-line effects to prevent longwave effects from becoming far too small in the stratosphere, is currently set to 0.0013 s^2m^{-1} for carbon dioxide and 0.03 s^2m^{-1} for ozone, from tuning experiments in single-column mode. It is omitted for water vapour, whose radiative effects are small at the relevant levels. If there is no water vapour, the scaled water vapour pathlength for the layer is set to $10^{-10}kgm^{-2}$ for line absorption, to prevent attempting to take the logarithm of zero. The total pathlength between two layer boundaries is the sum of these terms for the layers between.

For water vapour and ozone temperature dependence is ignored and the transmissivities originally calculated for T = 263 K (Appendix 1) are used for all temperatures. For CO_2, as well as the pressure scaling (above), the (pressure-scaled) absorber amount for each layer Δu is scaled with a factor dependent on temperature and the absorber amount itself, and then the emissivity for 263 K used:

$$\Delta u_{SCALED} = \Delta u . \ (T/T_C)^{POWER} \quad (2.3.2)$$

where T_C = 263K and

$$POWER = \max\ (2 \log_{10}(\Delta u/\Delta u_0),\ 0) \quad (2.3.3)$$

with $\Delta u_0 = 10^{-3\frac{1}{4}}\, kg\, m^{-2}$.

The transmissivities Tr for the line absorption by water vapour, carbon dioxide and ozone are calculated by linear interpolation in the logarithm of the total scaled pathlength for the given path from look-up tables (Table 2, derived as described in Appendix 1) for each term labelled 1-8 on Figure 1. A full angular integration is included in the derivation, so no diffusivity factor is needed.

Water vapour continuum absorption is taken to follow an exponential law:

$$Tr = \exp\ [\ -(k_1 u p + k_2 u e)] \quad (2.3.4)$$

where u is the water vapour pathlength, p is pressure and e the water vapour partial pressure. The term in k_1 is the "foreign broadening", which can be attributed to broadening of lines by collisions with other gases. The other, "self-broadening", term has been interpreted as implying that the continuum is produced by the dimer $(H_2O)_2$, but the continuum is now generally explained as the cumulative effect of the far wings of strong lines. In any case, the representation of the continuum is totally empirical, so that its origin is not relevant to its parametrization. Re-arranging (2.3.4):

$$Tr = \exp \left\{ -(k_1 u p\ (1 + \frac{k_2 q}{k_1 \xi}) \right\} \quad (2.3.5)$$

where ξ is the ratio of the molecular weights of water and dry air (about 0.622, usually written ϵ). We define a scaled absorber amount u_s such that:

$$1 - \epsilon\ (p',p) = Tr\ (p',p) = \exp\ [\ - k_1 u_s(p',p)\ ] \quad (2.3.6)$$

k_1/k_2 is taken to be 0.005 at the reference temperature $T_1 = 296\ K$ for all four of the bands which include the continuum. The strong temperature-dependence of the "e-type" absorption is represented following Roberts et al (1976), using their best estimate of $T_0 = 1800\ K$ for the temperature dependence parameter:

$$k_2(T) = k_2(T_1)\ \exp[T_0/T - T_0/T_1] = k_2\ (T_1)\ f_2(T) \quad (2.3.8)$$

where

$$f_2(T) = \exp \left\{ \frac{T_0}{T} - 6.081 \right\} \quad (2.3.9)$$

The contribution to u_s from layer k can then be written:

$$u_k = \frac{1.66}{g\, P_0}\, q_k\, p_k\, \Delta p_k \left(1 + \frac{k_2 q_k}{k_1 \epsilon} \right) \quad (2.3.10)$$

where P_0 is 101300 Pa and the diffusivity factor 1.66 is required to calculate the slab transmissivity (see discussion in the shortwave section below).

The values of k_1 in bands 2, 3 and both 4 and 5 (terms 9-11 in Figure 1) are taken to be 0.35×10^{-6}, and 0.15×10^{-6} and $0.05\times10^{-6}\,\mathrm{kg^{-1}\,m^2\,Pa^{-1}}$.

In bands 1 and 6 water vapour is the only gaseous absorber and the transmissivities are simply those for water vapour. For bands with two or more absorbers, the transmissivities are multiplied together to give the overlapped values. This assumes that the overlaps between the lines of different gases are random, a standard assumption on this wavenumber scale.

Gaseous absorption - "ECMWF-like" version

The "ECMWF-like" treatment of LW gaseous transmissivities is similar in basic principles to the standard treatment, and only a minimal description is given here - for a more detailed description of its physical justification, see Morcrette et al. (1986). For water vapour line absorption and CO_2, (2.3.1) is applied with $\alpha = 1$ and $D = 0$ to give a pressure-scaled pathlength:

$$\Delta u_{PSCALED} = m_K(p^2_{k-i/2} - p^2_{k+1/2})/2gp_0 \quad (2.4.1)$$

where again m_K is the mass mixing ratio and P_0 the standard pressure 101325 Pa, but now both have temperature scaling, of the form:

$$\exp\,(T_N(a+bP+cP^2) + T_N^2(d+eP+fP^2)) \quad (2.4.2)$$

where $P = 5 + \log(\Delta u_{PSCALED})/\log(\sqrt{10}$ $(\Delta u_{PSCALED}\,\mathrm{in\ gcm^{-2}})$ with the constraint $0 \preceq P \preceq 6$, the a-f are band-dependent constants given in Table 5.1 and T_N is the actual temperature less 250 K.

The gaseous transmissivities are then found from the total scaled pathlength u using Padé approximants:

$$Tr = \frac{\text{Padé}_1 + \text{Padé}_2\sqrt{u}}{\text{Padé}_1 + \text{Padé}_3\sqrt{u} + u} \quad (2.4.3)$$

with the values of Padé given in Table 5.2.

All the total pathlengths u used in this version of the LW contain a diffusivity factor 1.66 to allow for the angular integration: i.e. each u is 1.66 times the sum of the Δu across all the layers between the two layer boundaries that the transmissivity applies to.

For ozone two pathlengths are calculated, one with pressure weighting as for the other line absorption terms and one without (i.e. (2.3.1) with $\alpha = 0$ and $D = 0$). Both carry a simpler form of temperature scaling:

$$\exp\,(T_N O_1 + T_N^2 O_2) \quad (2.4.4)$$

where O_1 and O_2 equal $-0.326\times10^{-3}K^{-1}$ and $-1.02\times10^{-6}K^{-2}$ for the pathlength without pressure-scaling and $2.74\times10^{-3}K^{-1}$ and $-10.7\times10^{-6}K^{-2}$ for the one with.

The transmissivity of the ozone in the one band it affects is then calculated from the Malkmus expression (derived from a simple model of how spectral lines may overlap):

$$Tr = \exp\left\{-\bar{p}[\sqrt{(}1+O_4 u/\bar{p}) - 1]\right\} \quad (2.4.5)$$

where $\bar{p}$ is a weighted mean pressure for the total pathlength equal to the total pathlength with pressure scaling divided by the one without, and u is the unscaled pathlength. (2.4.5) is applied twice and the ozone transmissivity averaged over the band is an average, with 0.7554 weighting given to one with $O_4 = 4460\,\mathrm{Pa\,cm^2g^{-1}}$ and 0.2446 weighting to one with $O_4 = 200\,\mathrm{Pa\,cm^2g^{-1}}$.

The pathlengths for the foreign and self broadened water vapour continuum terms are simply the pressure-scaled water vapour pathlengths $\Delta u_{PSCALED}$ multiplied by the relevant fraction of the mass of the layer, i.e. *s* for the self and (1-*s*) for the foreign, where:

$$s = \frac{(1+\epsilon)q}{(1+\epsilon q)} \quad (2.4.6)$$

and again the self-broadened has temperature scaling, of the form:

$$\exp\{6.08(T_0/T - 1)\} \quad (2.4.7)$$

with $T_0 = 296\ K$.

The total pathlengths u are then used to find transmissivities in the simple exponential form:

$$Tr = \exp(-k_1 u_f - k_2 u_s) \quad (2.4.8)$$

where $k_1 = .224\ cm^2 g^{-1}$ and $k_2 = .024\ cm^2 g^{-1}$ in band 2, and in bands 3-5, $k_2 = 500\ k_1$, with k_1 equal to $.0125\ cm^2 g^{-1}$, $.01\ cm^2 g^{-1}$ and $.16\ cm^2 g^{-1}$, respectively.

Again, random overlap is assumed for different gases in the same band.

Gaseous Absorption - Version 1C

For an introduction to some of the basic ideas about gaseous absorption, the reader is directed to the first 3 paragraphs of the section 'Gaseous Absorption - Standard Code'.

The 1C code calculates scaled pathlengths for all gases (except CFCs, for which scaling is not required) and then uses lookup tables derived from the GENLN2 Code (Edwards 1992) to obtain the corresponding transmissivities. The tables are given in Appendix 1. For the two parts of the water vapour continuum, 'broadening' terms are included in the calculation. Some Doppler broadening is included in the tabulated transmissivity values but these are valid at reference temperatures and pressures inappropriate for the regime in which Doppler broadening dominates so extra terms are included in the calculations.

Mixing ratios and temperatures are assumed constant within model layers (as in longwave versions 1A and 1B). Gases are assumed to be randomly overlapped within bands.

Line Spectra (except CFCs):

The hydrostatic equation relates the height of a vertical air column of unit cross-sectional area (dz) to the change in pressure across it (dp), the density of air in it (r) and the acceleration due to gravity(g):

$$dp = -g\ r\ dz \quad (2.5.1)$$

The pathlength of a gas is the mass per unit area of that gas along a certain path, so in this case the pathlength of the air (du) may be written as

$$du = r\ dz \quad (2.5.2)$$

hence:

$$du = -\ dp / g \quad (2.5.3)$$

and for a gas (G) with mixing ratio m:

$$du_G = -\ m\ dp / g \quad (2.5.4)$$

Gaseous absorption varies considerably with temperature and pressure for those gases not in the weak limit. In the 1C code the pathlength is multiplied by simple scaling terms to account for this. The scaled pathlength for the gas (du_G') is given by:

$$du_G' = du\ (P/P_0)^a\ (T/T_0)^b \qquad (2.5.5)$$

where P_0 and T_0 are the reference temperature and pressure at which transmissivities have been calculated.

This must then be integrated over a model layer. Combining equations (2.5.4) and (2.5.5) and integrating over P gives:

$$u_G' = \frac{m\ (P_T^{a+1} - P_B^{a+1})\ T^b}{g\ P_0^a\ (a+1)\ T_0^B} \qquad (2.5.6)$$

where P_T and P_B are the pressure at the top and bottom of the layer, respectively. Integration should also be carried out over zenith angle to account for paths that are not vertical, but a good simplifying approximation is to multiply pathlength by a diffusivity factor (D) which has the value 1.66 in the strong line limit (Elsasser 1943).

Doppler broadening is incorporated by adding a small correction (d) to the pressure terms. Thus, for the path of a gas across a layer:

$$u_G' = \frac{D\ m\ (\ (P_T+d)^{a+1} - (P_B+d)^{a+1}\ )\ T^b}{g\ P_0^a\ (a+1)\ T_0^b} \qquad (2.5.7)$$

This equation is used for the H_2O line spectrum, CO_2, O_3, N_2O and CH_4. The Doppler terms were obtained empirically by comparison of heating rates from this code with those from high resolution radiation codes (see table 5.5). The scaling terms were obtained by performing a fit of transmissivities at different pressures and temperatures to those at the reference temperatures and pressures of the lookup table. This was achieved using an ESFT fitting code written by John Edwards (Edwards 1993). There are Doppler terms coded for each gas, and scaling terms for each band of each gas. The values of these are listed in Tables 5.3 and 5.4.

For any band of any gas the scaling may be switched off (by modifying the array SCALE in LWPTSC). This results in faster execution time but much more inaccurate values of transmissivity.

In this case pathlength is calculated using a much simpler expression obtained from integrating equation (2.5.4) and including the diffusivity factor :

$$u_G = D\ m\ (P_T - P_B)\ /\ g \qquad (2.5.8)$$

Continua:

The treatment of the water vapour continuum is slightly more complex than that given above. The continuum may be thought of as being composed of the far wings of broadened lines. In the troposphere the primary mechanism for broadening is collisions between molecules of the same species (in self broadening) and different species (in foreign broadening). The magnitude of the broadening depends on the density of the broadening species.

In the 1C code this is parametrized as follows, from equations (2.5.4) and (2.5.5) and including the diffusivity term

$$du_G = (P/P_0)^a\ (T/T_0)^b\ D\ m\ r_B\ dP\ /\ g \qquad (2.5.9)$$

where r_B is the density of the broadening species.

For the self-broadened continuum, the broadening density (r_S) is given by:

$$r_S = q\ P\ /\ R\ T \qquad (2.5.10)$$

where q is specific humidity, R is the molar gas constant (8.314 $JK^{-1}mol^{-1}$) and P and T are the pressure and temperature of the layer. Combining this with (2.5.9) and integrating gives the scaled pathlength :

$$U_s' = \frac{D\ q^2\ (P_T^{a+2} - P_B^{a+2})\ T^{b-1}}{g\ T_0^b\ P_0^a\ (a+2)} \qquad (2.5.11)$$

Similarly, for the foreign broadened continuum:

$$U_F' = \frac{D\,q(1-q)\,(P_T^{a+2} - P_B^{a+2})\,T^{b-1}}{g\,T_0^{b}\,P_0^{a}\,(a+2)} \qquad (2.5.12)$$

As with the line spectra, scaling may be switched off in any band for either continuum. In this case, the equations used are:

$$U_s' = \frac{D\,q^2\,(P_T^2 - P_B^2)}{2\,g\,R\,T} \qquad (2.5.13)$$

and

$$U_F' = \frac{D\,q(1-q)\,(P_T^2 - P_B^2)}{2\,g\,R\,T} \qquad (2.5.14)$$

Reference temperatures and pressures and scaling factors are given in tables 5.3 and 5.4. They have been derived in the same way as those for the line spectra.

CFCs:

CFCs are assumed to be in the weak limit, i.e. their transmissivities are a simple exponential function of pathlength. No scaling is required. The diffusivity factor is 2.0 (Elsasser 1943).
Thus the transmissivities are given by:

$$tr = \exp(-m\,D\,s/dv) \qquad (2.5.15)$$

where tr is the transmissivity, m the amount of absorber, D the diffusivity factor, S the source strength and dv the width of the band. The values of s/dv are obtained from measurements by Varanasi and Ko 1977 . Note that the values are quoted in $atm^{-1}cm^{-2}$, so conversion factors are included. In terms of model variables, the transmissivity is:

$$tr = \exp\left(\frac{-2\,dP\,m}{g}\;\frac{M_a}{0.01\,r_a\,M_g}\;\frac{s}{dv}\right) \qquad (2.5.16)$$

where dP is the pressure difference across the layer, m the mass mixing ratio, M_a the molecular weight of air, s the integrated source strength in $atm^{-1}cm^{-1}$, g the acceleration due to gravity, r_a the density of air at standard temperature and pressure, M_g the molecular weight of the gas and dv the width of the band in inverse centimetres. The first of the three terms in equation (2.5.16) is calculated by the longwave code, the second and third are pre-calculated and combined as constants. The values of these are listed in table 5.6.

Clouds - physical principles

The effects of clouds on longwave radiation are as important as their effects on sunlight. They reduce the longwave flux to space by blocking the surface flux and emitting at a lower temperature. Similarly they increase the downward surface flux by radiating at a higher temperature than the equivalent black-body temperature of the radiation from clear air. Thus their effects in the longwave tend to warm both the planet and the surface. The direct radiative effect on the atmosphere may be a heating or a cooling.

The effect of a typical cloud configuration on the infrared fluxes is shown in Fig 2. As remarked in the Introduction, clouds are assumed to occupy whole layers. They are also assumed to emit at the temperatures of the layer boundaries where their base and top are, i.e. to be ‘active’ with respect to thermal radiation only near their edges. In fact, unless a cloud is optically dense, the radiation it emits will come from various depths. The errors thus introduced may be considered to be subsumed in "tuning", and the emissivities used can be considered to be defined as bulk quantities for use in this way. They are calculated from the cloud water path:

$$\epsilon = 1 - \exp(-k.CWP) \qquad (2.6.1)$$

where k is $130\,m^2\,kg^{-1}$ for liquid water and $65\,m^2\,kg^{-1}$ for ice cloud. (The radiation code partitions cloud condensed water into liquid water and ice as a function of temperature as in the precipitation formulation, not as in the latent heat calculations. For mixed-phase cloud a weighted average of k is used. For convective cloud the temperature used is that of the centre of the highest layer through which the cloud extends.) The former seems fairly well based on both observational and modelling work (see, e.g. Table 3 of Stephens, 1984), but the latter is derived by tuning - such a form is not really valid for ice cloud, where the particles are so large that their radiative effectiveness depends on their total surface area as well as volume or mass. The clouds block radiation from beyond and generate source terms at the layer boundaries where their tops and bottoms are, just as the surface does (Fig 2), but rather than the whole grid-box they affect an equivalent black-body fraction of it given by multiplying the cloud area and emissivity. Cloud top and bottom temperatures are obtained by vertical interpolation from layer centres, done as described in UMDP S1.

Clouds - algorithmic details

If the code performed the calculations for each combination of overlaps separately, the total number of computations would be proportional to 2^{NCLDS}, where NCLDS is the total number of layers where cloud is permitted. This would be unacceptable, but it is easy to design more efficient algorithms. Although there are in principle 2^{NCLDS} types of overlap, when a particular pair of layers is being considered there are at most only three types of contribution to the flux at one layer boundary from the other: a clear-sky term, a "cloud" term (from a cloud top at the lower layer boundary or a cloud base at the upper), and nothing (where a cloud extends through the layer boundary, or the view of the source layer is blocked by an intervening cloud). The algorithm obviously must depend on the overlap assumption used. For random overlap it is based on the use of a mean source function for the parts of the grid-box which can contribute (i.e. do not have a cloud crossing the layer boundary), and of the fraction of the grid-box where each of the two layer boundaries can see the other. The former is dependent only on the source layer boundary and so can be pre-calculated, while the latter is calculated looping away from one layer through various values of the other.

Though the current code is set up for the sort of layer and convective cloud combination described in the introduction, the code implementing both algorithms is flexible and only one "interfacing" routine need be changed to allow any sort of clouds of any thicknesses.

CALCULATION OF INCOMING INSOLATION

Figure 3 illustrates the earth's orbit and shows several quantities discussed below. A more detailed discussion of positional astronomy may be found in Chapters II, V and VI of Smart (1944), for example. Let time t be measured from the beginning of the calendar year and perihelion (the earth's closest approach to the sun) occur at time τ . The mean anomaly M is defined:

$$M = \frac{2\pi\ (t - \tau\ )}{T_Y} \quad (3.1.1)$$

where T_Y is the length of the year. The true anomaly v, the angular distance of the earth round its orbit from perihelion, can be calculated from M for a Keplerian orbit, as an expansion called the equation of the centre. We use the third-order approximation (Smart, pp119-120):

$$v = M + (2e - e^3/4) \sin M + \frac{5}{4} e^2 \sin 2M + \frac{13}{12} e^3 \sin 3M \quad (3.1.2)$$

where e is the eccentricity of the earth's orbit (a geometric quantity which quantifies how non-circular an ellipse is). The normally directed incoming solar radiation at the top of the atmosphere is given by the inverse-square law:

$$S(t) = S_0 \frac{r_0^2}{r(t)^2} \quad (3.1.3)$$

where S_0 is the "solar constant", the incoming solar radiation on unit area exposed normally at the mean sun-earth distance r_0 , and r(t) is the actual sun-earth distance. From Kepler's Second Law:

$$S(t) = S_0 \left\{ \frac{(1 + e^2/2)}{(1 - e^2)} (1 + e \cos v) \right\}^2 \quad (3.1.4)$$

One other global quantity has to be found, the solar declination δ , the latitude where the sun is vertically overhead. This depends on the earth's rotation, which defines latitude, as well as its position in its orbit:

$$\sin\delta = \sin\epsilon\ \sin\theta \quad (3.1.5)$$

where ϵ is the obliquity of the ecliptic (the angle between the axes of the earth's rotation and of its orbit) and θ is the angular distance the earth has travelled round its orbit since the vernal equinox, the point in the earth's orbit (reached around 21st March) where δ is zero (the sun is overhead at the equator) and increasing (moving towards Northern summer). This is obviously equal to:
where γ is the angle from perihelion to the vernal equinox (the quantity $\pi - \gamma$ is called the longitude

$$\sin\delta = \sin\epsilon\ \sin(v - \gamma\ ) \quad (3.1.6)$$

of perihelion).

The above calculations are carried out with t for 1200 GMT on the current day. This conveniently makes daily mean incoming sunlight a function of latitude only, and introduces negligible error.

Calculating the incoming radiation perpendicular to the local vertical at some point requires the solar zenith angle ς there, i.e. the angle between the sun and the local vertical. This is also needed for the calculation of the gaseous absorption of sunlight (4.4.1), and of cloud optical properties (4.8.1, 4.8.7-9 & 4.8.19). At latitude (north) ϕ , longitude (east) λ and time t (now measured from Greenwich solar midnight), geometry gives:

$$\cos\varsigma = \cos\phi\ \cos\delta\ \cos\Omega + \sin\phi\ \sin\delta \quad (3.2.1)$$

where

$$\Omega = \lambda + \pi\ (2t/T_D - 1) \quad (3.2.2)$$

is the hour angle of the sun (the angle through which the earth has rotated since local solar noon) and T is the length of the day (e.g. Paltridge and Platt, 1976). We identify Greenwich solar time with GMT, in astronomical language assuming that the "equation of time" is zero. In reality the varying angular velocity of the earth in its orbit causes variation in the length of the solar day (the time for the sun to return to the same apparent position in the sky, consisting of one complete rotation of the earth plus as much extra rotation as is needed to catch up with the change in the earth/sun angle as it goes round the sun). These are of order 10 seconds and accumulate to give differences between solar and mean time of up to 17 minutes.

Integrating (3.2.1) gives the mean cos ς between hour angles Ω_1 and Ω_2:

$$\overline{\cos\varsigma} = \frac{\cos\varphi\ \cos\delta\ (\sin\Omega_2 - \sin\Omega_1) + \sin\varphi\ \sin\delta\ (\Omega_2 - \Omega_1)}{\Omega_2 - \Omega_1}$$

(3.2.3)

This must be calculated only for the part of the period (if any) when cos ς is positive, i.e. the sun is up. Where $\tan\varphi\ \tan\delta > 1$ there is perpetual day and where $\tan\varphi\ \tan\delta < -1$ perpetual night. At other latitudes the hour angles for sunset and sunrise are:

Thus, for example, at a point where the sun sets but does not rise within the period, cos ς is

$$\Omega_S = \cos^{-1}(-\tan\varphi\ \tan\delta) \quad (3.2.4)$$

$$\Omega_R = -\Omega_S \quad (3.2.5)$$

given by:

$$\overline{\cos\varsigma} = \frac{\cos\varphi\ \cos\delta\ (\sin\Omega_S - \sin\Omega_B)}{\Omega_S - \Omega_B} + \sin\varphi\ \sin\delta \quad (3.2.6)$$

where Ω_B is the hour angle for that point at the beginning of the period. Two separate periods of daylight need to be accounted for if the sun sets and then rises during a period. The mean $\overline{\cos\varsigma}$ over the whole period is then this value times the fraction of the period that the sun is up at that point.

The incoming solar radiation at any location is then S(t) times the mean $\overline{\cos\varsigma}$ for the whole period. The latter is calculated for every "physics" timestep and used to scale the atmospheric heating rates and surface SW flux where this is used in the "atmospheric" component of the model, i.e. over land and sea-ice. For the full solar calculations, typically performed only every few hours, $\overline{\cos\varsigma}$ meaned over all the sunlit part of the entire SW timestep is used to calculate gaseous absorption and cloud optical properties. (If this is less than 10^{-4}, it is set to 10^{-4} to avoid operand range problems on the CRAY, but to conserve energy the true value is always used to scale the heating rates and surface flux, unless it is less than 10^{-10}, when it is assumed to be an artifact of rounding error and set to zero.)

For organizational convenience, when run in climate mode the Unified Model uses a 360-day year, with each month 30 days in length. The distortions of the seasonal cycle of insolation thus introduced are minimised by altering the date of perihelion:

where the constant 0.71 is derived from the lengths of the months in the two calendars (program held

$$\tau_{360} = \tau_{365\frac{1}{4}} \frac{360}{365\frac{1}{4}} + 0.71 \quad (3.3.1)$$

by UM librarian). This changes the current mean value of τ from 2.5 days to 3.2 days. The actual value varies from year to year (more because of the effects of the moon and the other planets on the earth's orbit than because of the variation in the length of the calendar year) but in the model the only variation is that in forecast mode leap years have a slightly different distribution of insolation from other years. (Leap years are assumed to occur every fourth year, which is valid from 1901 to 2099.)

Otherwise the model normally uses the actual current mean values of the orbital and rotational parameters: $e = 0.0167$, $\sin \epsilon = .397789$ and $\gamma = 1.352631$. For paleoclimatic experiments, values of $\tau_{365\frac{1}{4}}$, e, $\sin \epsilon$ and γ can be calculated (e.g. Berger, 1978).

S_0 is set to 1365 Wm^{-2} (Lee et al 1986).

Note that in version 3.4 and before, the time passed to the solar calculations is one timestep later than it should be, unless a corrective modset is used.

TRUE SURFACE ALBEDO SPECIFICATION

Changes in surface albedo as the cover of sea-ice and snow change can provide an important feedback on climate change, and can also be significant on the forecast timescale. Surface albedo variations due to changes of vegetation may also affect the circulation, contributing to the formation of the permanent deserts and providing a positive feedback on drought. The unified model must therefore account for the dependence of surface albedo on these factors.

Although the standard form of the shortwave scheme uses four bands, and part of the motivation for this was to use band-dependent surface albedos and so calculate cloud/surface interactions more accurately, this has not yet been introduced. The dependence on solar zenith angle of the surface albedo for the direct beam (i.e. sunlight which has not been made diffuse by passing through clouds) is included only for ice-free sea at present. Note also that the true, or "single-interaction" surface albedos discussed in this section are modified to give "effective" surface albedos as discussed below (4.7.1). The formulations below can give absurd answers if the sea-ice cover or snow depth is inconsistent with the surface temperature. This will not happen in normal use of the model, but is possible in initial conditions which have not yet been through the model's surface scheme, or if the updating of snow depth has been removed for a run without the seasonal cycle.

Open sea

The true surface albedo for ice-free sea α_{TSEA} is set to 0.06 for diffuse light, and for direct light to the form of Briegleb and Ramanathan (1982):

$$\alpha_{TSEA} = \frac{0.05}{(1.1 \cos\varsigma^{1.4} + 0.15)}$$

The direct and diffuse values are equal when $\cos\varsigma = (41/66)^{5/7}$, when ς very nearly equals $\pi/4$.

Sea-ice

The albedo of sea-ice in reality depends on the thickness, state and age of the ice itself and of any snow cover, and on the solar zenith angle. Observations are for a particular surface state at a single point, while a large-scale model must parametrize small-scale effects in terms of the large-scale means of the quantities available, such as surface temperature. As the temperature rises, any snow ages faster (see also next sub-section), and more of the surface will be covered by melt-ponds. The simple form used to represent these effects is to increase the true surface albedo linearly from a minimum value α_M at melting point T_M to a "cold-ice" value α_C at and below $T_M - \Delta T$:

$$\alpha_{TICE} = \begin{cases} \alpha_C & T_* \le T_M - \Delta T \\ \alpha_M + (\alpha_C - \alpha_M)(T_M - T_*)/\Delta T & T_M - \Delta T \le T_* \le T_M \end{cases} \qquad (3.5.1)$$

T_M is 273.15 K (UMDP 5) but the other constants cannot be precisely determined from observations, so that values must be derived from tuning. This may have a significant effect on climate sensitivity, especially locally, but the values are within the range implied by observations (e.g. Robinson et al, 1986). α_M, α_C and ΔT are set by the user. The values which are now standard for climate use (and are also suitable for forecast use, where there is little sensitivity to them) are 0.6, 0.85 and 5 K respectively, so that sea-ice surface albedo reduces from 0.85 at and below 268.15K to 0.6 at 273.15.

Land

As described in UMDP 70, the albedo of snow-free land is specified as a function of climatological vegetation, land use and soil type, modified where necessary to remove unreasonable values.

Snow lying on the ground strongly modifies the surface albedo (as well as having the non-radiative effects described in UMDP 24, 25). This effect depends on vegetation, and on the depth, density and age of the snow. Robinson and Kukla (1984, 1985) report that albedo generally increases with snow depth, though bare patches tend to form during melting, giving smaller albedos than for the same average depth during accumulation, when the cover tends to be more even. Since there is no well-defined relationship the simple form:

$$\alpha_T = \alpha_0 + (\alpha_D - \alpha_0)(1 - e^{-aS}) \qquad (3.6.1)$$

is used (Hansen et al, 1983), where S is the snow amount, α_0 is the snow-free albedo, and α_D is the deep-snow albedo for the temperature and vegetation type. a is set to $0.2\,m^2kg^{-1}$ (Warrilow et al 1990), consistent with tuning experiments and the observations of Robinson and Kukla (1985).

The derivation of maximum deep-snow albedos for each vegetation type, α_D, following Buckley and Warrilow (1988), is documented in UMDP 70. These values are appropriate for fairly fresh snow. Ageing is fastest as the snow begins to melt - as well as the patchiness increasing, impurities become more concentrated near the surface, and the partial melting and refreezing increases the grain size (compare the effect of changing r_e on cloud optical depth, 4.8.23). A simple linear temperature dependence is used (Warrilow et al 1990), as for sea-ice:

$$\alpha_D = \begin{cases} \alpha_S & T_* \le T_M - \Delta T \\ \alpha_S + 0.3(\alpha_0 - \alpha_S)(T_* - T_M + \Delta T)/\Delta T & T_M - \Delta T \le T_* \le T_M \end{cases}$$

(3.6.2)

where DT is here taken as 2 K, so that α_D reduces from α_S at and below $T_M - 2K$ to $(0.7\alpha_S + 0.3\alpha_0)$ at T_M.

INTERACTION OF SHORTWAVE RADIATION WITH THE ATMOSPHERE AND EARTH SURFACE

Rayleigh scattering

This is the scattering of electromagnetic radiation by objects of size comparable to its wavelength: in this context the scattering of ultraviolet wavelengths by molecules. It is represented very simply by reflecting 3% of incoming insolation (all in the shortest wavelength band), before any interaction with the atmosphere. Thus it contributes about a tenth of the planetary albedo in the global mean, and around a third of it over cloud-free sea.

Gaseous absorption and spectral bands

As for the longwave, gaseous absorption of sunlight is very simple for the monochromatic case - the intensity just decreases as an exponential function of the scaled pathlength of the absorber, the constant inside the exponential being called the absorption coefficient. Thus in the monochromatic case the fractional absorption by a given amount of gas is independent of the past history of the beam. Again, spectral averaging converts this to an integral over exponential functions with different absorption coefficients, but now the weighting depends on the absorption which has already taken place in the band concerned. Thus the absorption depends on the total previous absorber pathlength as well as the amount of absorber locally. Adequate accuracy can nevertheless be obtained using a suitable set of spectral bands, and calculating the total pathlength of each absorber since the light concerned entered the atmosphere. (See, e.g. Slingo and Schrecker, 1982.) As in the longwave, rather than approximate gaseous effects as the sum of exponentials, look-up tables are used, and again it is the transmissivity that is calculated.

As for the longwave, the gases included are H_2O, CO_2 & O_3, and the look-up tables use linear interpolation in the logarithm of the total pathlength. Where there is more than one gas absorbing in a band (only actually the case for CO_2 and H_2O) the transmissivities are again multiplied, assuming their absorption to be randomly overlapped. The absorption data is of course dependent on the spectral bands used. The latter can in principle be set arbitrarily, but the look-up tables for absorption, *a* to *f* in (4.8.23)-(4.8.25), and the fraction of the solar constant in each band, must be altered to match. Tables 3 and 4 give the values for the UM's standard set of 4 bands recommended by Slingo (1989), whose bounds are $0.25\,\mu m$, $0.69\,\mu m$, $1.19\,\mu m$, $2.38\,\mu m$ and $4\,\mu m$. This set of bands were found to deal satisfactorily with cloud and gaseous radiative properties (and were also felt suitable to deal with the spectral variation of surface albedo, Slingo, pers. comm.). Note that only the first band is visible to the human eye: about half the sun's output is in the near infra-red, but it will all be referred to as sunlight here.

Physical effects on the gaseous pathlengths

As in the longwave, water vapour and carbon dioxide pathlengths are scaled with p^{α} (e.g. Houghton, 1977), assuming the mixing ratio constant through the layer. Thus the contribution to the vertical pathlength from layer k is:

$$\frac{m_k\left(p_{k-1/2}^{1+\alpha} - p_{k+1/2}^{1+\alpha}\right)}{(1+\alpha)\,g\,p_0^{\alpha}} \quad (4.3.1)$$

where m_k is the mass mixing ratio and p_0 is a standard pressure for that gas. For water vapour α is 0.9, as in the longwave, but for carbon dioxide it is 0.7. p_0 is 50 kPa and 25 kPa respectively. As in the longwave, if the specific humidity is zero, the scaled water vapour pathlength for the layer is set to $10^{-10}\mathrm{kgm}^{-2}$. For ozone no scaling is applied, which means no assumptions about the distribution of the gas within the layer are needed, and the contribution is just:

$$m_k(p_{k-1/2} - p_{k+1/2})/g \quad (4.3.2)$$

Geometric effects on the gaseous pathlengths

The above calculations give the contribution to the pathlength from crossing a model layer vertically. For light at an oblique angle, the pathlength must be increased. If the atmosphere were plane parallel the magnification factor for the direct beam would be $\sec\varsigma$ (where ς is the solar zenith angle, i.e. the angle incoming sunlight makes with the vertical). Taking curvature into account Houghton (1963) derived:

$$(1+\epsilon)(2\epsilon+\cos^2\varsigma)^{-1/2} \quad (4.4.1)$$

where ϵ = h/a, h height above the earth's surface (or half the "equivalent depth" of the atmosphere) and a the earth's radius.

The UM uses this with ϵ = 0.004 (h $\approx$ 25000 m) for all levels, as a typical height for ozone absorption, for which this effect is most important.

Sunlight which has become diffuse by reflection or by passing through a cloud contains light at all angles to the vertical. Detailed radiation models can consider the angular dependence explicitly, but this is not practical or necessary at this level of parametrization. Instead, it is usual to multiply the pathlengths for a vertical beam by a "diffusivity factor". The value used here is 1.66 (Elsasser, 1942).

Cloud geometry

The basic assumptions about cloud geometry and the type of cloud distribution permitted have been described in the Introduction. However, some sort of optical properties must be specified for each layer of any cloud that extends through more than one layer. Currently, as in previous models, convective cloud may do this, but all the absorption of sunlight occurs in its top layer, with the other layers acting only as a "light pipe" passing the light down around any other clouds that otherwise would have affected it.

As described above, random overlap in the horizontal is assumed for clouds not overlapping in the vertical. Where two layer clouds both overlap the convective cloud in the vertical, this is applied in the space outside the convective cloud only. These statements define the geometry completely. Some examples may help. If there were two layer clouds of ¼ cover and ½ cover and no convective cloud, they would overlap in ⅛ of the grid-box and occupy another ⅛ and ⅜ respectively unoverlapped, with ⅜ clear-sky (Fig 4(a)). If there were also a convective cloud of cover ⅓ overlapping only the *first* cloud in the vertical, the second cloud would overlap the first cloud in ⅛ still and the convective cloud in 1/6, with ⅛, 5/24 and 1/6 of unoverlapped first, second and convective clouds respectively, and 5/24 clear-sky (Fig 4(b)). However, if the convective cloud overlapped both in the vertical, they would overlap each other randomly in the ⅔ outside it, with the overlap coming to 3/16, the unoverlapped first and second cloud covering 1/16 and 5/16 respectively, and 5/48 clear-sky (Fig 4(c)).

More generally, the overlap of layer clouds may always be calculated as a simple random overlap if the true layer cloud fraction LCF_{TRUE} is replaced by the "fraction with overlap allowed for" LCF_{WO} defined by:

$$LCF_{WO} = \begin{cases} LCF_{TRUE}(1-CCF) & \text{if this layer overlaps the convective cloud in the vertical} \\ LCF_{TRUE} & \text{otherwise} \end{cases} \quad (4.5.1)$$

As noted above, LCF_{WO} is in fact the input to the scheme: LCF_{TRUE} is never needed.

Random cloud overlap with cloud in every layer can give unrealistically large total cloud amounts. The SW scheme does not at present allow any other overlap assumption, but to mitigate this problem it is possible to have cloud amounts restricted, so that there are only 3 layer clouds, "high", "medium" and "low". The boundaries between these are set at the model η layer boundaries closest to 0.37 and 0.79, the corresponding values for the old climate model. Within each of these three ranges, only the cloud with the greatest fractional cover is used (if there is a tie, the lower is chosen), but the cloud water assigned to it is the total cloud water from all the clouds in the range. Convective cloud is unaffected.

Beam construction

The description of the gaseous absorption and cloud optical properties and overlaps above is enough to define fully what happens to the unreflected insolation. As explained above, the fractional absorption of a beam at some level depends on the total pathlength for each gas that the beam has passed through since entering the atmosphere, which in turn depends on when (if at all) the beam became diffuse. This implies one must separate account of the strength of the part of the incoming sunlight that became diffuse at each level, i.e. we must divide up the sunlight according to the first cloud it was scattered by, but need not do any more than this. Cloud processes are assumed to be grey within each band (see below), so that for each beam we can take the strength as the fraction of the original solar input that would be produced by cloud processes alone, and the fractional reduction that the gaseous absorption for the appropriate pathlengths would produce alone, and just multiply them to get the total beam strength as a fraction of the original solar input.

The treatment of reflected light does require some further assumptions. In principle light can be re-reflected infinitely many times, requiring an infinite set of calculations of pathlengths and gaseous absorption. Obviously some simplifying assumptions must be made.

The current code continues to assume (as in Slingo, 1985) that the beams reflected from clouds pass directly to space without any further interactions with cloud, even under a complete overcast, but full gaseous absorption calculations are carried out.

Combining the downward diffuse beams

With the above logic every cloud generates a new diffuse beam which can be reflected from every cloud below through every layer up to space again. The pathlengths for the different downward beams in a given layer are similar, being the sum of the scaled pathlengths for each layer above, each multiplied either by the direct beam magnification factor or the diffusivity factor. Unless the sun is very low in the sky - when there is very little sunlight anyway - the logarithms of these pathlengths will not differ very much, especially considering the grossness of the cloud overlap assumptions. The calculation of gaseous transmissivities accounts for much of the expense of the scheme, so it is valuable to be able to calculate only one gaseous transmissivity for all the diffuse downward beams at a particular level. These beams can be thought of as being combined into one beam, with the total cloud factor (i.e. the fraction of the original incident beam which would be in this category considering only cloud processes, not gaseous absorption) for the diffuse light unaltered. Similarly, and more valuably, we can combine the upward beams originating from reflection at a particular layer boundary of light that was already diffuse. Again, we do not alter the total cloud factor, but use a single gaseous transmissivity for all this light. The pathlengths used are the average for the various beams that have been combined, weighted by the cloud factors for each beam summed over the bands in which water vapour absorbs. (Most ozone and carbon dioxide absorption of sunlight is above cloud top.)

Use of this option leaves the results unaltered at points with no cloud, one cloud or with total cover by the highest non-zero cloud, but reduces the number of transmissivities calculated from:

$$L+(C+1)(6L+C-C+3LC)$$

to:

$$2L+C+(2L-C)C$$

where L is the total number of layers and C the number of layers which may contain cloud. The total time taken by the shortwave scheme on the CRAY reduces similarly.

Code without the beams combined is available via the UI as version 1A of Section 1; code with them combined as version 1B (cloud allowed in all layers) or version 2 (layer cloud restricted to 3 layers, as described above).

Modifying the surface albedo to allow for multiple reflections

The increased surface absorption due to multiple reflections between cloud and surface can be important over highly reflective ice and snow surfaces (e.g. Schneider and Dickinson, 1976). Ignoring gaseous absorption allows one to calculate the net absorption from an infinite series of reflections and find the "effective albedo" that would give the same absorption in a single interaction:

$$\alpha_{\mathrm{Eff}} = \alpha_{\mathrm{T}} \frac{(1-\alpha_{\mathrm{C1}})}{(1-\alpha^{*}_{\mathrm{T}}\alpha_{\mathrm{C1}})} \quad (4.7.1)$$

where α_{Eff} is the effective surface albedo, dependent on band and whether the light is direct or diffuse, α_{T} the corresponding "true" or single-interaction surface albedo, α^{*}_{T} the α_{T} for diffuse light, and α_{C1} the mean albedo of the sky as seen from the surface:

$$\alpha_{\mathrm{C1}} = \sum_{\mathrm{clouds}}^{\mathrm{all}} \mathrm{CF}_{\mathrm{VS}} a_5 \quad (4.7.2)$$

where $\mathrm{CF}_{\mathrm{VS}}$ is the fractional cover of each cloud visible from the surface and α_5 is the diffuse-diffuse cloud reflectivity defined below.

The light initially incident on the surface is treated as being reflected from the surface using this albedo and then passing to space without interaction with clouds, but with full gaseous absorption calculations.

Note that:

1. Any such correction is approximate. The way this one treats gaseous absorption will tend to underestimate it, and so slightly overestimate the surface absorption. The way it ignores light passing through a cloud to be reflected back from a higher cloud (as when there is mist below an optically thick cloud) will tend to underestimate surface absorption. Given the errors always present in the clouds input, this does not seem to be a problem.

2. It effectively assumes that the horizontal dimensions of clouds are small compared with layer thicknesses, which is logically inconsistent with the assumption elsewhere that the clouds are so extensive horizontally that edge effects can be neglected. (See also Schneider and Dickinson, 1976.)

Cloud optical properties

These are calculated as in Slingo (1989), which in turn is based on the work of Zdunkowski et al (1980) (hereafter ZWK80) and Slingo and Schrecker (1982). For each cloud its condensed water path (CWP) and the effective radius of its drop size distribution (r_e) must be input. The optical properties depend on whether the incident beam is direct or diffuse, and in the former case on ς, or its cosine, μ. All reflected light is diffuse, but both quadratures below formally imply that some of the incident direct beam is transmitted through clouds as direct. As well as light which has not been scattered at all, this corresponds to the forward peak of Mie scattering - some cloud-transmitted light is smeared-out but still concentrated in the original direction. However, in a scheme such as this it is more convenient to have the direct beam reduced to zero under complete overcast, so a_1 below is added in to a_2.

The light which is not transmitted or reflected must of course be absorbed by the layer. Both in the analytic calculations and in the programming of the scheme it is natural for absorption to be implied as a residual. We therefore calculate only 5 gross optical properties, which ZWK80 show can be expressed:

Direct-direct transmissivity	$a_1 = \exp(-H\tau / \mu)$	(4.8.1)
Direct-diffuse transmissivity	$a_2 = a_1\gamma_2 - a_4\gamma_2 - a_5 a_1 \gamma_1$	(4.8.2)
Direct-diffuse reflectivity	$a_3 = \gamma_1 - a_5\gamma_2 - a_4 a_1 \gamma_1$	(4.8.3)
Diffuse-diffuse transmissivity	$a_4 = E(1-M^2)/D_1$	(4.8.4)
Diffuse-diffuse reflectivity	$a_5 = M(1-E^2)/D_1$	(4.8.5)

where

$$D_1 = 1-E^2M^2 \qquad (4.8.6)$$

$$\gamma_1 = \{\mu(\alpha_1\alpha_3+\alpha_2\alpha_4)-H\alpha_3\}/D_2 \qquad (4.8.7)$$

$$\gamma_2 = \{\mu(\alpha_1\alpha_4+\alpha_2\alpha_3)-H\alpha_4\}/D_2 \qquad (4.8.8)$$

$$D_2 = \epsilon^2\mu^2-H^2 \qquad (4.8.9)$$

$$E = \exp(-\epsilon\tau) \qquad (4.8.10)$$

$$M = \alpha_2/(\alpha_1+\epsilon) \qquad (4.8.11)$$

$$H = (1-\tilde{\omega}f) \qquad (4.8.12)$$

$$\epsilon^2 = \alpha_1^2-\alpha_2^2 \qquad (4.8.13)$$

$$\alpha_1 = U_1(1-\tilde{\omega}(1-\beta_0)) \qquad (4.8.14)$$

$$\alpha_2 = U_2\tilde{\omega}\beta_0 \qquad (4.8.15)$$

$$\alpha_3 = (1-f)\tilde{\omega}\beta(\mu) \qquad (4.8.16)$$

$$\alpha_4 = (1-f)\tilde{\omega}(1-\beta(\mu)) \qquad (4.8.17)$$

(Note that the nomenclature used here is based on that of Slingo, 1989, where β and β_0 are interchanged from that of ZWK80.)

A quadrature is required, i.e. a way of defining the quantities β_0, $\beta(\mu)$, f, U_1 and U_2 in terms of the physical quantities μ, τ, $\tilde{\omega}$ and g. τ is the total extinction optical depth of the cloud, thus including absorption and all scattering, even that part accounted as going back into the input beam. $\tilde{\omega}$ is the single scatter albedo, the fraction of extinction to be scattered rather than absorbed in a single interaction. g is a measure of how much the scattering is concentrated in the forward direction: it is called the first moment of the phase function and can be defined as the strength of the first Fourier component of the normalized probability distribution of the angular distribution (relative to the origin of the light) of the scattering in a single interaction.

The standard quadrature is ZWK80's Practical Improved Flux Method (PIFM), namely:

$$\beta_0 = \tfrac{3}{8}(1-g) \qquad (4.8.18)$$

$$\beta(\mu) = \tfrac{1}{2}-\tfrac{3}{4}\mu g/(1+g) \qquad (4.8.19)$$

$$f = g^2 \qquad (4.8.20)$$

$$U_1 = 2 \qquad (4.8.21)$$

$$U_2 = 2 \qquad (4.8.22)$$

This is very similar to the more widely-used δ-Eddington (ZWK80) but cannot give negative transmissivities for highly absorbing materials as the δ-Eddington can.

τ, $\tilde{\omega}$ and g are calculated as in Eq 15-17 of Slingo and Schrecker (1982):

$$\tau = CWP\,(a+b/r_e) \qquad (4.8.23)$$

$$1-\tilde{\omega} = c+dr_e \qquad (4.8.24)$$

$$g = e+fr_e \qquad (4.8.25)$$

where a to f are band-dependent constants ultimately calculated from Mie theory and the measured complex refractive index of liquid water (Slingo and Schrecker, 1982; Slingo, 1989). Though we cannot derive r_e physically, using it makes the microphysical assumptions explicit in a way that the schemes of Stephens (1978, corrected by Stephens et al, 1984) and of Liou & Wittman (1979) do not, and allows examination of the sensitivity to it.

This scheme is theoretically well-based for liquid water cloud, and, as Slingo (1989) shows, agrees well with observations, at least in the absence of "anomalous absorption". (See, e.g. Roach & al, 1988, for a discussion of this.) For ice cloud there is no justification for using it apart from its having been tuned (through r_e and partly CWP), and it is hoped to replace it in the near future with something closer to our (very partial) understanding of the real physics.

As remarked above, all cloud-radiation interactions are treated as "grey" within each spectral band: i.e. they are assumed to affect the total strength of a beam in a specific band but not its detailed spectral composition, and so to have no effect on the fractional gaseous absorption. In reality of course there is spectral variation, correlated especially with the water vapour absorption, but the bands have been selected to minimise such errors, representing the important correlations between cloud and gaseous absorption by placing them in different bands.

Cloud Droplet Effective Radius

In the original configuration of the code, water droplets have a prescribed effective radius of 7µm, and ice particles have an effective radius of 30µm. Clouds are assumed to be purely water at temperatures warmer than 0°C and purely ice at temperatures colder than -15°C, with a smooth transition in between; for convective cloud, it is the layer-centre temperature of the highest layer into which the convection extends which is used. The fraction of cloud water which is liquid is calculated in the same fashion as in the precipitation scheme. The effective radius of particles in mixed-phase clouds is calculated as a weighted mean of 7 and 30µm, depending on how much of the cloud water is frozen.

There is also an option to calculate the effective radius of cloud water droplets interactively in the model (the effective radius of mixed phase clouds is calculated as above, as a weighted mean between this interactively calculated water droplet effective radius and the ice particle radius of 30µm, depending on temperature). This is based on the work of Bower & Choularton (1992) and Martin *et al.* (1994), and is only available when using the "3 cloud layers in the shortwave" option. For stratiform clouds, the effective radius r_e (m) is calculated from

$$r_e = (3L/4\pi\rho_w\kappa N_{tot})^{1/3}$$

where L is the cloud liquid water content (kg m^{-3}) and ρ_w is the density of water. The value of the dimensionless constant κ (the ratio of the cubes of the mean volume radius and the effective radius of the cloud droplet spectrum) depends on whether it is a land point (κ=0.67) or an ocean point (κ=0.80). N_{tot} is the number concentration (m^{-3}) of activated cloud droplets, which is currently prescribed as $6x10^8$ m^{-3} over land, and $1.5x10^8$ m^{-3} over ocean. The water content L which is input to the above is the total (water + ice) water content, the rationale being that the fraction of water which is liquid implies not how much of a homogeneous mixture of ice and water is unfrozen, but what areal fraction of a distribution of water substance of constant mass mixing ratio is unfrozen: if a cloud (of 100% cover for clarity) has a total condensed water mixing ratio of $0.2x10^{-3}$ kg/kg, and a liquid fraction of 10%, the assumption is not that the 90% of ice is uniformly distributed over the gridbox, and then intermingled with the 10% liquid water also uniformly distributed over the gridbox. This would imply a liquid mass mixing ratio of 0.1 x $0.2x10^{-3}$ kg/kg. What is intended is that the mixing ratio of water substance throughout the gridbox is $0.2x10^{-3}$ kg/kg, but that 90% of the area is ice, and 10% is water. Thus a sensible effective radius for the liquid fraction is calculated, and it is assigned its relative importance to the ice fraction in the weighting between it and the 30µm ice r_e.

Medium and high stratiform clouds use the above formula directly. For low clouds, an attempt is made to account for the observed distribution of water in stratocumulus clouds, whereby the cloud water content rises from zero at cloud base in a roughly linear manner to a maximum at cloud top. The water content presented to the shortwave code by the cloud scheme is assumed to be an average water content, representing the water content halfway between cloud base and cloud top (for a linear increase in water content). However, it is the water content at cloud top which is relevant for the cloud's optical properties, and so the water content used is twice the mean mid-point value.

For convective cloud, the droplet effective radius depends on the cloud depth Δz. This is approximated using

$$\Delta z = (RT/g) \ln(p_{BOT}/p_{TOP})$$

where T is the layer-centre temperature of the uppermost convective cloud layer, R is the specific gas constant for dry air, and p_{BOT} and p_{TOP} are the base and top pressures respectively of the convective cloud. Although this depth calculation is not very accurate, it is adequate for establishing whether the convection is shallow (<500m) or deep. For shallow clouds, the formula for r_e given above is used. For deep convection, the amount of entrainment present means that r_e is essentially constant with height, and is prescribed as 9.5µm over land, and 13.5µm over ocean.

As this code is part of the shortwave radiation, it is not called at night points. Neither is it called when there is no cloud present, and it is not meaningful to assign such points an r_e of zero. Consequently the diagnostics provided weight r_e by a factor based on cloud amount (this weight is also a diagnostic), which must be divided out to obtain r_e. The r_e diagnosed is for the liquid portion of the cloud only.

ALLOWING FOR LEADS

At sea-ice points, both ice and open water may be present in the grid-box (UMDP 24), and extra calculations are needed to account for this sub-grid-scale variation. In common with the rest of the leads code, it is assumed that atmospheric quantities are homogeneous even in the bottom model layer, and that it is only the surface itself that varies. The true surface albedo calculation and the surface parts of both the longwave and shortwave schemes proper are affected.

Sea-ice fraction A_{Ice} is used to recover T_{*Ice}, the average surface temperature of the sea-ice, from the grid-box-mean surface temperature, assuming that the leads are at T_{FS}, the freezing point of sea-water, as in the boundary-layer scheme (UMDP 24).

Then, in the longwave, the grid-box-mean upward surface longwave flux in each band is:

$$B_* = A_{Ice} B(T_{Ice}) + (1-A_{Ice})\, B(T_{FS}) \quad (0.1.1)$$

which is used to calculate the atmospheric heating rates, while the separate B are used to calculate separate surface net downward fluxes for each part of the grid-box, one for use in the atmospheric model's surface scheme, which deals with land and sea-ice surfaces (UMDP 24), and one in the ocean model.

In the surface albedo calculations, T_{Ice} is similarly recovered from A_{Ice}, and used in (3.5.1) to give true surface albedos for the ice fraction of the grid-box. These are then combined with those for the open sea fraction to give grid-box-mean true surface albedos:

$$\alpha_T = A_{Ice}\alpha_{TIce} + (1-A_{Ice})\, \alpha_{TSea} \quad (0.2.1)$$

These are used in (4.7.1) to give grid-box-mean effective albedos. Doing this, rather than applying (4.7.1) to the true surface albedos separately and combining the effective albedos in proportion to their area, is appropriate if the scale of the transition between leads and sea-ice is small compared to the separation of clouds from surface. This is obviously not realistic if the "leads" are really polynyas and not very good if there is low optically dense cloud. However, observations (e.g. Gardiner, 1987) imply that leads absorb sunlight which has been multiply reflected between clouds and surface, to give total net absorption considerably greater than there would be if the ice and water in the grid-box were well separated, and that this can be important in the overall energy budget.

The net surface shortwave flux must be calculated not only as a grid-box-mean but also appropriately split between the ice and the leads. Given that (4.7.1) applies equally to direct and diffuse albedos, one might expect it also to be valid for converting albedos that apply only to a fraction of the grid-box. Perhaps surprisingly, applying the same approximations as went into (4.7.1) actually gives a rather more complex formula:

$$\alpha_{EffSea} = \alpha_{TSea} - \frac{\alpha_T \alpha_{C1}(1-\alpha^*_{TSea})}{(1-\alpha^*_T \alpha_{C1})} \quad (0.3.1)$$

with notation as (4.7.1), with α^*_T the grid-box-mean surface albedo to diffuse light in the band concerned.

APPENDIX 1 LONGWAVE LOOK-UP TABLES

The look-up tables for gaseous transmissivity used in version 1A of the LW were constructed by applying the version of the Goody (1952) random band model described by Hunt and Mattingly (1976) to an AFGL data tape (Rothman 1981). The line strength s_i and line width α_i for each lines for each gas in each spectral interval were extracted and converted from values for 296 K to values at 20 K intervals from 180 to 320 K usingÿequations 4-7 of Hunt and Mattingly (1976). $\sum s_i$ and $\sum\sqrt{(s_i \alpha_i)}$ were then calculated in sub-intervals (typically 50 cm^{-1}) in which the Planck function can be taken to be constant. The band model program calculated the transmission τ in each sub-interval at 30 K intervals from 203 to 323 K and at a pressure of 1000 mb for a range of absorber amounts u from 10^{-9} to 10^{3} kg m^{-2} in half-decade intervals. The band model approximation to τ in a direction $\cos^{-1} \mu$ to the normal is:

$$\tau = \exp\left\{ - \frac{C_1 u}{\mu} \sqrt{\left(1 + \frac{C_2 u}{\mu}\right)} \right\} \quad (A.1.1)$$

where

$$C_1 = \sum_{i=1}^{M} S_i / \Delta \upsilon \quad \text{and} \quad C_2 = \left\{ \frac{1}{2} \sum_{i=1}^{M} S_i \Big/ \sum_{i=1}^{M} \sqrt{(S_i \alpha_i)} \right\}^2 \quad (A.1.2)$$

and M is the number of lines in the sub-interval of width $\Delta \upsilon$.

These transmissions were integrated over zenith angle by Gaussian quadrature to give the slab transmission τ', thus avoiding the need for a diffusivity factor.

The slab transmissions for each gas were weighted with the Planck function B(w,T) for wavenumber w and temperature T and integrated over w to give the mean transmissivity Tr_j and emissivity ϵ_j in each band j:

$$Tr_j(u,T) = \int_j \tau'(w,u,T) \frac{dB(w,T)}{dT} dw \Big/ \int \frac{dB(w,T)}{dT} dw \quad (A.1.5)$$

$$\epsilon_j(u,T) = \int_j (1-\tau'(w,u,T)).B(w,T)dw \Big/ \int_j B(w,T)dw \quad (A.1.5)$$

The programs used are held by the UM librarian.

The numbers used in the code are given in Table 2.

For a pathlength less than the smallest pathlength the table caters for, linear interpolation between that first transmissivity in the table and 1 is used. For a pathlength greater than the largest the table caters for, the last transmissivity in the table is used.

APPENDIX 2 SHORTWAVE LOOK-UP TABLES

The quantities *a* to *f* used in (4.8.23)-(4.8.25) are calculated from the values given by Slingo (1989) for each of the Slingo and Schrecker (1982) bands, by averaging the values for those bands that make up the UM band with weighting by the fraction of the solar constant in that band, as described by Slingo (1989). The program used can be used on any set of bands each of which is a combination of Slingo and Schrecker bands. It is held by the UM librarian. The values for the four standard bands and the full 24-band set are given in Table 3.

The gaseous transmission data for the shortwave for O_3, H_2O and CO_2 were derived from LOWTRAN 7 (A. Slingo and J. Edwards, pers. comm.). The values are given in Tables 4.1, 4.2 and 4.3 for the standard set of bands.

As in the LW, when an absorber amount is less than the smallest value the table caters for, linear interpolation between the first transmissivity in the table and 1 is used, and when it is greater than the largest value, the last transmissivity in the table is used.

APPENDIX 3 - OZONE CLIMATOLOGIES

The basic climatological ozone data which is standard for the UM comes in fact from two sources, the proposed CIRA climatology of Keating et al (1987) and re-processed data from the SBUV (Solar Back-scattered Ultra-Violet) satellite instrument for 1979-81. Both were kindly made available by Dr K.P.Shine, who in turn obtained the latter from Dr R.D.McPeters. Both datasets are monthly and zonally meaned values for each calendar month, but for different latitudes and levels. The Keating et al data is at every 10° from 80°N to 80°S inclusive at 24 levels from 0.3 Pa to 2000 Pa, while the SBUV data is at every 5° from 77.5°N to 77.5°S inclusive, for 12 slabs extending nominally from the surface to TOA. The Keating et al data, a homogenized multi-satellite dataset, is used above η = .0225, with the lowest 5 layers of the SBUV data used below, at levels where any satellite data is less reliable but coverage by other means is limited. (Ozone amounts vary little with longitude in the time-mean, and zonal means are usual when specifying climatological data.)

Neither dataset is in SI units. The Keating et al data in ppmv is just multiplied by 10^{-6} x 48 / 28.964 to get mass mixing ratios. The SBUV data in "milli centi atm m" is multiplied by 10^{-5} x 2.1435 x g and divided by each layer's pressure thickness to get mmr.

For use in the model, the data must also be got onto the rows and levels of the model run concerned. *A separate job exists to do this which it is hoped will be incorporated into the UM system soon.* It is currently usual to use this for global runs but use the reconfiguration (UMDP S1) to produce data for limited-area runs, from a global dataset. In global runs the control code expands the data from zonal mean into full fields each SW or LW timestep for use by the plug-compatible code. No time interpolation is done - each set of values is used unaltered throughout the month it applies to.

The interpolation in the horizontal is done first, linearly in sin(latitude) from the nominal latitudes of the input data to those of the output. (Polewards of the limit of data for each source, the polemost two rows' data is extrapolated similarly.) No fix is applied to avoid non-conservation, though the form of the interpolation is such as to tend to minimize this for fine grids.

The vertical transposition is defined as an integration rather than an interpolation, to keep it as conservative as possible. Each input value is assumed to apply as a constant across a slab, and the value for each output layer (the layers for which the dataset is wanted) is the mean of those for each input layer which overlaps it, mass-weighted (i.e. by the fraction of mass from that input layer in the output layer). For the Keating et al data, for which only nominal levels of validity were provided, layer boundaries were assigned to round numbers subjectively (η = .0225, .0175, .0125, .0085, .006, .004, .0025, .00175, .00125, .00085, .0006, .0004, .00025, .000175, .000125, .000085, .00006, .00004, .000025, .0000175, .0000125, .0000085, .000006, .000004, .000002).

If the output layers always covered the same range as the input layers, this would conserve the total amount of ozone in the column. However, they normally stop considerably lower than the 0.2 Pa taken as the top of the Keating et al data. The code therefore has an option to impose conservation of total column ozone through the vertical transposition, by multiplying by the appropriate ratio for each column.

All the calculation described in the above two paragraphs is done in terms of η or equivalently σ, the surface pressure used being the nominal SBUV one of 101325 Pa. When the data is used in the model, consistency is maintained by the fact that the pressures used to convert the mass mixing ratios to pathlengths are obtained by combining the same standard pressure with the As and Bs for the layer concerned. Thus in particular all points round a latitude circle have the same ozone pathlengths in any given η layer, not on a given pressure surface as would seem strictly more accurate. However, with the usual UM layer specifications most ozone is high enough to be in pure pressure layers, and that lower down will mostly be in the troposphere where the precise vertical distribution of radiative heating is less important.

The ozone values generated thus depend only on the η values at the layer boundaries. *However, the UM control code will reject an ozone dataset if any of the layer centre or boundary As or Bs differ.*

The input ozone values are given in Table 6.

REFERENCES

Berger,A.L., 1978, Long-term variations of daily insolation and quaternary climate change. J.Atmos.Sci., 35, 2362-2367.

Buckley, E. and Warrilow, D.A., 1988, Derivation of land surface parameter datasets for use in the Met O 20 GCM. Met O 20 Internal Note No 81.

Bower, K. N. and Choularton, T. W., 1992, A parametrisation of the effective radius of ice free clouds for use in global climate models. *Atmos. Res*., **27**, 305-339.

Edwards, D.P., 1992, GENLN2. A general line-by-line atmospheric transmittance and radiance model. Version 3.0 Description and Users Guide NCAR/TN-367+STR

Edwards, J.M., 1993, A Users Guide to the New Radiation Code (available from the author, Hadley Centre, London Rd., Bracknell Berks)

Elsasser, W.M., 1942, Heat transfer by infrared radiation in the atmosphere. Blue Hill Meteorological Observatory, Massachusetts.

Elsasser, W.M., 1943, Heat Transfer by Infrared Radiation in the Atmosphere. Harvard Meteorological Studies No.6 Harvard University Press

Gardiner, B.G., 1987, Solar radiation transmitted to the ground through cloud in relation to surface albedo. *J. Geophys. Res*., **92**, 4010-4018.

Geleyn,J.-F., and Hollingsworth,A, 1979, An economical analytical method for the computation of the interaction between scattering and line absorption of radiation. Beit.Phys.Atmos., 52, 1-16.

Goody, R.M., 1952, A statistical model for water vapour absorption. *Quart. J.R. Met. Soc.*, 78, 165-169.

Hansen, J.E., Russell,G., Rind,D., Stone,P., Lacis,A.A., Lebedeff,S. Ruedy,R., and Travis, L., 1983, Efficient three dimensional global models for climate studies, Models I and II. *Mon. Weather Rev*., **111,** 609-662.

Houghton, J.T., 1963, The absorption of solar infra-red radiation by the lower stratosphere. *Quart. J. Roy. Met. Soc.*, **89**, 319-331.

Houghton, J.T., 1977, The physics of atmospheres. CUP.

Hunt G.E. and Mattingly S.R. 1976 Infrared radiative transfer in planetary atmospheres - I Effects of computational and spectroscopic economies on thermal heating/cooling rates. J. Quant. Spectrosc. Radiat. Transfer., 16, 505-520.

Keating,G.M., Young,D.F. and Pitts,M.C., 1987, Ozone reference models for CIRA Adv. Space Res., 7, 105-115.

Lee,R.B., Barkstrom,B.R. and Luther,M.R., 1986, Solar irradiance measurements using the Earth Radiation Budget Experiment solar monitors. Proc. 6th AMS Conf. on Atm. Rad., Williamsburg, AMS, Boston, Mass.

Liou,K.-N., and Wittman,G.D., 1979, Parametrization of the radiative properties of clouds. *J. Atmos. Sci*., **36**, 7, 1261-1273.

Manabe, S., and Möller, F., 1961, On the radiative equilibrium and heat balance of the atmosphere. *Mon. Weath. Rev*., **89,** 503-532.

Martin, G. M., Johnson, D. W. and Spice, A., 1994, The measurement and parametrisation of effective radius of droplets in warm stratocumulus clouds.*J. Atmos. Sci.*, **51**, 1823-

1842.

Morcrette J.-J., Smith L.D. and Fouquart Y., 1986 Pressure and temperature dependence of the absorption in longwave radiation parametrizations. Beitr. Phys. Atmosph., 59, 455-469.

Neckel, H. and Labs,D., 1981, Improved data of solar spectral irradiance from 0.33 to 1.25 micron. Solar Phys., 74, 231-249.

Paltridge G.W. and Platt C.M.R. 1976 Radiative processes in meteorology and climatology. Developments in atmospheric science, 5, Elsevier.

Ramanathan, V. and Briegleb,B.P., 1982, Spectral and diurnal variations in clear sky planetary albedo. *J.Appl. Met*., **21,** 1160-1171.

Roach,W.T, Foot,J.S., Rawlins,F., and KIlsby,C.G., 1988, Radiative transfer studies at the Meteorological Research Flight.MRF IN 46

Roberts R.E., Selby,J.E.A., and Biberman,L.M., 1976, Infrared continuum absorption by atmospheric water vapor in the 8-12 μm window. Applied Optics, 15, 2085-2090.

Robinson, D.A. and Kukla, G., 1984, Albedo of dissipating snow cover. *J. Clim. Appl. Met*., **23,** 1626-1634.

Robinson, D.A. and Kukla, G., 1985, Maximum surface albedo of seasonally snow-covered lands in the Northern Hemisphere. J. Clim. Appl. Met., **24**, 402-411.

Robinson, D. A., Scharfen, G., Serreze, M.C., Kukla, G., and Barry, R.G., 1986, Snow melt and surface albedo in the Arctic Basin. *Geophys. Res. Lett*., **13,** 945-948.

Rogers, C.D. and Walshaw, C.D., 1966 The Computation of Infrared Cooling Rates in Planetary Atmospheres. *Quart. J. Royal Met. Soc.* 92 67

Rossow, W.B., Mosher, F., Kinsella,E., Arking,A., Desbois,M., Harrison,E., Minnis,P., Ruprecht,E., Seze,G., Simmer,C. and Smith,E., 1985, ISCCP cloud algorithm intercomparison. *J. Clim. Appl. Met*., **24,** 877-903.

Rothman, L.S., 1981: AFGL atmospheric absorption line parameters compilation: 1980 version. Applied Optics, 20, 791-795.

Schneider,S.H., and Dickinson,R.E., 1976, Parametrization of fractional cloud amounts in climatic models: the importance of modeling multiple reflections. *J. Appl. Met.*, **15**, 1050-1056.

Selby,J.E.A., Shettle,E.P., and McClatchey,R., 1976, Atmospheric transmittance from 0.25 to 28.5 μm: supplement LOWTRAN 3B (1976). AFGL-TR-76-0258, Hanscon Air Force Base, Massachusetts.

Slingo,A.(ed.), 1985, Handbook of the Meteorological Office 11-layer atmospheric general circulation model. Vol 1: model description. DCTN 29.

Slingo,A., 1989, A GCM Parametrization for the Shortwave Radiative Properties of Water Clouds. *J. Atmos. Sci*., **46**, 10, 1419-1427.

Slingo,A. and Schrecker, H.M., 1982, On the shortwave radiative properties of stratiform water clouds. *Quart. J. Roy. Met. Soc*., **108,** 407-426.

Slingo,A., and Wilderspin, R.C., 1986: Development of a revised longwave radiation scheme for an atmospheric general circulation model. *Quart. J. Roy. Met. Soc.*, **112**, 371-386.

Smart, W.M., 1944, Textbook on Spherical Astronomy. CUP. (Fourth edition)

Stephens,G.L., 1978, Radiation profiles in extended water clouds. II: Parametrization schemes. J. Atmos. Sci., **35,** 2123-2132.

Stephens, G.L., 198 The parametrization of radiation for numerical weather prediction and climate models. *Mon. Wea. Rev.*, 112, 826-867.

Stephens,G.L., Ackerman,S., and Smith,E.A., 1984, A shortwave parametrization revised to improve cloud absorption. *J. Atmos. Sci*., **41**, 687-690.

Tian,L., and Curry,J.A.,1989, Cloud overlap statistics. J. Geophys. Res., 94, 9925-9935.

Wang W-C. et al., 1992 Inadequacy of Effective CO2 as a proxy in assessing the regional climate change due to other radiatively active gases. Geophs.Res. Let. 19 no.13 1375-1378

Warrilow, D.A., Smith, R.N.B and Hewer, F.E. 1990 Snow processes in the 5th Annual-Cycle Integration, Met O 20 Internal Note 93 (to appear).

Wu,M.-L.C., 1980, The exchange of infrared radiative energy in the troposphere. J.Geophys. Res., 85, 4084-4090.

Zdunkowski,W.G., Welch,R.M., and Korb,G. 1980, An investigation of the structure of typical two-stream-methods for the calculation of solar fluxes and heating rates in clouds. Beitr. Phys. Atmosph., **53,** 147-166.

The 3A-Radiation Scheme

Numerical Formulation

The purpose of the radiation code is to calculate radiative fluxes, from which heating rates and related quantities may be determined. In this radiation scheme these fluxes are determined by summing the results of a number of quasi-monochromatic calculations, each carried out using a two-stream approximation. The algorithm can perhaps most clearly be explained by describing first the spectral integration in broad terms, then the treatment of the quasi-monochromatic calculations in an atmospheric column composed of homogeneous layers, working backwards to the original physical inputs, before passing on to a discussion of the treatment of overlapping gaseous absorption and the treatment of fractional cloudiness.

Spectral data for the parametrizations used and the decomposition of each spectral region into bands are stored in a spectral file, generated by a pre-processing package and converted to a namelist for the Unified Model. The pre-processing package does not constitute a part of the Model and is therefore not discussed here: some aspects are discussed in Edwards and Slingo (1996). It is, however, important to note that parametrizations which require spectrally dependent data may be selected only if such data are present in the spectral file, and therefore that parametrizations must be selected with due consideration to the spectral data available. Once created a spectral file may be used with any subsequent version of the Unified Model, provided that backward compatibility is maintained: there is no need to regenerate spectral files in the manner of ancillary files.

Spectral Integration

In this section F will denote any flux, whether direct, diffuse or net. The spectral region under consideration is divided into a number of spectral bands within which all quantities except the gaseous mass absorption coefficient are treated as independent of frequency. The total flux is then the sum over the partial fluxes, $F_j^{(b)}$, in each of the bands:

$$F = \sum_j F_j^{(b)} \ .$$

The flux in a band is calculated by dividing the band into a number of quasi-monochromatic regions in each of which the gaseous absorption coefficients for the active absorbing gases within the band have fixed values. A weight, w_k, is assigned to the kth region, and the flux, taking the appropriate values of the gaseous absorption coefficients, is calculated for this region. The flux in the band is then a weighted sum of these quasi-monochromatic fluxes, $F_k^{(qm)}$

$$F_j^{(b)}=\sum_k w_k F_k^{(qm)}.$$

The number of quasi-monochromatic calculations and the weights are determined by the method adopted for treating overlapping gaseous absorption and the data for exponential-sum fitting of the transmissivities of the gases.

The Calculation of Monochromatic Fluxes

To calculate monochromatic fluxes the atmosphere is divided into N layers which are treated as homogeneous. The layers are numbered from 1 to N, starting at the top. The boundaries of these layers, referred to as levels, are numbered from 0 to N, again starting at the top; so that the i th level marks the base of the i th layer.

In order to minimize the execution time, it is convenient to choose the upward flux, U, the total downward flux, V, and the direct solar flux, Z, as the primary variables in the solar region (notice the non-standard choice of the total rather than the diffuse downward flux). In the infra-red it is convenient to use the upward and downward differential fluxes (the actual upward and downward fluxes less πB), which we here denote as U and V to achieve a unified description valid in both spectral regions. For applications where only heating rates or net fluxes are required, it is often convenient to work with the net flux $N=V-U$. The fluxes in a column consisting of homogeneous layers are then determined from the equations

$$\begin{aligned} U_{i-1}&=T_i U_i+R_i V_{i-1}+S_i^+,\\ V_i&=T_i V_{i-1}+R_i U_i+S_i^-\\ Z_i&=T_{0i} Z_{i-1}.\end{aligned}$$

T and R are the diffuse transmission and reflection coefficients and T_0 is the direct transmission coefficient. The subscripts on fluxes refer to levels and those on T, R, T_0 and S refer to layers. At the top of the atmosphere there is no incident diffuse flux, so the boundary condition for solar radiation is $V_0=Z_0=\Phi_0/\chi_0$ where Φ_0 is the solar irradiance in the band at the top of the atmosphere and χ_0 is the secant of the solar zenith angle. In the infra-red, the boundary condition is $V_0=0$. At the surface the appropriate boundary condition on the shortwave fluxes is

$$U_N=(\alpha_s-\alpha_d)Z_N+\alpha_d V_N$$

where α_s and α_d are the surface albedos for direct and diffuse radiation. In the infra-red

$$U_N=\alpha_d V_N+\epsilon_* \pi B_*$$

where ϵ_* is the emissivity of the surface and B_* is the corresponding Planckian function.

The source terms, $S^{\pm}$, are related to the direct solar flux or to variations in the Planckian source function across the layer, as appropriate to the spectral region. In the solar,

$$S_i^+=c_{1i}Z_{i-1} \quad \text{and} \quad S_i^-=c_{2i}Z_{i-1}$$

where the c_j are constants, and in the infra-red

$$S_i^+=c_{1i}\Delta_{1i}+c_{2i}\Delta_{2i} \quad \text{and} \quad S_i^-=-c_{1i}\Delta_{1i}+c_{2i}\Delta_{2i}.$$

where Δ_1 and Δ_2 are related to the first and second differences of the Planck function across the layer, and terms involving Δ_2 are present only if the Planckian source function is assumed to vary quadratically across the layer. Explicitly,

$$\Delta_{1i}=B_i-B_{i-1}$$
$$\Delta_{1i}=2(B_i+B_{i-1}-2B_i^{(m)}).$$

where B denotes the Planckian function integrated across the band at the appropriate level in the atmosphere and $B_i^{(m)}$ denotes the Planckian function at the middle of the i th layer. B is given by a polynomial:

$$B=\sum_{k=0}^{n}\beta_k(\theta/\theta_R)^k,$$

where the order of the polynomial, n, the coefficients β_k and the reference temperature, θ_R, are determined externally.

The constants c_j are defined below for each spectral region.

The Properties of Layers

T, T_0, R and the c_j are related to the optical properties of the layer. Since each layer may be considered independently, the subscript i may be dropped in this section. The fundamental optical properties of a layer are the optical depth, τ, the albedo of single scattering, ω, and the asymmetry g. The precise way in which these determine the overall transmission and reflection coefficients depends on the actual two-stream approximation selected (there are several two-stream approximations: see, for example, Zdunkowski *et al.* (1980)). Here they determine two quantities s and d in the first instance. (Usually the two-stream equations are expressed in terms of the diffuse fluxes, $F^{\pm}$ as

$$\frac{dF^+}{d\tau}=\alpha_1 F^+-\alpha_2 F^- -Q^+$$
$$\frac{dF^-}{d\tau}=\alpha_2 F^+-\alpha_1 F^- +Q^-.$$

where $Q^\pm$ are source terms. In terms of the variables used here, $s=\alpha_1+\alpha_2$ and $d=\alpha_1-\alpha_2$).

In the Eddington approximation,

$$s=\frac{3}{2}(1-\omega g)$$
$$d=2(1-\omega).$$

Using the approximation given by Zdunkowski *et al.* (1985), which we denote as PIFM85,

$$s=D-\frac{3}{2}\omega g$$
$$d=D(1-\omega),$$

where D is the diffusivity factor, which is taken as 2 by these authors, though 1.66 is more commonly used in the infra-red to agree with Elsasser's value. The original version of the approximation given by Zdunkowski *et al.* (1980) is

$$s=2-\frac{3}{2}\omega g-\frac{1}{2}\omega$$
$$d=2(1-\omega).$$

This approximation follows less naturally from the derivation, but agrees more closely with reference results in the solar region. Using discrete ordinates,

$$s=\sqrt{3}(1-\omega g)$$
$$d=\sqrt{3}(1-\omega).$$

Under the Hemispheric mean approximation,

$$s=2(1-\omega g)$$
$$d=2(1-\omega).$$

These quantities determine the diffuse transmission and reflection coefficients:

$$
\begin{aligned}
\lambda &= \sqrt{sd} \\
p &= e^{-\lambda\tau} \\
\Gamma &= \frac{s-\lambda}{s+\lambda} \\
T &= \frac{p(1-\Gamma^2)}{1-p^2\Gamma^2} \\
R &= \frac{\Gamma(1-p^2)}{1-p^2\Gamma^2}.
\end{aligned}
$$

In the infra-red,

$$
\begin{aligned}
c_1 &= \frac{1-T+R}{s\tau} \\
c_2 &= -\frac{1}{s\tau}\left[1+R+T-2\frac{1-T-R}{\tau d}\right]
\end{aligned}
$$

It will be noticed that these expressions become indeterminate in the limit $\tau \to 0$. This indeterminacy is removed by adding a small tolerance (the square root of the precision of the machine) to the terms $s\tau$, $d\tau$, $1-T+R$, and $1+R+T$. However, when τ is very small we prefer to use the asymptotic form for the second term within square brackets in c_2 *viz.*:

$$
\frac{1-T-R}{\tau d} \sim 2-\tau d
$$

To define the c_j in the solar region we introduce the quantity ξ_0, where

$$
\xi_0 = \frac{3g}{2\chi_0}
$$

for all the above two-stream approximations, except the discrete ordinate approximation, for which

$$
\xi_0 = \frac{\sqrt{3}g}{\chi_0}.
$$

In this spectral region we now define

$$
\begin{aligned}
f &= \omega\frac{\chi_0}{2} \\
\nu_+ &= f(s-\chi_0-\xi_0(d-\chi_0)) \\
\nu_- &= f(s+\chi_0+\xi_0(d+\chi_0)).
\end{aligned}
$$

Then,

$$c_1=(\nu_+-\boldsymbol{R}(1+\nu_-))-\nu_+TT_0$$
$$c_2=T_0(1+\nu_--\boldsymbol{R}\nu_+)-(1+\nu_-)T.$$

The Rescaling of the Optical Properties

The rather crude representation of the angular variation of the radiance in the two-stream equations causes unacceptable inaccuracies in the representation of scattering. However, these errors can be substantially reduced by the δ-rescaling transformation (Joseph, 1976) which allows for the strong forward scattering exhibited by most atmospheric scatterers. A forward scattering fraction, f, is defined, using the standard prescription $f=g^2$, and the optical properties are rescaled using the transformation

$$\begin{aligned}&\tau\leftarrow\tau(1-\omega f),\\&\omega\leftarrow\omega(1-f)/((1-\omega f)\\&g\leftarrow(g-f)/(1-f).\end{aligned}$$

The Calculation of the Single Scattering Properties

The optical properties most easily related to the physical sources are the mass extinction and scattering coefficients, $k^{(e)}$ and $k^{(s)}$, and the asymmetry g. When a number of optical processes are active in a region the contributions from each of them are combined in accordance with the formulae:

$$\begin{aligned}k^{(e)}&=\sum_j k_j^{(e)},\\k^{(s)}&=\sum_j k_j^{(s)},\\g&=\sum_j k_j^{(s)}g_j/\sum_j k_j^{(s)}\\f&=\sum_j k_j^{(s)}f_j/\sum_j k_j^{(s)},\end{aligned}$$

where, for each process, indexed by j, $f_j=g_j^2$. The optical depth and asymmetry are then determined from the formulae:

$$\begin{aligned}\tau&=k^{(e)}\,\Delta m\\\omega&=\frac{k^{(s)}}{(k^{(e)}+k^{(s)})}.\end{aligned}$$

The Representation of Optical Processes

Gaseous Absorption

If there are M active absorbing gases, $j=1,...,M$ in a band, each will enter a single quasi-monochromatic calculation with an effective mass extinction coefficient $K_j^{(g)}$. The total contribution to the mass extinction coefficient is then

$$k^{(e,g)}=\sum_j^M K_j^{(g)} q_j f_j(p,\theta),$$

where q_j is the mixing ratio of the j th gas and f_j is the scaling function, depending on the pressure, p, and the temperature, θ. Two forms for f are allowed within the code:

$$f=\left(\frac{p+\Delta}{p_0+\Delta}\right)^{\alpha}\left(\frac{\theta}{\theta_0}\right)^{\beta}$$

$$f=\left(\frac{p+\Delta}{p_0+\Delta}\right)^{\alpha}\left[1+A\left(\frac{\theta-\theta_0}{\theta_0}\right)+B\left(\frac{\theta-\theta_0}{\theta_0}\right)^2\right]$$

The second form is generally preferred as being more flexible and simpler to compute. The free parameters α, β, Δ, A and B are determined by fitting to gaseous transmission data and are chosen such that if they are given values of 0 then $f=1$. p_0 and θ_0 are a reference pressure and temperature. Δ represents the effects of Doppler broadening. A different scaling function may be used for each ESFT exponent, or one value may be used across the band; the latter being more usual since it is faster. All these choices are determined from the data in the spectral file.

Continuum Absorption

Two continua are normally included in radiative calculations: the self and foreign-broadened continua of water vapour. Their contribution to the mass extinction coefficient is

$$k^{(e,c)}=K_f^{(c)} q_w f_f \rho_{bf}+K_s^{(c)} q_w f_s \rho_{bs}$$

where q_w is the mixing ratio of water vapour, f is the scaling function and ρ_b is the molar density of the appropriate broadening species; the subscripts f and s stand for the foreign and self-broadened continua respectively. The coefficients $K_f^{(c)}$ and $K_s^{(c)}$ are determined externally by fitting and the coefficients are read from the spectral file. For the self-broadened continuum the broadening species is water vapour, and for the foreign-broadened continuum it comprises all other species except water vapour. The same functional forms for the scaling function that were used in the treatment of gaseous absorption are employed here. In the Unified Model it is often convenient to combine the line data and the foreign continuum data, making use of the fact that ρ_{bf} is almost exactly a function of the pressure and the temperature. ESFT fits are then determined for the combined transmission.

Absorption and Scattering by Aerosols

The radiation code contains provision for treating aerosols. This section is concerned only with the description of the radiative treatment of aerosols within the code. The specification of mixing ratios and aerosol models is described later.

For each species of aerosol in each spectral band the contributions to the total and scattering extinctions are simply set proportional to mass mixing ratio of the aerosol: the constants of proportionality and the asymmetry are determined externally and read from the spectral file. There is no allowance for variations in the shape of the size distribution. Hence,

$$k^{(e,a)} = \sum_j K_j^{(e,a)} q_j,$$
$$k^{(s,a)} = \sum_j K_j^{(s,a)} q_j,$$
$$g^{(a)} = \sum_j K_j^{(s,a)} q_j g_j / k^{(s,a)},$$

where the sum is taken over all the species of aerosols present and the mixing ratios are denoted by q_j. D. L. Roberts's parametrization of the influence of humidity on the optical properties hygroscopic aerosols is included.

Rayleigh Scattering

Rayleigh scattering is represented by adding to the scattering and total extinctions a constant value for each spectral band, again determined externally and read from the spectral file. The asymmetry for Rayleigh scattering is 0.

Absorption and Scattering by Water Droplets

The properties of water droplets are determined from the mass mixing ratio of liquid water, L, and the effective radius of the droplets, r_e, using a parametrization.With the parametrization of Slingo and Schrecker (1982),

$$k^{(e)} = L(a + b/r_e)$$
$$k^{(s)} = k^{(e)}(1 - c - dr_e)$$
$$g = e + fr_e$$

where the constants $a, \ldots, f$ are determined externally. An alternative is the parametrization of Ackerman and Stephens (Ackerman and Stephens, 1987):

$$k^{(e)}=L(a_1+b_1 r_e^{c_1})$$
$$k^{(s)}=k^{(e)}(1-a_2-b_2 r_e^{c_2})$$
$$g=a_3+b_3 r_e^{c_3}.$$

Again, the a_j, b_j and c_j are determined externally by fitting and are read from the spectral file.

Absorption and Scattering by Ice Crystals

The properties of ice crystals are determined from the mass mixing ratio of ice, I, and the effective radius of the crystals, r_e, using a parametrization. Using the functional form of Slingo and Schrecker (1982) in analogy with the parametrization of water droplets,

$$k^{(e)}=I(a+b/r_e)$$
$$k^{(s)}=k^{(e)}(1-c-dr_e)$$
$$g=e+fr_e$$

where the constants $a,...,f$ are determined externally.

The Treatment of Overlapping Gaseous Absorption

If several gases absorb in a spectral band which does not cover too large a range of frequencies, their spectral lines may be taken to overlap randomly. In representing this absorption using ESFT it is necessary to consider the overlap of each exponent for one gas with each exponent for every other gas active in the band. This full treatment of random overlap is available within the code, but it is computationally expensive, and computationally faster approximations to it are provided.

In the approximation of Fast ESFT (FESFT) introduced by Ritter and Geleyn (1992), the so-called grey fluxes, ignoring gaseous absorption, in each band are initially calculated. Then, for each absorber, $j=1,...,M$, an effective transmission, E_j, is calculated: $E_j=F_j/F_0$ where F_0 is the grey flux and F_j is the flux calculated including grey processes and absorption by the j th gas. The final flux is approximated as

$$F=\prod_j E_j.F_0$$

This approximation is applicable to the actual fluxes in the solar region, but to the differential or net fluxes in the infra-red region.

Equivalent extinction is an extension of FESFT in which the effects of minor gases are represented by a single absorption coefficient within the band, but that coefficient is determined for the local atmospheric conditions by a subsidiary calculation. In the infra-red region, supposing a minor gas to have ESFT exponents $K_r,\ r=1,...,n$ the net flux, N_r, including just absorption by the rth ESFT exponent of the gas (and any non-cloudy grey absorption) is calculated. The equivalent extinction is then defined as

$$\bar{K}=\sum_r w_r K_r N_r / \sum_r w_r N_r,$$

where the w_r are the corresponding ESFT weights. A practical point concerning the numerical implementation of this approximation is that fluxes are calculated on levels, whereas the extinction coefficient must be a representative value in a layer. The equivalent extinction is therefore calculated using the mean net flux in the layer, which is taken as a simple average of the values at the boundaries. This is described more fully in Edwards (1996).

In the solar region it is less easy to define an equivalent extinction, since the character of downwelling radiation may be quite different from that of upwelling radiation, and the scheme adopted is provisional. For each minor gas the direct transmission through any atmospheric layer may be calculated and these transmissions are multiplicative, so the direct flux may be calculated precisely and efficiently at all atmospheric levels. To calculate the diffuse fluxes it is assumed that the absorption by the minor gas falls into weak and strong parts, so that radiation which is scattered into the diffuse beam will be effectively denuded in parts of the band where absorption is strong. If the remaining absorption is weak it may be treated as grey. The equivalent extinction for diffuse radiation is therefore taken to have a uniform value

$$\bar{K}=\sum_r w_r K_r Z_{*r} / \sum_r w_r Z_{*r}.$$

where Z_{*r} is the direct flux at the surface for the rth ESFT term. One further approximation is necessary to fit in with the calculation of cloudy transmission and reflection coefficients: in the calculation of source terms across a cloudy layer the direct flux is taken to vary from its true value at the top of the layer with the effect of minor gases being represented by the direct transmission calculated using the equivalent extinction.

FESFT is not completely robust and may yield unphysical results when treating several gases. For this reason equivalent extinction is normally recommended.

The Treatment of Clouds

A fairly general prescription is adopted for the treatment of clouds. Within any atmospheric layer, i , a fractional cloud cover, W_i, may be specified. This cloud is divided into N_T *types*, each constituting a fraction ,ϕ_j, of the total amount of cloud. Each of these sub-clouds is made up of mixtures of various *components*. The rule which determines how the components are partitioned between the types of cloud is termed a *representation.* For use in the Unified Model two representations are provided, depending on the treatment of ice and water clouds. Clouds consist of four components: stratiform water and ice and convective water and ice. Mixed-phase clouds may be represented as *homogeneous*, in which case there are two types, stratiform and convective, with homogeneous mixtures of water and ice in each; or as *segregated*, in which case there are four types of clouds, each consisting of a different component.

The geometry of the clouds affects the radiative fluxes. In this code there is no allowance for three-dimensional effects since clouds are treated as plane parallel. Geometrical considerations are therefore restricted to the overlapping of clouds in the vertical. The overalpping algorithm is a generalization of that described by Zdunkowski *et al.* (1982). For reasons of numerical efficiency we do not consider the overlap between each individual type of cloud in a layer, but aggregate them into *regions*. Within each region the fluxes are considered to be horizontally uniform and at the boundaries between layers the fluxes are transferred from one region to another in accordance with a rule determined by the assumption regarding overlaps. There are two methods of decomposing the layer into regions at present. All cloud may be aggregated into one region (the original scheme), thus splitting the layer into clear and cloudy parts, or the convective and stratiform clouds may be aggregated into separate regions, thus giving three regions in the layer and maintaining the vertical coherence of convective cloud. (From the algorithmic point of view, this aggregation is performed implicitly in the original scheme, but explicitly in the new scheme).

The overlapping is represented by the coefficients used to mix fluxes at the boundaries of layers. For the upward flux we write:

$$\hat{U}^{+}_{ij}=\sum_k u_{ijk}\check{U}^{+}_{ik}$$

where U_{ij} denotes the upward flux in the j th region at the i th level, with the circumflex denoting a value just above the boundary and the hacek a value just below it. Similarly, for the downward flux we write

$$\hat{V}_{ij}=\sum_k v_{ijk}\check{V}_{ik}$$

with an identical equation for Z. Let X_{ij} denote the area within the i th layer covered by the j th region and Y_{ijk} denote the area on the i th level where the j th region overlies the kth.. Then, generally, we have

$$u_{ijk}=Y_{ikj}/X_{i+1,j}$$

and

$$v_{ijk}=Y_{ijk}/X_{ij}$$

The assumption regarding the overlap determines the Y_{ijk}. If random overlap is assumed

$$Y_{ijk}=X_{ij}X_{i+1,k}.$$

If maximum-random overlap is assumed, similar regions are maximally overlapped, but dissimilar ones are randomly overlapped, so we take

$$Y_{ijj}=\min(X_{ij},X_{i+1,j})$$

and if $k\neq j$

$$Y_{ijk}=(X_{ij}-Y_{ijj})(X_{i+1,k}-Y_{i+1,kk})$$

In the case where $X_{ij}=0$, u_{ijk} is undefined, and its value does not affect the radiative fluxes, but it is necessary to assign a legitimate value for the execution of the subsequent algorithm. In such cases we set u_{ijk} to 1 if $j=k$ and 0 otherwise; a similar rule is applied to v_{ijk}.

Algorithmic Details

The above description specifies the algorithm completely, but some ordering of the calculations is desirable to achieve numerical efficiency.

The coefficients for calculating the flow of energy between cloudy layers and other spectrally independent quantities are calculated initially. Within a spectral band, the scaling functions are applied to the continua, and to gases if they are the same for each ESFT term, and the grey contributions to the total extinction, the scattering extinction and the asymmetry factor are determined: if rescaling is requested the asymmetry is rescaled at this point. The algorithm now follows different branches, depending on the treatment of overlapping gaseous absorption, though the general procedure is much the same for each option. For each combination of ESFT terms the gaseous extinctions are calculated and the quasi-monochromatic single scattering properties are determined. A quasi-monochromatic calculation of the fluxes is performed. The total flux in the band is then a sum of these partial fluxes.

The Solution of the two-stream equations

The two-stream equations generate a set of linear simultaneous equations which may be solved by any standard algorithm of linear algebra. Whilst the method of solution of these equations is not strictly part of the physical basis of the scheme, it is useful to comment on the efficiency of the method of solution adopted. Coding the equations for the fluxes generates a banded matrix containing a significant proportion of zeros even along those diagonals in which every element is not zero. It therefore turns out that the most efficient and accurate method to solve these equations numerically is not to generate a full banded matrix and employ a standard algorithm directly, but rather to construct a set of algebraic recurrences which follow the pattern of Gaussian elimination, but take full account of the position of zero entries in the matrix, thus reducing the operation count to a minimum.

The first stage of this reduction is to generate a set of relations between the upward flux just above the boundary of a layer and the downward fluxes just below it. Using the notation of the earlier section on cloud properties we write

$$\hat{U}_{ij}=\sum_k \alpha_{i+1,jk}\check{V}_{ik}+G^{+}_{i+1,j}$$

where α is a generalized albedo and G is independent of U and V. The boundary condition at the surface is of this form with G including the solar term. It is convenient to work with $\hat{U}$ and $\check{V}$, so the diacritical marks on the fluxes may be dropped. To form the recurrence we take the preceeding equation and substitute for V, thus obtaining

$$U_{ij}=\sum_k \alpha_{i+1,jk}[\sum_l \nu_{ikl}(T_{il}V_{i-1,l}+R_{il}U_{il}+S^-_{ik})]+G^+_{i+1,j}$$

We now define

$$\theta_{ijl}=\sum_k \alpha_{i+1,jk}\nu_{ikl}$$

so that

$$\sum_l (\delta_{jl}-\theta_{ijl}R_{il})U_{il}=\sum_l \theta_{ijl}T_{il}V_{i-1,l}+\sum_l \theta_{ijl}S^-_{il}+G^+_{i+1,j}$$

which is of the form

$$\sum_l \beta_{ijl}U_{il}=\sum_l \gamma_{ijl}V_{i-1,l}+H^+_{ij}$$

and by taking linear combinations of these equations as necessary we can ensure that $\beta_{ijl}=0$ whenever $l>j$. We now take the equation for the upward fluxes

$$U_{i-1,j}=\sum_k u_{i-1,jk}(T_{ik}U_{ik}+R_{ik}V_{i-1,k}+S^+_{ik})$$

and observe that this is of the form

$$U_{i-1,j}=\sum_k \zeta_{ijk}U_{ik}+\sum_k \alpha_{ijk}V_{i-1,k}+G^+_{ij}.$$

By using the previous equation but one U may be eliminated from the right to give us an equation of the original form with i replaced by $i-1$. In layers above clouds this scheme can be simplified for efficiency.

Back substitution proceeds easily. Suppose that at the i th level we know the downward fluxes just above the boundary, $\hat{V}_{ij}$, then we may calculate the downward fluxes just below the boundary using the coefficients ν_{ijk}. The upward fluxes just below the boundary may be determined from

$$\sum_l \beta_{ijl}U_{il}=\sum_l \gamma_{ijl}V_{i-1,l}+H^+_{ij}$$

The downward fluxes at the base of the layer may now be determined from the equations of transfer, thus completeing the recurrence.

Approximate Scattering in the Longwave Region

This scheme may be applied in both spectral regions, but in the longwave region scattering is not so important as in the shortwave region and its effects may be treated approximately. The transmission and reflection coefficients of the layers are calculated including the effects of scattering, but the equations of transfer are solved using the first two stages of an iterative scheme. Recall that the code is formulated in terms of differential fluxes in this spectral region. Thus if we assume that the upward flux at a level in the atmosphere is Planckian at the local temperature we may calculate the downward differential flux setting the upward differential flux to 0 and therefore these fluxes may be calclated by transmitting them down from the top of the atmosphere. Knowing the downward differential fluxes at each level we may then work upwards through the atmosphere calculating the upward fluxes. This procedure includes the effect of scattering in reducing the upward radiation from the top of clouds by reducing the emissivity, but it does not represent the increased downward emission from the base of a cloud through the direct reflection of radiation when it overlies a warmer surface. However, the former effect is the main result of including scattering and for most purposes it will be found preferable to approximate scattering in the longwave in order to reduce the execution time of the code.

The assignment of physical inputs

The physical variables used above to describe the calculation of radiative fluxes are not all directly available from the Unified Model, but must be calculated in the interfacing routines. This conversion will now be described for each group of physical variables.

Gaseous Mixing Ratios

The assignment of gaseous mixing ratios is straightforward. The Model carries mixing ratios for water vapour and ozone as spatially varying fields and the mixing ratios of other gases as constant values. These constant values are used to fill an array of gaseous mixing ratios carrying values for each gas in each layer at each grid-point, since this code contains provision to treat all gases as spatially non-uniform. Where spatially dependent mixing ratios are given it is a simple matter to transfer them to the new arrays.

Thermodynamic Qunatities

The Model supplies the temperatures at the middle of each layer, and the pressures at the middle and boundaries of each layer may be calculated from the level-dependent constants A and B and the surface pressure, p_*. The mass in a layer, Δm, is found assuming hydrostatic balance so

$$\Delta m = (p_{base} - p_{\mathrm{T}})/g$$

where p_{top} and p_{base} are the pressures at the top and bottom of the layer and g is the acceleration due to gravity. Although temperatures at the middles of layers are provided, values at the boundaries of layers are not and must be interpolated using the PEXNER function, described in another documentation paper: this does not provide values at the top and bottom boundaries of the atmosphere. At the top boundary of the Model's atmosphere the temperature is set equal to the temperature in the middle of the top layer. At the surface a temperature, T_*, is provided, but this applies to the ground itself. The temperature of the air in contact with the ground is taken as the temperature of the air in the middle of the bottom layer, so that we ignore the radiative effect of the very thin layer of air over which the temperature changes from the surface value. At grid-points containing sea ice there is a complication, since the sea and the ice may be at rather different temperatures. At such points it is assumed that the sea is at a fixed temperature, T_{fs} set by the ice model while T_* gives the mean surface temperature at the gridpoint, from these temperatures a temperature for the ice may be determined. The upward fluxes emitted into the atmosphere from the sea and the ice are calculated separately, but the air itself is treated as uniform across the gridbox.

Cloud Fields

At each grid-point, the Model defines a fraction of convective cloud, W_C, the boundaries of the layers in which this cloud is found and the convective water path within the cloud, P_C. It also defines a fraction of stratiform cloud in each layer (outside convective cloud) W_{Si} and for these clouds it provides the mass mixing ratio of condensed water q_{Si} as a sum of two quantities, LCCWC1 and LCCWC2. This code works with a fraction of total cloud in each layer, W, so we define

$$W_i = W_C + W_{Si}(1 - W_C)$$

in layers where convective cloud is present and set it equal to the fraction of stratiform cloud in other layers.

As explained above, the cloud in any layer is divided into a number of different types, and the setting of the fractions of each of these types of clouds and their condensed water paths must be considered. The first step is to reduce P_C to mixing ratios in each layer. This is done assuming that the mixing ratio in the cloud is uniform.

$$q_{Ci} = P_C / \sum_j \Delta m_j$$

in each layer in which there is convective cloud, where the sum is taken over all layers containing such cloud. The partitioning between ice and water in mixed-phase clouds is determined by the function FOCWWIL, described elsewhere, which returns the fraction of liquid water, f, as a function of the temperature. In convective clouds f is set for the whole cloud from the temperature at the middle of the top layer, for consistency with other radiation schemes, but in stratiform clouds f is calculated separately for each layer using the temperature at the mid-point of that layer.

The interpretation of this partitioning varies depending on the cloud model adopted. If the option of treating mixed-phase clouds as homogeneously mixed is selected f is used to partition the mixing ratios of ice and water. If segregated clouds are considered f is used to set the area fractions of ice and water clouds. To describe these schemes explicitly, consider just one layer and let f_C and f_S denote the partitioning fractions for convective and startiform cloud, $q^{(CI)}$, $q^{(CW)}$, $q^{(SI)}$ and $q^{(SW)}$ be the mixing ratios for ice in convective cloud, ice in startiform cloud, water in convective cloud and water in stratiform cloud. Let ϕ with appropriate subscripts denote the fraction of the cloud in a layer constituted by the type indicated by the suffix. Note that $\sum_j \phi_j = 1$.

Considering homogeneously mixed clouds we set

$$q^{(CI)}=q_C(1-f_C)$$
$$q^{(CW)}=q_C f_C$$
$$q^{(SI)}=q_L(1-f_L)$$
$$q^{(SW)}=q_L f_L$$

There are two types of cloud, convective and stratiform, so we set

$$\phi_C=W_C/W$$
$$\phi_S=W_S/W$$

where W is the total amount of cloud in the layer and W_S and W_C are the amounts of stratiform and convective cloud in the layer.

In the case of segregated clouds f sets the values of the ϕ_j:

$$\phi_{CI}=W_C(1-f_C)/W$$
$$\phi_{CW}=W_C f_C/W$$
$$\phi_{SI}=W_S(1-f_S)/W$$
$$\phi_{SW}=W_S f_S/W$$

The mixing ratios of both ice and water are then set to the same values.

$$q^{(CI)}=q_C$$
$$q^{(CW)}=q_C$$
$$q^{(SI)}=q_S$$
$$q^{(SW)}=q_S$$

in each layer.

For the microphysical parametrizations effctive radii must be set. The normal option is to set standard values of 7 μm for droplets of water and 30 μm for ice crystals. Ice crystals, of course, are not spherical, but the treatment of non-spherical crystals is a topic of current research and most present parametrizations attempt to provide an effective radius based on the geometry of the crystal. For water droplets, there is the alternative of using the microphysical parametrization developed jointly by MRF and UMIST (Bower and Choularton 1992, Martin *et al.* 1994, Jones *et al.* 1994). In any cloud the effective radius is set from the formula

$$r_e=\left(\frac{3q\rho_a}{4\pi\rho_w Kn}\right)^{1/3},$$

where q is the mixing ratio of condensed water in the cloud, ρ_a and ρ_w are the densities of air and water, K is a constant which takes the values 0.67 over land and 0.8 over sea, and n is the number density of droplets. In homogeneous clouds q includes the contributions from both ice and water, but in segregated clouds only the contribution from liquid water is considered. r_e is adjusted, if necessary, to lie within the range .35 μm to 37μm, since extreme values may lie outside the range of validity of some parametrizations of the optical properties: there is no intrinsic reason to choose these particular values and they were derived for a particular parametrization. In deep convective clouds (those of a depth exceeding 500 m) r_e is set to the standard values of 9.5 µm over land and 13.5 µm over sea. n is strictly determined from the number of cloud condensation nuclei, but this is not robustly calculated by the model at present and standard values for n are normally used, these being 6.0×10^8 over land and 1.5×10^8 over sea. If the sulphur cycle is switched on and indirect effects are included n is determined from the predicted mixing ratio of the accumulation model of the sulphate aerosol, assuming that this has a log-normal distribution with a mean radius 0.05 microns and a standard deviation of 2. From the mixing ratio the number density of cloud condensation nuclei, n_c, is inferred and n is determined from the equation

$$n=3.75\times10^{8}(1.0-\exp(-2.5\times10^{-9}n_c)).$$

This parametrization is still being developed and these values may be changed.

Specification of the Mixing Ratios of Aerosols

Aerosols may be specified in two ways. From 4.1 of the model onwards there is a sulphur cycle. Two modes of sulphate aerosol are specified, an accumulation mode and an Aitken mode. As mentioned above, the accumulation mode may be used to derive effective radii. If the direct effects of sulphate aerosols are enabled both modes are used within the radiation code, the mass mixing ratios being determined by the sulphur cycle itself.

4.2 also includes a climatological aerosol model, which may be selected in place of or in addition to the sulphur cycle. This model is intended to represent non-anthropogenic background aerosols. It is based on the SRA types Continental-I and Maritime-I described in the appendix to the report WCP-55 (Deepak & Gerber, 1983) with the amendments specified in section 4 of that report: the ratios of number density for the three modes of oceanic particles are taken from d'Aleimda et al. (1991). Five aerosol species are included: water soluble particles, (mid-latitude) dust, oceanic particles (in three size modes), soot and droplets of sulphuric acid. The first four are confined to the troposphere and the last one to the stratosphere. The mass of each aerosol within the boundary layer, the free troposphere and the stratosphere is prescribed from the above documents, but the loading in the boundary layer and the free troposphere, though not the strat osphere, is scaled with the surface pressure to account for the reduced aerosol loading over orography. A Continental-I aerosol model is used over land which is not covered by ice with a loading in excess of 5000 kgm^{-2} and a Maritime-I aerosol over the oceans and ice sheets.

Physical Outputs and Diagnostics

The radiation code itself calculates the net flux at the boundaries of each layer in the model. The physical outputs used to advance the rest of the model are the heating rates in each layer (used in the form of increments to the temperature over a time-step) and the net flux at the surface. The net flux at the surface is directly available, but the heating rates must be calculated from the net fluxes using the expression

$$\frac{d\theta}{dt} = \frac{g}{c_P}\frac{N_{top} - N_{base}}{p_{base} - p_{top}}$$

where c_P is the specific heat of air at constant pressure. The fluxes at the surface and the top of the atmosphere can be deduced directly from the net flux. Clear-sky fluxes and heating rates are available as diagnostics and these are obtained in exactly the same manner from clear-sky fluxes calculated at each level by repeating the radiative calculations ignoring clouds.

The total cloud cover is calculated consistently with the assumption for overlap assumed. The algorithm proceeds by calculating the fraction of the grid-box which is completely free of clouds. We begin in the topmost layer by setting the fraction of the grid-box which is free of cloud,

$$\Psi \leftarrow 1$$

The algorithm is now to step down from boundary to boundary, multiplying by an appropriate factor representing the effect of cloud in the layer below the boundary with due allowance for the overlap assumption.With pure random overlap, clear-sky regions in one layer overlap with clear-sky regions in the next layer, so at each boundary we perform the calculation

$$\Psi \leftarrow \Psi(1 - W_{-})$$

where W_{-} is the fraction of cloud in the layer below the boundary. With maximum random overlap the appropriate calculation is

$$\Psi \leftarrow \Psi(1 - W_{-})/(1 - W_{+})$$

where W_{+} is the fraction of cloud in the layer above the boundary. Once we have crossed into the bottom layer Ψ holds the fraction of the gridbox which is totally clear, and by subtracting from 1 the total cloud cover may be found.

For coupling to the ocean or for the calculation of photosynethically active radiation it is necessary to calculate the net shortwave flux at the surface on the shortwave side of .69 microns.To calculate this flux a weighting factor, w, is derived for each band by assuming that the distribution of the energy within the band is uniform in frequency:

$$w = \frac{\min(1/(2\times10^{-7}), 1/\lambda_1) - \max(1/(6.9\times10^{-7}), 1/\lambda_2))}{1/(2\times10^{-7}) - 1/(6.9\times10^{-7})}$$

where λ_1 and λ_2 are the shorter and longer wavelength limits of the band in metres. The required flux is then calculated by multiplying the flux in each band by the appropriate weight for that band.

References

Ackerman, S. A. and Stephens, G. L. (1987) "The Absorption of Solar Radiation by Cloud Droplets: An Application of Anomalous Diffraction Theory," J. Atm. Sci., **44**, p. 1574-1588 d'Almeida, G., A., Koepe, P. and Shettle, E.P. (1991) "Atmospheric Aerosols: Global Climatology and Radiation Characteristics," A. Deepak Publishing, Hampton, Virginia.

Bower, K. N. and Choularton, T. W. (1992) "A Parametrization of the effective radius of ice-free clouds for use in global climate models." Atmos. Res., **27**, p. 305-339

Deepak, A. and Gerber, H. E. (1983) "Report of thhe Experts' Meeting on Aerosols and their Climatic Effects," World Climate Programme, **WCP-55**.

Edwards, J. M. (1996) "Efficient Calculation of Infrared Fluxes and Cooling Rates Using the two-stream equations," J. Atm. Sci., **53**, p. 1921-1932.

Edwards, J. M. and Slingo, A. (1996) "Studies with a flexible new radiation code. I: Choosing a configuration for a large-scale model," Q. J. Roy. Meteorol. Soc., **122**, p. 689-719

Jones, A., Roberts, D. L. and Slingo A. (1994) "A climate model study of indirect radiative forcing by antropogenic sulphate aerosols," Nature, **370**, p. 450-453

Joseph, J. H., Wiscombe, W. J. and Weinman, J. A. (1976) "The δ-Eddington Approximation for radiative flux transfer," J. Atm. Sci., **33**, p. 2452-2459

Martin, G. M., Johnson, D. W. and Spice, A. (1994) "The measurement and parametrization of effectice radius of droplets in warm stratocumulus clouds." J. Atmos. Sci., **51**, p. 1878-1893

Ritter, B. and Geleyn, J.-F. (1992) "A Comprehensive Radiation Scheme for Numerical Weather Prediction Models with Potential Applications in Climate Simulations," Mon. Wea. Rev., **120,** p. 303-325

Slingo, A. and Schrecker, H. M. (1982) "On the Shortwave Radiative Properties of Stratiform Water Clouds," Q. J. Roy. Meteorol. Soc., **108**, 407-426

Zdunkowski, W. G., Welch, R. M. and Korb, G. (1980) "An investigation of the structure of typical two-stream methods form the calculation of solar fluxes and heating rates in clouds," Beitr. Phys. Atmosph., **53**, p. 147-166

Zdunkowski, W. G., Panhans, W. G., Welch, R. M. and Korb G. J. (1982) "A radiation scheme for circulation and climate models," Beitr. Phys. Atmosph., **55**, p. 215-238.

Zdunkowski, W. G. and Korb, G. J. (1985) "Numerische Methoden zur Lösung der Strahlungsübertragungsgleichung," Promet **2/3** p.26-39.

Table 1

Coefficients of the cubic fit to the Planck function spectrally integrated over the standard set of UM longwave bands, in SI units (Wm^{-2} to $Wm^{-2} K^{-3}$).

Band	Order of term 0	1	2	3
1	-7.05873	-0.0288741	$1.41539 * 10^{-3}$	$-1.31802 * 10^{-6}$
2	28.9946	-0.556455	$3.09318 * 10^{-3}$	$-2.50228 * 10^{-6}$
3	94.6759	-1.33625	$5.27366 * 10^{-3}$	$-2.12247 * 10^{-6}$
4	24.2084	-0.100461	$-1.39883 * 10^{-3}$	$7.19088 * 10^{-6}$
5	22.2919	-0.107828	$-1.18008 * 10^{-3}$	$6.62392 * 10^{-6}$
6	-368.734	5.54521	-0.0282063	$4.88197 * 10^{-5}$

Coefficients of the quintic fit to the Planck function spectrally integrated over the "ECMWF" set of UM longwave bands (Wm^{-2}).

Band	Order of term 0	1	2	3	4	5
1	46.430621	129.28299	207.32648	313.98411	183.73177	-114.12303
2	73.604774	278.87914	270.76947	-57.322111	-64.742459	87.23828
3	37.050866	204.98759	375.58029	174.01171	-133.50302	-37.651795
4	14.930141	89.16116	177.93062	93.43386	-70.64602	-26.37315
5	40.386780	108.55270	50.75501	-31.49619	0.127913	1.801777
6	9.0811926	75.073923	246.54438	393.32612	293.85281	89.107921

Coefficients of the cubic fit to the Planck function spectrally integrated over the 1C set of longwave bands in SI units (Wm^{-2} to $Wm^{-2} K^{3}$)

Band	Order 0	1	2	3
1	-0.131802E-05	0.141538E-02	-0.289392E-01	-0.705836E+01
2	-0.233160E-05	0.285844E-02	-0.507511E+00	0.260282E+02
3	-0.229445E-05	0.550935E-02	-0.138542E+01	0.976612E+02
4	0.910328E-06	0.878510E-03	-0.333197E+00	0.284186E+02
5	0.292361E-05	0.325001E-04	-0.228451E+00	0.250211E+02
6	0.565092E-05	-0.168856E-02	0.106521E+00	0.391224E+01
7	0.432840E-05	-0.180022E-02	0.246546E+00	-0.108268E+02
8	0.178377E-04	-0.917725E-02	0.161556E+01	-0.968828E+02
9	0.309824E-04	-0.190293E-01	0.392979E+01	-0.271858E+03

Table 2.1

Transmissivities *Tr'* at half-decade intervals from 10^{-9} kgm^{-2} to 10^{+3} kgm^{-2} for the terms ① to ⑧ in Fig 2.1, respectively.

1.000000	1.000000	1.000000	0.999999	0.999998	0.999994	0.999982	0.999942	0.999819	0.999434
0.998280	0.995067	0.987393	0.973997	0.959815	0.949495	0.941013	0.933567	0.927381	0.923460
0.920901	0.915737	0.906090	0.894397	0.886219					

0.000001	0.000003	0.000007	0.000021	0.000064	0.000199	0.000624	0.001921	0.005716	0.015889
0.039565	0.085871	0.163718	0.280355	0.436379	0.616295	0.785396	0.907413	0.971860	0.995187
0.999727	0.999998	1.000000	1.000000	1.000000					

0.000000	0.000001	0.000001	0.000001	0.000002	0.000005	0.000014	0.000043	0.000136	0.000425
0.001318	0.003973	0.011315	0.029286	0.066541	0.131776	0.232392	0.373559	0.548906	0.728973
0.871597	0.955796	0.991047	0.999316	0.999991					

0.000000	0.000000	0.000000	0.000000	0.000001	0.000001	0.000002	0.000004	0.000009	0.000026
0.000080	0.000250	0.000774	0.002326	0.006601	0.017021	0.038865	0.078960	0.145342	0.245687
0.383204	0.549012	0.717914	0.858247	0.948660					

0.000001	0.000001	0.000001	0.000001	0.000001	0.000001	0.000001	0.000001	0.000002	0.000002
0.000002	0.000003	0.000006	0.000017	0.000052	0.000162	0.000507	0.001569	0.004701	0.013256
0.033742	0.075159	0.146773	0.257595	0.414612					

0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000001	0.000001	0.000002	0.000002
0.000004	0.000011	0.000032	0.000098	0.000305	0.000945	0.002846	0.008119	0.021162	0.048976
0.099854	0.182165	0.304880	0.472012	0.667507					

0.000001	0.000002	0.000002	0.000003	0.000008	0.000023	0.000070	0.000218	0.000680	0.002092
0.006194	0.017028	0.041440	0.086449	0.156336	0.252392	0.369201	0.491601	0.602731	0.695892
0.774360	0.842258	0.899450	0.942593	0.969193					

0.000001	0.000001	0.000002	0.000004	0.000011	0.000033	0.000101	0.000319	0.000998	0.003088
0.009236	0.025764	0.063415	0.130036	0.220852	0.326688	0.444288	0.565652	0.677635	0.772631
0.853045	0.922197	0.970659	0.993562	0.999466					

Table 2.2

As Table 2.1 but for transmissivities *Tr*.

0.999999	0.999997	0.999993	0.999979	0.999936	0.999801	0.999376	0.998079	0.994284	0.984111
0.960435	0.914129	0.836292	0.719645	0.563621	0.383705	0.214604	0.092587	0.028140	0.004813
0.000273	0.000002	0.000000	0.000000	0.000000					

1.000000	0.999999	0.999999	0.999999	0.999998	0.999995	0.999986	0.999957	0.999864	0.999575
0.998682	0.996027	0.988685	0.970714	0.933459	0.868224	0.767608	0.626441	0.451094	0.271027
0.128403	0.044202	0.008953	0.000684	0.000009					

1.000000	1.000000	1.000000	1.000000	0.999999	0.999999	0.999998	0.999996	0.999991	0.999974
0.999920	0.999750	0.999226	0.997674	0.993399	0.982979	0.961135	0.921040	0.854658	0.754313
0.616796	0.450988	0.282086	0.141753	0.051340					

0.999999	0.999999	0.999999	0.999999	0.999999	0.999999	0.999999	0.999999	0.999998	0.999998
0.999998	0.999997	0.999994	0.999983	0.999948	0.999838	0.999493	0.998431	0.995299	0.986744
0.966258	0.924841	0.853227	0.742405	0.585388					

1.000000	1.000000	1.000000	1.000000	1.000000	1.000000	0.999999	0.999999	0.999998	0.999998
0.999996	0.999989	0.999968	0.999902	0.999695	0.999055	0.997154	0.991881	0.978838	0.951024
0.900146	0.817835	0.695120	0.527988	0.332493					

0.999999	0.999998	0.999998	0.999997	0.999992	0.999977	0.999930	0.999782	0.999320	0.997908
0.993806	0.982972	0.958560	0.913551	0.843664	0.747608	0.630799	0.508399	0.397269	0.304108
0.225640	0.157742	0.100550	0.057407	0.030807					

0.999999	0.999999	0.999998	0.999996	0.999989	0.999967	0.999899	0.999681	0.999002	0.996912
0.990764	0.974236	0.936585	0.869964	0.779148	0.673112	0.555712	0.434348	0.322365	0.227369
0.146955	0.077803	0.029342	0.006438	0.000534					

0.159732	0.159732	0.159732	0.159731	0.159730	0.159724	0.159706	0.159650	0.159474	0.158927
0.157284	0.152713	0.141800	0.122774	0.102678	0.088127	0.076221	0.065748	0.057276	0.052070
0.048772	0.042168	0.029829	0.014874	0.004415					

Table 2.3 - Transmissivities for 1C code

Transmissivities at 1/12 decade intervals within the following ranges:

H_2OS 10^{-8} - 10^{+4}
H_2OF 10^{-6} - 10^{+6}
H_2OL 10^{-7} - 10^{+5}
CO_2 10^{-9} - 10^{+3}
O_3 10^{-9} - 10^{+3}
N_2O 10^{-9} - 10^{+3}
CH_4 10^{-9} - 10^{+3}

```
!
!    GAS: CARBON DIOXIDE
!    AT PRESSURE =  2.500E+04 Pa  AND TEMPERATURE =2.250E+02K.
!    IN BAND     3:    1.250E-05m TO   1.818E-05m.

  9.99999988E-01,9.99999986E-01,9.99999983E-01,9.99999971E-01,
  9.99999954E-01,9.99999930E-01,9.99999912E-01,9.99999884E-01,
  9.99999854E-01,9.99999807E-01,9.99999751E-01,9.99999690E-01,
  9.99999610E-01,9.99999511E-01,9.99999396E-01,9.99999258E-01,
  9.99999087E-01,9.99998876E-01,9.99998618E-01,9.99998301E-01,
  9.99997916E-01,9.99997438E-01,9.99996870E-01,9.99996170E-01,
  9.99995321E-01,9.99994285E-01,9.99992997E-01,9.99991444E-01,
  9.99989543E-01,9.99987236E-01,9.99984436E-01,9.99981055E-01,
  9.99976954E-01,9.99971942E-01,9.99965874E-01,9.99958565E-01,
  9.99949614E-01,9.99938850E-01,9.99925811E-01,9.99909891E-01,
  9.99890836E-01,9.99867805E-01,9.99839951E-01,9.99806275E-01,
  9.99765483E-01,9.99716203E-01,9.99656781E-01,9.99585134E-01,
  9.99498818E-01,9.99394853E-01,9.99269984E-01,9.99120062E-01,
  9.98940550E-01,9.98725977E-01,9.98470304E-01,9.98166418E-01,
  9.97806763E-01,9.97382666E-01,9.96885029E-01,9.96304178E-01,
  9.95630090E-01,9.94852636E-01,9.93961839E-01,9.92947902E-01,
  9.91801156E-01,9.90511974E-01,9.89070378E-01,9.87465457E-01,
  9.85685765E-01,9.83718352E-01,9.81549181E-01,9.79162868E-01,
  9.76541940E-01,9.73665680E-01,9.70509408E-01,9.67043636E-01,
  9.63233970E-01,9.59041934E-01,9.54425077E-01,9.49338136E-01,
  9.43733547E-01,9.37562103E-01,9.30774735E-01,9.23323584E-01,
  9.15164049E-01,9.06257336E-01,8.96573179E-01,8.86092519E-01,
  8.74810565E-01,8.62738830E-01,8.49907208E-01,8.36364305E-01,
  8.22177404E-01,8.07431779E-01,7.92229111E-01,7.76684645E-01,
  7.60923373E-01,7.45074319E-01,7.29261809E-01,7.13595401E-01,
  6.98158190E-01,6.82996197E-01,6.68111864E-01,6.53464705E-01,
  6.38980517E-01,6.24568169E-01,6.10137760E-01,5.95615550E-01,
  5.80949404E-01,5.66107394E-01,5.51071946E-01,5.35834290E-01,
  5.20393103E-01,5.04754004E-01,4.88931265E-01,4.72949335E-01,
  4.56844799E-01,4.40668714E-01,4.24489641E-01,4.08395479E-01,
  3.92492493E-01,3.76900244E-01,3.61740684E-01,3.47123580E-01,
  3.33130586E-01,3.19802079E-01,3.07130593E-01,2.95062179E-01,
  2.83506583E-01,2.72353773E-01,2.61492258E-01,2.50825392E-01,
  2.40281025E-01,2.29812844E-01,2.19394300E-01,2.09007929E-01,
  1.98635840E-01,1.88254891E-01,1.77838306E-01,1.67361776E-01,
  1.56810799E-01,1.46186430E-01,1.35508279E-01,1.24814373E-01,
  1.14158659E-01
!
!     GAS: CARBON DIOXIDE
!     AT PRESSURE =  2.500E+04 Pa  AND TEMPERATURE =  2.250E+02 K.
!     IN BAND     5:    1.010E-05m TO   1.136E-05m.
```

```
  1.00000000E+00,1.00000000E+00,1.00000000E+00,1.00000000E+00,
  1.00000000E+00,1.00000000E+00,1.00000000E+00,1.00000000E+00,
  1.00000000E+00,1.00000000E+00,1.00000000E+00,1.00000000E+00,
  1.00000000E+00,1.00000000E+00,1.00000000E+00,1.00000000E+00,
  1.00000000E+00,1.00000000E+00,1.00000000E+00,1.00000000E+00,
  1.00000000E+00,1.00000000E+00,1.00000000E+00,1.00000000E+00,
  1.00000000E+00,1.00000000E+00,1.00000000E+00,1.00000000E+00,
  1.00000000E+00,1.00000000E+00,1.00000000E+00,1.00000000E+00,
  1.00000000E+00,1.00000000E+00,1.00000000E+00,1.00000000E+00,
  1.00000000E+00,1.00000000E+00,1.00000000E+00,1.00000000E+00,
  1.00000000E+00,1.00000000E+00,1.00000000E+00,1.00000000E+00,
  1.00000000E+00,1.00000000E+00,1.00000000E+00,1.00000000E+00,
  1.00000000E+00,1.00000000E+00,1.00000000E+00,1.00000000E+00,
  1.00000000E+00,1.00000000E+00,1.00000000E+00,1.00000000E+00,
  1.00000000E+00,9.99999999E-01,9.99999997E-01,9.99999994E-01,
  9.99999988E-01,9.99999984E-01,9.99999976E-01,9.99999965E-01,
  9.99999948E-01,9.99999919E-01,9.99999873E-01,9.99999818E-01,
  9.99999757E-01,9.99999682E-01,9.99999595E-01,9.99999486E-01,
  9.99999348E-01,9.99999199E-01,9.99999005E-01,9.99998761E-01,
  9.99998466E-01,9.99998104E-01,9.99997643E-01,9.99997104E-01,
  9.99996430E-01,9.99995615E-01,9.99994621E-01,9.99993401E-01,
  9.99991895E-01,9.99990068E-01,9.99987819E-01,9.99985092E-01,
  9.99981788E-01,9.99977686E-01,9.99972761E-01,9.99966743E-01,
  9.99959403E-01,9.99950536E-01,9.99939660E-01,9.99926549E-01,
  9.99910608E-01,9.99891432E-01,9.99868195E-01,9.99840270E-01,
  9.99806366E-01,9.99765257E-01,9.99715486E-01,9.99655391E-01,
  9.99582696E-01,9.99494982E-01,9.99388771E-01,9.99260405E-01,
  9.99105404E-01,9.98918409E-01,9.98693047E-01,9.98421952E-01,
  9.98095731E-01,9.97704157E-01,9.97234608E-01,9.96673102E-01,
  9.96003231E-01,9.95206323E-01,9.94261770E-01,9.93146570E-01,
  9.91836345E-01,9.90304991E-01,9.88525767E-01,9.86472156E-01,
  9.84118496E-01,9.81440732E-01,9.78416559E-01,9.75024453E-01,
  9.71243111E-01,9.67048377E-01,9.62411382E-01,9.57295388E-01,
  9.51654704E-01,9.45433786E-01,9.38568075E-01,9.30984086E-01,
  9.22600152E-01,9.13326640E-01,9.03066427E-01,8.91714807E-01,
  8.79161364E-01,8.65291660E-01,8.49990018E-01,8.33144063E-01,
  8.14650050E-01
!
!     GAS: CARBON DIOXIDE
!     AT PRESSURE =  2.500E+04 Pa  AND TEMPERATURE =  2.250E+02 K.
!     IN BAND     6:    8.929E-06m TO   1.010E-05m.

  1.00000000E+00,1.00000000E+00,1.00000000E+00,1.00000000E+00,
  1.00000000E+00,1.00000000E+00,1.00000000E+00,1.00000000E+00,
  1.00000000E+00,1.00000000E+00,1.00000000E+00,1.00000000E+00,
  1.00000000E+00,1.00000000E+00,1.00000000E+00,1.00000000E+00,
  1.00000000E+00,1.00000000E+00,1.00000000E+00,1.00000000E+00,
```

```
  1.00000000E+00,1.00000000E+00,1.00000000E+00,1.00000000E+00,
  1.00000000E+00,1.00000000E+00,1.00000000E+00,1.00000000E+00,
  1.00000000E+00,1.00000000E+00,1.00000000E+00,1.00000000E+00,
  1.00000000E+00,1.00000000E+00,1.00000000E+00,1.00000000E+00,
  1.00000000E+00,1.00000000E+00,1.00000000E+00,1.00000000E+00,
  1.00000000E+00,1.00000000E+00,1.00000000E+00,1.00000000E+00,
  1.00000000E+00,1.00000000E+00,1.00000000E+00,1.00000000E+00,
  1.00000000E+00,1.00000000E+00,1.00000000E+00,9.99999999E-01,
  9.99999999E-01,9.99999998E-01,9.99999997E-01,9.99999996E-01,
  9.99999994E-01,9.99999990E-01,9.99999988E-01,9.99999980E-01,
  9.99999966E-01,9.99999952E-01,9.99999929E-01,9.99999876E-01,
  9.99999828E-01,9.99999776E-01,9.99999713E-01,9.99999636E-01,
  9.99999535E-01,9.99999417E-01,9.99999280E-01,9.99999100E-01,
  9.99998885E-01,9.99998614E-01,9.99998282E-01,9.99997877E-01,
  9.99997389E-01,9.99996784E-01,9.99996050E-01,9.99995150E-01,
  9.99994041E-01,9.99992701E-01,9.99991077E-01,9.99989104E-01,
  9.99986663E-01,9.99983664E-01,9.99980024E-01,9.99975573E-01,
  9.99970157E-01,9.99963583E-01,9.99955631E-01,9.99946017E-01,
  9.99934346E-01,9.99920218E-01,9.99903148E-01,9.99882463E-01,
  9.99857405E-01,9.99827151E-01,9.99790604E-01,9.99746414E-01,
  9.99693016E-01,9.99628124E-01,9.99549785E-01,9.99455072E-01,
  9.99340778E-01,9.99202741E-01,9.99036087E-01,9.98835352E-01,
  9.98593614E-01,9.98302816E-01,9.97953593E-01,9.97535168E-01,
  9.97034557E-01,9.96437388E-01,9.95727005E-01,9.94884810E-01,
  9.93890611E-01,9.92722413E-01,9.91356846E-01,9.89770469E-01,
  9.87939392E-01,9.85840747E-01,9.83453353E-01,9.80757396E-01,
  9.77733906E-01,9.74364548E-01,9.70628171E-01,9.66500235E-01,
  9.61949536E-01,9.56937111E-01,9.51416262E-01,9.45332545E-01,
  9.38625155E-01,9.31227625E-01,9.23067732E-01,9.14069080E-01,
  9.04150985E-01,8.93231150E-01,8.81225945E-01,8.68054399E-01,
  8.53640913E-01,8.37919845E-01,8.20840593E-01,8.02374592E-01,
  7.82520859E-01
!
!     CONTINUUM TYPE: FOREIGN-BRDND H2O
!     AT PRESSURE =  5.000E+04 Pa  AND TEMPERATURE =  2.500E+02 K.
!     IN BAND     1:    2.500E-05m TO   1.000E-03m.

  9.99999803E-01,9.99999761E-01,9.99999710E-01,9.99999649E-01,
  9.99999575E-01,9.99999485E-01,9.99999376E-01,9.99999244E-01,
  9.99999084E-01,9.99998890E-01,9.99998655E-01,9.99998371E-01,
  9.99998026E-01,9.99997609E-01,9.99997103E-01,9.99996490E-01,
  9.99995748E-01,9.99994849E-01,9.99993760E-01,9.99992440E-01,
  9.99990842E-01,9.99988906E-01,9.99986560E-01,9.99983720E-01,
  9.99980279E-01,9.99976112E-01,9.99971066E-01,9.99964954E-01,
  9.99957554E-01,9.99948595E-01,9.99937748E-01,9.99924618E-01,
  9.99908726E-01,9.99889494E-01,9.99866222E-01,9.99838067E-01,
  9.99804009E-01,9.99762817E-01,9.99713006E-01,9.99652783E-01,
  9.99579987E-01,9.99492011E-01,9.99385714E-01,9.99257314E-01,
  9.99102259E-01,9.98915076E-01,9.98689191E-01,9.98416715E-01,
  9.98088194E-01,9.97692309E-01,9.97215538E-01,9.96641745E-01,
  9.95951723E-01,9.95122662E-01,9.94127551E-01,9.92934511E-01,
  9.91506058E-01,9.89798319E-01,9.87760187E-01,9.85332499E-01,
  9.82447197E-01,9.79026647E-01,9.74983107E-01,9.70218515E-01,
  9.64624685E-01,9.58084070E-01,9.50471145E-01,9.41654490E-01,
  9.31499415E-01,9.19870989E-01,9.06637103E-01,8.91671333E-01,
  8.74855296E-01,8.56081288E-01,8.35256283E-01,8.12309625E-01,
  7.87206543E-01,7.59967619E-01,7.30691581E-01,6.99574326E-01,
  6.66915018E-01,6.33100604E-01,5.98561952E-01,5.63701211E-01,
  5.28797379E-01,4.93911780E-01,4.58823488E-01,4.23022183E-01,
  3.85779026E-01,3.46314258E-01,3.04082857E-01,2.59156188E-01,
  2.12561818E-01,1.66343317E-01,1.23173653E-01,8.56252083E-02,
  5.54441316E-02,3.31660167E-02,1.81762446E-02,9.08567492E-03,
  4.20711715E-03,1.96199878E-03,1.13443410E-03,9.55206554E-04,
  1.04300259E-03,1.27320357E-03,1.66131162E-03,2.31256456E-03,
  3.42863293E-03,5.22712175E-03,7.01389154E-03,5.90741718E-03,
  2.78526046E-03,9.15395614E-04,2.31199246E-04,4.37463557E-05,
  5.84568305E-06,5.13309066E-07,2.71571744E-08,7.78059323E-10,
  1.05857856E-11,5.82774625E-14,1.06973627E-16,5.18315166E-20,
  0.0,0.0,0.0,0.0,
  0.0,0.0,0.0,0.0,
  0.0,0.0,0.0,0.0,
  0.0,0.0,0.0,0.0,
  0.0,0.0,0.0,0.0,
  0.0
!
!     CONTINUUM TYPE: FOREIGN-BRDND H2O
!     AT PRESSURE =  5.000E+04 Pa  AND TEMPERATURE =  2.500E+02 K.
!     IN BAND     2:    1.818E-05m TO   2.500E-05m.

  9.99999994E-01,9.99999993E-01,9.99999991E-01,9.99999990E-01,
  9.99999988E-01,9.99999985E-01,9.99999982E-01,9.99999978E-01,
  9.99999973E-01,9.99999967E-01,9.99999961E-01,9.99999952E-01,
  9.99999942E-01,9.99999930E-01,9.99999915E-01,9.99999897E-01,
  9.99999875E-01,9.99999849E-01,9.99999817E-01,9.99999778E-01,
  9.99999731E-01,9.99999674E-01,9.99999605E-01,9.99999522E-01,
  9.99999420E-01,9.99999298E-01,9.99999149E-01,9.99998969E-01,
  9.99998751E-01,9.99998487E-01,9.99998167E-01,9.99997779E-01,
  9.99997310E-01,9.99996741E-01,9.99996051E-01,9.99995216E-01,
  9.99994204E-01,9.99992978E-01,9.99991494E-01,9.99989695E-01,
  9.99987515E-01,9.99984875E-01,9.99981677E-01,9.99977804E-01,
  9.99973111E-01,9.99967428E-01,9.99960543E-01,9.99952205E-01,
  9.99942107E-01,9.99929876E-01,9.99915066E-01,9.99897131E-01,
  9.99875414E-01,9.99849119E-01,9.99817283E-01,9.99778742E-01,
  9.99732086E-01,9.99675611E-01,9.99607259E-01,9.99524541E-01,
  9.99424452E-01,9.99303362E-01,9.99156891E-01,9.98979750E-01,
  9.98765558E-01,9.98506619E-01,9.98193647E-01,9.97815448E-01,
  9.97358529E-01,9.96806637E-01,9.96140202E-01,9.95335689E-01,
  9.94364811E-01,9.93193617E-01,9.91781409E-01,9.90079491E-01,
  9.88029747E-01,9.85563054E-01,9.82597576E-01,9.79036973E-01,
  9.74768608E-01,9.69661905E-01,9.63566930E-01,9.56313524E-01,
  9.47711278E-01,9.37550869E-01,9.25607500E-01,9.11647184E-01,
  8.95436787E-01,8.76758569E-01,8.55429719E-01,8.31326647E-01,
  8.04412931E-01,7.74767009E-01,7.42603933E-01,7.08282041E-01,
  6.72283881E-01,6.35162570E-01,5.97452113E-01,5.59554504E-01,
  5.21633925E-01,4.83561349E-01,4.44946889E-01,4.05270041E-01,
  3.64077688E-01,3.21192427E-01,2.76872250E-01,2.31883406E-01,
  1.87466371E-01,1.45194598E-01,1.06747506E-01,7.36414606E-02,
  4.69679112E-02,2.71742052E-02,1.39280477E-02,6.14468875E-03,
  2.25501885E-03,6.61277350E-04,1.47770867E-04,2.37841362E-05,
  2.57806003E-06,1.73653985E-07,6.59794913E-09,1.25713406E-10,
  1.04016657E-12,3.13262962E-15,2.76684061E-18,5.50884332E-22,
  1.79746928E-26,0.0,0.0,0.0,
  0.0,0.0,0.0,0.0,
  0.0,0.0,0.0,0.0,
  0.0,0.0,0.0,0.0,
  0.0
!
!     CONTINUUM TYPE: FOREIGN-BRDND H2O
!     AT PRESSURE =  5.000E+04 Pa  AND TEMPERATURE =  2.500E+02 K.
!     IN BAND     3:    1.250E-05m TO   1.818E-05m.

  1.00000000E+00,1.00000000E+00,1.00000000E+00,1.00000000E+00,
  9.99999999E-01,9.99999999E-01,9.99999999E-01,9.99999999E-01,
  9.99999999E-01,9.99999999E-01,9.99999998E-01,9.99999998E-01,
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  9.99999998E-01,9.99999997E-01,9.99999997E-01,9.99999996E-01,
  9.99999995E-01,9.99999994E-01,9.99999992E-01,9.99999991E-01,
  9.99999989E-01,9.99999987E-01,9.99999984E-01,9.99999980E-01,
  9.99999976E-01,9.99999971E-01,9.99999965E-01,9.99999958E-01,
  9.99999949E-01,9.99999938E-01,9.99999925E-01,9.99999909E-01,
  9.99999890E-01,9.99999867E-01,9.99999838E-01,9.99999804E-01,
  9.99999763E-01,9.99999713E-01,9.99999652E-01,9.99999578E-01,
  9.99999489E-01,9.99999381E-01,9.99999250E-01,9.99999091E-01,
  9.99998899E-01,9.99998666E-01,9.99998384E-01,9.99998043E-01,
  9.99997629E-01,9.99997127E-01,9.99996519E-01,9.99995783E-01,
  9.99994892E-01,9.99993811E-01,9.99992503E-01,9.99990918E-01,
  9.99988998E-01,9.99986672E-01,9.99983856E-01,9.99980444E-01,
  9.99976313E-01,9.99971310E-01,9.99965252E-01,9.99957916E-01,
  9.99949036E-01,9.99938285E-01,9.99925273E-01,9.99909524E-01,
  9.99890466E-01,9.99867407E-01,9.99839510E-01,9.99805767E-01,
  9.99764957E-01,9.99715610E-01,9.99655947E-01,9.99583828E-01,
  9.99496668E-01,9.99391355E-01,9.99264137E-01,9.99110501E-01,
  9.98925016E-01,9.98701160E-01,9.98431102E-01,9.98105464E-01,
  9.97713023E-01,9.97240383E-01,9.96671587E-01,9.95987677E-01,
  9.95166205E-01,9.94180683E-01,9.93000000E-01,9.91587797E-01,
  9.89901843E-01,9.87893441E-01,9.85506941E-01,9.82679451E-01,
  9.79340850E-01,9.75414264E-01,9.70817181E-01,9.65463429E-01,
  9.59266280E-01,9.52142952E-01,9.44020688E-01,9.34844333E-01,
  9.24584984E-01,9.13248514E-01,9.00882138E-01,8.87576176E-01,
  8.73457638E-01,8.58673120E-01,8.43360254E-01,8.27610535E-01,
  8.11431380E-01,7.94719054E-01,7.77254992E-01,7.58731228E-01,
  7.38799422E-01,7.17126009E-01,6.93435291E-01,6.67531332E-01,
  6.39298504E-01,6.08681660E-01,5.75643040E-01,5.40105025E-01,
  5.01911027E-01,4.60854084E-01,4.16800688E-01,3.69884178E-01,
  3.20688028E-01,2.70325403E-01,2.20361419E-01,1.72604253E-01,
  1.28854297E-01,9.06935936E-02,5.93220464E-02,3.53861775E-02,
  1.87943652E-02,8.62735922E-03,3.30089149E-03,1.00787084E-03,
  2.33313615E-04,3.85783185E-05,4.25183756E-06,2.88008380E-07,
  1.08815406E-08
!
!     CONTINUUM TYPE: FOREIGN-BRDND H2O
!     AT PRESSURE =  5.000E+04 Pa  AND TEMPERATURE =  2.500E+02 K.
!     IN BAND     4:    1.136E-05m TO   1.250E-05m.

  1.00000000E+00,1.00000000E+00,1.00000000E+00,1.00000000E+00,
  1.00000000E+00,1.00000000E+00,1.00000000E+00,1.00000000E+00,
  1.00000000E+00,1.00000000E+00,1.00000000E+00,1.00000000E+00,
  1.00000000E+00,1.00000000E+00,1.00000000E+00,1.00000000E+00,
  1.00000000E+00,1.00000000E+00,1.00000000E+00,1.00000000E+00,
  1.00000000E+00,1.00000000E+00,1.00000000E+00,1.00000000E+00,
  9.99999999E-01,9.99999999E-01,9.99999999E-01,9.99999999E-01,
  9.99999999E-01,9.99999999E-01,9.99999998E-01,9.99999998E-01,
  9.99999997E-01,9.99999997E-01,9.99999996E-01,9.99999995E-01,
  9.99999994E-01,9.99999993E-01,9.99999992E-01,9.99999990E-01,
  9.99999988E-01,9.99999985E-01,9.99999982E-01,9.99999978E-01,
  9.99999973E-01,9.99999968E-01,9.99999961E-01,9.99999953E-01,
  9.99999943E-01,9.99999931E-01,9.99999916E-01,9.99999898E-01,
  9.99999877E-01,9.99999851E-01,9.99999819E-01,9.99999781E-01,
  9.99999735E-01,9.99999679E-01,9.99999611E-01,9.99999529E-01,
  9.99999429E-01,9.99999308E-01,9.99999162E-01,9.99998985E-01,
  9.99998770E-01,9.99998510E-01,9.99998194E-01,9.99997812E-01,
  9.99997350E-01,9.99996789E-01,9.99996110E-01,9.99995287E-01,
  9.99994290E-01,9.99993082E-01,9.99991619E-01,9.99989846E-01,
  9.99987699E-01,9.99985097E-01,9.99981945E-01,9.99978126E-01,
  9.99973500E-01,9.99967895E-01,9.99961106E-01,9.99952881E-01,
  9.99942917E-01,9.99930846E-01,9.99916225E-01,9.99898513E-01,
  9.99877059E-01,9.99851072E-01,9.99819597E-01,9.99781476E-01,
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  9.99735307E-01,9.99679394E-01,9.99611685E-01,9.99529696E-01,
  9.99430421E-01,9.99310223E-01,9.99164702E-01,9.98988534E-01,
  9.98775280E-01,9.98517156E-01,9.98204752E-01,9.97826703E-01,
  9.97369285E-01,9.96815946E-01,9.96146729E-01,9.95337599E-01,
  9.94359637E-01,9.93178086E-01,9.91751236E-01,9.90029121E-01,
  9.87952002E-01,9.85448638E-01,9.82434314E-01,9.78808655E-01,
  9.74453219E-01,9.69228979E-01,9.62973747E-01,9.55499807E-01,
  9.46591912E-01,9.36006103E-01,9.23469623E-01,9.08682438E-01,
  8.91320573E-01,8.71041818E-01,8.47493985E-01,8.20326247E-01,
  7.89204109E-01,7.53829697E-01,7.13969253E-01,6.69491558E-01,
  6.20419635E-01,5.66994702E-01,5.09746339E-01,4.49551899E-01,
  3.87663608E-01,3.25680180E-01,2.65450173E-01,2.08909246E-01,
  1.57869657E-01,1.13796111E-01,7.76123524E-02,4.95815551E-02,
  2.92893307E-02
!
!     CONTINUUM TYPE: FOREIGN-BRDND H2O
!     AT PRESSURE =  5.000E+04 Pa  AND TEMPERATURE =  2.500E+02 K.
!     IN BAND     8:    6.667E-06m TO   8.333E-06m.

  9.99999994E-01,9.99999993E-01,9.99999992E-01,9.99999990E-01,
  9.99999988E-01,9.99999986E-01,9.99999982E-01,9.99999979E-01,
  9.99999974E-01,9.99999969E-01,9.99999962E-01,9.99999954E-01,
  9.99999945E-01,9.99999933E-01,9.99999919E-01,9.99999901E-01,
  9.99999881E-01,9.99999855E-01,9.99999825E-01,9.99999788E-01,
  9.99999743E-01,9.99999688E-01,9.99999622E-01,9.99999542E-01,
  9.99999445E-01,9.99999328E-01,9.99999186E-01,9.99999014E-01,
  9.99998805E-01,9.99998553E-01,9.99998247E-01,9.99997876E-01,
  9.99997427E-01,9.99996883E-01,9.99996225E-01,9.99995427E-01,
  9.99994461E-01,9.99993291E-01,9.99991875E-01,9.99990160E-01,
  9.99988085E-01,9.99985573E-01,9.99982534E-01,9.99978857E-01,
  9.99974410E-01,9.99969033E-01,9.99962533E-01,9.99954680E-01,
  9.99945195E-01,9.99933742E-01,9.99919921E-01,9.99903248E-01,
  9.99883146E-01,9.99858920E-01,9.99829738E-01,9.99794608E-01,
  9.99752340E-01,9.99701515E-01,9.99640442E-01,9.99567112E-01,
  9.99479139E-01,9.99373703E-01,9.99247475E-01,9.99096545E-01,
  9.98916333E-01,9.98701497E-01,9.98445836E-01,9.98142196E-01,
  9.97782364E-01,9.97356987E-01,9.96855492E-01,9.96266053E-01,
  9.95575583E-01,9.94769816E-01,9.93833491E-01,9.92750681E-01,
  9.91505347E-01,9.90082169E-01,9.88467734E-01,9.86652131E-01,
  9.84630931E-01,9.82407423E-01,9.79994850E-01,9.77418314E-01,
  9.74715879E-01,9.71938329E-01,9.69147083E-01,9.66409650E-01,
  9.63792631E-01,9.61352911E-01,9.59129056E-01,9.57135440E-01,
  9.55361186E-01,9.53773654E-01,9.52323477E-01,9.50947278E-01,
  9.49566640E-01,9.48086798E-01,9.46400958E-01,9.44403273E-01,
  9.42006555E-01,9.39155764E-01,9.35829637E-01,9.32028739E-01,
  9.27753306E-01,9.22977150E-01,9.17626066E-01,9.11572218E-01,
  9.04654236E-01,8.96723211E-01,8.87701026E-01,8.77629088E-01,
  8.66689383E-01,8.55189818E-01,8.43511157E-01,8.32016476E-01,
  8.20929919E-01,8.10205474E-01,7.99421472E-01,7.87739917E-01,
  7.73958931E-01,7.56660906E-01,7.34430604E-01,7.06097906E-01,
  6.70947635E-01,6.28842890E-01,5.80242149E-01,5.26149790E-01,
  4.68058690E-01,4.07884986E-01,3.47826174E-01,2.90088810E-01,
  2.36531998E-01,1.88370859E-01,1.46099169E-01,1.09683323E-01,
  7.89118418E-02,5.36652771E-02,3.39271560E-02,1.95618685E-02,
  1.00667345E-02,4.50942632E-03,1.70694899E-03,5.26754726E-04,
  1.26844939E-04

!
!     GAS: WATER VAPOUR
!     AT PRESSURE =  5.000E+04 Pa  AND TEMPERATURE =  2.500E+02 K.
!     IN BAND     1:    2.500E-05m TO   1.000E-03m.
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  9.99964653E-01,9.99957004E-01,9.99947721E-01,9.99936480E-01,
  9.99922892E-01,9.99906373E-01,9.99886333E-01,9.99862138E-01,
  9.99832853E-01,9.99797452E-01,9.99754745E-01,9.99703052E-01,
  9.99640416E-01,9.99564750E-01,9.99473590E-01,9.99363724E-01,
  9.99231381E-01,9.99071996E-01,9.98880539E-01,9.98650652E-01,
  9.98375717E-01,9.98047064E-01,9.97655088E-01,9.97189627E-01,
  9.96638704E-01,9.95988563E-01,9.95224831E-01,9.94331715E-01,
  9.93292618E-01,9.92089554E-01,9.90704413E-01,9.89118315E-01,
  9.87310589E-01,9.85261785E-01,9.82950057E-01,9.80353545E-01,
  9.77448349E-01,9.74209819E-01,9.70610406E-01,9.66620775E-01,
  9.62208949E-01,9.57338754E-01,9.51971697E-01,9.46065358E-01,
  9.39575071E-01,9.32454630E-01,9.24656420E-01,9.16131993E-01,
  9.06831704E-01,8.96705076E-01,8.85700156E-01,8.73764606E-01,
  8.60846398E-01,8.46895623E-01,8.31865305E-01,8.15713388E-01,
  7.98404336E-01,7.79911472E-01,7.60218823E-01,7.39323782E-01,
  7.17239492E-01,6.93997485E-01,6.69649953E-01,6.44271637E-01,
  6.17959372E-01,5.90830336E-01,5.63017240E-01,5.34662519E-01,
  5.05911025E-01,4.76903628E-01,4.47771180E-01,4.18632063E-01,
  3.89593372E-01,3.60756635E-01,3.32227036E-01,3.04121463E-01,
  2.76573481E-01,2.49732646E-01,2.23760308E-01,1.98824511E-01,
  1.75096246E-01,1.52746784E-01,1.31943051E-01,1.12838317E-01,
  9.55549804E-02,8.01615588E-02,6.66511743E-02,5.49325102E-02,
  4.48417275E-02,3.61742974E-02,2.87259393E-02,2.23276859E-02,
  1.68639350E-02,1.22704012E-02,8.51577680E-03,5.57426207E-03,
  3.39847709E-03,1.90258403E-03,9.62326803E-04,4.31622707E-04,
  1.67984394E-04,5.53171845E-05,1.49741763E-05,3.23327487E-06,
  5.46959322E-07,7.60753576E-08,1.09129218E-08,2.02786520E-09,
  3.99666832E-10,6.43664354E-11,7.53364184E-12,5.91488915E-13,
  2.84459083E-14,7.50603105E-16,9.52461413E-18,4.96548770E-20,
  8.80493922E-23,4.22864005E-26,4.17493887E-30,0.0,
  0.0,.00000000E+00,.00000000E+00,.00000000E+00,
  .00000000E+00,.00000000E+00,.00000000E+00,.00000000E+00,
  .00000000E+00,.00000000E+00,.00000000E+00,.00000000E+00,
  .00000000E+00,.00000000E+00,.00000000E+00,.00000000E+00,
  .00000000E+00,.00000000E+00,.00000000E+00,.00000000E+00,
  .00000000E+00,.00000000E+00,.00000000E+00,.00000000E+00,
  .00000000E+00
!
!     GAS: WATER VAPOUR
!     AT PRESSURE =  5.000E+04 Pa  AND TEMPERATURE =  2.500E+02 K.
!     IN BAND     2:    1.818E-05m TO   2.500E-05m.

  9.99999548E-01,9.99999441E-01,9.99999290E-01,9.99999090E-01,
  9.99998852E-01,9.99998581E-01,9.99998261E-01,9.99997858E-01,
  9.99997361E-01,9.99996757E-01,9.99996003E-01,9.99995096E-01,
  9.99993998E-01,9.99992680E-01,9.99991121E-01,9.99989218E-01,
  9.99986878E-01,9.99984018E-01,9.99980547E-01,9.99976362E-01,
  9.99971257E-01,9.99965025E-01,9.99957453E-01,9.99948267E-01,
  9.99937189E-01,9.99923762E-01,9.99907577E-01,9.99887894E-01,
  9.99864054E-01,9.99835219E-01,9.99800113E-01,9.99757695E-01,
  9.99706571E-01,9.99644767E-01,9.99570377E-01,9.99480532E-01,
  9.99372086E-01,9.99241938E-01,9.99085549E-01,9.98897834E-01,
  9.98673559E-01,9.98405650E-01,9.98086573E-01,9.97707346E-01,
  9.97258582E-01,9.96729014E-01,9.96107177E-01,9.95378976E-01,
  9.94530731E-01,9.93546643E-01,9.92409949E-01,9.91101819E-01,
  9.89603184E-01,9.87892051E-01,9.85945809E-01,9.83740392E-01,
  9.81251934E-01,9.78455111E-01,9.75327299E-01,9.71845494E-01,
  9.67988740E-01,9.63736640E-01,9.59069204E-01,9.53966600E-01,
  9.48407851E-01,9.42370206E-01,9.35828734E-01,9.28754792E-01,
  9.21116339E-01,9.12876106E-01,9.03992234E-01,8.94416395E-01,
  8.84092682E-01,8.72955166E-01,8.60925912E-01,8.47914727E-01,
  8.33820577E-01,8.18535789E-01,8.01951103E-01,7.83961285E-01,
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  7.64469683E-01,7.43391546E-01,7.20656845E-01,6.96213422E-01,
  6.70031005E-01,6.42104947E-01,6.12460026E-01,5.81153441E-01,
  5.48278295E-01,5.13967447E-01,4.78399400E-01,4.41804119E-01,
  4.04468565E-01,3.66740024E-01,3.29025170E-01,2.91783434E-01,
  2.55512727E-01,2.20726415E-01,1.87922813E-01,1.57548365E-01,
  1.29960151E-01,1.05394150E-01,8.39493013E-02,6.55918258E-02,
  5.01785216E-02,3.74897654E-02,2.72615987E-02,1.92093839E-02,
  1.30420847E-02,8.47085445E-03,5.21530689E-03,3.00897978E-03,
  1.60407534E-03,7.76808746E-04,3.34827508E-04,1.25318962E-04,
  3.95208106E-05,1.01240438E-05,2.01608786E-06,2.96239491E-07,
  3.02008976E-08,1.98544732E-09,7.70641639E-11,1.58565696E-12,
  1.51489801E-14,5.70929789E-17,6.94879153E-20,2.13840536E-23,
  1.23514835E-27,0.0,0.0,.00000000E+00,
  .00000000E+00,.00000000E+00,.00000000E+00,.00000000E+00,
  .00000000E+00,.00000000E+00,.00000000E+00,.00000000E+00,
  .00000000E+00,.00000000E+00,.00000000E+00,.00000000E+00,
  .00000000E+00
!
!     GAS: WATER VAPOUR
!     AT PRESSURE =  5.000E+04 Pa  AND TEMPERATURE =  2.500E+02 K.
!     IN BAND     3:    1.250E-05m TO   1.818E-05m.

  9.99999991E-01,9.99999988E-01,9.99999983E-01,9.99999978E-01,
  9.99999969E-01,9.99999957E-01,9.99999942E-01,9.99999928E-01,
  9.99999911E-01,9.99999889E-01,9.99999855E-01,9.99999820E-01,
  9.99999769E-01,9.99999707E-01,9.99999630E-01,9.99999536E-01,
  9.99999421E-01,9.99999285E-01,9.99999111E-01,9.99998903E-01,
  9.99998636E-01,9.99998315E-01,9.99997932E-01,9.99997470E-01,
  9.99996914E-01,9.99996233E-01,9.99995377E-01,9.99994354E-01,
  9.99993123E-01,9.99991625E-01,9.99989793E-01,9.99987574E-01,
  9.99984838E-01,9.99981509E-01,9.99977480E-01,9.99972579E-01,
  9.99966690E-01,9.99959548E-01,9.99950825E-01,9.99940245E-01,
  9.99927463E-01,9.99911918E-01,9.99893190E-01,9.99870418E-01,
  9.99842912E-01,9.99809647E-01,9.99769447E-01,9.99720861E-01,
  9.99662301E-01,9.99591859E-01,9.99507074E-01,9.99404908E-01,
  9.99282291E-01,9.99134953E-01,9.98958927E-01,9.98748746E-01,
  9.98498260E-01,9.98200826E-01,9.97848489E-01,9.97432731E-01,
  9.96944164E-01,9.96372264E-01,9.95705830E-01,9.94932919E-01,
  9.94040815E-01,9.93015905E-01,9.91844425E-01,9.90511962E-01,
  9.89003237E-01,9.87302241E-01,9.85391783E-01,9.83253620E-01,
  9.80867781E-01,9.78213191E-01,9.75267581E-01,9.72007503E-01,
  9.68408198E-01,9.64443768E-01,9.60085633E-01,9.55302384E-01,
  9.50059370E-01,9.44317919E-01,9.38034755E-01,9.31162118E-01,
  9.23646681E-01,9.15430525E-01,9.06449798E-01,8.96636762E-01,
  8.85919787E-01,8.74224645E-01,8.61475829E-01,8.47598724E-01,
  8.32521503E-01,8.16177882E-01,7.98510215E-01,7.79472775E-01,
  7.59034841E-01,7.37184119E-01,7.13930785E-01,6.89310646E-01,
  6.63389448E-01,6.36265572E-01,6.08072589E-01,5.78979878E-01,
  5.49190225E-01,5.18933840E-01,4.88458912E-01,4.58018984E-01,
  4.27858441E-01,3.98198143E-01,3.69222815E-01,3.41073311E-01,
  3.13846691E-01,2.87604019E-01,2.62383393E-01,2.38214086E-01,
  2.15127453E-01,1.93163656E-01,1.72372982E-01,1.52811855E-01,
  1.34534302E-01,1.17580960E-01,1.01969545E-01,8.76895982E-02,
  7.47031389E-02,6.29519448E-02,5.23701985E-02,4.28993988E-02,
  3.45001665E-02,2.71548791E-02,2.08581865E-02,1.55985992E-02,
  1.13389513E-02,8.00455768E-03,5.48380390E-03,3.64059083E-03,
  2.33320197E-03,1.43222328E-03,8.31193023E-04,4.47848857E-04,
  2.19004021E-04,9.46428748E-05,3.50446506E-05,1.07233834E-05,
  2.59740434E-06
!
!     GAS: WATER VAPOUR
!     AT PRESSURE =  5.000E+04 Pa  AND TEMPERATURE =  2.500E+02 K.
```

```
!     IN BAND     4:    1.136E-05m TO   1.250E-05m.

  1.00000000E+00,1.00000000E+00,1.00000000E+00,1.00000000E+00,
  1.00000000E+00,1.00000000E+00,1.00000000E+00,1.00000000E+00,
  1.00000000E+00,1.00000000E+00,1.00000000E+00,1.00000000E+00,
  1.00000000E+00,1.00000000E+00,1.00000000E+00,1.00000000E+00,
  1.00000000E+00,1.00000000E+00,1.00000000E+00,1.00000000E+00,
  9.99999999E-01,9.99999998E-01,9.99999998E-01,9.99999997E-01,
  9.99999996E-01,9.99999996E-01,9.99999990E-01,9.99999980E-01,
  9.99999972E-01,9.99999961E-01,9.99999934E-01,9.99999909E-01,
  9.99999884E-01,9.99999845E-01,9.99999794E-01,9.99999723E-01,
  9.99999616E-01,9.99999523E-01,9.99999386E-01,9.99999250E-01,
  9.99999060E-01,9.99998836E-01,9.99998544E-01,9.99998206E-01,
  9.99997773E-01,9.99997270E-01,9.99996642E-01,9.99995892E-01,
  9.99994986E-01,9.99993849E-01,9.99992472E-01,9.99990778E-01,
  9.99988747E-01,9.99986333E-01,9.99983365E-01,9.99979750E-01,
  9.99975437E-01,9.99970111E-01,9.99963613E-01,9.99955734E-01,
  9.99946100E-01,9.99934433E-01,9.99920389E-01,9.99903462E-01,
  9.99882946E-01,9.99857912E-01,9.99827517E-01,9.99790791E-01,
  9.99746346E-01,9.99692847E-01,9.99628048E-01,9.99549758E-01,
  9.99455153E-01,9.99340513E-01,9.99202280E-01,9.99035704E-01,
  9.98835552E-01,9.98594739E-01,9.98305106E-01,9.97957510E-01,
  9.97542535E-01,9.97047295E-01,9.96458535E-01,9.95760028E-01,
  9.94934836E-01,9.93964047E-01,9.92828616E-01,9.91507912E-01,
  9.89981289E-01,9.88229363E-01,9.86232407E-01,9.83973583E-01,
  9.81436697E-01,9.78606819E-01,9.75470629E-01,9.72013067E-01,
  9.68218674E-01,9.64069137E-01,9.59542075E-01,9.54610276E-01,
  9.49241275E-01,9.43395727E-01,9.37029313E-01,9.30092732E-01,
  9.22532267E-01,9.14291650E-01,9.05310817E-01,8.95527713E-01,
  8.84876774E-01,8.73289639E-01,8.60695387E-01,8.47021146E-01,
  8.32193500E-01,8.16139290E-01,7.98787259E-01,7.80069689E-01,
  7.59924659E-01,7.38299284E-01,7.15154443E-01,6.90470168E-01,
  6.64251406E-01,6.36534075E-01,6.07389291E-01,5.76925130E-01,
  5.45284180E-01,5.12635003E-01,4.79159872E-01,4.45039476E-01,
  4.10442500E-01,3.75522963E-01,3.40429052E-01,3.05323759E-01,
  2.70411746E-01,2.35965777E-01,2.02343353E-01,1.69986833E-01,
  1.39404399E-01,1.11134428E-01,8.56979692E-02,6.35440538E-02,
  4.49913412E-02,3.01708554E-02,1.89825929E-02,1.10850096E-02,
  5.93414859E-03
!
!     GAS: WATER VAPOUR
!     AT PRESSURE =  5.000E+04 Pa  AND TEMPERATURE =  2.500E+02 K.
!     IN BAND     5:    1.010E-05m TO   1.136E-05m.

  1.00000000E+00,1.00000000E+00,1.00000000E+00,1.00000000E+00,
  1.00000000E+00,1.00000000E+00,1.00000000E+00,1.00000000E+00,
  1.00000000E+00,1.00000000E+00,1.00000000E+00,1.00000000E+00,
  1.00000000E+00,1.00000000E+00,1.00000000E+00,1.00000000E+00,
  1.00000000E+00,1.00000000E+00,1.00000000E+00,1.00000000E+00,
  1.00000000E+00,1.00000000E+00,1.00000000E+00,9.99999998E-01,
  9.99999997E-01,9.99999996E-01,9.99999994E-01,9.99999989E-01,
  9.99999986E-01,9.99999982E-01,9.99999975E-01,9.99999967E-01,
  9.99999956E-01,9.99999942E-01,9.99999925E-01,9.99999903E-01,
  9.99999877E-01,9.99999841E-01,9.99999797E-01,9.99999753E-01,
  9.99999688E-01,9.99999604E-01,9.99999505E-01,9.99999375E-01,
  9.99999229E-01,9.99999056E-01,9.99998845E-01,9.99998579E-01,
  9.99998247E-01,9.99997848E-01,9.99997369E-01,9.99996762E-01,
  9.99996044E-01,9.99995152E-01,9.99994064E-01,9.99992745E-01,
  9.99991103E-01,9.99989127E-01,9.99986748E-01,9.99983802E-01,
  9.99980280E-01,9.99976005E-01,9.99970734E-01,9.99964382E-01,
  9.99956636E-01,9.99947311E-01,9.99936126E-01,9.99922448E-01,
  9.99905873E-01,9.99885680E-01,9.99861261E-01,9.99831829E-01,
  9.99796300E-01,9.99753249E-01,9.99701408E-01,9.99639100E-01,
  9.99563790E-01,9.99473086E-01,9.99364217E-01,9.99233464E-01,
  9.99076543E-01,9.98888892E-01,9.98665085E-01,9.98399406E-01,
  9.98084472E-01,9.97712286E-01,9.97274747E-01,9.96762300E-01,
  9.96165496E-01,9.95473377E-01,9.94674710E-01,9.93757262E-01,
  9.92708189E-01,9.91511244E-01,9.90151782E-01,9.88608969E-01,
  9.86861883E-01,9.84886878E-01,9.82656883E-01,9.80144133E-01,
  9.77316981E-01,9.74143483E-01,9.70587570E-01,9.66612091E-01,
  9.62176563E-01,9.57238296E-01,9.51750195E-01,9.45662056E-01,
  9.38920003E-01,9.31467077E-01,9.23243473E-01,9.14187872E-01,
  9.04237059E-01,8.93327185E-01,8.81394021E-01,8.68373542E-01,
  8.54202846E-01,8.38821231E-01,8.22171873E-01,8.04202712E-01,
  7.84868841E-01,7.64133994E-01,7.41974594E-01,7.18384225E-01,
  6.93378706E-01,6.67001115E-01,6.39324560E-01,6.10453112E-01,
  5.80519416E-01,5.49681132E-01,5.18115542E-01,4.86012907E-01,
  4.53567942E-01,4.20969725E-01,3.88391219E-01,3.55981560E-01,
  3.23866492E-01,2.92160914E-01,2.60992408E-01,2.30529294E-01,
  2.01000811E-01,1.72699505E-01,1.45962399E-01,1.21135423E-01,
  9.85321380E-02
!
!     GAS: WATER VAPOUR
!     AT PRESSURE =  5.000E+04 Pa  AND TEMPERATURE =  2.500E+02 K.
!     IN BAND     6:    8.929E-06m TO   1.010E-05m.

  1.00000000E+00,1.00000000E+00,1.00000000E+00,1.00000000E+00,
  1.00000000E+00,1.00000000E+00,1.00000000E+00,1.00000000E+00,
  1.00000000E+00,1.00000000E+00,1.00000000E+00,1.00000000E+00,
  1.00000000E+00,1.00000000E+00,1.00000000E+00,1.00000000E+00,
  1.00000000E+00,1.00000000E+00,1.00000000E+00,1.00000000E+00,
  1.00000000E+00,9.99999999E-01,9.99999998E-01,9.99999997E-01,
  9.99999996E-01,9.99999995E-01,9.99999994E-01,9.99999991E-01,
  9.99999987E-01,9.99999977E-01,9.99999962E-01,9.99999948E-01,
  9.99999931E-01,9.99999913E-01,9.99999891E-01,9.99999856E-01,
  9.99999819E-01,9.99999774E-01,9.99999714E-01,9.99999645E-01,
  9.99999554E-01,9.99999443E-01,9.99999284E-01,9.99999079E-01,
  9.99998862E-01,9.99998588E-01,9.99998267E-01,9.99997861E-01,
  9.99997364E-01,9.99996739E-01,9.99995999E-01,9.99995096E-01,
  9.99994012E-01,9.99992690E-01,9.99991085E-01,9.99989095E-01,
  9.99986711E-01,9.99983798E-01,9.99980261E-01,9.99975930E-01,
  9.99970670E-01,9.99964290E-01,9.99956523E-01,9.99947121E-01,
  9.99935777E-01,9.99921942E-01,9.99905165E-01,9.99884878E-01,
  9.99860309E-01,9.99830607E-01,9.99794747E-01,9.99751142E-01,
  9.99698758E-01,9.99635488E-01,9.99558898E-01,9.99466872E-01,
  9.99356054E-01,9.99222276E-01,9.99062038E-01,9.98869975E-01,
  9.98640169E-01,9.98365784E-01,9.98038713E-01,9.97650643E-01,
  9.97191873E-01,9.96650558E-01,9.96015902E-01,9.95274311E-01,
  9.94412043E-01,9.93414110E-01,9.92264330E-01,9.90945471E-01,
  9.89439268E-01,9.87724308E-01,9.85778096E-01,9.83574924E-01,
  9.81086994E-01,9.78284313E-01,9.75134127E-01,9.71601500E-01,
  9.67648557E-01,9.63235500E-01,9.58320948E-01,9.52862101E-01,
  9.46815369E-01,9.40135801E-01,9.32776830E-01,9.24688621E-01,
  9.15817202E-01,9.06103157E-01,8.95481570E-01,8.83880572E-01,
  8.71222764E-01,8.57425526E-01,8.42402555E-01,8.26066668E-01,
  8.08333153E-01,7.89123816E-01,7.68372012E-01,7.46027591E-01,
  7.22062114E-01,6.96472276E-01,6.69283664E-01,6.40552406E-01,
  6.10367083E-01,5.78850307E-01,5.46160193E-01,5.12490761E-01,
  4.78070676E-01,4.43158162E-01,4.08033051E-01,3.72988182E-01,
  3.38321545E-01,3.04331961E-01,2.71317608E-01,2.39574758E-01,
  2.09393379E-01,1.81046249E-01,1.54771572E-01,1.30754040E-01,
  1.09111309E-01,8.98910071E-02,7.30780328E-02,5.86047678E-02,
  4.63595166E-02
!
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!     GAS: WATER VAPOUR
!     AT PRESSURE =  5.000E+04 Pa  AND TEMPERATURE =  2.500E+02 K.
!     IN BAND     7:    8.333E-06m TO   8.929E-06m.

  1.00000000E+00,1.00000000E+00,1.00000000E+00,1.00000000E+00,
  1.00000000E+00,1.00000000E+00,9.99999999E-01,9.99999999E-01,
  9.99999999E-01,9.99999999E-01,9.99999997E-01,9.99999996E-01,
  9.99999995E-01,9.99999994E-01,9.99999993E-01,9.99999991E-01,
  9.99999984E-01,9.99999972E-01,9.99999959E-01,9.99999950E-01,
  9.99999938E-01,9.99999921E-01,9.99999902E-01,9.99999856E-01,
  9.99999819E-01,9.99999780E-01,9.99999713E-01,9.99999635E-01,
  9.99999543E-01,9.99999417E-01,9.99999280E-01,9.99999103E-01,
  9.99998896E-01,9.99998638E-01,9.99998297E-01,9.99997888E-01,
  9.99997384E-01,9.99996794E-01,9.99996077E-01,9.99995197E-01,
  9.99994095E-01,9.99992786E-01,9.99991187E-01,9.99989237E-01,
  9.99986842E-01,9.99983963E-01,9.99980458E-01,9.99976241E-01,
  9.99971125E-01,9.99964943E-01,9.99957452E-01,9.99948271E-01,
  9.99937024E-01,9.99923355E-01,9.99906847E-01,9.99887023E-01,
  9.99862944E-01,9.99833758E-01,9.99798500E-01,9.99755809E-01,
  9.99703871E-01,9.99641457E-01,9.99566376E-01,9.99475864E-01,
  9.99366608E-01,9.99234712E-01,9.99076500E-01,9.98887238E-01,
  9.98660031E-01,9.98388488E-01,9.98064083E-01,9.97678715E-01,
  9.97222615E-01,9.96683837E-01,9.96050556E-01,9.95310434E-01,
  9.94448040E-01,9.93449251E-01,9.92298828E-01,9.90980205E-01,
  9.89476650E-01,9.87769066E-01,9.85837803E-01,9.83659894E-01,
  9.81210293E-01,9.78461154E-01,9.75381112E-01,9.71935690E-01,
  9.68088686E-01,9.63801233E-01,9.59034425E-01,9.53748311E-01,
  9.47903490E-01,9.41460772E-01,9.34378780E-01,9.26613674E-01,
  9.18116810E-01,9.08833509E-01,8.98702448E-01,8.87654643E-01,
  8.75614147E-01,8.62498712E-01,8.48221902E-01,8.32694738E-01,
  8.15827834E-01,7.97533382E-01,7.77728066E-01,7.56336919E-01,
  7.33298906E-01,7.08572885E-01,6.82144040E-01,6.54029982E-01,
  6.24285209E-01,5.93004872E-01,5.60326844E-01,5.26432613E-01,
  4.91546052E-01,4.55930482E-01,4.19883569E-01,3.83730182E-01,
  3.47812522E-01,3.12476803E-01,2.78058757E-01,2.44870035E-01,
  2.13189274E-01,1.83258158E-01,1.55280148E-01,1.29421453E-01,
  1.05813066E-01,8.45576733E-02,6.57400382E-02,4.94348960E-02,
  3.57011904E-02,2.45554664E-02,1.59307721E-02,9.64112049E-03,
  5.37344526E-03,2.71731825E-03,1.22527689E-03,4.82703285E-04,
  1.62189072E-04,4.51572081E-05,1.00571901E-05,1.71458221E-06,
  2.11644063E-07
!
!     GAS: WATER VAPOUR
!     AT PRESSURE =  5.000E+04 Pa  AND TEMPERATURE =  2.500E+02 K.
!     IN BAND     8:    6.667E-06m TO   8.333E-06m.

  9.99998948E-01,9.99998708E-01,9.99998408E-01,9.99998054E-01,
  9.99997605E-01,9.99997068E-01,9.99996418E-01,9.99995605E-01,
  9.99994620E-01,9.99993413E-01,9.99991949E-01,9.99990175E-01,
  9.99988031E-01,9.99985412E-01,9.99982263E-01,9.99978397E-01,
  9.99973742E-01,9.99968074E-01,9.99961204E-01,9.99952867E-01,
  9.99942784E-01,9.99930619E-01,9.99915855E-01,9.99897796E-01,
  9.99876131E-01,9.99849817E-01,9.99818125E-01,9.99779825E-01,
  9.99733544E-01,9.99677580E-01,9.99610093E-01,9.99528634E-01,
  9.99430613E-01,9.99312600E-01,9.99170865E-01,9.99000927E-01,
  9.98797407E-01,9.98554303E-01,9.98264887E-01,9.97921012E-01,
  9.97514141E-01,9.97034737E-01,9.96472490E-01,9.95816234E-01,
  9.95054582E-01,9.94175453E-01,9.93167041E-01,9.92017222E-01,
  9.90714272E-01,9.89245823E-01,9.87599913E-01,9.85763393E-01,
  9.83723042E-01,9.81463972E-01,9.78969664E-01,9.76221843E-01,
  9.73199955E-01,9.69880260E-01,9.66237128E-01,9.62241624E-01,
  9.57862729E-01,9.53067199E-01,9.47819942E-01,9.42085251E-01,
  9.35826634E-01,9.29007969E-01,9.21593463E-01,9.13549211E-01,
  9.04841307E-01,8.95438043E-01,8.85308777E-01,8.74424384E-01,
  8.62757276E-01,8.50281184E-01,8.36971359E-01,8.22807894E-01,
  8.07777384E-01,7.91878408E-01,7.75125105E-01,7.57550019E-01,
  7.39205106E-01,7.20159876E-01,7.00498788E-01,6.80316516E-01,
  6.59713369E-01,6.38789966E-01,6.17641291E-01,5.96352118E-01,
  5.74993964E-01,5.53625739E-01,5.32296883E-01,5.11051642E-01,
  4.89930633E-01,4.68968491E-01,4.48189937E-01,4.27606637E-01,
  4.07218322E-01,3.87018502E-01,3.67002313E-01,3.47173718E-01,
  3.27548985E-01,3.08154788E-01,2.89021142E-01,2.70172150E-01,
  2.51618471E-01,2.33356135E-01,2.15373933E-01,1.97667583E-01,
  1.80255375E-01,1.63189997E-01,1.46562378E-01,1.30497305E-01,
  1.15142332E-01,1.00652677E-01,8.71735431E-02,7.48215727E-02,
  6.36679532E-02,5.37271453E-02,4.49554299E-02,3.72616561E-02,
  3.05286964E-02,2.46394859E-02,1.94990502E-02,1.50448751E-02,
  1.12436361E-02,8.07800616E-03,5.53044035E-03,3.56989440E-03,
  2.14427379E-03,1.17903598E-03,5.81585110E-04,2.51087731E-04,
  9.20963276E-05,2.76941049E-05,6.54280582E-06,1.15414606E-06,
  1.43018940E-07,1.15709659E-08,5.59693707E-10,1.45570394E-11,
  1.79153408E-13,8.94279820E-16,1.50362428E-18,6.80577452E-22,
  6.32511076E-26
!
!     GAS: WATER VAPOUR
!     AT PRESSURE =  5.000E+04 Pa  AND TEMPERATURE =  2.500E+02 K.
!     IN BAND     9:    5.000E-06m TO   6.667E-06m.

  9.99992476E-01,9.99990789E-01,9.99988728E-01,9.99986197E-01,
  9.99983115E-01,9.99979414E-01,9.99974914E-01,9.99969446E-01,
  9.99962754E-01,9.99954685E-01,9.99944843E-01,9.99932899E-01,
  9.99918430E-01,9.99901016E-01,9.99879837E-01,9.99854191E-01,
  9.99822961E-01,9.99785184E-01,9.99739523E-01,9.99684407E-01,
  9.99617724E-01,9.99536841E-01,9.99439114E-01,9.99321153E-01,
  9.99178555E-01,9.99006510E-01,9.98798654E-01,9.98547749E-01,
  9.98245713E-01,9.97881954E-01,9.97444594E-01,9.96919645E-01,
  9.96290402E-01,9.95538148E-01,9.94641022E-01,9.93574477E-01,
  9.92310473E-01,9.90818732E-01,9.89066181E-01,9.87017619E-01,
  9.84636477E-01,9.81885893E-01,9.78728715E-01,9.75129135E-01,
  9.71052293E-01,9.66464417E-01,9.61332420E-01,9.55622927E-01,
  9.49301577E-01,9.42333293E-01,9.34681177E-01,9.26307371E-01,
  9.17172430E-01,9.07234948E-01,8.96451031E-01,8.84774955E-01,
  8.72159502E-01,8.58557221E-01,8.43921757E-01,8.28208259E-01,
  8.11374293E-01,7.93380451E-01,7.74190719E-01,7.53774075E-01,
  7.32106650E-01,7.09174810E-01,6.84978018E-01,6.59531864E-01,
  6.32870694E-01,6.05050864E-01,5.76154625E-01,5.46295446E-01,
  5.15624099E-01,4.84334096E-01,4.52665468E-01,4.20903705E-01,
  3.89372856E-01,3.58421103E-01,3.28399383E-01,2.99637042E-01,
  2.72417795E-01,2.46960430E-01,2.23404353E-01,2.01801484E-01,
  1.82114640E-01,1.64225850E-01,1.47957475E-01,1.33104887E-01,
  1.19472807E-01,1.06903417E-01,9.52879657E-02,8.45618113E-02,
  7.46902159E-02,6.56533626E-02,5.74350653E-02,5.00145899E-02,
  4.33605782E-02,3.74275367E-02,3.21569740E-02,2.74833151E-02,
  2.33417823E-02,1.96745968E-02,1.64337594E-02,1.35809264E-02,
  1.10858360E-02,8.92414500E-03,7.07476381E-03,5.51684910E-03,
  4.22708958E-03,3.17834836E-03,2.34024361E-03,1.68136514E-03,
  1.17203905E-03,7.86357224E-04,5.02649907E-04,3.02477525E-04,
  1.69093374E-04,8.65353023E-05,3.98697970E-05,1.62096892E-05,
  5.67011881E-06,1.65150661E-06,3.84051358E-07,6.76555971E-08,
  8.47008851E-09,6.98309010E-10,3.46337221E-11,9.27765470E-13,
  1.17948027E-14,6.08790916E-17,1.05602601E-19,4.89476841E-23,
  4.58964356E-27,0.0,0.0,.00000000E+00,
  .00000000E+00,.00000000E+00,.00000000E+00,.00000000E+00,
  .00000000E+00,.00000000E+00,.00000000E+00,.00000000E+00,
```

```
  .00000000E+00
!
!
!     CONTINUUM TYPE: SELF-BRDND H2O
!     AT PRESSURE =  5.000E+04 Pa  AND TEMPERATURE =  2.500E+02 K.
!     IN BAND     2:    1.818E-05m TO   2.500E-05m.

  9.99999994E-01,9.99999993E-01,9.99999991E-01,9.99999990E-01,
  9.99999987E-01,9.99999985E-01,9.99999981E-01,9.99999978E-01,
  9.99999973E-01,9.99999967E-01,9.99999960E-01,9.99999952E-01,
  9.99999941E-01,9.99999929E-01,9.99999914E-01,9.99999896E-01,
  9.99999874E-01,9.99999847E-01,9.99999815E-01,9.99999775E-01,
  9.99999728E-01,9.99999670E-01,9.99999601E-01,9.99999516E-01,
  9.99999414E-01,9.99999290E-01,9.99999140E-01,9.99998958E-01,
  9.99998738E-01,9.99998471E-01,9.99998147E-01,9.99997755E-01,
  9.99997280E-01,9.99996705E-01,9.99996008E-01,9.99995164E-01,
  9.99994142E-01,9.99992903E-01,9.99991403E-01,9.99989585E-01,
  9.99987383E-01,9.99984716E-01,9.99981486E-01,9.99977573E-01,
  9.99972834E-01,9.99967094E-01,9.99960142E-01,9.99951722E-01,
  9.99941525E-01,9.99929177E-01,9.99914223E-01,9.99896116E-01,
  9.99874192E-01,9.99847646E-01,9.99815507E-01,9.99776598E-01,
  9.99729494E-01,9.99672473E-01,9.99603449E-01,9.99519900E-01,
  9.99418773E-01,9.99296377E-01,9.99148247E-01,9.98968982E-01,
  9.98752053E-01,9.98489570E-01,9.98172003E-01,9.97787844E-01,
  9.97323221E-01,9.96761416E-01,9.96082313E-01,9.95261732E-01,
  9.94270640E-01,9.93074232E-01,9.91630847E-01,9.89890711E-01,
  9.87794501E-01,9.85271710E-01,9.82238831E-01,9.78597360E-01,
  9.74231720E-01,9.69007189E-01,9.62768031E-01,9.55336059E-01,
  9.46510021E-01,9.36066168E-01,9.23760428E-01,9.09332363E-01,
  8.92510920E-01,8.73020857E-01,8.50588169E-01,8.24941128E-01,
  7.95803765E-01,7.62880564E-01,7.25838539E-01,6.84304288E-01,
  6.37903803E-01,5.86370543E-01,5.29721966E-01,4.68460259E-01,
  4.03719540E-01,3.37290720E-01,2.71508499E-01,2.09028929E-01,
  1.52522336E-01,1.04295530E-01,6.58931625E-02,3.77805453E-02,
  1.92221232E-02,8.44333287E-03,3.09861283E-03,9.14091178E-04,
  2.07104086E-04,3.41311626E-05,3.83207662E-06,2.70790338E-07,
  1.09404414E-08,2.24846948E-10,2.03823285E-12,6.84884230E-15,
  6.90683888E-18,1.61908366E-21,6.47765903E-26,0.0,
  0.0,0.0,0.0,0.0,
  0.0,0.0,0.0,0.0,
  0.0,0.0,0.0,0.0,
  0.0,0.0,0.0,0.0,
  0.0,0.0,0.0,0.0,
  0.0
!
!
!
!     CONTINUUM TYPE: SELF-BRDND H2O
!     AT PRESSURE =  5.000E+04 Pa  AND TEMPERATURE =  2.500E+02 K.
!     IN BAND     3:    1.250E-05m TO   1.818E-05m.

  9.99999998E-01,9.99999998E-01,9.99999997E-01,9.99999997E-01,
  9.99999996E-01,9.99999995E-01,9.99999994E-01,9.99999993E-01,
  9.99999991E-01,9.99999989E-01,9.99999987E-01,9.99999984E-01,
  9.99999981E-01,9.99999976E-01,9.99999971E-01,9.99999965E-01,
  9.99999958E-01,9.99999949E-01,9.99999938E-01,9.99999925E-01,
  9.99999910E-01,9.99999891E-01,9.99999867E-01,9.99999839E-01,
  9.99999805E-01,9.99999764E-01,9.99999714E-01,9.99999654E-01,
  9.99999581E-01,9.99999492E-01,9.99999384E-01,9.99999254E-01,
  9.99999096E-01,9.99998905E-01,9.99998674E-01,9.99998393E-01,
  9.99998053E-01,9.99997642E-01,9.99997143E-01,9.99996539E-01,
  9.99995806E-01,9.99994919E-01,9.99993845E-01,9.99992543E-01,
```

```
  9.99990966E-01,9.99989056E-01,9.99986742E-01,9.99983938E-01,
  9.99980542E-01,9.99976428E-01,9.99971445E-01,9.99965409E-01,
  9.99958098E-01,9.99949244E-01,9.99938519E-01,9.99925531E-01,
  9.99909803E-01,9.99890756E-01,9.99867693E-01,9.99839768E-01,
  9.99805958E-01,9.99765026E-01,9.99715474E-01,9.99655492E-01,
  9.99582890E-01,9.99495021E-01,9.99388683E-01,9.99260009E-01,
  9.99104325E-01,9.98915985E-01,9.98688174E-01,9.98412668E-01,
  9.98079547E-01,9.97676859E-01,9.97190209E-01,9.96602280E-01,
  9.95892263E-01,9.95035181E-01,9.94001102E-01,9.92754217E-01,
  9.91251772E-01,9.89442837E-01,9.87266910E-01,9.84652349E-01,
  9.81514642E-01,9.77754536E-01,9.73256071E-01,9.67884560E-01,
  9.61484681E-01,9.53878780E-01,9.44865675E-01,9.34220184E-01,
  9.21693767E-01,9.07016549E-01,8.89901073E-01,8.70047898E-01,
  8.47153164E-01,8.20917903E-01,7.91059116E-01,7.57322591E-01,
  7.19498700E-01,6.77443184E-01,6.31106749E-01,5.80578376E-01,
  5.26144305E-01,4.68358188E-01,4.08108193E-01,3.46658208E-01,
  2.85638384E-01,2.26964411E-01,1.72676153E-01,1.24701966E-01,
  8.45778615E-02,5.31724797E-02,3.04905708E-02,1.56371884E-02,
  7.00429095E-03,2.66346850E-03,8.31140303E-04,2.04346371E-04,
  3.76855996E-05,4.91153429E-06,4.20899170E-07,2.17440535E-08,
  6.10012415E-10,8.18916713E-12,4.50457208E-14,8.37466906E-17,
  4.14424769E-20,4.07311882E-24,5.58396329E-29,0.0,
  0.0,0.0,0.0,0.0,
  0.0,0.0,0.0,0.0,
  0.0,0.0,0.0,0.0,
  .00000000E+00
!
!     CONTINUUM TYPE: SELF-BRDND H2O
!     AT PRESSURE =  5.000E+04 Pa  AND TEMPERATURE =  2.500E+02 K.
!     IN BAND     4:    1.136E-05m TO   1.250E-05m.

  9.99999999E-01,9.99999999E-01,9.99999999E-01,9.99999999E-01,
  9.99999999E-01,9.99999998E-01,9.99999998E-01,9.99999997E-01,
  9.99999997E-01,9.99999996E-01,9.99999995E-01,9.99999994E-01,
  9.99999993E-01,9.99999992E-01,9.99999990E-01,9.99999988E-01,
  9.99999985E-01,9.99999982E-01,9.99999978E-01,9.99999974E-01,
  9.99999968E-01,9.99999961E-01,9.99999953E-01,9.99999943E-01,
  9.99999931E-01,9.99999917E-01,9.99999899E-01,9.99999878E-01,
  9.99999852E-01,9.99999821E-01,9.99999783E-01,9.99999737E-01,
  9.99999682E-01,9.99999614E-01,9.99999533E-01,9.99999434E-01,
  9.99999314E-01,9.99999169E-01,9.99998994E-01,9.99998781E-01,
  9.99998523E-01,9.99998211E-01,9.99997832E-01,9.99997374E-01,
  9.99996818E-01,9.99996145E-01,9.99995329E-01,9.99994342E-01,
  9.99993145E-01,9.99991694E-01,9.99989938E-01,9.99987809E-01,
  9.99985231E-01,9.99982106E-01,9.99978321E-01,9.99973736E-01,
  9.99968180E-01,9.99961450E-01,9.99953296E-01,9.99943417E-01,
  9.99931448E-01,9.99916949E-01,9.99899382E-01,9.99878100E-01,
  9.99852317E-01,9.99821081E-01,9.99783240E-01,9.99737396E-01,
  9.99681859E-01,9.99614578E-01,9.99533074E-01,9.99434339E-01,
  9.99314734E-01,9.99169853E-01,9.98994358E-01,9.98781789E-01,
  9.98524327E-01,9.98212508E-01,9.97834882E-01,9.97377599E-01,
  9.96823909E-01,9.96153567E-01,9.95342113E-01,9.94360007E-01,
  9.93171603E-01,9.91733918E-01,9.89995173E-01,9.87893061E-01,
  9.85352726E-01,9.82284380E-01,9.78580574E-01,9.74113052E-01,
  9.68729244E-01,9.62248362E-01,9.54457272E-01,9.45106221E-01,
  9.33904803E-01,9.20518580E-01,9.04567114E-01,8.85624415E-01,
  8.63223393E-01,8.36866144E-01,8.06042641E-01,7.70260830E-01,
  7.29091205E-01,6.82228622E-01,6.29572720E-01,5.71324601E-01,
  5.08092098E-01,4.40986884E-01,3.71686507E-01,3.02423773E-01,
  2.35863448E-01,1.74836820E-01,1.21940948E-01,7.90663142E-02,
  4.69836431E-02,2.51548476E-02,1.18908160E-02,4.84414378E-03,
  1.65230379E-03,4.55800725E-04,9.75237060E-05,1.53826256E-05,
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  1.68097297E-06,1.17922781E-07,4.83669978E-09,1.03481067E-10,
  1.00553261E-12,3.75401072E-15,4.40031144E-18,1.26871586E-21,
  6.69200333E-26,0.0,0.0,0.0,
  0.0,0.0,0.0,0.0,
  0.0,0.0,0.0,0.0,
  0.0
!
!     CONTINUUM TYPE: SELF-BRDND H2O
!     AT PRESSURE =  5.000E+04 Pa  AND TEMPERATURE =  2.500E+02 K.
!     IN BAND     5:    1.010E-05m TO   1.136E-05m.

  1.00000000E+00,9.99999999E-01,9.99999999E-01,9.99999999E-01,
  9.99999999E-01,9.99999999E-01,9.99999999E-01,9.99999998E-01,
  9.99999998E-01,9.99999998E-01,9.99999997E-01,9.99999997E-01,
  9.99999996E-01,9.99999995E-01,9.99999994E-01,9.99999993E-01,
  9.99999991E-01,9.99999989E-01,9.99999987E-01,9.99999984E-01,
  9.99999980E-01,9.99999976E-01,9.99999971E-01,9.99999965E-01,
  9.99999958E-01,9.99999949E-01,9.99999938E-01,9.99999925E-01,
  9.99999909E-01,9.99999890E-01,9.99999867E-01,9.99999839E-01,
  9.99999804E-01,9.99999763E-01,9.99999713E-01,9.99999652E-01,
  9.99999579E-01,9.99999489E-01,9.99999381E-01,9.99999251E-01,
  9.99999092E-01,9.99998900E-01,9.99998667E-01,9.99998385E-01,
  9.99998044E-01,9.99997630E-01,9.99997129E-01,9.99996521E-01,
  9.99995786E-01,9.99994894E-01,9.99993814E-01,9.99992506E-01,
  9.99990920E-01,9.99989000E-01,9.99986673E-01,9.99983854E-01,
  9.99980439E-01,9.99976301E-01,9.99971288E-01,9.99965215E-01,
  9.99957857E-01,9.99948943E-01,9.99938143E-01,9.99925060E-01,
  9.99909209E-01,9.99890005E-01,9.99866740E-01,9.99838555E-01,
  9.99804409E-01,9.99763042E-01,9.99712928E-01,9.99652218E-01,
  9.99578672E-01,9.99489578E-01,9.99381651E-01,9.99250914E-01,
  9.99092550E-01,9.98900729E-01,9.98668392E-01,9.98386996E-01,
  9.98046202E-01,9.97633503E-01,9.97133770E-01,9.96528714E-01,
  9.95796228E-01,9.94909605E-01,9.93836608E-01,9.92538342E-01,
  9.90967925E-01,9.89068914E-01,9.86773436E-01,9.84000009E-01,
  9.80651004E-01,9.76609717E-01,9.71737061E-01,9.65867854E-01,
  9.58806810E-01,9.50324297E-01,9.40152149E-01,9.27979840E-01,
  9.13451691E-01,8.96165910E-01,8.75676717E-01,8.51501331E-01,
  8.23133933E-01,7.90069415E-01,7.51840061E-01,7.08068060E-01,
  6.58536175E-01,6.03276044E-01,5.42669922E-01,4.77553517E-01,
  4.09299185E-01,3.39846619E-01,2.71642673E-01,2.07452708E-01,
  1.50029674E-01,1.01672678E-01,6.37712092E-02,3.64863006E-02,
  1.87211863E-02,8.44481580E-03,3.27161782E-03,1.05898894E-03,
  2.77160560E-04,5.63756922E-05,8.49101740E-06,8.92065837E-07,
  6.07060563E-08,2.44093081E-09,5.17653329E-11,5.03593034E-13,
  1.89539832E-15,2.24403209E-18,6.50407402E-22,3.40743388E-26,
  0.0,0.0,0.0,0.0,
  0.0,0.0,0.0,0.0,
  0.0
!
!     CONTINUUM TYPE: SELF-BRDND H2O
!     AT PRESSURE =  5.000E+04 Pa  AND TEMPERATURE =  2.500E+02 K.
!     IN BAND     6:    8.929E-06m TO   1.010E-05m.

  1.00000000E+00,1.00000000E+00,1.00000000E+00,1.00000000E+00,
  9.99999999E-01,9.99999999E-01,9.99999999E-01,9.99999999E-01,
  9.99999999E-01,9.99999999E-01,9.99999998E-01,9.99999998E-01,
  9.99999997E-01,9.99999997E-01,9.99999996E-01,9.99999995E-01,
  9.99999994E-01,9.99999993E-01,9.99999992E-01,9.99999990E-01,
  9.99999988E-01,9.99999985E-01,9.99999982E-01,9.99999978E-01,
  9.99999974E-01,9.99999968E-01,9.99999962E-01,9.99999953E-01,
  9.99999944E-01,9.99999932E-01,9.99999917E-01,9.99999900E-01,
  9.99999878E-01,9.99999853E-01,9.99999822E-01,9.99999784E-01,
  9.99999738E-01,9.99999683E-01,9.99999616E-01,9.99999534E-01,
  9.99999436E-01,9.99999316E-01,9.99999172E-01,9.99998997E-01,
  9.99998784E-01,9.99998527E-01,9.99998216E-01,9.99997838E-01,
  9.99997381E-01,9.99996827E-01,9.99996156E-01,9.99995342E-01,
  9.99994357E-01,9.99993164E-01,9.99991717E-01,9.99989965E-01,
  9.99987843E-01,9.99985271E-01,9.99982156E-01,9.99978381E-01,
  9.99973808E-01,9.99968268E-01,9.99961556E-01,9.99953424E-01,
  9.99943572E-01,9.99931637E-01,9.99917176E-01,9.99899657E-01,
  9.99878432E-01,9.99852718E-01,9.99821566E-01,9.99783824E-01,
  9.99738100E-01,9.99682706E-01,9.99615597E-01,9.99534296E-01,
  9.99435803E-01,9.99316484E-01,9.99171939E-01,9.98996837E-01,
  9.98784725E-01,9.98527788E-01,9.98216570E-01,9.97839622E-01,
  9.97383091E-01,9.96830223E-01,9.96160758E-01,9.95350205E-01,
  9.94368979E-01,9.93181363E-01,9.91744266E-01,9.90005752E-01,
  9.87903294E-01,9.85361720E-01,9.82290805E-01,9.78582482E-01,
  9.74107644E-01,9.68712533E-01,9.62214735E-01,9.54398867E-01,
  9.45012140E-01,9.33760054E-01,9.20302719E-01,9.04252542E-01,
  8.85174334E-01,8.62589333E-01,8.35985292E-01,8.04835156E-01,
  7.68627671E-01,7.26913271E-01,6.79368694E-01,6.25881789E-01,
  5.66655160E-01,5.02320248E-01,4.34044951E-01,3.63604245E-01,
  2.93371848E-01,2.26185661E-01,1.65050972E-01,1.12686579E-01,
  7.09906370E-02,4.05845140E-02,2.06375726E-02,9.11351730E-03,
  3.39620348E-03,1.03204857E-03,2.45471001E-04,4.35043862E-05,
  5.41457618E-06,4.40497803E-07,2.14698264E-08,5.63882462E-10,
  7.01579174E-12,3.53616932E-14,5.96890261E-17,2.67479810E-20,
  2.39527071E-24,3.02937050E-29,0.0,0.0,
  0.0,0.0,0.0,0.0,
  0.0
!
!     CONTINUUM TYPE: SELF-BRDND H2O
!     AT PRESSURE =  5.000E+04 Pa  AND TEMPERATURE =  2.500E+02 K.
!     IN BAND     7:    8.333E-06m TO   8.929E-06m.

  1.00000000E+00,1.00000000E+00,1.00000000E+00,1.00000000E+00,
  1.00000000E+00,9.99999999E-01,9.99999999E-01,9.99999999E-01,
  9.99999999E-01,9.99999999E-01,9.99999998E-01,9.99999998E-01,
  9.99999998E-01,9.99999997E-01,9.99999997E-01,9.99999996E-01,
  9.99999995E-01,9.99999994E-01,9.99999993E-01,9.99999991E-01,
  9.99999990E-01,9.99999987E-01,9.99999985E-01,9.99999981E-01,
  9.99999977E-01,9.99999973E-01,9.99999967E-01,9.99999960E-01,
  9.99999951E-01,9.99999941E-01,9.99999929E-01,9.99999914E-01,
  9.99999895E-01,9.99999873E-01,9.99999847E-01,9.99999814E-01,
  9.99999775E-01,9.99999727E-01,9.99999670E-01,9.99999600E-01,
  9.99999515E-01,9.99999412E-01,9.99999288E-01,9.99999137E-01,
  9.99998955E-01,9.99998734E-01,9.99998466E-01,9.99998142E-01,
  9.99997748E-01,9.99997272E-01,9.99996695E-01,9.99995996E-01,
  9.99995149E-01,9.99994123E-01,9.99992880E-01,9.99991374E-01,
  9.99989549E-01,9.99987339E-01,9.99984661E-01,9.99981416E-01,
  9.99977485E-01,9.99972723E-01,9.99966953E-01,9.99959963E-01,
  9.99951494E-01,9.99941234E-01,9.99928804E-01,9.99913745E-01,
  9.99895500E-01,9.99873398E-01,9.99846620E-01,9.99814180E-01,
  9.99774879E-01,9.99727267E-01,9.99669587E-01,9.99599711E-01,
  9.99515062E-01,9.99412518E-01,9.99288297E-01,9.99137822E-01,
  9.98955549E-01,9.98734766E-01,9.98467349E-01,9.98143465E-01,
  9.97751215E-01,9.97276205E-01,9.96701029E-01,9.96004644E-01,
  9.95161621E-01,9.94141256E-01,9.92906489E-01,9.91412636E-01,
  9.89605866E-01,9.87421414E-01,9.84781469E-01,9.81592718E-01,
  9.77743507E-01,9.73100594E-01,9.67505506E-01,9.60770517E-01,
  9.52674387E-01,9.42958002E-01,9.31320259E-01,9.17414728E-01,
  9.00847827E-01,8.81179657E-01,8.57929116E-01,8.30585326E-01,
  7.98628140E-01,7.61560796E-01,7.18958233E-01,6.70533741E-01,
  6.16225402E-01,5.56299334E-01,4.91461352E-01,4.22957809E-01,
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  3.52635214E-01,2.82917044E-01,2.16651830E-01,1.56801396E-01,
  1.05980805E-01,6.59321992E-02,3.70962872E-02,1.84790115E-02,
  7.94214516E-03,2.85448339E-03,8.26009450E-04,1.83800551E-04,
  2.97441068E-05,3.27175895E-06,2.25359388E-07,8.80048712E-09,
  1.72721068E-10,1.47231313E-12,4.56815063E-15,4.16647019E-18,
  8.62855239E-22,2.96976031E-26,0.0,0.0,
  0.0,0.0,0.0,0.0,
  0.0
!
!     CONTINUUM TYPE: SELF-BRDND H2O
!     AT PRESSURE =  5.000E+04 Pa  AND TEMPERATURE =  2.500E+02 K.
!     IN BAND     8:    6.667E-06m TO   8.333E-06m.

  9.99999999E-01,9.99999999E-01,9.99999998E-01,9.99999998E-01,
  9.99999998E-01,9.99999997E-01,9.99999997E-01,9.99999996E-01,
  9.99999995E-01,9.99999994E-01,9.99999993E-01,9.99999991E-01,
  9.99999989E-01,9.99999987E-01,9.99999984E-01,9.99999981E-01,
  9.99999976E-01,9.99999971E-01,9.99999965E-01,9.99999958E-01,
  9.99999949E-01,9.99999939E-01,9.99999926E-01,9.99999910E-01,
  9.99999891E-01,9.99999868E-01,9.99999840E-01,9.99999806E-01,
  9.99999765E-01,9.99999715E-01,9.99999655E-01,9.99999582E-01,
  9.99999494E-01,9.99999388E-01,9.99999259E-01,9.99999103E-01,
  9.99998915E-01,9.99998687E-01,9.99998412E-01,9.99998079E-01,
  9.99997678E-01,9.99997193E-01,9.99996608E-01,9.99995902E-01,
  9.99995051E-01,9.99994025E-01,9.99992789E-01,9.99991300E-01,
  9.99989508E-01,9.99987352E-01,9.99984760E-01,9.99981646E-01,
  9.99977908E-01,9.99973425E-01,9.99968054E-01,9.99961626E-01,
  9.99953942E-01,9.99944770E-01,9.99933837E-01,9.99920825E-01,
  9.99905364E-01,9.99887027E-01,9.99865323E-01,9.99839686E-01,
  9.99809475E-01,9.99773965E-01,9.99732347E-01,9.99683723E-01,
  9.99627116E-01,9.99561474E-01,9.99485676E-01,9.99398542E-01,
  9.99298825E-01,9.99185203E-01,9.99056239E-01,9.98910312E-01,
  9.98745507E-01,9.98559445E-01,9.98349054E-01,9.98110295E-01,
  9.97837867E-01,9.97524921E-01,9.97162760E-01,9.96740502E-01,
  9.96244600E-01,9.95658229E-01,9.94960585E-01,9.94126209E-01,
  9.93124413E-01,9.91918749E-01,9.90466397E-01,9.88717315E-01,
  9.86612926E-01,9.84084100E-01,9.81048318E-01,9.77406185E-01,
  9.73037715E-01,9.67798880E-01,9.61518779E-01,9.53997461E-01,
  9.45004269E-01,9.34276296E-01,9.21516772E-01,9.06393671E-01,
  8.88539089E-01,8.67549966E-01,8.42990395E-01,8.14395841E-01,
  7.81281839E-01,7.43163314E-01,6.99595395E-01,6.50247961E-01,
  5.95021198E-01,5.34192594E-01,4.68565293E-01,3.99573516E-01,
  3.29305744E-01,2.60417070E-01,1.95904889E-01,1.38730885E-01,
  9.13160658E-02,5.50187411E-02,2.97858429E-02,1.41674078E-02,
  5.76148993E-03,1.93835163E-03,5.18412628E-04,1.05040870E-04,
  1.52144704E-05,1.46876644E-06,8.68497325E-08,2.84086632E-09,
  4.54485115E-11,3.06301908E-13,7.25239743E-16,4.83312298E-19,
  6.91161164E-23,1.52232568E-27,0.0,0.0,
  0.0,0.0,0.0,0.0,
  0.0
!
!
!
!     GAS: OZONE
!     AT PRESSURE =  2.500E+04 Pa  AND TEMPERATURE =  2.250E+02 K.
!     IN BAND     3:    1.250E-05m TO   1.818E-05m.

  1.00000000E+00,1.00000000E+00,1.00000000E+00,1.00000000E+00,
  1.00000000E+00,1.00000000E+00,1.00000000E+00,1.00000000E+00,
  1.00000000E+00,1.00000000E+00,1.00000000E+00,1.00000000E+00,
  9.99999999E-01,9.99999999E-01,9.99999997E-01,9.99999997E-01,
  9.99999995E-01,9.99999992E-01,9.99999990E-01,9.99999988E-01,
```

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  9.99999985E-01,9.99999982E-01,9.99999977E-01,9.99999969E-01,
  9.99999960E-01,9.99999949E-01,9.99999936E-01,9.99999909E-01,
  9.99999872E-01,9.99999824E-01,9.99999750E-01,9.99999645E-01,
  9.99999503E-01,9.99999291E-01,9.99999027E-01,9.99998628E-01,
  9.99998103E-01,9.99997449E-01,9.99996675E-01,9.99995757E-01,
  9.99994651E-01,9.99993274E-01,9.99991595E-01,9.99989552E-01,
  9.99987075E-01,9.99984101E-01,9.99980452E-01,9.99976045E-01,
  9.99970712E-01,9.99964271E-01,9.99956501E-01,9.99947087E-01,
  9.99935674E-01,9.99921850E-01,9.99905183E-01,9.99884985E-01,
  9.99860539E-01,9.99830893E-01,9.99794972E-01,9.99751490E-01,
  9.99698921E-01,9.99635200E-01,9.99558021E-01,9.99464590E-01,
  9.99351408E-01,9.99214375E-01,9.99048484E-01,9.98847639E-01,
  9.98604605E-01,9.98310502E-01,9.97954736E-01,9.97524374E-01,
  9.97004094E-01,9.96375418E-01,9.95616069E-01,9.94699634E-01,
  9.93594390E-01,9.92262686E-01,9.90659963E-01,9.88733556E-01,
  9.86421908E-01,9.83653283E-01,9.80344934E-01,9.76402330E-01,
  9.71718923E-01,9.66176231E-01,9.59645164E-01,9.51988300E-01,
  9.43063424E-01,9.32728975E-01,9.20850823E-01,9.07310753E-01,
  8.92015927E-01,8.74908542E-01,8.55974881E-01,8.35252006E-01,
  8.12830821E-01,7.88854937E-01,7.63513798E-01,7.37032527E-01,
  7.09659219E-01,6.81653447E-01,6.53277073E-01,6.24788560E-01,
  5.96438805E-01,5.68467592E-01,5.41099076E-01,5.14536659E-01,
  4.88957672E-01,4.64508103E-01,4.41298808E-01,4.19403621E-01,
  3.98859824E-01,3.79671753E-01,3.61816090E-01,3.45247949E-01,
  3.29906406E-01,3.15718990E-01,3.02605123E-01,2.90479961E-01,
  2.79256942E-01,2.68849010E-01,2.59167694E-01,2.50121165E-01,
  2.41613140E-01,2.33544204E-01,2.25816008E-01,2.18338543E-01,
  2.11037542E-01,2.03860761E-01,1.96780860E-01,1.89794139E-01,
  1.82914998E-01,1.76169137E-01,1.69586265E-01,1.63193841E-01,
  1.57012561E-01,1.51054687E-01,1.45323007E-01,1.39812115E-01,
  1.34510481E-01,1.29403009E-01,1.24473679E-01,1.19707601E-01,
  1.15091461E-01
!
!     GAS: OZONE
!     AT PRESSURE =  2.500E+04 Pa  AND TEMPERATURE =  2.250E+02 K.
!     IN BAND     6:    8.929E-06m TO   1.010E-05m.

  9.99999976E-01,9.99999975E-01,9.99999972E-01,9.99999965E-01,
  9.99999958E-01,9.99999949E-01,9.99999933E-01,9.99999911E-01,
  9.99999877E-01,9.99999820E-01,9.99999742E-01,9.99999625E-01,
  9.99999455E-01,9.99999227E-01,9.99998901E-01,9.99998430E-01,
  9.99997809E-01,9.99997097E-01,9.99996276E-01,9.99995248E-01,
  9.99993959E-01,9.99992333E-01,9.99990406E-01,9.99988139E-01,
  9.99985359E-01,9.99982006E-01,9.99978040E-01,9.99973154E-01,
  9.99967231E-01,9.99960134E-01,9.99951539E-01,9.99941188E-01,
  9.99928596E-01,9.99913213E-01,9.99894656E-01,9.99872376E-01,
  9.99845125E-01,9.99812141E-01,9.99772246E-01,9.99723643E-01,
  9.99665054E-01,9.99593871E-01,9.99507801E-01,9.99403583E-01,
  9.99277252E-01,9.99124287E-01,9.98939165E-01,9.98715091E-01,
  9.98443905E-01,9.98115762E-01,9.97718641E-01,9.97238306E-01,
  9.96657556E-01,9.95955621E-01,9.95107432E-01,9.94083420E-01,
  9.92847718E-01,9.91358039E-01,9.89563992E-01,9.87406010E-01,
  9.84813991E-01,9.81706518E-01,9.77988743E-01,9.73552293E-01,
  9.68274311E-01,9.62017891E-01,9.54633398E-01,9.45961416E-01,
  9.35837573E-01,9.24099797E-01,9.10598743E-01,8.95209595E-01,
  8.77846741E-01,8.58478881E-01,8.37141465E-01,8.13945403E-01,
  7.89078348E-01,7.62796999E-01,7.35410056E-01,7.07254725E-01,
  6.78670746E-01,6.49976902E-01,6.21453265E-01,5.93330391E-01,
  5.65785101E-01,5.38938548E-01,5.12856397E-01,4.87549242E-01,
  4.62974946E-01,4.39042314E-01,4.15618882E-01,3.92543466E-01,
  3.69644236E-01,3.46759604E-01,3.23758156E-01,3.00554549E-01,
  2.77118864E-01,2.53480808E-01,2.29731233E-01,2.06022262E-01,
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  1.82564855E-01,1.59620644E-01,1.37486147E-01,1.16470161E-01,
  9.68685511E-02,7.89405410E-02,6.28900589E-02,4.88530591E-02,
  3.68903520E-02,2.69850227E-02,1.90440454E-02,1.29054889E-02,
  8.35177666E-03,5.12841244E-03,2.96583501E-03,1.60153806E-03,
  7.99606830E-04,3.64979618E-04,1.50341409E-04,5.50463394E-05,
  1.75941015E-05,4.80176768E-06,1.08898236E-06,1.98507755E-07,
  2.79305321E-08,2.88316714E-09,2.04201446E-10,9.06948080E-12,
  2.24720652E-13,2.69068631E-15,1.31298393E-17,2.13782912E-20,
  9.16069709E-24,7.77594341E-28,9.27660565E-33,1.02670229E-38,
  .00000000E+00,.00000000E+00,.00000000E+00,.00000000E+00,
  .00000000E+00,.00000000E+00,.00000000E+00,.00000000E+00,
  .00000000E+00
!
!     GAS: NITROUS OXIDE
!     IN BAND     3:    1.250E-05m TO   1.818E-05m.
!     AT PRESSURE =  2.500E+04 Pa  AND TEMPERATURE =  2.250E+02 K.

  1.00000E+00,1.00000E+00,1.00000E+00,1.00000E+00,1.00000E+00,
  1.00000E+00,9.99999E-01,9.99999E-01,9.99999E-01,9.99999E-01,
  9.99999E-01,9.99999E-01,9.99999E-01,9.99999E-01,9.99998E-01,
  9.99998E-01,9.99998E-01,9.99997E-01,9.99997E-01,9.99997E-01,
  9.99996E-01,9.99995E-01,9.99995E-01,9.99994E-01,9.99993E-01,
  9.99992E-01,9.99991E-01,9.99989E-01,9.99988E-01,9.99986E-01,
  9.99984E-01,9.99981E-01,9.99979E-01,9.99975E-01,9.99972E-01,
  9.99968E-01,9.99963E-01,9.99957E-01,9.99951E-01,9.99943E-01,
  9.99935E-01,9.99925E-01,9.99914E-01,9.99901E-01,9.99887E-01,
  9.99870E-01,9.99851E-01,9.99829E-01,9.99803E-01,9.99775E-01,
  9.99740E-01,9.99702E-01,9.99659E-01,9.99608E-01,9.99550E-01,
  9.99483E-01,9.99407E-01,9.99319E-01,9.99218E-01,9.99103E-01,
  9.98969E-01,9.98818E-01,9.98641E-01,9.98440E-01,9.98214E-01,
  9.97947E-01,9.97645E-01,9.97297E-01,9.96898E-01,9.96442E-01,
  9.95918E-01,9.95318E-01,9.94628E-01,9.93846E-01,9.92930E-01,
  9.91900E-01,9.90738E-01,9.89374E-01,9.87837E-01,9.86071E-01,
  9.84062E-01,9.81774E-01,9.79164E-01,9.76199E-01,9.72822E-01,
  9.69028E-01,9.64643E-01,9.59771E-01,9.54360E-01,9.48120E-01,
  9.41225E-01,9.33487E-01,9.24905E-01,9.15422E-01,9.04961E-01,
  8.93528E-01,8.81065E-01,8.67742E-01,8.53182E-01,8.38004E-01,
  8.22291E-01,8.05552E-01,7.88622E-01,7.71387E-01,7.54209E-01,
  7.37297E-01,7.20806E-01,7.04972E-01,6.89861E-01,6.75710E-01,
  6.62108E-01,6.49515E-01,6.37745E-01,6.26216E-01,6.15260E-01,
  6.04523E-01,5.93962E-01,5.83448E-01,5.72833E-01,5.62052E-01,
  5.50966E-01,5.39628E-01,5.27616E-01,5.15319E-01,5.02661E-01,
  4.89086E-01,4.75089E-01,4.60389E-01,4.45109E-01,4.29323E-01,
  4.12974E-01,3.96266E-01,3.79402E-01,3.62508E-01,3.45843E-01,
  3.29547E-01,3.13873E-01,2.98896E-01,2.84742E-01,2.71482E-01,
  2.59153E-01,2.47770E-01,2.37328E-01,2.27817E-01,2.19227E-01
!
!     GAS: NITROUS OXIDE
!     IN BAND     7:    8.333E-06m TO   8.929E-06m.
!     AT PRESSURE =  2.500E+04 Pa  AND TEMPERATURE =  2.250E+02 K.
  1.00000000E+00,1.00000000E+00,1.00000000E+00,1.00000000E+00,
  1.00000000E+00,1.00000000E+00,1.00000000E+00,1.00000000E+00,
  1.00000000E+00,1.00000000E+00,1.00000000E+00,9.99999999E-01,
  9.99999999E-01,9.99999998E-01,9.99999998E-01,9.99999997E-01,
  9.99999996E-01,9.99999994E-01,9.99999986E-01,9.99999971E-01,
  9.99999965E-01,9.99999954E-01,9.99999933E-01,9.99999910E-01,
  9.99999873E-01,9.99999826E-01,9.99999722E-01,9.99999582E-01,
  9.99999429E-01,9.99999277E-01,9.99999096E-01,9.99998850E-01,
  9.99998490E-01,9.99998093E-01,9.99997591E-01,9.99996990E-01,
  9.99996244E-01,9.99995323E-01,9.99994176E-01,9.99992771E-01,
  9.99991028E-01,9.99988876E-01,9.99986218E-01,9.99982903E-01,
  9.99978882E-01,9.99974006E-01,9.99968223E-01,9.99961142E-01,
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  9.99952568E-01,9.99942193E-01,9.99929360E-01,9.99913924E-01,
  9.99895478E-01,9.99873118E-01,9.99846289E-01,9.99813933E-01,
  9.99774526E-01,9.99726825E-01,9.99668879E-01,9.99598719E-01,
  9.99513864E-01,9.99411253E-01,9.99287145E-01,9.99136838E-01,
  9.98954946E-01,9.98735189E-01,9.98469224E-01,9.98147839E-01,
  9.97759918E-01,9.97291633E-01,9.96726861E-01,9.96046437E-01,
  9.95227533E-01,9.94243211E-01,9.93061968E-01,9.91647316E-01,
  9.89956796E-01,9.87942266E-01,9.85549018E-01,9.82716477E-01,
  9.79378407E-01,9.75463708E-01,9.70898333E-01,9.65606752E-01,
  9.59514782E-01,9.52551184E-01,9.44649460E-01,9.35747588E-01,
  9.25786523E-01,9.14706045E-01,9.02439498E-01,8.88908710E-01,
  8.74020464E-01,8.57666945E-01,8.39729561E-01,8.20085338E-01,
  7.98615861E-01,7.75216633E-01,7.49808061E-01,7.22346992E-01,
  6.92839713E-01,6.61353687E-01,6.28027551E-01,5.93076203E-01,
  5.56791030E-01,5.19532890E-01,4.81721158E-01,4.43818433E-01,
  4.06313867E-01,3.69705203E-01,3.34477222E-01,3.01075075E-01,
  2.69871439E-01,2.41132935E-01,2.14993426E-01,1.91445524E-01,
  1.70356427E-01,1.51505959E-01,1.34633681E-01,1.19480027E-01,
  1.05809868E-01,9.34192086E-02,8.21328240E-02,7.18018213E-02,
  6.23062979E-02,5.35612055E-02,4.55200874E-02,3.81722208E-02,
  3.15318273E-02,2.56221247E-02,2.04590798E-02,1.60388586E-02,
  1.23319524E-02,9.28470277E-03,6.82660548E-03,4.88029677E-03,
  3.37059750E-03,2.22981809E-03,1.39827448E-03,8.21350849E-04,
  4.46259035E-04,2.21391742E-04,9.90064241E-05,3.93986442E-05,
  1.37601212E-05
!
!     GAS: NITROUS OXIDE
!     IN BAND     8:    6.667E-06m TO   8.333E-06m.
!     AT PRESSURE =  2.500E+04 Pa  AND TEMPERATURE =  2.250E+02 K.

  9.99999994E-01,9.99999990E-01,9.99999986E-01,9.99999981E-01,
  9.99999975E-01,9.99999964E-01,9.99999948E-01,9.99999934E-01,
  9.99999903E-01,9.99999866E-01,9.99999816E-01,9.99999742E-01,
  9.99999668E-01,9.99999586E-01,9.99999467E-01,9.99999335E-01,
  9.99999170E-01,9.99998960E-01,9.99998702E-01,9.99998387E-01,
  9.99997994E-01,9.99997514E-01,9.99996909E-01,9.99996178E-01,
  9.99995284E-01,9.99994166E-01,9.99992812E-01,9.99991166E-01,
  9.99989160E-01,9.99986757E-01,9.99983833E-01,9.99980241E-01,
  9.99975878E-01,9.99970674E-01,9.99964319E-01,9.99956715E-01,
  9.99947563E-01,9.99936367E-01,9.99922840E-01,9.99906476E-01,
  9.99886539E-01,9.99862517E-01,9.99833439E-01,9.99798292E-01,
  9.99755681E-01,9.99704088E-01,9.99641671E-01,9.99566222E-01,
  9.99474956E-01,9.99364656E-01,9.99231494E-01,9.99070680E-01,
  9.98876654E-01,9.98642880E-01,9.98361391E-01,9.98022890E-01,
  9.97616529E-01,9.97129527E-01,9.96547278E-01,9.95852905E-01,
  9.95027206E-01,9.94048984E-01,9.92894864E-01,9.91539721E-01,
  9.89957321E-01,9.88120632E-01,9.86003110E-01,9.83579400E-01,
  9.80826036E-01,9.77721837E-01,9.74247273E-01,9.70383200E-01,
  9.66109178E-01,9.61401164E-01,9.56229905E-01,9.50560637E-01,
  9.44353591E-01,9.37566586E-01,9.30157434E-01,9.22086912E-01,
  9.13322206E-01,9.03840383E-01,8.93631750E-01,8.82704553E-01,
  8.71087684E-01,8.58833634E-01,8.46019520E-01,8.32745920E-01,
  8.19133652E-01,8.05318920E-01,7.91446498E-01,7.77662681E-01,
  7.64107183E-01,7.50903902E-01,7.38151147E-01,7.25912452E-01,
  7.14210690E-01,7.03028755E-01,6.92316348E-01,6.82001388E-01,
  6.72001531E-01,6.62233542E-01,6.52617958E-01,6.43083117E-01,
  6.33566272E-01,6.24015948E-01,6.14392742E-01,6.04670808E-01,
  5.94837211E-01,5.84891558E-01,5.74842546E-01,5.64704235E-01,
  5.54492417E-01,5.44221456E-01,5.33904792E-01,5.23557098E-01,
  5.13198067E-01,5.02855941E-01,4.92569580E-01,4.82387926E-01,
  4.72368170E-01,4.62571985E-01,4.53063197E-01,4.43906219E-01,
  4.35165391E-01,4.26904021E-01,4.19182284E-01,4.12053244E-01,
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  4.05557393E-01,3.99717136E-01,3.94532229E-01,3.89976381E-01,
  3.85996887E-01,3.82516272E-01,3.79438578E-01,3.76657753E-01,
  3.74069074E-01,3.71579684E-01,3.69115968E-01,3.66625884E-01,
  3.64075871E-01,3.61445058E-01,3.58719415E-01,3.55887234E-01,
  3.52937803E-01
!
!     GAS: METHANE
!     IN BAND     8:    6.667E-06m TO   8.333E-06m.
!     AT PRESSURE =  2.500E+04 Pa  AND TEMPERATURE =  2.250E+02 K.

  9.99999990E-01,9.99999986E-01,9.99999982E-01,9.99999974E-01,
  9.99999963E-01,9.99999949E-01,9.99999928E-01,9.99999896E-01,
  9.99999841E-01,9.99999779E-01,9.99999703E-01,9.99999614E-01,
  9.99999506E-01,9.99999352E-01,9.99999186E-01,9.99998987E-01,
  9.99998720E-01,9.99998417E-01,9.99998036E-01,9.99997566E-01,
  9.99997014E-01,9.99996302E-01,9.99995451E-01,9.99994429E-01,
  9.99993180E-01,9.99991667E-01,9.99989829E-01,9.99987571E-01,
  9.99984871E-01,9.99981572E-01,9.99977582E-01,9.99972690E-01,
  9.99966798E-01,9.99959610E-01,9.99950902E-01,9.99940318E-01,
  9.99927535E-01,9.99912052E-01,9.99893368E-01,9.99870642E-01,
  9.99843065E-01,9.99809617E-01,9.99769157E-01,9.99720289E-01,
  9.99661181E-01,9.99589500E-01,9.99502974E-01,9.99398252E-01,
  9.99272031E-01,9.99119663E-01,9.98935767E-01,9.98714227E-01,
  9.98447350E-01,9.98126419E-01,9.97741094E-01,9.97279097E-01,
  9.96726564E-01,9.96067316E-01,9.95283140E-01,9.94353627E-01,
  9.93255974E-01,9.91966196E-01,9.90458442E-01,9.88706432E-01,
  9.86684133E-01,9.84366541E-01,9.81731123E-01,9.78758401E-01,
  9.75432002E-01,9.71739125E-01,9.67669287E-01,9.63213411E-01,
  9.58361409E-01,9.53101048E-01,9.47416493E-01,9.41287666E-01,
  9.34690681E-01,9.27597729E-01,9.19976747E-01,9.11792168E-01,
  9.03004542E-01,8.93570364E-01,8.83442428E-01,8.72570129E-01,
  8.60899871E-01,8.48376804E-01,8.34945955E-01,8.20554359E-01,
  8.05153518E-01,7.88701937E-01,7.71167325E-01,7.52528575E-01,
  7.32777147E-01,7.11918818E-01,6.89975602E-01,6.66988517E-01,
  6.43021187E-01,6.18163355E-01,5.92534465E-01,5.66285086E-01,
  5.39596166E-01,5.12675086E-01,4.85748759E-01,4.59053761E-01,
  4.32824069E-01,4.07277172E-01,3.82599878E-01,3.58934903E-01,
  3.36369843E-01,3.14930447E-01,2.94580968E-01,2.75233941E-01,
  2.56769346E-01,2.39058646E-01,2.21987061E-01,2.05468021E-01,
  1.89447949E-01,1.73903564E-01,1.58835072E-01,1.44258726E-01,
  1.30200624E-01,1.16692692E-01,1.03771220E-01,9.14771592E-02,
  7.98571080E-02,6.89634928E-02,5.88526816E-02,4.95807415E-02,
  4.11971864E-02,3.37379379E-02,2.72190505E-02,2.16324032E-02,
  1.69438464E-02,1.30934653E-02,9.99813138E-03,7.55704637E-03,
  5.66062236E-03,4.20124660E-03,3.08298289E-03,2.22739656E-03,
  1.57463771E-03,1.08091239E-03,7.14190802E-04,4.49815670E-04,
  2.67150332E-04
```

TABLE 3

Band i	Spectral limits (μm)	a_i (10 $\mathrm{m^2 kg^{-1}}$)	b_i (μm $\mathrm{m^2 g^{-1}}$)	c_i	d_i ($\mu\mathrm{m}^{-1}$)	e_i	f_i (10^{3} $\mathrm{m^{-1}}$)	w_i ($\times 10^6$)
1	0.25–0.30	3.094	1.252	7.90E-7	3.69E-7	0.844	1.558	10 094
2	0.30–0.33	2.944	1.270	−6.50E-7	4.33E-7	0.841	1.680	17 224
3	0.33–0.36	3.308	1.246	−3.00E-7	2.36E-7	0.839	1.946	24 017
4	0.36–0.40	2.801	1.293	1.00E-6	0	0.836	2.153	34 645
5	0.40–0.44	2.668	1.307	0	0	0.840	1.881	50 524
6	0.44–0.48	2.698	1.315	1.00E-6	0	0.820	3.004	59 520
7	0.48–0.52	2.672	1.320	0	0	0.828	2.467	57 464
8	0.52–0.57	2.838	1.300	0	0	0.825	2.776	66 188
9	0.57–0.64	2.831	1.317	−1.20E-6	4.00E-7	0.828	2.492	85 882
10	0.64–0.69	2.895	1.315	−1.20E-7	4.40E-7	0.818	2.989	54 202
11	0.69–0.75	3.115	1.244	−2.70E-7	1.40E-6	0.804	3.520	60 863
12	0.75–0.78	2.650	1.349	2.30E-6	1.70E-6	0.809	3.387	25 044
13	0.78–0.87	2.622	1.362	3.30E-6	2.80E-6	0.806	3.355	68 135
14	0.87–1.00	2.497	1.376	9.80E-6	2.10E-5	0.783	5.035	83 962
15	1.00–1.10	2.632	1.365	−4.60E-5	5.00E-5	0.784	4.745	49 082
16	1.10–1.19	2.589	1.385	−2.80E-5	8.00E-5	0.780	4.989	39 072
17	1.19–1.28	2.551	1.401	6.20E-5	2.60E-4	0.773	5.405	29 133
18	1.28–1.53	2.463	1.420	2.40E-4	8.56E-4	0.754	6.555	65 845
19	1.53–1.64	2.237	1.452	1.20E-4	6.67E-4	0.749	6.931	20 611
20	1.64–2.13	1.970	1.501	1.20E-3	2.16E-3	0.740	7.469	50 793
21	2.13–2.38	1.850	1.556	1.90E-4	2.54E-3	0.769	5.171	14 226
22	2.38–2.91	1.579	1.611	1.23E-1	9.35E-3	0.851	2.814	18 681
23	2.91–3.42	1.950	1.540	4.49E-1	1.54E-3	0.831	6.102	9 588
24	3.42–4.00	−1.023	1.933	2.50E-2	1.22E-2	0.726	6.652	5 205
1	0.25–0.69	2.817	1.305	−5.62E-8	1.63E-7	0.829	2.482	459 760
2	0.69–1.19	2.682	1.346	−6.94E-6	2.35E-5	0.794	4.226	326 158
3	1.19–2.38	2.264	1.454	4.64E-4	1.24E-3	0.754	6.560	180 608
4	2.38–4.00	1.281	1.641	2.01E-1	7.56E-3	0.826	4.353	33 474

For c_i and d_i, the values are abbreviated using Fortran exponential format.

Table 4.1
Fractional ozone transmissivity for shortwave band 1 of the standard model. (Ozone does not absorb in bands 2-4.) Values are for every tenth-decade from 0.2x10 kgm^{-2} to 0.2 kgm^{-} .

.999721	.999649	.999560	.999449	.999310	.999137	.998911	.998639
.998304	.997905	.997421	.996827	.996140	.995327	.994397	.993338
.992178	.990903	.989540	.988132	.986673	.985179	.983627	.982006
.980291	.978461	.976524	.974414	.972120	.969655	.966930	.963926
.960547	.956720	.952319	.947216	.941332	.934339	.926017	.916281
.904617	.890829	.874387	.854918	.831874	.804833	.773879	.738109
.697762	.654226						

Table 4.2
Fractional water vapour transmissivity for shortwave bands 2-4 respectively of the standard model. (Water vapour does not absorb in band 1.) Values are for every fifth-decade from 10 kgm^{-2} to 10 kgm .

.999925	.999902	.999873	.999834	.999782	.999712	.999627	.999515
.999373	.999182	.998941	.998628	.998221	.997700	.997019	.996140
.995004	.993543	.991673	.989243	.986138	.982166	.977118	.970772
.962696	.952648	.940233	.925080	.906964	.885235	.860017	.831196
.798890	.763523	.724730	.683486	.640193	.595601	.550869	.506163
.463130	.422344	.384329					
.999351	.999162	.998924	.998615	.998220	.997710	.997056	.996219
.995155	.993775	.992024	.989785	.986943	.983364	.978792	.973070
.965924	.957079	.946315	.933128	.917455	.899109	.878105	.854785
.829092	.801972	.773946	.745562	.717345	.688908	.660691	.632481
.604137	.575597	.546026	.515551	.483807	.450740	.416722	.381512
.346202	.311246	.277160					
.996628	.995673	.994443	.992886	.990863	.988295	.985024	.980869
.975646	.968990	.960674	.950325	.937567	.922114	.903300	.881119
.855402	.826302	.794441	.759906	.724076	.687667	.651233	.615066
.578117	.540298	.500889	.459635	.416955	.372655	.328404	.285283
.244560	.207373	.173516	.143549	.117077	.0938588	.0738897	.0568386
.0430195	.0322597	.0242632					

Table 4.3
Fractional carbon dioxide transmissivity for shortwave bands 3 and 4 respectively of the standard model. (Carbon dioxide does not absorb in bands 1-2.) Values are for every half-decade from 10 kgm to 10 kgm^{-2} .

.999997	.999994	.999986	.999969	.999937	.999869	.999734	.999460
.998918	.997831	.995705	.991615	.984135	.971311	.951543	
.999893	.999783	.999560	.999106	.998194	.996355	.992726	.985687
.972763	.950973	.920079	.885743	.855990	.831226	.809535	

Table 5.1
Coefficients for temperature scaling of pathlengths (2.4.2) for water vapour line absorption (first 6 lines are the 6 bands in standard order) and carbon dioxide (first for band 2 and then the values used for both bands 3 and 4).

a	b	c	d	e	f
2.98199E-3	-3.94023E-4	3.19566E-5	-1.06432E-5	6.60324E-7	1.74356E-7
1.43676E-2	3.66501E-3	-1.60822E-3	-5.53979E-5	-1.01701E-5	9.20868E-6
1.97861E-2	3.15542E-3	-1.74547E-3	-8.77012E-5	5.13302E-5	5.23138E-7
2.89560E-2	-2.08807E-3	-1.21943E-3	-1.65960E-4	1.57704E-4	-1.46427E-5
1.03800E-2	4.36296E-3	-1.61431E-3	-2.76744E-5	-3.27381E-5	1.27646E-5
8.68859E-3	-9.72752E-4	0	-2.78412E-5	-7.13940E-7	-1.17469E-6
2.50073E-4	4.55875E-4	1.09242E-4	1.99846E-6	-2.16313E-6	1.75991E-7
3.07423E-2	1.10879E-3	-3.22172E-4	-1.08482E-4	2.58096E-6	-8.14575E-7

Table 5.2
Padw coefficients used for calculating transmissivities for water vapour line absorption (first 6 lines, in standard order) and carbon dioxide (for band 2 and then for both 3 and 4).

Padw	Padw	Padw
7.3585943E-3	-1.0847662E-3	0.10475952
1.2167192	0.52341830	1.0800762
7.9978921	7.1929934	7.3878952
24.063614	10.392022	10.509317
0.18097099	-0.025423873	0.42353379
-3.7133165	0.44809588	-8.1329826
0.077659686	1.2191543	2.0855896
13.213894	22.259478	22.268925

Table 5.3 - Pressure Scaling Coefficients for 1C code

gas band	self	forn	h2o	co2	o3	n2o	ch4	cfc11	cfc12
1	0.0	0.0	.97	0.0	0.0	0.0	0.0	0.0	0.0
2	-.05	0.0	.97	0.0	0.0	0.0	0.0	0.0	0.0
3	-.06	0.0	.97	.82	.17	.81	0.0	0.0	0.0
4	0.0	0.0	.96	0.0	0.0	0.0	0.0	0.0	0.0
5	0.0	0.0	.94	.68	0.0	0.0	0.0	0.0	0.0
6	0.0	0.0	.93	.68	.32	0.0	0.0	0.0	0.0
7	0.0	0.0	.92	0.0	0.0	.82	0.0	0.0	0.0
8	-.03	0.0	.90	0.0	0.0	.82	.83	0.0	0.0
9	0.0	0.0	.95	0.0	0.0	0.0	0.0	0.0	0.0

Table 5.4 - Temperature Scaling Coefficients for 1C code

gas band	self	forn	h2o	co2	o3	n2o	ch4	cfc11	cfc12
1	0.0	-1.4	.82	0.0	0.0	0.0	0.0	0.0	0.0
2	-2.0	-1.2	3.5	0.0	0.0	0.0	0.0	0.0	0.0
3	-2.8	-2.3	4.3	2.4	.13	-3.1	0.0	0.0	0.0
4	-3.5	-.27	6.2	0.0	0.0	0.0	0.0	0.0	0.0
5	-3.5	0.0	7.2	8.9	0.0	0.0	0.0	0.0	0.0
6	-3.6	0.0	7.5	8.3	.02	0.0	0.0	0.0	0.0
7	-3.0	0.0	5.5	0.0	0.0	5.1	0.0	0.0	0.0
8	-1.2	-.62	4.7	0.0	0.0	-2.4	.68	0.0	0.0
9	0.0	0.0	-1.2	0.0	0.0	0.0	0.0	0.0	0.0

Table 5.5 - Doppler Broadening Coefficients for the 1C code

self	forn	h2o	co2	o3	n2o	ch4
0.0	0.0	3.E3	150.	1E5	0.0	0.0

Table 5.6 - Absorption Coefficients for CFCs

(see equation 2.5.16 for details)

CFC11	band 4	-2.7e2
	6	-9.2e1
CFC12	band 5	-2.9e2
	6	-2.5e2
	7	-2.4e2

TABLE 6.1 Zonal Mean Ozone Mixing Ratios (ppmv) as Function of Pressure
(standard typeface: only 1 data set used in average,
italics: standard deviation of data types > 10% ,
underlined: standard deviation ≤ 10%)

average ozone (ppmv) for January

p (mb)	-80°	-70°	-60°	-50°	-40°	-30°	-20°	-10°	0°	10°	20°	30°	40°	50°	60°	70°	80°
.003	.55	.72	.80	.78	.70	.63	.57	.53	.53	.52	.52	.66	.81	.84	.83	.77	.72
.005	.26	.35	.45	.51	.49	.46	.43	.42	.41	.38	.35	.42	.50	.52	.50	.46	.43
.007	.18	.21	.28	.35	.36	.36	.37	.38	.39	.37	.32	.30	.31	.30	.27	.25	.23
.010	.15	.15	.18	.22	.24	.26	.29	.31	.33	.34	.32	.28	.23	.19	.14	.13	.12
.015	.16	.15	.15	.16	.15	.16	.19	.20	.21	.23	.27	.28	.26	.23	.17	.16	.15
.020	.17	.16	.15	.14	.14	.13	.14	.16	.16	.17	.21	.25	.27	.28	.24	.22	.21
.030	.21	.19	.18	.17	.15	.14	.15	.15	.15	.16	.17	.19	.24	.32	.37	.34	.32
.050	.31	.28	.26	.25	.24	.22	.22	.22	.23	.23	.24	.27	.30	.37	.47	.43	.41
.070	.41	.38	.37	.36	.34	.32	.31	.32	.32	.32	.34	.41	.46	.49	.53	.49	.46
.100	.54	.53	.52	*.49*	*.48*	.48	.49	.49	.47	.46	.49	*.53*	.69	.69	.67	.62	.58
.150	.76	.74	.73	*.73*	*.74*	*.76*	.74	.71	.68	*.68*	*.69*	*.75*	*.79*	1.01	.93	.86	.80
.200	.89	.90	.92	.92	*.96*	*.98*	.96	.92	.89	*.89*	*.92*	*.99*	*1.04*	1.28	1.19	1.10	1.03
.300	1.13	1.17	1.21	1.25	1.32	1.37	1.35	1.30	1.27	1.27	1.33	*1.42*	*1.48*	1.77	1.63	1.50	1.41
.500	1.41	1.50	1.62	1.75	1.86	1.93	1.91	1.85	1.83	1.84	1.88	1.99	2.16	*2.26*	2.07	1.91	1.79
.700	1.66	1.80	1.97	2.14	2.28	2.36	2.35	2.30	2.29	2.29	2.31	2.45	2.71	2.80	2.70	2.36	2.22
1.000	2.15	2.28	2.46	2.63	2.82	2.97	3.03	3.03	3.04	3.05	3.10	3.33	3.67	3.75	3.55	3.04	2.89
1.500	2.99	3.07	3.26	3.43	3.67	3.92	4.10	4.19	4.23	4.28	4.42	4.74	5.05	5.04	4.65	3.98	3.75
2.000	3.92	3.97	4.17	4.38	4.66	4.95	5.20	5.35	5.40	5.46	5.60	5.87	6.03	5.88	5.33	4.65	4.34
3.000	5.45	5.48	5.77	6.13	6.48	6.82	7.13	7.34	7.35	7.31	7.27	7.21	7.04	6.65	5.96	5.34	5.06
5.000	5.99	6.26	6.96	7.63	8.20	8.66	9.07	9.36	9.14	8.79	8.33	7.79	7.29	6.67	6.14	5.55	5.39
7.000	5.49	5.94	6.94	7.82	8.54	9.08	9.56	9.96	9.68	9.16	8.35	7.60	6.99	6.34	6.02	5.37	5.27
10.000	4.62	5.14	6.32	7.30	8.10	8.66	9.15	9.71	9.62	9.03	7.96	7.11	6.52	5.98	5.83	5.01	4.91
15.000	3.86	4.36	5.52	6.41	7.08	7.45	7.78	8.15	8.09	7.66	6.92	6.41	6.10	5.78	5.52	4.62	4.45
20.000	3.52	3.96	4.99	5.68	6.10	6.25	6.36	6.42	6.27	6.12	5.91	5.84	5.82	5.67	5.19	4.34	4.14

average ozone (ppmv) for February

p (mb)	-80°	-70°	-60°	-50°	-40°	-30°	-20°	-10°	0°	10°	20°	30°	40°	50°	60°	70°	80°
.003	.43	.56	.64	.64	.60	.57	.60	.69	.73	.70	.65	.63	.66	.73	.75	.77	.74
.005	.21	.29	.37	.39	.38	.39	.44	.47	.47	.47	.44	.42	.42	.43	.41	.37	.36
.007	.14	.18	.24	.28	.30	.35	.41	.42	.42	.42	.39	.33	.30	.27	.23	.18	.17
.010	.13	.14	.16	.20	.23	.29	.35	.35	.36	.38	.38	.33	.27	.22	.17	.12	.12
.015	.14	.13	.14	.14	.16	.18	.21	.22	.24	.26	.30	.32	.31	.28	.24	.20	.19
.020	.15	.15	.14	.14	.13	.14	.15	.16	.17	.18	.21	.26	.30	.31	.30	.27	.26
.030	.20	.19	.18	.17	.15	.15	.15	.16	.16	.16	.17	.19	.23	.29	.35	.38	.36
.050	.30	.29	.28	.26	.24	.24	.23	.23	.23	.24	.25	.27	.29	.32	.39	.46	.44
.070	.40	.40	.40	.38	.36	.34	.33	.32	.32	.32	.36	.40	.43	.45	.48	.52	.50
.100	.56	.54	*.53*	*.52*	*.50*	.50	.50	.50	.48	.46	*.48*	*.52*	*.53*	.64	.63	.64	.61
.150	.76	.75	.75	*.77*	*.78*	*.77*	.75	.73	.71	.70	*.70*	*.71*	*.72*	*.75*	*.74*	.85	.82
.200	.92	.92	.94	*.97*	*1.01*	*1.01*	.98	.94	.92	.91	*.93*	*.94*	*.95*	*.95*	*.93*	1.04	1.00
.300	1.20	1.22	1.26	1.31	*1.39*	1.41	1.36	1.30	1.29	1.30	1.34	1.37	*1.37*	*1.35*	*1.32*	1.50	1.44
.500	1.59	1.63	1.73	1.83	1.93	1.96	1.91	1.83	1.82	1.85	1.88	1.94	2.02	2.14	2.22	2.25	2.16
.700	2.00	2.01	2.12	2.25	2.37	2.42	2.34	2.24	2.22	2.25	2.29	2.40	2.60	2.86	2.98	2.95	2.60
1.000	2.73	2.68	2.73	2.86	3.00	3.09	3.03	2.90	2.86	2.91	3.02	3.24	3.58	3.93	4.00	3.80	3.22
1.500	3.81	3.71	3.71	3.81	3.98	4.11	4.10	3.95	3.87	3.98	4.20	4.58	5.10	5.38	5.22	4.79	4.11
2.000	4.65	4.61	4.68	4.80	4.98	5.15	5.17	5.06	4.99	5.09	5.30	5.73	6.24	6.29	5.92	5.41	4.82
3.000	5.60	5.84	6.16	6.42	6.68	6.91	7.03	7.08	7.05	7.04	7.09	7.37	7.45	7.04	6.47	6.07	5.69
5.000	5.52	6.28	7.10	7.58	8.05	8.60	9.02	9.37	9.23	8.99	8.76	8.39	7.73	7.00	6.49	6.42	6.30
7.000	4.84	5.78	6.90	7.56	8.21	9.00	9.60	10.20	10.10	9.68	9.09	8.20	7.32	6.72	6.31	6.46	6.31
10.000	3.98	4.84	6.12	7.02	7.85	8.63	9.33	10.03	10.10	9.59	8.73	7.52	6.68	6.37	6.15	6.42	6.07
15.000	3.39	4.08	5.27	6.07	6.82	7.46	7.95	8.37	8.38	7.97	7.37	6.63	6.15	6.03	6.01	6.06	5.72
20.000	3.22	3.78	4.76	5.34	5.89	6.21	6.40	6.50	6.39	6.22	6.12	5.94	5.82	5.82	5.80	5.54	5.30

TABLE 6.1 - continued

average ozone (ppmv) for March

p (mb)	latitude																
	-80°	-70°	-60°	-50°	-40°	-30°	-20°	-10°	0°	10°	20°	30°	40°	50°	60°	70°	80°
.003	.37	.58	.66	.68	.74	.82	.81	.74	.69	.71	.76	.77	.68	.58	.57	.60	.61
.005	.21	.28	.31	.38	.48	.53	.52	.47	.44	.46	.49	.48	.42	.35	.33	.31	.27
.007	.15	.21	.24	.30	.38	.43	.43	.41	.40	.41	.42	.41	.36	.30	.26	.22	.16
.010	.12	.19	.22	.26	.33	.38	.37	.34	.33	.34	.37	.39	.38	.34	.28	.22	.15
.015	.12	.15	.16	.20	.24	.25	.23	.21	.20	.22	.26	.32	.38	.39	.36	.31	.23
.020	.15	.15	.14	.15	.17	.18	.16	.15	.16	.16	.19	.24	.33	.38	.39	.37	.31
.030	.20	.18	.17	.15	.14	.15	.17	.17	.17	.17	.17	.18	.23	.29	.37	.43	.41
.050	.30	.30	.29	.27	.25	.25	.25	.24	.23	.24	.25	.27	.28	.30	.37	.46	.48
.070	.40	.40	.41	.40	.38	.35	.34	.33	.31	.32	.36	.39	.41	.43	.46	.50	.52
.100	.55	.54	*.53*	*.53*	*.51*	*.50*	.51	.50	.48	.47	*.48*	*.49*	*.52*	*.54*	*.55*	*.58*	.61
.150	.79	.77	*.77*	*.78*	*.77*	*.75*	.75	.74	.73	.72	*.71*	*.72*	*.74*	*.74*	*.73*	*.74*	*.75*
.200	.99	.97	*.98*	*1.00*	*.99*	*.97*	.96	.96	.95	.94	*.93*	*.92*	*.95*	*.94*	*.91*	*.91*	*.93*
.300	1.33	1.35	1.36	1.38	1.39	1.37	1.34	1.33	1.34	1.33	1.32	*1.32*	*1.33*	*1.32*	*1.28*	*1.29*	1.35
.500	1.97	1.96	1.92	1.93	1.95	1.93	1.89	1.88	1.89	1.90	1.92	1.94	1.94	1.96	2.02	2.12	2.27
.700	2.82	2.58	2.42	2.40	2.40	2.37	2.32	2.30	2.30	2.31	2.35	2.41	2.42	2.50	2.69	2.89	3.00
1.000	3.86	3.62	3.30	3.20	3.17	3.11	2.99	2.90	2.88	2.92	3.03	3.17	3.27	3.45	3.75	3.96	3.93
1.500	5.01	5.04	4.66	4.46	4.36	4.28	4.06	3.83	3.77	3.86	4.10	4.39	4.67	5.02	5.33	5.33	5.00
2.000	5.41	5.80	5.69	5.53	5.45	5.37	5.12	4.80	4.71	4.85	5.15	5.51	5.92	6.29	6.42	6.18	5.74
3.000	5.39	6.26	6.76	6.93	7.00	7.06	6.93	6.60	6.48	6.63	6.91	7.21	7.61	7.73	7.41	6.88	6.49
5.000	5.08	6.05	7.00	7.58	8.03	8.43	8.77	8.95	8.91	8.90	8.84	8.65	8.48	7.99	7.31	6.65	6.50
7.000	4.65	5.40	6.51	7.32	8.00	8.68	9.34	9.94	10.05	9.80	9.31	8.71	8.13	7.45	6.78	6.28	6.30
10.000	4.09	4.52	5.64	6.67	7.55	8.45	9.36	10.28	10.59	10.12	9.27	8.26	7.38	6.72	6.24	6.03	6.18
15.000	3.73	3.98	4.87	5.81	6.55	7.26	7.93	8.54	8.70	8.37	7.83	7.14	6.48	6.08	5.86	5.86	5.95
20.000	3.61	3.85	4.49	5.19	5.70	6.10	6.42	6.66	6.67	6.57	6.47	6.23	5.91	5.73	5.65	5.68	5.58

average ozone (ppmv) for April

p (mb)	latitude																
	-80°	-70°	-60°	-50°	-40°	-30°	-20°	-10°	0°	10°	20°	30°	40°	50°	60°	70°	80°
.003	.95	.91	.77	.83	.92	.93	.84	.77	.76	.79	.93	1.01	.83	.59	.52	.56	.63
.005	.39	.37	.35	.43	.54	.57	.50	.44	.43	.48	.62	.72	.61	.43	.36	.38	.42
.007	.26	.25	.24	.32	.41	.44	.41	.39	.39	.41	.49	.56	.51	.41	.34	.32	.30
.010	.28	.26	.25	.30	.35	.35	.34	.36	.36	.36	.39	.46	.48	.45	.41	.35	.26
.015	.31	.29	.28	.27	.26	.22	.20	.22	.23	.22	.24	.33	.41	.44	.43	.39	.29
.020	.31	.29	.28	.22	.19	.16	.15	.15	.16	.16	.17	.23	.31	.35	.37	.37	.31
.030	.29	.27	.26	.18	.15	.16	.17	.16	.17	.17	.17	.19	.21	.23	.26	.30	.37
.050	.35	.34	.32	.28	.27	.26	.26	.25	.25	.26	.27	.27	.28	.29	.31	.35	.39
.070	.46	.44	.42	.41	.40	.38	.37	.35	.34	.34	.37	.38	.39	.41	.43	.46	.49
.100	.62	.59	.56	*.57*	*.55*	.54	.54	.53	.50	.49	*.50*	*.49*	*.49*	*.50*	*.53*	*.55*	*.56*
.150	.88	.84	.80	*.81*	*.79*	*.79*	.80	.78	.76	.75	*.75*	*.74*	*.73*	*.73*	*.73*	*.73*	*.73*
.200	1.17	1.11	1.06	*1.05*	*1.02*	1.01	1.01	1.00	.98	.97	*.96*	*.95*	*.95*	*.93*	*.91*	*.90*	*.89*
.300	1.70	1.61	1.54	1.50	1.43	1.40	1.39	1.38	1.36	1.35	1.35	1.33	1.32	1.29	1.26	*1.24*	1.24
.500	2.50	2.38	2.27	2.17	2.04	1.96	1.93	1.94	1.94	1.94	1.94	1.94	1.89	1.84	1.83	1.86	1.90
.700	3.50	3.34	2.96	2.77	2.56	2.42	2.36	2.37	2.37	2.37	2.40	2.41	2.33	2.26	2.28	2.37	2.48
1.000	4.64	4.64	4.19	3.87	3.52	3.25	3.07	2.99	2.98	3.00	3.06	3.11	3.03	2.96	3.03	3.18	3.35
1.500	5.59	6.06	5.84	5.48	5.01	4.57	4.16	3.94	3.89	3.94	4.08	4.21	4.18	4.16	4.31	4.48	4.57
2.000	5.65	6.39	6.65	6.51	6.14	5.71	5.23	4.90	4.83	4.93	5.13	5.31	5.35	5.39	5.55	5.63	5.49
3.000	5.18	5.98	6.93	7.34	7.40	7.30	6.99	6.58	6.49	6.66	6.95	7.12	7.25	7.31	7.30	7.02	6.42
5.000	4.94	5.54	6.48	7.22	7.84	8.44	8.82	8.63	8.42	8.65	8.77	8.66	8.69	8.50	7.82	6.99	6.14
7.000	4.66	5.09	5.90	6.73	7.53	8.46	9.27	9.63	9.62	9.55	9.27	8.91	8.61	8.10	7.29	6.37	5.68
10.000	4.18	4.50	5.23	6.08	6.95	8.07	9.21	10.16	10.45	10.00	9.25	8.64	7.95	7.22	6.47	5.78	5.40
15.000	3.73	4.15	4.82	5.45	6.12	7.02	7.89	8.62	8.80	8.48	7.95	7.48	6.86	6.29	5.77	5.40	5.30
20.000	3.46	4.03	4.63	5.02	5.45	6.01	6.46	*6.79*	6.85	6.79	6.66	6.49	6.11	5.74	5.41	5.24	5.26

TABLE 6.1 - continued

average ozone (ppmv) for May

p (mb)	-80°	-70°	-60°	-50°	-40°	-30°	-20°	-10°	0°	10°	20°	30°	40°	50°	60°	70°	80°
.003	.94	1.06	.99	.99	1.02	.92	.75	.65	.63	.67	.75	.85	.84	.74	.64	.56	.48
.005	.48	.55	.51	.51	.57	.53	.46	.42	.41	.43	.52	.62	.63	.56	.49	.41	.33
.007	.31	.35	.33	.33	.39	.39	.40	.42	.43	.43	.45	.50	.51	.46	.41	.33	.25
.010	.26	.29	.27	.27	.30	.32	.37	.41	.42	.40	.39	.39	.38	.36	.33	.28	.21
.015	.23	.26	.24	.24	.22	.23	.24	.27	.26	.25	.24	.25	.25	.25	.24	.21	.19
.020	.21	.24	.22	.22	.18	.17	.17	.18	.17	.17	.17	.19	.19	.20	.19	.19	.18
.030	.21	.24	.22	.22	.17	.16	.16	.16	.16	.17	.18	.19	.20	.20	.19	.19	.21
.050	.28	.32	.30	.30	.28	.28	.27	.26	.27	.27	.27	.27	.28	.29	.28	.29	.31
.070	.39	.44	.41	.41	.41	.40	.39	.38	.38	.38	.38	.37	.38	.39	.39	.40	.43
.100	.56	.63	.59	.59	.57	.56	.57	.55	.53	.53	.53	.51	.49	.51	.53	.54	.54
.150	.80	.91	.85	.85	.81	.81	.83	.81	.79	.79	.80	.78	.76	.76	.76	.75	.73
.200	1.06	1.20	1.12	1.12	1.05	1.03	1.05	1.03	1.01	1.02	1.02	1.00	.97	.95	.94	.91	.88
.300	1.58	1.79	1.68	1.67	1.52	1.43	1.43	1.41	1.39	1.40	1.39	1.36	1.33	1.29	1.25	1.20	1.16
.500	2.32	2.64	2.47	2.46	2.24	2.02	1.96	1.97	1.97	1.97	1.96	1.95	1.89	1.82	1.74	1.66	1.59
.700	3.06	3.66	3.50	3.35	2.89	2.54	2.43	2.42	2.42	2.42	2.42	2.40	2.33	2.23	2.12	2.04	1.97
1.000	4.05	4.97	4.91	4.79	4.09	3.49	3.18	3.09	3.07	3.06	3.07	3.03	2.92	2.79	2.67	2.59	2.59
1.500	4.96	6.30	6.39	6.61	5.85	4.98	4.33	4.10	4.05	4.04	4.06	4.02	3.88	3.74	3.62	3.54	3.64
2.000	5.13	6.52	6.77	7.38	6.94	6.15	5.41	5.10	5.03	5.05	5.11	5.08	4.94	4.81	4.72	4.62	4.75
3.000	4.89	6.07	6.39	7.46	7.76	7.54	7.06	6.74	6.68	6.77	6.93	6.92	6.82	6.73	6.60	6.31	6.30
5.000	4.38	5.79	5.73	6.78	7.57	8.15	8.39	8.31	8.27	8.57	8.71	8.64	8.50	8.20	7.59	6.75	6.19
7.000	3.87	5.46	5.31	6.21	7.12	8.03	8.77	9.12	9.18	9.27	9.20	8.98	8.70	8.16	7.35	6.26	5.47
10.000	3.37	4.93	4.93	5.69	6.57	7.61	8.74	9.64	9.95	9.44	8.94	8.57	8.09	7.57	6.75	5.63	4.84
15.000	3.12	4.43	4.74	5.33	5.95	6.72	7.60	8.28	8.55	8.39	7.91	7.59	7.10	6.57	5.92	5.06	4.43
20.000	3.02	4.13	4.61	5.09	5.47	5.92	6.36	6.63	6.77	6.86	6.71	6.59	6.30	5.88	5.38	4.76	4.32

average ozone (ppmv) for June

p (mb)	-80°	-70°	-60°	-50°	-40°	-30°	-20°	-10°	0°	10°	20°	30°	40°	50°	60°	70°	80°
.003	.75	.77	.87	.86	.80	.78	.59	.47	.47	.54	.62	.73	.87	.94	.88	.72	.57
.005	.47	.48	.54	.54	.50	.50	.38	.34	.38	.41	.43	.51	.63	.63	.50	.39	.32
.007	.33	.34	.38	.37	.35	.37	.34	.35	.38	.39	.36	.39	.46	.42	.30	.25	.22
.010	.25	.26	.29	.29	.27	.30	.30	.31	.31	.30	.28	.27	.29	.26	.19	.18	.17
.015	.20	.20	.23	.22	.21	.22	.21	.20	.19	.19	.18	.17	.18	.18	.17	.16	.16
.020	.17	.17	.20	.19	.18	.17	.16	.15	.14	.15	.15	.15	.16	.17	.17	.17	.17
.030	.17	.17	.20	.19	.18	.17	.17	.16	.16	.17	.17	.17	.19	.20	.20	.20	.21
.050	.29	.30	.34	.33	.31	.30	.28	.26	.26	.26	.26	.27	.27	.28	.27	.28	.30
.070	.42	.43	.49	.48	.45	.45	.41	.38	.37	.37	.38	.39	.38	.38	.38	.39	.40
.100	.54	.56	.63	.62	.58	.57	.56	.57	.57	.58	.58	.55	.52	.53	.57	.55	.56
.150	.76	.79	.89	.88	.82	.82	.83	.83	.83	.85	.88	.84	.80	.80	.80	.80	.78
.200	.99	1.02	1.15	1.14	1.06	1.04	1.05	1.06	1.06	1.08	1.11	1.08	1.03	1.01	.99	.96	.93
.300	1.43	1.47	1.67	1.64	1.53	1.44	1.44	1.47	1.47	1.48	1.49	1.45	1.39	1.35	1.30	1.24	1.18
.500	2.10	2.17	2.46	2.42	2.26	2.02	1.98	2.00	2.00	1.99	1.98	1.95	1.87	1.78	1.67	1.56	1.46
.700	2.86	2.94	3.56	3.54	2.96	2.56	2.46	2.46	2.46	2.45	2.44	2.41	2.30	2.16	1.99	1.83	1.71
1.000	3.92	4.02	5.01	5.16	4.29	3.56	3.30	3.22	3.19	3.16	3.13	3.05	2.88	2.68	2.47	2.28	2.16
1.500	5.14	5.28	6.50	7.11	6.19	5.06	4.51	4.30	4.24	4.19	4.15	3.98	3.73	3.49	3.24	3.05	2.97
2.000	5.52	5.68	6.77	7.74	7.27	6.16	5.55	5.30	5.23	5.21	5.20	5.01	4.73	4.49	4.24	4.05	4.03
3.000	5.30	5.48	6.20	7.36	7.96	7.43	7.05	6.91	6.88	6.94	7.02	6.84	6.59	6.38	6.07	5.83	5.87
5.000	4.73	4.93	5.64	6.37	7.53	7.93	8.27	8.43	8.55	8.72	8.78	8.63	8.36	7.84	7.14	6.38	6.08
7.000	4.32	4.50	5.32	5.74	7.04	7.82	8.47	8.94	9.19	9.28	9.17	8.99	8.63	7.91	7.01	5.91	5.37
10.000	3.94	4.05	5.02	5.29	6.53	7.45	8.11	8.88	9.23	9.11	8.67	8.45	7.95	7.42	6.52	5.29	4.71
15.000	3.78	3.86	4.82	5.19	5.93	6.48	7.04	7.67	7.97	7.84	7.38	7.22	6.83	6.36	5.66	4.68	4.18
20.000	3.70	3.79	4.68	5.25	5.57	5.76	5.97	6.20	6.36	6.40	6.20	6.15	6.00	5.64	5.09	4.33	3.94

TABLE 6.1 - continued

average ozone (ppmv) for July

	latitude																
p (mb)	-80°	-70°	-60°	-50°	-40°	-30°	-20°	-10°	0°	10°	20°	30°	40°	50°	60°	70°	80°
.003	.48	.51	.56	.58	.66	.63	.53	.48	.47	.51	.60	.66	.71	.85	.93	.80	.58
.005	.28	.30	.33	.34	.41	.41	.37	.34	.37	.40	.42	.44	.49	.55	.52	.40	.31
.007	.20	.21	.23	.24	.29	.32	.32	.33	.35	.36	.35	.34	.36	.37	.30	.23	.21
.010	.17	.18	.19	.20	.24	.27	.29	.28	.28	.27	.25	.24	.24	.23	.19	.16	.17
.015	.17	.19	.20	.21	.20	.20	.19	.17	.16	.16	.16	.16	.16	.16	.16	.16	.16
.020	.17	.19	.20	.21	.17	.16	.15	.14	.14	.14	.14	.14	.15	.16	.17	.17	.17
.030	.18	.19	.21	.22	.17	.16	.16	.16	.17	.17	.16	.16	.18	.20	.20	.20	.21
.050	.26	.27	.30	.31	.31	.29	.26	.25	.25	.25	.24	.24	.27	.28	.28	.28	.31
.070	.36	.38	.41	.43	.46	.45	.39	.36	.36	.36	.35	.36	.39	.39	.38	.39	.42
.100	.51	.54	.58	.61	*.60*	*.60*	.57	.55	.55	.56	.58	.57	.55	.55	.57	.55	.56
.150	.74	.79	.85	.89	*.85*	*.86*	*.83*	.82	.81	.84	.87	.88	.85	.82	.81	.81	.79
.200	.94	1.01	1.09	1.14	*1.09*	*1.08*	*1.06*	1.04	1.04	1.06	1.11	1.12	1.09	1.04	1.00	.98	.95
.300	1.22	1.30	1.41	1.47	1.53	1.49	1.45	1.44	1.44	1.46	1.50	1.51	1.46	1.39	1.32	1.26	1.19
.500	1.77	1.89	2.05	2.14	2.22	2.07	2.00	1.99	1.99	1.99	2.00	2.00	1.93	1.81	1.68	1.55	*1.44*
.700	2.34	2.49	2.85	3.03	2.86	2.60	2.48	2.44	2.44	2.44	2.48	2.49	2.39	2.20	2.00	1.82	1.66
1.000	3.31	3.48	4.06	4.40	4.05	3.58	3.34	3.23	3.19	3.18	3.22	3.19	3.01	2.76	2.52	2.30	2.14
1.500	4.53	4.81	5.62	6.28	5.76	5.04	4.61	4.39	4.31	4.29	4.31	4.18	3.91	3.61	3.32	3.08	2.97
2.000	5.08	5.44	6.24	7.17	6.86	6.13	5.69	5.47	5.38	5.37	5.38	5.21	4.90	4.59	4.28	4.03	3.97
3.000	5.28	5.57	6.22	7.39	7.79	7.43	7.23	7.16	7.12	7.15	7.18	6.98	6.68	6.37	6.00	5.66	5.64
5.000	5.08	5.23	5.79	6.63	7.47	8.04	8.35	8.62	8.76	8.87	8.85	8.67	8.34	7.88	7.11	6.21	5.84
7.000	4.72	4.81	5.39	5.91	6.98	7.81	8.42	8.98	9.26	9.34	9.17	8.99	8.59	7.97	6.98	5.79	5.18
10.000	4.19	4.28	4.98	5.29	6.41	7.19	7.95	8.77	9.11	9.08	8.65	8.45	7.95	7.23	6.28	5.14	4.50
15.000	3.82	3.97	4.74	5.08	5.83	6.35	6.90	7.53	7.81	7.79	7.35	7.19	6.80	6.22	5.45	4.51	3.95
20.000	3.71	3.89	4.65	5.14	5.52	5.73	5.92	6.14	6.31	6.41	6.17	6.08	5.91	5.55	4.94	4.14	3.68

average ozone (ppmv) for August

	latitude																
p (mb)	-80°	-70°	-60°	-50°	-40°	-30°	-20°	-10°	0°	10°	20°	30°	40°	50°	60°	70°	80°
.003	.60	.62	.62	.66	.69	.67	.61	.60	.61	.62	.65	.68	.67	.65	.67	.60	.44
.005	.36	.37	.37	.40	.43	.43	.41	.40	.40	.41	.44	.46	.43	.41	.41	.35	.24
.007	.25	.26	.26	.29	.32	.34	.35	.36	.36	.36	.38	.36	.32	.29	.28	.22	.18
.010	.22	.23	.23	.25	.28	.30	.32	.31	.30	.30	.31	.27	.23	.20	.18	.15	.15
.015	.24	.25	.25	.23	.24	.24	.22	.19	.18	.18	.19	.17	.16	.15	.14	.14	.13
.020	.23	.24	.24	.20	.19	.18	.16	.14	.14	.14	.15	.14	.14	.14	.14	.15	.15
.030	.23	.24	.24	.19	.17	.17	.17	.16	.16	16	.17	16	.16	.17	.18	.18	.19
.050	.32	.33	.33	.32	.31	.30	.26	.25	.25	.25	.25	.24	.25	.26	.27	.27	.29
.070	.42	.44	.44	.47	.48	.44	.38	.36	.36	.35	.34	.35	.36	.38	.38	.38	.39
.100	.58	.60	.60	*.61*	*.62*	*.59*	*.54*	.52	.53	.53	.52	.52	.53	*.53*	.52	.53	.54
.150	.81	.84	.84	*.85*	*.88*	*.87*	*.82*	.79	.79	.79	.79	.80	*.81*	*.80*	.77	.75	.73
.200	.97	1.01	1.01	*1.09*	*1.12*	*1.11*	*1.05*	*1.02*	1.01	1.01	1.03	1.04	*1.05*	*1.02*	.96	.92	.90
.300	1.13	1.18	1.18	1.56	*1.58*	*1.54*	1.47	1.43	1.40	1.39	1.43	1.46	1.45	1.38	1.30	1.23	1.18
.500	1.82	1.90	1.90	2.19	2.22	2.11	2.00	1.97	1.95	1.94	1.97	2.02	1.98	1.85	1.74	1.64	1.56
.700	2.20	2.50	2.55	2.76	2.79	2.60	2.45	2.41	2.39	2.40	2.45	2.50	2.44	2.26	2.11	2.01	1.92
1.000	2.84	3.35	3.54	3.87	3.87	3.55	3.29	3.17	3.13	3.14	3.22	3.28	3.18	2.95	2.77	2.65	2.55
1.500	3.78	4.41	4.97	5.51	5.43	4.97	4.55	4.31	4.24	4.27	4.39	4.42	4.25	3.98	3.78	3.61	3.48
2.000	4.38	4.92	5.79	6.60	6.55	6.09	5.68	5.42	5.33	5.37	5.51	5.49	5.27	4.99	4.77	4.53	4.32
3.000	4.88	5.21	6.35	7.57	7.78	7.54	7.37	7.23	7.16	7.20	7.32	7.23	6.94	6.64	6.34	5.86	5.43
5.000	5.24	5.34	6.14	7.42	8.06	8.32	8.65	9.04	9.07	9.15	9.07	8.69	8.31	7.81	7.06	6.18	5.30
7.000	5.17	5.29	5.59	6.73	7.56	8.10	8.72	9.46	9.54	9.60	9.39	8.93	8.45	7.73	6.78	5.69	4.68
10.000	4.83	5.11	4.94	5.88	6.74	7.36	8.14	9.43	9.51	9.53	9.16	8.60	8.01	7.13	6.11	4.94	4.06
15.000	4.37	4.63	4.59	5.33	5.99	6.43	6.98	7.74	7.84	7.89	7.58	7.19	6.78	6.06	5.21	4.28	3.62
20.000	3.96	4.14	4.53	5.16	5.59	5.78	5.96	6.22	6.31	6.43	6.26	6.05	5.84	5.35	4.66	3.95	3.45

TABLE 6.1 - continued

average ozone (ppmv) for September

p (mb)	-80°	-70°	-60°	-50°	-40°	-30°	-20°	-10°	0°	10°	20°	30°	40°	50°	60°	70°	80°
	latitude																
.003	.42	.58	.59	.64	.74	.79	.77	.77	.77	.75	.76	.76	.69	.61	.60	.56	.46
.005	.27	.33	.36	.39	.46	.52	.51	.48	.48	.48	.49	.53	.47	.37	.31	.28	.21
.007	.24	.26	.29	.33	.38	.43	.43	.40	.38	.38	.40	.42	.38	.29	.24	.21	.16
.010	.24	.28	.31	.35	.37	.37	.35	.32	.30	.29	.32	.34	.31	.25	.21	.19	.16
.015	.27	.32	.31	.32	.30	.27	.23	.21	.20	.19	.21	.22	.22	.19	.17	.16	.17
.020	.28	.30	.27	.25	.23	.19	.17	.16	.16	.15	.16	.17	.17	.16	.15	.15	.18
.030	.28	.28	.22	.19	.17	.16	.17	.17	.16	.16	.16	.15	.15	.16	.16	.17	.21
.050	.33	.33	.31	.31	.29	.28	.26	.24	.23	.24	.24	.23	.23	.26	.26	.27	.29
.070	.41	.43	.45	.45	.45	.42	.37	.34	.33	.34	.34	.34	.35	.38	.39	.38	.38
.100	.52	.57	.58	.59	.58	.54	.50	.49	.50	.49	.47	.46	.48	.49	.48	.49	.50
.150	.70	.80	.80	.83	.84	.80	.77	.76	.76	.74	.72	.70	.72	.73	.70	.67	.67
.200	.87	.99	1.01	1.05	1.06	1.03	1.00	.99	.98	.97	.96	.96	.97	.97	.94	.89	.86
.300	1.28	1.35	1.40	1.47	1.48	1.43	1.41	1.41	1.38	1.36	1.38	1.40	1.40	1.40	1.36	1.28	1.25
.500	1.78	1.88	1.98	2.10	2.10	2.02	1.96	1.95	1.93	1.92	1.94	1.96	1.95	1.92	1.89	1.87	1.93
.700	2.38	2.34	2.48	2.67	2.64	2.47	2.38	2.36	2.35	2.36	2.38	2.40	2.38	2.36	2.37	2.41	2.48
1.000	3.19	3.18	3.38	3.66	3.62	3.36	3.16	3.06	3.04	3.07	3.15	3.23	3.23	3.23	3.30	3.37	3.34
1.500	4.26	4.38	4.72	5.10	5.07	4.71	4.35	4.13	4.08	4.15	4.34	4.48	4.51	4.54	4.66	4.69	4.33
2.000	4.86	5.16	5.72	6.23	6.26	5.90	5.50	5.21	5.13	5.21	5.45	5.60	5.59	5.60	5.67	5.52	4.87
3.000	5.34	5.89	6.86	7.58	7.80	7.63	7.36	7.08	6.97	7.04	7.25	7.31	7.17	7.03	6.82	6.23	5.22
5.000	5.36	5.94	6.86	7.76	8.45	8.81	9.04	8.99	8.96	8.98	8.98	8.80	8.41	7.89	7.17	6.07	4.97
7.000	5.28	5.62	6.45	7.31	8.06	8.64	9.20	9.54	9.61	9.57	9.34	8.98	8.43	7.63	6.67	5.47	4.58
10.000	5.15	5.18	5.81	6.61	7.34	8.02	8.80	9.25	9.39	9.31	8.84	8.35	7.71	6.74	5.75	4.71	4.14
15.000	4.38	4.51	5.12	5.85	6.38	6.83	7.31	7.81	7.94	7.91	7.45	7.04	6.58	5.76	4.94	4.13	3.75
20.000	3.50	3.97	4.75	5.42	5.79	6.00	6.14	6.30	6.38	6.42	6.15	5.92	5.71	5.18	4.54	3.89	3.53

average ozone (ppmv) for October

p (mb)	-80°	-70°	-60°	-50°	-40°	-30°	-20°	-10°	0°	10°	20°	30°	40°	50°	60°	70°	80°
	latitude																
.003	.57	.56	.54	.61	.80	.93	.87	.80	.84	.81	.76	.84	.87	.75	.66	.65	.63
.005	.38	.41	.41	.45	.58	.66	.60	.53	.55	.54	.51	.55	.55	.44	.34	.30	.23
.007	.31	.38	.41	.44	.50	.52	.47	.42	.43	.42	.39	.42	.41	.33	.25	.19	.12
.010	.29	.38	.43	.45	.44	.39	.34	.33	.33	.32	.30	.30	.31	.28	.23	.19	.12
.015	.26	.32	.35	.35	.31	.26	.24	.24	.24	.23	.22	.22	.22	.23	.25	.25	.20
.020	.23	.24	.25	.25	.23	.19	.19	.19	.20	.18	.18	.18	.18	.20	.25	.29	.25
.030	.24	.21	.20	.19	.18	.17	.17	.18	.18	.17	.16	.16	.16	.18	.24	.33	.31
.050	.35	.33	.32	.31	.29	.26	.26	.26	.25	.24	.24	.25	.26	.26	.28	.36	.37
.070	.45	.45	.44	.43	.41	.39	.38	.37	.36	.35	.35	.36	.37	.38	.38	.40	.41
.100	.56	.55	.54	.53	.50	.48	.48	.46	.46	.45	.52	.53	.55	.56	.54	.51	.49
.150	.78	.75	.75	.76	.74	.74	.73	.71	.69	.69	.79	.66	.68	.70	.69	.72	.69
.200	.97	.93	.94	.96	.96	.97	.96	.94	.92	.92	.93	.92	.93	.93	.91	.94	.90
.300	1.31	1.28	1.30	1.33	1.37	1.39	1.40	1.39	1.37	1.38	1.41	1.40	1.37	1.36	1.36	1.37	1.31
.500	1.76	1.79	1.86	1.92	1.93	1.94	1.96	1.97	1.97	1.97	1.96	1.94	1.97	2.07	2.16	2.16	2.09
.700	2.16	2.18	2.33	2.40	2.36	2.31	2.33	2.35	2.37	2.37	2.34	2.32	2.44	2.68	2.84	2.88	2.94
1.000	2.83	2.87	3.10	3.22	3.17	3.07	3.04	3.03	3.04	3.06	3.10	3.18	3.44	3.80	4.05	4.06	3.97
1.500	3.86	3.93	4.26	4.47	4.43	4.27	4.14	4.05	4.03	4.09	4.27	4.53	4.96	5.41	5.66	5.49	4.96
2.000	4.75	4.91	5.34	5.64	5.66	5.47	5.27	5.11	5.03	5.11	5.35	5.67	6.09	6.42	6.49	6.07	5.26
3.000	5.92	6.33	6.93	7.39	7.58	7.47	7.24	6.98	6.82	6.86	7.10	7.32	7.41	7.30	6.92	6.18	5.18
5.000	6.19	6.87	7.70	8.30	8.74	9.04	9.17	9.06	8.90	8.87	8.89	8.66	8.01	7.33	6.75	5.92	5.03
7.000	6.00	6.61	7.39	7.99	8.47	9.06	9.53	9.76	9.75	9.68	9.45	8.83	7.79	6.91	6.24	5.52	4.81
10.000	5.76	6.08	6.66	7.14	7.50	8.18	8.90	9.52	9.77	9.89	9.48	8.53	7.26	6.27	5.54	4.99	4.45
15.000	4.86	5.27	5.96	6.30	6.44	6.92	7.47	7.99	8.05	8.16	7.79	7.09	6.21	5.52	4.97	4.49	3.98
20.000	3.92	4.64	5.60	5.84	5.82	6.03	6.24	6.36	6.33	6.44	6.26	5.90	5.45	5.05	4.70	4.19	3.62

TABLE 6.1 - continued

average ozone (ppmv) for November

p (mb)	-80°	-70°	-60°	-50°	-40°	-30°	-20°	-10°	0°	10°	20°	30°	40°	50°	60°	70°	80°
.003	.50	.60	.67	.74	.82	.84	.77	.76	.79	.80	.78	.84	.98	.97	.88	.88	.77
.005	.33	.41	.48	.54	.59	.59	.55	.53	.55	.57	.54	.54	.59	.52	.45	.45	.40
.007	.24	.30	.37	.42	.45	.45	.43	.43	.45	.47	.43	.41	.41	.32	.24	.24	.21
.010	.18	.22	.27	.31	.32	.33	.32	.33	.35	.37	.35	.33	.30	.24	.18	.18	.16
.015	.15	.17	.19	.21	.22	.23	.23	.24	.25	.25	.26	.25	.24	.25	.22	.22	.19
.020	.17	.17	.18	.18	.18	.18	.18	.20	.20	.20	.20	.20	.20	.24	.26	.26	.23
.030	.21	.20	.21	.20	.19	.18	.17	.18	.17	.16	.18	.18	.19	.24	.31	.31	.27
.050	.31	.30	.30	.30	.28	.27	.26	.25	.25	.24	.26	.27	.28	.31	.38	.38	.33
.070	.43	.42	.41	.41	.40	.39	.38	.37	.36	.37	.38	.39	.41	.43	.44	.44	.39
.100	.54	.52	.52	.49	.46	.46	.46	.46	.47	.48	.57	.58	.58	.59	.58	.58	.51
.150	.74	.73	.74	.73	.72	.72	.72	.70	.70	.71	.73	.70	.70	.71	.79	.79	.70
.200	.91	.91	.91	.93	.93	.94	.94	.94	.93	.94	.95	.96	.95	.92	.91	.91	.80
.300	1.20	1.21	1.24	1.28	1.32	1.35	1.38	1.40	1.38	1.38	1.41	1.45	1.43	1.37	1.27	1.27	1.12
.500	1.59	1.64	1.72	1.80	1.85	1.90	1.94	1.98	1.98	1.98	1.96	1.99	2.08	2.19	2.09	2.09	1.84
.700	1.86	1.93	2.07	2.15	2.21	2.26	2.30	2.36	2.40	2.37	2.31	2.37	2.60	2.87	2.98	2.89	2.42
1.000	2.42	2.47	2.63	2.72	2.78	2.86	2.94	3.02	3.07	3.06	3.04	3.22	3.68	4.14	4.24	3.98	3.24
1.500	3.37	3.38	3.55	3.64	3.71	3.82	3.94	4.02	4.06	4.09	4.19	4.60	5.34	5.87	5.76	5.26	4.14
2.000	4.38	4.39	4.59	4.71	4.79	4.90	5.01	5.04	5.05	5.09	5.26	5.76	6.46	6.77	6.38	5.78	4.55
3.000	5.96	6.06	6.32	6.61	6.76	6.85	6.90	6.81	6.70	6.72	6.92	7.25	7.43	7.18	6.45	5.88	4.74
5.000	6.39	6.76	7.29	7.93	8.40	8.67	8.82	8.69	8.36	8.35	8.27	8.03	7.46	6.78	6.04	5.67	4.29
7.000	6.03	6.45	7.09	7.84	8.49	8.97	9.34	9.41	9.11	9.01	8.70	8.08	7.01	6.26	5.67	5.39	3.82
10.000	5.58	5.87	6.46	7.11	7.76	8.41	9.00	9.45	9.43	9.32	8.73	7.83	6.39	5.72	5.31	5.00	3.42
15.000	5.05	5.26	5.81	6.22	6.67	7.23	7.74	8.17	8.23	7.93	7.46	6.78	5.78	5.33	4.98	4.52	3.18
20.000	4.67	4.90	5.40	5.64	5.89	6.22	6.46	6.61	6.53	6.37	6.18	5.82	5.30	5.05	4.68	4.11	3.01

average ozone (ppmv) for December

p (mb)	-80°	-70°	-60°	-50°	-40°	-30°	-20°	-10°	0°	10°	20°	30°	40°	50°	60°	70°	80°
.003	.54	.70	.79	.80	.75	.66	.58	.57	.55	.52	.60	.79	.94	.96	.96	.85	.82
.005	.28	.35	.44	.52	.53	.47	.44	.45	.45	.42	.41	.49	.58	.57	.57	.50	.49
.007	.20	.22	.27	.35	.38	.36	.37	.40	.41	.39	.36	.36	.37	.33	.33	.29	.28
.010	.17	.17	.19	.23	.26	.26	.28	.33	.33	.33	.34	.31	.27	.21	.21	.19	.18
.015	.17	.17	.17	.17	.17	.18	.20	.22	.22	.23	.26	.27	.26	.24	.24	.21	.21
.020	.18	.18	.17	.16	.16	.15	.16	.17	.17	.18	.20	.23	.25	.27	.27	.24	.23
.030	.22	.21	.20	.19	.18	.16	.16	.17	.17	.17	.17	.19	.23	.31	.31	.27	.27
.050	.33	.30	.29	.28	.27	.25	.24	.25	.25	.24	.26	.30	.34	.39	.39	.34	.33
.070	.43	.41	.40	.39	.39	.38	.36	.35	.35	.35	.38	.45	.49	.51	.51	.45	.44
.100	.58	.57	.52	.50	.48	.49	.51	.50	.49	.48	.49	.65	.71	.70	.70	.62	.60
.150	.78	.77	.76	.75	.75	.77	.77	.74	.71	.72	.72	.76	.80	.99	.99	.87	.85
.200	.94	.93	.95	.95	.96	1.00	1.01	.97	.94	.94	.97	1.02	1.04	1.25	1.25	1.10	1.07
.300	1.20	1.22	1.26	1.29	1.33	1.40	1.42	1.39	1.36	1.37	1.42	1.48	1.50	1.78	1.78	1.57	1.52
.500	1.47	1.55	1.65	1.77	1.86	1.93	1.97	1.98	1.98	1.98	1.97	1.99	2.09	1.94	1.94	1.71	1.66
.700	1.65	1.77	1.94	2.10	2.21	2.29	2.34	2.40	2.44	2.41	2.35	2.38	2.57	2.72	2.68	2.21	2.15
1.000	2.11	2.23	2.42	2.57	2.72	2.86	2.99	3.11	3.18	3.15	3.13	3.25	3.63	3.92	3.74	3.00	2.93
1.500	2.92	3.00	3.19	3.34	3.53	3.77	4.01	4.18	4.27	4.29	4.35	4.66	5.27	5.59	5.10	4.14	4.03
2.000	3.90	3.95	4.13	4.31	4.54	4.81	5.08	5.25	5.32	5.35	5.45	5.80	6.37	6.49	5.79	4.86	4.72
3.000	5.61	5.64	5.83	6.16	6.45	6.71	6.96	7.04	6.99	6.97	7.02	7.18	7.31	6.92	6.10	5.39	5.21
5.000	6.27	6.46	7.03	7.71	8.18	8.57	8.90	8.89	8.55	8.26	7.97	7.74	7.28	6.54	5.94	5.19	4.98
7.000	5.79	6.13	6.99	7.82	8.47	8.97	9.38	9.49	9.08	8.66	8.10	7.62	6.89	6.07	5.69	4.81	4.62
10.000	4.99	5.40	6.40	7.41	8.16	8.75	9.24	9.60	9.36	8.79	7.90	7.25	6.38	5.65	5.42	4.37	4.25
15.000	4.35	4.72	5.62	6.41	7.01	7.44	7.77	8.04	7.93	7.53	6.87	6.44	5.85	5.42	5.10	4.08	4.00
20.000	4.10	4.38	5.13	5.66	6.05	6.29	6.40	6.44	6.27	6.11	5.85	5.73	5.48	5.30	4.77	3.86	3.77

Table 6.2

SBUV ozone data 3-year (1979-81) average

In milli centi atmosphere metres for the latitudes indicated and layers with bases at 3166 Pa, 6333 Pa, 12666 Pa, 25331 Pa & 101325 Pa respectively (top layer's top taken as base of bottom layer of the Keating et al data)

JAN

-77.50	-72.50	-67.50	-62.50	-57.50	-52.50	-47.50	-42.50	-37.50	-32.50	-27.50	-22.50	-17.50	-12.50	-7.50	-2.50
41.35	42.91	48.42	53.42	58.00	61.44	64.19	65.91	66.42	66.47	66.30	66.58	67.20	67.01	65.99	65.07
63.76	62.91	66.72	70.40	72.66	72.30	70.24	67.31	63.10	59.64	56.60	53.76	51.12	47.89	45.39	44.41
91.81	88.52	80.98	75.76	69.59	60.36	49.10	39.87	32.87	27.82	23.42	19.50	16.19	13.68	12.42	11.66
44.24	46.08	43.77	41.60	38.96	33.58	26.92	21.01	16.33	13.31	10.76	8.57	6.85	5.90	5.69	5.59
27.27	27.73	28.45	29.08	29.58	29.53	29.25	28.47	27.43	26.83	26.33	25.65	24.92	24.23	23.84	23.75

2.50	7.50	12.50	17.50	22.50	27.50	32.50	37.50	42.50	47.50	52.50	57.50	62.50	67.50	72.50	77.50
64.37	63.51	63.27	63.35	63.51	64.70	66.63	68.20	69.19	69.78	68.49	65.38	60.07	58.76	57.75	56.48
43.89	44.32	46.78	51.38	58.04	66.62	77.03	86.96	94.20	97.09	94.47	87.55	78.26	76.01	75.74	74.88
11.01	10.59	10.73	12.48	16.49	23.19	34.09	48.92	60.33	66.56	70.62	73.88	77.34	83.01	83.17	83.05
5.52	5.49	5.53	6.04	7.34	9.91	15.00	23.32	31.10	36.22	40.68	44.63	46.58	50.90	51.00	50.92
23.70	24.02	24.54	25.05	25.39	25.67	26.37	27.86	29.92	31.53	32.45	32.72	32.33	33.41	33.48	33.42

FEB

-77.50	-72.50	-67.50	-62.50	-57.50	-52.50	-47.50	-42.50	-37.50	-32.50	-27.50	-22.50	-17.50	-12.50	-7.50	-2.50
38.80	40.39	46.99	51.31	55.23	58.86	62.05	64.32	65.15	65.37	65.50	65.85	66.39	66.21	65.31	64.64
64.21	63.40	66.50	68.45	69.39	68.88	67.29	64.89	61.22	57.56	54.00	50.72	48.05	45.52	43.44	42.78
85.16	85.70	77.36	70.93	63.63	53.99	43.34	35.19	29.47	24.81	20.80	17.31	14.52	12.72	11.84	11.38
35.54	38.78	38.91	36.92	34.03	28.80	22.89	18.00	14.37	11.75	9.65	7.86	6.49	5.78	5.63	5.57
26.15	26.46	27.68	28.26	28.71	28.76	28.63	27.97	27.03	26.41	25.86	25.18	24.55	24.01	23.64	23.54

2.50	7.50	12.50	17.50	22.50	27.50	32.50	37.50	42.50	47.50	52.50	57.50	62.50	67.50	72.50	77.50
63.91	62.91	62.85	63.76	64.63	65.67	66.68	67.36	68.41	70.51	71.25	71.13	69.31	66.04	64.50	60.98
45.00	42.18	44.19	48.96	55.94	65.29	76.11	86.68	94.77	101.05	102.67	100.07	93.14	86.27	85.46	83.74
10.77	10.38	10.56	12.73	17.40	25.00	37.14	54.90	70.52	79.84	84.26	86.04	87.64	92.18	99.76	100.37
5.49	5.49	5.55	6.19	7.89	11.03	16.93	27.60	38.07	44.19	48.06	52.87	58.28	63.61	69.98	68.26
23.42	23.85	24.26	24.76	25.30	25.86	26.71	28.36	30.81	32.93	34.56	36.17	37.19	38.06	40.31	39.05

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MAR
  -77.50  -72.50  -67.50  -62.50  -57.50  -52.50  -47.50  -42.50  -37.50  -32.50  -27.50  -22.50  -17.50  -12.50   -7.50   -2.50
   42.61   44.80   47.37   50.14   53.33   56.62   59.80   62.19   63.91   64.86   65.33   65.82   66.69   67.13   66.88   66.84
   60.64   67.41   70.22   70.27   70.09   69.46   68.09   65.70   62.56   59.05   55.17   51.27   48.46   46.40   45.10   44.99
   71.14   73.86   73.16   68.00   60.62   51.83   41.78   33.86   28.74   24.36   20.28   16.61   13.96   12.58   12.21   12.15
   32.90   33.64   33.28   32.40   30.08   26.30   21.35   16.99   13.85   11.49    9.40    7.61    6.33    5.73    5.69    5.69
   26.56   27.00   27.14   27.54   27.96   28.24   28.33   27.84   26.93   26.29   25.68   24.95   24.31   23.84   23.66   23.62

    2.50    7.50   12.50   17.50   22.50   27.50   32.50   37.50   42.50   47.50   52.50   57.50   62.50   67.50   72.50   77.50
   66.60   66.05   65.95   66.50   67.17   68.23   68.71   67.89   66.93   66.95   66.57   67.05   68.34   69.07   68.66   66.23
   45.01   45.70   48.05   52.26   58.10   66.34   75.36   83.23   89.04   94.33   98.22  101.35  103.48  102.66   97.33   92.37
   12.02   12.02   12.57   15.03   20.09   28.30   40.69   57.65   73.10   85.47   94.80   97.84   99.31  100.29  100.91  104.08
    5.68    5.73    5.88    6.77    8.97   12.83   19.56   30.52   41.97   49.65   55.10   56.79   60.04   66.25   73.91   77.41
   23.64   24.02   24.58   25.11   25.66   26.23   27.20   28.92   31.19   33.10   34.82   36.38   38.59   41.13   43.18   43.11

APR
  -77.50  -72.50  -67.50  -62.50  -57.50  -52.50  -47.50  -42.50  -37.50  -32.50  -27.50  -22.50  -17.50  -12.50   -7.50   -2.50
   40.97   44.47   50.64   54.46   56.64   58.10   59.68   61.25   62.76   64.24   65.15   65.71   66.69   67.54   67.91   68.33
   59.70   63.36   71.41   75.77   77.28   75.80   73.07   69.69   65.79   62.20   58.10   53.65   49.96   47.79   46.67   46.83
   69.68   67.73   63.78   61.53   58.83   52.85   43.67   35.28   29.33   24.95   20.75   16.85   13.77   12.38   12.22   12.43
   32.11   32.74   31.94   30.39   28.35   25.72   21.75   17.46   13.92   11.60    9.51    7.69    6.30    5.69    5.65    5.69
   26.19   27.09   28.22   28.51   28.25   28.14   28.23   27.87   26.94   26.26   25.64   24.99   24.28   23.79   23.56   23.57

    2.50    7.50   12.50   17.50   22.50   27.50   32.50   37.50   42.50   47.50   52.50   57.50   62.50   67.50   72.50   77.50
   68.61   68.63   68.77   69.13   69.49   70.06   69.83   68.68   67.22   66.30   64.38   62.89   61.81   61.43   61.78   62.71
   47.79   49.67   53.48   58.06   63.10   68.67   74.26   79.18   82.98   86.34   88.42   90.62   93.09   96.07   98.46   97.76
   12.86   13.63   15.35   18.86   24.72   32.52   42.82   55.84   68.88   80.50   90.57   98.22  104.06  107.91  108.34  105.43
    5.79    5.99    6.43    7.81   10.72   15.02   21.41   30.76   41.59   50.14   56.34   60.77   64.52   67.66   69.53   71.84
   23.76   24.27   25.10   25.73   26.23   26.78   27.74   29.24   31.27   32.95   34.08   35.31   36.80   38.57   40.33   40.91
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  -77.50 -72.50 -67.50 -62.50 -57.50 -52.50 -47.50 -42.50 -37.50 -32.50 -27.50 -22.50 -17.50 -12.50  -7.50  -2.50
   41.57  44.95  49.08  54.58  60.44  62.36  62.81  63.23  63.49  63.95  64.52  65.59  66.81  67.43  67.91  68.55
   58.34  60.72  65.76  71.63  77.90  81.48  81.31  78.27  73.03  67.53  62.11  57.23  53.14  49.98  48.53  48.59
   63.21  63.56  62.76  59.47  53.99  50.65  46.10  39.99  33.51  27.20  21.74  17.37  14.10  12.36  12.20  12.54
   31.44  31.61  33.17  33.72  30.72  26.20  22.68  19.36  15.71  12.35   9.72   7.75   6.35   5.68   5.64   5.68
   27.22  27.37  28.24  29.32  29.89  29.08  28.40  27.86  27.04  26.29  25.71  25.08  24.45  23.97  23.75  23.67

    2.50   7.50  12.50  17.50  22.50  27.50  32.50  37.50  42.50  47.50  52.50  57.50  62.50  67.50  72.50  77.50
   69.18  70.02  70.40  70.48  70.62  70.71  70.51  69.51  68.07  66.88  64.50  62.01  59.31  56.06  53.21  51.14
   49.21  51.86  56.30  60.38  64.31  68.28  72.50  76.44  79.13  81.30  81.75  81.95  81.82  81.21  81.02  83.42
   12.95  14.28  16.91  20.80  26.57  33.47  42.04  52.94  63.71  73.31  80.87  87.21  92.43  98.00 103.11 106.61
    5.72   5.97   6.64   8.25  11.35  15.49  21.12  29.43  39.22  47.46  53.38  58.32  62.56  67.95  73.37  70.12
   23.69  24.02  24.94  25.69  26.26  26.93  27.80  29.25  31.16  32.58  33.30  33.92  34.47  35.07  35.96  35.37

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  -77.50 -72.50 -67.50 -62.50 -57.50 -52.50 -47.50 -42.50 -37.50 -32.50 -27.50 -22.50 -17.50 -12.50  -7.50  -2.50
   48.76  49.46  50.40  52.90  59.24  63.35  65.14  65.11  65.53  65.49  65.28  65.77  66.85  67.30  67.54  68.22
   66.39  67.23  68.20  70.37  78.75  84.79  86.90  84.76  80.01  73.78  67.02  61.30  56.93  53.02  50.84  50.80
   60.73  60.59  60.49  60.74  56.30  51.06  47.79  44.28  39.04  31.34  23.83  18.48  14.77  12.68  12.46  12.94
   32.82  32.75  32.69  32.83  31.56  27.54  24.04  21.37  18.13  14.03  10.32   7.98   6.44   5.70   5.66   5.75
   28.76  28.70  28.65  28.77  29.51  29.62  28.94  28.08  27.12  26.40  25.78  25.26  24.72  24.28  24.06  24.00

    2.50   7.50  12.50  17.50  22.50  27.50  32.50  37.50  42.50  47.50  52.50  57.50  62.50  67.50  72.50  77.50
   69.21  70.71  71.26  70.93  70.31  69.95  69.53  68.65  67.52  66.05  63.84  60.84  56.83  52.68  49.47  46.99
   51.52  54.13  57.89  60.92  63.17  65.55  68.24  71.65  74.75  77.02  77.50  76.66  74.61  72.05  70.23  70.38
   13.60  15.08  17.54  21.13  25.85  31.11  37.02  44.97  54.28  63.51  70.57  76.00  80.21  84.58  89.40  93.87
    5.82   6.05   6.63   8.18  10.97  14.34  18.32  24.06  31.92  39.30  44.69  49.56  53.37  58.00  64.39  64.55
   23.93  23.98  24.67  25.48  26.16  26.84  27.57  28.65  30.16  31.26  31.67  31.94  31.80  31.68  32.06  31.81
```

```
 -77.50 -72.50 -67.50 -62.50 -57.50 -52.50 -47.50 -42.50 -37.50 -32.50 -27.50 -22.50 -17.50 -12.50  -7.50  -2.50
  46.14  47.17  48.00  53.63  58.96  62.12  64.21  65.06  65.79  66.38  66.18  66.22  66.79  67.09  67.35  68.23
  61.26  61.96  62.18  72.82  83.91  89.35  90.74  88.20  82.48  76.18  69.69  63.88  58.83  54.49  52.11  52.39
  63.69  63.79  63.66  63.73  61.47  58.55  55.82  51.75  44.16  34.65  26.29  20.14  15.58  13.25  13.04  13.76
  33.07  33.13  33.06  34.73  33.18  30.47  28.19  25.55  21.07  15.69  11.36   8.53   6.62   5.80   5.79   5.93
  27.90  27.94  27.89  29.01  29.77  29.91  29.59  28.75  27.64  26.63  25.94  25.46  24.95  24.44  24.24  24.19

   2.50   7.50  12.50  17.50  22.50  27.50  32.50  37.50  42.50  47.50  52.50  57.50  62.50  67.50  72.50  77.50
  69.54  71.27  72.05  71.02  69.94  69.09  68.36  67.35  66.19  64.72  62.39  59.26  55.12  50.41  46.66  43.77
  53.65  55.98  58.77  60.58  61.97  63.16  64.94  67.17  70.00  72.48  73.53  72.84  70.60  67.43  64.67  64.46
  14.69  16.10  18.19  21.16  25.00  28.69  32.93  38.11  45.05  53.48  61.57  67.29  71.39  75.68  79.75  84.59
   6.05   6.26   6.76   8.24  10.72  13.29  16.21  19.88  25.16  31.24  36.97  41.13  43.79  46.98  50.49  49.64
  24.09  24.00  24.48  25.34  26.11  26.75  27.43  28.26  29.34  30.17  30.47  30.49  30.09  29.55  29.22  28.49

AUG
 -77.50 -72.50 -67.50 -62.50 -57.50 -52.50 -47.50 -42.50 -37.50 -32.50 -27.50 -22.50 -17.50 -12.50  -7.50  -2.50
  42.25  44.69  49.86  54.24  57.13  60.47  63.97  65.67  66.69  67.05  66.97  66.79  67.46  67.76  67.91  68.91
  53.84  54.95  65.08  79.51  87.46  88.97  88.05  86.08  82.93  77.72  72.14  65.77  59.86  55.45  53.19  53.75
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  32.45  33.27  32.87  33.50  34.72  34.03  32.69  30.46  25.07  18.20  12.97   9.46   7.11   6.11   6.08   6.22
  26.15  26.99  27.87  28.80  29.68  29.95  30.11  29.63  28.26  27.02  26.25  25.74  25.12  24.58  24.37  24.29

   2.50   7.50  12.50  17.50  22.50  27.50  32.50  37.50  42.50  47.50  52.50  57.50  62.50  67.50  72.50  77.50
  70.09  71.60  72.26  70.91  69.29  68.41  67.66  66.73  65.35  63.23  60.35  56.85  52.90  48.47  44.42  42.07
  54.73  56.34  58.46  59.59  60.22  61.63  63.30  65.40  67.98  69.73  70.50  69.66  67.70  65.35  64.02  65.73
  15.68  16.65  18.21  20.44  23.35  26.80  30.51  34.72  40.10  47.33  55.06  61.00  65.51  70.24  75.92  80.81
   6.31   6.45   6.83   8.08  10.15  12.50  15.07  17.97  21.72  26.55  30.99  34.42  36.41  37.56  38.08  38.00
  24.15  24.00  24.29  25.09  25.84  26.50  27.19  27.95  28.83  29.46  29.44  29.26  28.77  27.98  27.02  26.61
```

```
SEP
  -77.50 -72.50 -67.50 -62.50 -57.50 -52.50 -47.50 -42.50 -37.50 -32.50 -27.50 -22.50 -17.50 -12.50  -7.50  -2.50
   36.46  41.90  48.97  54.98  60.28  64.17  66.84  66.71  67.27  67.66  67.92  68.11  68.70  68.88  68.90  69.41
   41.99  50.87  66.63  78.02  85.33  87.17  86.72  84.36  81.46  77.05  72.00  66.69  60.90  56.20  54.00  53.83
   65.70  65.39  70.12  75.51  78.49  74.95  67.69  61.04  53.03  42.29  32.88  25.51  19.46  16.15  15.36  15.45
   28.64  28.94  30.91  36.19  40.96  41.06  38.03  33.79  27.47  20.10  14.51  10.64   7.80   6.52   6.35   6.35
   25.61  26.17  27.29  29.32  31.18  31.56  31.24  30.17  28.64  27.35  26.53  26.00  25.34  24.77  24.51  24.34

    2.50   7.50  12.50  17.50  22.50  27.50  32.50  37.50  42.50  47.50  52.50  57.50  62.50  67.50  72.50  77.50
   70.04  71.11  71.61  70.12  68.32  67.10  66.36  65.39  63.68  61.37  58.30  55.03  51.43  47.46  44.40  42.37
   53.84  54.77  56.93  57.81  58.23  59.59  61.65  64.32  67.23  69.53  70.49  70.38  69.06  67.11  65.93  62.78
   15.55  15.95  17.22  18.84  21.15  24.06  27.45  31.56  36.75  44.38  52.61  59.49  64.75  69.32  72.71  71.46
    6.33   6.35   6.68   7.68   9.35  11.27  13.43  15.99  19.40  23.83  27.72  30.66  31.84  31.99  32.06  31.16
   24.15  23.91  24.20  24.89  25.53  26.19  26.80  27.51  28.45  28.94  28.70  28.38  27.74  26.94  26.47  26.12

OCT
  -77.50 -72.50 -67.50 -62.50 -57.50 -52.50 -47.50 -42.50 -37.50 -32.50 -27.50 -22.50 -17.50 -12.50  -7.50  -2.50
   42.18  46.45  57.49  64.40  67.78  68.33  68.48  67.26  67.67  68.24  68.70  68.99  69.38  69.08  67.76  68.29
   46.61  55.22  74.02  86.03  90.98  88.86  85.53  81.92  78.50  74.09  69.31  64.75  60.03  55.23  52.00  50.51
   64.81  70.55  77.38  83.33  84.76  77.88  68.06  60.41  51.56  41.58  32.96  25.96  20.19  16.38  14.70  13.91
   29.24  30.42  39.00  45.58  47.96  44.10  38.65  33.69  26.81  19.95  14.77  10.89   8.01   6.55   6.18   6.01
   26.66  26.81  30.21  32.81  33.71  32.55  31.46  30.15  28.61  27.40  26.62  26.01  25.44  24.91  24.52  24.22

    2.50   7.50  12.50  17.50  22.50  27.50  32.50  37.50  42.50  47.50  52.50  57.50  62.50  67.50  72.50  77.50
   68.39  69.14  69.35  68.26  66.85  65.82  64.64  63.09  61.93  60.35  58.66  56.78  54.30  51.02  46.14  42.51
   49.54  50.51  52.89  54.41  56.02  58.50  61.67  65.13  69.73  72.94  75.02  75.53  73.30  69.36  62.32  58.72
   13.31  13.51  14.39  15.86  18.52  21.68  25.28  29.51  35.68  44.29  53.11  58.96  62.45  64.81  67.41  69.35
    5.87   5.83   6.07   6.84   8.37  10.13  12.09  14.38  17.92  22.40  26.01  28.17  29.89  31.38  33.15  32.51
   23.89  23.74  24.08  24.63  25.26  25.89  26.52  27.19  27.99  28.40  28.21  28.11  28.14  28.02  27.55  26.63
```

```
NOV
  -77.50  -72.50  -67.50  -62.50  -57.50  -52.50  -47.50  -42.50  -37.50  -32.50  -27.50  -22.50  -17.50  -12.50   -7.50   -2.50
   54.22   54.65   59.40   62.22   63.79   64.42   65.42   65.94   67.34   68.61   69.40   69.59   69.80   69.46   68.44   67.55
   71.88   73.57   80.96   84.30   84.27   81.16   78.14   75.29   72.55   69.17   65.49   61.71   57.81   54.13   50.79   48.76
   78.75   82.80   85.33   84.96   81.21   72.23   61.28   52.57   44.86   37.38   30.62   24.63   19.45   16.00   14.11   12.87
   36.77   40.06   45.38   46.81   45.71   40.76   34.50   28.85   22.95   17.95   13.83   10.40    7.72    6.35    5.98    5.76
   28.91   29.36   31.28   32.00   31.91   31.06   30.37   29.45   28.22   27.27   26.55   25.90   25.24   24.67   24.29   24.11

    2.50    7.50   12.50   17.50   22.50   27.50   32.50   37.50   42.50   47.50   52.50   57.50   62.50   67.50   72.50   77.50
   67.19   67.49   67.57   66.98   66.03   65.00   63.99   63.30   63.14   63.35   62.46   61.02   56.60   51.76   47.40   43.84
   47.67   48.49   51.02   53.42   56.39   59.72   64.51   70.70   77.25   81.62   81.77   78.65   72.82   67.22   62.07   59.63
   12.09   12.07   12.55   13.94   16.89   20.36   24.90   31.46   39.21   47.39   53.76   58.30   65.04   68.28   69.15   68.77
    5.62    5.62    5.71    6.29    7.63    9.29   11.42   14.71   18.89   23.13   26.95   31.55   36.28   37.06   35.32   35.13
   23.90   23.89   24.20   24.59   25.11   25.66   26.24   26.96   27.80   28.44   28.98   29.77   29.96   29.46   28.55   28.39

DEC
  -77.50  -72.50  -67.50  -62.50  -57.50  -52.50  -47.50  -42.50  -37.50  -32.50  -27.50  -22.50  -17.50  -12.50   -7.50   -2.50
   49.20   49.78   53.38   56.91   60.43   63.23   65.34   66.70   67.50   68.01   68.14   68.39   68.92   68.61   67.22   66.07
   76.20   73.96   75.00   76.45   76.68   75.43   72.95   69.81   66.13   63.07   60.64   57.89   54.94   51.23   47.35   45.78
   96.44   93.90   87.77   82.06   74.90   65.27   53.97   44.17   36.85   31.23   26.54   22.01   17.93   14.80   12.78   11.73
   48.23   49.90   48.86   45.77   42.26   36.69   30.17   23.72   18.55   14.92   12.00    9.36    7.23    6.06    5.72    5.57
   29.65   29.81   30.17   30.28   30.37   30.06   29.70   28.80   27.72   26.97   26.43   25.79   25.08   24.47   24.04   23.96

    2.50    7.50   12.50   17.50   22.50   27.50   32.50   37.50   42.50   47.50   52.50   57.50   62.50   67.50   72.50   77.50
   65.39   65.29   65.10   64.99   64.74   64.88   65.43   66.03   66.70   67.48   66.76   62.89   57.38   54.67   53.65   52.89
   45.18   46.54   49.11   52.76   57.46   63.71   71.42   79.50   86.66   90.00   87.34   81.37   74.12   71.83   70.81   69.93
   11.03   10.90   10.99   12.55   15.99   21.17   28.67   38.26   46.99   53.01   58.38   65.39   70.21   69.92   70.04   70.19
    5.49    5.48    5.48    5.95    7.17    9.24   12.68   17.61   22.94   27.49   32.81   37.94   40.09   39.92   39.99   40.08
   23.93   24.18   24.52   24.82   25.17   25.57   26.18   27.05   28.40   29.69   30.69   30.89   30.69   30.56   30.62   30.68
```

Complete list of figures is:

Fig. 1 Sprectral bands used in the longwave, and the terms in each from each gaseous absorber.

Fig. 2 terms contributing to the net longwave flux at a particular layer boundary.

Fig. 3 The Earth’s orbit.

Fig. 4 (a) -(c) Examples of cloud overlap.

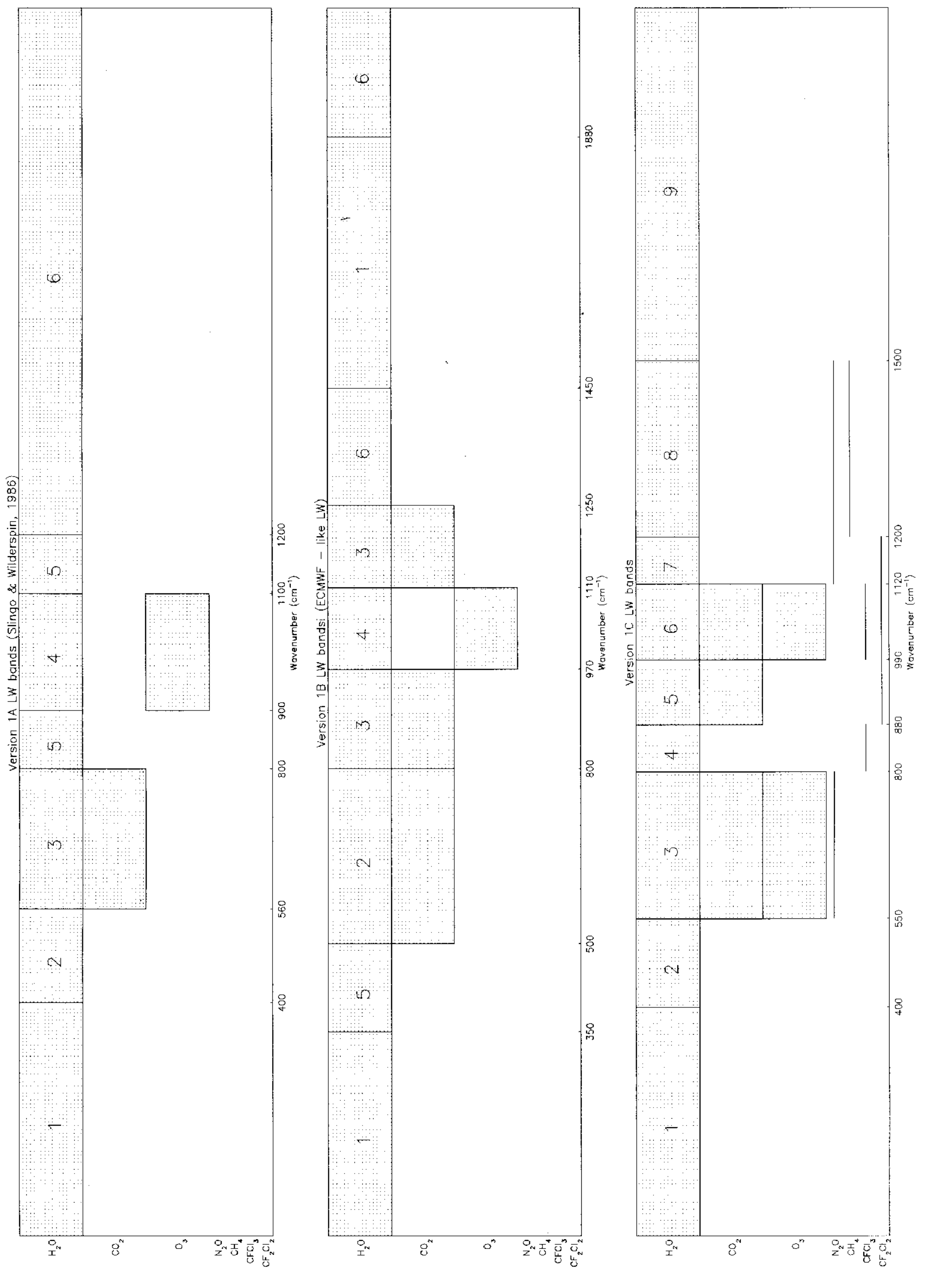

Fig. 1 Spectral Bands used in the three versions of the Longwave code, indicating which gases absorb in which bands and what the conventional order used in the code is.

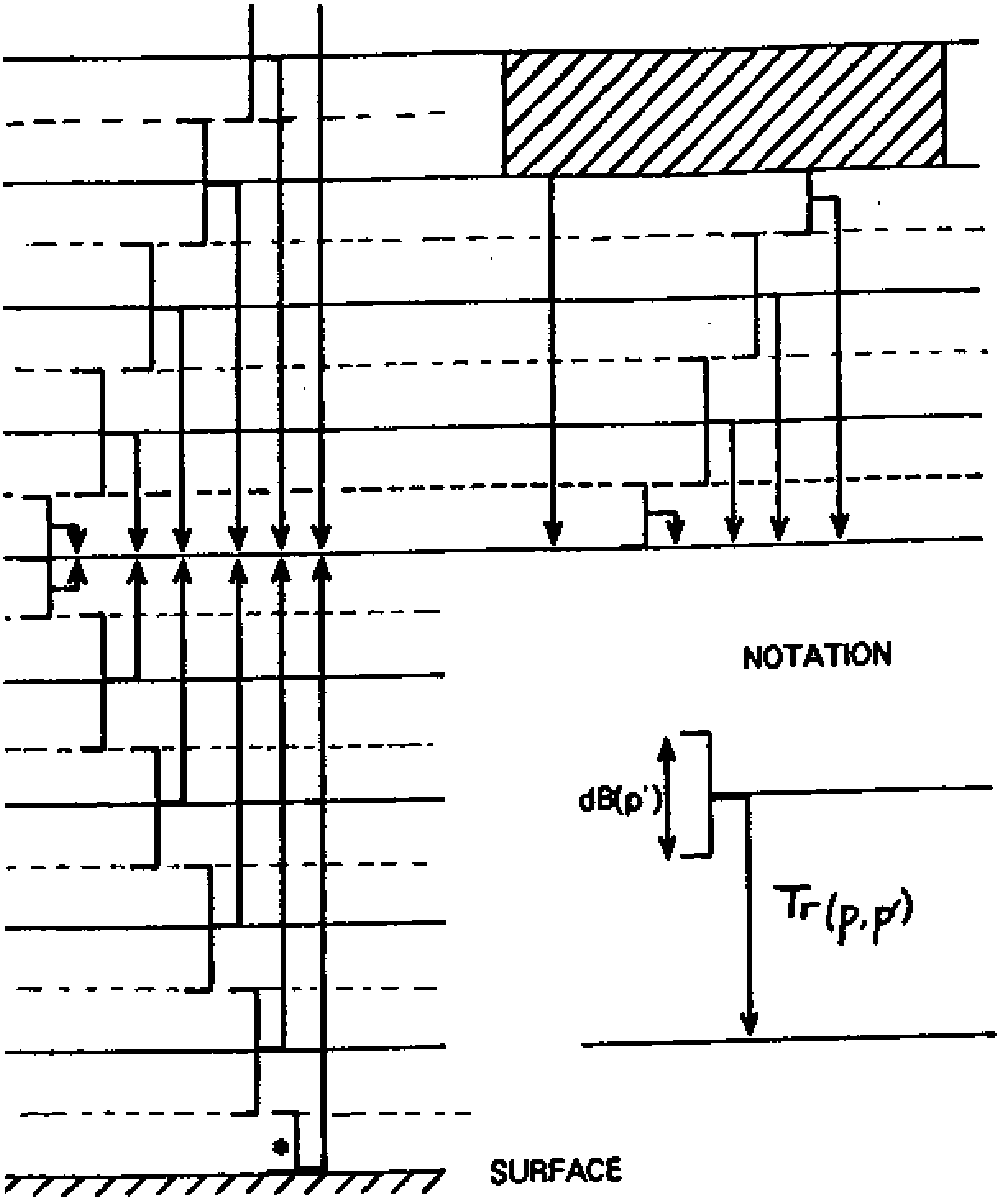

Fig 2. Terms contributing to the net longwave flux at a particular layer boundary. Layer boundaries are represented solid, layer centres dashed, transmissivities and differences of Planck functions in the vertical as shown bottom right. On the left, the clear-sky terms: clouds are active only at layer boundaries where they act as black bodies just like the surface, but covering a fraction of the grid-box given by the product of their amount and emissivity, as shown top right for a cloud above the layer boundary.

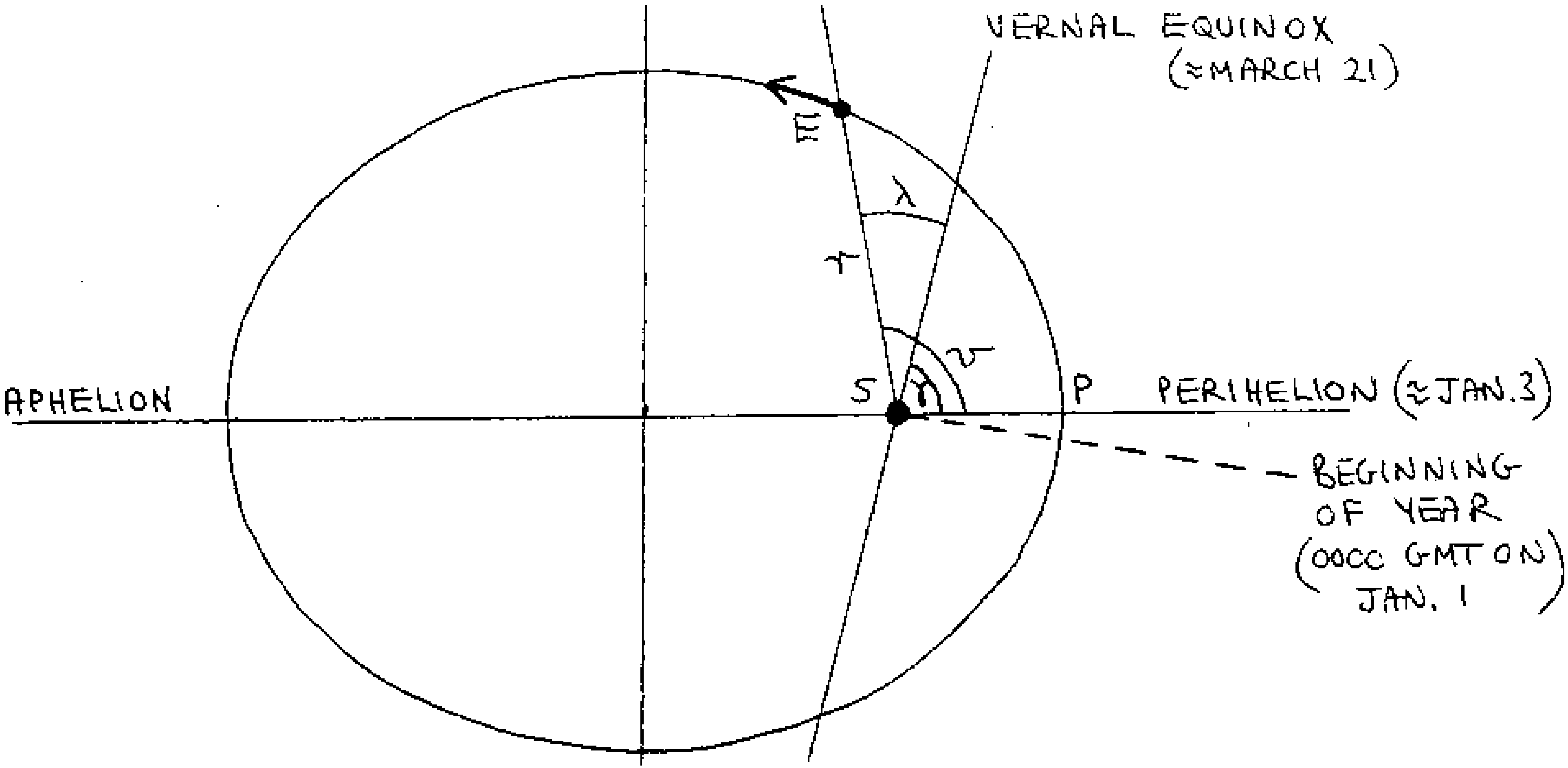

Figure 3 Schematic diagram of the Earth's orbit

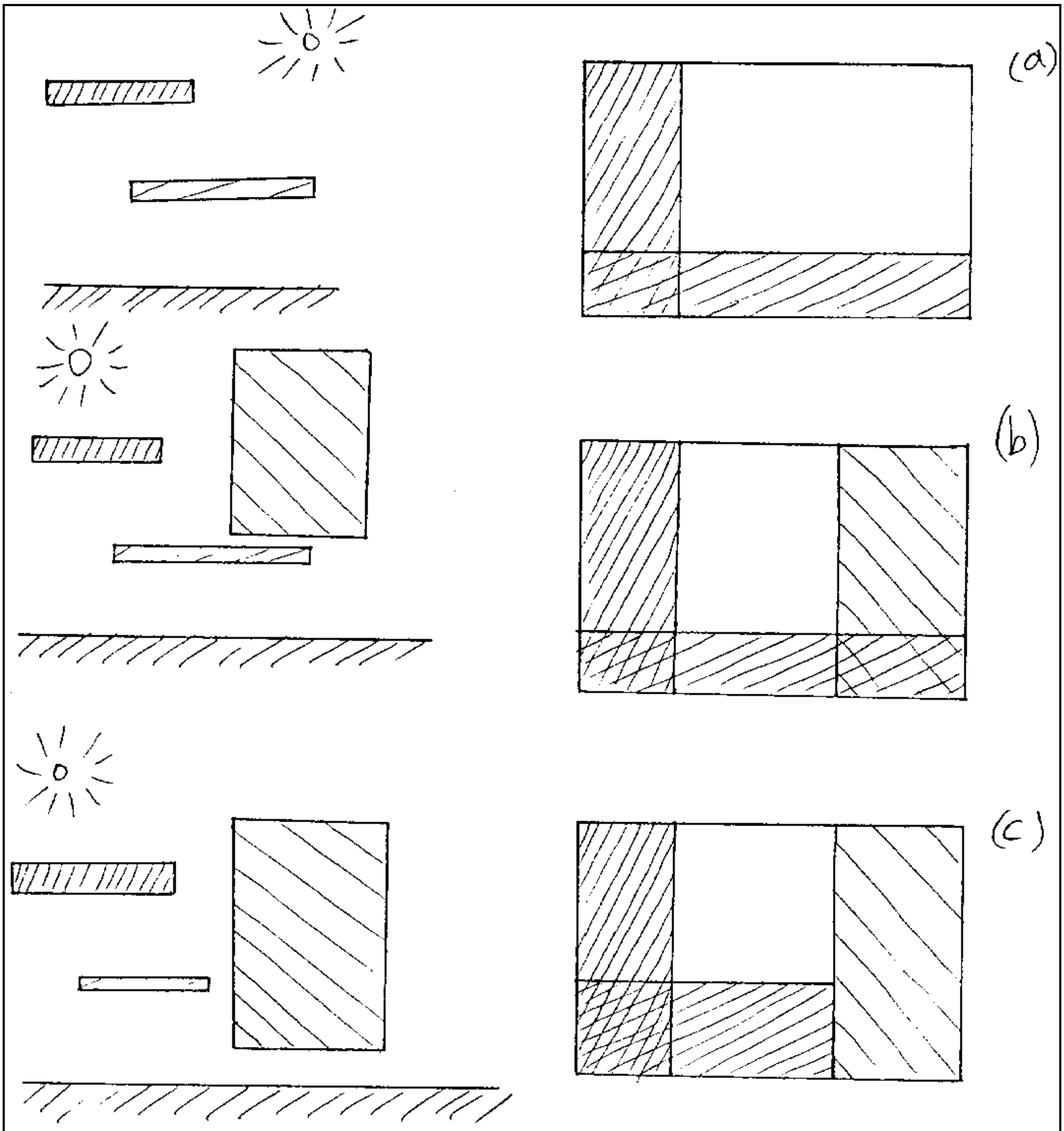

Fig. 4 Examples of cloud overlap. On the left, schematic representations of the distribution in the vertical, as seen from the side, of two layer clouds and (in (b) and (c)) a convective tower. On the right, schematic representations of their overlap as seen from above, the outer box representing the whole model grid-box.