Cloud Model Upgrade to the GIFTS Fast Radiative Transfer Model

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1 INTRODUCTION

The GIFTS fast radiative transfer model (GIFTSFRTE) computes simulated top-of-atmosphere radiances and/or brightness temperatures for the GIFTS instrument. On 7 January 2003, a fast radiative transfer code for cirrus ice clouds and liquid phase clouds [9] was delivered to SSEC. The purpose of this document is to detail the installation, testing and verification of this code and the changes made to the GIFTS fast radiative transfer model to facilitate the incorporation of the new cloud model. Throughout this document we shall refer to the cloud model in GIFTSFRTE prior to this release as the Old cloud model. The current, newly implemented model will be referred to as Yang:2003.

2 DELIVERED CODE

The new cloud model (Yang:2003) was created under contract to SSEC by Ping Yang and Heli Wei at Texas A&M University. Yang:2003 was integrated by the Heli Wei into GIFTSFRTE and supercedes the Old cloud model in the code development branch `/cvs/devel/Model/giftsrte/src/giftsfrte.f`. Upon delivery some code changes were made at SSEC to allow successful compilation with GNU `g77` under the LINUX operating system. Specifically, some F90 MODULE definitions were replaced with an include file (`texcloud.i`) comprising certain parameters and a common block (`/wei_common/`). These changes were made expediently to allow the code to be tested in the presence of one of the code developers, namely Heli Wei, during his short visit to SSEC.

Fig. 1 shows the common blocks named in the source modules that make up the GIFTS fast radiative transfer model. Fig. 2 shows the call tree for the revised GIFTSFRTE, as it was delivered on 7 January 2003, but after the minor code modifications indicated in the preceeding paragraph. In Fig. 2, function `radwnplank` is equivalent to `wnplan` (in source file `wnplan.f`) except that `radwnplank` accepts a single precision waveneumber whereas `wnplan` accepts a double precision wavenumber. Text files `parameters.txt`, `cld.par` and `testout.dat` are hard-coded into the source file `giftsfrte.f`, as are binary files `wvnLW.bin` and `wvnSMW.bin`. Binary files `test.bin`, `outLW.bin` and `outSMW.bin` are listed in the parameter file `parameters.txt`, and the text file `usstandout.dat` is named in the cloud parameter file `cld.par`. The source module `gifts_tran_od` is `gifts_tran` modified to return optical depths.

```
common block            source file             routines
------------            -----------             --------

/wei_common/            texcloud.i              main
                                                read_fitted_database
                                                interpolation_rt

/gifts_vn/              giftsfrte.f             main
                        vn_gifts.f              vn_gifts

/taudwo/                giftsfrte.f             main
                        gifts_tran_od.f         gifts_tran_od

/atmstd/                irt_sub_101.f           reference_atmosphere (block data)
                        gifts_tran_od.f         gifts_tran_od

/gifts_be/              vn_gifts.f              vn_gifts
```

Figure 1: COMMON blocks in GIFTS foward model with Yang:2003 cloud model (as delivered).

```
source file         call tree                inputs from        outputs to
-----------         ---------                -----------        ----------

giftsfrte.f         main                     STDIN              STDOUT
                    | (texcloud.i)           parameters.txt     testout.dat
                    |                        (test.bin)         (outLW.bin)
                    |                                           (outSMW.bin)
                    |                        cld.par            wvnLW.bin
                    |                        (usstandout.dat)   wvnSMW.bin
                    |
subroutines.f       +--read_fitted_database  fitedcoeRc.dat
                    |     (texcloud.i)       fitedcoeRw.dat
                    |                        fitedcoeTc.dat
                    |                        fitedcoeTw.dat
                    |
                    +--topbt
                    |  |
                    |  +--interpolation_rt
                    |  |  |  (texcloud.i)
                    |  |  |
                    |  |  +--sumfit
                    |  |
                    |  +--radwnplank
                    |  |
                    |  +--radtolayer
                    |  |  |
                    |  |  +--radwnplank
                    |  |
wnbrit.f            |  +--wnbrit
                    |
                    +--wnbrit
                    |
gifts_tran_od.f     +--gifts_tran_od         giftsfr1.dry
                    |  |                     giftsfr1.ozo
                    |  |                     giftsfr1.wco
                    |  |                     giftsfr1.wtl
                    |  |                     giftsfr1.wts
                    |  |                     giftsfr2.dry
                    |  |                     giftsfr2.ozo
                    |  |                     giftsfr2.wco
                    |  |                     giftsfr2.wtl
                    |  |                     giftsfr2.wts
                    |  |
irt_sub_101.f       |  +--conpir
                    |  |  |
                    |  |  +--gphite
                    |  |
                    |  +--taudoc
                    |  |
                    |  +--calpir
                    |  |
                    |  +--tauwtr
                    |
lsurface.f          +--lsurface
                    |
wnmrad.f            +--wnmrad
                    |
vn_gifts.f          +--vn_gifts
```

Figure 2: Call tree for GIFTS foward model with Yang:2003 cloud model (as delivered). The include file `texcloud.i` is included in the program units indicated. Files in brackets, e.g.(`test.bin`), are named in input files.

3 GIFTS FAST MODEL UPGRADE

After delivery, changes were made to prepare GIFTSFRTE for production release. `giftsfrte.f` was split into two source code modules, named `giftsfrte_main.f` and `giftsfrte.f`. The main program absorbs the task formerly handled by subroutine `read_fitted_database`, however the coefficient files to be read are left as they were delivered, i.e. as text files, but have been concatenated into a single file, namely `clouds.dat`. The remaining tasks are performed by subroutine GIFTSFRTE. This separation of the fast model into a main program (performing input and output), and a subprogram (responsible, with its subsiduary routines, for the science outcome) is a design goal for future GIFTS code development. This source code structure simpifiles the preparation of pipeline science-only modules for cluster processing, a future requirement for GIFTS real-time data processing (not covered in this document).

The new call tree is shown in Fig. 3. Subprogram units `topbt`, `interpolation_rt`, `sumfit` and `radtolayer` (and the now redundant subroutine `read_fitted_database`) have been combined into a single file, that being `texas_cloud_model.f`.

Legacy codes `wnbrit`, `wnmrad`, `lsurface` and the utility routines in `irt_sub_101.f` have not been modified (other than to embed revision information in their compiled object modules). The GIFTS fast transmittance code, `gifts_tran_od`, has been replaced with `gifts_tran` from the main code development branch.[1] `gifts_tran` has also been modified to access the regression coefficients it requires in directories other than the current working directory.

Inputs are from coefficient files, atmospheric profile files from the mesoscale model MM5 [3] and from standard input, typically in the form of a redirected parameter file. The parameter file contains the paths to the regression coefficient files (the wildcard expansion of {`giftsfr?.*`}) and to the cloud parameterization (`clouds.dat`) together with a range of processing options. An example GIFTSFRTE parameter file can be found in Appendix C.

[1] `gifts_tran_od` is an offshoot developed to satisfy a "one-off" request that was never checked back into the code repository.

```
source file            call tree          inputs from          outputs to
-----------            ---------          -----------          ----------

giftsfrte_main.f       giftsfrte_main     STDIN                STDOUT
                       | (giftsfrte.i)
                       |                  profile.bin          wvnLW.bin
                       |                  diams.bin            wvnSMW.bin
                       |                  clouds.dat           prefix_radLW.bin
                       |                                       prefix_radSMW.bin
                       |                                       prefix_btLW.bin
                       |                                       prefix_btSMW.bin
                       |                                       prefix_tauLW.bin
                       |                                       prefix_tauSMW.bin
                       |
giftsfrte.f            +--giftsfrte
                       |  | (giftsfrte.i)
                       |  |
                       |  |
texas_cloud_model.f    |  +--topbt
                       |  |  |
                       |  |  +--interpolation_rt
                       |  |  |  |  (giftsfrte.i)
                       |  |  |  |
                       |  |  |  +--sumfit
                       |  |  |
                       |  |  +--radtolayer
                       |  |  |  |
                       |  |  |  +--radwnplank
                       |  |  |
                       |  |  +--radwnplank
                       |  |  |
wnbrit.f               |  |  +--wnbrit
                       |  |
                       |  +--wnbrit
                       |  |
gifts_tran.f           |  +--gifts_tran    giftsfr1.dry
                       |  |  |             giftsfr1.ozo
                       |  |  |             giftsfr1.wco
                       |  |  |             giftsfr1.wtl
                       |  |  |             giftsfr1.wts
                       |  |  |             giftsfr2.dry
                       |  |  |             giftsfr2.ozo
                       |  |  |             giftsfr2.wco
                       |  |  |             giftsfr2.wtl
                       |  |  |             giftsfr2.wts
                       |  |  |
irt_sub_101.f          |  |  +--conpir
                       |  |  |  |
                       |  |  |  +--gphite
                       |  |  |
                       |  |  +--taudoc
                       |  |  |
                       |  |  +--calpir
                       |  |  |
                       |  |  +--tauwtr
                       |  |
lsurface.f             |  +--lsurface
                       |  |
wnmrad.f               |  +--wnmrad
                       |  |
vn_gifts.f             |  +--vn_gifts
                       |
                       +--vn_gifts
                       |
strcompress.f          +--strcompress
```

Figure 3: Call tree for upgraded GIFTS fast radiative transfer model (GIFTSFRTE). Inputs are from coefficient files, MM5 atmospheric profile files and from standard input, typically in the form of a redirected parameter file.

The include file previously named `texcloud.i` has been renamed to `giftsfrte.i` and the common block nominated therein is now called /`cld_common`/. In spite of a preference in modern FORTRAN code development to avoid the use of COMMON blocks, they have not been eliminated in this code release in the interests of delivering the modified code in a reasonable time and without introducing errors into existing, stable code (e.g. `gifts_tran`() which references common blocks /`taudwo`/ and /`atmstd`/). The COMMON blocks in this code release are listed in Fig. 4. A GNU makefile (Fig. 5) generates the executable called `giftsfrte` (not `giftsfrte_main`).

```
common block        source file         routines
------------        -----------         --------

/cld_common/        giftsfrte.i         main
                                        interpolation_rt

/gifts_vn/          giftsfrte.f         giftsfrte
                    vn_gifts.f          vn_gifts

/taudwo/            giftsfrte.f         giftsfrte
                    gifts_tran.f        gifts_tran

/atmstd/            irt_sub_101.f       reference_atmosphere (block data)
                    gifts_tran.f        gifts_tran

/gifts_be/          vn_gifts.f          vn_gifts
```

Figure 4: COMMON blocks in the upgraded GIFTS fast radiative transfer model GIFTSFRTE.

```
#
#  $Id: Makefile,v 1.4 2003/06/06 20:31:31 rayg Exp $
#
#  Description:
#  Makefile for the GIFTS fast radiative transfer model with clouds
#
FC     = g77
FFLAGS = -Wall -O3 ${CFLAGS}
LFLAGS = -static
LIBS   =
BASE = giftsfrte
EXEC = ../bin/giftsfrte
INCL = ${BASE}.i
SRCS = ${BASE}_main.f ${BASE}.f gifts_tran.f irtsub_101.f vn_gifts.f \
       lsurface.f wnbrit.f wnmrad.f wnplan.f texas_cloud_model.f atmosrad.f \
       strcompress.f
OBJS = $(SRCS:.f=.o)

${EXEC}:  ${OBJS}
${FC} ${OBJS} ${LFLAGS} ${LIBS} -o ${EXEC}

${OBJS}:  ${INCL}

${INCL}:

clean:
/bin/rm -f ${EXEC} ${OBJS}
```

Figure 5: Makefile for GIFTSFRTE.

4 GIFTS DATA CUBES

GIFTS data cubes comprise a 128 × 128 array, with a third dimension that contains spectral information (such as radiance, brightness temperature, transmittance or optical depth). A 128 × 128 array of atmospheric profiles and surface conditions may also be considered as a GIFTS data cube, these data are the output of MM5 model executions (reformatted for use with GIFTS fast model simulations) and one of the inputs to GIFTSFRTE. Within the 128 × 128 data arrays, row and column pixels are defined to be on the interval [–64:64] with row 0 and column 0 skipped.

Some example contour plots drawn from MM5 data are shown in the next few figures. Fig. 6 shows the surface heights for GIFTS data cube 06122002_2200_2_3. The data cube is centered at approximately 34.51° N, 86.82° W, each pixel is 4 km square.

Fig. 7 and Fig. 8 show the total column liquid water and ice, respectively, for GIFTS data cube 06122002_2200_2_3. There is an accumulation of column liquid water in

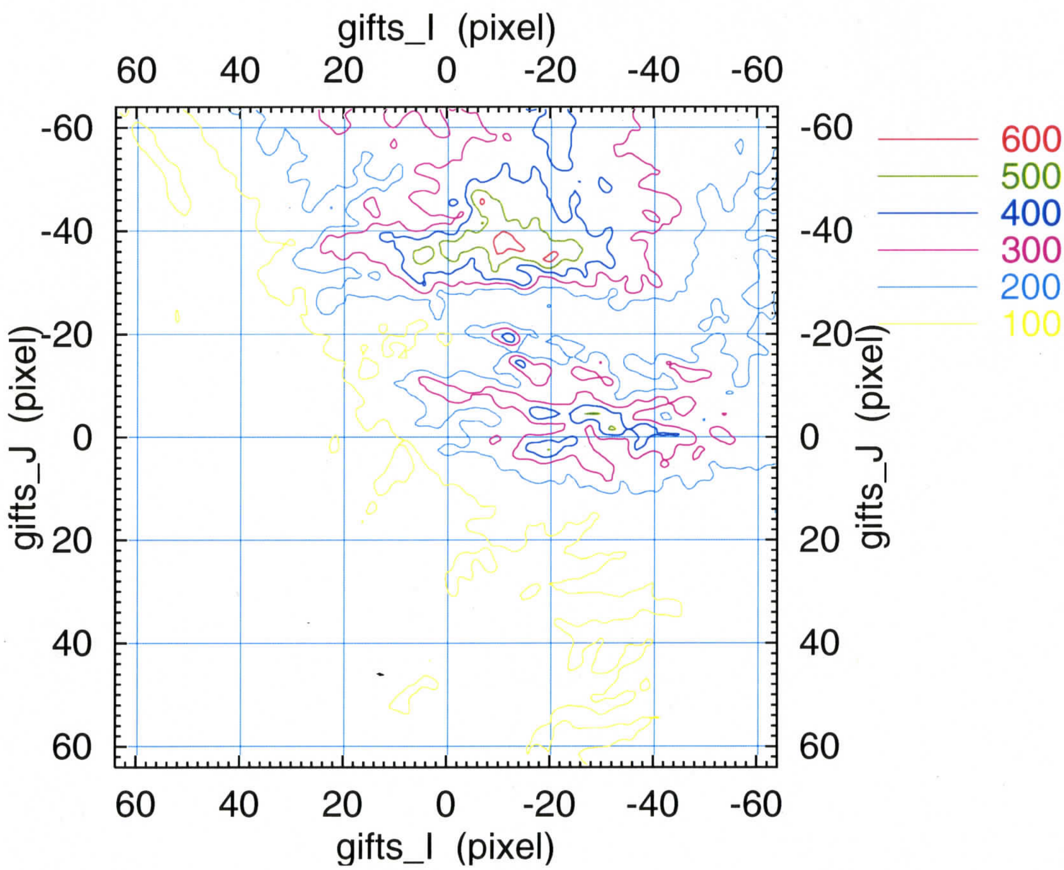

Figure 6: Surface height (m) contour plot for GIFTS data cube 06122002_2200_2_3.

the vicinity of (–31,–32).

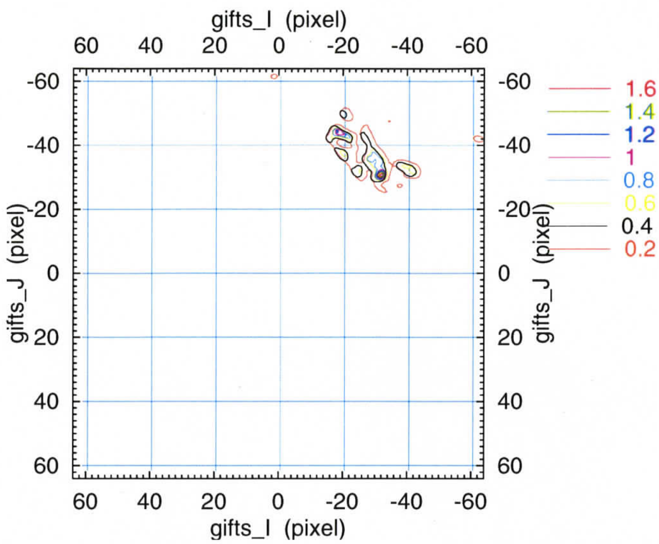

Figure 7: Liquid water path (g/cm^2) contour plot for GIFTS data cube 06122002_2200_2_3.

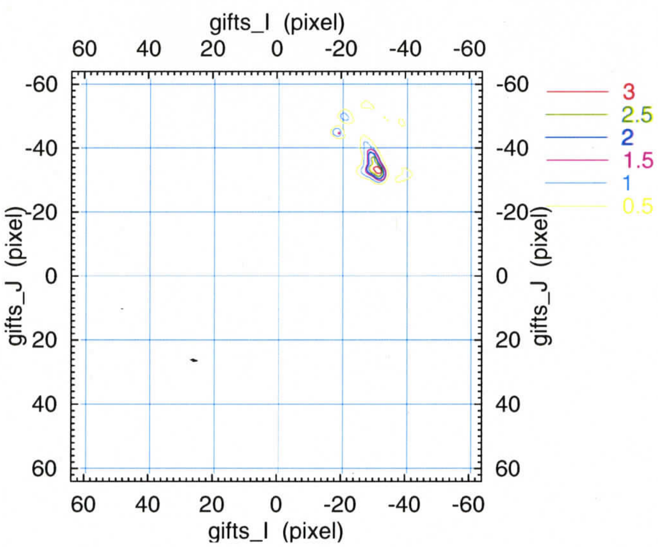

Figure 8: Ice water paths (g/cm^2) contour plot for GIFTS data cube 06122002_2200_2_3.

4.1 Atmospheric Profile Data

Atmospheric profile data are represented as 312 single precision floating point numbers in a binary record; 16384 (128 × 128) records constitute a GIFTS atmospheric profile data cube. The first 303 values per record are ordered as 101 temperatures (K), 101 water vapour concentrations (g/kg) and 101 ozone concentrations (ppmv). The ordering is lowest pressure to highest pressure. The 101 values are matched to 101 standard pressure levels to be found as data in source file `giftsfrte_main.f`. The remaining 9 values are, in this order, liquid water path (g/m^2), ice water path (g/m^2), surface skin temperature (K), surface altitude (m), latitude (deg +N), longitude (deg +E), pressure level where liquid condensate is located (hPa), pressure level where ice condensate is located (hPa) and, finally, surface pressure (hPa). Fig. 9 shows an example atmospheric profile together with values of these nine non-profile data quantities. The brightness temperatures that GIFTSFRTE computes for this cloud-free atmosphere are shown in Fig. 10 (LW band) and Fig. 11 (SMW band).

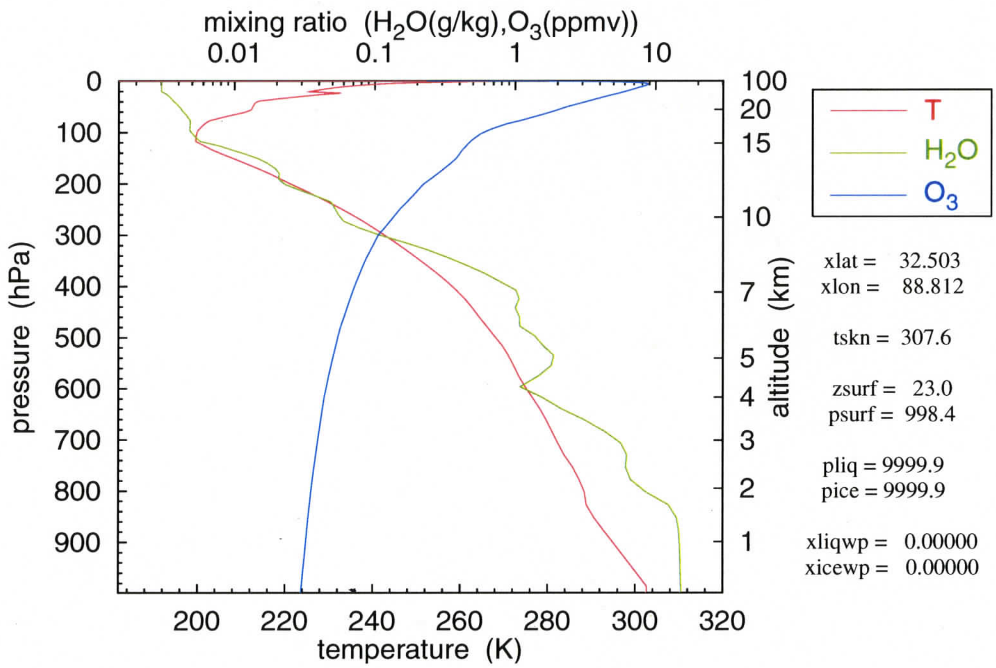

Figure 9: Example atmospheric profile. The nine non-profile quantities are listed to the right of the plotted profile data. In this example the pressure levels of liquid water and ice condensate, `pliq` and `pice` respectively, have been assigned flag values. Liquid water and ice water paths, `xliqwp` and `xicewp` respectively, are zero — i.e. this is a "clear" atmospheric profile.

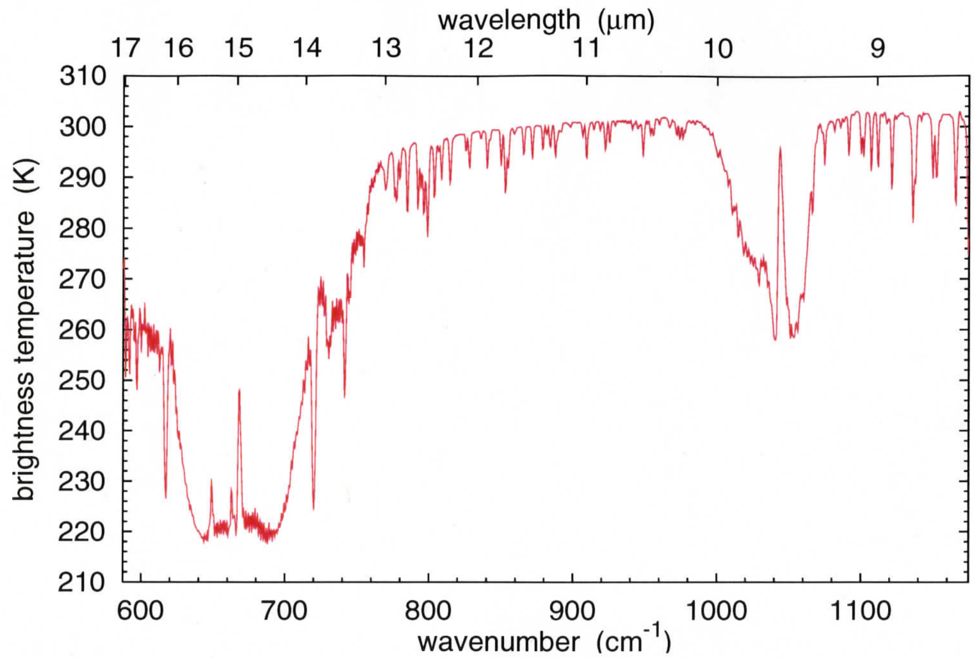

Figure 10: GIFTSFRTE LW brightness temperature spectrum for the clear atmospheric profile of Fig. 9, nadir viewing.

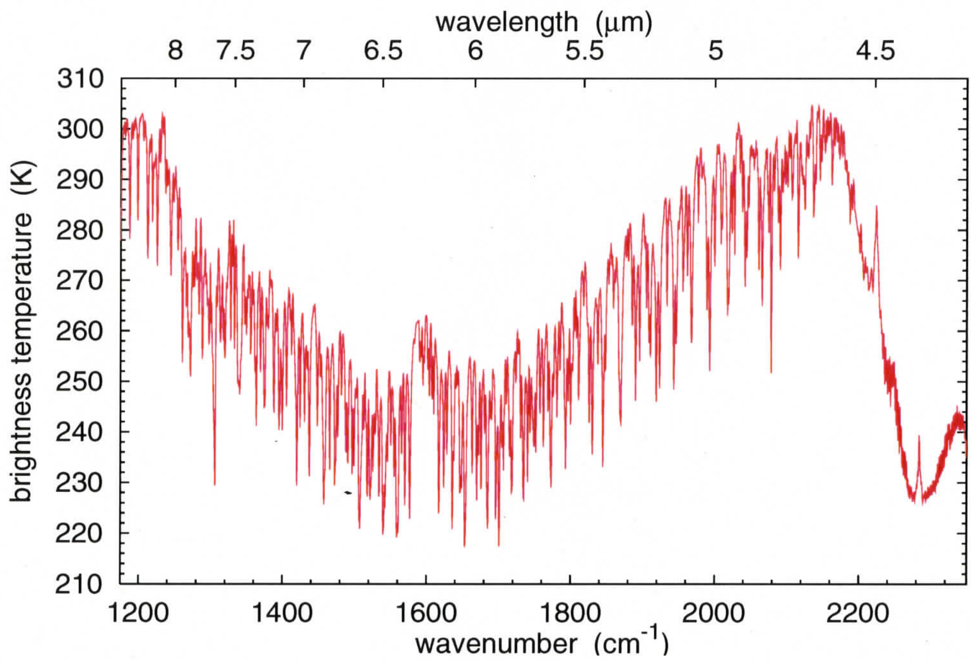

Figure 11: GIFTSFRTE SMW brightness temperature spectrum for the clear atmospheric profile of Fig. 9, nadir viewing.

4.2 Effective Layer Temperature

There are a number of techniques for calculating the radiance emergent from an atmospheric layer across which there is a temperature gradient. Since the Planck radiance is a function of temperature, an important consideration is how a single temperature is assigned to an atmospheric layer. Three methods of computing the effective temperature of an atmospheric layer are discussed and compared in this section.

The version of GIFTSFRTE delivered on 7 January 2003 (along with the Yang:2003 cloud model) has the upwelling radiance contribution from each atmospheric layer computed using the optical depth of the layer and its lower boundary temperature, call this Method 1. A more accurate alternative is to use the layer optical depth and the arithmetic mean Planck radiance, $\frac{1}{2}[B(T_n) + B(T_f)]$, where T_n and T_f are the temperatures of the near and far boundaries. Call this Method 2. For the example clear atmosphere of Fig. 9, there can be differences in top-of-atmosphere brightness temperatures of up to approximately 1 K between the two methods, as shown in Fig. 12 and Fig. 13.

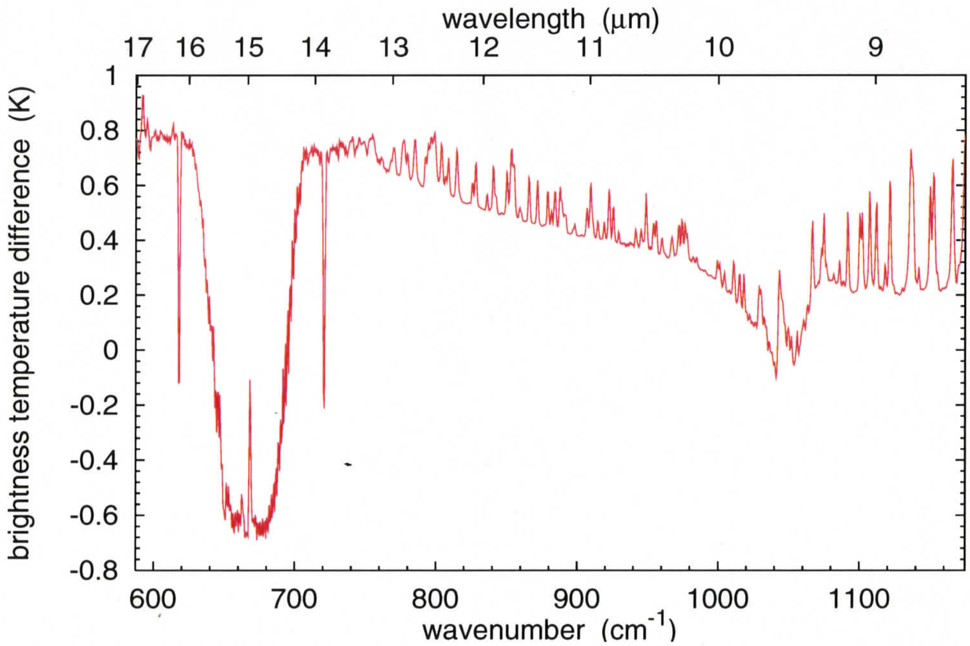

Figure 12: GIFTS LW band Method 1 brightness temperature less Method 2 brightness temperature for atmospheric profile of Fig. 9, nadir viewing.

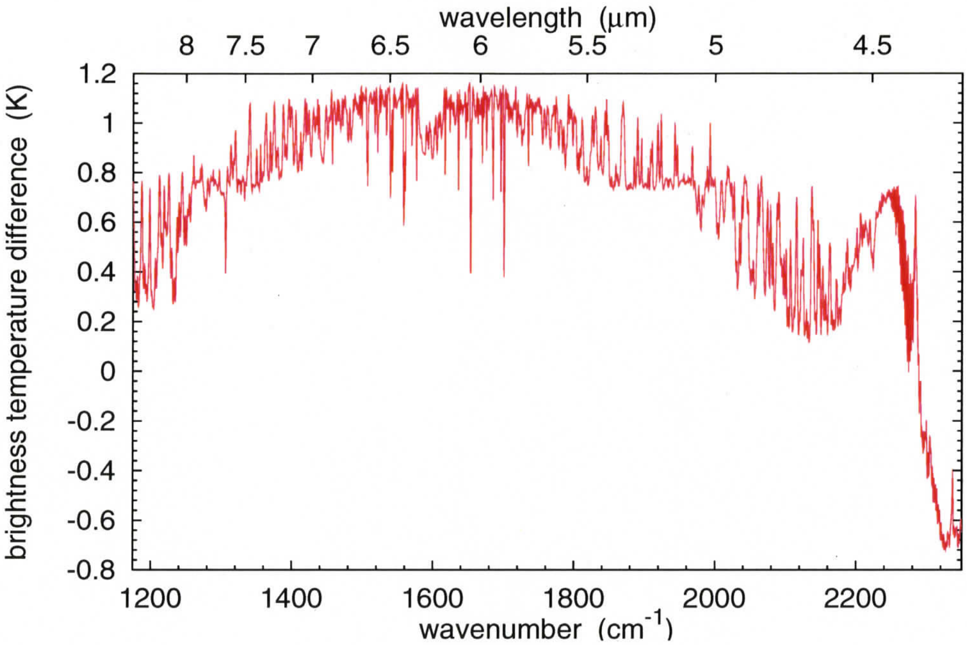

Figure 13: GIFTS SMW band Method 1 brightness temperature less Method 2 brightness temperature for atmospheric profile of Fig. 9, nadir viewing.

Following the suggestion of Dave Turner[2], a third method (Method 3) was also investigated, in which a two term Padé approximation to the effective Planck function of an atmospheric layer (of optical depth, δ) is given by, [1],

$$B(T_e) = \frac{\frac{1}{2}[B(T_n) + B(T_f)] + \left(a\delta + b\delta^2\right)\ B(T_n)}{1 + a\delta + b\delta^2} \quad , \tag{1}$$

where T_e is the layer effective temperature. In Eqn. (1) $a = 0.193$ and $b = 0.013$.

The brightness temperature differences between Method 3 and Method 2 for nadir viewing are shown in Fig. 14 and Fig. 15. There is only a small difference in brightness temperature, not more than 0.1 K, depending on channel. Fig. 16 and Fig. 17 show that at an observation zenith of 60° this small difference is increased only a small amount compared to nadir viewing. On the authority of [1], Method 3 is selected as the operational algorithm for GIFTSFRTE.

[2] Pacific Northwest National Laboratories

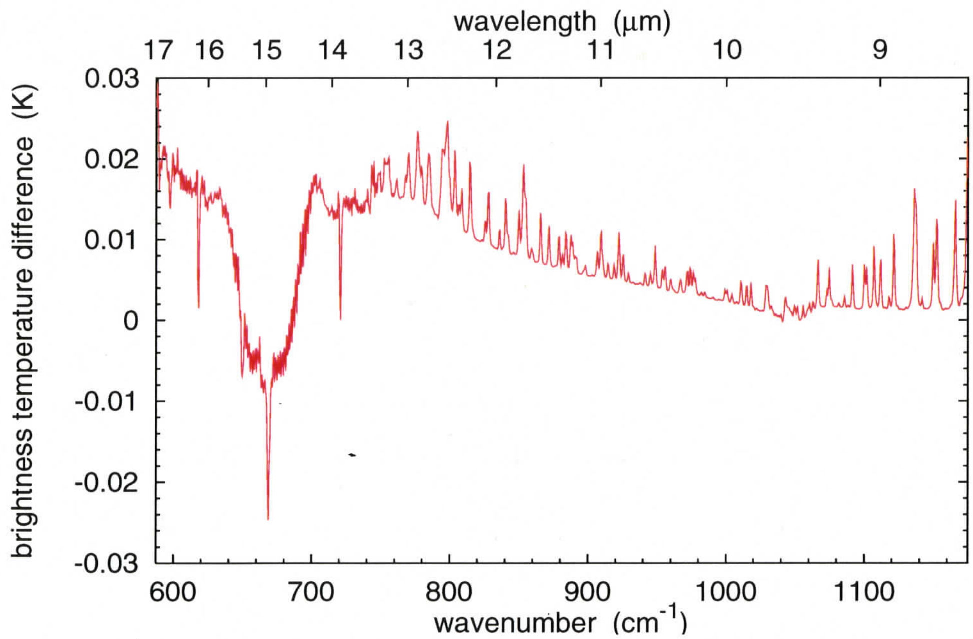

Figure 14: GIFTS LW band Method 3 brightness temperature less Method 2 brightness temperature for atmospheric profile of Fig. 9, nadir viewing.

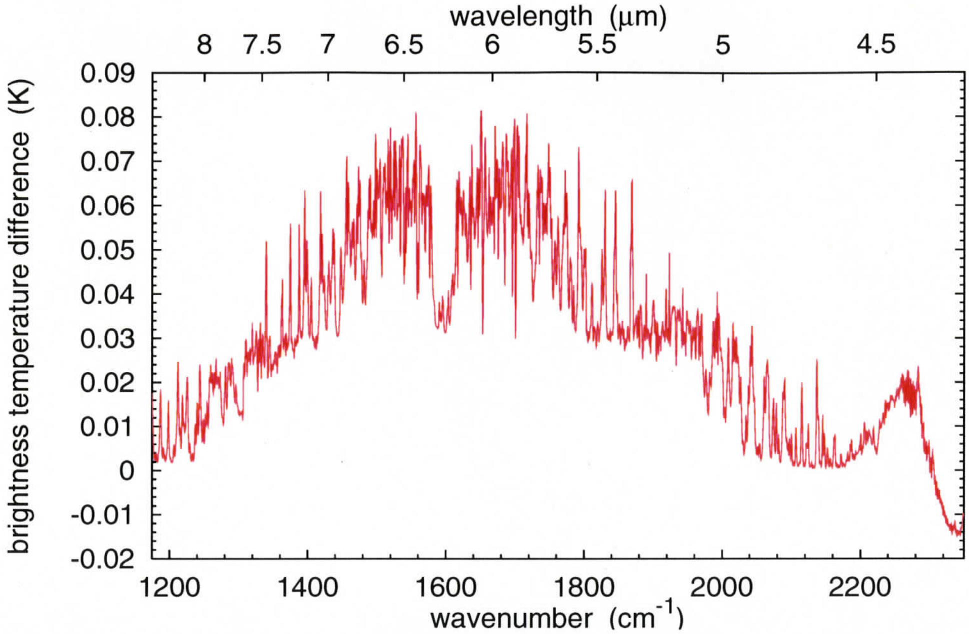

Figure 15: GIFTS SMW band Method 3 brightness temperature less Method 2 brightness temperature for atmospheric profile of Fig. 9, nadir viewing.

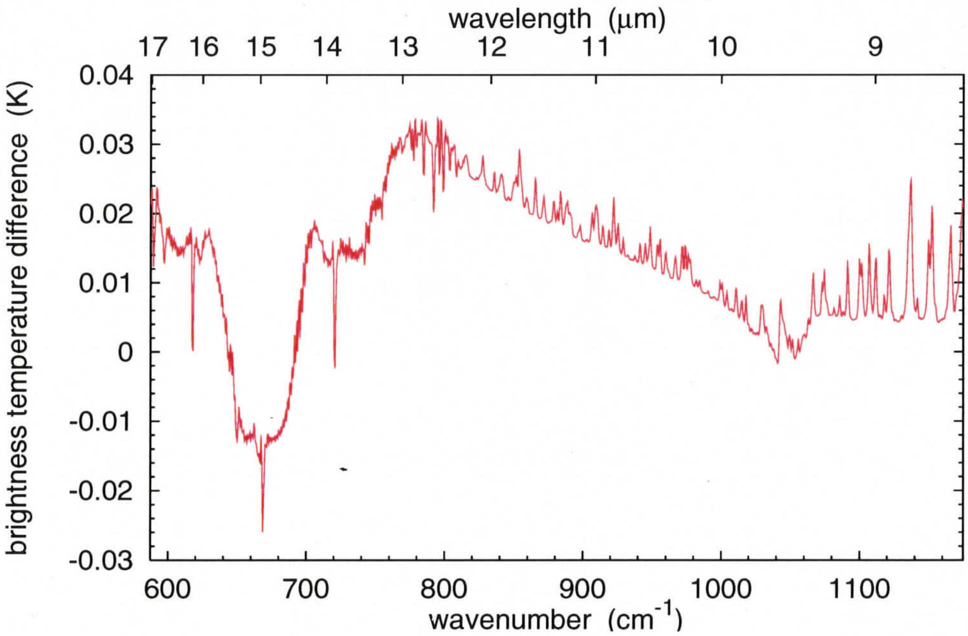

Figure 16: GIFTS LW band Method 3 brightness temperature less Method 2 brightness temperature for atmospheric profile of Fig. 9, 60 deg observation zenith angle.

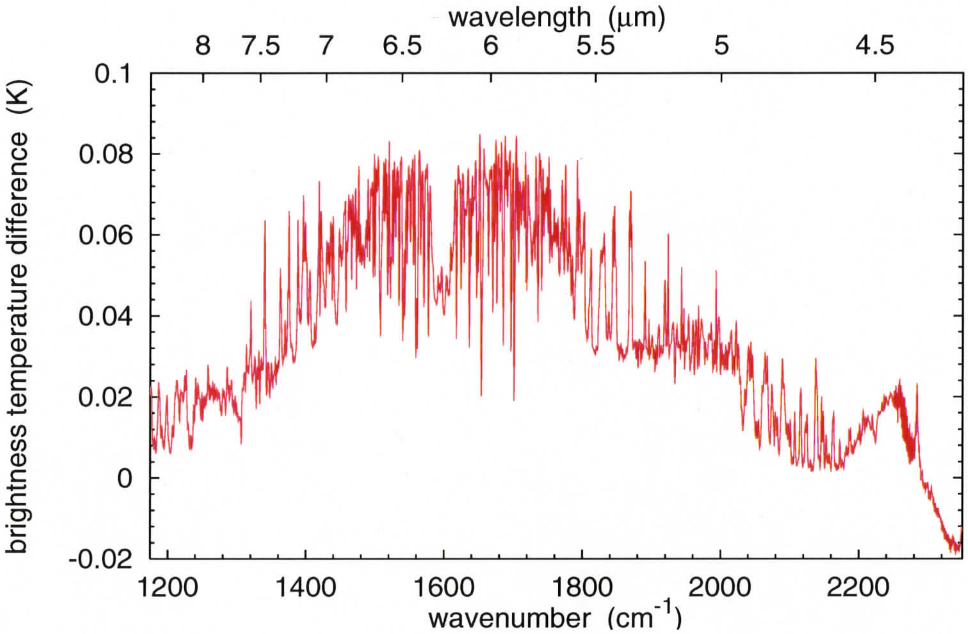

Figure 17: GIFTS SMW band Method 3 brightness temperature less Method 2 brightness temperature for atmospheric profile of Fig. 9, 60 deg observation zenith angle.

4.3 Cloud Particle Effective Diameter

The Yang:2003 cloud model in GIFTSFRTE accepts inputs such as the effective diameter of cloud droplets, the cloud phase (liquid or ice), the optical thickness of the cloud at visible wavelengths and the pressure level at the cloud top. The model can accommodate a single cloud layer of either ice crystals or liquid water droplets. The mesoscale model MM5 can deliver the concentrations and effective diameters of five condensate types (two liquid, three ice) at 101 atmospheric levels, i.e. complete profiles. The two liquid condensates are denoted "rain" and "liquid", and the three ice condensates are "ice", "snow" and "graupel".

Fig. 18 shows the atmospheric profile where there is both liquid water and ice cloud present. The pressure levels denoted `pliq` and `pice` are the designated cloud top pressures for liquid water and ice clouds respectively; they are the lowest pressures at which a mass-in-mass mixing ratio of 1×10^{-6} is observed.

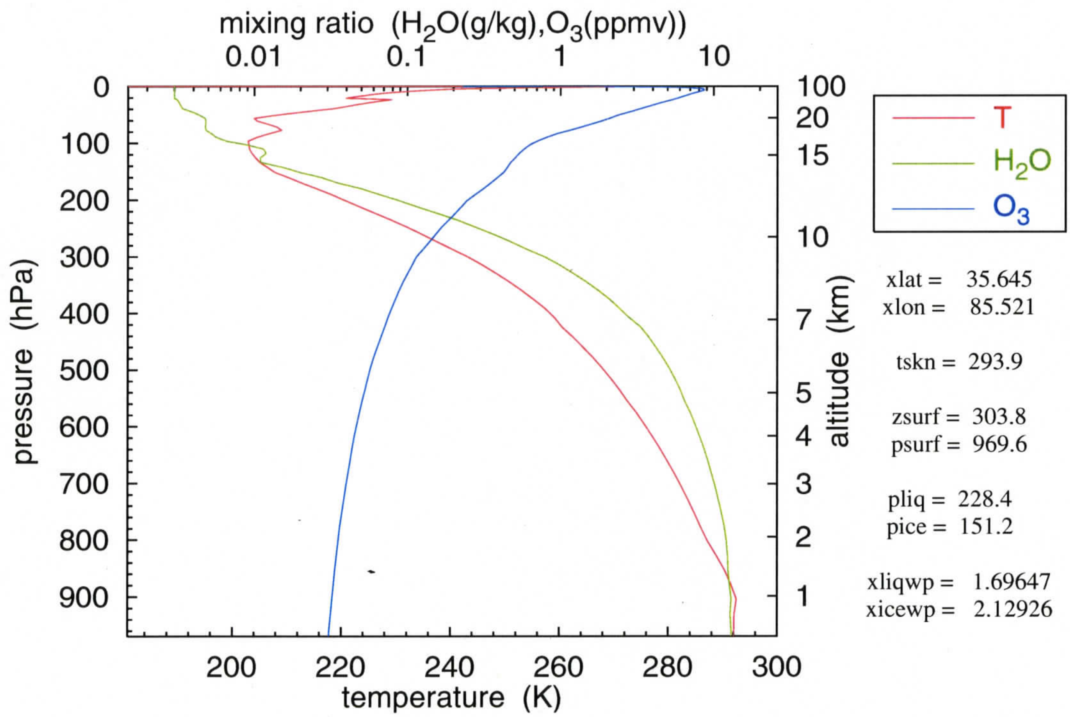

Figure 18: Atmospheric profiles from GIFTS data cube 06122002_2200_2_3 at (−31,−32). At this location the liquid water path (`xliqwp`) is 1.6965 $\mathrm{g\,cm^{-2}}$ and the ice water path (`xicewp`) is 2.1293 $\mathrm{g\,cm^{-2}}$.

Fig. 19 and Fig. 20 show the condensate mixing ratio and effective diameter profiles, respectively.

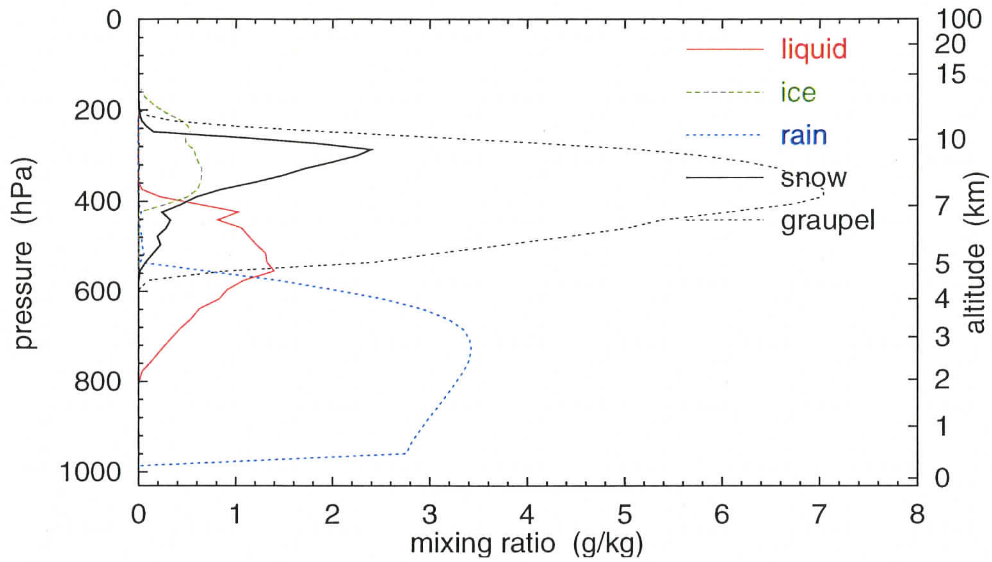

Figure 19: Condensate mixing ratio profile from GIFTS data cube 06122002_2200_2_3 at (–31,–32).

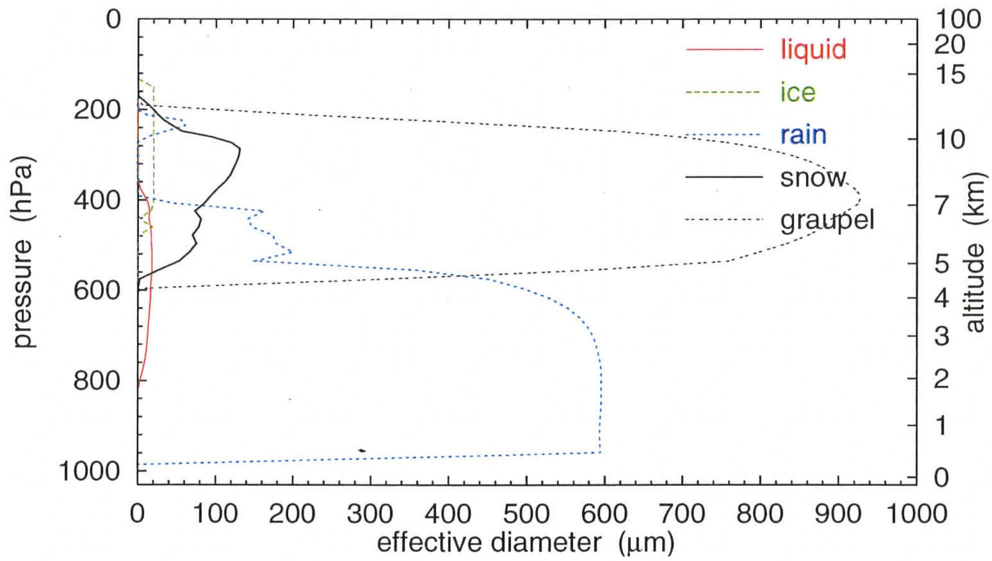

Figure 20: Effective diameter profile from GIFTS data cube 06122002_2200_2_3 at (–31,–32). The larger particle sizes are beyond the bounds of applicability of the new cloud model (100 μm for liquid, 150 μm for ice); this example was selected because it shows all five condensate species.

The condensate profile data must be pre-processed to provide an estimate of the model input parameters of cloud phase, effective diameter and optical depth. The following describes how this is achieved. Section 5 on page 24 assesses the efficacy of this simple approach.

4.3.1 Liquid phase cloud

In the Yang:2003 cloud model, liquid water clouds are assumed to contain spherical droplets with a size distribution based on Deirmendjian's modified gamma distribution [2]. The effective size of liquid cloud droplets, D_l, is [9],

$$D_l = \frac{\int_0^\infty n(D)\, D^3\, dD}{\int_0^\infty n(D)\, D^2\, dD} \quad , \tag{2}$$

where $n(D)$ is the number density in the diameter range D to $D + dD$. For an external mixture of "liquid" and "rain" (these are the names given to the two liquid phase condensate size distributions in the MM5 output files),

$$D_l = \frac{\int_0^\infty [n_{rain}(D) + n_{liquid}(D)]\, D^3\, dD}{\int_0^\infty [n_{rain}(D) + n_{liquid}(D)]\, D^2\, dD} \quad . \tag{3}$$

Presently the mixing ratio, M, and the effective diameter, D, are available to `gifsftre` from the MM5 condensate profiles. The effective diameter of a mixture of "liquid" and "rain" is computed as,

$$D_l = \frac{M_{rain} + M_{liquid}}{M_{rain}/D_{rain} + M_{liquid}/D_{liquid}} \quad , \tag{4}$$

where M and D are interpolated to pressure `pliq`. M, the mass of condensate per unit mass of moist air, has replaced the condensate volume in the numerator of Eqn. (3) since M is proportional to condensate volume for air masses at the same atmospheric pressure, i.e. `pliq` or `pice`.

4.3.2 Ice phase cloud

The effective size of hexagonal ice crystals is [4, 9],

$$D_i = \frac{3}{2} \times \frac{\text{volume}}{\text{projected area}} = \frac{3\sqrt{3}a^2 L}{\sqrt{3}a^2 + 2aL} \quad , \tag{5}$$

where a is the half-width of cross section and L is the crystal length (i.e. the longest dimension). The crystal aspect ratio, $\frac{2a}{L}$, is related to L via [9],

$$\frac{2a}{L} = \begin{cases} 1 \quad , & L \leq 40\,\mu m \quad , \\ \exp\left[-0.017835\,(L-40)\right] \quad , & 40 < L \leq 50\,\mu m \quad , \\ \dfrac{5.916}{\sqrt{L}} \quad , & L > 50\,\mu m \quad . \end{cases} \tag{6}$$

If the effective diameters of ice phase condensates provided by MM5 are derived from expressions similar to Eqn. (5), it is not possible to recover L and a in order to generate an appropriately weighted effective diameter, D_i. For present purposes,

$$D_i = \frac{M_{ice} + M_{snow} + M_{graupel}}{M_{ice}/D_{ice} + M_{snow}/D_{snow} + M_{graupel}/D_{graupel}} \quad , \tag{7}$$

where M is the mass mixing ratio and D the effective diameter from the MM5 condensate profile interpolated to pressure `pice`. "ice", "snow" and "graupel" are the names given to the three ice phase condensate size distributions in the MM5 output files.

4.4 Selection Rule

Given that the cloud model delivered for GIFTSFRTE can include a single layer cloud of liquid water or ice, but not both, a selection rule must be invoked in the presence of mixed phase cloud and multi-layer clouds. The selection rule is simply that the cloud phase found at the highest altitude (lowest pressure) is the one used for forward model simulations. The optical depth is determined by the column amount of that phase but the effective diameter of particles is drawn from the condensate profile interpolated to the nominated cloud top pressure.

5 VERIFICATION

To verify that GIFTSFRTE is operating correctly we employ LBLRTM [1] to generate layer gaseous optical depths. These are merged with the single scattering properties of clouds which are then processed by DISORT [6] to generate simulated radiances at the top of the atmosphere at a specified spectral resolution. LBLDIS is a computer code which facilitates this task [7, 8].

Spectral reduction to GIFTS channel radiances and conversion to brightness temperatures permit comparisons to be made with the GIFTS forward model. Spectral reduction is achieved by the MATLAB code `gifts.m` written by Dave Tobin.

The atmosphere is divided into 101 layers for LBLRTM (and, subsequently, DISORT) calculations. This is to match the layering in GIFTSFRTE which has been hard-coded to the 101 pressure levels defined for retrievals from the Atmospheric Infra-Red Sounder (AIRS). These 101 pressure levels are shown in Table 1. The atmospheric profiles initially used to generate GIFTS radiances (and brightness temperatures) are the LOWTRAN standard atmospheres which are defined only to 1013 hPa. As a consequence AIRS layers 1, 2 and 3 will normally not be used except under conditons of high barometric pressure and over land surfaces that are below sea level.

Brightness temperatures computed in this way are compared to GIFTSFRTE brightness temperatures that are generated for the same atmospheric profile. The cloud model in GIFTSFRTE can simulate only single-layer, single-phase clouds so that, in the first instance, only equivalently idealised profiles are provided to LBLDIS. That is, cloud optical properties are merged into a single AIRS layer in the LBLDIS processing, and reflection and transmission functions for a cloud layer (at the top of the given AIRS layer) in the GIFTSFRTE processing.

The procedure to verify GIFTSFRTE can be summarised as,

1. execute LBLRTM in optical depth mode to generate layer optical depths for a standard clear atmosphere (layers defined using the AIRS pressure levels),
2. define a cloud layer in terms of its altitude, type (i.e. liquid or ice) and moments of its size distribution
3. execute LBLDIS to generate radiances at some specified resolution and spectrally reduce to GIFTS channels radiances, convert to brightness temperatures,
4. construct an atmosphere in the GIFTS data cube format which is equivalent to the standard atmosphere used by LBLRTM/DISORT plus a single cloud layer occupying one of the AIRS layers,
5. execute GIFTSFRTE and compare brightness temperatures computed by the fast model (GIFTSFRTE) and the verification code (LBLRTM/LBLDIS), and

6. repeat items 2 to 5 above for both liquid water and ice clouds.

layer	P (hPa)	OD file	layer	P (hPa)	OD file
101	0.0000 — 0.0050	ODdeflt_098			
100	0.0050 — 0.0161	ODdeflt_097	50	151.2664 — 160.4959	ODdeflt_047
99	0.0161 — 0.0384	ODdeflt_096	49	160.4959 — 170.0784	ODdeflt_046
98	0.0384 — 0.0769	ODdeflt_095	48	170.0784 — 180.0183	ODdeflt_045
97	0.0769 — 0.1370	ODdeflt_094	47	180.0183 — 190.3203	ODdeflt_044
96	0.1370 — 0.2244	ODdeflt_093	46	190.3203 — 200.9887	ODdeflt_043
95	0.2244 — 0.3454	ODdeflt_092	45	200.9887 — 212.0277	ODdeflt_042
94	0.3454 — 0.5064	ODdeflt_091	44	212.0277 — 223.4415	ODdeflt_041
93	0.5064 — 0.7140	ODdeflt_090	43	223.4415 — 235.2338	ODdeflt_040
92	0.7140 — 0.9753	ODdeflt_089	42	235.2338 — 247.4085	ODdeflt_039
91	0.9753 — 1.2972	ODdeflt_088	41	247.4085 — 259.9691	ODdeflt_038
90	1.2972 — 1.6872	ODdeflt_087	40	259.9691 — 272.9191	ODdeflt_037
89	1.6872 — 2.1526	ODdeflt_086	39	272.9191 — 286.2617	ODdeflt_036
88	2.1526 — 2.7009	ODdeflt_085	38	286.2617 — 300.0000	ODdeflt_035
87	2.7009 — 3.3398	ODdeflt_084	37	300.0000 — 314.1369	ODdeflt_034
86	3.3398 — 4.0770	ODdeflt_083	36	314.1369 — 328.6753	ODdeflt_033
85	4.0770 — 4.9204	ODdeflt_082	35	328.6753 — 343.6176	ODdeflt_032
84	4.9204 — 5.8776	ODdeflt_081	34	343.6176 — 358.9665	ODdeflt_031
83	5.8776 — 6.9567	ODdeflt_080	33	358.9665 — 374.7241	ODdeflt_030
82	6.9567 — 8.1655	ODdeflt_079	32	374.7241 — 390.8926	ODdeflt_029
81	8.1655 — 9.5119	ODdeflt_078	31	390.8926 — 407.4738	ODdeflt_028
80	9.5119 — 11.0038	ODdeflt_077	30	407.4738 — 424.4698	ODdeflt_027
79	11.0038 — 12.6492	ODdeflt_076	29	424.4698 — 441.8819	ODdeflt_026
78	12.6492 — 14.4559	ODdeflt_075	28	441.8819 — 459.7118	ODdeflt_025
77	14.4559 — 16.4318	ODdeflt_074	27	459.7118 — 477.9607	ODdeflt_024
76	16.4318 — 18.5847	ODdeflt_073	26	477.9607 — 496.6298	ODdeflt_023
75	18.5847 — 20.9224	ODdeflt_072	25	496.6298 — 515.7200	ODdeflt_022
74	20.9224 — 23.4526	ODdeflt_071	24	515.7200 — 535.2322	ODdeflt_021
73	23.4526 — 26.1829	ODdeflt_070	23	535.2322 — 555.1669	ODdeflt_020
72	26.1829 — 29.1210	ODdeflt_069	22	555.1669 — 575.5248	ODdeflt_019
71	29.1210 — 32.2744	ODdeflt_068	21	575.5248 — 596.3062	ODdeflt_018
70	32.2744 — 35.6505	ODdeflt_067	20	596.3062 — 617.5112	ODdeflt_017
69	35.6505 — 39.2566	ODdeflt_066	19	617.5112 — 639.1398	ODdeflt_016
68	39.2566 — 43.1001	ODdeflt_065	18	639.1398 — 661.1920	ODdeflt_015
67	43.1001 — 47.1882	ODdeflt_064	17	661.1920 — 683.6673	ODdeflt_014
66	47.1882 — 51.5278	ODdeflt_063	16	683.6673 — 706.5654	ODdeflt_013
65	51.5278 — 56.1260	ODdeflt_062	15	706.5654 — 729.8857	ODdeflt_012
64	56.1260 — 60.9895	ODdeflt_061	14	729.8857 — 753.6275	ODdeflt_011
63	60.9895 — 66.1253	ODdeflt_060	13	753.6275 — 777.7897	ODdeflt_010
62	66.1253 — 71.5398	ODdeflt_059	12	777.7897 — 802.3714	ODdeflt_009
61	71.5398 — 77.2396	ODdeflt_058	11	802.3714 — 827.3713	ODdeflt_008
60	77.2396 — 83.2310	ODdeflt_057	10	827.3713 — 852.7880	ODdeflt_007
59	83.2310 — 89.5204	ODdeflt_056	9	852.7880 — 878.6201	ODdeflt_006
58	89.5204 — 96.1138	ODdeflt_055	8	878.6201 — 904.8659	ODdeflt_005
57	96.1138 — 103.0172	ODdeflt_054	7	904.8659 — 931.5236	ODdeflt_004
56	103.0172 — 110.2366	ODdeflt_053	6	931.5236 — 958.5911	ODdeflt_003
55	110.2366 — 117.7775	ODdeflt_052	5	958.5911 — 986.0666	ODdeflt_002
54	117.7775 — 125.6456	ODdeflt_051	4	986.0666 — 1013.948	ODdeflt_001†
53	125.6456 — 133.8462	ODdeflt_050	3	1013.948 — 1042.232	N/A
52	133.8462 — 142.3848	ODdeflt_049	2	1042.232 — 1070.917	N/A
51	142.3848 — 151.2664	ODdeflt_048	1	1070.917 — 1100.000	N/A

Table 1: 101 AIRS atmospheric layers. The "OD file" is the filename of gaseous spectral optical depths computed by LBLRTM. The atmospheric profiles initially used to generate GIFTS radiances (and brightness temperatures) are the LOWTRAN standard atmospheres which are defined only to 1013 hPa.

†NOTE: The lower boundary of ODdeflt_001 is at pressure level 1013 hPa *not* the AIRS pressure level 1013.948 hPa.

5.1 Clear Soundings

The procedure outlined above for verification of GIFTSFRTE first requires that GIFTS channel radiances from LBLRTM and from LBLDIS be in agreement for clear atmospheres. The method adopted to test this is,

1. execute LBLRTM in radiance mode to simulate nadir observation of a standard atmosphere,
2. extract the monochromatic radiances (using `fsc2asc` from Paul van Delst),
3. spectrally reduce to generate GIFTS channel radiances (using `gifts.m` from Dave Tobin; *aflag*=1: KaiserBessel # 6 apodization),
4. execute LBLRTM in optical depth mode for the same standard atmosphere,
5. execute LBLDIS (using the layer optical depths generated by LBLRTM) to generate radiances at some specified resolution[3] and spectrally reduce to generate GIFTS channel radiances (via `gifts.m`), and
6. convert GIFTS channel radiances to brightness temperatures and compare results.

Fig. 21 shows the brightness temperature from GIFTS LW band radiances simulated with LBLRTM for the US 1976 standard atmosphere. Also shown in Fig. 21 are the differences between this result and the results obtained using LBLDIS for different spectral resolutions. The comparisons show that, for LBLDIS executed with spectral step size 0.02 cm^{-1}, discrepencies of as large as 4 K occur in the CO_2 band centred at 15 μm and discrepencies of about 2 K occur in the 9.6 μm O_3 band. Reducing the spectral step size to 0.01 cm^{-1}, which is only possible with the modified LBLDIS code, can reduce discrepencies to about 3 K in the CO_2 band and about 1 K in the O_3 band. In the window region between these major absorption features, LBLDIS under-estimates the brightness temperature by about 1 K. Reducing the spectral step size further to 0.001 cm^{-1} assists in removing brightness temperature difference fluctuations in the O_3 band but the magnitude of the discrepencies in the CO_2 band and the window region remain largely unchanged.

[3]A minor source code modification was made to LBLDIS to enable the wavenumber bandpass to be reduced below approximately 0.2 cm^{-1}. This involved changing layer bandpass transmittances, $\bar{\tau}$, from $\bar{\tau} = \frac{1}{N}\Sigma_{i=1}^{N}\tau_i$ to $\bar{\tau} = \int_a^b \tau(x)\,dx/(b-a)$ where $\tau(x)$ is an interpolating function. a and b are the wavenumber limits of a boxcar bandpass, τ_i are monochromatic transmittances for a given layer taken from LBLRTM monochromatic layer optical depth files.

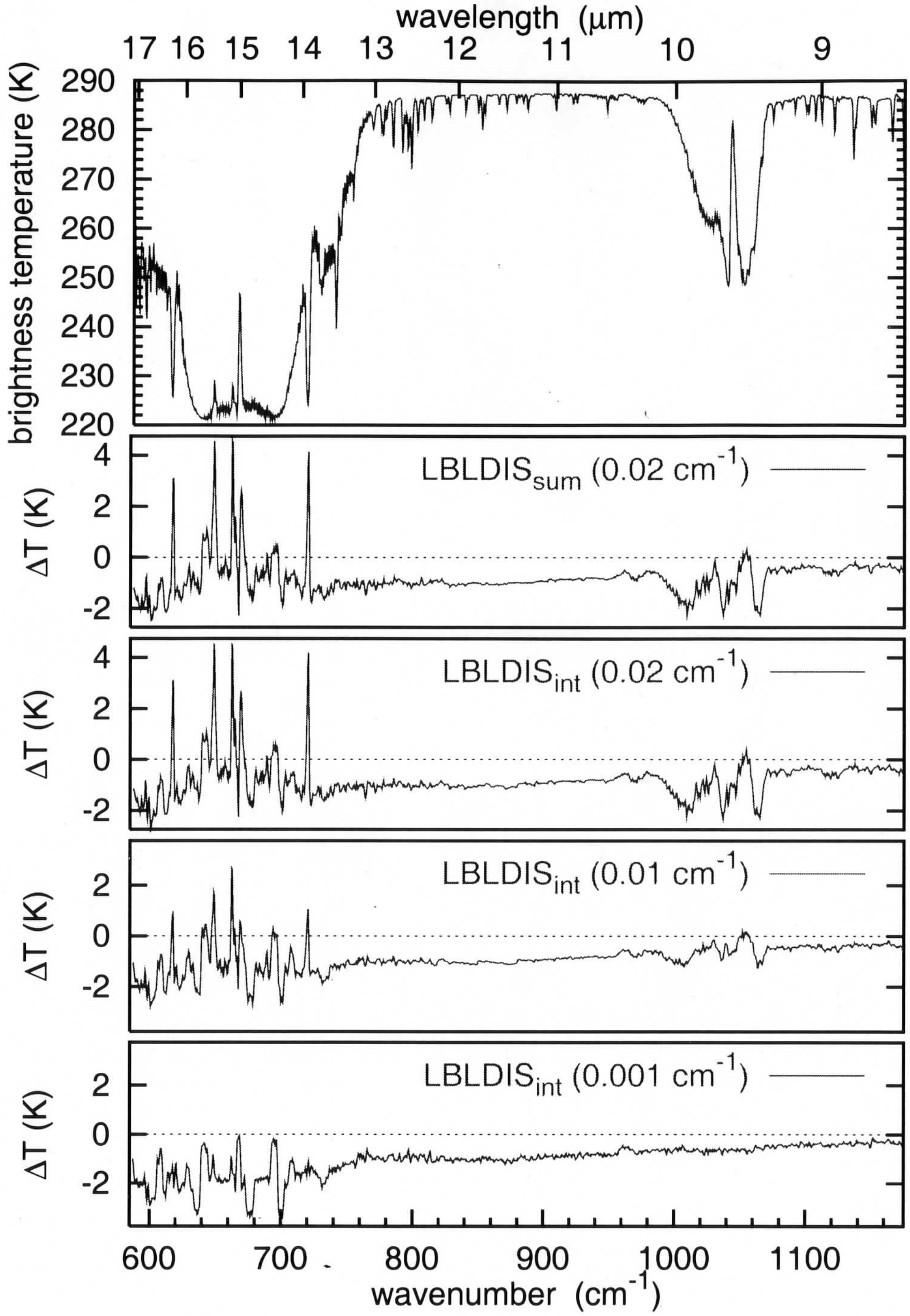

Figure 21: LBLRTM vs DISORT for clear US 1976 standard atmosphere. The upper panel shows the top-of-atmosphere brightness temperature computed by LBLRTM and spectrally reduced to GIFTS LW channels. The panels beneath this show the brightness temperature difference arrived at by subtracting the upper pane result from LBLDIS computations for the same clear atmosphere. Subscript "int" indicates the version of LBLDIS modified according to the footnote of the previous page.

It is thought that the reason for the discrepencies exhibited in Fig. 21 are in the formulation of effective layer optical depth, required by DISORT over a finite width bandpass. The implicit assumption is that the illumination over a narrow bandpass is spectrally flat, an approximation which, for any given bandpass width, becomes increasingly poor with increasing altitude.

In the profile data for which GIFTS radiance data cubes are synthesised there are no clouds with tops above 150 hPa. Consequently, to reduce the discrepencies noted above, LBLDIS is run below the maximum cloud top altitude and LBLRTM separately computes the radiances and transmittances above the maximum cloud top altitude. The LBLDIS and LBLRTM components are then joined in the following manner,

$$L_i' = \mathrm{TRP}[\nu_i^*, M, \nu, L] \times \tau_i^* + L_i^* \quad , \tag{8}$$

where L_i^* and τ_i^* are the monochromatic radiances and transmittances from LBLRTM at wavenumber ν_i^*. L and ν are the narrow bandpass radiances and transmittances from LBLDIS and `TRP` is a linear interpolation function [5]. By way of explanation, if X and Y (N element vectors, X monotonic) and if x is a scalar within the span of X, the statement $y = \mathtt{TRP}[x, N, X, Y]$ assigns to y the value $Y_i + \frac{x - X_i}{X_{i+1} - X_i}(Y_{i+1} - Y_i)$, where x falls between the elements X_i and X_{i+1}. Spectral reduction of L' to GIFTS channel radiances (via `gifts.m`) provides the simulated top-of-atmosphere radiances. In the implementation of Eqn. (8) we computed L from the surface (1013 hPa) to 103.017 hPa, the latter being coincident with an AIRS pressure level and above the level of clouds. L_i^* and τ_i^* are computed from 103.017 hPa to space with the lower boundary characterized by unit emissivity and absolute zero temperature.

Separately computing radiances and transmittances above 103.017 hPa reduces the discrepency between LBLRTM top-of-atmosphere radiances and those computed with DISORT up to the top-of-atmosphere. Fig. 22 shows differences for the GIFTS LW band and Fig. 23 the differences for the GIFTS SMW band. Discrepencies are typically no greater than 0.1 K except in the 9.6 μm ozone band where discrepencies of 0.15 K can be found.

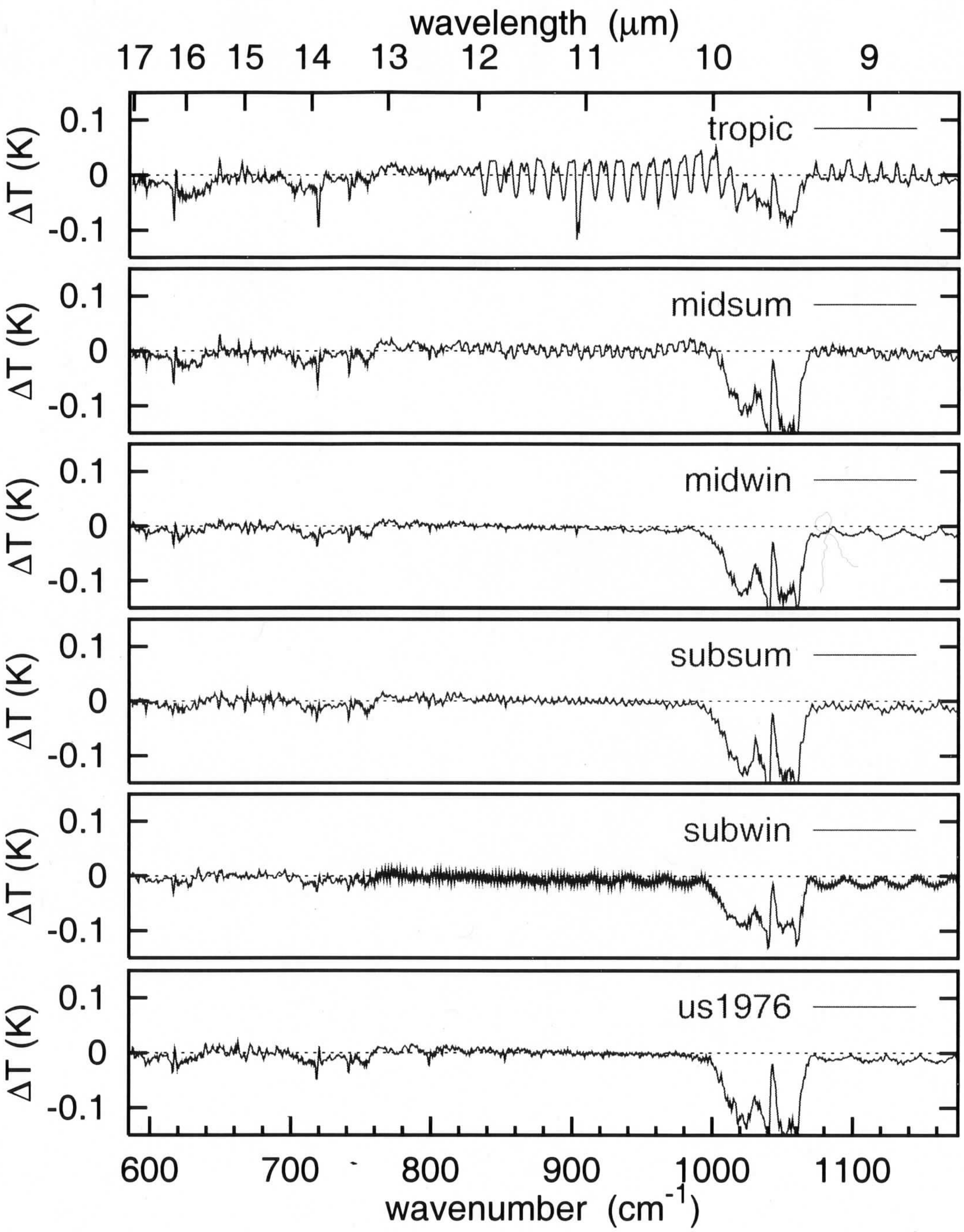

Figure 22: LW brightness temperature differences between DISORT and LBLRTM for the six LOWTRAN standard atmospheres. Discrepencies are typically much less than 0.1 K except in the 9.6 μm ozone band where they may rise to 0.15 K.

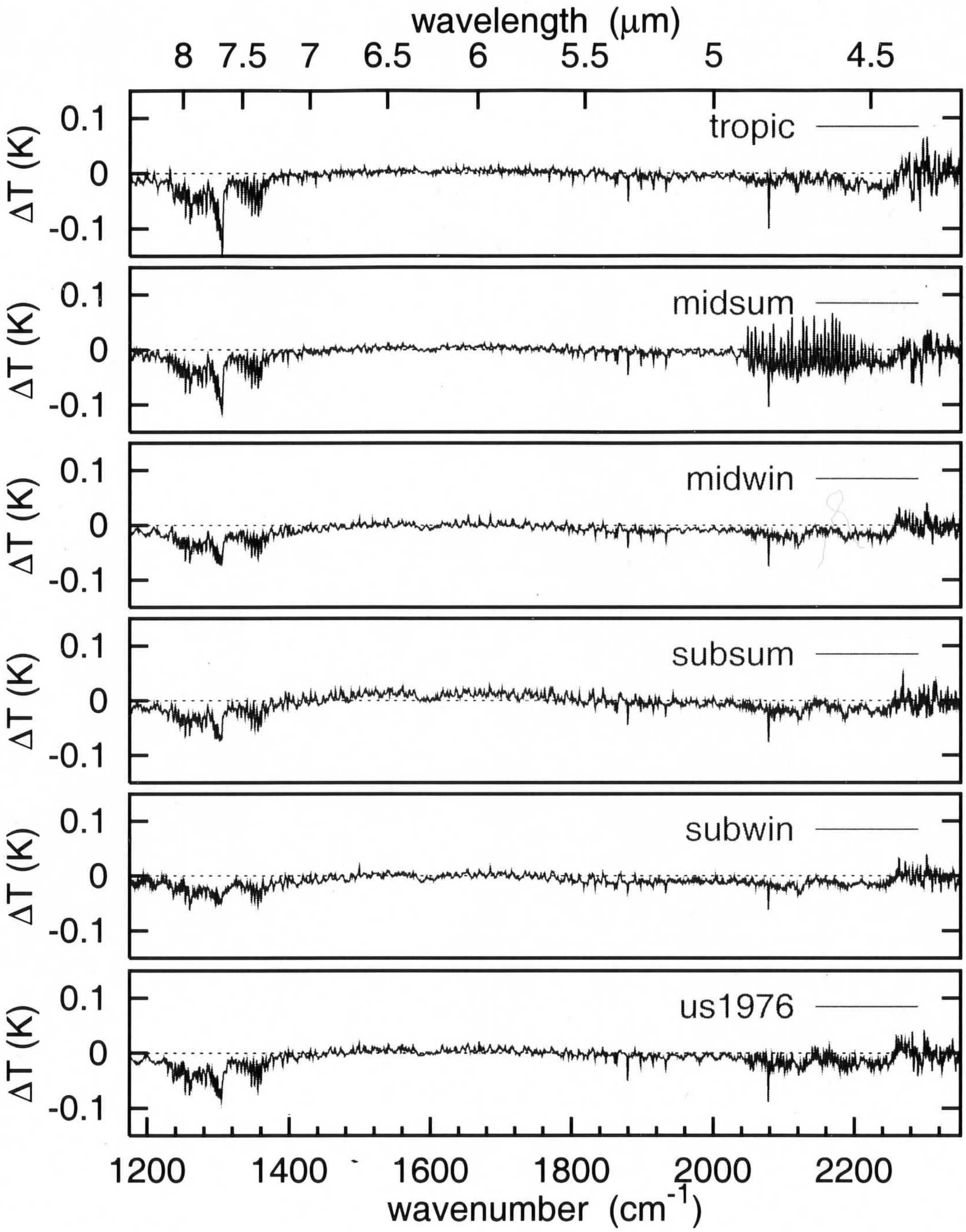

Figure 23: SMW brightness temperature differences between DISORT and LBLRTM for the six LOWTRAN standard atmospheres. Discrepencies are typically of the order 0.05 K and do not rise above 0.15 K in this band.

5.2 Cloudy Soundings

Verification of the accuracy of cloudy atmosphere performance consists of comparing top-of-atmosphere brightness temperatures computed by GIFTSFRTE and by LBLDIS for a test set of idealised cloudy atmospheres. For the purposes of verification, the LBLDIS results (obtained in the manner described in Section 5.1) are denoted "TRUTH" and the equivalent GIFTSFRTE results are denoted "FAST".

The atmospheres are idealized in the sense that for TRUTH, cloud droplets are confined to a single AIRS layer and are described by a mono-modal size distribution of variable mode radius but fixed width parameter. For FAST, the cloud layer is defined at the pressure level at the top of the TRUTH layer.

Comparisons are made for liquid and ice clouds, each for four effective diameters, six optical depths and three altitudes. In each case the clear atmosphere profile, to which cloud properties are added, is the US 1976 standard atmosphere.

When the effective diameter of liquid or ice particles is stipulated, rather than computed from a profile of condensate effective sizes and abundances, the size can be entered in the GIFTSFRTE input parameter file. An example input file for GIFTSFRTE is given in Appendix C and for LBLDIS in Appendix D.

5.2.1 Liquid phase cloud

For liquid cloud, cloud top altitudes of approximately 1, 2, and 3 km (more precisely, 1.187, 2.176 and 3.199 km to coincide with AIRS pressure levels at 878.62, 777.79 and 683.67 hPa, respectively) were nominated. The effective diameters of liquid droplets, denoted D_l, chosen for comparison are 2, 10, 20 and 40 μm. Optical depths are 0.1, 0.5, 1, 2, 3, and 5, defined at 10 μm. The Mie extinction efficiencies for liquid droplets illuminated by 10 μm radiation are shown in Table 2.

LBLDIS permits the optical depth to be specified at 10 μm (or at other infrared wavelengths) for a given D_l but this information is provided to GIFTSFRTE through D_l and `xliqwp`. As a consequence, to provide GIFTSFRTE with cloudy profiles equivalent to the profile processed by LBLDIS, the liquid water path is computed as,

$$\texttt{xliqwp} = \frac{D_l\,\rho_l}{\langle Q_e \rangle} \times \delta_l \quad . \tag{9}$$

Internally, the visible wavelength optical depth $\delta_l(vis)$, which is one dimension of the four-dimensional cloud reflection and transmission look-up tables, is computed as,

D_l (μm)	$\langle Q_e \rangle$
2	0.14368
10	1.13316
20	2.30230
40	2.56237

Table 2: Mie extinction efficiencies $\langle Q_e \rangle$ for different effective diameters of liquid droplets. $\langle Q_e \rangle$ is the extinction efficiency as a wavelength of 10 μm; the angle brackets indicate that this is for an ensemble of particles with sizes distributed about the stipulated effective diameter D_l.

$$\delta_l(vis) = 2 \times \frac{\texttt{xliqwp}}{D_l\, \rho_l} \quad , \tag{10}$$

on the assumption that $\langle Q_e \rangle \approx 2$ at visible wavelengths for particles in the size range of interest.

The brightness temperature comparisons, FAST less TRUTH, in terms of RMS error and average deviation, are shown in Fig. 24 (LW band) and Fig. 25 (SMW band). Significant discrepencies are still present, and these are at their greatest for droplets with $D_l = 2\ \mu$m in the vicinity of unit optical depth. At each of the altitudes, 1, 2, and 3 km, there is a temperature differential of approximately 1.5 K across the layer that, in TRUTH simulations, represents the cloud layer (but which in FAST simulations is not present since reflection and transmission properties are assigned to an infinitesimally thin layer).

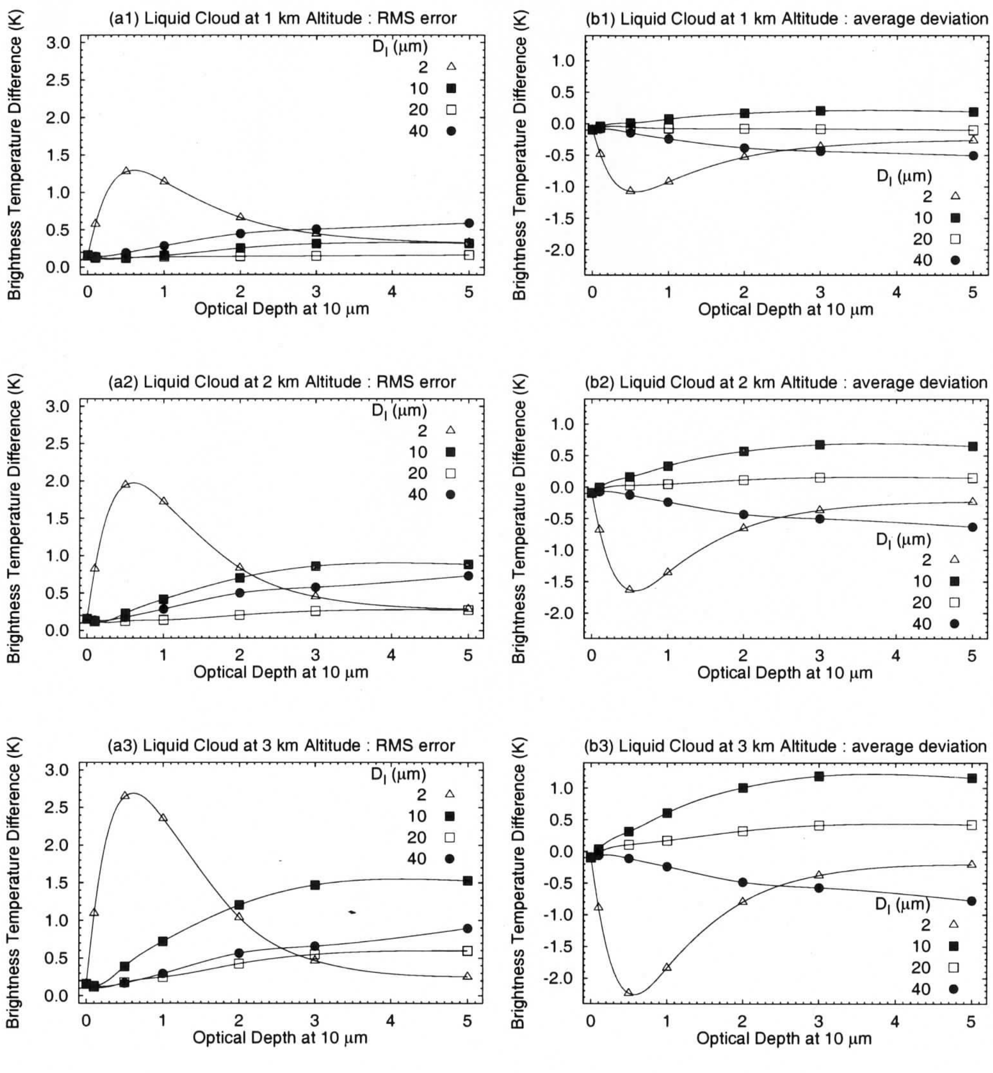

Figure 24: RMS and average deviations (FAST minus TRUTH) for liquid clouds (GIFTS LW).

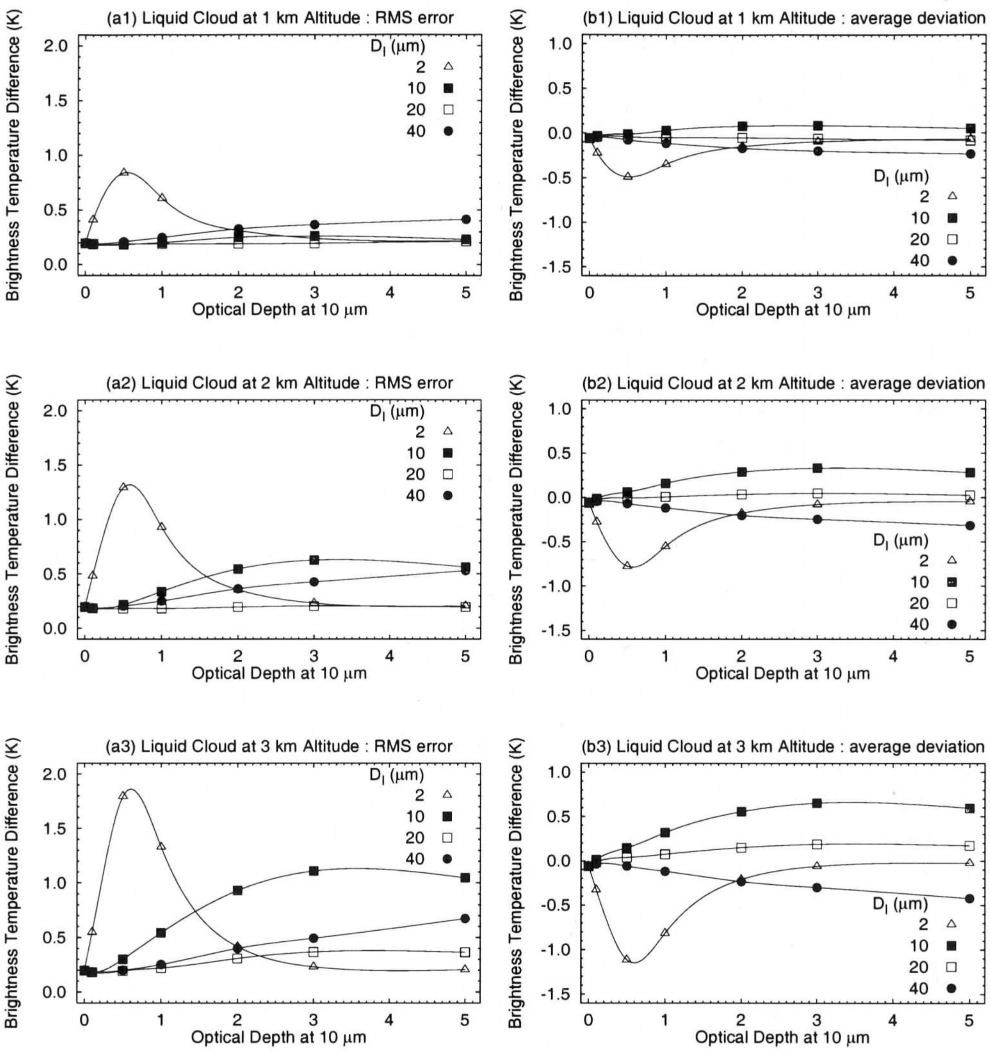

Figure 25: RMS and average deviations (FAST minus TRUTH) for liquid clouds (GIFTS SMW).

D_i (μm)	$\langle Q_e \rangle$
10	1.06671
20	1.98813
40	2.17719
100	2.06158

Table 3: Extinction efficiencies $\langle Q_e \rangle$ for different effective diameters of hexagonal ice crystals.

5.2.2 Ice phase cloud

Following the procedure for liquid phase cloud, detailed in Section 5.2.1, ice phase cloud top altitudes of approximately 5, 10, and 15 km were nominated (more precisely, 5.073, 10.125 and 15.177 km to coincide with AIRS pressure levels at 535.156, 259.893 and 117.766 hPa, respectively). The effective diameters of liquid droplets chosen for comparison are 10, 20, 40 and 100 μm. Optical depths are 0.1, 0.5, 1, 2, 3, and 5, defined at 10 μm. The extinction efficiencies for hexagonal ice crystals illuminated by 10 μm radiation are shown in Table 3.

LBLDIS permits the optical depth to be specified at 10 μm (or at other infrared wavelengths) for a given D_i but this information is provided to GIFTSFRTE through D_i and `xliqwp`. As a consequence, to provide GIFTSFRTE with cloudy profiles equivalent to the profile processed by LBLDIS, the ice water path `xicewp` is computed as,

$$\texttt{xicewp} = \frac{2}{3} \frac{D_i \, \rho_l}{\langle Q_e \rangle} \times \delta_i \quad . \tag{11}$$

The factor $\frac{2}{3}$ arises out of consideration of the assymetry of the ice crystal habit [9].

Internally, the visible wavelength optical depth $\delta_i(vis)$ is computed as,

$$\delta_i(vis) = 3 \times \frac{\texttt{xicewp}}{D_i \, \rho_i} \quad , \tag{12}$$

on the assumption that $\langle Q_e \rangle \approx 2$ at visible wavelengths for particles in the size range of interest. `xicewp` is the ice water path in g/m^2, D_i is the ice particle effective diameter in μm and ρ_i is the density of ice in g/cm^3. We have used $\rho_i = 0.917$ g/cm^3.

The brightness temperature comparisons, FAST less TRUTH, in terms of RMS error and average deviation, are shown in Fig. 26 (LW band) and Fig. 27 (SMW band). Discrepencies are still present, which, like the liquid cloud case, are at their greatest for particles at the small end of the range, specifically $D_i = 10$ μm, and in the vicinity of two optical depths. At both 5 and 10 km altitudes, there is a temperature differential of approximately 2 K across the layer that, in TRUTH simulations, represents the cloud layer (but which in FAST simulations is, again, not present). However, at 15 km the US 1976 atmosphere is isothermal.

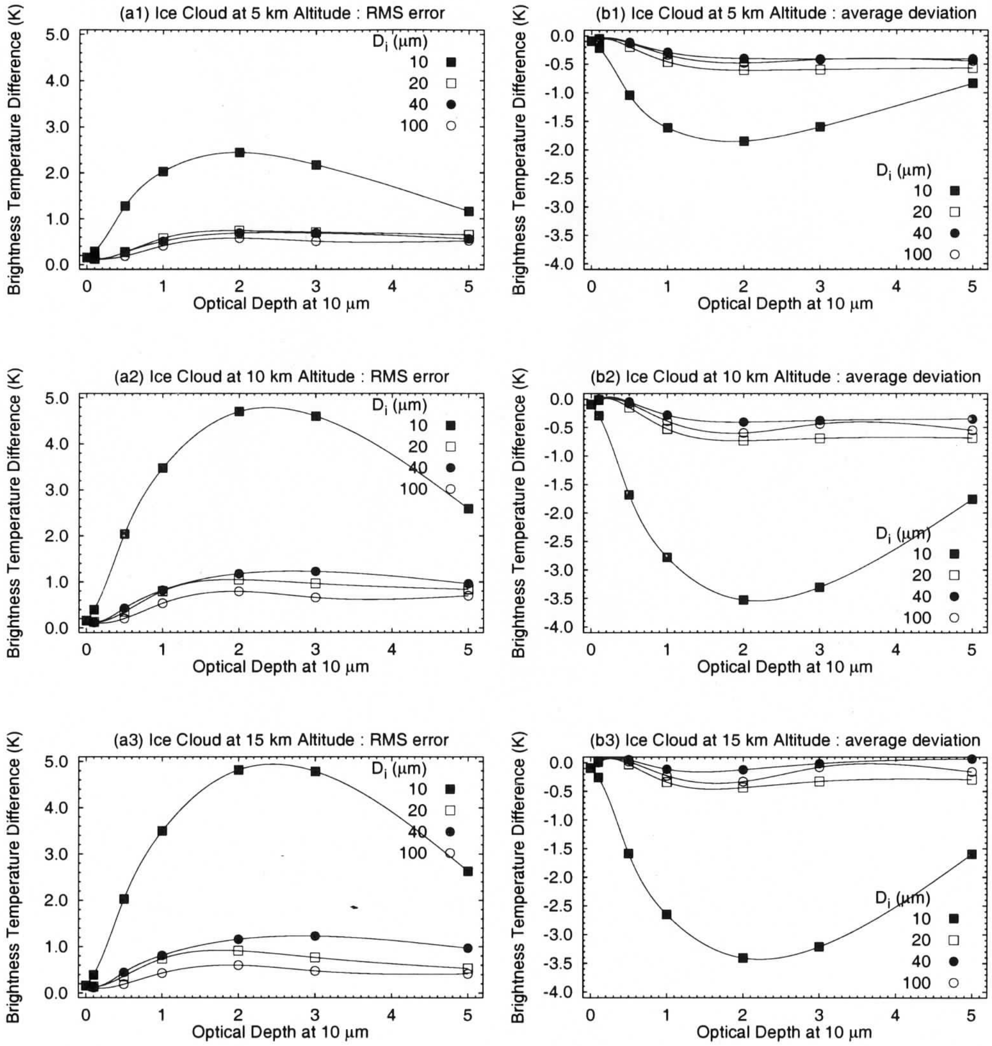

Figure 26: RMS and average deviations (FAST minus TRUTH) for ice clouds (GIFTS LW).

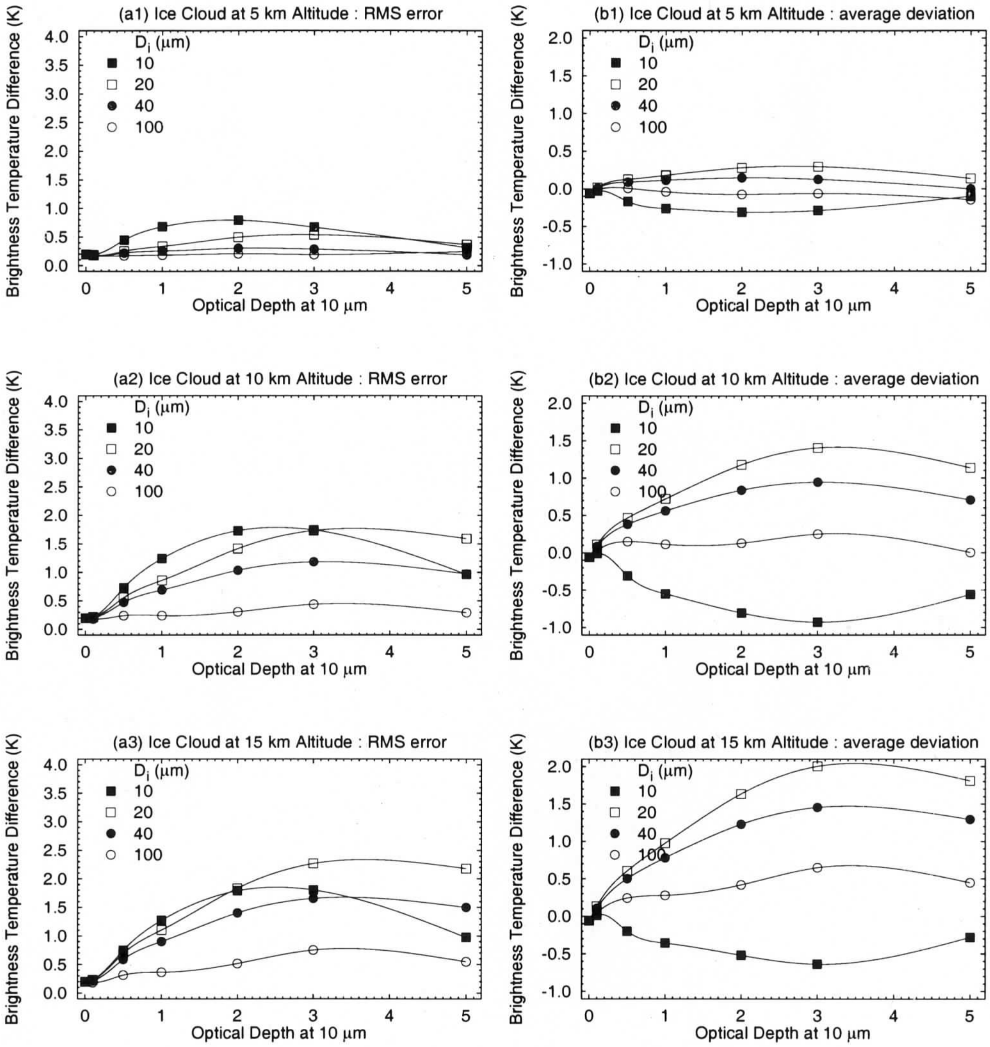

Figure 27: RMS and average deviations (FAST minus TRUTH) for ice clouds (GIFTS SMW).

6 CONCLUSION

A new liquid cloud and ice cloud model has been delivered to SSEC for use with the existing GIFTS fast radiative transfer model (GIFTSFRTE). The verification of this code against the more rigourously tested LBLRTM and DISORT shows that discrepencies on the scale of a few degrees Kelvin still exist which cannot be accounted for by the finite geometric thickness of the cloud layer in LBLRTM/DISORT.

There also remain some significiant issues with regard to forward modeling of cloudy GIFTS radiances in the presence of mixed phase and multi-level cloud. The cloud model, as delivered, does not seek to account for the impact of cloud below the highest cloud bank. A significant mass of water cloud in the lower troposphere beneath thin cirrus has a spectral emission quite different from thin cirrus alone, the latter being the case that, as presently configured, GIFTSFRTE would simulate.

We are confident, however, that relative changes in GIFTS brightness temperature spectra are more representative of cloud phase and effective diameter than the Old cloud model incorporated into previous versions of GIFTSFRTE.

Acknowledgements

Thanks to Dave Turner for access to, and advice on, LBLDIS. Thanks also to Brian Osborne for helpful comments on the presentation of this document.

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A TAPE5 FILE FOR LNFL

Below is the TAPE5 file used to generate a line file using LNFL. The first 7 molecular species in the HITRAN database are used, namely H_2O, CO_2, O_3, N_2O, CO, CH_4, and O_2.

```
aer_hitran_2000_updat_01; 0-10000cm-1;  7 mol; No strength rejection
     0.000 10000.000
1111111000000000000000000000000
```

B TAPE5 FILE FOR LBLRTM

Below is an example TAPE5 file for LBLRTM. In this example, radiances and transmittances are generated for a nadir view of the US1976 standard atmosphere. These values are stored in the binary output file named TAPE12. The surface emissivity is set to unity and the surface temperature is set to 288.2 K which is the boundary layer air temperature. To generate optical depth files, MG on line 4 is set to 1. Otherwise the input file can be left unchanged. The pressure levels stipulated are the AIRS atmospheric pressure levels that are used in the GIFTS forward model. The CO_2 mixing ratio is set to 380 ppmv and freons have not been included.

```
         1         2         3         4         5         6         7         8
123456789 123456789 123456789 123456789 123456789 123456789 123456789 123456789
$ Standard atmosphere TAPE5 created by jplot._writetape5
 HI=1 F4=1 CN=1 AE=0 EM=1 SC=0 FI=0 PL=0 TS=0 AM=1 MG=0 LA=0 OD=0 XS=0    00    00
   500.000  2500.000                                             0.0002     0.001
   288.200     1.000     0.000     0.000     0.000     0.000     0.000
    6    2   -99    1     1    7    1                                       380.000
 5.000E-05  1013.000   180.000
  1013.000   986.067   958.591   931.524   904.866   878.620   852.788   827.371
   802.371   777.790   753.628   729.886   706.565   683.667   661.192   639.140
   617.511   596.306   575.525   555.167   535.232   515.720   496.630   477.961
   459.712   441.882   424.470   407.474   390.893   374.724   358.966   343.618
   328.675   314.137   300.000   286.262   272.919   259.969   247.409   235.234
   223.441   212.028   200.989   190.320   180.018   170.078   160.496   151.266
   142.385   133.846   125.646   117.777   110.237   103.017    96.114    89.520
    83.231    77.240    71.540    66.125    60.990    56.126    51.528    47.188
    43.100    39.257    35.650    32.274    29.121    26.183    23.453    20.922
    18.585    16.432    14.456    12.649    11.004     9.512     8.165     6.957
     5.878     4.920     4.077     3.340     2.701     2.153     1.687     1.297
 9.750E-01 7.140E-01 5.060E-01 3.450E-01 2.240E-01 1.370E-01 7.700E-02 3.800E-02
 1.600E-02 5.000E-03 5.000E-05
-1.
%%%
```

C EXAMPLE INPUT FILE FOR GIFTSFRTE

Below is an example input file for GIFTSFRTE. In this example MM5 temperature, mositure and ozone profiles are in file `06122002_2200_2_3.bin`, condensate effective diameters and mixing ratios are in file `06122002_2200_2_3_diams.bin`. The regression coefficients for clear sky are in files located on the path

/home/jimd/PROJECT/GIFTS/DOC/VERIFY/experiment_v6.01/FAST/

as are, in this case, the cloud optical properties file `clouds.dat`. Output files are to be prefixed by `liq_`. Records 594 to 599 are to be processed for both channels (1 is LW, 2 is SMW). Effective diameters for liquid and ice phase particles are given flag values (2000,2000 which are flag values if above 1000 (μm)) which means that the effective particle sizes will be computed from the condensate profiles as indicated in Sections 4.3.1 and 4.3.2. The final line, (0,5) sets the verbosity to zero (minimal output to STDOUT) and instructs GIFTSFRTE to generate only wavenumber files and brightness temperature files — the final number is a bitmask to indicate output required; bit 0 for wavenumbers, bit 1 for radiances, bit 2 for brightness temperatures and bit 3 for column transmittances.

```
06122002_2200_2_3.bin
06122002_2200_2_3_diams.bin
/home/jimd/PROJECT/GIFTS/DOC/VERIFY/experiment_v6.01/FAST/
/home/jimd/PROJECT/GIFTS/DOC/VERIFY/experiment_v6.01/FAST/
liq_
594,599
1,2
2000,2000
0,5
```

D EXAMPLE INPUT FILE FOR LBLDIS

Below is an example input file for LBLDIS. In this example, radiances generated for a nadir view over the spectral range 550.0 to 2400.0 wavenumbers at 0.01 stepsize. Radiances for six optical depths are computed, for a single layer cloud whose top is at 10.1249 km. The effective particle *radius* [4] is 50 μm at 1000 cm^{-1} (i.e. 10 μm). The gaseous optical depth files from LBLRTM are located in directory /abyss/Users/jimd/water_cloud_experiment_v6.01/iatm6_1013_to_103p018 and the single scattering property database files are listed with fully qualified path names. The surface skin temperature is 288.2 K and the surface emissivity is 1 at 100 cm^{-1} linearly interpolated to 1 at 3000 cm^{-1} (i.e. the emissivity is constant with value 1).

```
Header line
000.0
550.0 2400.0 0.01
6
1
2 10.1249 50.0 1000. 0.1 0.5 1.0 2.0 3.0 5.0
/abyss/Users/jimd/water_cloud_experiment_v6.01/iatm6_1013_to_103p018
3
/home/jimd/LBLDIS/single_scat_properties/ssp_db.mie_wat.gamma_sigma_0p100
/home/jimd/LBLDIS/single_scat_properties/ssp_db.mie_ice.gamma_sigma_0p100
/home/jimd/LBLDIS/single_scat_properties/ssp_db.hex_ice.gamma.0p100
288.2
2
100 1
3000 1
```

[4]Some care is required since LBLDIS specifies particle single scattering properties by their phase, crystal habit (if appropriate) and effective *radius* whereas GIFTSFRTE specifies on phase and effective *diameter*.