P2.26 Fast Model Cloudy Radiances for Infrared Hyperspectral Observations

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1. INTRODUCTION

The accurate and rapid computation of the infrared emission of the Earth's atmosphere at high spectral resolution is important to the development of algorithms for retrieving geophysical quantities from hyperspectral satellite observations. Variations in the microphysical properties of clouds, in terms of the phase, size distribution, number density, and vertical distribution, make the inclusion of clouds less than straightforward.

Yang (2002) parameterized cloud optical properties into transmittance and reflectance functions with the aid of the well respected multiple scattering code DISORT (Stamnes et al., 1988). Computations were performed for both ice and liquid clouds for a range of effective droplet diameters, cloud optical depths and observation zenith angles at 201 wavenumbers covering the spectral range from 500 to 2500 wavenumbers. Coupled with a clear sky fast model, the resulting parameterized cloud transmittance and reflectance functions enable the rapid simulation of hyperspectral observations of top-of-atmosphere radiance in the presence of clouds.

This code, presently known as GIFSTFRTE, was initially developed to simulate single-phase clouds of one layer. To assess the accuracy of the radiances simulated by the fast model, comparisons are made with simulations performed with LBLDIS (Turner, 2003), a computer code that combines DISORT with high spectral resolution optical depths generated by LBLRTM (Clough and Iacono, 1995).

We present the results of our comparisons between fast model simulations using GIFTSFRTE and those from the verification code LBLDIS. The fast model is presently being extended to simulate radiances from atmospheric profiles containing multi-layer and mixed phase clouds.

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2. FAST MODEL INPUTS

For GIFTS simulations, fast model input and output data are organized into data cubes. A data cube has dimensions 128 by 128 to correspond with the GIFTS sensor array, with a third dimension that contains atmospheric profile information (inputs) or spectral information (outputs). Figure 1 shows the surface heights for a GIFTS data cube centered at approximately 34.51° N, 86.82° W. Rows and columns are defined to be on the interval [-64:64] with row 0 and column 0 unassigned. Each pixel is 4 km square.

Atmospheric profile data are represented as 312 floating-point values in a binary record; 16384 such records constitute a GIFTS atmospheric profile data cube. The first 303 values per record are ordered as 101 temperatures (K), 101 water vapor 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 the source file giftsfrte_main.f.

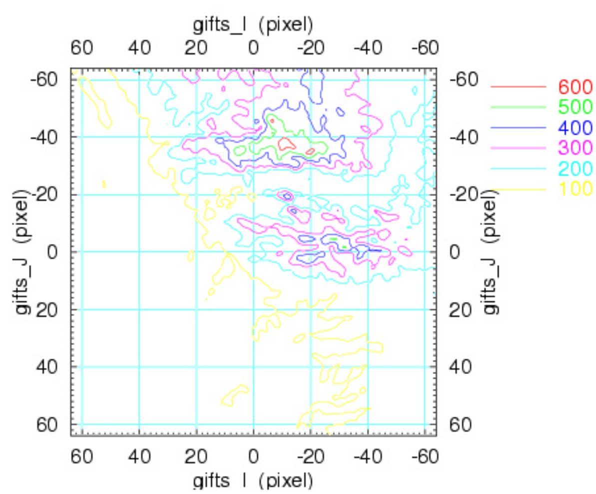

Fig. 1: Surface height contour plot for an arbitrary GIFTS data cube. Rows and columns are defined to be on the interval [-64:64] with row 0 and column 0 unassigned.

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 of liquid condensate (hPa), pressure level of ice condensate (hPa) and, finally, surface pressure (hPa). Figure 2 shows an example atmospheric profile where both liquid water and ice cloud are present. The values of the nine non-profile data quantities are also listed.

The Yang (2002) cloud model accepts as input the effective diameter of cloud droplets, the cloud phase (liquid or ice), the visible optical thickness of the cloud and the pressure level at the cloud top. The fast model can accommodate a single cloud layer of either ice crystals or liquid water droplets. The mesoscale model MM5 (Grell at al., 1994) is able to deliver the concentrations and effective diameters of five condensate types (two liquid, three ice) at the 101 atmospheric levels defined in the fast model. The two liquid condensates are denoted “rain” and “liquid”, and the three ice condensates are denoted “ice”, “snow” and “graupel”. Figure 3 shows an example condensate mixing ratio profile generated by MM5 and Figure 4. is the effective condensate diameter profile at the same location.

The condensate profile data are pre-processed to provide an estimate of the model input parameters of cloud phase, effective diameter and optical depth. The effective diameter, D_l, of a mixture of “liquid” and “rain” is computed as,

$$D_l = \frac{M_{rain} + M_{liquid}}{M_{rain}/D_{rain} + M_{liquid}/D_{liquid}} \quad , \qquad (1)$$

where M and D are, respectively, the mixing ratios and effective diameters of each liquid condensate species.

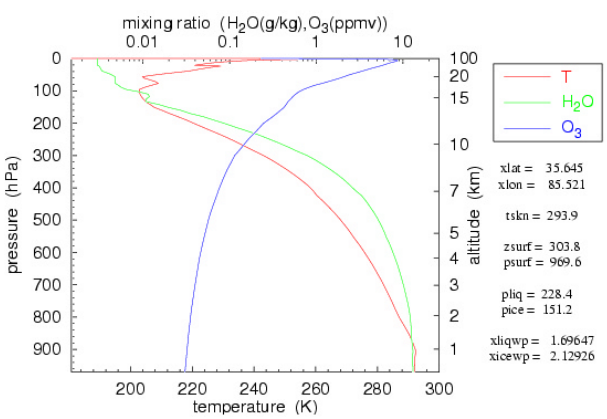

Fig. 2: Cloudy atmospheric profile. The liquid water path (xliqwp) is 1.696 g/cm^2 and the ice water path (xicewp) is 1.129 g/cm^2. The surface skin temperature is 293.9 (K) and liquid and ice cloud cloud-top pressures are 228.4 and 151.2 hPa respectively. Cloud-top pressures are the lowest pressures at which a mass-in-mass mixing ratio of 1 x 10^{-6} is observed.

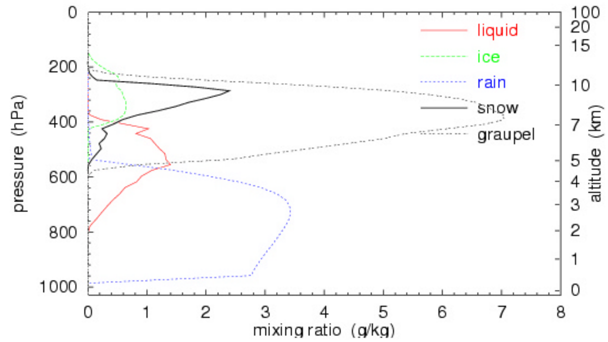

Fig. 3: Condensate mixing ratio profile generated by MM5. This example shows all five condensate types.

Similarly for a mixture of ice condensates, the effective diameter, D_i, is estimated as,

$$D_i = \frac{M_{ice} + M_{snow} + M_{graupel}}{M_{ice}/D_{ice} + M_{snow}/D_{snow} + M_{graupel}/D_{graupel}} \qquad (2)$$

The fast model can presently include only a single layer cloud of liquid water or ice, but not both. Consequently a selection rule must be applied in the presence of mixed phase cloud and multi-layer clouds. The selection rule invoked is that the cloud phase found at the highest altitude is the one included in 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. Figure 5 shows three spectra simulated by the fast model; for clear sky, for liquid cloud at 2 km altitude and for ice cloud at 10 km altitude.

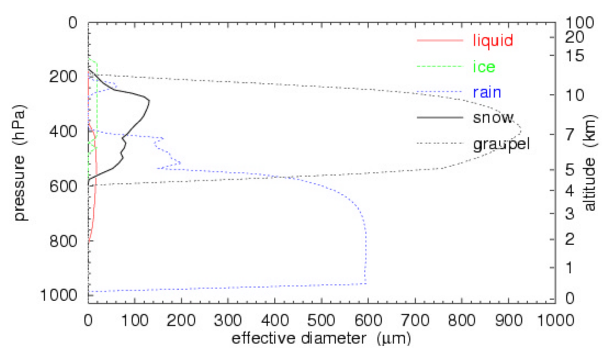

Fig. 4: Profile of effective diameters of condensates generated by the mesoscale model, MM5.

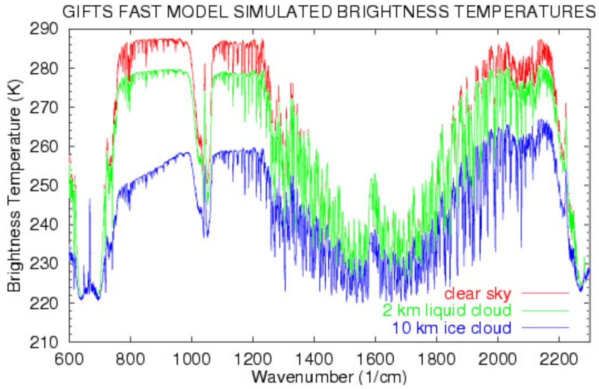

Fig. 5: Fast model simulated spectra at GIFTS spectral resolution for clear sky, liquid cloud at 2 km altitude and ice cloud at 10 km altitude. The ice cloud is comprised of hexagonal ice crystals and the liquid cloud consists of spherical water droplets. In both cases the effective particle size is 40 µm and the optical depth is 2.

3. FAST MODEL VERIFICATION

To verify the accuracy of the fast model we employ LBLRTM to generate layer gaseous optical depths which LBLDIS merges with cloud single scattering properties and then executes DISORT to generate simulated radiances at the top of the atmosphere (Davies et al., 2003). The high spectral resolution output (0.01 cm^{-1}) is spectrally reduced to GIFTS channel radiances and converted to brightness temperatures. For verification purposes, these brightness temperatures are considered "truth".

Fast model and "truth" brightness temperatures are computed for a test set of idealized cloudy atmospheres in which cloud droplets of either liquid or ice are confined to a single atmospheric layer and are described by a mono-modal size distribution of specified mode radius and fixed width parameter. For fast model simulations, the cloud layer is defined at the pressure level of the top of the "truth" layer.

For liquid phase cloud, cloud-top altitudes of approximately 1, 2, and 3 km (more precisely, 1.187, 2.176 and 3.199 km to coincide with "standard" pressure levels at 878.62, 777.79 and 683.67 hPa, respectively) were nominated. The effective diameters of liquid droplets, 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

Figure 6 shows the RMS difference between fast model and "truth" brightness temperatures for the case of liquid clouds with cloud-top altitudes of 1, 2 and 3 km. The RMS difference is computed for GIFTS channel brightness temperatures over the wavenumber range 587 to 2350 cm^{-1}. In general the RMS difference is less than 0.5 K, but for higher cloud and for the smallest diameter droplets tested (2 µm), the RMS error can be three times this.

For ice phase cloud, 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 "standard" 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.

Figure 7 shows the RMS difference between fast model and "truth" brightness temperatures for the case of ice clouds with cloud-top altitudes of 5, 10 and 15 km. Again, the RMS difference is computed for GIFTS channel brightness temperatures over the wavenumber range 587 to 2350 cm^{-1}.

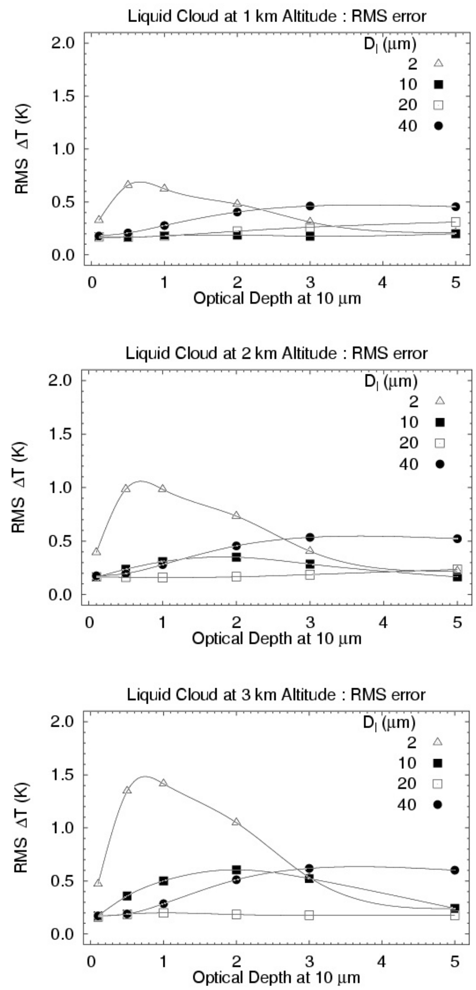

Fig 6: RMS difference between fast model and "truth" brightness temperatures for the case of liquid cloud. The RMS difference is computed for GIFTS channel brightness temperatures over the wavenumber range 587 to 2350 cm^{-1}. The upper panel is for a cloud-top altitude of 1 km, the middle panel 2 km and the lower panel 3 km.

Figure 7 shows that, in general the RMS difference is less than 1 K at 5 km, less than 2 K at 10 km and less than 3 K at 15 km. Performance is poorest for optically thick ice clouds comprised of crystals with effective diameter 20 μm.

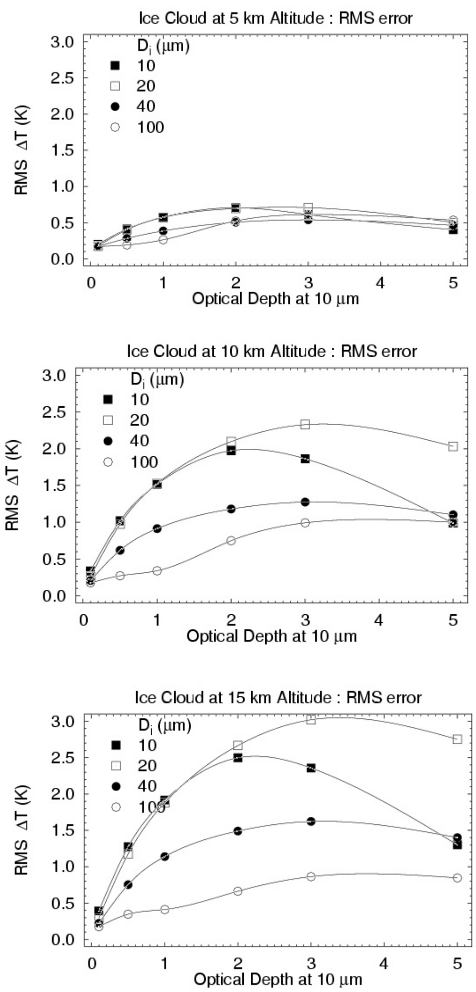

Fig 7: RMS difference between fast model and "truth" brightness temperatures for the case of ice cloud. The RMS difference is computed for GIFTS channel brightness temperatures over the wavenumber range 587 to 2350 cm^{-1}. The upper panel is for a cloud-top altitude of 5 km, the middle panel 10 km and the lower panel 15 km.

6. SUMMARY

A new liquid cloud and ice cloud model has been incorporated into the GIFTS fast radiative transfer model (GIFTSFRTE). The verification of this code against the more rigorously tested LBLRTM and DISORT shows that discrepancies on the scale of a few degrees Kelvin still exist.

There also remain some significant issues with regard to forward modeling high spectral resolution radiances in the presence of mixed phase and multi-level cloud. Our present focus is to improve our ability to model radiances from vertically thick but optically thin clouds.

ACKNOWLEDGEMENT

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REFERENCES

Clough, S. A., and M. J. Iacono, 1995: "Line-by-line calculations of atmospheric fluxes and cooling rates. 2: Applications to carbon dioxide, ozone, methane, nitrous oxide and the halocarbons." *J. Geophys. Res.*, 100, 16519–16535.

Davies, J. E., E. R. Olson, and D. J. Posselt, 2003: "Cloud model upgrade to the GIFTS Fast Radiative Transfer Model". University of Wisconsin-Madison, Space Science and Engineering Center. 43p. *UW SSEC Publication No.03.09.D1*.

Grell, G. A., J. Dudhia and D. R. Stauffer, 1994: "A description of the fifth-generation Penn State/NCAR mesoscale model (MM5)", *NCAR Tech. Note TN-398+STR*,117 pp.

Stamnes, K., S-C., Tsay, W. Wiscombe, and K. Jayaweera, 1988: "Numerically stable algorithm for discrete--ordinate—method radiative transfer in multiple scattering and emitting layered media". *Applied Optics*, 27 (12), 2502–2509.

Turner, D., 2003: "Microphysical properties of single and mixed-phase Arctic clouds derived from ground-based AERI observations". *Ph.D. thesis*. University of Wisconsin - Madison, Madison, Wisconsin.

Yang, P., 2002: "A fast radiative transfer code for cirrus clouds and water clouds", Department of Atmospheric Sciences, Texas A\&M University, College Station, Texas 77843.