# **P1-38** PARAMETERIZATION OF CLOUD-TOP BRIGHTNESS TEMPERATURES AT SOLAR-IR AND IR WAVELENGTHS FOR LOW CLOUDS AND FOG

Robert F. Arduini*
Science Applications International Corporation
Hampton, VA

P. Minnis and D. F. Young
NASA Langley Research Center
Hampton, VA

## 1. INTRODUCTION

A recent paper by Minnis et al. (1998) describes a parameterization technique to obtain reflectance and effective emittance for satellite remote sensing of cloud properties. The emittance parameterization is limited to situations where the temperature contrast between the surface and the cloud top is greater than 4K due to the logarithmic dependence of the emittance on the temperature difference between the surface and the cloud. This dependence prohibits its use in commonly occurring situations where the cloud and surface are at nearly the same temperature or when the cloud is warmer than the surface. This work describes a new parameterization to account for these situations at night-time, explicitly. Rather than modeling the effective emittance at the solar-infrared and infrared wavelengths, we parameterize the brightness temperatures at the cloud-top.

## 2. RADIATIVE TRANSFER CALCULATIONS

An adding-doubling radiative transfer code was used to simulate cloud-top brightness temperatures at night for clouds comprised of water droplets and ice crystals. The calculations were done at wavelengths of 3.75, 10.8, and 11.9 µm to correspond with the central wavelengths of the Advanced Very High Resolution Radiometer (AVHRR) channels 3, 4, and 5. The brightness temperatures were calculated for clouds above a non-reflecting surface at temperatures ranging from 240 to 300K. The cloud − surface temperature difference, ΔT, had values of –3, 0, 3, 10, 20, 30, and 40 K which covers cases of near isothermal temperature distribution, to extreme inversions which are common, especially in polar regions. The optical depths of the clouds were scaled to correspond to a visible wavelength of 0.65 µm and had values of 0.25, 0.5, 1, 2, 4, 8, 16, and 32.

Water-droplet clouds were represented by using modified Gamma distributions of spherical droplets having effective radii of $r_e$=4, 8, and 16 µm and an effective variance of 0.1 (Hansen and Travis, 1974) The optical properties of the water droplets were determined using the Mie scattering program of Wiscombe (1980). The ice-crystal clouds were made up of distributions of hexagonal ice crystals whose optical properties were based on the ray-tracing results of Takano and Liou (1989) and the spheroidal approximations of Takano et al. (1992). These distributions were representative of contrail, cirrostratus, and cirrus uncinus clouds having effective diameters of ($D_e$) 18.2, 41.2, and 123.1 µm, respectively, to span a range of typically encountered cirrus clouds (for details, see Minnis et al. 1998).

## 3. REGRESSION ANALYSIS

An approach similar to that used by Minnis, et al. (1998) was used to analyze the model calculations to determine a parameterization which would describe the variability of the apparent cloud top brightness temperature for a wide range of droplet sizes and ice crystal distributions. The modeled data were assembled according to cloud particle size and spectral channel. Since the zenith angles seen from satellites rarely exceeds 75°, the data used in the analysis was limited to viewing zenith angles less than 78° or $\mu > 0.2$, where µ is the cosine of the viewing zenith angle. The data were further subdivided according to the visible optical depth. Regression analyses were used to determine that the variability of the equivalent blackbody temperature at cloud top could be described using µ, the temperature of the cloud, $T_{cloud}$, and the temperature contrast between the cloud and surface, $\Delta T = T_{cloud} - T_{surf}$. It was found that the following simple regression produced a consistently accurate reproduction of the modeled data

$$T_{param} = \sum_{i=1}^{9} a_i x_i$$

where the nine independent variables were made up combinations of powers of μ, $T_{cloud}$, and ΔT:

$$x_1 = \mu$$
$$x_2 = \Delta T$$
$$x_3 = T_{cloud}$$
$$x_4 = \mu^2$$
$$x_5 = \mu \Delta T$$
$$x_6 = \mu T_{cloud}$$
$$x_7 = T_{cloud}{}^2$$
$$x_8 = \Delta T T_{cloud}$$
$$x_9 = \mu^2 \Delta T$$

The coefficients $a_i$ were determined using a standard linear least squares multiple regression technique. This set of variables was found to effectively describe the variation in the temperature with the root mean square of the residuals well within 0.5 K for all of the modeled data. A separate set of coefficients was determined for each of the 8 modeled values of optical depth.

Figures 1 and 2 show regression plots and the residuals for the 3.75 μm channel for a 4-μm water droplet cloud at the extremes of the optical depth cases. Four surface temperatures are shown with ΔT ranging from –3 to 40K. The largest residuals, which occur at the largest viewing zenith angles, are smaller than 1.5K. The root mean square of the residuals for these optical depths are 0.28 and 0.38 K for $\tau_{vis}$ = 0.25 and 32 respectively. Table 1 shows the residuals for both the water-droplet and ice-crystal clouds for all three channels. The residuals are consistently below 0.5K and for the larger particles and longer wavelengths where scattering plays less of a role the residuals are below 0.2K.

To apply the parameterization to optical depths other than the node points where the parameterization was developed, an interpolation scheme for the coefficients is required. A spline interpolation based on the method of Akima (deBoor, 1978) was selected. Figures 3 and 4 show the variation of cloud-top temperature with the cosine of the viewing zenith at a rather thick optical depth of 12.8. These results are for a surface temperature of 275K. Four values of ΔT are shown. The difference between the parameterization and the modeled brightness temperature is, again, below 0.5K for all angles and temperature inversions. Similar results are seen for other optical depths and for the larger water droplets and ice crystals.

## 4. CONCLUSIONS

The night-time brightness temperature at the top of a cloud whose temperature is nearly the same as the temperature of the surface, or warmer, may be parameterized using a simple polynomial function of the cosine of the viewing zenith angle, the temperature of the cloud, and the temperature difference between the cloud and the surface. This parameterization has been developed for solar infrared and infrared wavelengths corresponding to the AVHRR channels 3, 4, and 5.

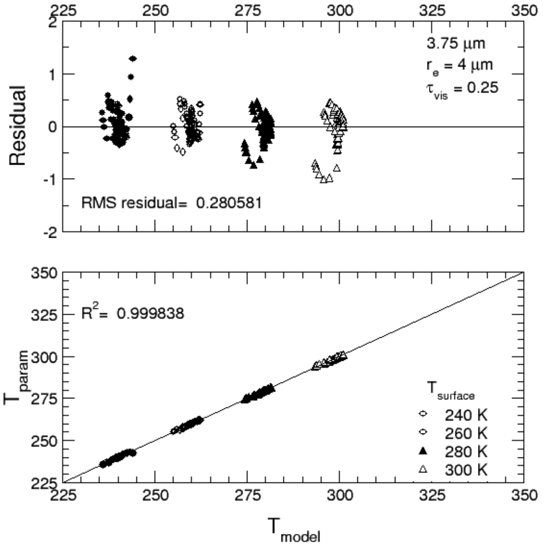

**Figure 1.** Regression analysis for Channel 3, $r_e$=4 μm, $\tau_{vis}$=0.25 comparing the modeled top-of-cloud temperature vs the parameterized temperature. Upper panel shows residuals.

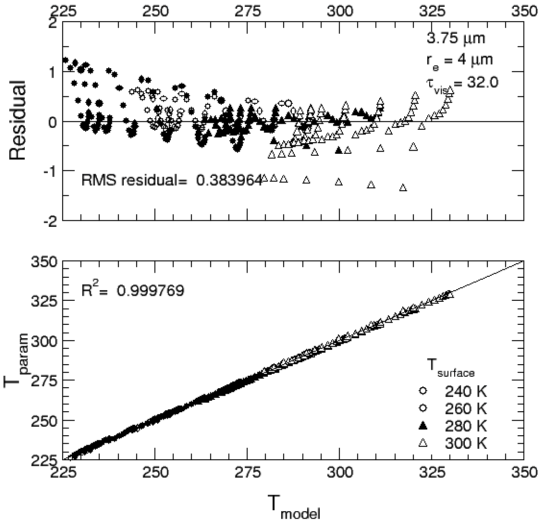

**Figure 2.** Same as Figure 1 except $\tau_{vis}$=32.

| Chan-nel | $\tau_{vis}$ | 4µm | 16µm | CON | CU |
|---|---|---|---|---|---|
| **3.75 µm** | 0.25 | 0.2806 | 0.2349 | 0.2339 | 0.2201 |
| | 0.50 | 0.3246 | 0.2064 | 0.1714 | 0.2041 |
| | 1.0 | 0.3252 | 0.1874 | 0.2134 | 0.2668 |
| | 2.0 | 0.3300 | 0.2542 | 0.2530 | 0.2483 |
| | 4.0 | 0.3552 | 0.2099 | 0.1706 | 0.1107 |
| | 8.0 | 0.3714 | 0.1461 | 0.1245 | 0.0228 |
| | 16 | 0.3817 | 0.1478 | 0.1273 | 0.0207 |
| | 32 | 0.3840 | 0.1489 | 0.0622 | 0.0101 |
| **10.8 µm** | 0.25 | 0.1388 | 0.1944 | 0.2070 | 0.2214 |
| | 0.5 | 0.1711 | 0.1444 | 0.1698 | 0.1752 |
| | 1.0 | 0.1317 | 0.2300 | 0.0860 | 0.0845 |
| | 2.0 | 0.1610 | 0.2690 | 0.1706 | 0.1504 |
| | 4.0 | 0.2124 | 0.1746 | 0.0892 | 0.0609 |
| | 8.0 | 0.1378 | 0.1661 | 0.0501 | 0.0267 |
| | 16 | 0.1299 | 0.1705 | 0.0560 | 0.0315 |
| | 32 | 0.1340 | 0.1702 | 0.0267 | 0.0150 |
| **11.9 µm** | 0.25 | 0.1711 | 0.1966 | 0.1765 | 0.2104 |
| | 0.5 | 0.1747 | 0.1333 | 0.1017 | 0.1571 |
| | 1.0 | 0.0883 | 0.1990 | 0.1819 | 0.0954 |
| | 2.0 | 0.1677 | 0.2370 | 0.1788 | 0.1703 |
| | 4.0 | 0.1399 | 0.1433 | 0.1034 | 0.0773 |
| | 8.0 | 0.0860 | 0.1375 | 0.1061 | 0.0545 |
| | 16 | 0.0916 | 0.1415 | 0.1083 | 0.0598 |
| | 32 | 0.0926 | 0.1414 | 0.0515 | 0.0283 |

**Table 1. Root mean square of residuals of cloud-top brightness temperature for water droplet and ice crystal clouds at AVHRR channels 3, 4, and 5 wavelengths.**

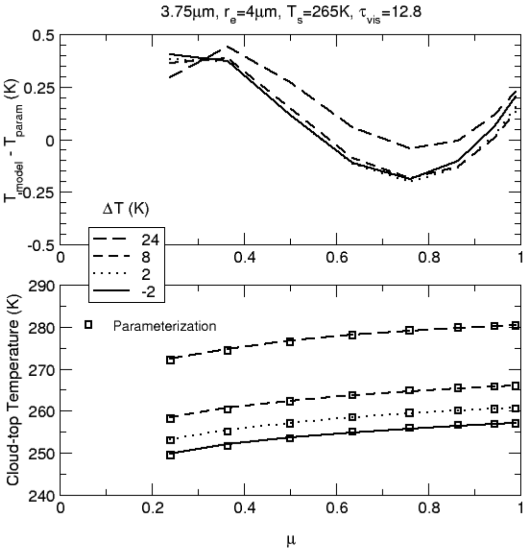

**Figure 3.** Comparison of 3.75-µm channel parameterization for $r_e$=4 µm cloud with model. Symbols represent the parameterized cloud-top temperature for four different inversion temperatures, while the lines depict the adding-doubling results. The upper panel shows the difference between the two.

It is very simple and can easily be applied to actual satellite data by accounting for the absorption of the intervening atmosphere. This parameterization is intended to extend the capabilities of existing cloud property retrieval methods by providing the means to analyze low-lying clouds and fog. These types of temperature inversion situations are especially important in polar regions.

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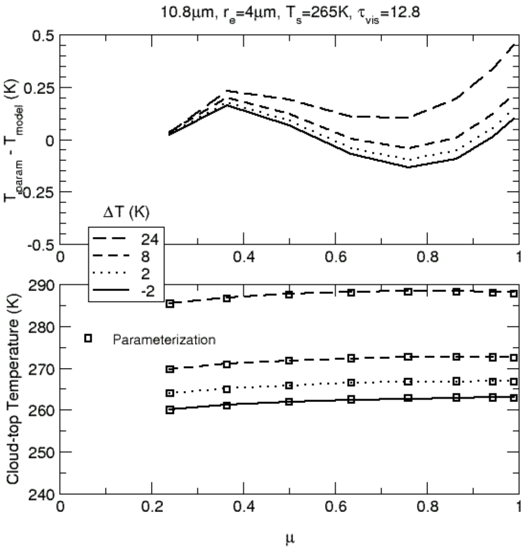

**Figure 4.** Same as Figure 3, except for 10.8-μm channel.

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