Using a new Radiative Transfer Model to estimate the Effect of Cirrus Clouds on AMSU-B Radiances.

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1 Introduction

The mm channels on AMSU-B provide global data on the distribution of humidity in the upper troposphere which is currently one of the largest uncertainties in climate models. Our goal is eventually to improve the utilization of these data by better quantifying the cirrus cloud impact. The radiative transfer (RT) model development is the first essential step towards this goal.

2 Model Description

The general radiative transfer equation for an atmosphere taking into account extinction, emission, and scattering is [3]

$$d\,\mathbf{I}(\mathbf{n}) \;/\; d\,s = -\mathbf{K}(\mathbf{n})\,\mathbf{I}(\mathbf{n}) + \mathbf{a}(\mathbf{n})\,B(T) + \int_{4\pi} d\,\mathbf{n}'\,\mathbf{Y}(\mathbf{n},\mathbf{n}')\,\mathbf{I}(\mathbf{n}') \qquad (1)$$

- $\mathbf{I}(\mathbf{n})$: the four component specific intensity vector of multiply scattered radiation propagating in the direction $\mathbf{n}$.
- $d\,s$: the pathlength element measured in the direction of $\mathbf{n}$.
- $\mathbf{K}(\mathbf{n})$: the 4x4 extinction coefficient matrix which includes the extinction due to gas and particles.
- $\mathbf{a}(\mathbf{n})$: the absorption coefficient vector which includes the absorption due to gas and particles.
- $B(T)$: the Planck function at temperature T.
- $\mathbf{Y}(\mathbf{n},\mathbf{n}')$: the scattering efficiency matrix.

In this study eq. (1) is solved iteratively in a plane-parallel atmosphere for the scalar case, i.e., only for the first component of the specific intensity vector. The first guess radiation field for the iterative solution method can either be the clear sky radiation field or the Extinction and Thermal Source (ETS) field. By ETS field we mean the radiation field generated by the first two term of eq. (1). A detailed explanation of the model can be found in [5].

3 Simulation Setup

- **Observation Frequencies**: 89 GHz, 150 GHz, 176 Ghz, 180 GHz and 182 GHz.
- **Reference Atmosphere and Absorption Calculation**:
  - atmospheric scenario : tropical
  - species : water vapour, oxygen, and nitrogen. The gaseous absorption coefficients are calculated using the radiative transfer model ARTS [1].
  - surface emissivity : 0.65, surface temperature : 299 K
  - cosmic background temperature : 2.75 K.
- **Size and Shape of Ice particles**:
  - shape : spherical
  - size : modified gamma distribution with median mass diameter $D_{me} = 200\ \mu$m.

$$N(D) = aDexp[(-\alpha + 3.67)D/D_{me}]$$

Here α is taken to be 1 and D is varied from 20 μm to 2000 μm.

- **Single Scattering Properties**:
  - calculated using Mishchenko's T-matrix code for non-spherical particles in random orientation [4].
  - Figure 1 shows that the contribution of absorption to the extinction is very small compared to scattering.

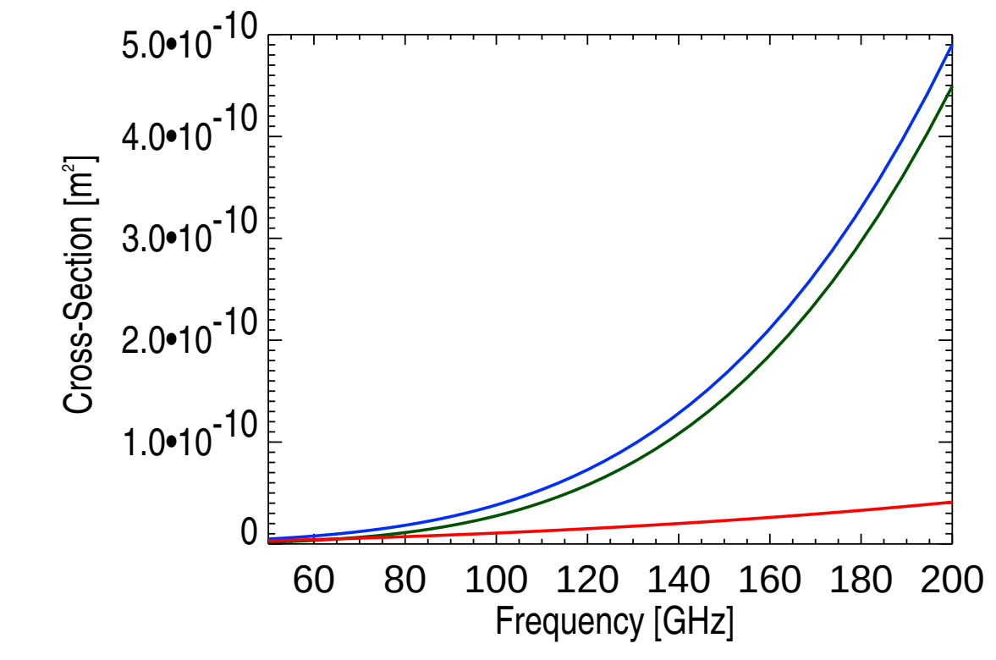

Figure 1: The extinction, scattering and absorption cross-section in the frequency range 50-200 Ghz. The blue curve is the extinction cross-section, the green curve is the scattering cross-section and the red curve is the absorption cross-section.

4 Convergence Test

The scattering convergence test is for determining the consistency of the radiative transfer calculations done here.The only factor which changes the field in this case is the scattering due to cloud particles. Figure 2 shows that after 10 iterations the field converges to the clear sky case.

- frequency : 182 GHz
- cosmic background temperature : 300 K
- surface emissivity : 0
- no gaseous absorption and particle absorption
- D_{me} : 200 μm, imc : 0.5 g/m^3, cloud height : 9 - 11 km

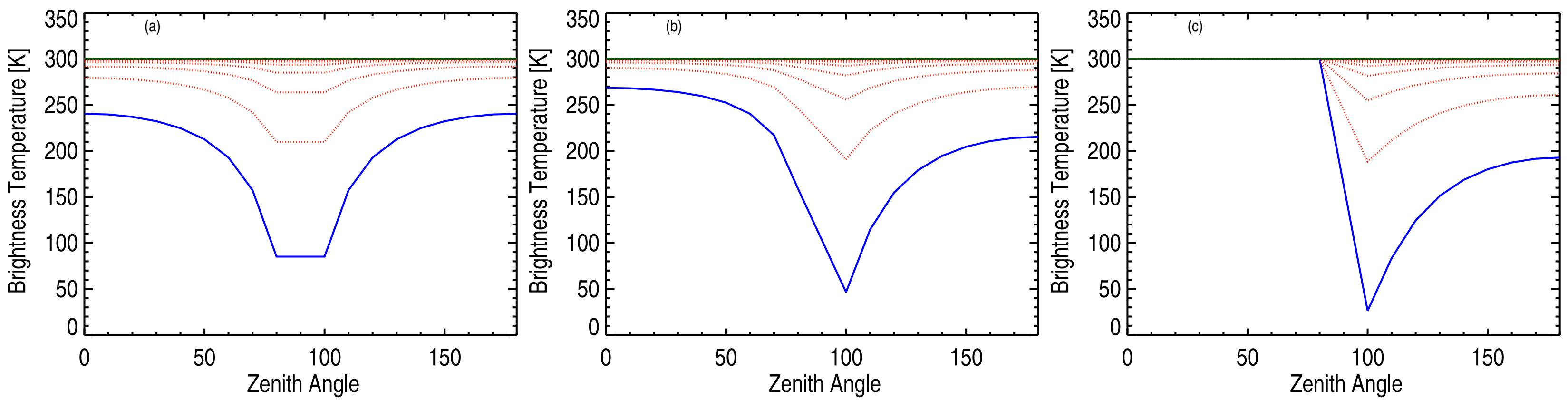

Figure 2: The convergence of the multiply scattered field to the clear sky field at (a) 6 km (b) 10 km and (c) 80 km. The green curve represents the clear sky field, the blue curve the ETS field and the red curves are the first 9 multiply scattered fields. Each plot shows the intensity as a function of propagation direction where 180^0 means nadir. The altitudes are below, inside and above the cloud respectively.

5 Realistic Cloud Case

Here all conditions (frequency, imc, size and shape, and cloud height) remain the same as in the previous case except

- cosmic background temperature : 2.735 K
- surface emissivity : 0.65
- included gaseous absorption and particle absorption.

From Figure 3 it can be seen that the clear sky field remains almost constant for the downlooking angles at all altitudes. In the up-looking case at 6 km emission from the top is seen whereas at 25 km only cosmic background is seen. The scattered field converges after about 7 iterations. For downlooking angles viewing from above the cloud (25 km), scattering decreases the brightness temperature compared to the clear sky case. The kink at 90^0 is due to the plane parallel model geometry. Of particular interest is the field inside the cloud at 10 km where we see how scattering actually does an angular redistribution of radiative energy by comparing the scattered field with the clear sky field. Overall, the effect of such a cloud with total ice water path = 1250 g/m^2 on upwelling radiances is small.

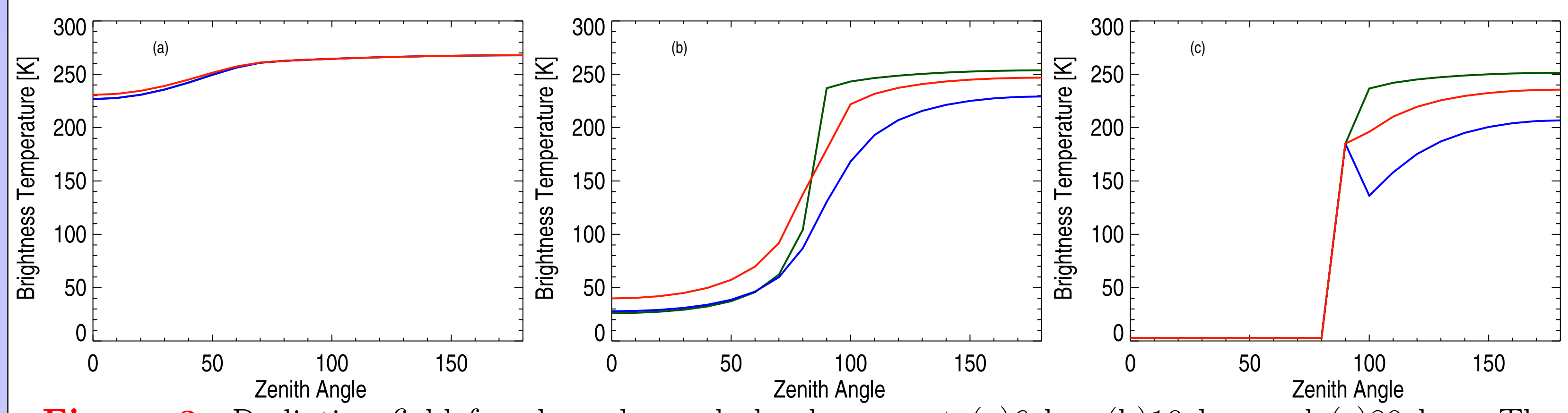

Figure 3: Radiation field for clear sky and cloudy case at (a)6 km (b)10 km and (c)80 km. The green curve represents the clear sky field, the blue curve the ETS field and the red curve the multiply scattered field. See Figure 2 for more details.

6 Effect of IMC on AMSU-B Channels

The brightness temperature difference of channels 19 and 20 to channel 18 of AMSU-B can be used to detect and screen out strong convective systems before doing water vapor retrieval [2]. The model presented here confirms this effect when the IMC exceeds about 1500 g/m^2 (Figure 4). The figure shows nicely how the ice signature depends on the cloud altitude (so called water vapour screening effect).

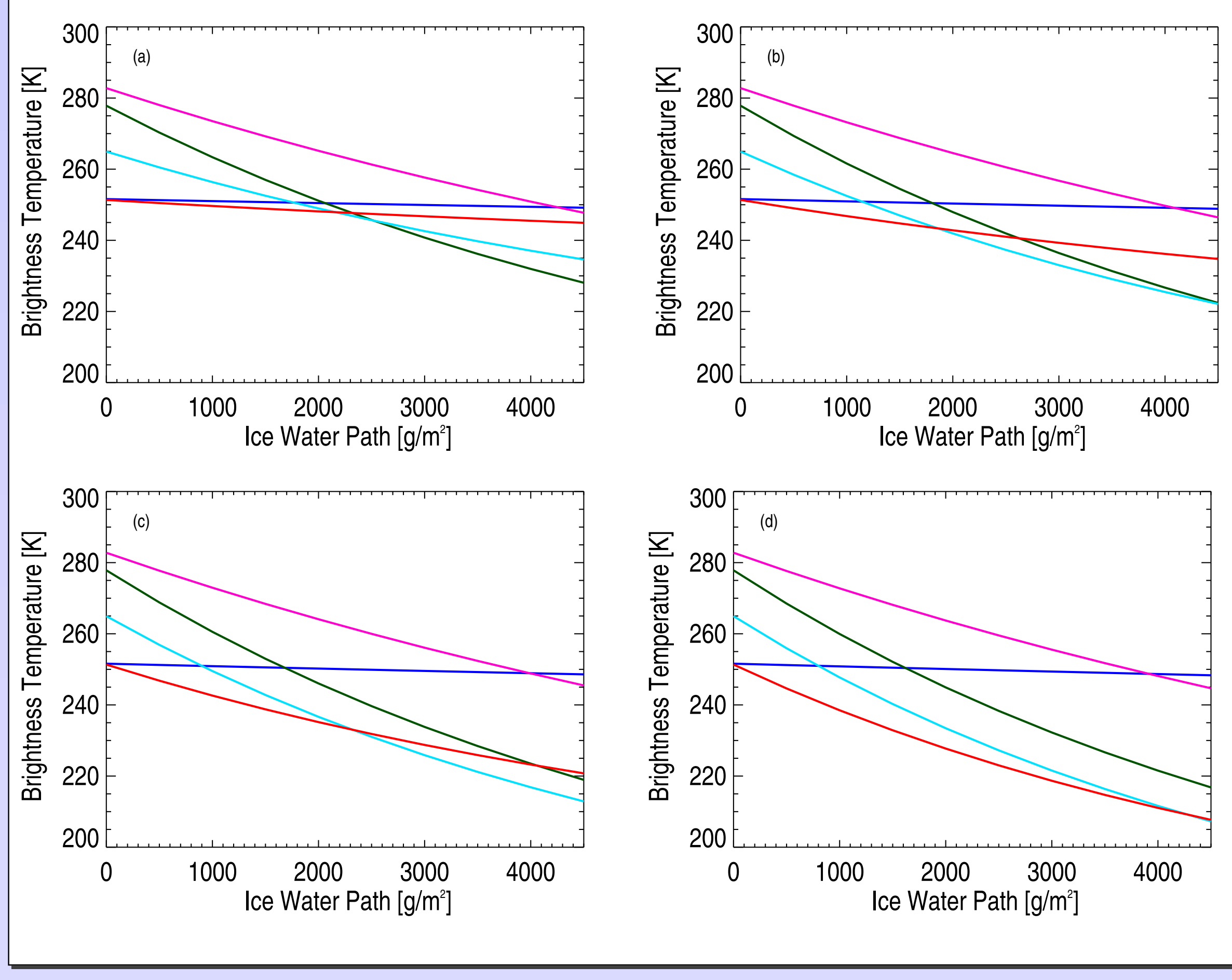

Figure 4: Effect of IMC on AMSU-B brightness temperature at cloud heights (a) 6 - 8 km (b) 7 - 9 km(c) 8 - 10 km and (d) 9-11 km. The frequencies are represented as: blue - 89 GHz, pink - 150 GHz, green - 176 GHz, light blue - 180 GHz and red - 182 GHz.

7 Conclusions and Future Work

- A one dimensional plane parallel radiative transfer model for the first Stokes component taking into account ice particle scattering has been developed for the mm/sub-mm wavelength range.
- The model will be extended to take into account the other components of the Stokes vector.
- The model passes a convergence test which shows that it is self-consistent.
- First simulations indicate that the model gives reasonable results for realistic cloud cases.

References

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