Cloud optical properties: modeling and sensitivity study

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Cloud optical properties: modeling and sensitivity study

- **Part 1: Fast radiative transfer code for radiative transfer under cloudy condition**

- **Part 2: Sensitivity of high-spectral-resolution-infrared radiance to cirrus properties**

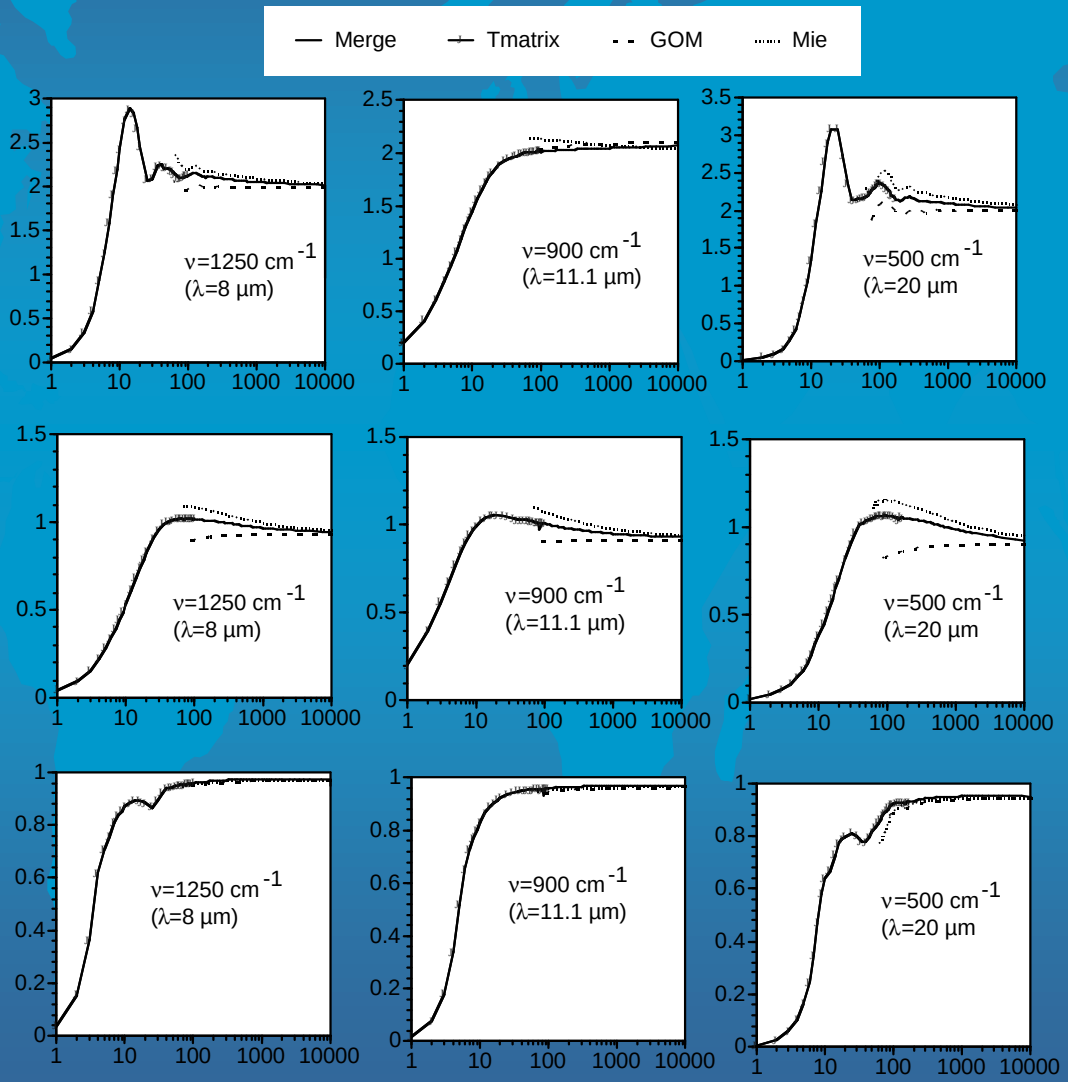
Part 1: Fast radiative transfer code under cloudy condition

- Calculations of the single-scattering properties (extinction efficiency, absorption efficiency and asymmetry factor) of ice and water cloud particles
- Bulk optical properties of ice and water clouds, and parameterization
- Radiative transfer model under cloudy condition

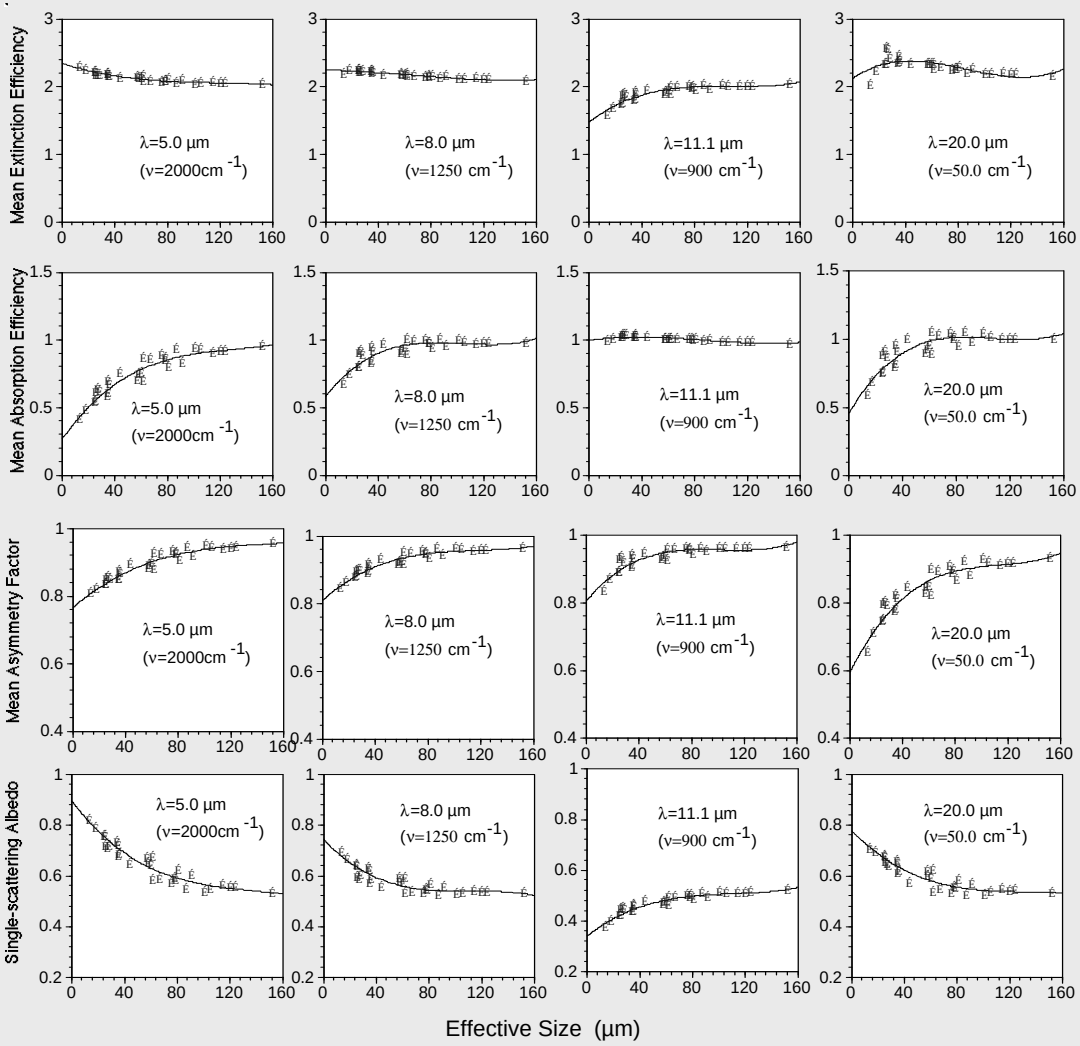
Continued

- Database of albedo and tansmissivity function for water and cirrus clouds and fast search code
- Merge the fast model for clouds with clear sky model
- Results

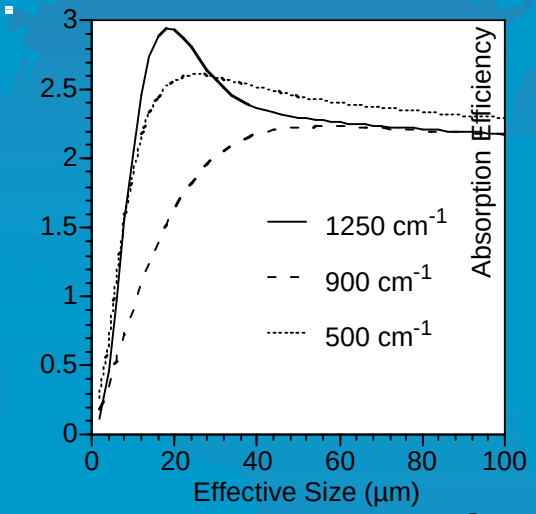
A composite method for the calculation of the single-scattering properties of ice crystals

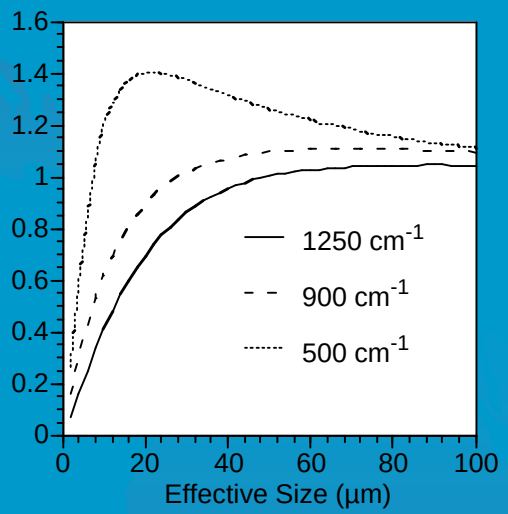


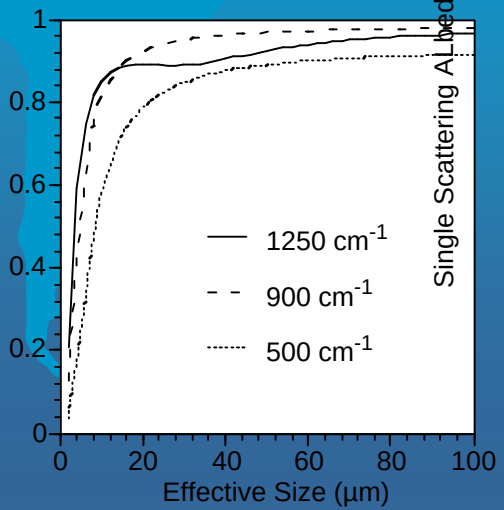
Bulk optical properties of cirrus clouds and parameterization

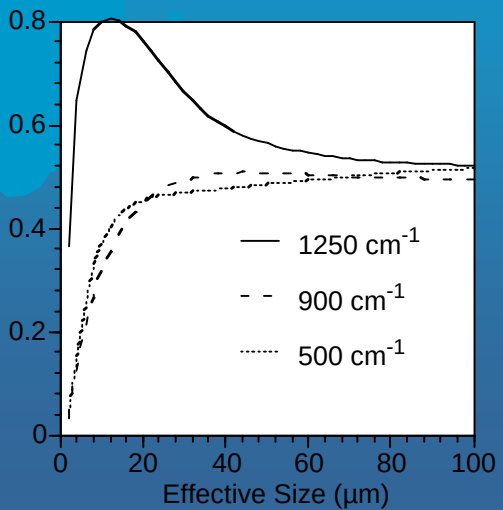


The mean extinction efficiency, absorption efficiency, asymmetry factor, and single-scattering albedo for water clouds



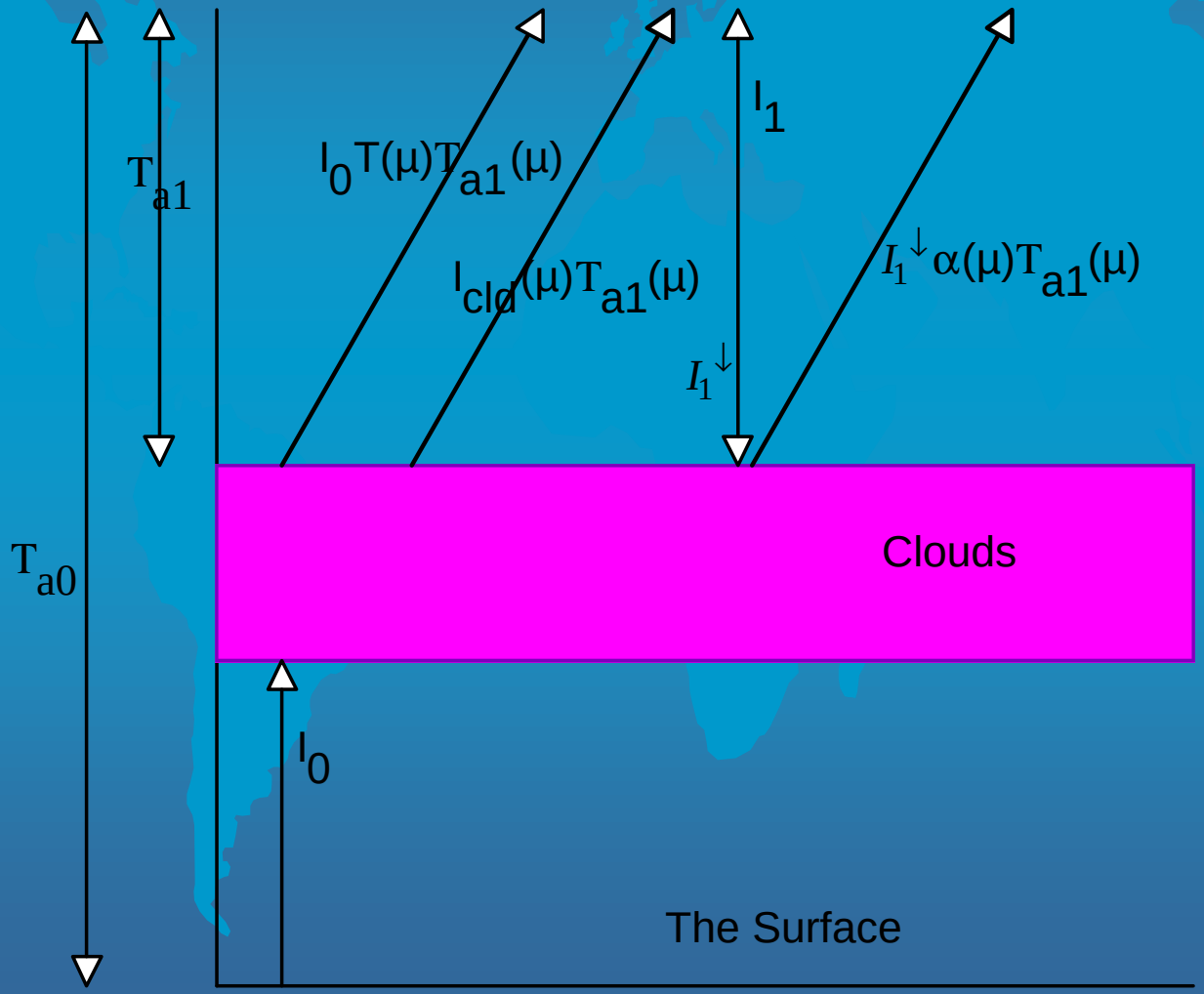






The scheme of radiative transfer for clouds

$$I_{top}(\mu) = I_0 T(\mu) T_{a1}(\mu) + I_{cld} T_{a1}(\mu) + I_1 + I_1^{\downarrow} \alpha(\mu) T_{a1}(\mu)$$



$$I_{top}(\mu) = I_0 T(\mu) T_{a1}(\mu) + I_{cld} T_{a1}(\mu) + I_1 + I_1^{\downarrow} \alpha(\mu) T_{a1}(\mu)$$

Where:

$$I_0 = B(t_s) T_{a0} + \int_{T_{a0}}^{T_{a1}} B(t) dT_a$$

$$I_1 = \int_{T_{a1}}^{1} B(t) dT_a$$

$$I_{cld}(\mu) = [1 - R(\mu) - T(\mu)] * B(t_c)$$

$$I_1^{\downarrow} = \int_{T_{a1}}^{1} B(t) \frac{T_{a1}}{T_a^2} dT_a$$

T_{a0} and T_{a1} are clear sky atmospheric transmission from the out space to the surface and to cloud top, respectively.

Database of albedo and tansmissivity function for water and ice clouds

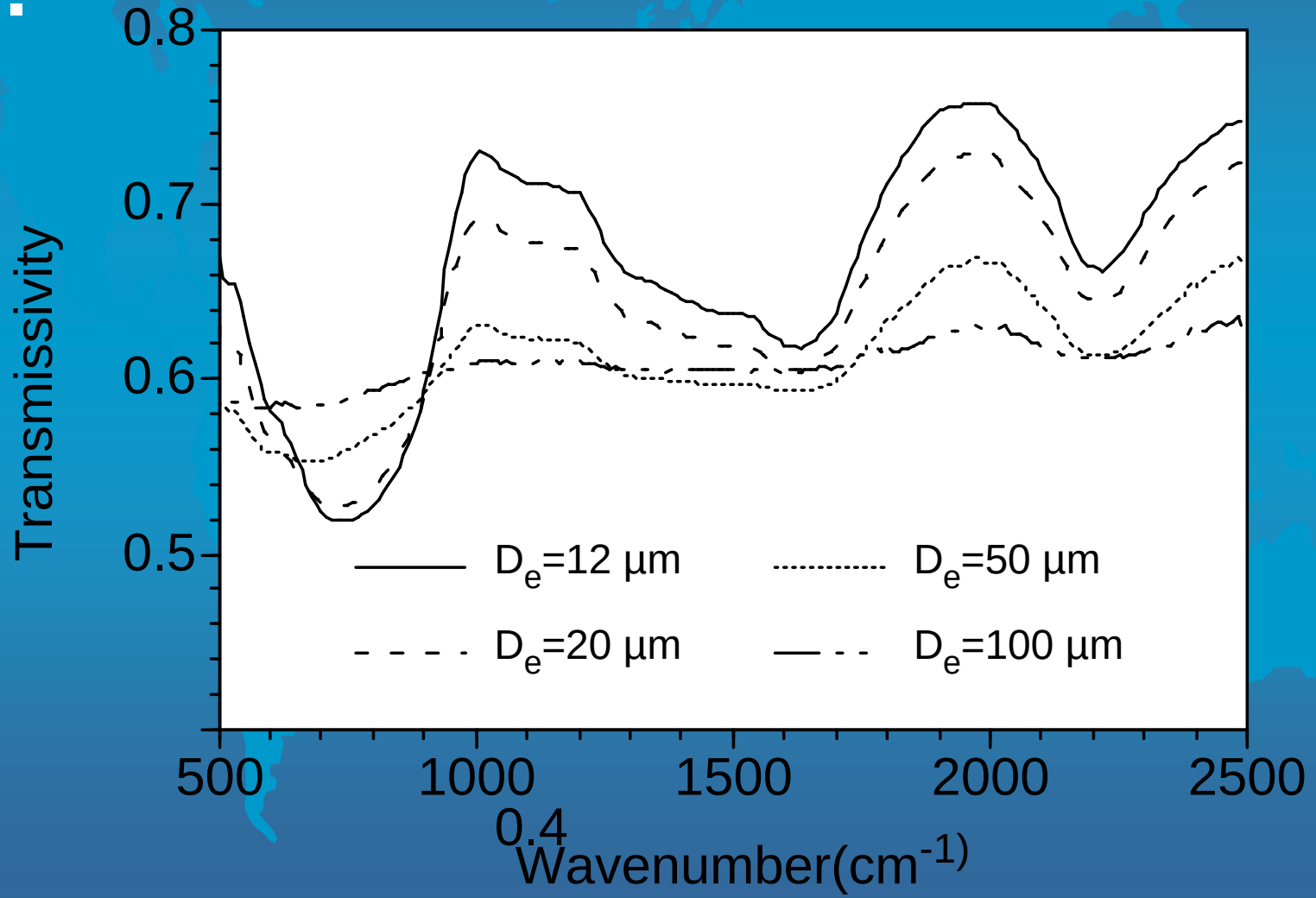
For ice clouds:

- ✓ Optical thickness: 0.04-50
- ✓ Effective size: 10-157μm
- ✓ Zenith angle: (0-80^{o})
- ✓ Wavenumber:(500-2500cm^{-1})

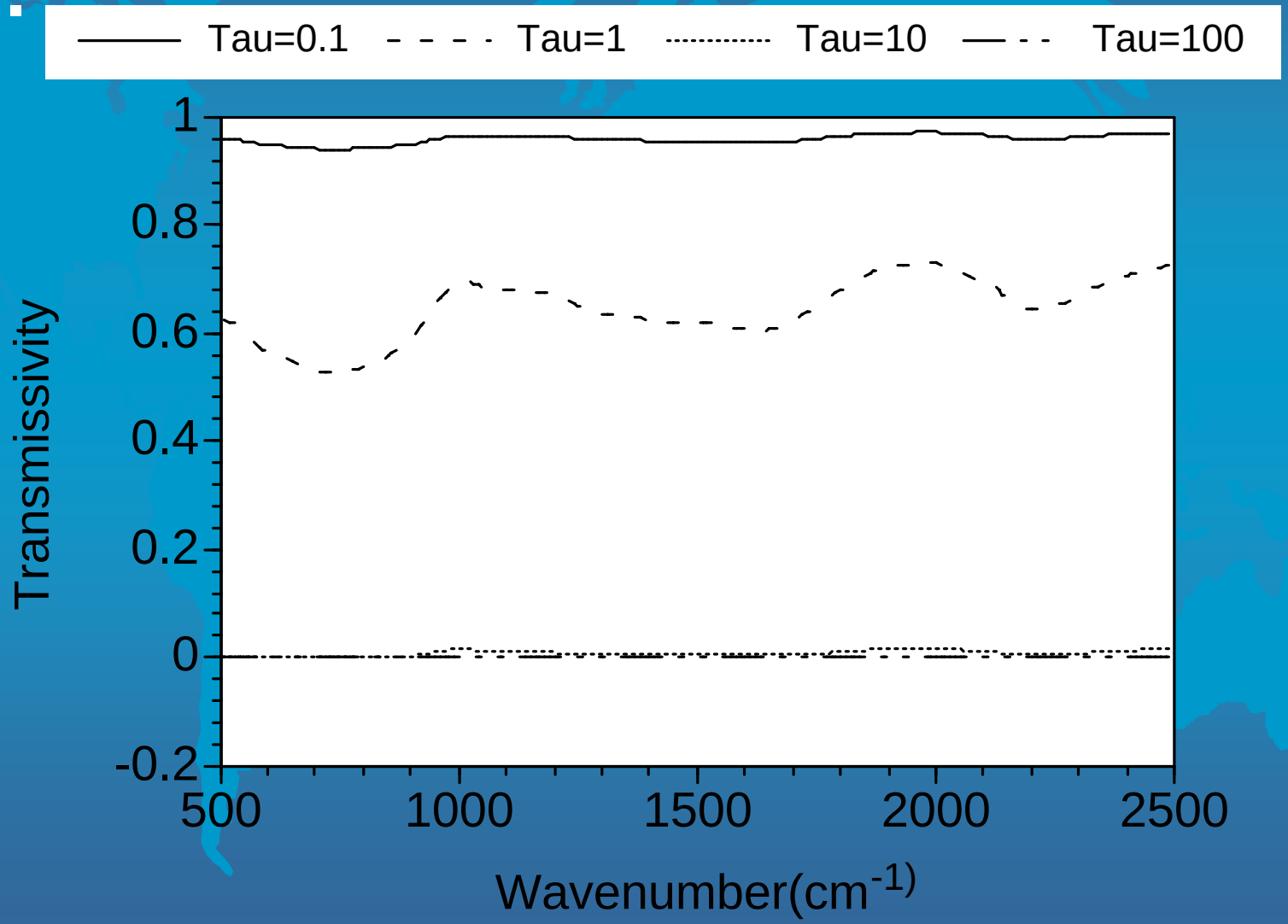
For water clouds:

- ✓ Optical thickness: 0.06-150
- ✓ Effective size: 2-20 μm
- ✓ Zenith angle: (0-80^{o})
- ✓ Wavenumber:(500-2500cm^{-1})

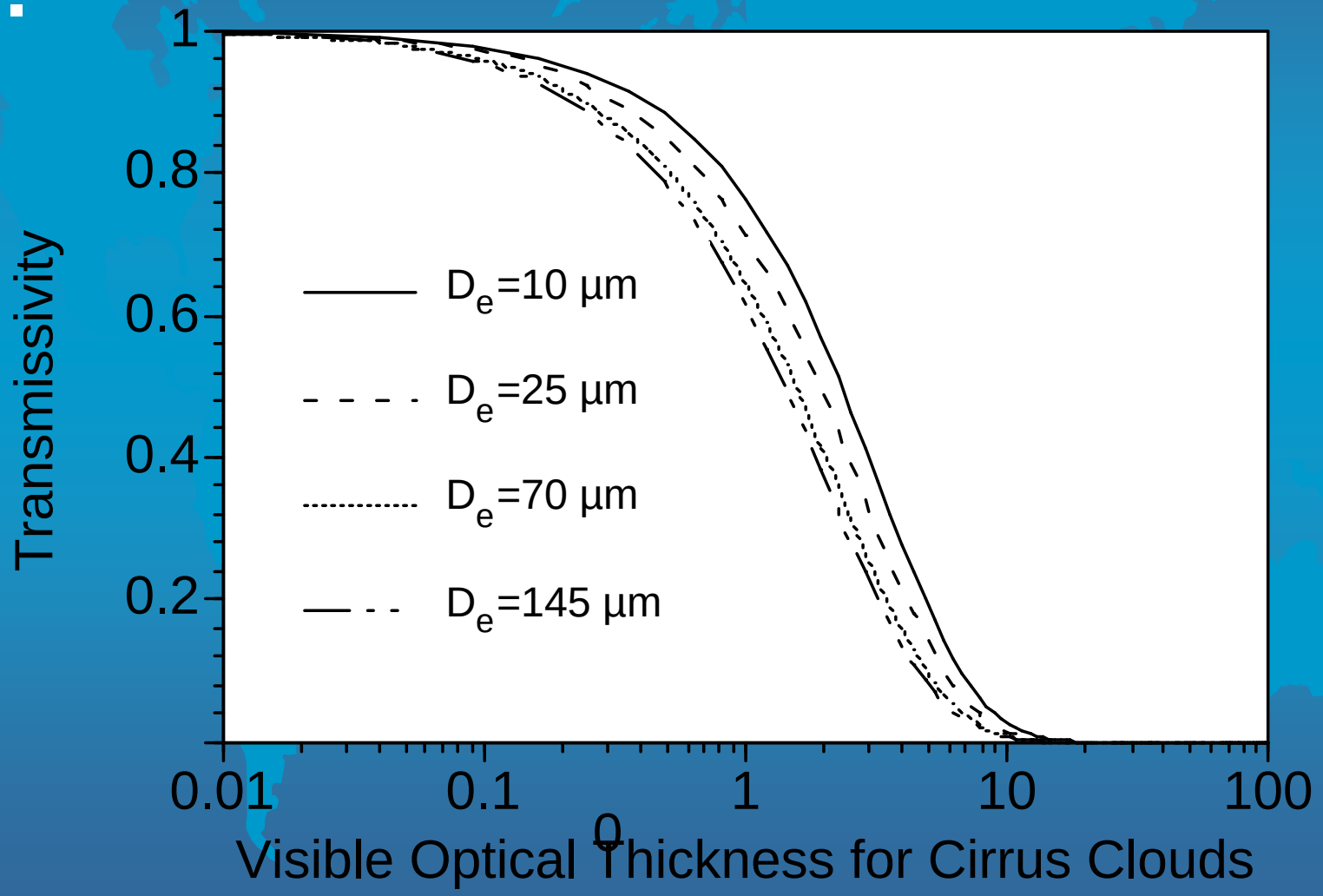
Transmissivity vs. wavenumber for 4 effective sizes (cirrus cloud, Tau=1.0)



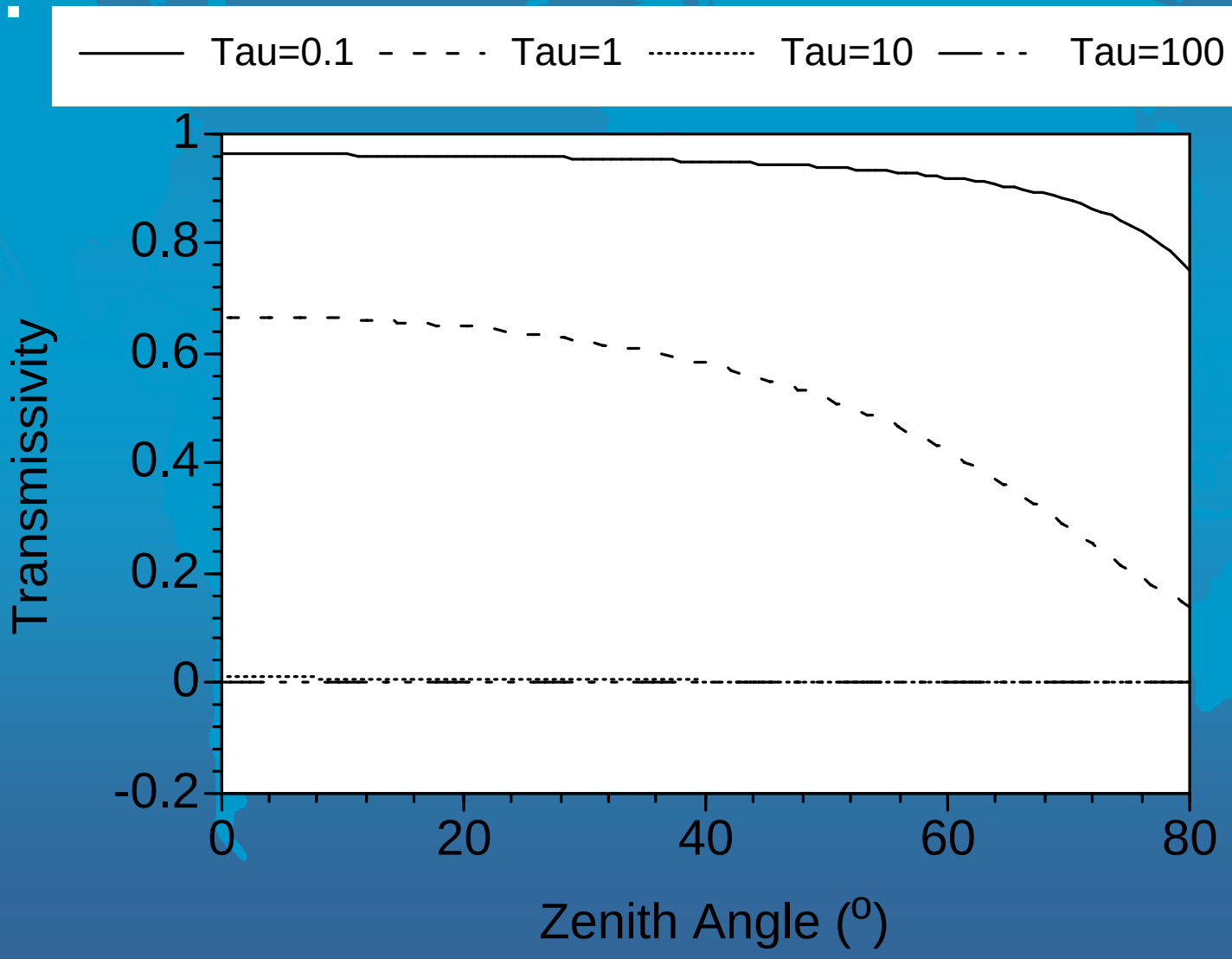
Transmissivity vs. wavenumber for 4 optical thicknesses (ice cloud, D_{ei}=50μm)



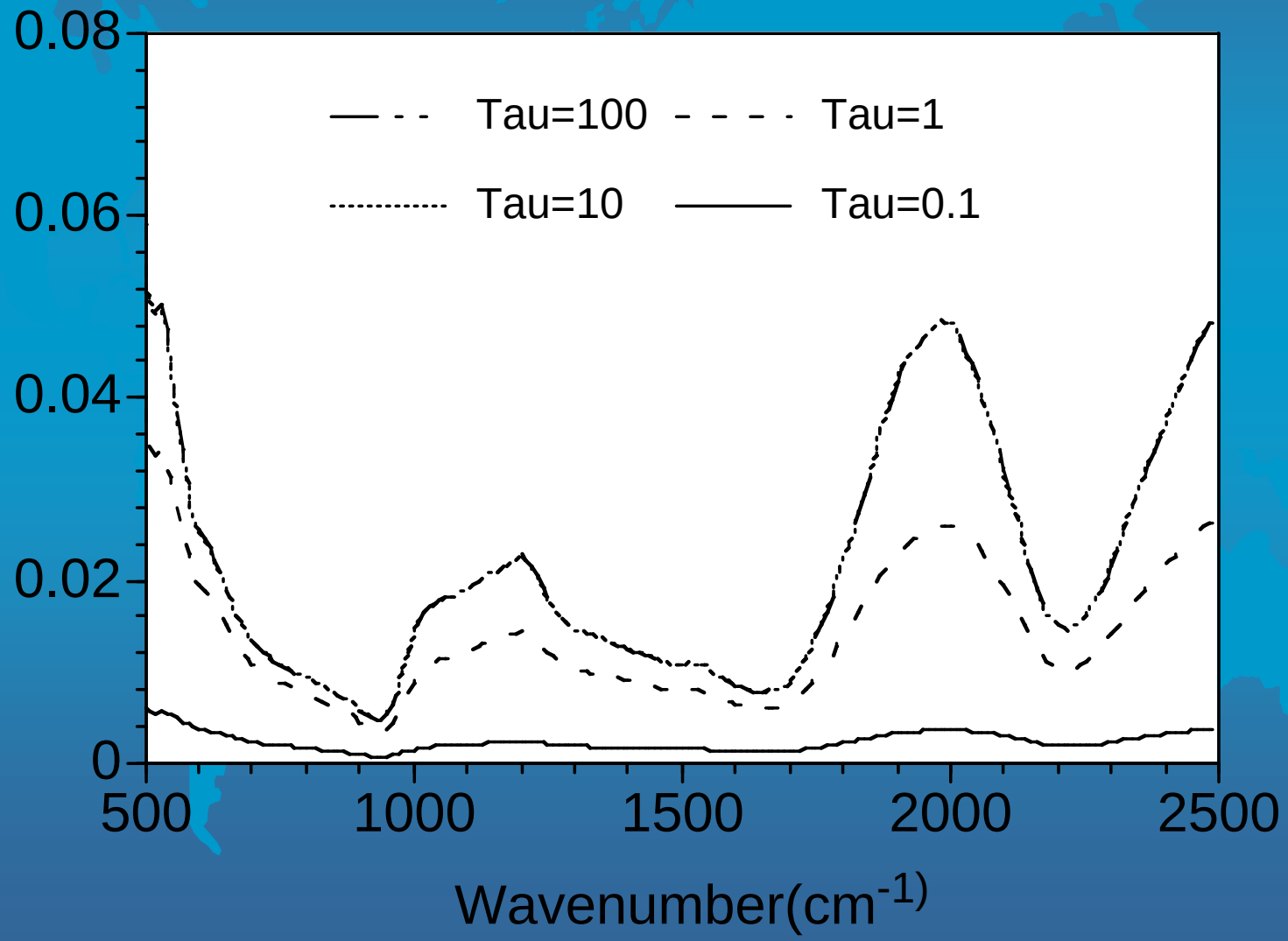
Transmissivity vs. optical thickness for 4 effective sizes (cirrus cloud, λ=8μm)



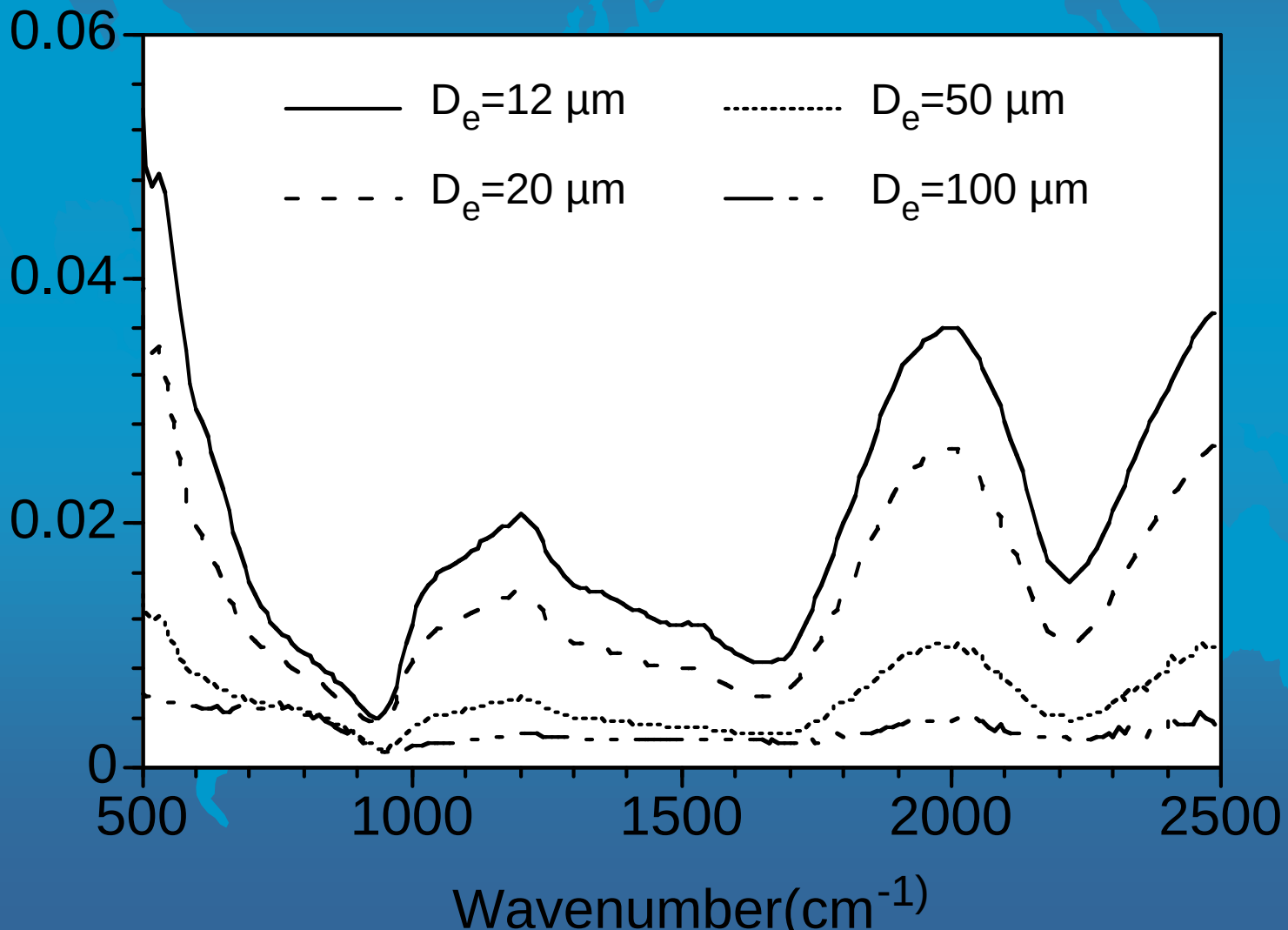
The transmissivity function vs. zenith angle at 4 optical thicknesses for ice clouds



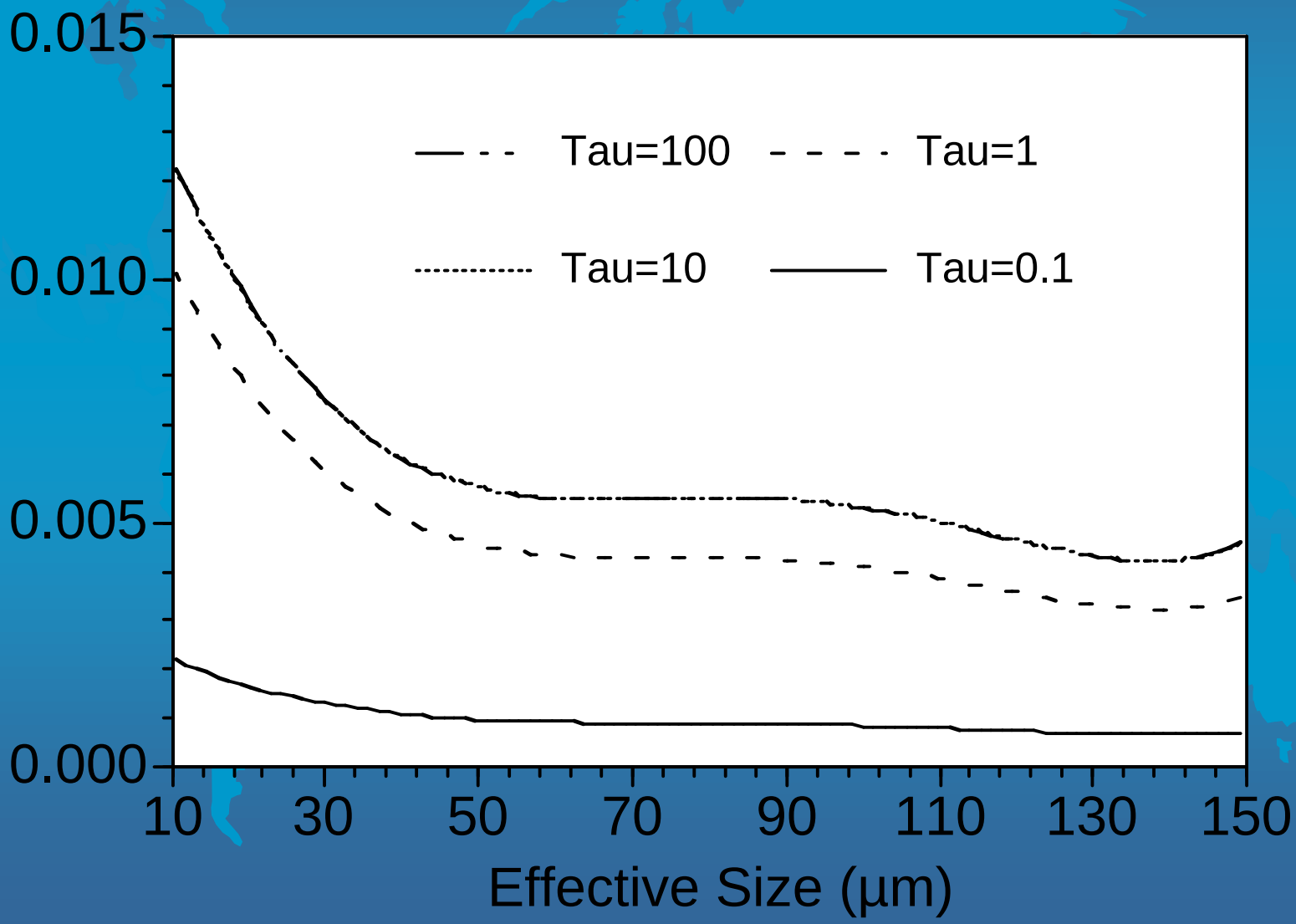
Albedo vs. wavenumber for 4 optical thicknesses (cirrus cloud)



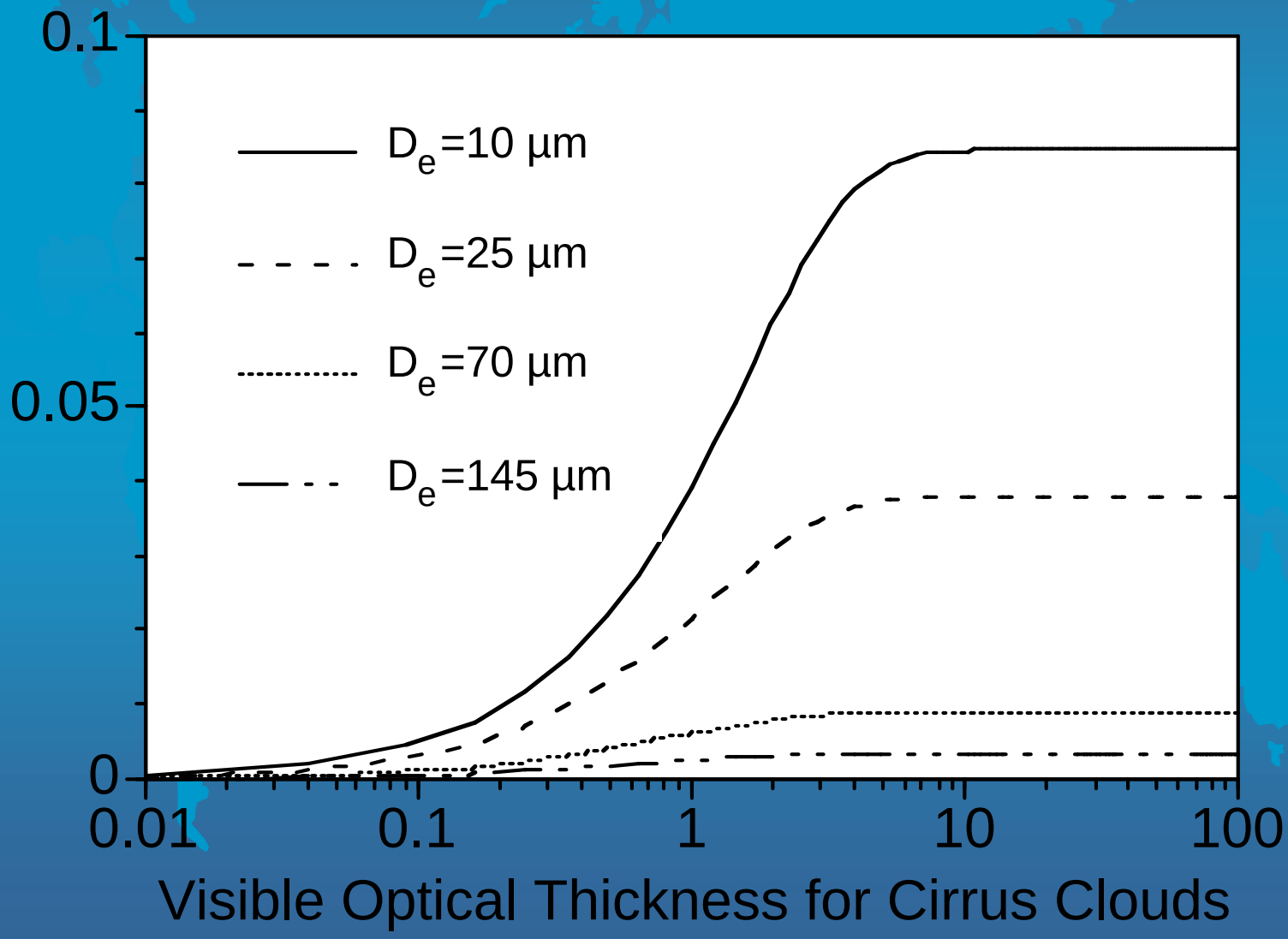
Albedo vs. wavenumber for 4 effective sizes (cirrus cloud)



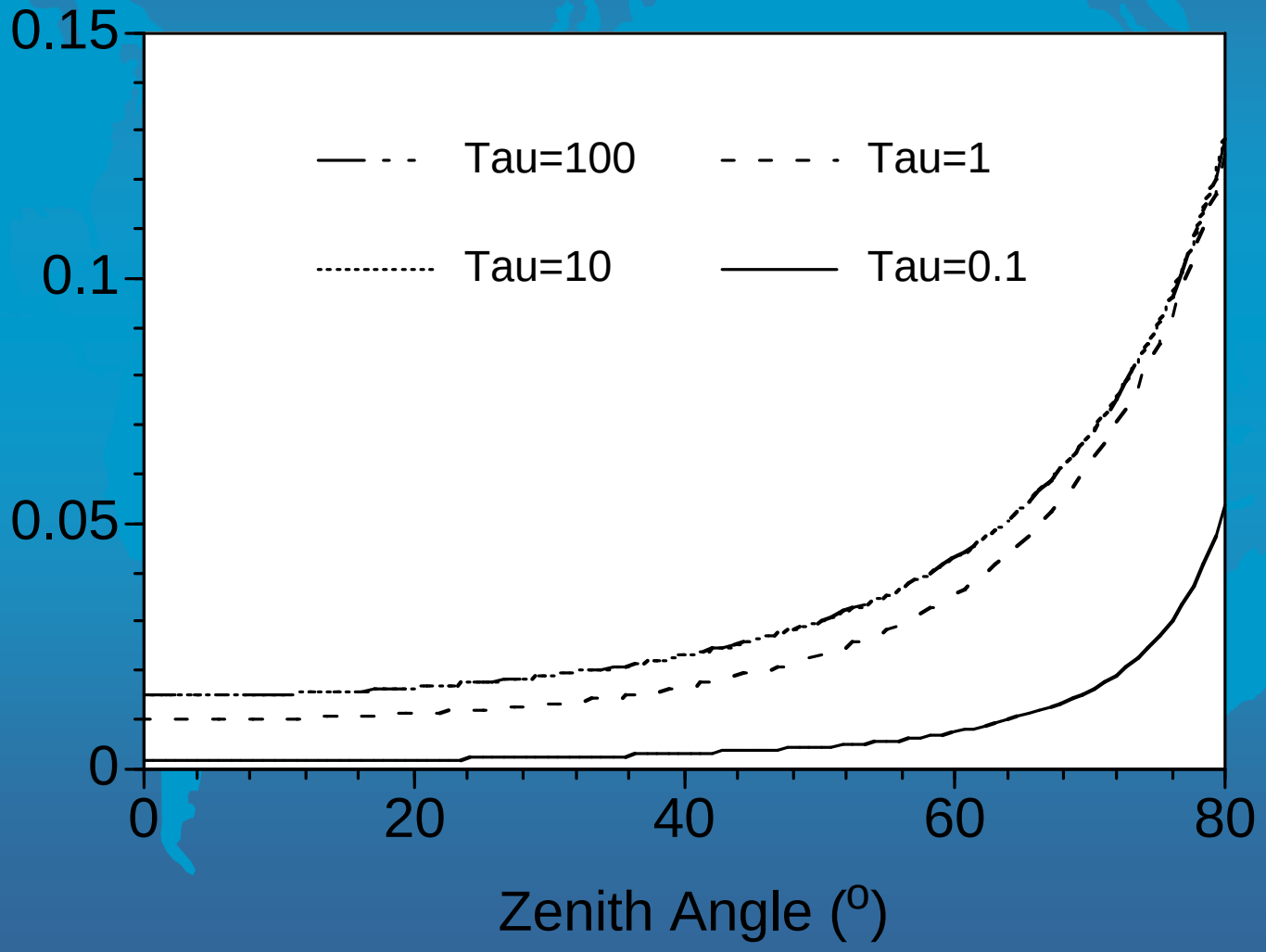
Albedo vs. effective size for 4 optical thicknesses (cirrus cloud, λ=8μm)



Albedo function vs. optical thicknesses for 4 effective sizes (cirrus cloud)



Albedo vs. zenith angle for 4 optical thicknesses (cirrus cloud)

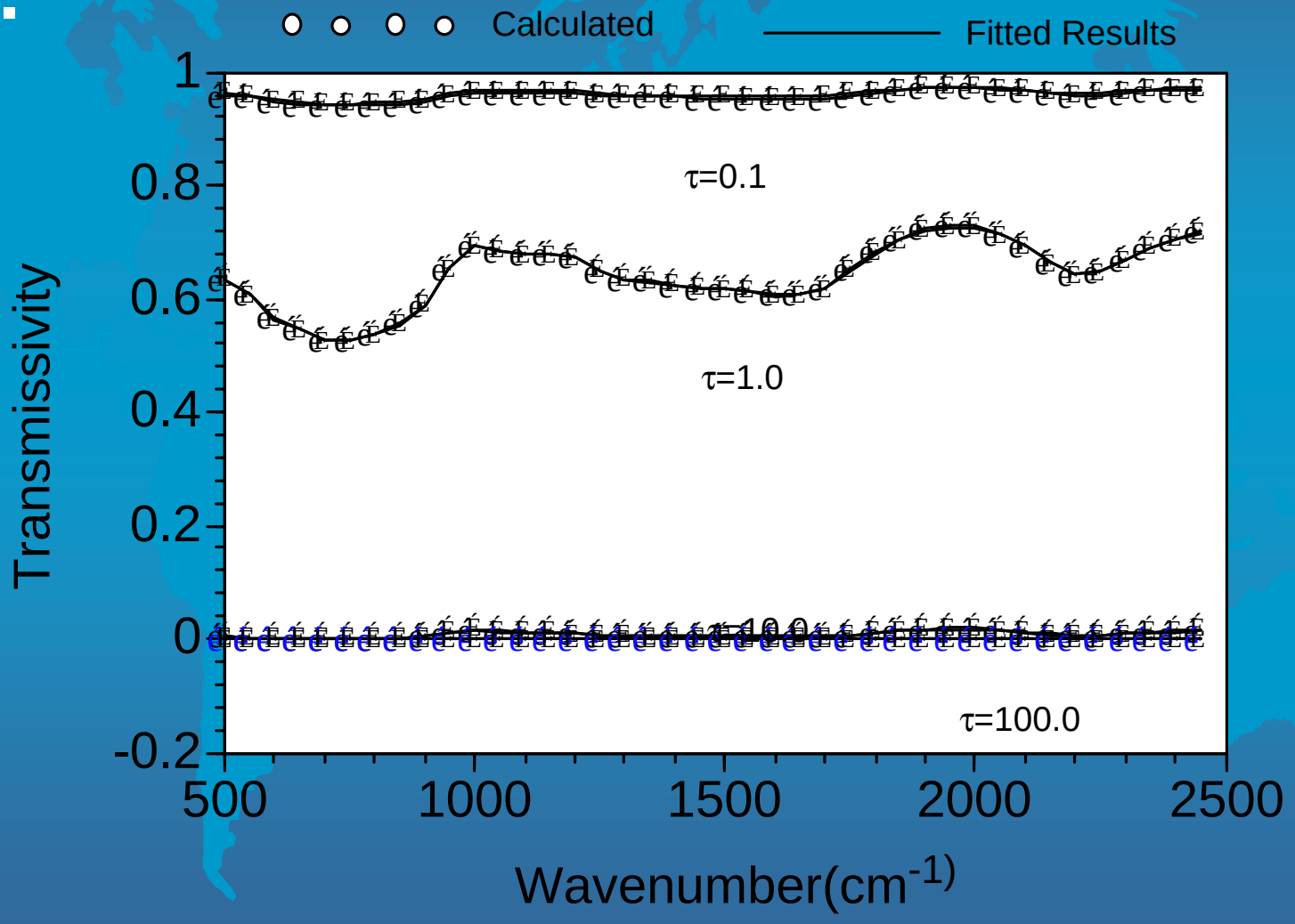


Interpolate albedo and transmissivity from database

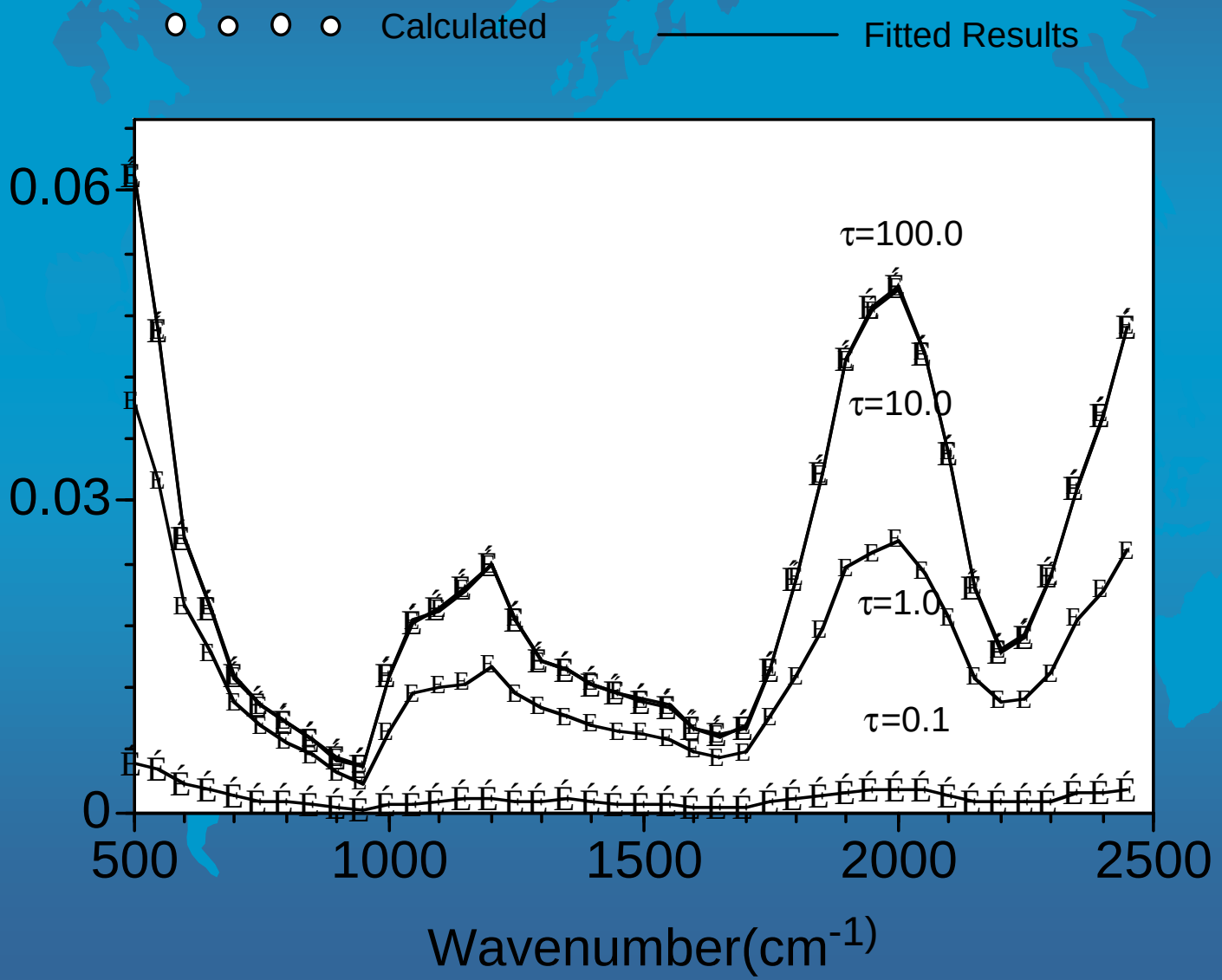
A code is developed to interpolate albedo and transmissivity from a pre-calculated database

for given wavelength, zenith angle, effective sizes and optical thickness (cirrus and water clouds) by using two-dimensional (2D) polynomial fitting and 2D interpolation

Interpolate transmissivity of clouds from the pre-calculated database



Interpolate albedo of clouds from the pre-calculated database



Merge the cloudy and clear-sky fast models

- We developed a computational package to compute the radiance at any atmospheric level for given profiles of clear-sky atmospheric optical thickness and temperature (which are from the clear sky fast model) and the parameters of clouds

Results

Accuracy

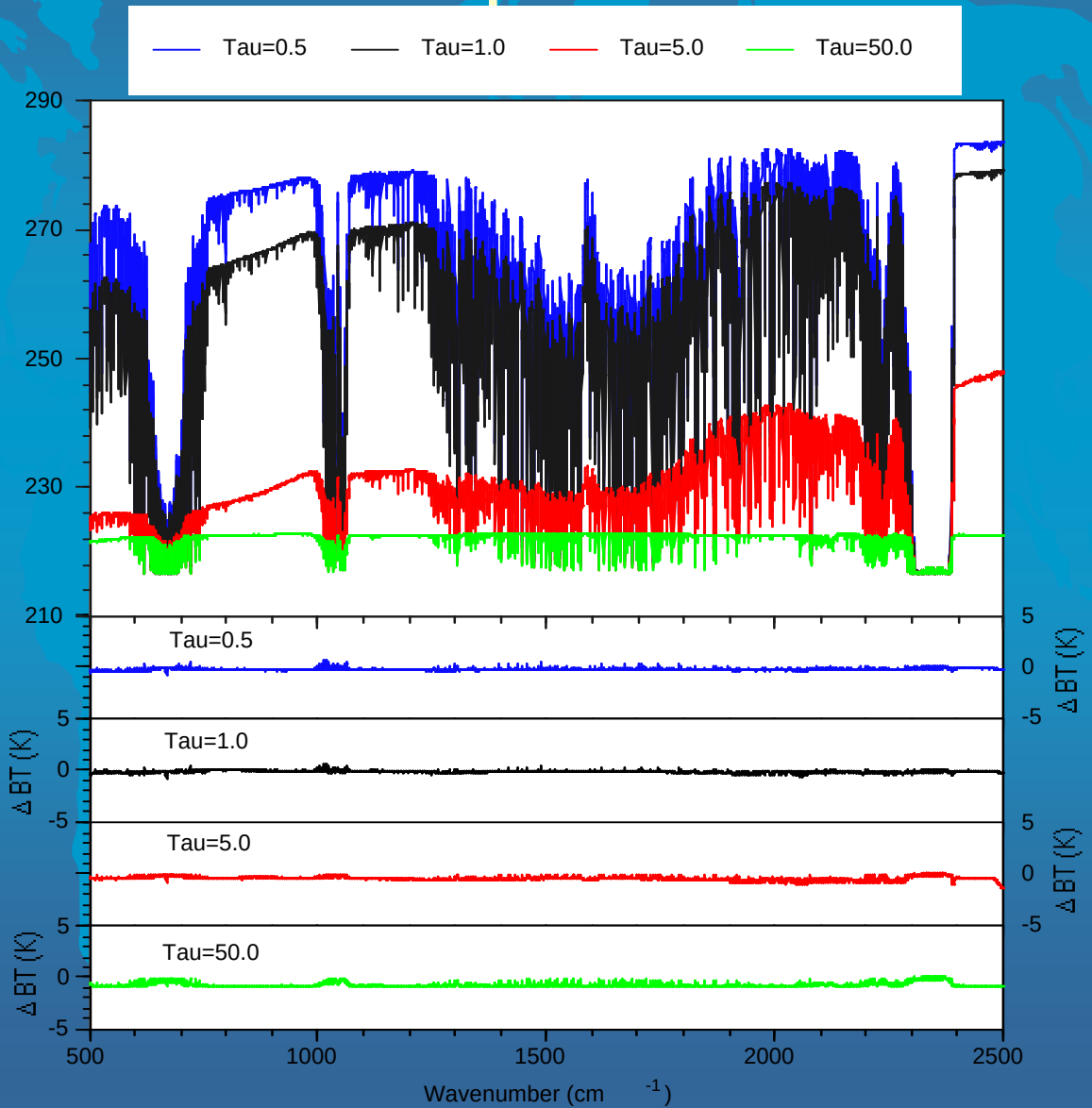
- The root-mea- square(RMS) difference between the fast model and DISORT is less than 0.5K, as illustrated in the attached diagrams

Speed:

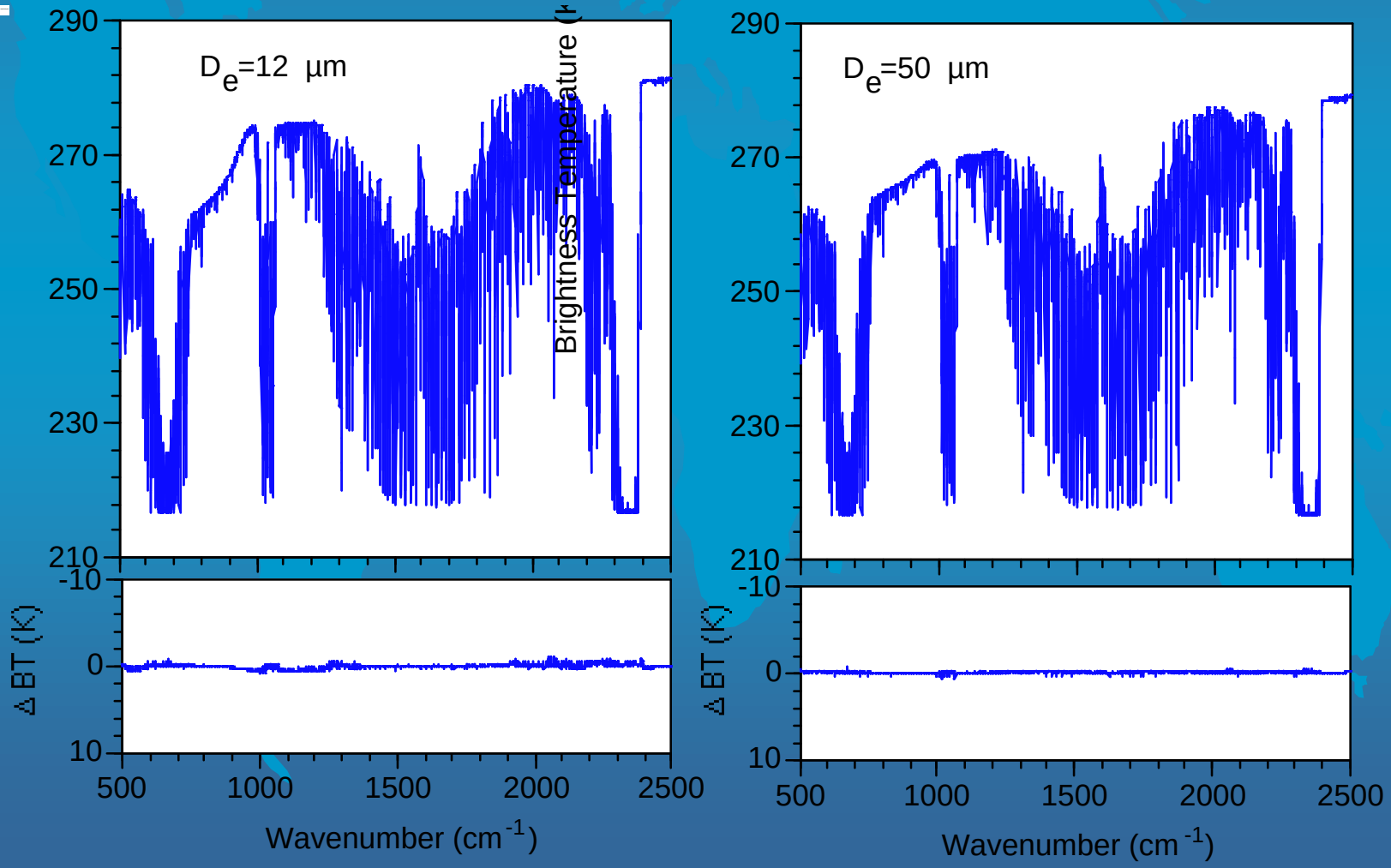
- The computational speed of the fast model is approximately 1000 times faster than the DISORT model.

  Test case: 8000 wavenumbers(500-2500cm^{-1}) and 100 layers atmosphere with single-layer clouds on Dell Precision 530 workstation. It takes 254s for DISORT whereas the fast model needsonly 0.25s.

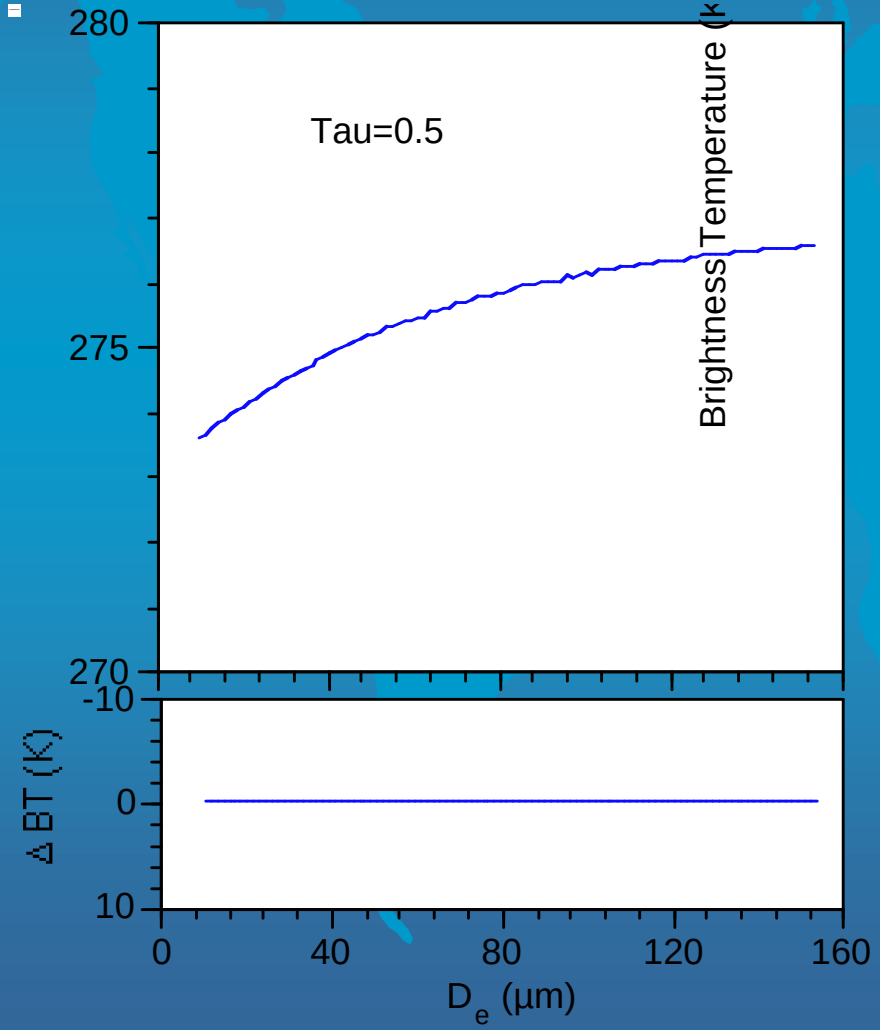
Spectra calculated by the fast model and the deviations compared with DISORT

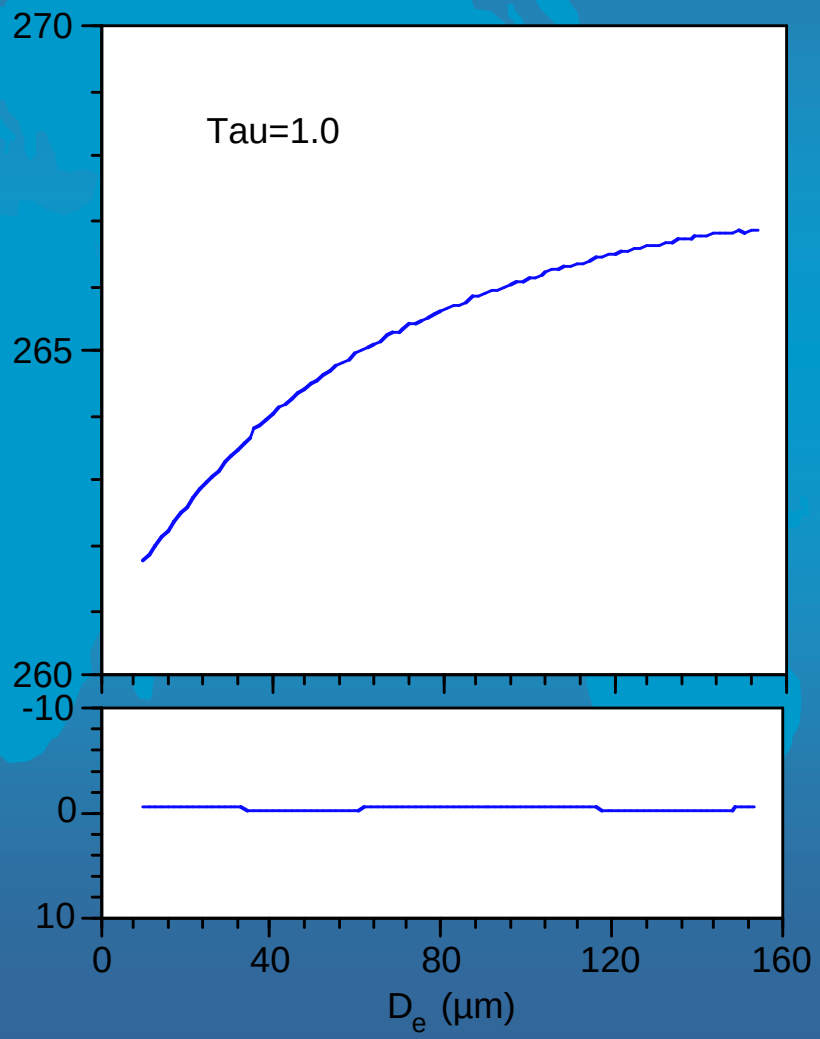


Comparison of the results from the fast model and the DISORT model

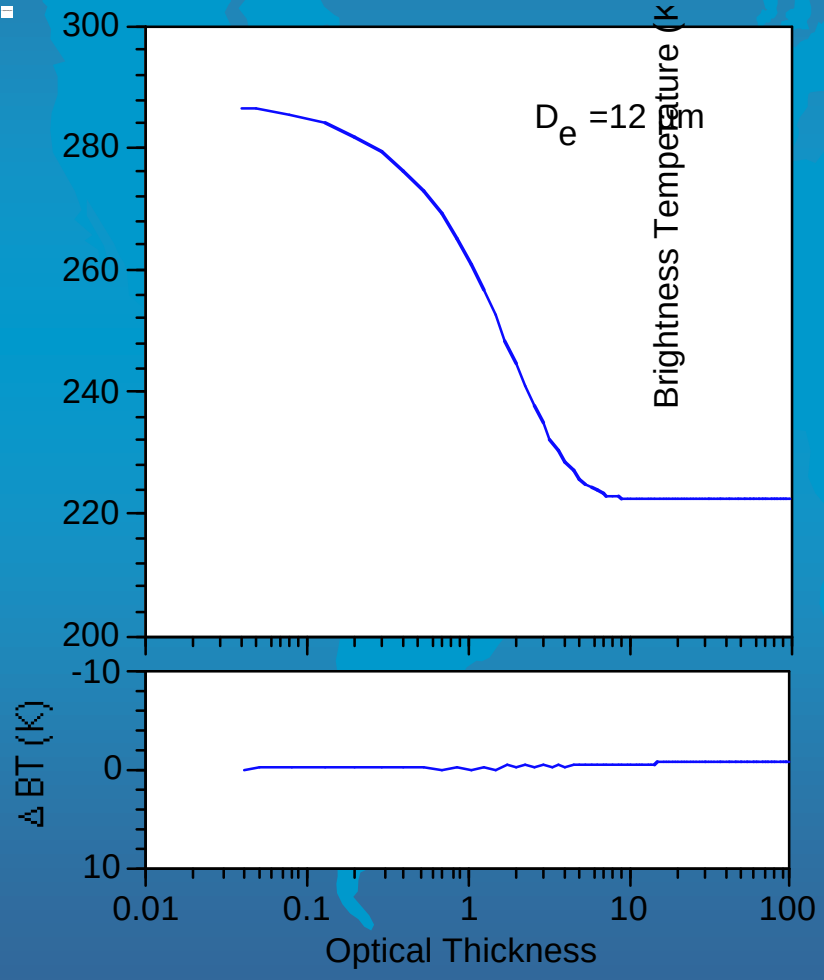


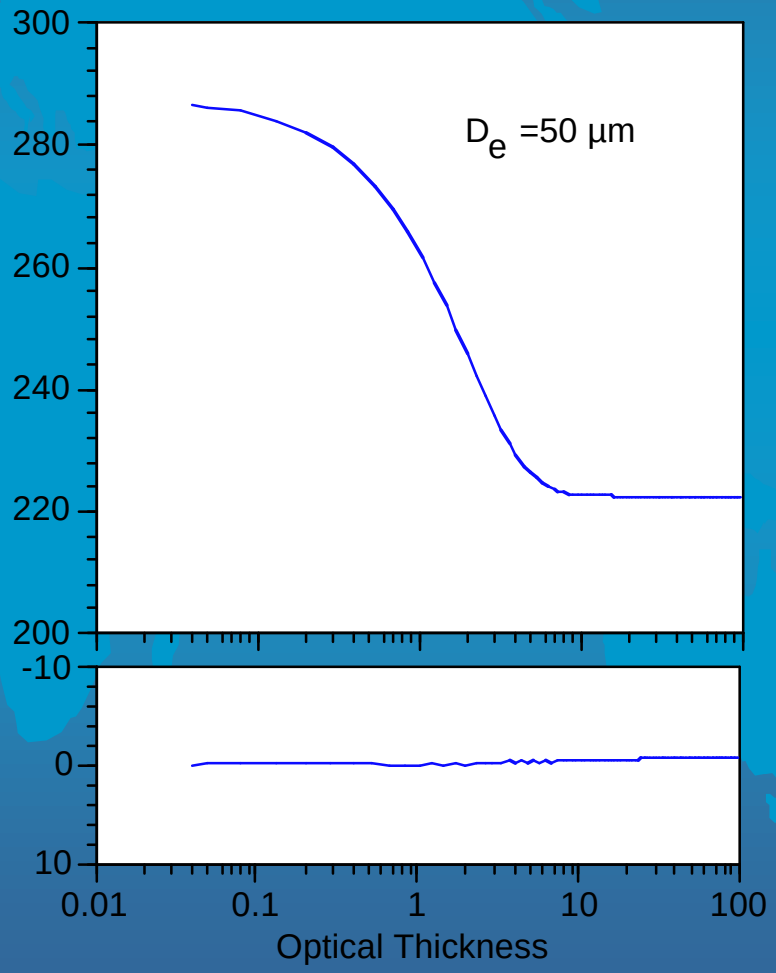
Comparison of the results from the fast model and DISORT(variation of BT versus effective size)



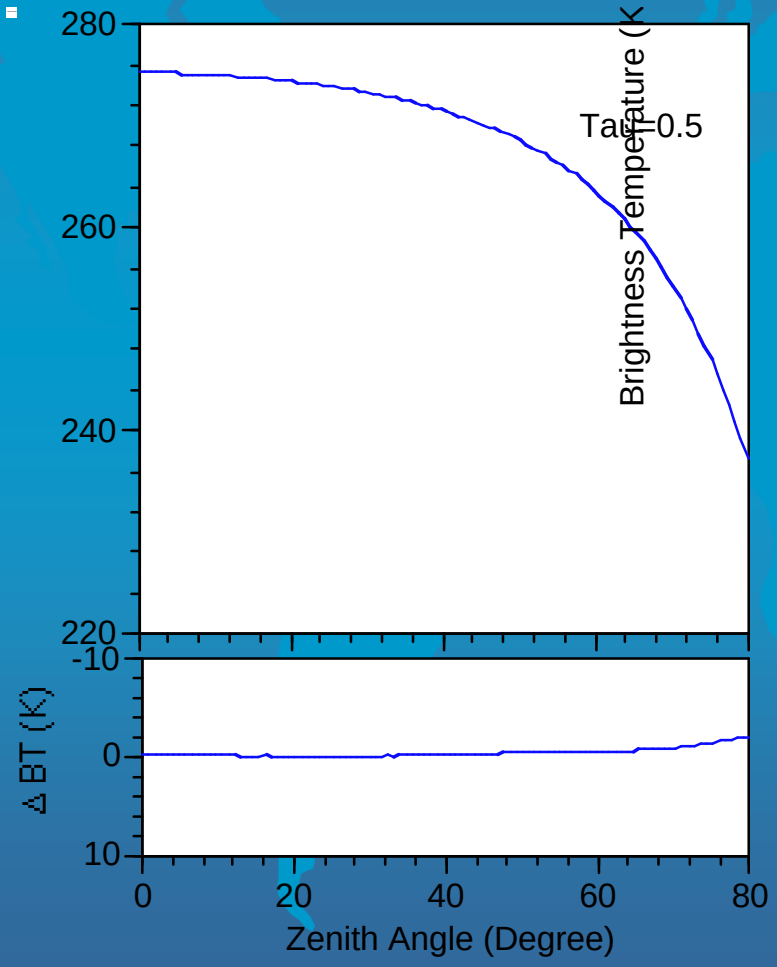


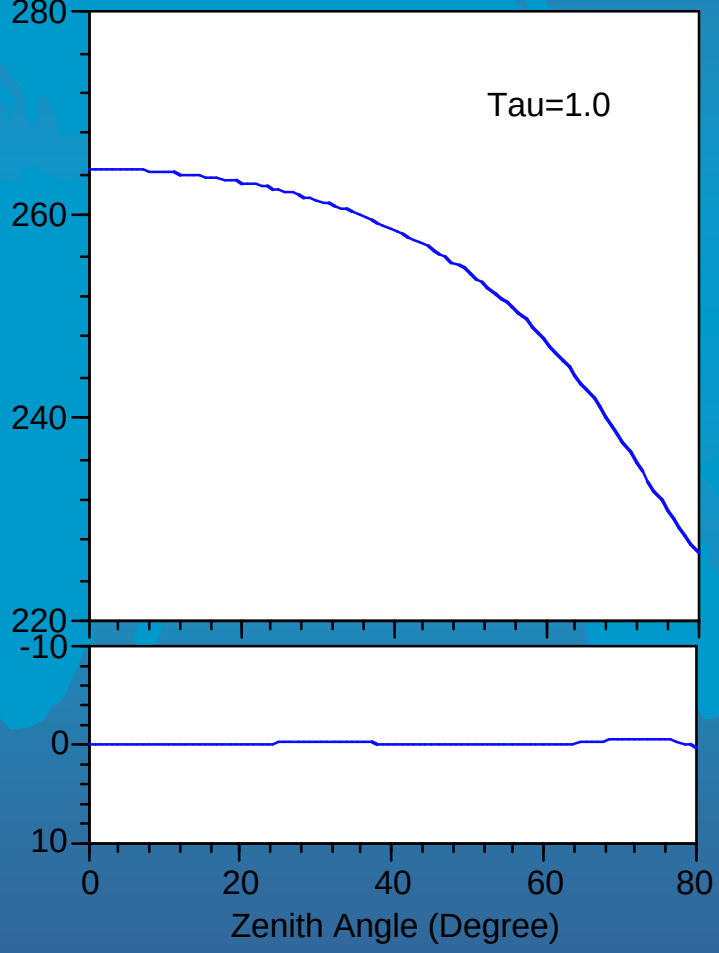
Comparison of the results from the fast model and DISORT(variation of BT versus optical thickness)



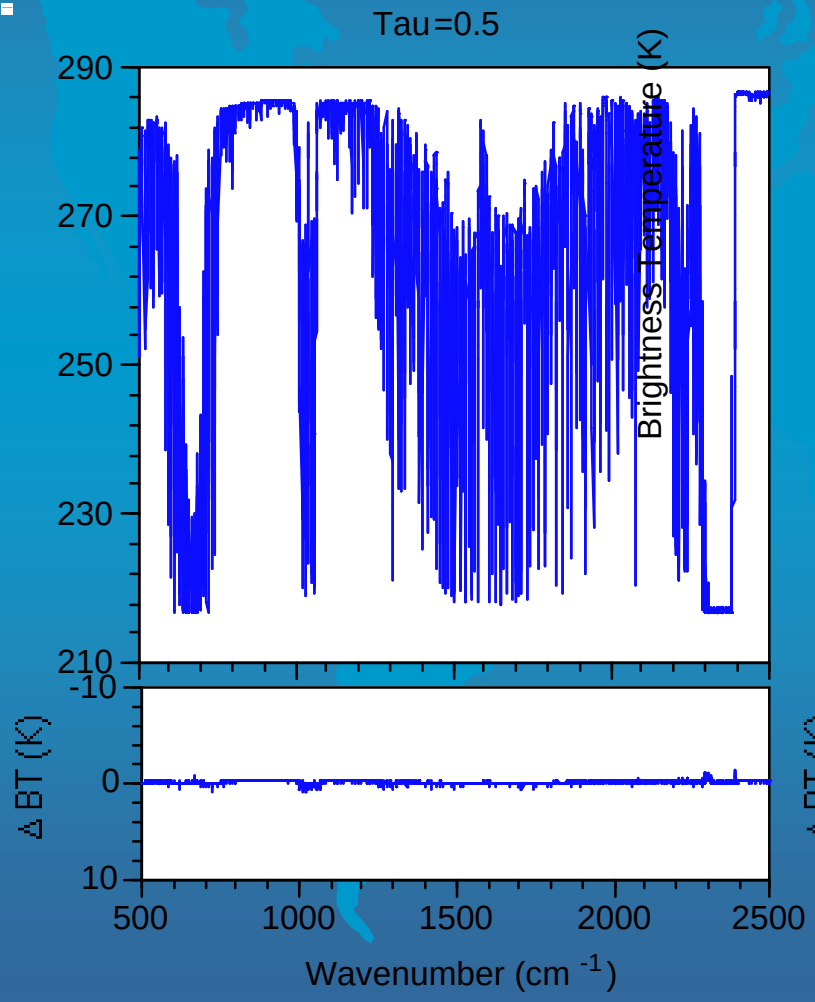


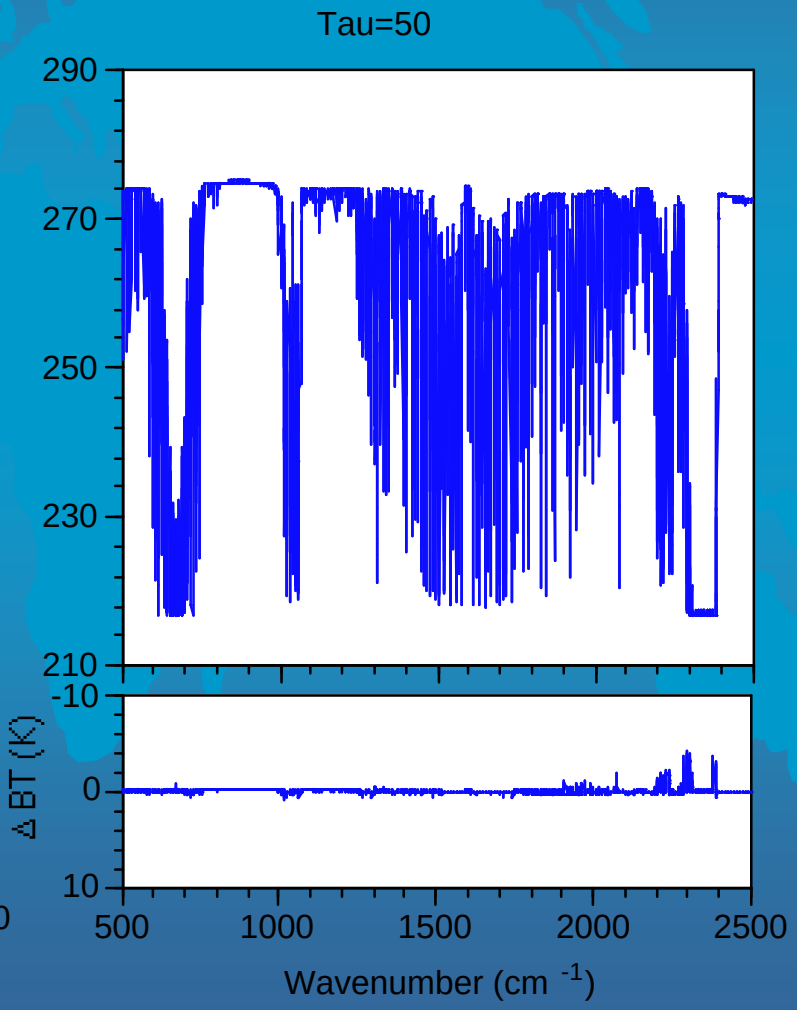
Comparisons the results of the fast model to DISORT(variation of BT versus zenith angle)





Comparisons the results of the fast model to DISORT for water clouds

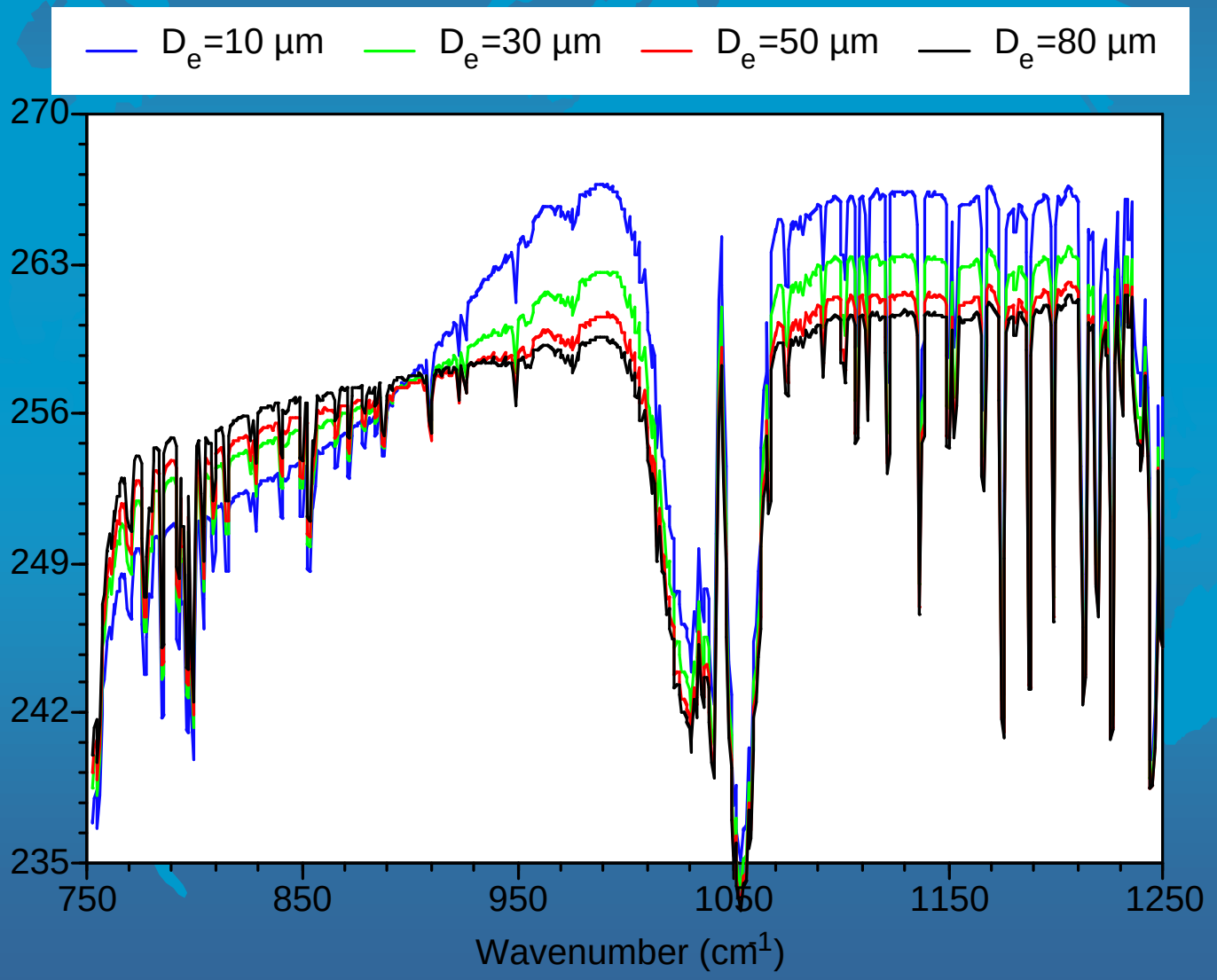




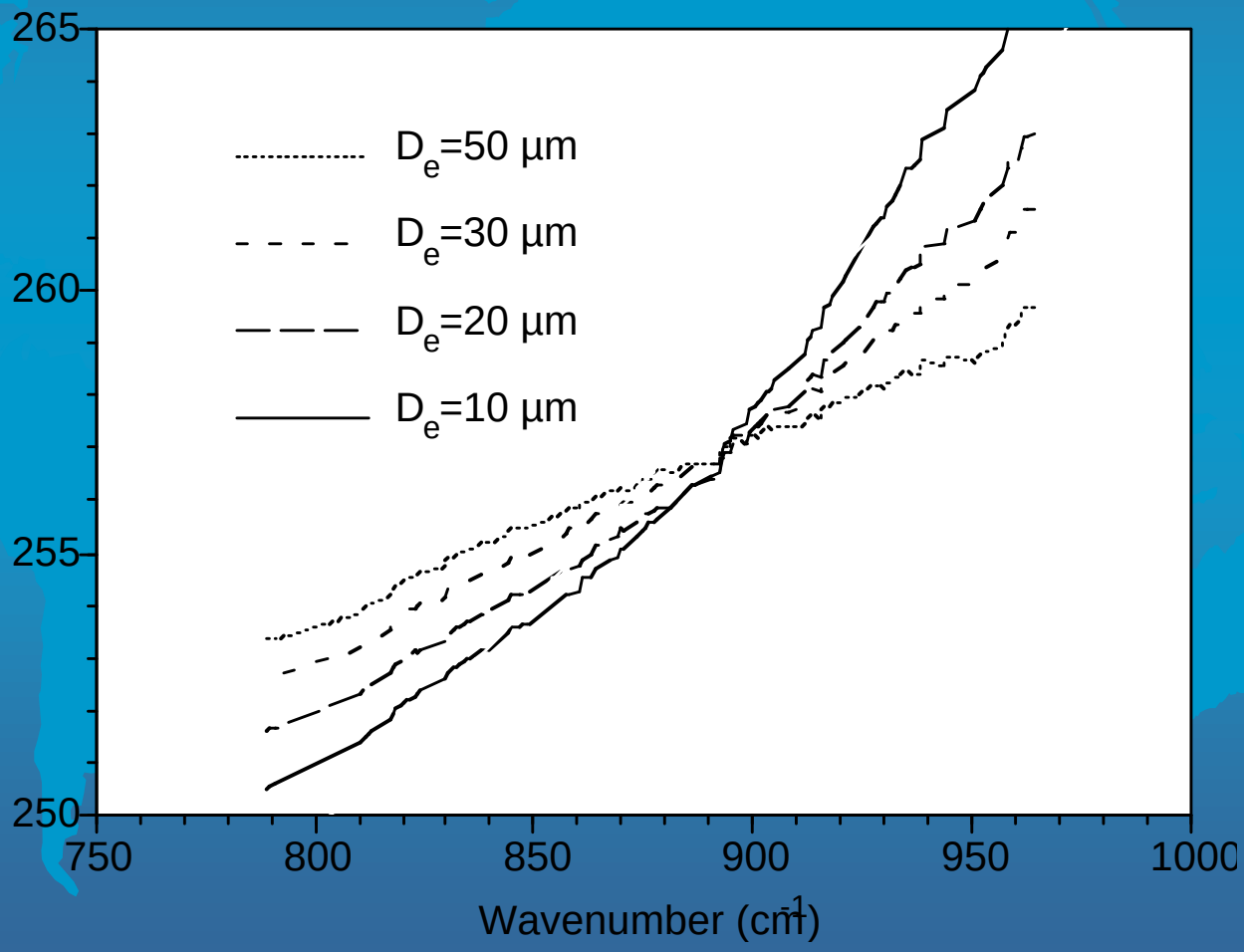
Part 2:**Sensitivity study of Cirrus Properties**

- Sensitivity study
  - Effective particle size
  - Visible optical thickness
- Simultaneous retrieval of the optical thickness and effective particle size of cirrus clouds

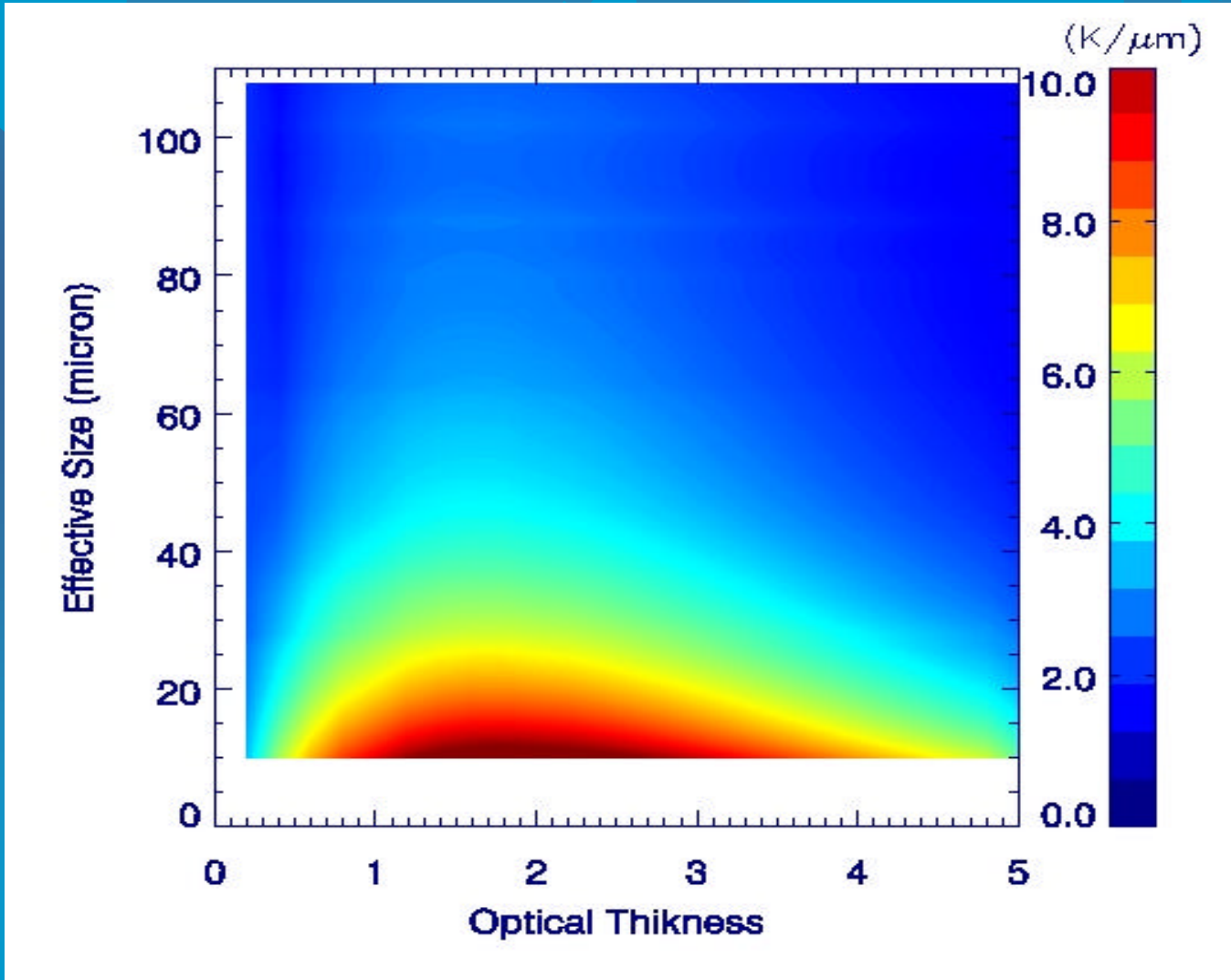
The sensitivity of upwelling brightness temperature to the effective size of cirrus clouds



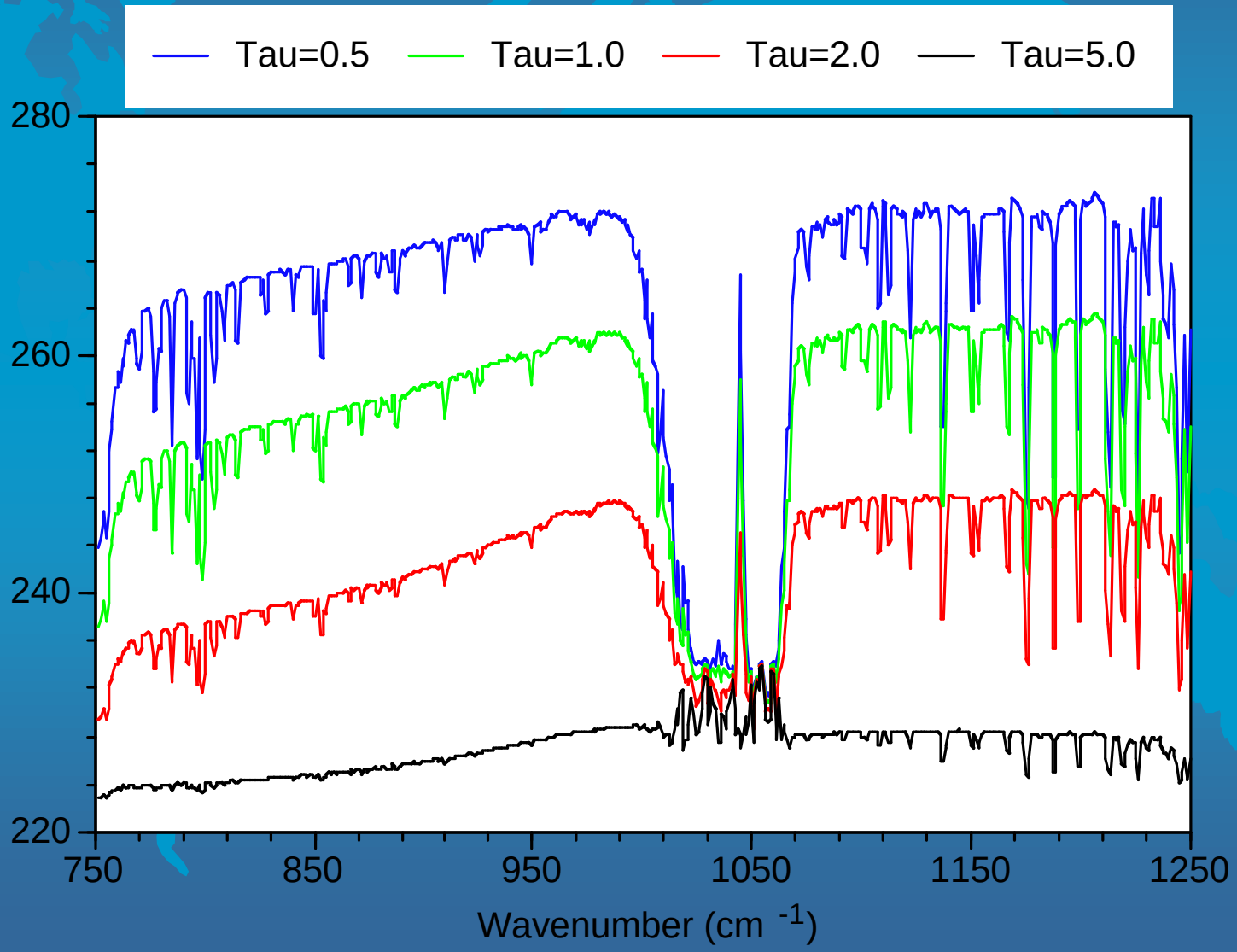
The sensitivity of the slope to the effective size of cirrus clouds

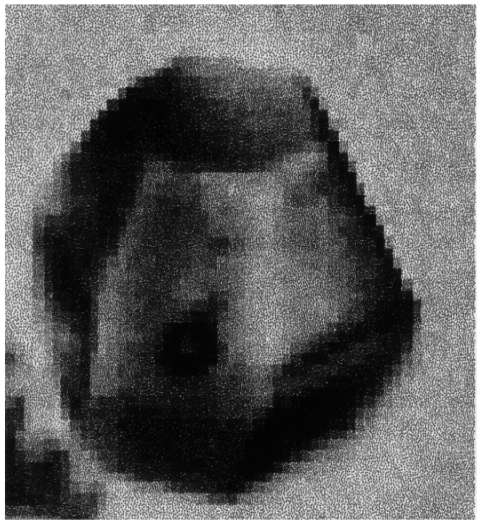


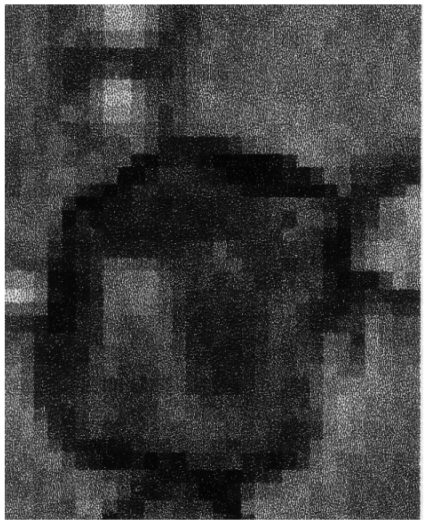
Sensitivity of the slope to the effective size and optical thickness of cirrus clouds

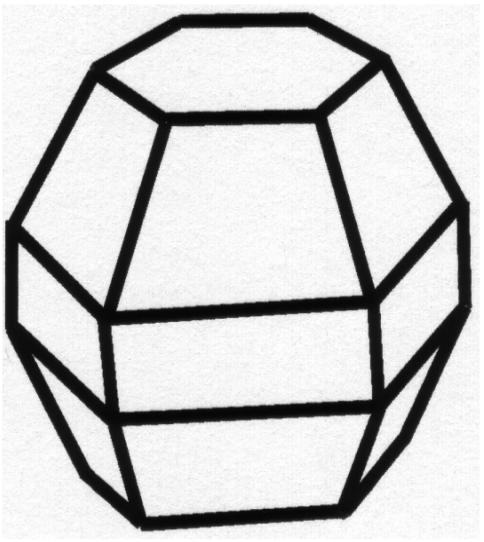


Sensitivity of upwelling brightness temperature to the optical thickness of cirrus clouds

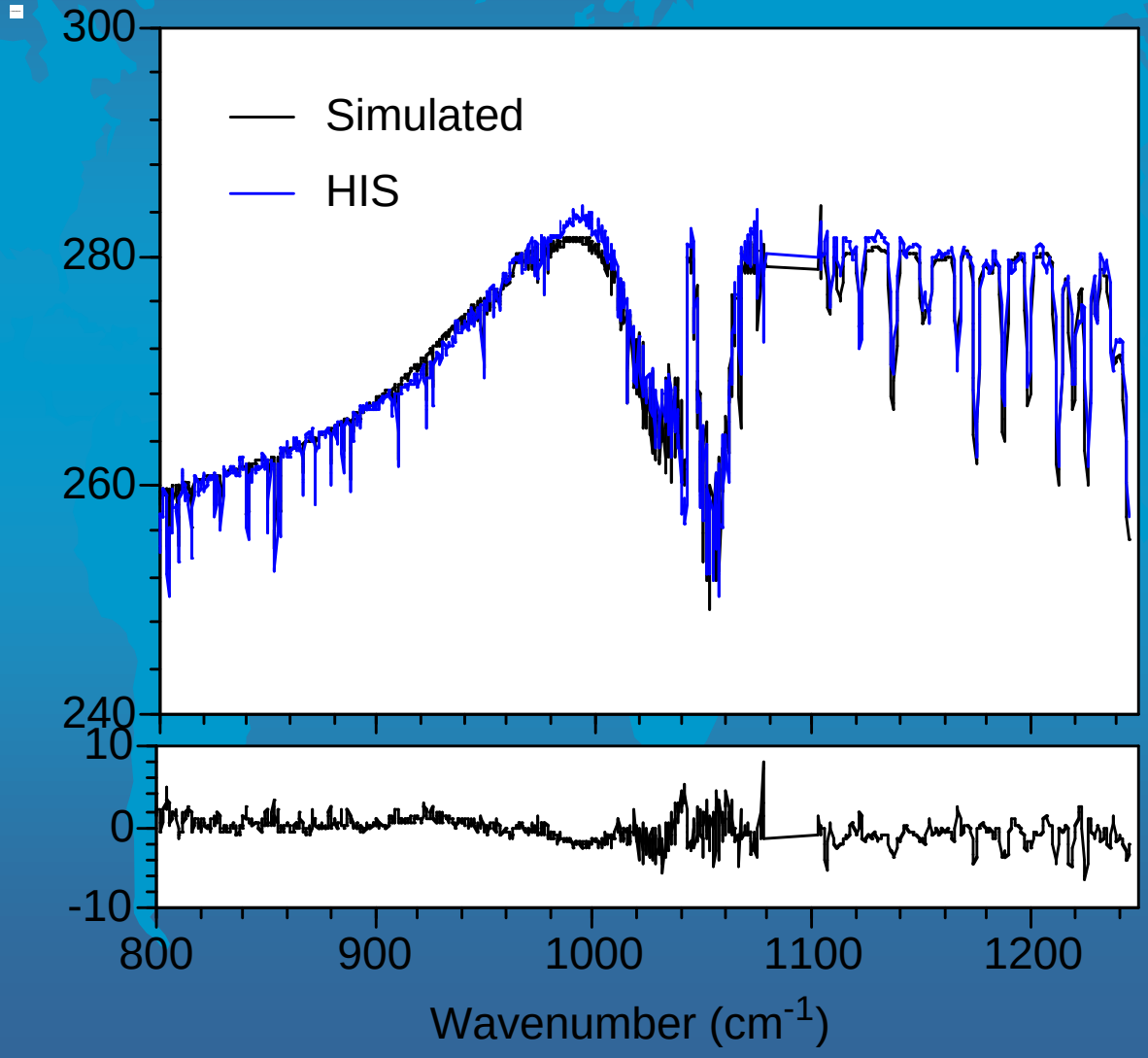




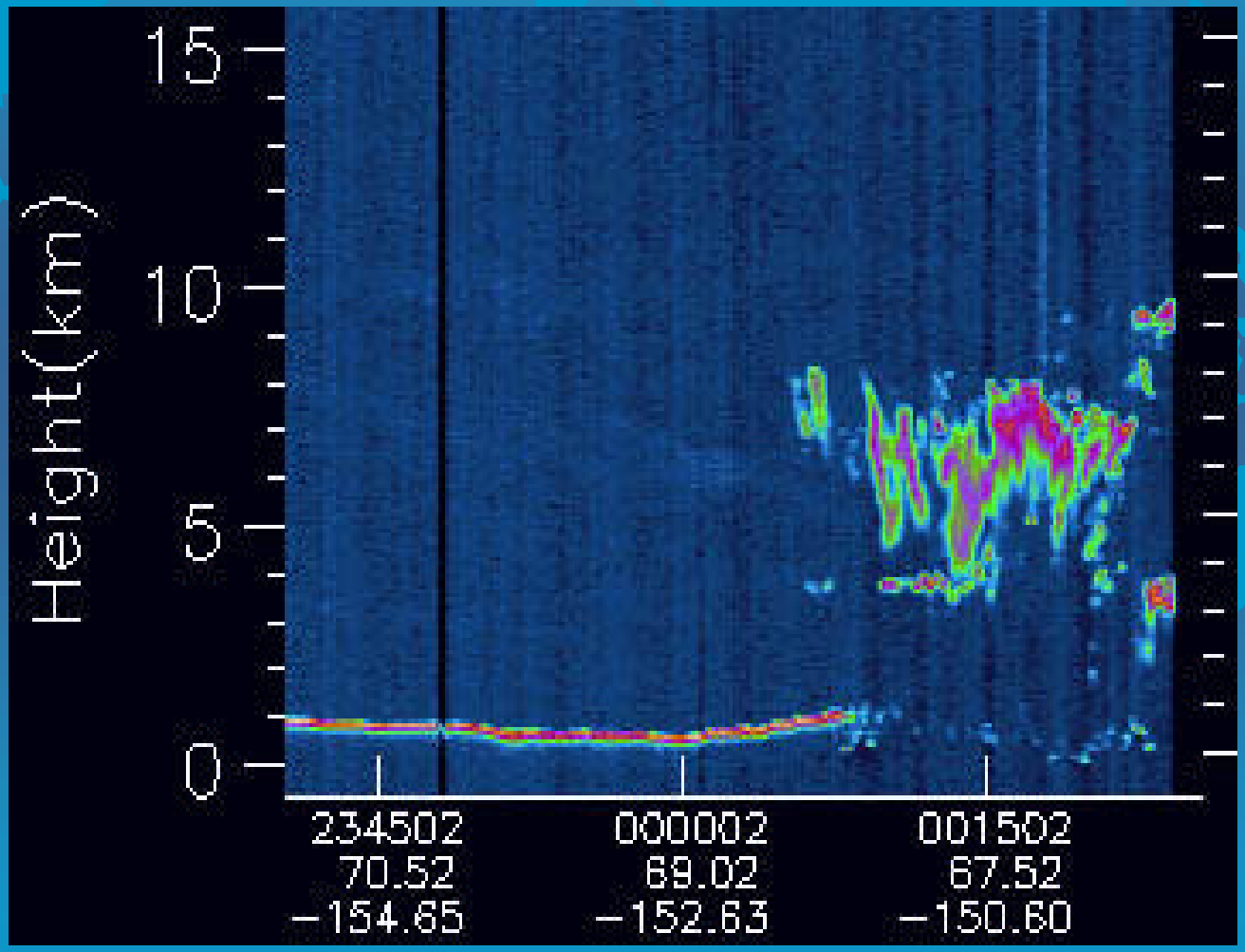




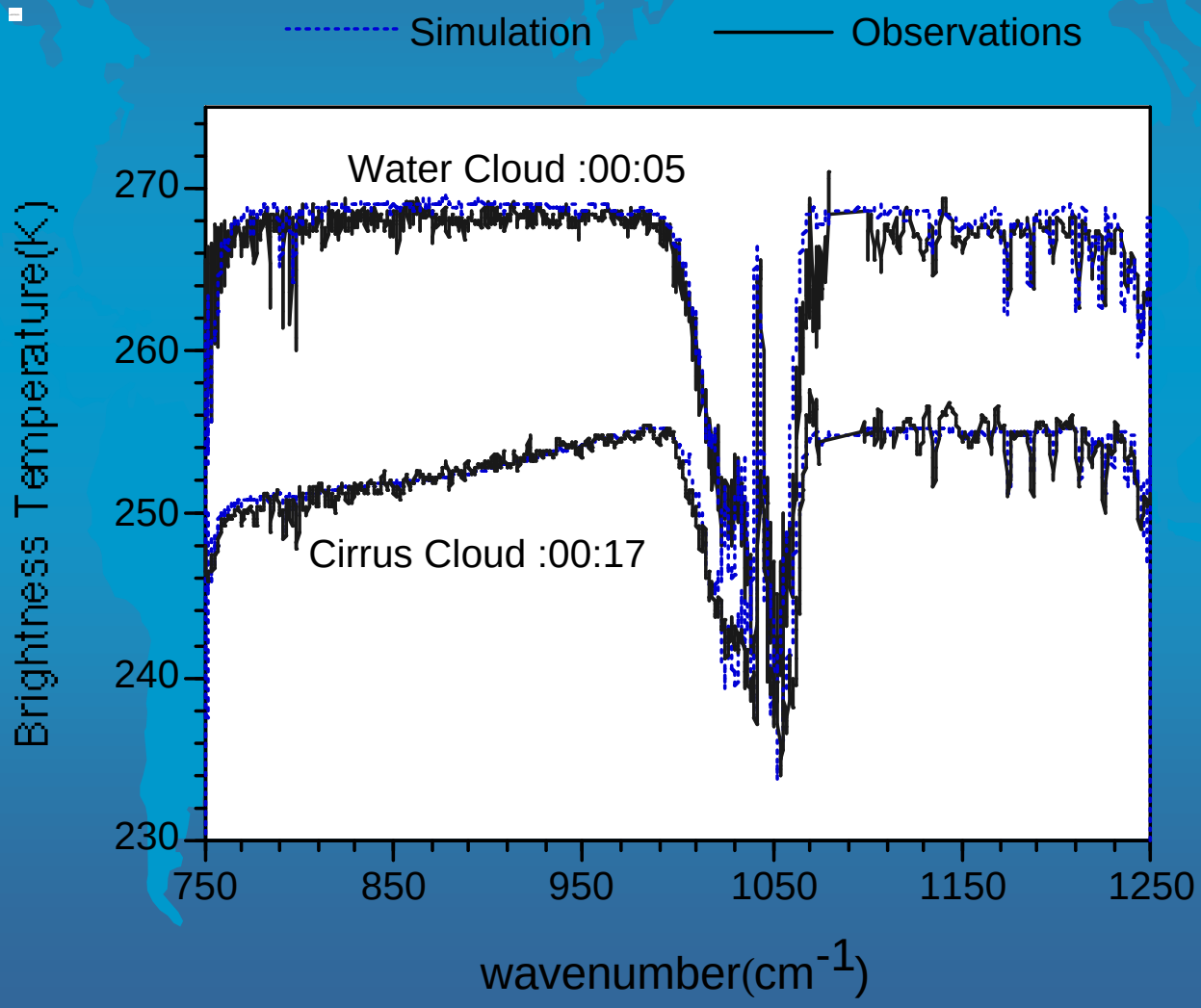
Comparison of observed and simulated upwelling IR spectra for a jet contrail composed of primarily small ice particles.



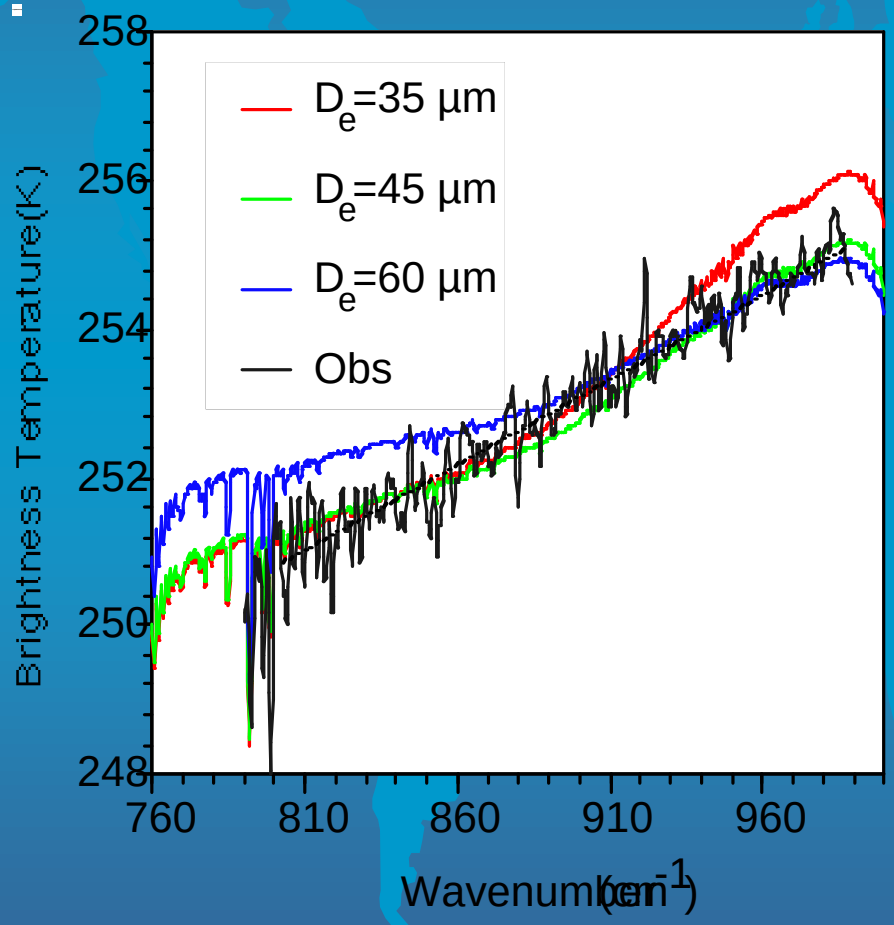
Cloud Lidar System (CLS) image

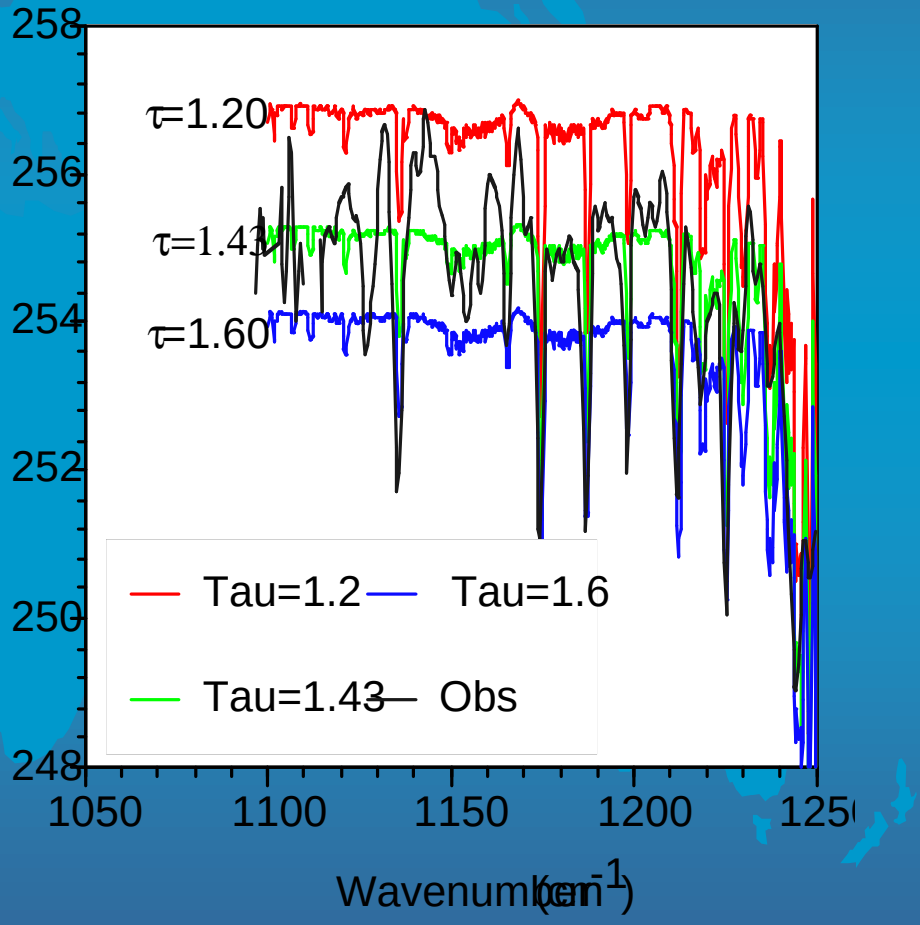


Observed and simulated upwelling IR spectra for cirrus and water cloud conditions



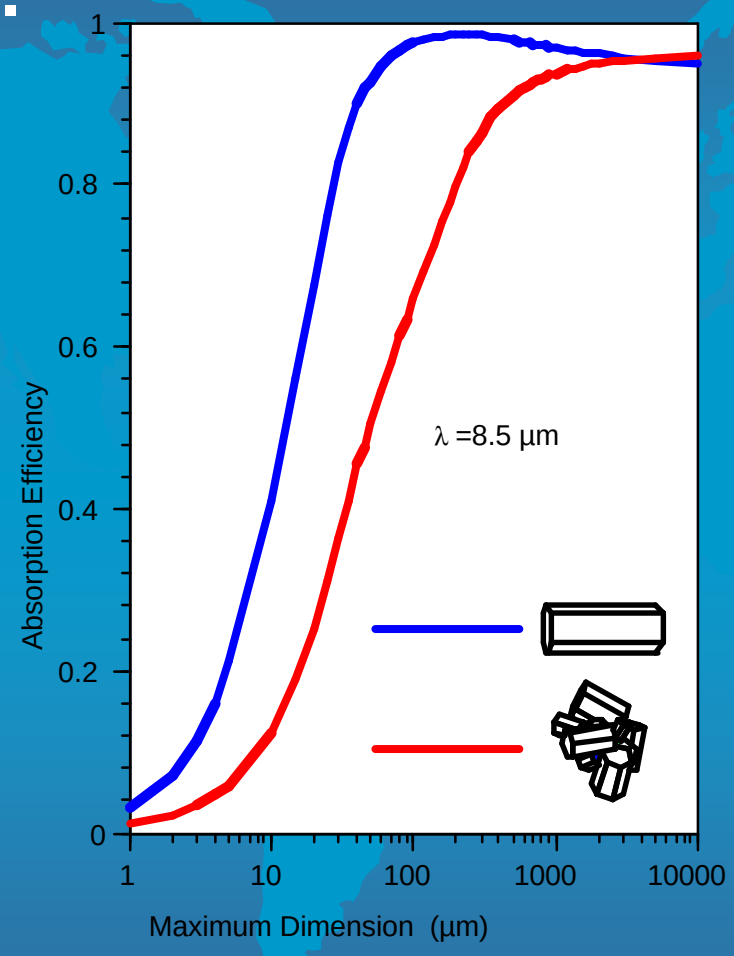
The simultaneous retrieval of the effective size and optical thickness from HIS spectra

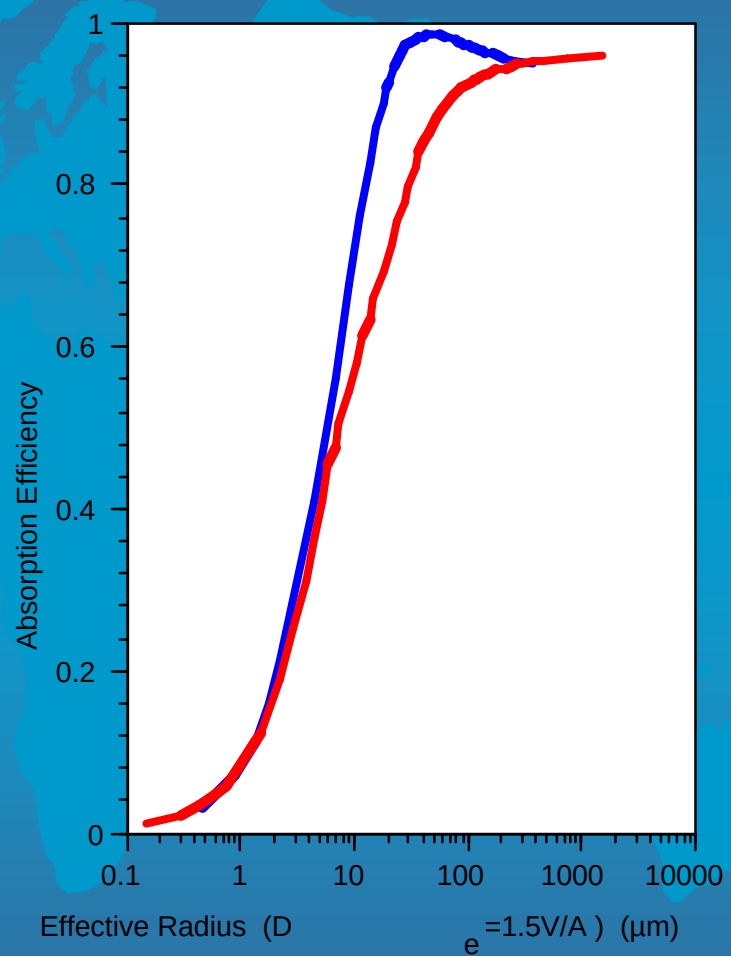




Plan for Next Year

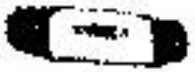
- Improve the modeling of the single-scattering properties of clouds (ice, water and mixed-phase clouds)
  - More realistic habits
  - Recent microphysical measurement (e.g., CRYSTAL-FACE data)
- Improve the speed and accuracy of the fast cloudy radiative transfer model
- Consider multi-layered cloud system
- Fast model for mixed-phase clouds


Absorption Efficiency
1
0.8
0.6
0.4
0.2
0
λ =8.5 μm
1
10
100
1000
10000
Maximum Dimension (μm)


Absorption Efficiency
1
0.8
0.6
0.4
0.2
0
0.1
1
10
100
1000
10000
Effective Radius (D
e
=1.5V/A) (μm)

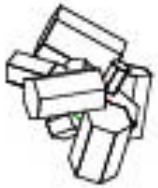
hollow column

plate



bullet rosette

aggregate

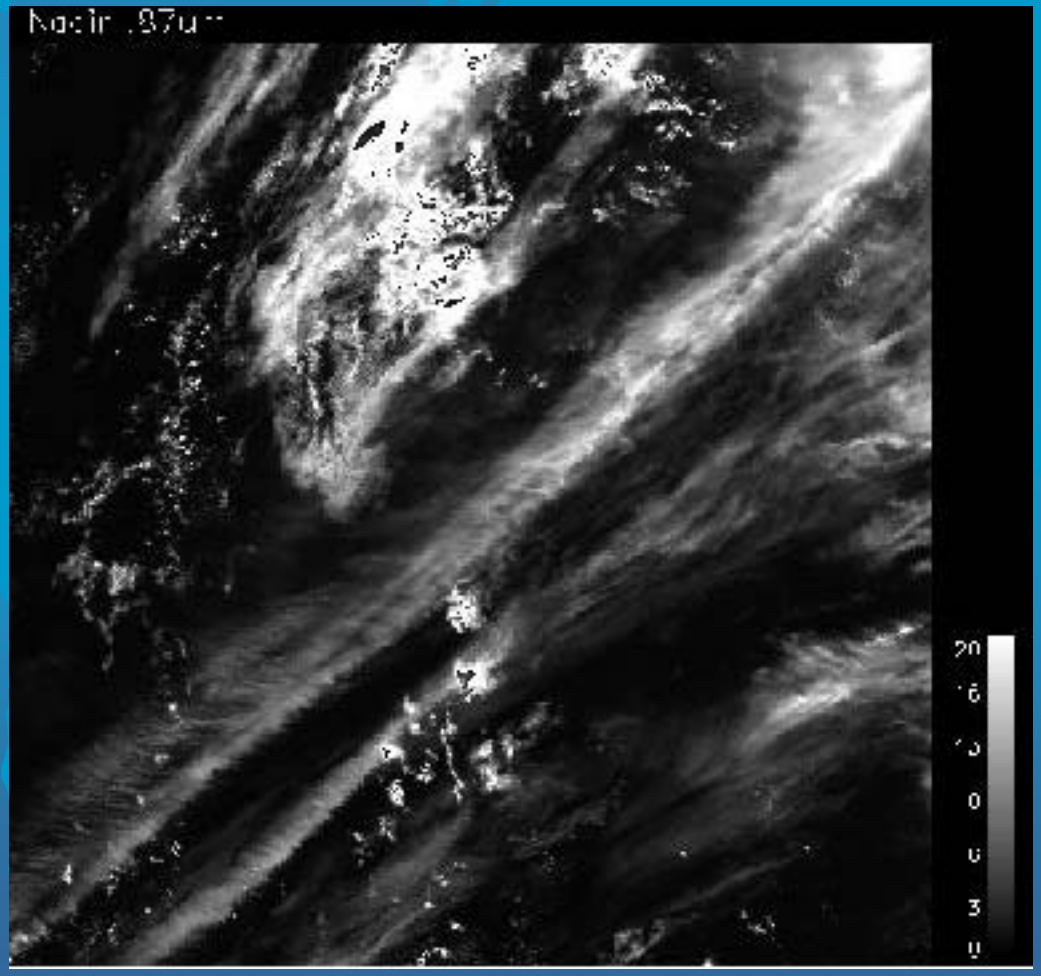


Test of Cirrus Scattering Model developed by Yang et al. for MODIS

ATSR-2 Data at 0.65 μm

21 July, 1996; Latitude -32.5°; Longitude -95.9°

(Courtesy of A. Baran, UK Met Office)

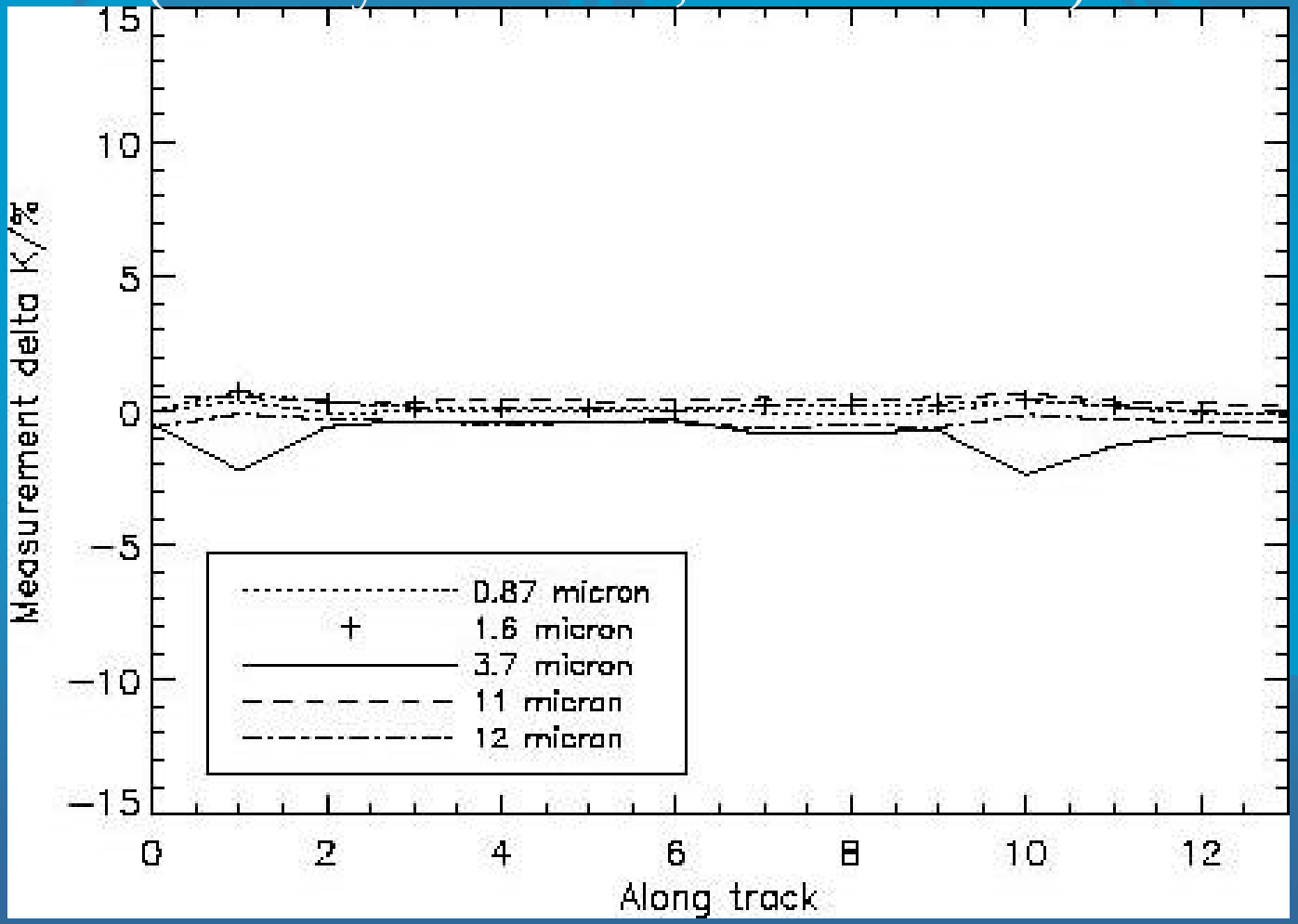


ATSR-2 Cirrus Results

21 July, 1996;

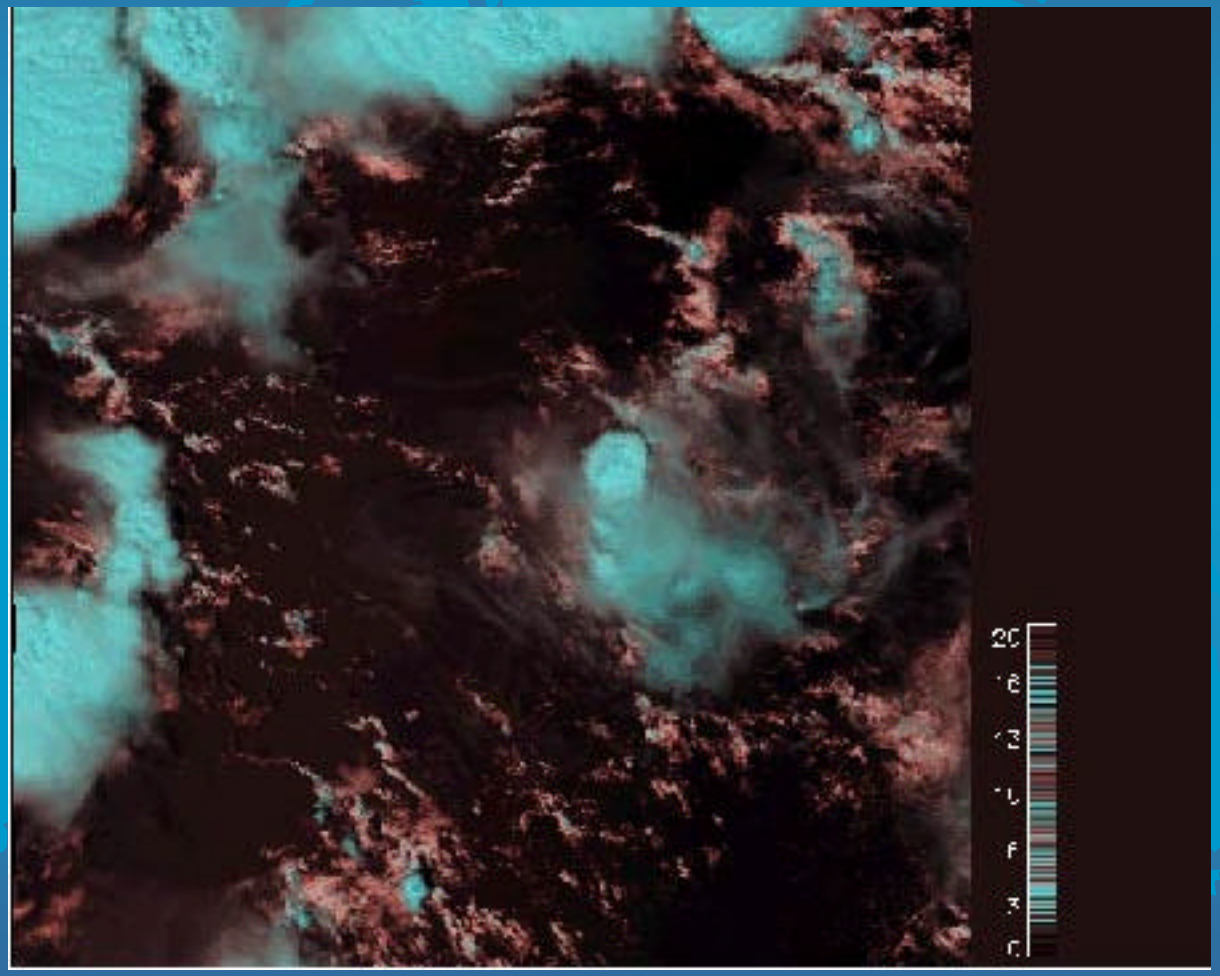
Latitude -32.5°; Longitude -95.9°; Scattering angle: 118.9° (nadir)

(Courtesy of A. Baran, UK Met Office)

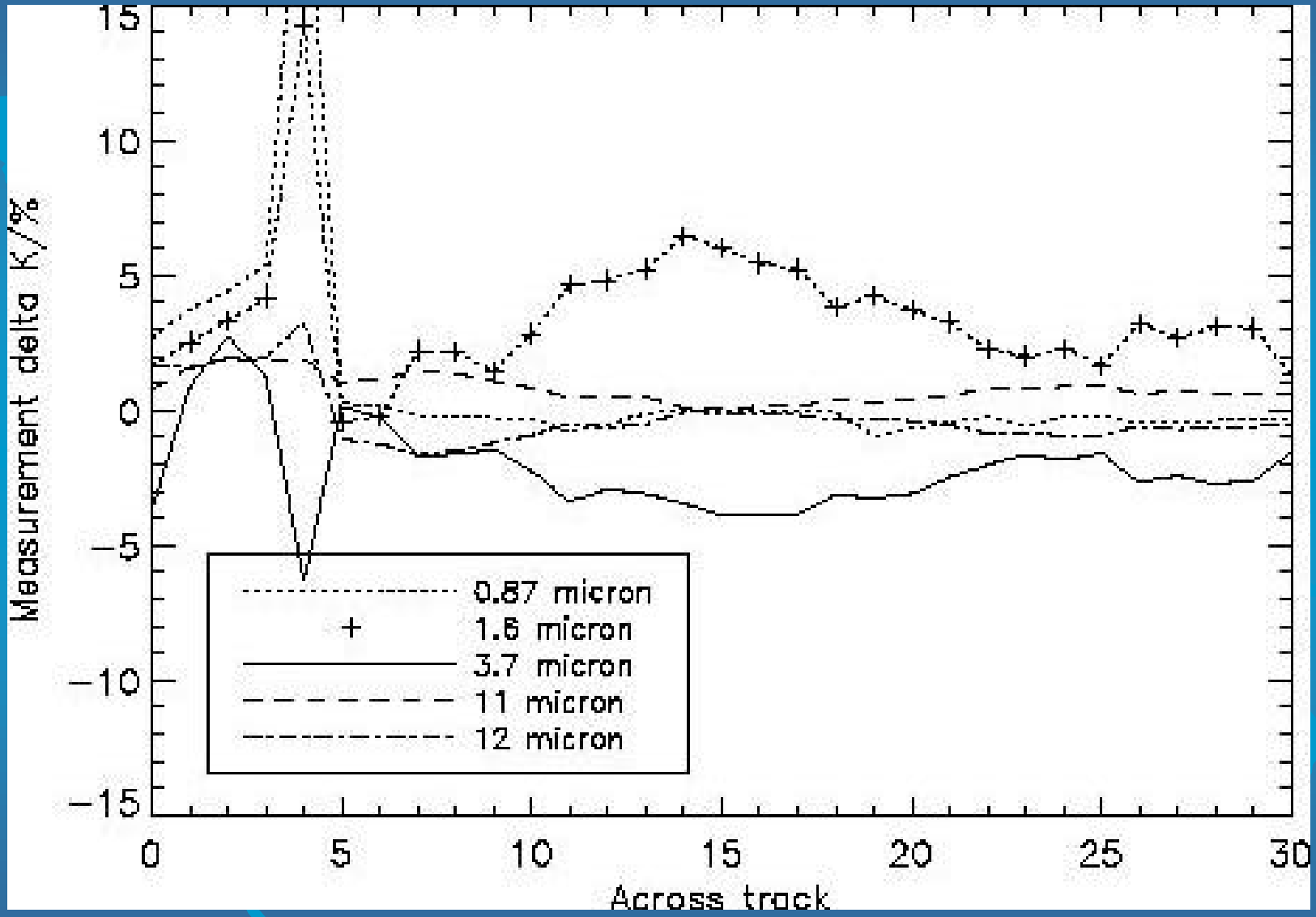


ATSR-2 Data at 0.65 mm
23 July, 1996; Latitude -10.1°; Longitude -122.6°

False Color Image
R: 0.65 μm reflectance
G: 0.87 μm reflectance
B: 1.6 μm reflectance



(Courtesy of A. Baran, UK Met Office)


Measurement delta K/%
15
10
5
0
−5
−10
−15
0
5
10
15
20
25
30
Across track
0.67 micron
1.6 micron
3.7 micron
11 micron
12 micron

Thank you!