MW- and submm-Radiative-Transfer and Modelling of Cirrus Clouds

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Part I

- Concept of ARTS
- Scattering
- Iterative solution for vector radiative transfer equation (VRTE)
- Test results
- Summary and outlook

ARTS 1.0

- Radiative transfer model for microwave to the IR region
- 1D Spherical Atmosphere
- Refraction implemented
- Absorption: JPL, HITRAN, different continuum models
- Modular program
- ARTS 1.0 is available for download:

http://www.sat.uni-bremen.de/arts

Model Intercomparison

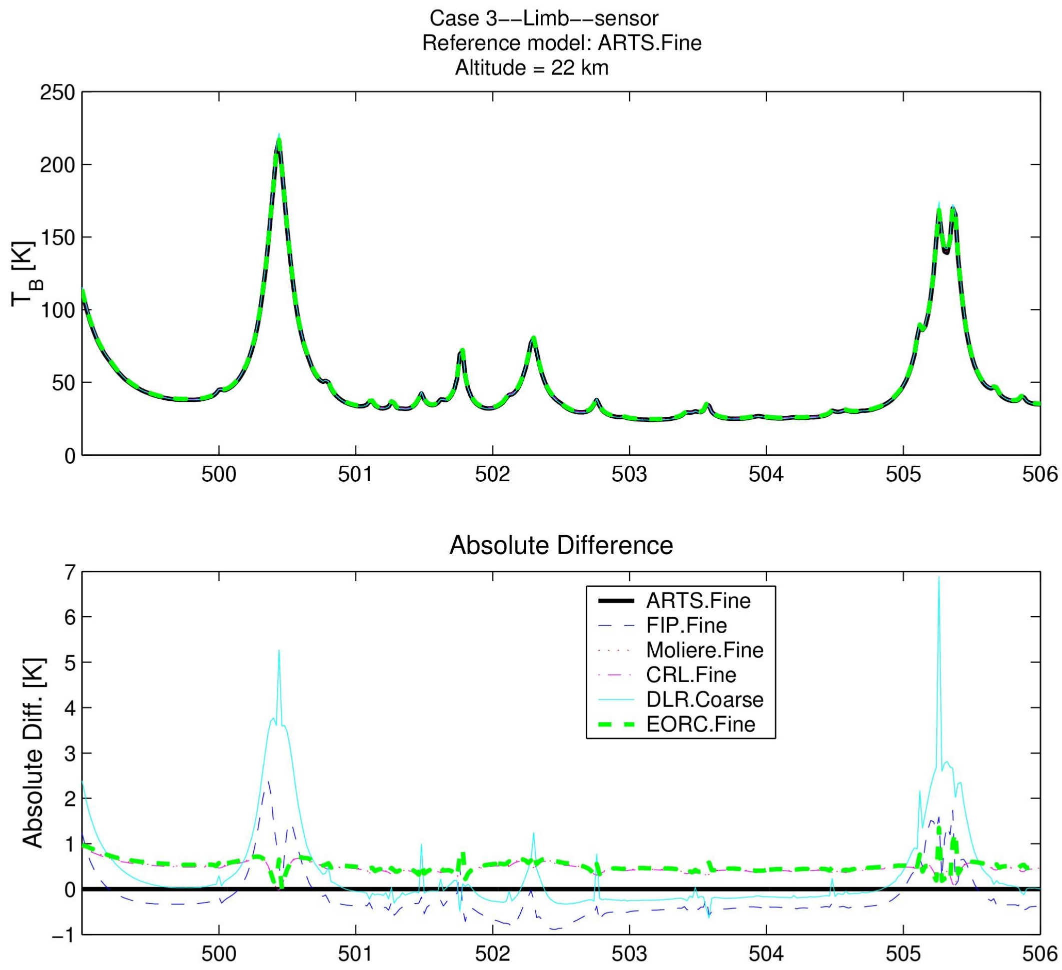
- Participating models:
  - ARTS
  - MAES (CRL, Japan)
  - MOLIERE (Observatoire de Bordeaux, France)
  - EORC (NASDA, Japan)
  - „Karlsruhe“ Model (Forschungszentrum Karlruhe)
  - MIRART (DLR)
  - SMOCO (CRL and FACOM, Japan)
- Results have shown the reliability and accuracy of ARTS

Example for test

Test of radiative transfer codes, assuming a limb measurement

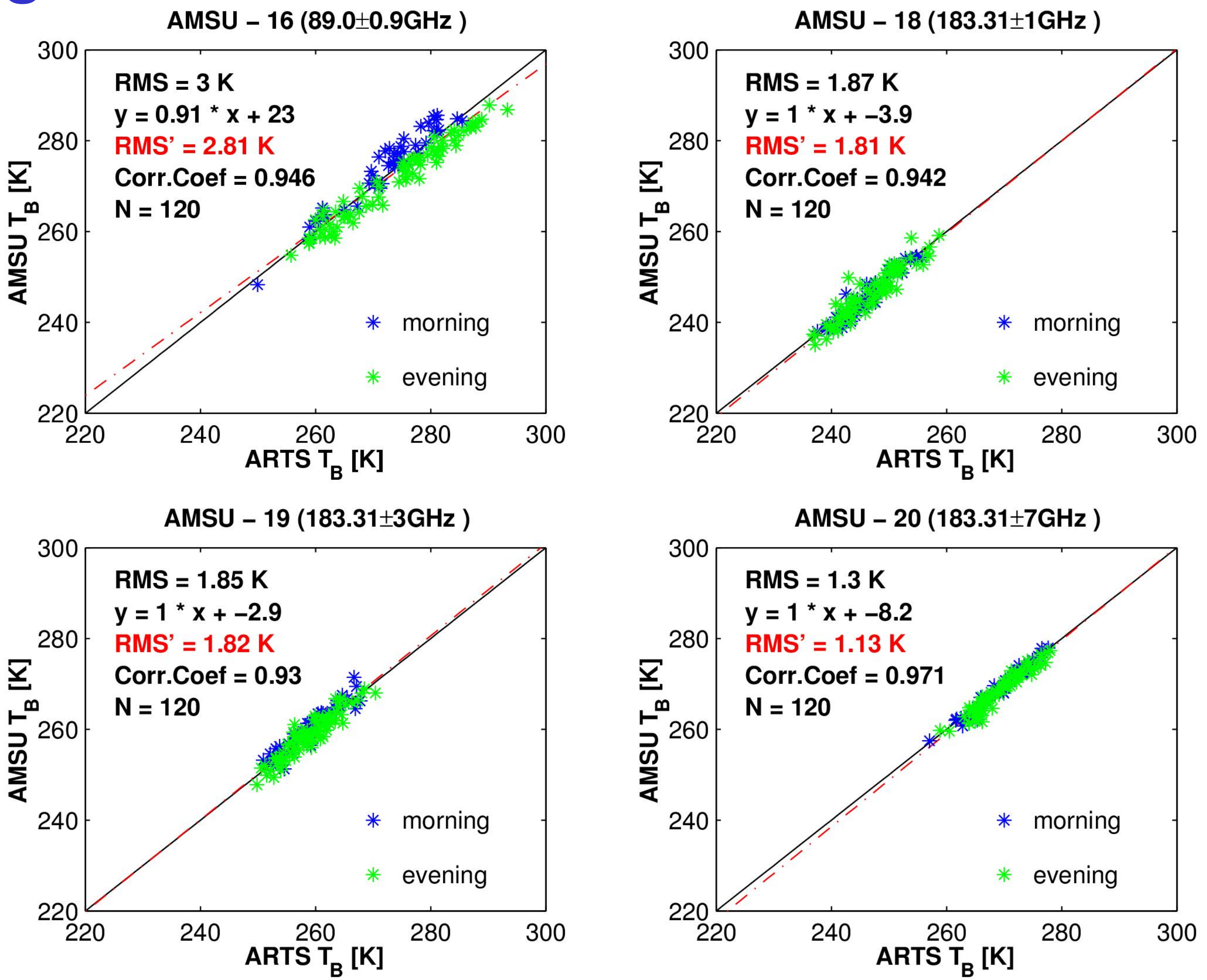
Input for the Intercomparison:

- Pre-calculated absorption coefficients
- Atmospheric profiles
- Instrumental characteristics



Validation of ARTS

Comparison between ARTS and AMSU data using radio sondes

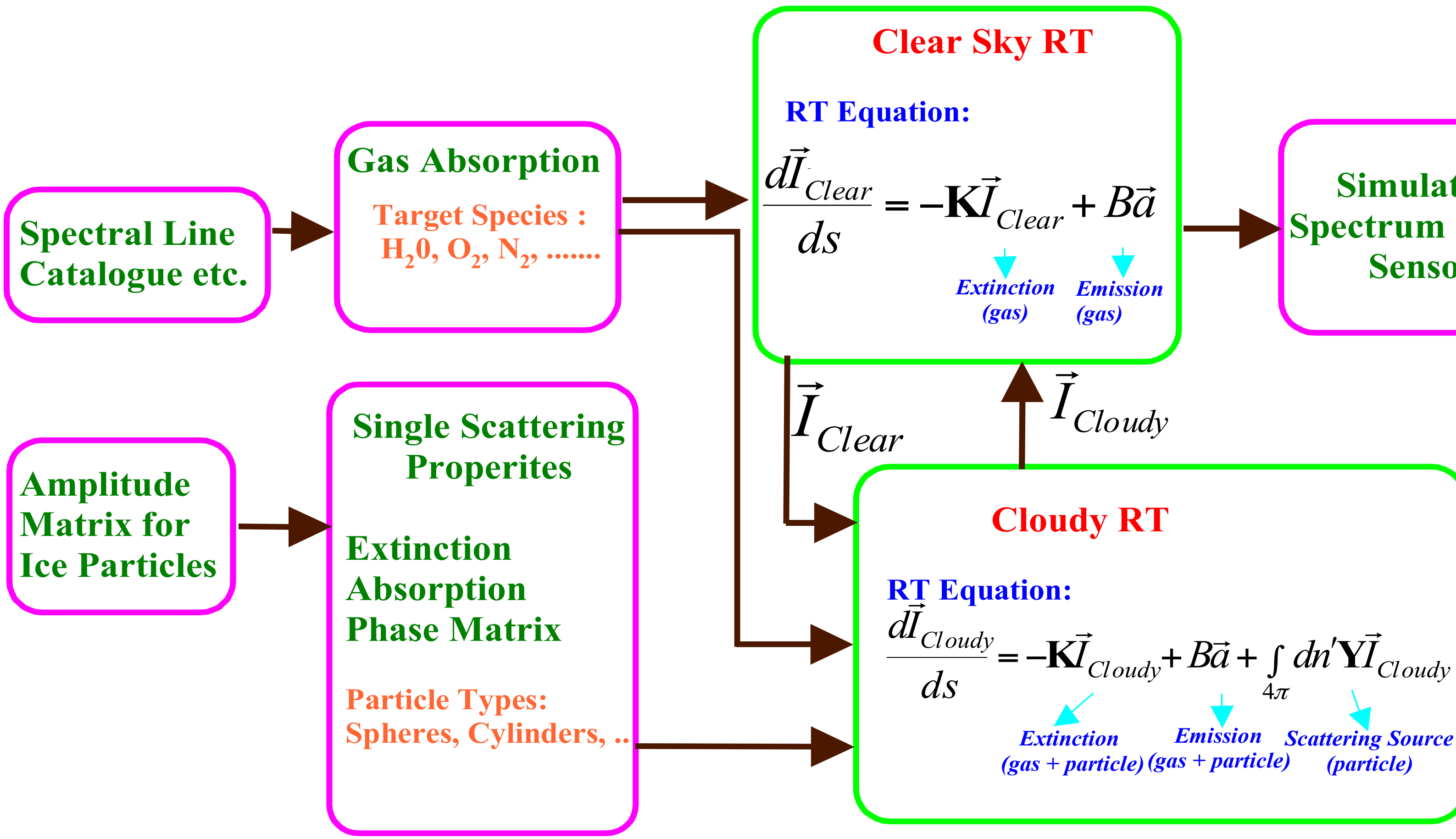


3D Scattering Radiative Transfer Model Vector Radiative Transfer Equation (VRTE)

Under Developments ready by mid 2003

- General scattering scheme
- Polarization
- 3D atmosphere. Atmospheric horizontal inhomogeneities have to be included for accurate scattering simulations
- Zeeman Effect, an expression for Zeeman splitting is at present only available in a dedicated radiative transfer model

Concept of ARTS



Iterative Solution Method for VRTE

$$\frac{d\vec{I}_{Cloudy}}{ds} = -\mathbf{K}\vec{I}_{Cloudy} + B\vec{a} + \int_{4\pi} dn'\mathbf{Y}\vec{I}_{Cloudy}$$

1. First guess radiation field in cloud box assuming clear sky field.
2. Calculate scattering integral field using clear sky field
3. Solve VRTE using the scattering integral field
   ⇨ First Iteration
4. Calculate scattering integral field using the first Iteration field.
5. Repeat steps 3 and 4
6. Convergence test after each iteration
   ⇨ final Solution

Absorption

- Absorption coefficients for atmospheric species are taken from catalogues (HITRAN, JPL), selected by the user

Continuum absorption

- O_2 and H_2O, MPM and PWR
  T. Kuhn, H. J. Liebe, P. W. Rosenkranz

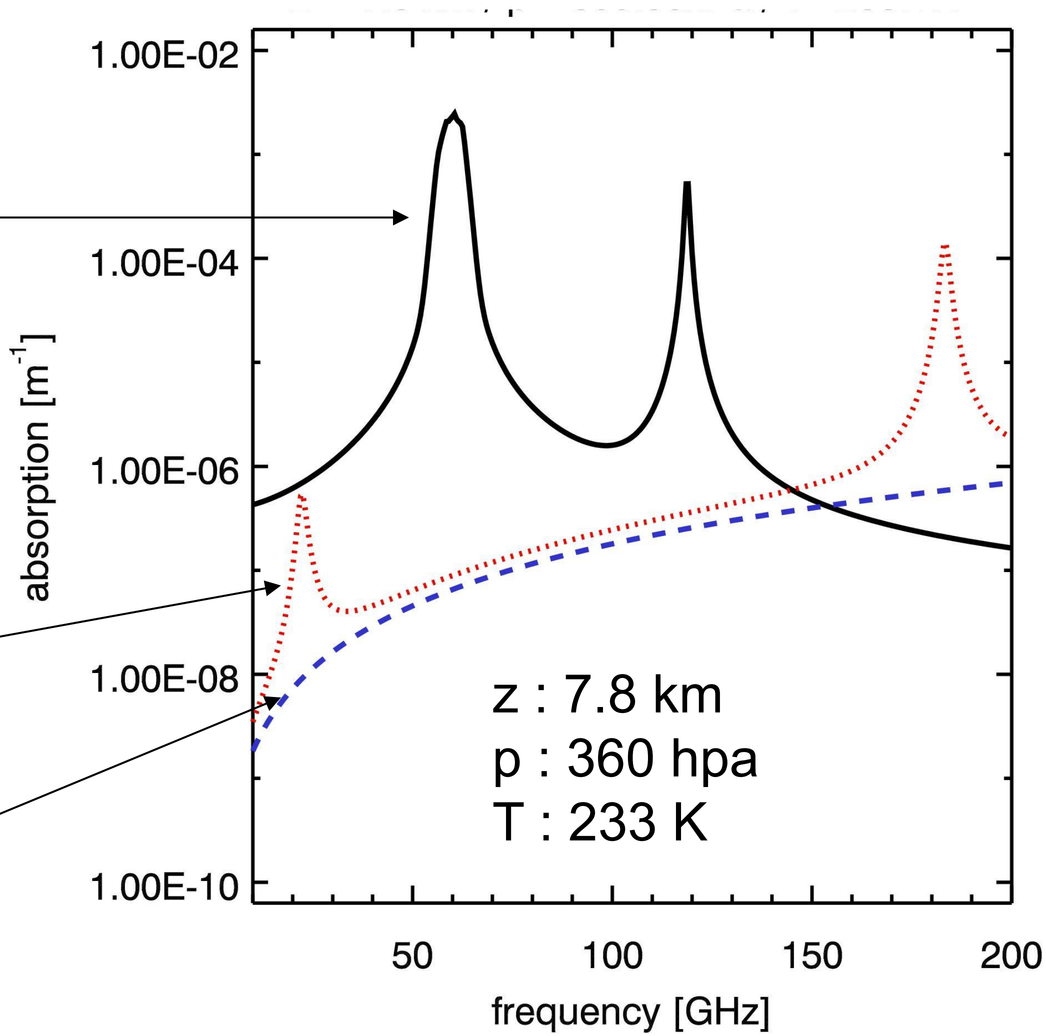
- N_2 Quantum mechanical model and MPM
  A. Borysow and L. Frommhold, "Collision induced Rototranslational Absorption Spectra of -N2 Pairs for Temperatures from 50 to 300 K", Astrophysical Journal, Vol. 311, 1986

Example

O_2 PWR

H_2O PWR

N_2 Continuum



Single Scattering Properties

Depending on particle shape, different methods are required

- Mie theory: spherical particles
- T-matrix (Trasition) method: cylinders, plates, spheroids, spheres
- DDA (Discrete Dipole Approximation): arbitrary shape

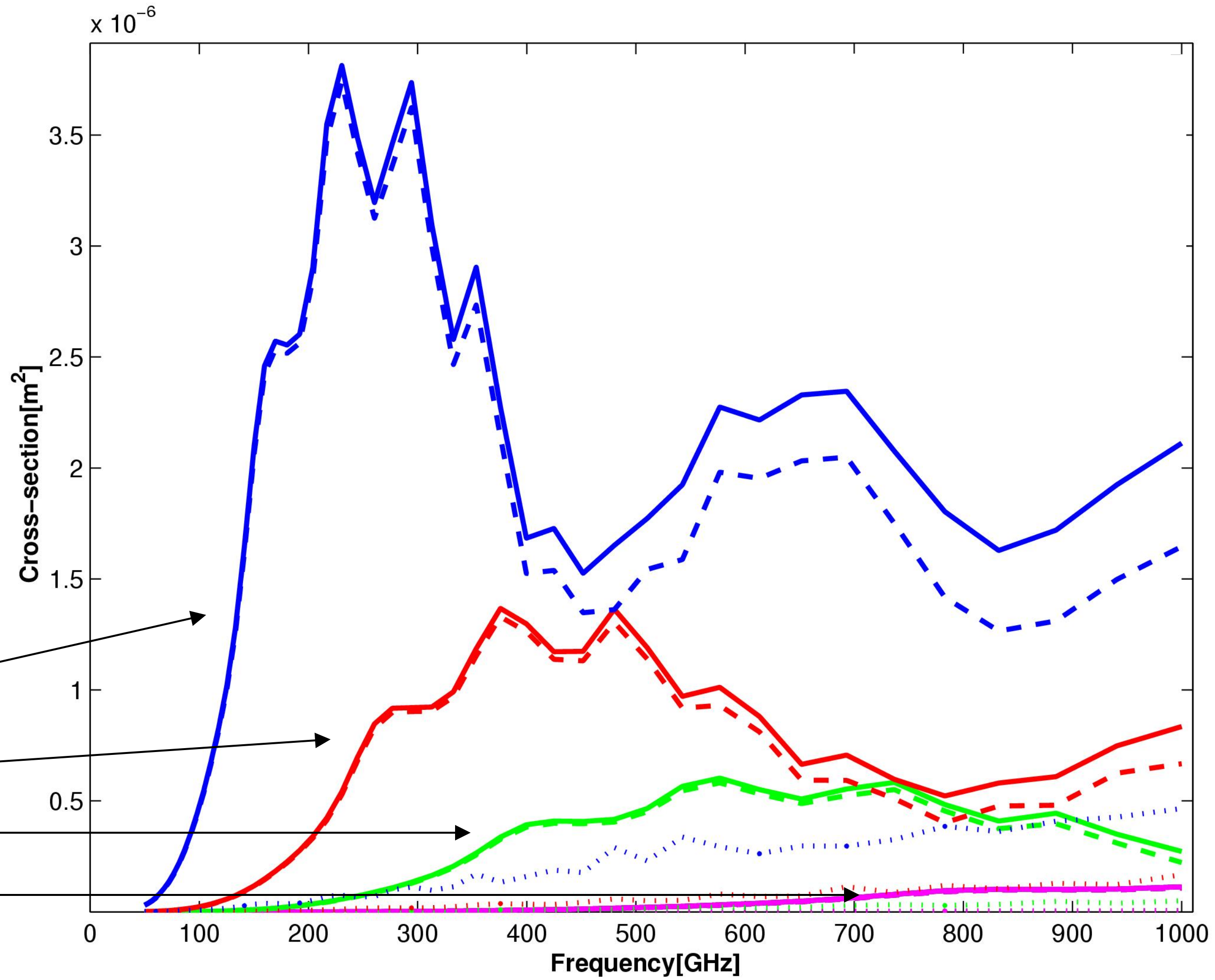
Single scattering properties database

- Amplitude matrix data for different types are stored in a database
- From the amplitude matrix the optical properties are derived
- *All methods can be used to create files for the database*

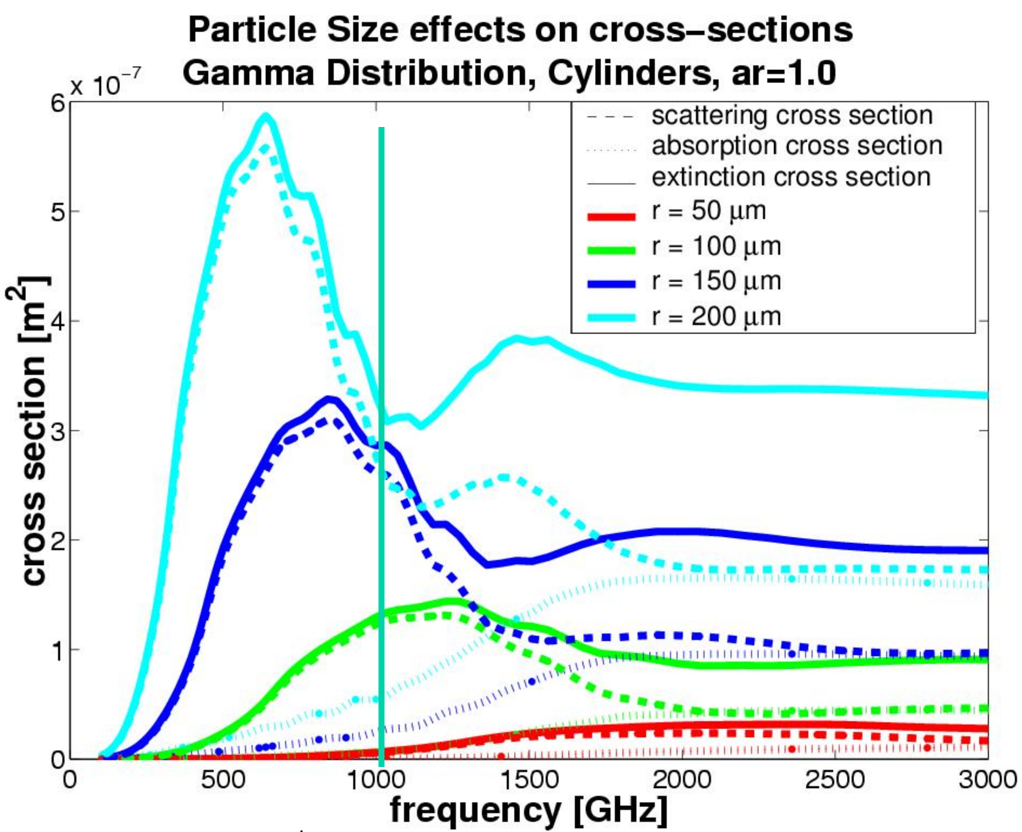
Example

solid: Extinction cross section
dashed: Scattering cross section
dotted: Absorption cross section

Spherical particles
with Radius:
500 µm
300 µm
200 µm
100 µm



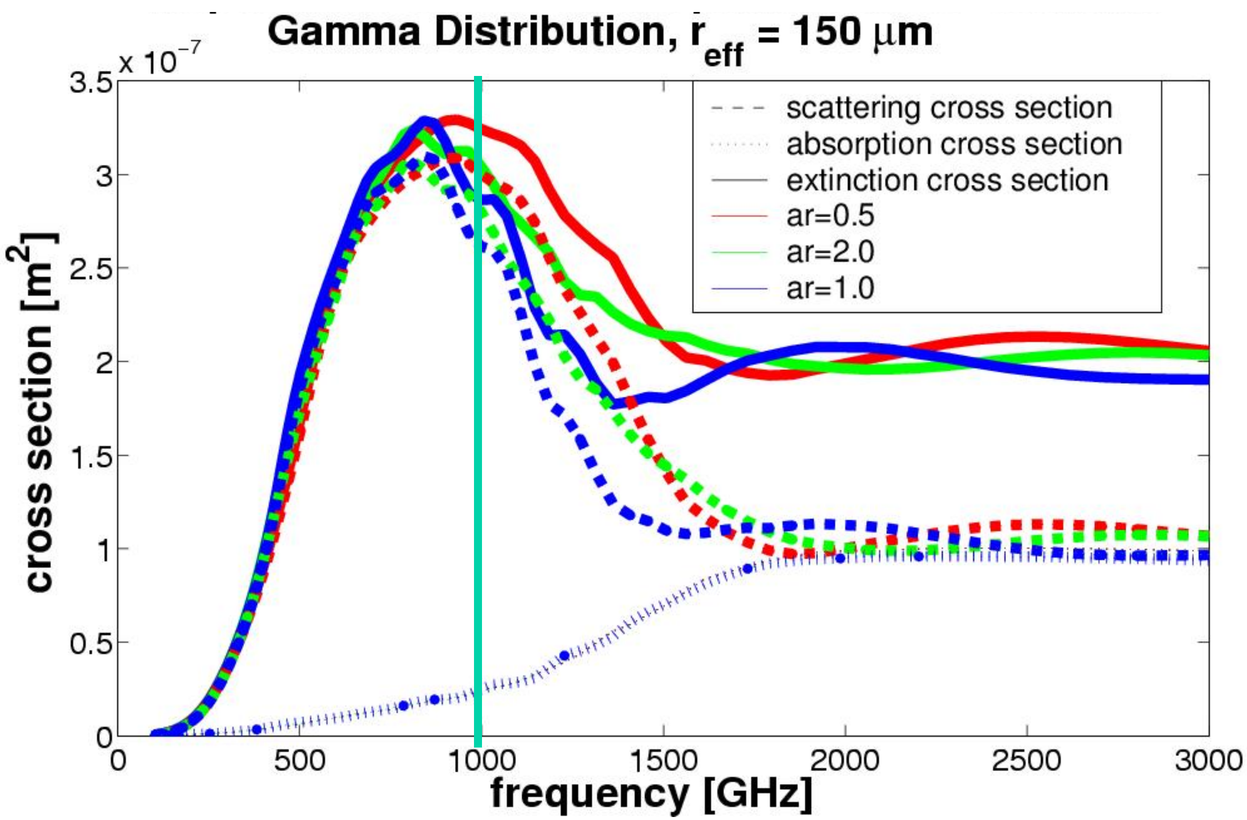
Particle Size Effects



Gamma Distribution:

$$u(r) = \frac{1}{r_{eff}\left(\frac{1-2b}{b}\right)}\left(\frac{r}{r_{eff}b}\right)^{(1-3b)/b}\exp\left(-\frac{r}{r_{eff}b}\right) \qquad b=1$$

Particle Aspect Ratio Effect



Test results

Setup for 1D test calculation

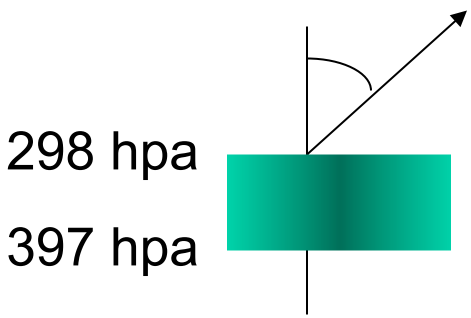
- Frequency: 325 GHz
- Cloud: - Cylindrical particles, size radius r=200 μm (equal volume sphere)
  - Particle number density: 5000 m^{-3}
  - Range: 397 – 298 hpa (approximately 8 - 9.5 km)
- Convergence limit: 0.03 K

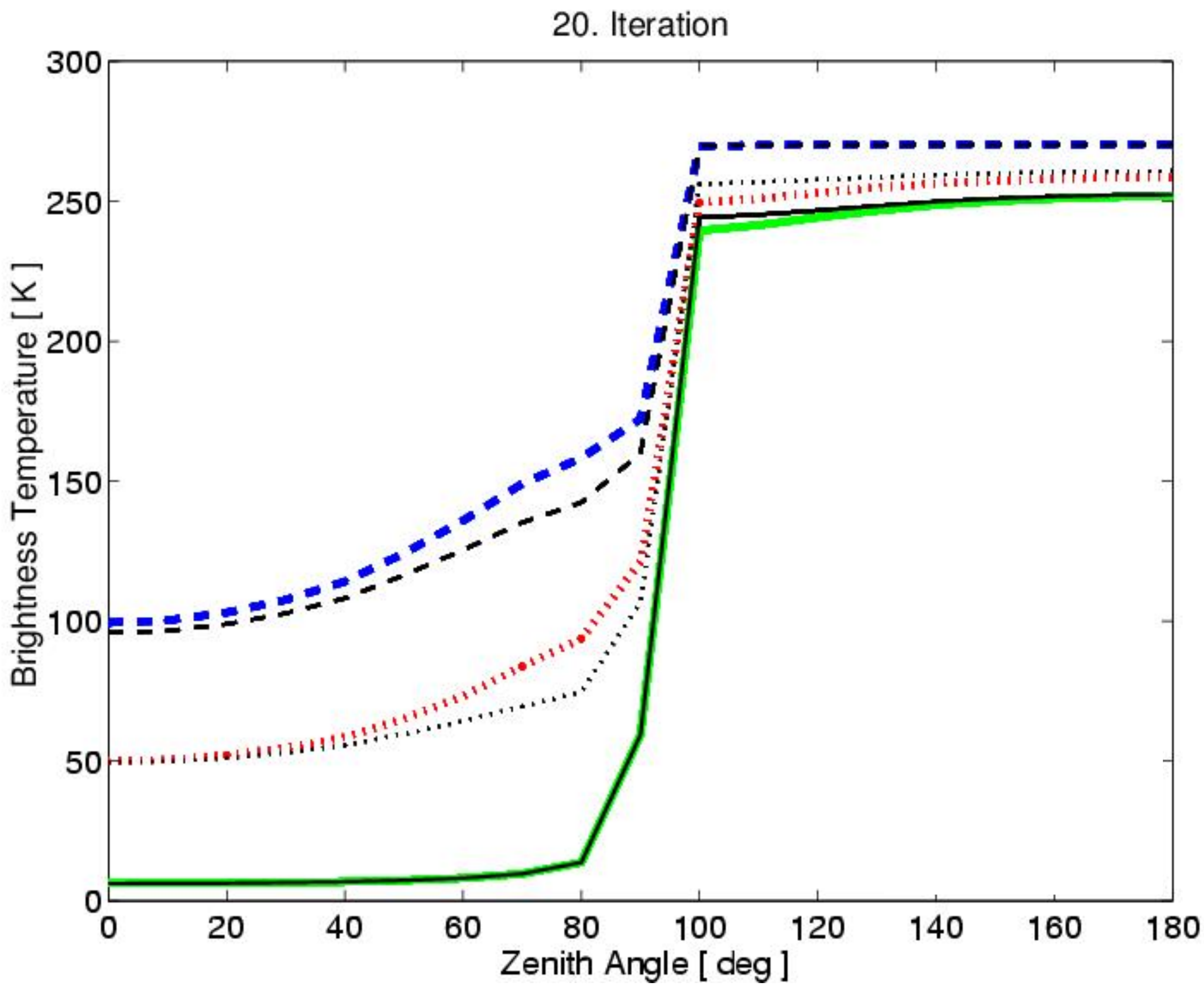
Example

black: clear sky
colour: scattered
solid: p=298 hpa
dotted : p=336 hpa
dashed : p=397 hpa

<u>Cylindrical Particles</u>

Zenith angle





Test for particle shape and size distribution

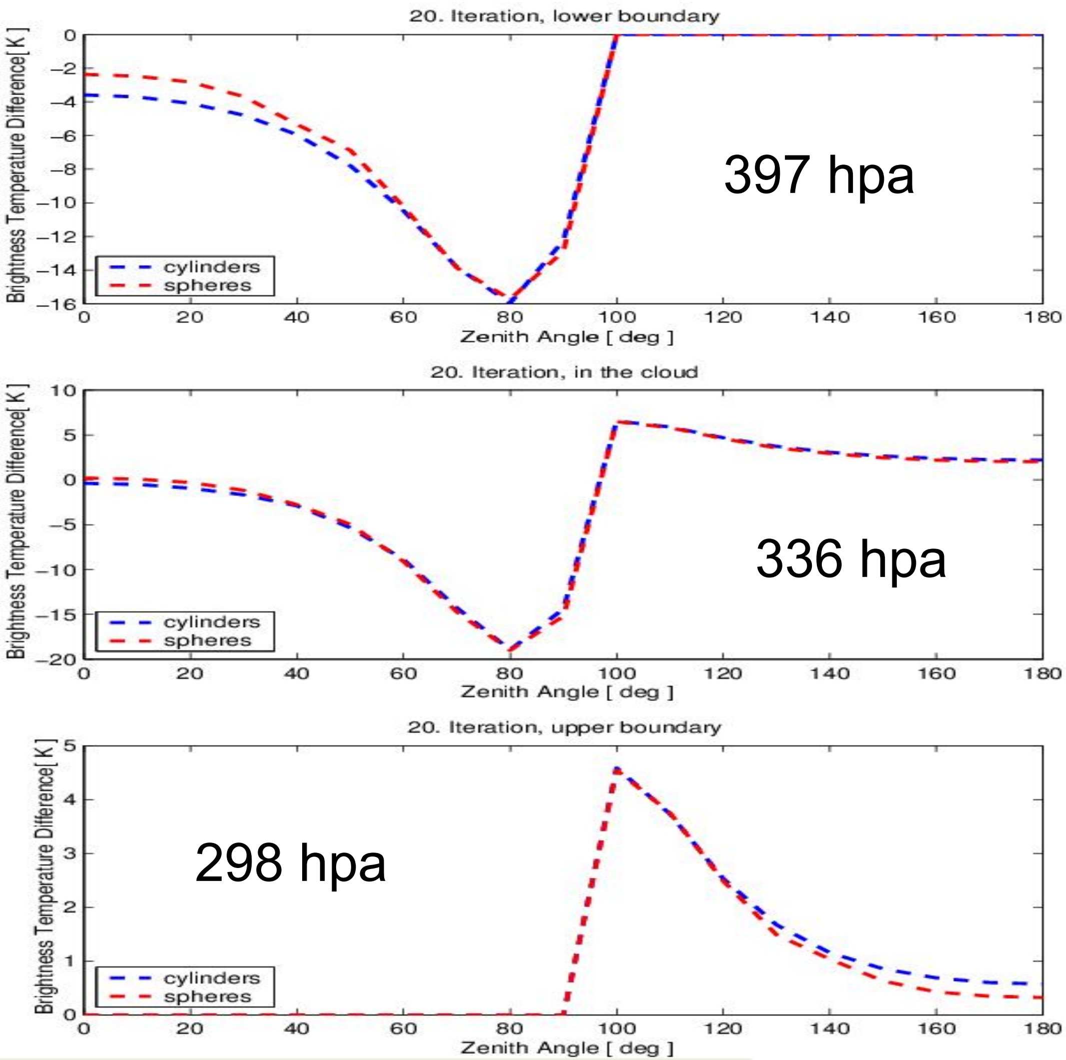
- Cloud: a) Cylindrical particles, size r_{eff}= 200 μm (equal volume sphere) Aspect ratio ar=0.5 (Length/Diameter)
  b) Spherical particles, size r=200 μm
- Particle number density: 5000 m^{-3}
- Range: 397 – 298 hpa (approximately 8 - 9.5 km)
- Convergence limit: 0.03 K

Example

Shown is the difference between the case with and without scattering at different altitudes for:

cylindrical particles: blue

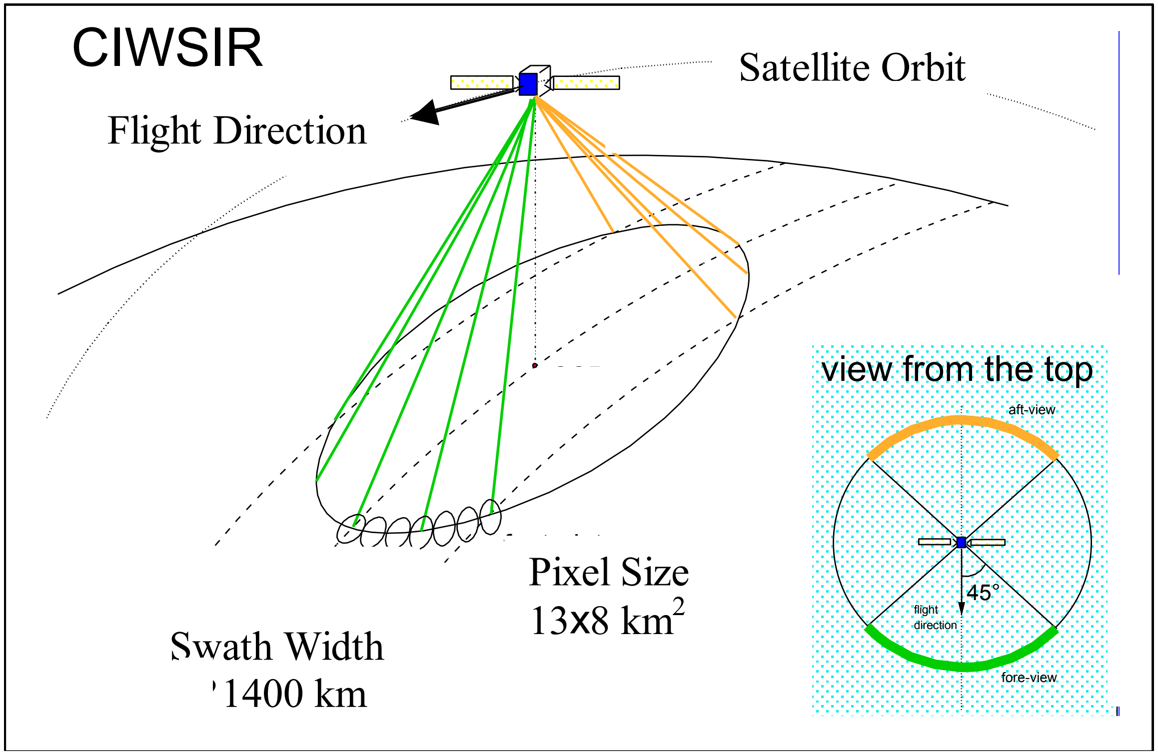
spherical particles: red



Summary and outlook

- ARTS 3D polarized scattering model for the microwave to the IR region is under development and is being validated, will be ready end 2003
- Test calculations show the expected behaviour
- The general approach is very versatile for many applications, including limb sounding
- The 3D geometry allows to consider many situations of importance in meteorology

Part II
Sensor



CIWSIR
Cloud Ice Water Sub-millimetre Imaging Radiometer

- CIWSIR - Scientific Goals
- Channel selection
- Effect of cirrus clouds in the mm/sub-mm range - Observations
- Effect of cirrus clouds in the mm/sub-mm range - Simulations
- Retrieval using CIWSIR
- Some technical Information
- Summary

Objectives

CIWSIR is a space-born sub-mm sensor which can give daily coverage of upper tropospheric ice cloud information by providing:

- Global and continuous observations

This will support:

- The Climatology of cirrus properties
- Help to improve the parameterized treatment of ice clouds in models
- better understanding of ice cloud microphysics

What CIWSIR Observes

In the presence of cirrus clouds, the up welling radiation from lower layers of the atmosphere is reduced.

In the frequency range used for CIWSIR the lower troposphere is opaque.

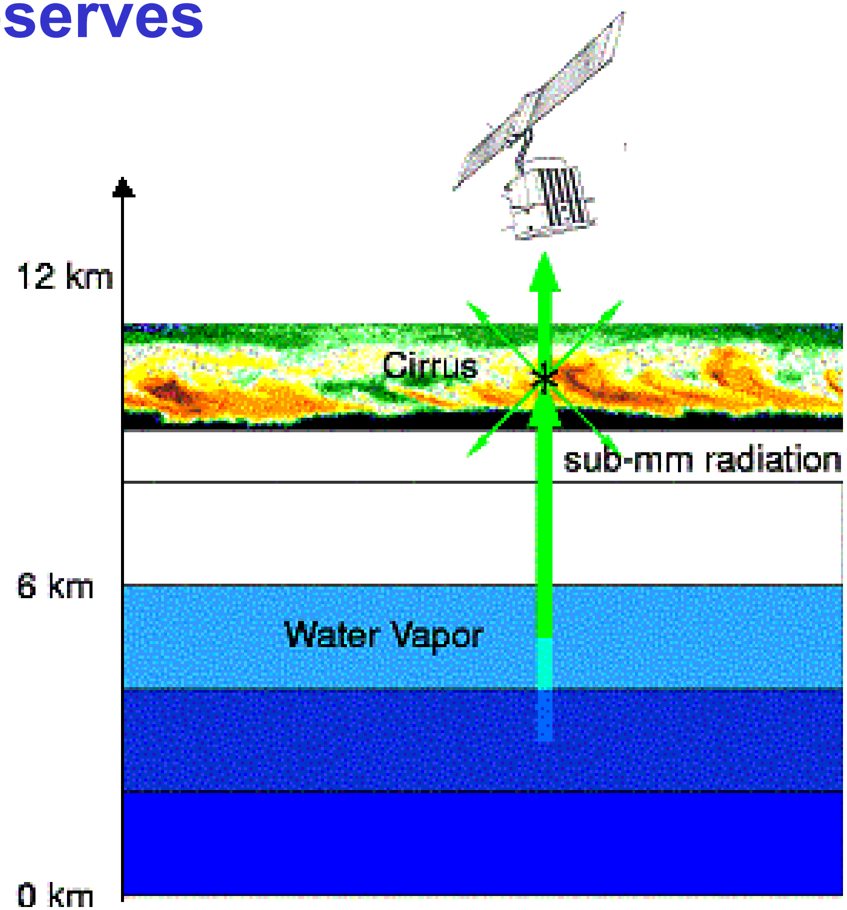
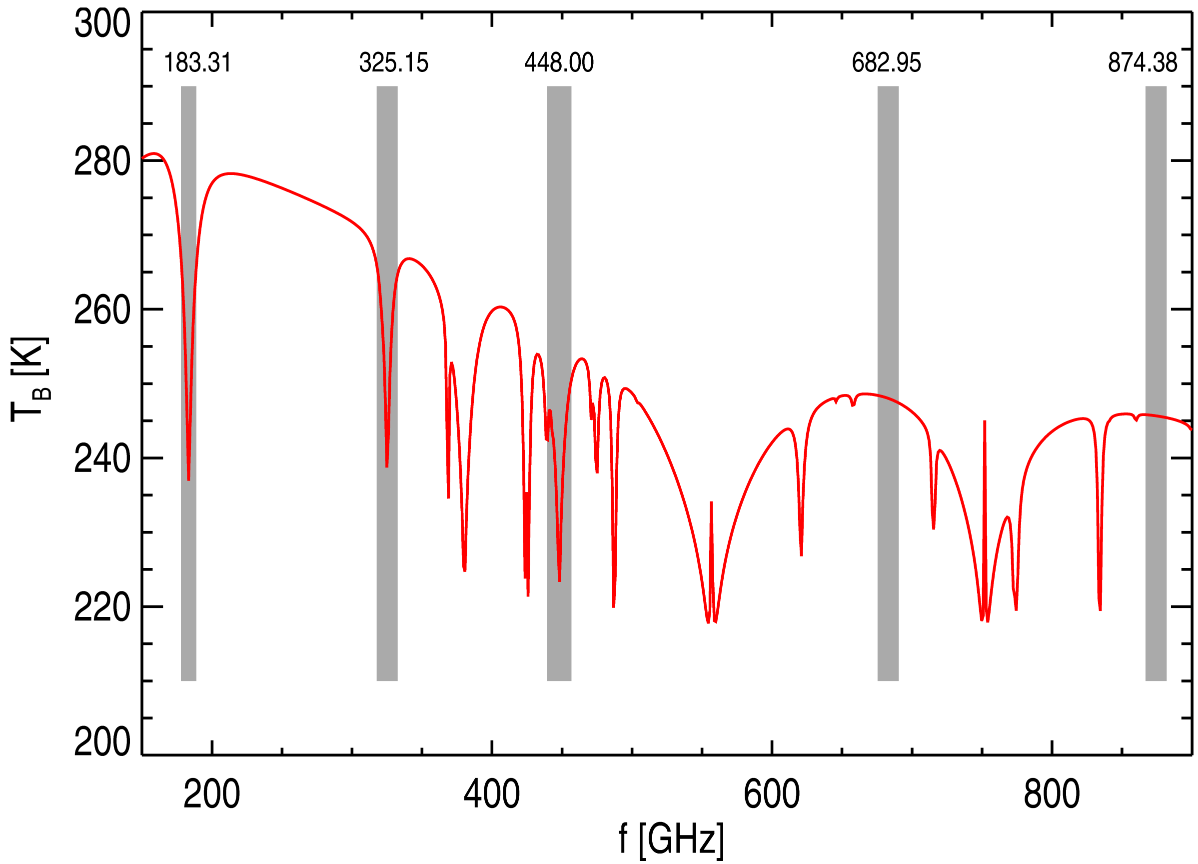


Figure personal communication, F. Evans

CIWSIR Channels

The clear sky radiance spectrum as measured by a satellite radiometer with the 5 CIWSIR bands



Effect of IWP

The Signal of ice clouds in the sub-mm wave spectral range is quite strong for large IWPs. This is because scattering causes brightness temperatures to go well below physical temperatures.

5 CIWSIR bands

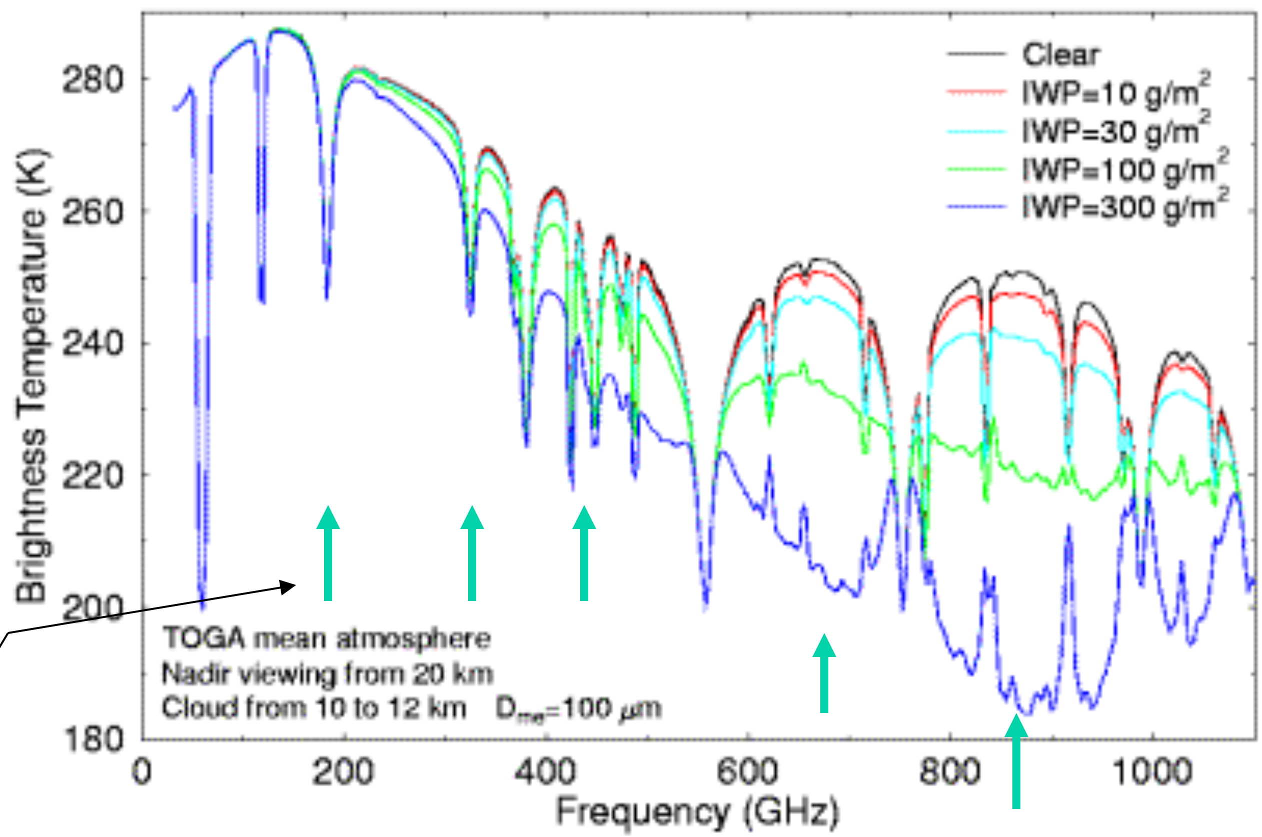
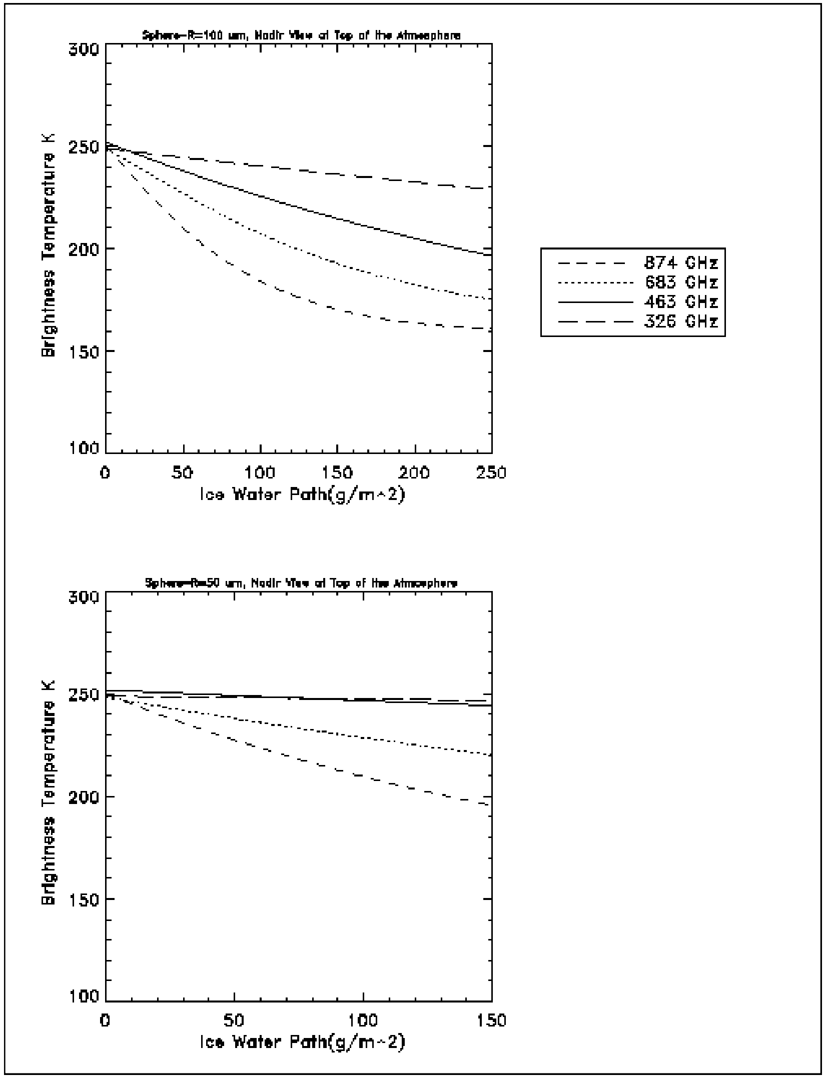


Figure personal communication, F. Evans

Effect of IWP at CIWSIR channels

Top plot: Cloud from 5 to 7 km altitude, particle radius 100 µm.

Bottom plot: Cloud from 9 to 10 km altitude, particle radius 50 µm.



Effect of Size

For small particles maximum signal occurs at high frequency. for larger particles the frequency of the maximum signal depend on particle size

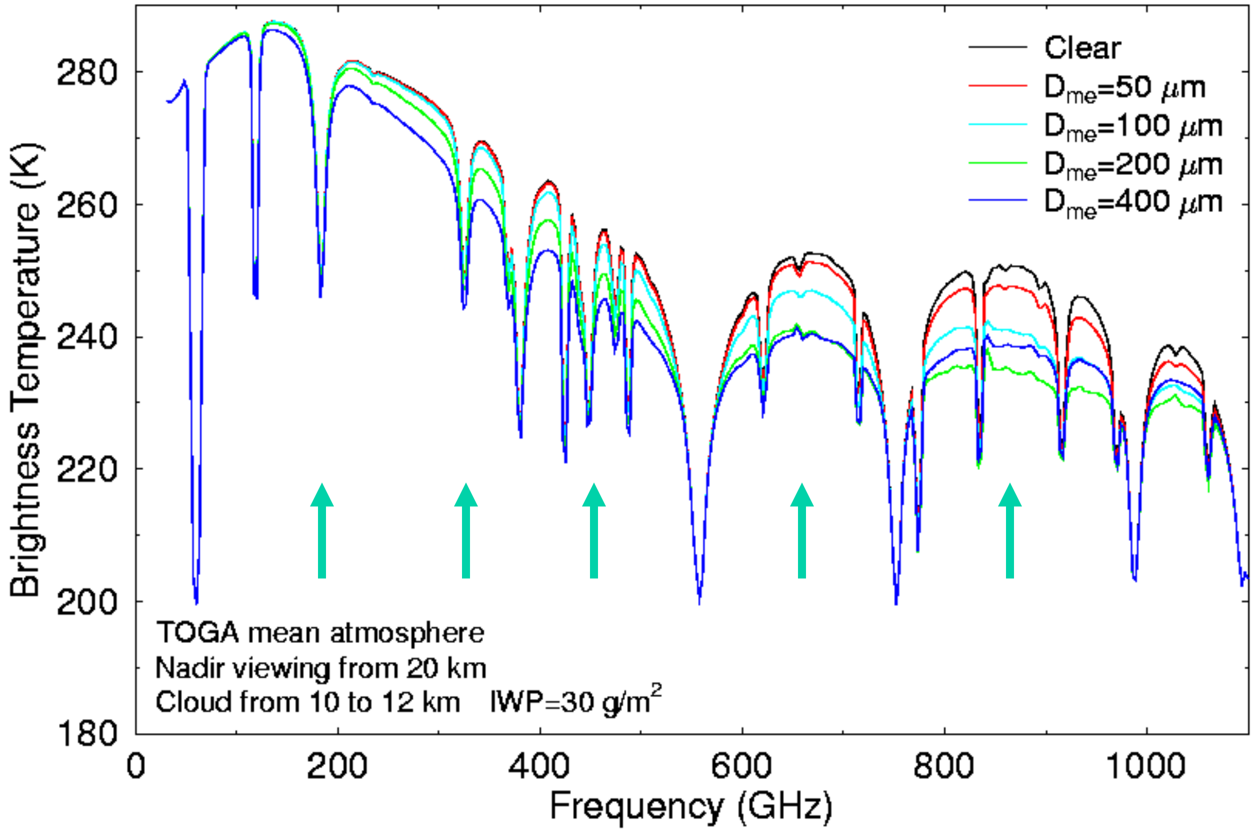
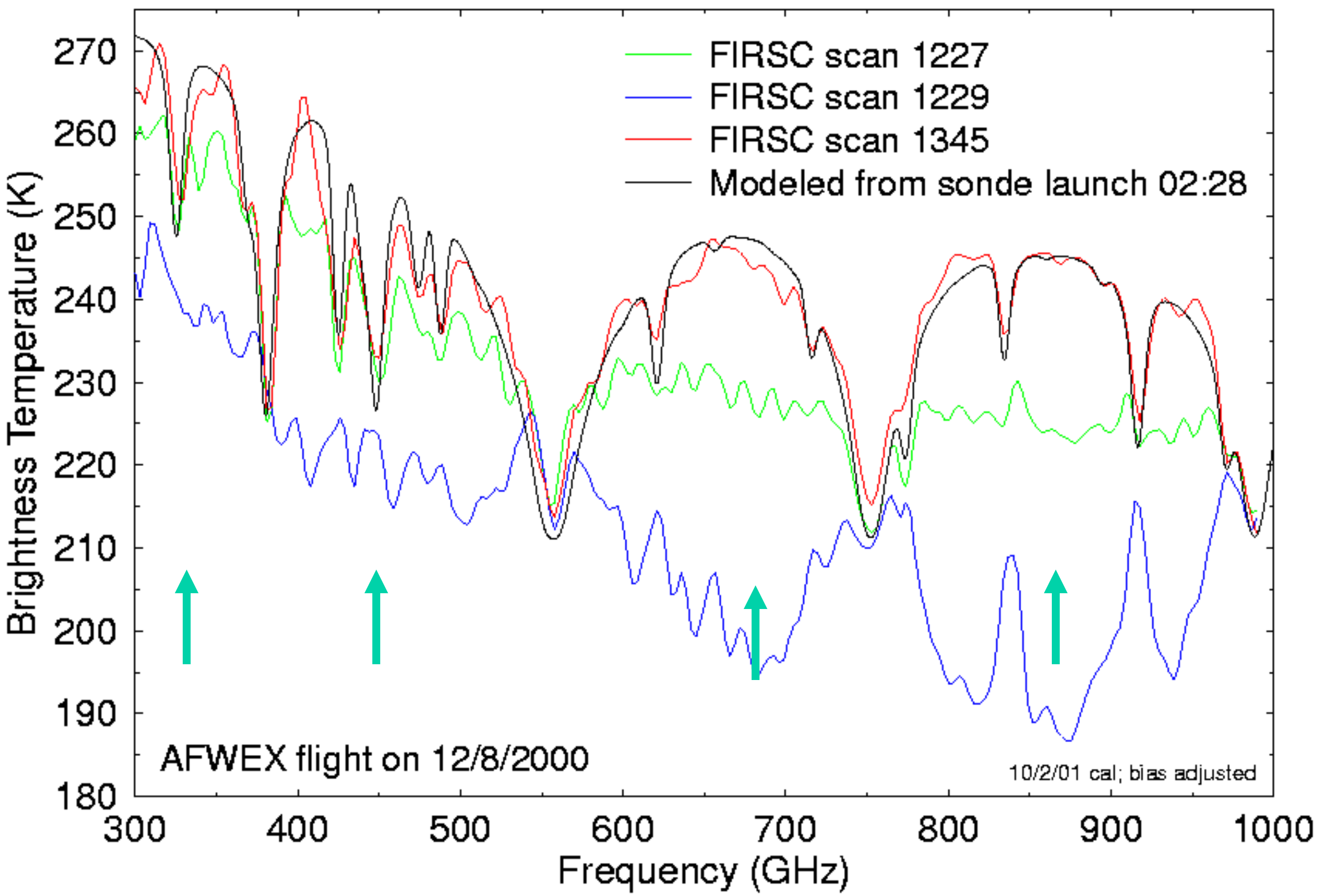


Figure personal communication, F. Evans

Sensitivity of sub-mm radiance to UT ice clouds

FIRSC observations on December 8, 2000 UTC near the ARM site in Oklahoma (Vanek et.al, 2001)

Scan 1345 was for clear sky, and scans 1227 and 1229 were two situations with cirrus



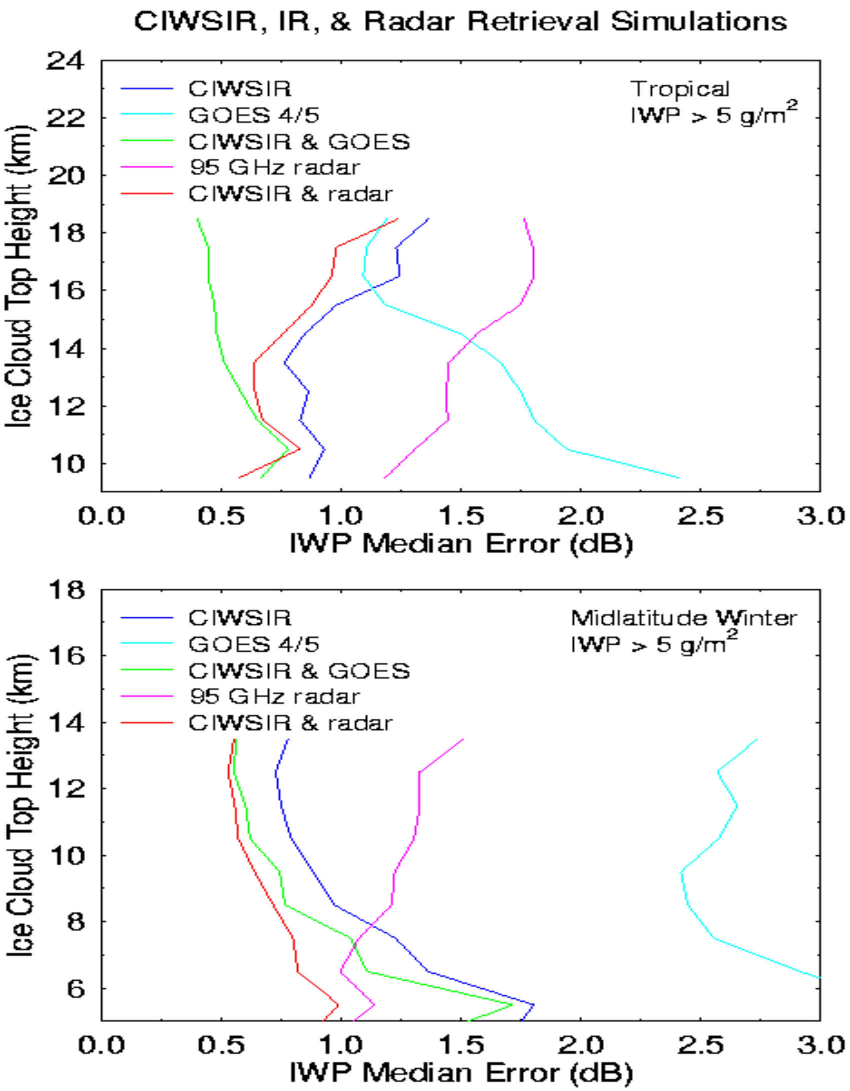
CIWSIR – Retrieval parameters

- Ice Water Path (IWP): Brightness temperature depression is directly proportional to IWP
- Ice Particle Size: Ratio of brightness temperature depressions measured at two frequencies can be used to determine particle size. A convenient measure is the median diameter of the mass equivalent sphere
- Ice Particle shape: The depolarization effect of horizontally oriented non-spherical ice particles can be used to obtain particle shape information

CIWSIR Retrievals

IWP median error as a function of cloud top height for tropical and mid-latitude winter retrieval simulations. The full 11 channel CIWSIR configuration is compared to, and combined with 10.7μm and 12 μm GOES channels and with integrated backscatter and mean height from a 95 GHz Radar.

(Figure from CIWSIR proposal, provided by F.Evans)

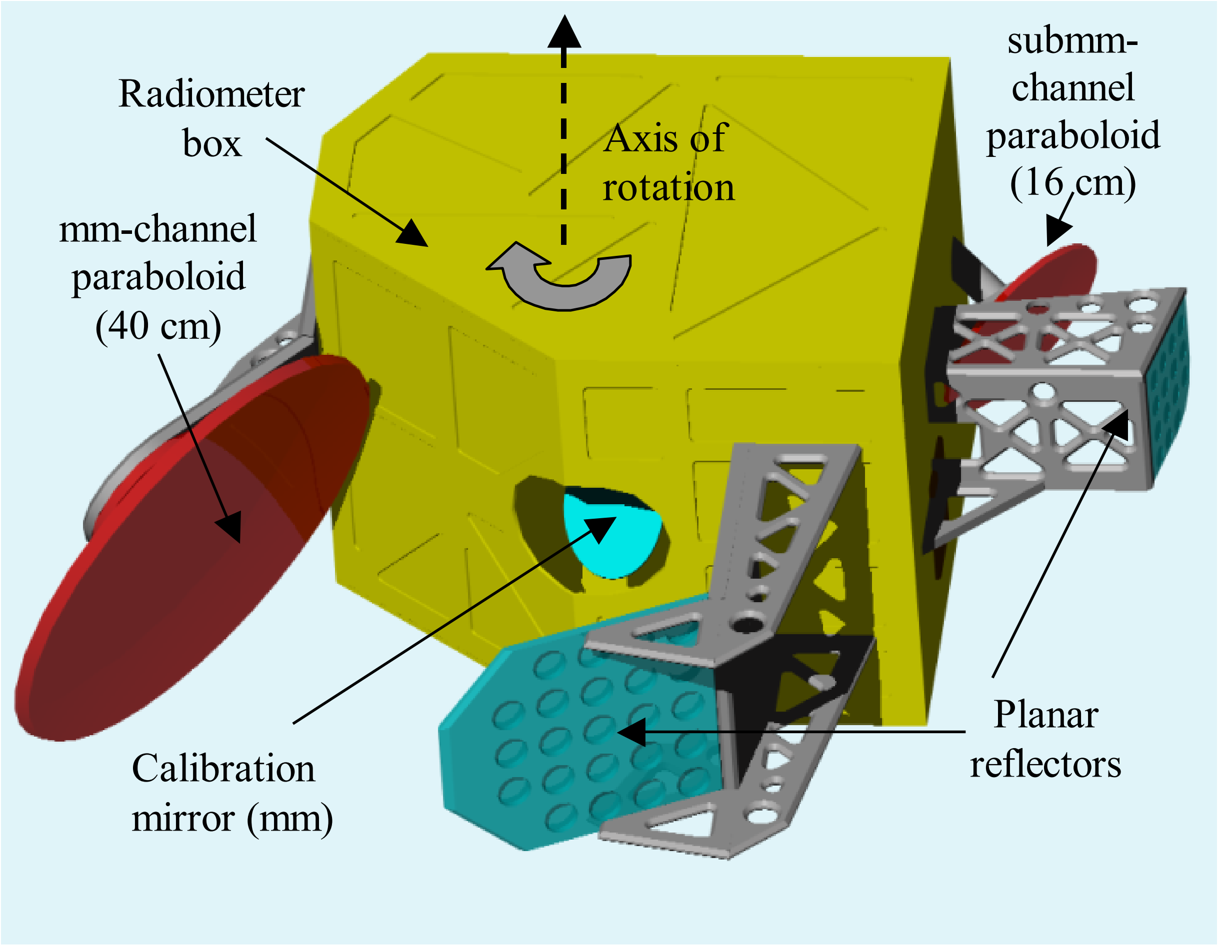


Technical Characteristics for CIWSIR

- 5 channels over the range of 183 to 889 GHz
- Conical scan, 1400 km swath width
- Antenna IFOV 0.35° corresponding to a 13x7.8 km^2 elliptical area
- Antenna major diameter: 40 cm for channels 1 and 2,
  16 cm for channels 3,4 and 5

- Subharmonic Mixers for channels (system noise in parenthesis) 1 (1000), 2 (2000) and 3 (2500), fundamentally pumped mixers for channels 4 (3000) and 5 (5000)

- mass 70 kg, volume Diameter 1100 mm, height 430 mm, power 100 W, data rate ≈ 60 kbps

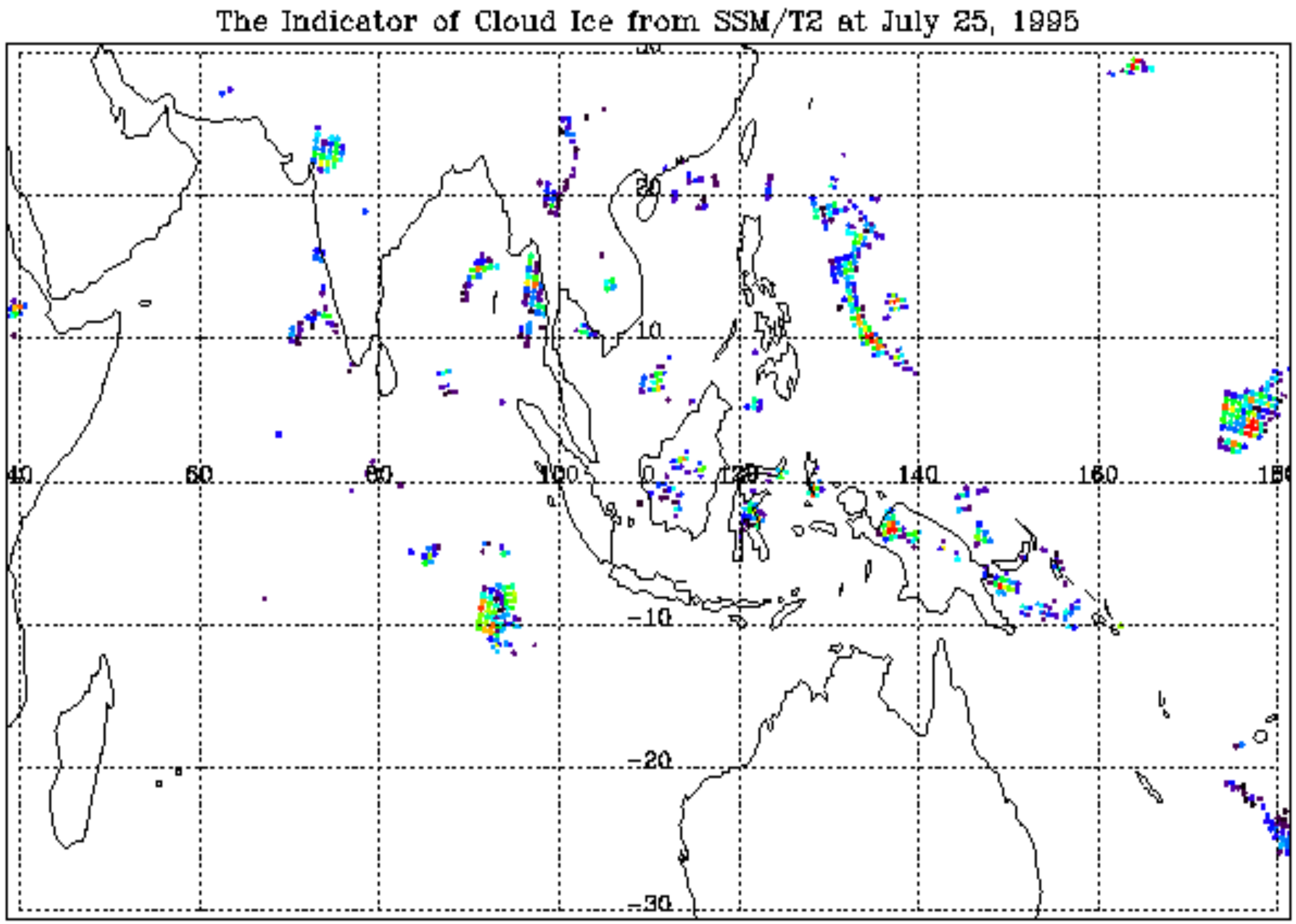

Radiometer box
Axis of rotation
submm-channel paraboloid (16 cm)
mm-channel paraboloid (40 cm)
Calibration mirror (mm)
Planar reflectors

A “precursor” to CIWSIR

- The SSM/T2 or AMSU-B 183 GHz brightness temperature differences can be used as a cloud ice indicator
- For clear sky, channels closer to the line centre are always coldest. With ice clouds the difference is decreased, or even reversed
- Because of the relatively low frequencies, this is useful only for strong convective ice clouds, not for thin cirrus

Example

The colour indicates the total amount of cloud ice, which increases from blue through green to red.



Part III

Observations from Geostationary Orbit

- Early Proposals for Geostationary Microwave Radiometers
- Sounding Altitudes for Temperature retrieval
- Sounding Altitudes for Water vapour measurements

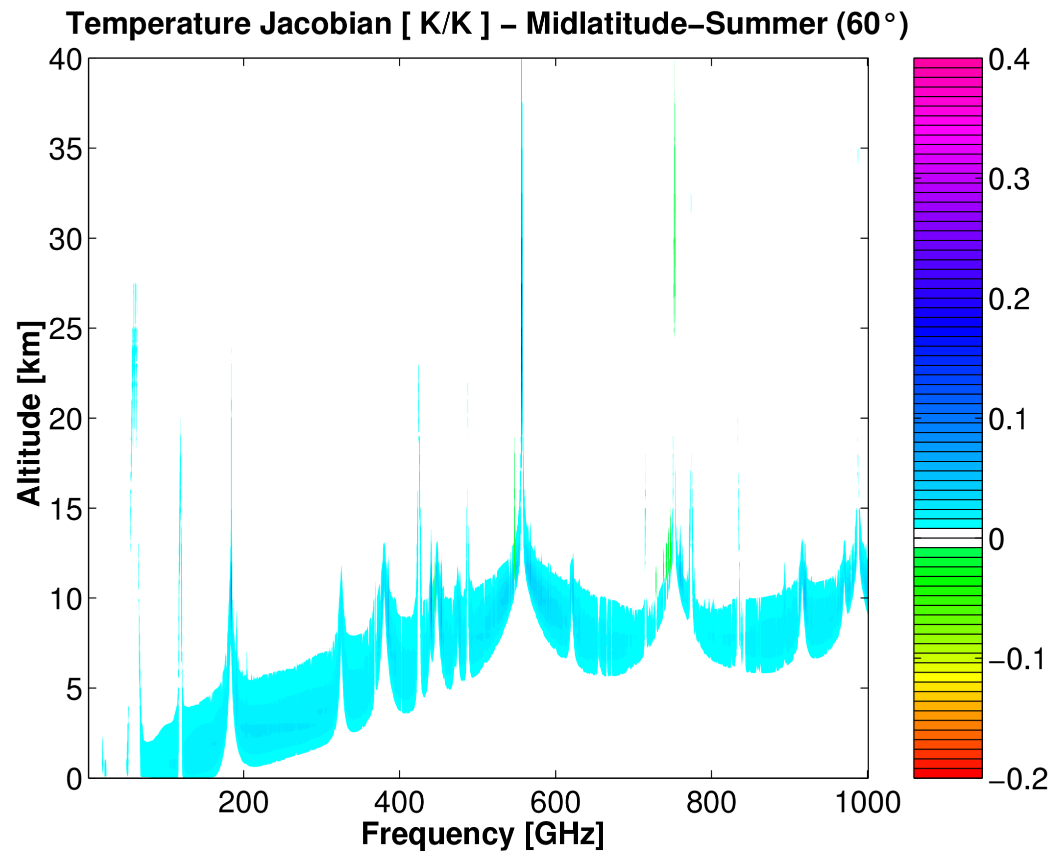
Early Proposals <1990

- 1978 Geosynchrous Microwav Atmospheric Sounding, MASR
  Feasibility Study by HUGHES Aircraft
  Bands: 183 GHz (6 channels), 140 GHz, 118 GHz (11 channels), 104 GHz
  Antenna diameter: 4.4 m

- 1987 mm wave Sounder Study for Meteosat Second Generation
  Marconi Space Systems
  Bands: 183 GHz (3 channels), 150 GHz, 110 GHz, 118 GHz (5 channels)
  Antenna diameter: 2.7 m

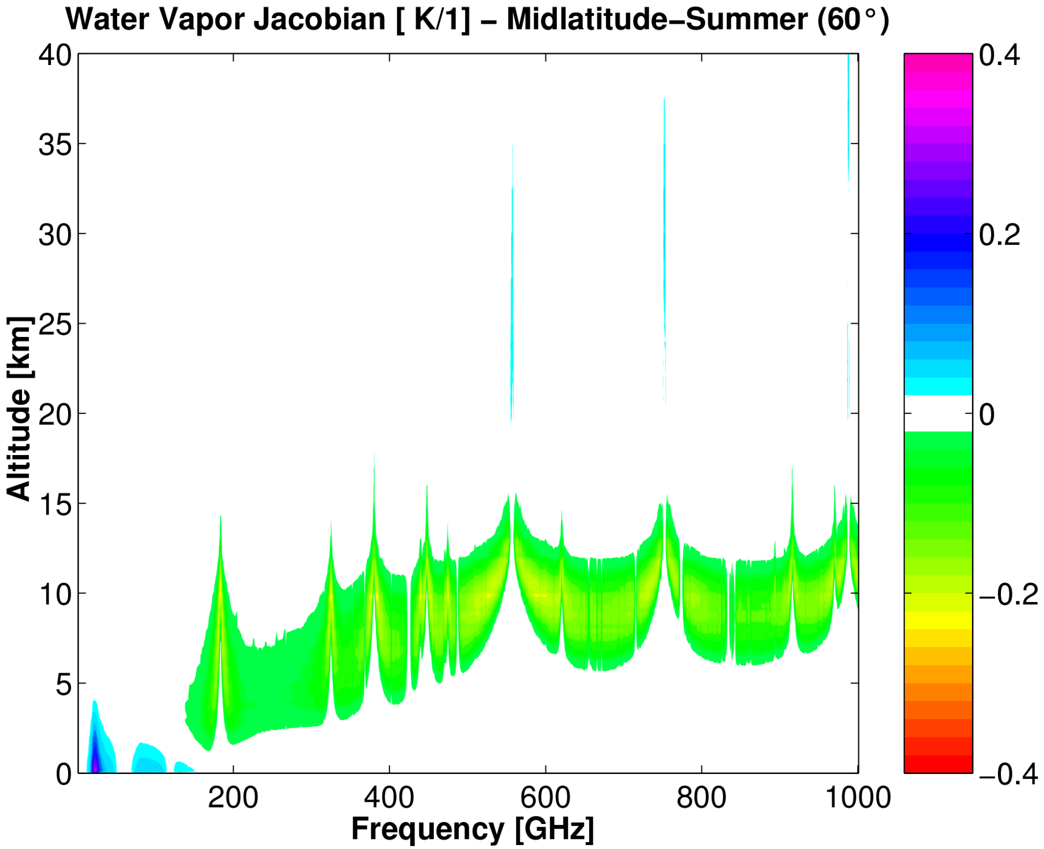
Sounding altitude of a mm/sub-mm sensor in geostationary orbit - Temperature

The sounding altitudes vary with frequency, increases from lower troposphere to upper troposphere from 100 – 500 GHz and stays in the upper troposphere for higher frequencies.
(A viewing angle of 60^{O} is assumed, corresponding to mid latitudes)



Sounding altitudes of a mm/sub-mm sensor in geostationary orbit – Water vapor

Sensitivity at different frequencies to changes in water vapour. The most sensitive altitude is from 7-11 km.



Summary and Conclusion

- A sub-mm Sensor similar to CIWSIR can provide information on cloud ice water content, ice crystal shape and ice crystal size distribution
- The theoretical background, radiative transfer including scattering is available
- The technology up to ≈1000 GHz is available
- Limiting factor for geostationary applications will be antenna size, complexity of a 2D scan mechanism and receiver sensitivity

- **Required are more measurements using airborne sensors**
- **Better in situ data for validation of remote measurements**
- **A space demonstration mission in LEO**