Validation of the submillimeter cirrus remote sensing technique: Is it ready for space?

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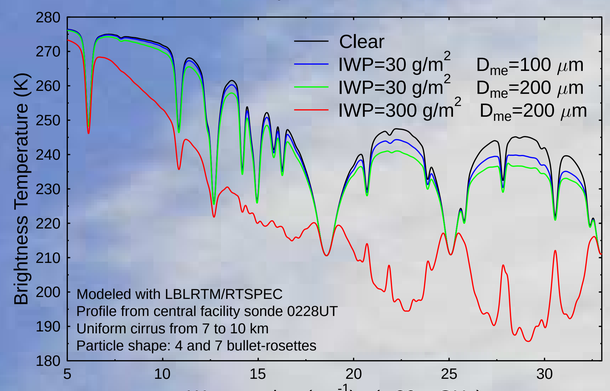
Background

1) Submillimeter radiometry is a new technique for remote sensing cirrus cloud ice water path (IWP) and median mass particle diameter (D_{me}).
2) Theoretical studies have shown that submillimeter brightness temperature depressions due to scattering by cirrus are more directly related to IWP than visible, infrared, or radar data.
3) Modeling has shown that multifrequency submillimeter radiometers should be able to retrieve accurate IWP and D_{me} for IWP>10 g/m^2, D_{me}>75 μm, and T<-30 C.
4) FIRSC is the first aircraft instrument to measure submillimeter brightness temperatures for cirrus retrievals.
5) The ARM FIRE Water vapor Experiment (AFWEX) is the first opportunity to validate the submillimeter cirrus technique by comparing retrievals to ARM radar data.

Submillimeter Cirrus Sensing Theory

Modeled FIRSC Spectra for AFWEX 2000-12-8



- There is significant T_b depression at 30 cm^{-1} even for thin cirrus (e.g. IWP=30 g/m^2, D_{me}=200 μm has τ_{vis}=1.0 for these bullete-rosettes).
- The submillimeter technique does not saturate for high IWP cirrus.
- The differential response with frequency to particle size allows both IWP and D_{me} to be retrieved with multiple channels.

Submillimeter Technology for Space

- Two technologies exist for spaceborne submillimeter radiometers:
  1) Far infrared bolometers with spectral filters
  2) Microwave heterodyne receivers

Far-IR bolometers:

- High temperature superconductor (YBaCuO) bolometers operating at 80 K are sensitive enough for 1 to 4 cm^{-1} wide submm bands.
- Far IR band-pass filters use series of photolithographic metal meshes.
- It is the only inexpensive space technology for > 25 cm^{-1} (750 GHz).
- UnESS phase A study of "CIRRUS" instrument:
  Four channels: 15, 22, 28, 45 cm^{-1} (NEΔT=2.3, 1.1, 0.7, 0.6 K).
  Single stage mechanical cooler maintains dewer at 80 K.
  Nadir viewing 10 km FOV with 20 cm telescope on Space Station.
  Mass: 146 kg Power: 364 W Size: under (1 m)^3

Heterodyne receivers:

- Room temperature planar Schottky diode mixers give T_{sys}<3000 K.
- Gunn diode and frequency multiplier local oscillators provide enough power for receivers up to ~700 GHz (higher in future).
- Integration time of <0.1 sec gives NEΔT<0.5 K and allows scanning.
- Narrow band-passes (<1 GHz) allow multiple channels on absorption lines for profiling, which improves cirrus retrievals.
- Technology is now in space on Odin astronomy/aeronomy satellite.

Far-Infrared Sensor for Cirrus (FIRSC)

- Developed at NASA Langley by Ira Nolt and Mike Vanek
- Fourier Transform Spectrometer with polarizing beam splitter
- Cryogenically cooled bolometer detector (0.3 K)
- Current spectral range: 10 to 33 cm^{-1} (300 to 990 GHz)
- Spectral resolution: 0.1 cm^{-1}; FTS scan time: 4 sec
- NEΔT: 1.0 K at 30 cm^{-1} ($\propto 1/\nu^2$)
- Nadir viewing with 1.7° beamwidth
- Operates autonomously on Proteus aircraft
- FIRSC operated successfully during AFWEX (AFWEX occurred at ARM Oklahoma site in December 2000)

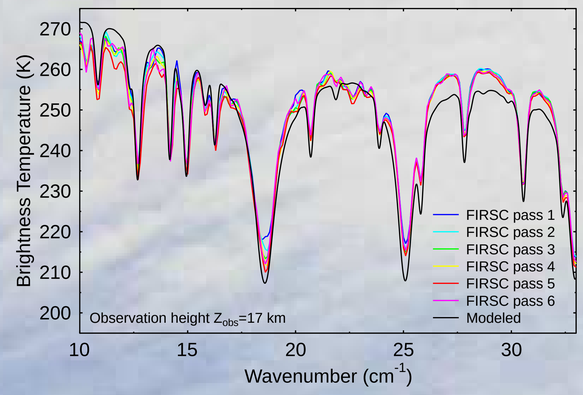
FIRSC in the lab at Langley

Proteus during AFWEX. FIRSC flew in lower pod.

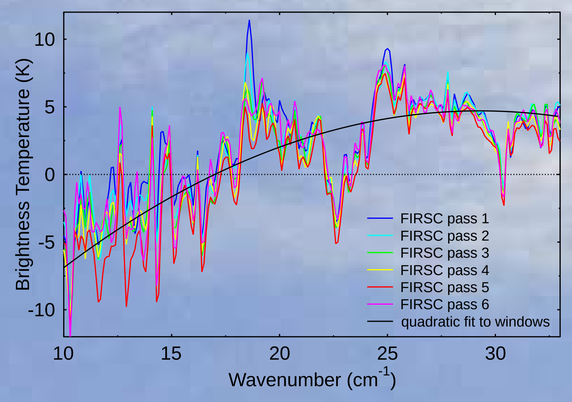
Clear Sky Analysis

- Mostly clear night on December 7, 2000 UTC at ARM site.
- Temperature and water vapor profiles were well measured:
  Used: Wallops chilled mirror sonde (PI: F. Schmidlin) above 13 km,
  Diode laser hygrometer on DC-8 (PI: G. Sachse) from 7.8 to 12.7 km,
  and CART Raman lidar below 7.5 km.
- Molecular absorption modeled with LBLRTM (CKD_2.4 continuum).
- FIRSC spectra averaged for each of 6 overpasses (134 spectra total).
- Significant discrepency between FIRSC and modeled spectra: could be FIRSC calibration or water vapor continuum uncertainties.

Clear Sky FIRSC and Modeled Spectra (AFWEX 2000-12-7)

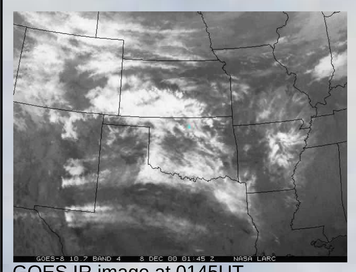


FIRSC - Modeled Residual (AFWEX on 2000-12-7)

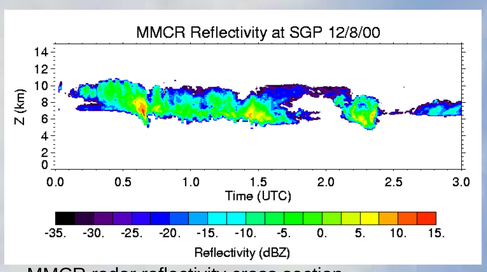


Cirrus Retrievals and Validation Attempt

- IWP and D_{me} retrieved with Bayesian algorithm (Evans et al., 2001, in press JGR).
- Retrieval database contains 200,000 cases with random profiles/cirrus properties and associated simulated brightness temperatures.
- Statistics of temperature and water vapor profiles from 10 ARM sondes on 2000-12-8.
- Statistics of cirrus top and bottom IWC/D_{me} (correlated to temperature) from 2DC and 2DP data obtained in FIRE-I cirrus experiment.
- Scattering properties of 4 and 7-bullet rosettes computed with DDA.
- Gaussian distribution of cloud top height and thickness (means 10.5 and 4 km).
- FIRSC spectrum is "bias adjusted" with quadratic fit to clear sky residuals.
- T_b spectrum is compressed using principal components (6 EOFs used).
- Retrieved cirrus properties are weighted average of cases that match observations.

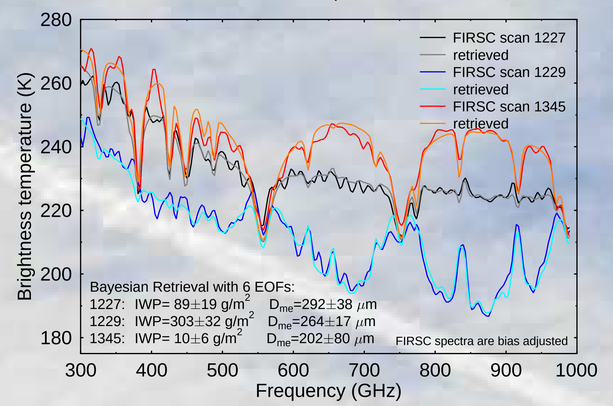


GOES IR image at 0145UT.



MMCR radar reflectivity cross section.

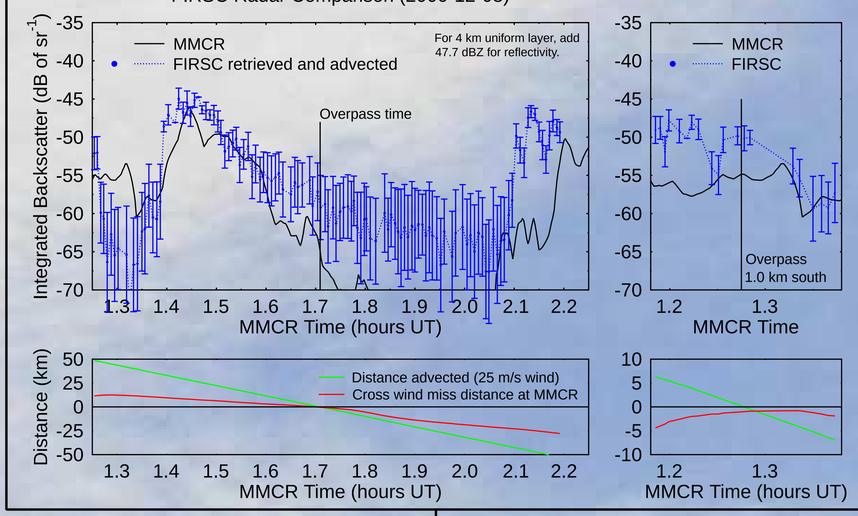
FIRSC and Retrieved Spectra from 2000-12-8



Evaluate FIRSC cirrus retrievals with MMCR radar data:

- Bayesian algorithm can also retrieve integrated 35 GHz radar reflectivity.
- Compare with FIRSC retrieved integrated reflectivity advected to radar location.
- On two overpasses cirrus was too thin for good retrieval (one shown left below). One overpass missed MMCR by 1 km (right below).

FIRSC Radar Comparison (2000-12-08)



Conclusions

1) Validation of submillimeter cirrus retrievals is inconclusive due to few overpasses of a fixed radar, highly variable cirrus field, and uncertainties in FIRSC calibration.
2) Validation of submillimeter cirrus sensing technique should be achieved during the CRYSTAL-FACE experiment in Florida in July 2002.
3) There are two existing technologies for submillimeter radiometers that could be used for spaceborne cirrus remote sensing.