FIRSC Measurements of Cirrus Anvils

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Gerry Heymsfield and Lihua Li for Cloud Radar System data
Bill Smith, Dan Zhou, and Paolo Antonelli for NAST-I data

Background

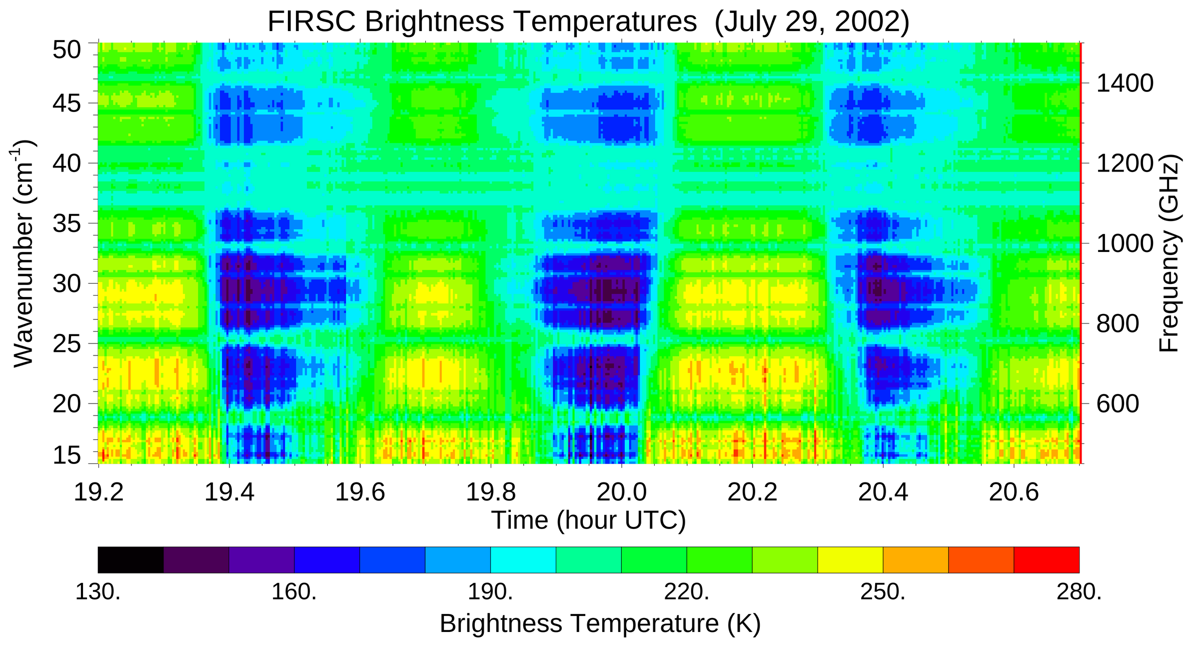
1) Submillimeter radiometry is a new technique for remote sensing cirrus cloud ice water path (IWP) and median mass equivalent sphere particle diameter (D_{me}).
2) Theoretical studies have shown that submillimeter brightness temperature depressions due to scattering by cirrus are more directly related 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 was the first aircraft instrument to measure submillimeter brightness temperatures for cirrus retrievals.

- Our objective for CRYSTAL-FACE was to demonstrate and validate this new technique with the wealth of data available.

Examples of FIRSC Data

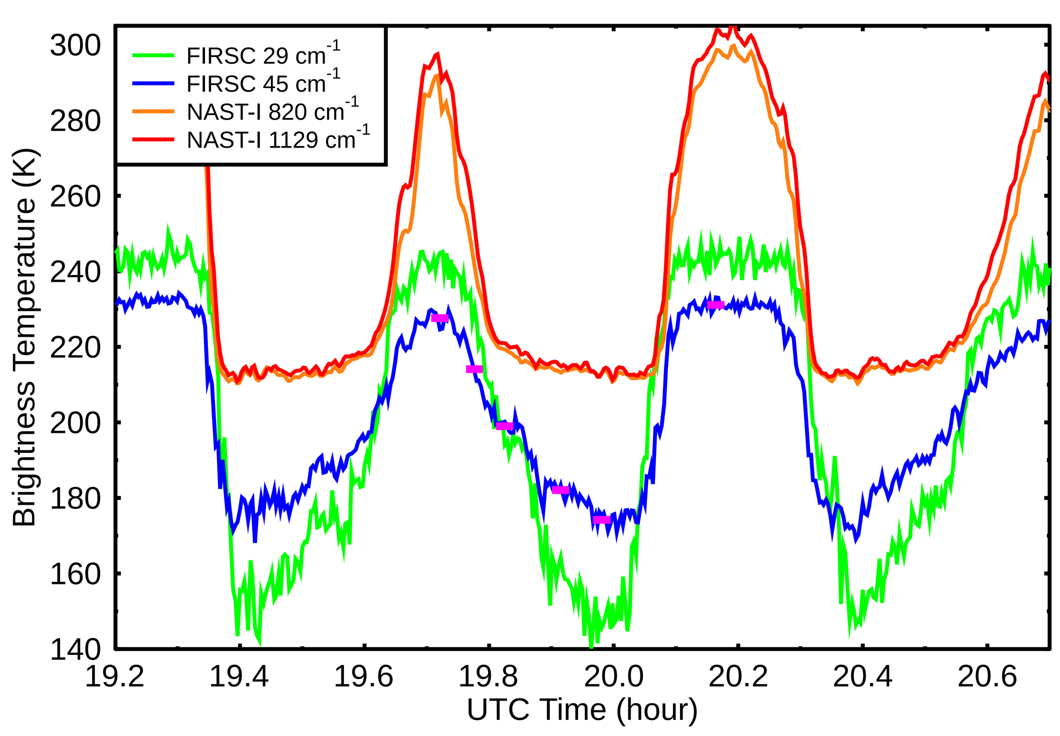
- All data on the poster are from July 29, the flight with the best FIRSC data.
- FIRSC measures the nadir viewing T_b spectrum as a function of time:

FIRSC Brightness Temperatures (July 29, 2002)



- On each anvil core overpass FIRSC measures deep brightness temperature depressions due to ice scattering (largest at 29 cm^{-1}).

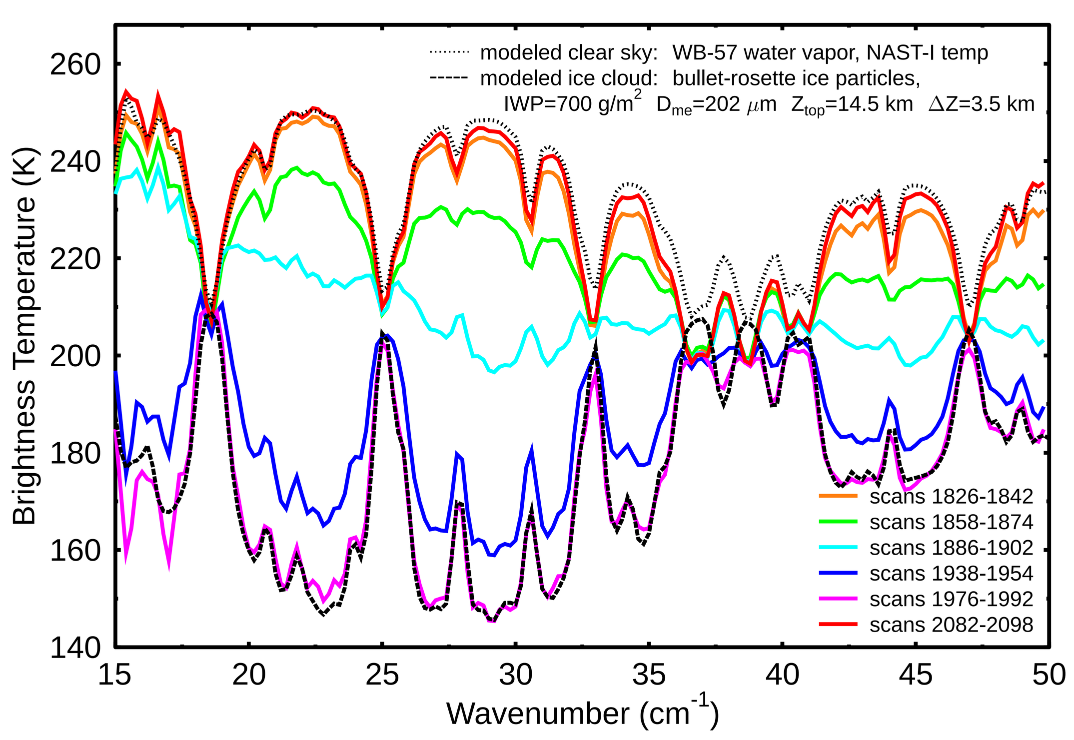
FIRSC and NAST-I Window T_b



- Submillimeter has scattering signal when IR is saturated in deep anvil.
- Measurable submm ΔT_b when IR optical depth is small at anvil edges.

Magenta bars show times of 9 scan average spectra in plot below.

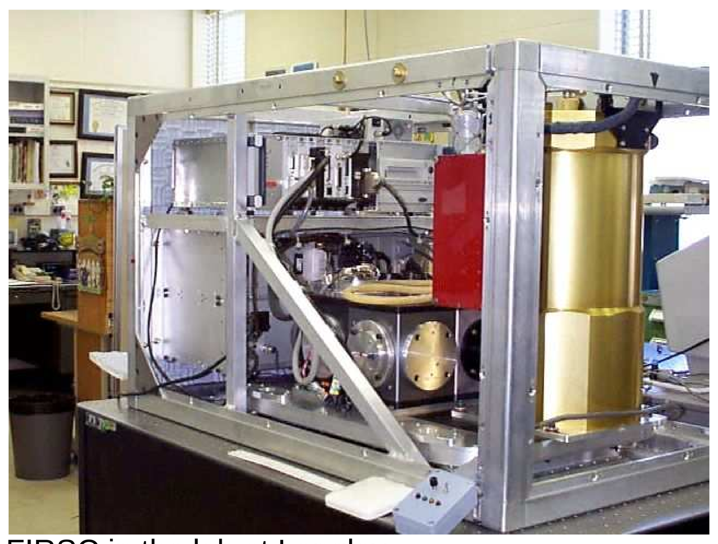
FIRSC and Modeled Spectra



- Observed FIRSC spectra agree reasonably well with modeled clear sky and modeled ice cloud spectra (cloud parameters from eyeballl fit).
- Substantial ΔT_b in 45 cm^{-1} window for anvils with high cloud tops, though larger ΔT_b (and less water vapor absorption) at 22 and 28 cm^{-1}.

Far-Infrared Sensor for Cirrus (FIRSC)

- Developed at NASA Langley by Mike Vanek and Ira Nolt
- Fourier Transform Spectrometer with polarizing beam splitter
- Cryogenically cooled bolometer detector (0.3 K)
- Current spectral range: 15 to 50 cm^{-1} (450 to 1500 GHz)
- Spectral resolution: 0.2 cm^{-1}; FTS scan time: 4 sec
- NEΔT: > 1.1 K at 45 cm^{-1} (increases as $1/\nu^2$ for lower wavenumbers)
- Nadir viewing with 1.7° beamwidth
- Operates autonomously on Proteus aircraft



FIRSC in the lab at Langley

Proteus pod with NAST-M, FIRSC, NAST-I, and RSP (left to right).

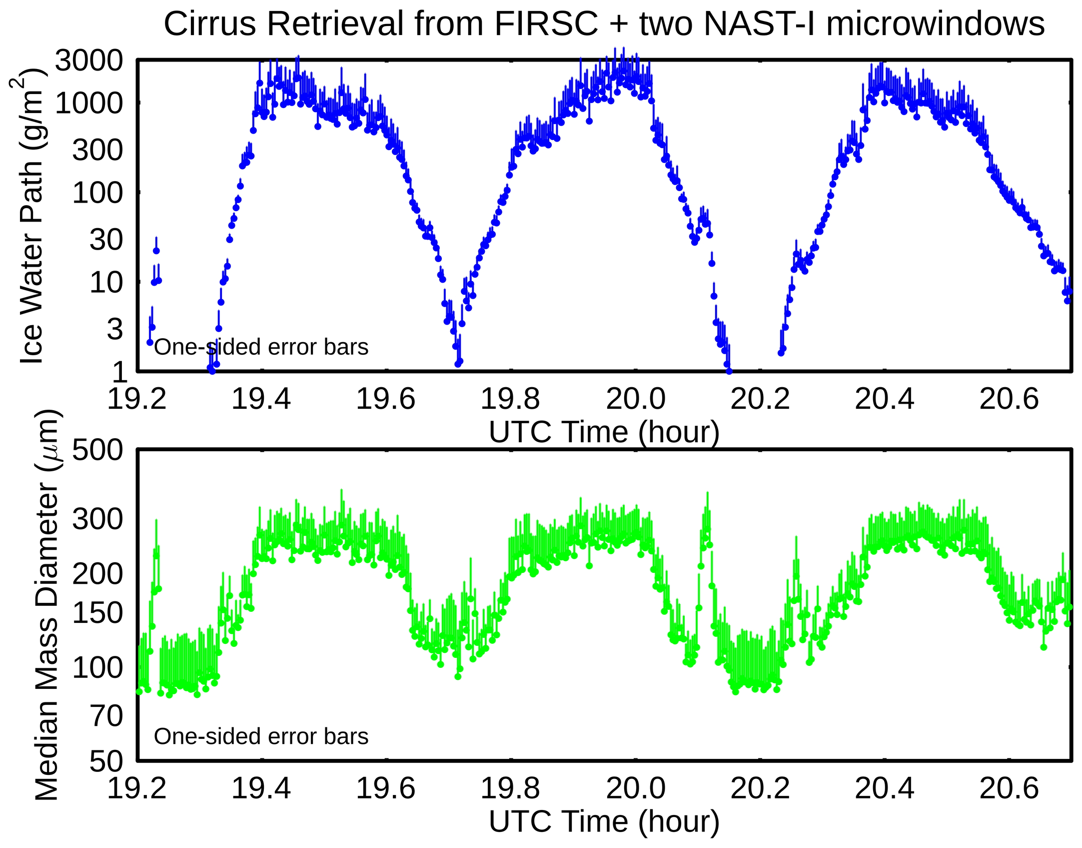
FIRSC Performance during CRYSTAL-FACE

- FIRSC operated successfully during 7 Proteus flights; 4756 spectra archived.
- FIRSC didn't operate during flights on July 3, 13, 16, 17, 19.
- Scans were taken 12 seconds apart on July 7, 9, 11, and 6 to 8 seconds apart on July 21, 23, 26, 29. Computer shutdown error caused loss of data (14 to 88 minutes) at end of flights after July 11.
- Interferometer mirror position sampling errors caused the noise to be much higher than anticipated. Odd FTS scans were much noisier than even scans, so only even scans are used in the analysis.

Combined FIRSC and NAST-I Retrievals

- FIRSC data are combined with two NAST-I microwindow radiances (819.9 and 1128.6 cm^{-1}), since a principal components analysis of 18 microwindow IR radiances on July 29 shows there are only two independent quantities.

Cirrus Retrieval from FIRSC + two NAST-I microwindows

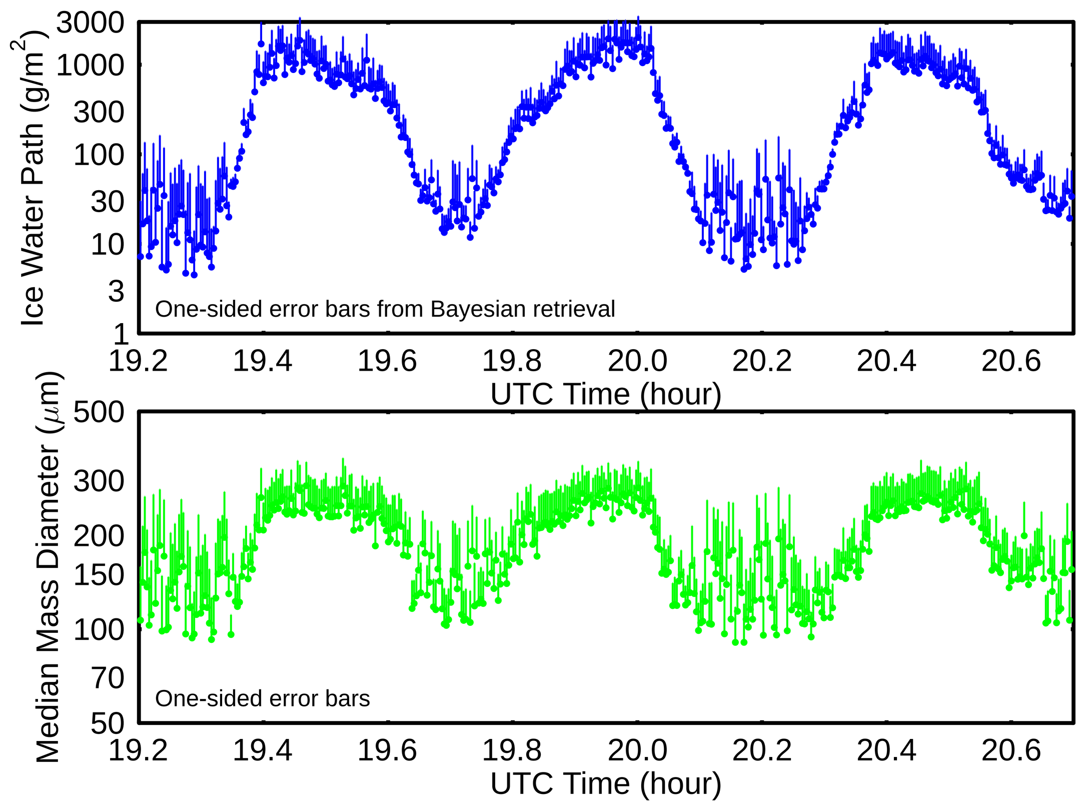


- IR radiances are highly complementary to submillimeter data: IR extends sensitivity to low IWP, while submillimeter provides useful information in optically thick anvils.

Cirrus Retrievals and Evaluation

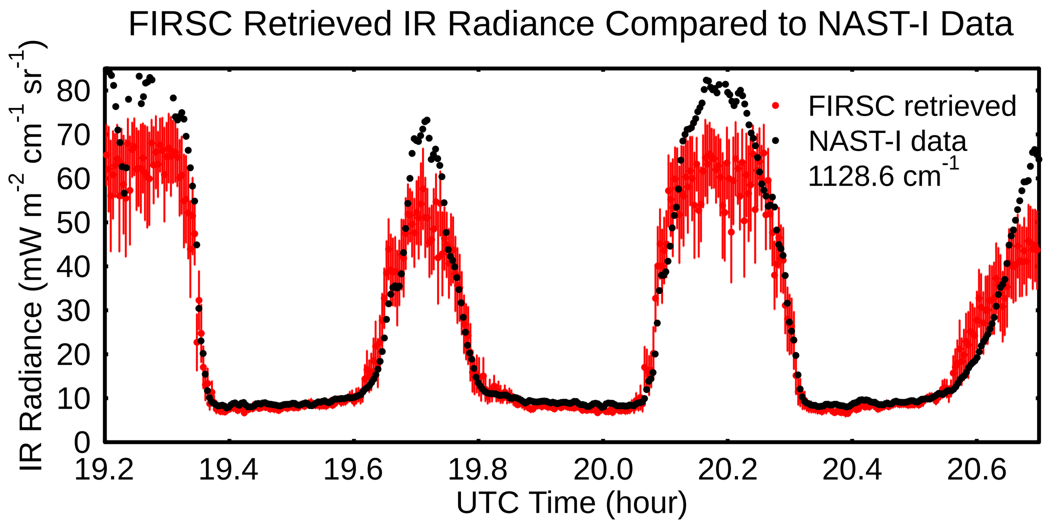
- IWP and D_{me} retrieved with Bayesian algorithm of Evans et al. (JGR, Feb 2002).
- Retrieval database contains 400,000 cases with random profiles/cirrus properties and associated simulated brightness temperatures.
- Statistics of temperature and relative humidity profiles are from 25 C-F sondes.
- Statistics of cirrus top and bottom IWC/D_{me} (correlated to temperature) are from 2DC data from CEPEX. Will use CRYSTAL-FACE microphysics in the future.
- Scattering properties for 4 and 7-bullet rosettes and ρ=0.46 g/cm^3 spheres.
- Gaussian distribution of cloud top height (mean = 12.7 km, std dev=1.2 km) and exponential distribution of thickness (mean = 5.0 km) are derived from radar.
- FIRSC T_b spectrum is compressed using principal components (6 PCs used).
- Retrieved properties are weighted average of cases that match observations.

Cirrus Retrieval from FIRSC



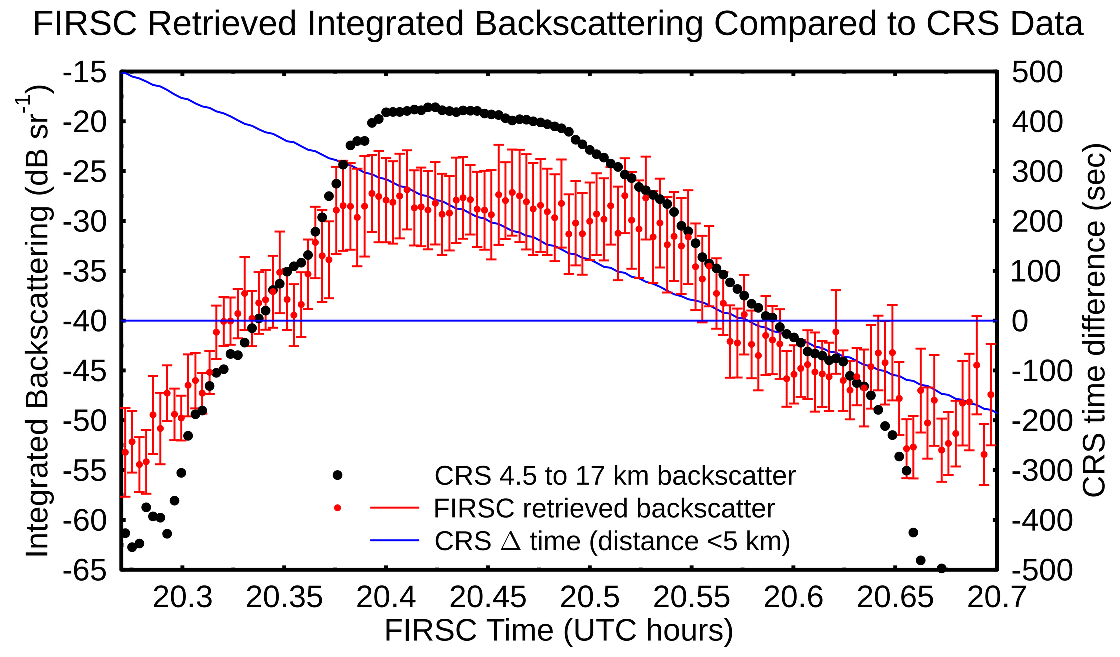
- We believe that evaluation of passive remote sensing retrievals should be done using other remote sensing data (with independent physics) that match the sensing volume, to avoid sampling errors of in situ cloud probes.
- The Bayesian algorithm can also retrieve NAST-I microwindow IR radiances and integrated 94 GHz radar backscattering.

FIRSC Retrieved IR Radiance Compared to NAST-I Data



- FIRSC retrieved IR radiances agree within error bars except for clear regions where FIRSC noise gives cirrus with IWP=10-30 g/m^2.

FIRSC Retrieved Integrated Backscattering Compared to CRS Data



- Cloud Radar System is a 94 GHz radar on ER-2. During C-F there was only one colocation over thick anvil when FIRSC and CRS were working.
- FIRSC retrievals agree within error bars except for thinnest regions (lack of sensitivity) and deep precipitating anvil where lower frequencies are needed to sense lower altitudes.
- FIRSC retrieved backscattering error bars are much larger than for CoSSIR retrievals (see CoSSIR poster) due to FIRSC's high noise and lack of low frequencies.

Conclusions

1) The spectral signature due to anvil cirrus particle scattering measured by FIRSC from 15 to 50 cm^{-1} confirms theoretical expectations.
2) Submillimeter radiometry can sense cirrus from low optical depth to thick anvils, where visible and infrared methods saturate. Combined infrared and submillimeter data can measure the full range of cirrus.
3) Comparisons of FIRSC retrievals with NAST-I window IR radiances and vertically integrated radar backscattering indicate that lower noise is required for sensing thin cirrus and lower microwave frequencies are required for deep, precipitating anvils.