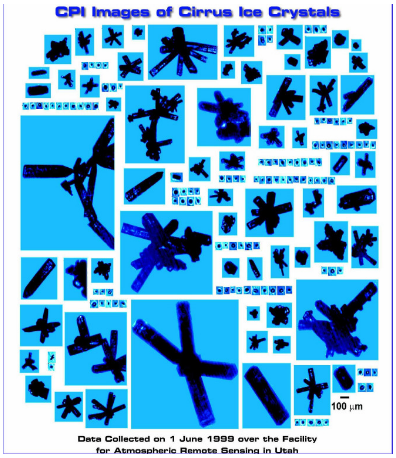

Ground Based Remote Sensing Of Small Ice Crystals In Arctic Cirrus Clouds

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ABSTRACT

Measurement of small ice crystals (D < 60 µm) remains an unsolved and controversial issue in the cloud physics community. Concentrations of small ice crystals are hard to measure due to shattering of crystals at probe inlets. However, these small ice crystals alter cirrus cloud radiative properties and may affect the cirrus cloud feedback in global climate models. To facilitate better estimation of small ice crystal concentrations in cirrus clouds, a new ground-based remote sensing technique has been used in combination with in situ aircraft measurements. That is, data from the Mixed-Phase Arctic Cloud Experiment (M-PACE) conducted at Barrow on the north slope of Alaska (Fall 2004) is being used to develop an Arctic ice particle size distribution (PSD) scheme, that in combination with the anomalous diffraction approximation (for ice cloud optical properties), serves as the framework of the retrieval algorithm.

How Photon Tunneling Can be Used to Remotely Detect Small Ice Crystals in Cirrus

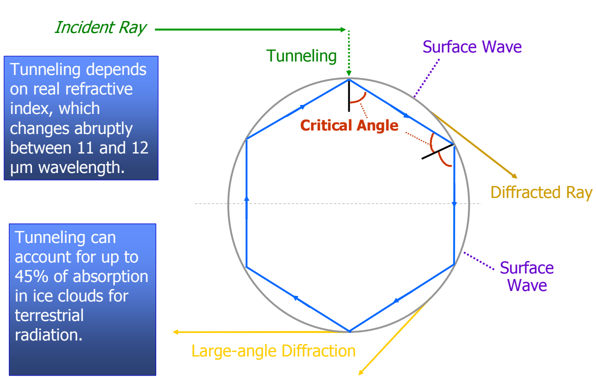
Photon Tunneling is the process by which radiation beyond the physical cross-section of a particle is either absorbed or scattered outside the forward diffraction peak. Tunneling is strongest when:

1) Effective size and wavelength are comparable

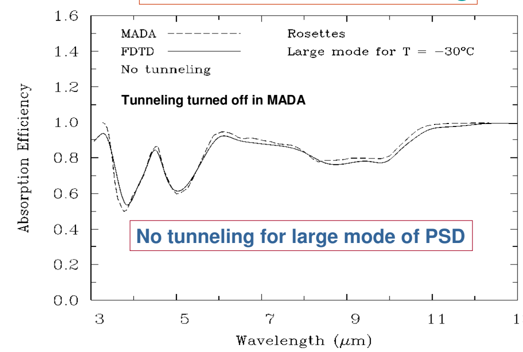
2) Particle shape is spherical or quasi-spherical

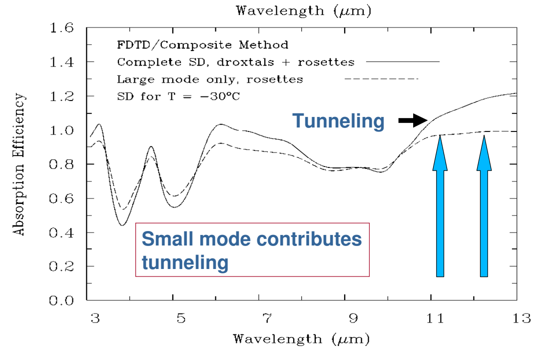
3) The real refractive index is relatively large

Therefore tunneling contributions at terrestrial wavelengths are greatest for smallest (D < 60 µm) ice crystals. To detect the tunneling signal is to detect small ice crystals.

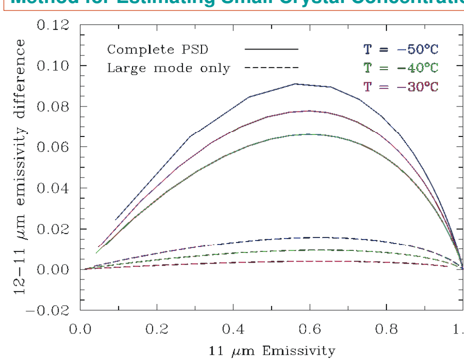


How to measure tunneling



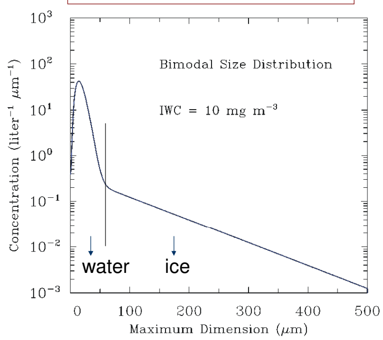


Method for Estimating Small Crystal Concentrations

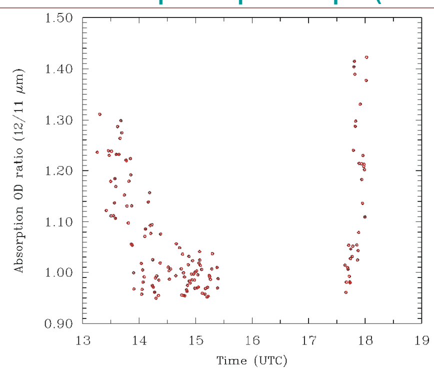


1. Begin with retrievals of cloud temperature and cloud emissivity (ε) at 11 and 12 µm wavelength channels.
2. Use retrieved temperature to estimate PSD mean size $\bar{D}$ and dispersion (ν) for large and small mode. Difference between the solid and dashed curves above results primarily from differences in contribution of small PSD mode to the ice water content (IWC). This also determines the effective diameter, D_e. Note large mode $\bar{D}$ and ν have little influence on above curves.
3. Locate the retrieved Δε and the 11 µm ε by (1) incrementing the modeled ice water path (IWP) to increase ε(11 µm) and (2) incrementing small mode contribution to the cloud IWC, which elevates the curve.
4. If all IWC is in small mode and retrieved Δε and ε(11 µm) are still not located, then decrease small mode $\bar{D}$ to locate them.
5. This method retrieves IWP, De, the small-to-large mode ice crystal concentration ratio, and ice particle concentration for a given IWC.

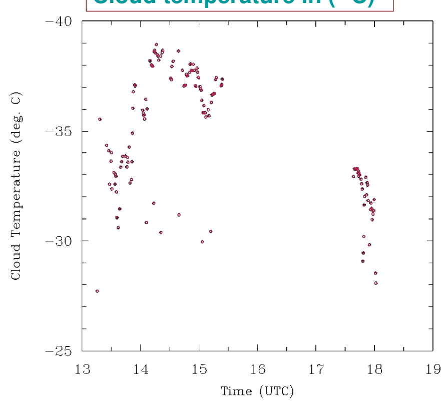
Size Distribution Scheme



Ratio of the Absorption Optical Depth (12 /11) μm

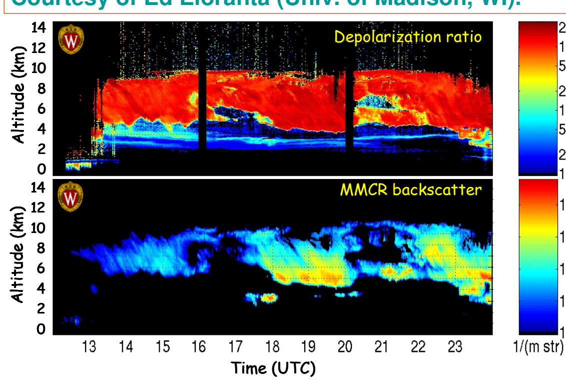


Cloud temperature in (° C)

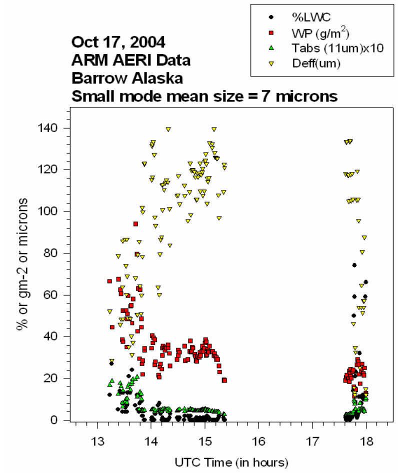


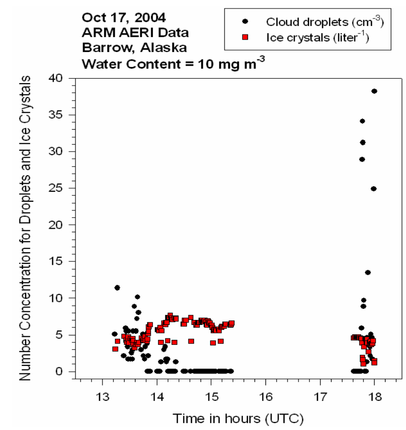
Absorption optical depth (AOD) of these clouds for three wavelengths (12.19 μm, 11.09 μm and 8.73 μm) are obtained from the Atmospheric Emitted Radiance Interferometer (AERI). An AOD ratio above 1.1 suggests the presence of liquid water in the cloud (Giraud et al. 1997, 2001). The cloud temperature ranges between -27 ℃ and -39 ℃ . Super cooled water may be present along with ice in clouds at temperatures above -36 ℃ (supported by AERI AOD values higher than 1.1). Recent findings shown on our website, http://www.dri.edu/Projects/Mitchell/ , indicate that cirrus PSD is either monomodal or weakly bimodal. Therefore our retrieval algorithm is modified to interpret all condensate in the small mode as liquid water. The small mode mean diameter, Dsm, and the dispersion parameter are assumed to be 7 μm and 9, respectively, which may be representative of droplet spectra in mixed phase conditions.

Lidar depolarization ratios and MMCR backscatter for 10/17/2004 (M-PACE) at Barrow, Alaska. Courtesy of Ed Eloranta (Univ. of Madison, WI).



Retrieval results: M-PACE case study of 17th October 2004





Combining the small crystal information (from AERI radiances) with the PSD scheme describing the larger particle concentrations yields the retrieved PSD. The products from this AERI retrieval scheme are the PSD and ice particle number concentration for a given IWC, as well as the ice water path, effective diameter (D_{eff}, representing both liquid and ice) and the ratio of the small mode-to-large mode number concentration. However, this presumes that the cloud does not contain significant amounts of liquid water. D_{eff} is largest between 14.2 and 15.4 UTC when the cloud is glaciated (LWC is negligible). At least over this time period, AERI radiances indicate the PSD is generally monomodal with ice particle concentrations of about 4 – 7 liter^{-1} when the IWC = 10 mg m^{-3}. For other time periods having significant liquid water, the cloud droplet number concentration N_d can exceed 30 cm^{-3}. Changing the algorithm to assume that the small mode is comprised of ice crystals (based on Ivanova et al. 2001) instead of cloud droplets, N_{ice} ranged from about 1 to 10 cm^{-3} in the regions where the AOD ratio exceeds 1.08. It seems unlikely that N_{ice} would change so abruptly, making the mixed phase explanation most reasonable. T_{abs} is minimum between 14.2 and 15.4 UTC, which corresponds to glaciated cloud conditions, lower N and larger D_{eff}. High lidar depolarization ratios indicate the dominance of ice phase,consistent with our results.

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