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

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OUTLINE

- Introduction to the tunneling concept
- Physics behind remote sensing technique
- Discussion on case study
- Conclusions

Problems In Measuring Small Ice Crystals

Problem 1: Instruments aboard aircraft that measure the ice particle size distribution (PSD) cannot accurately measure the concentrations of small ice crystals. Larger ice particles may shatter on the probe inlet, producing tiny artifact ice crystals.

Problem 2: Global climate models are very sensitive to the concentrations of small ice crystals in cirrus.

Possible solution: Improved instruments + new remote sensing methods that estimate small ice crystal concentrations.

Photon Tunneling

- 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

Photon Tunneling Processes

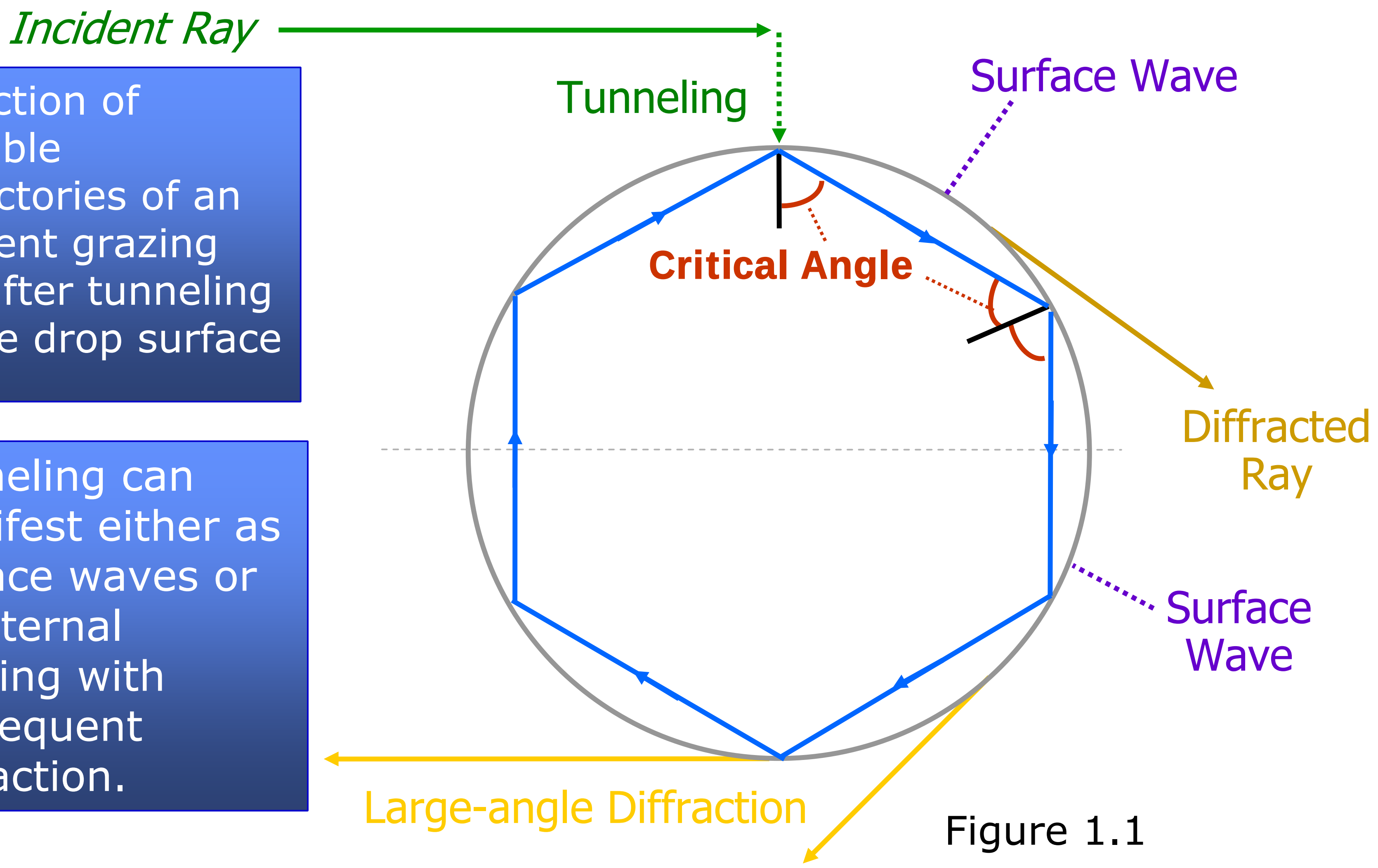


Figure 1.1

Depiction of possible trajectories of an incident grazing ray after tunneling to the drop surface

Tunneling can manifest either as surface waves or as internal orbiting with subsequent diffraction.

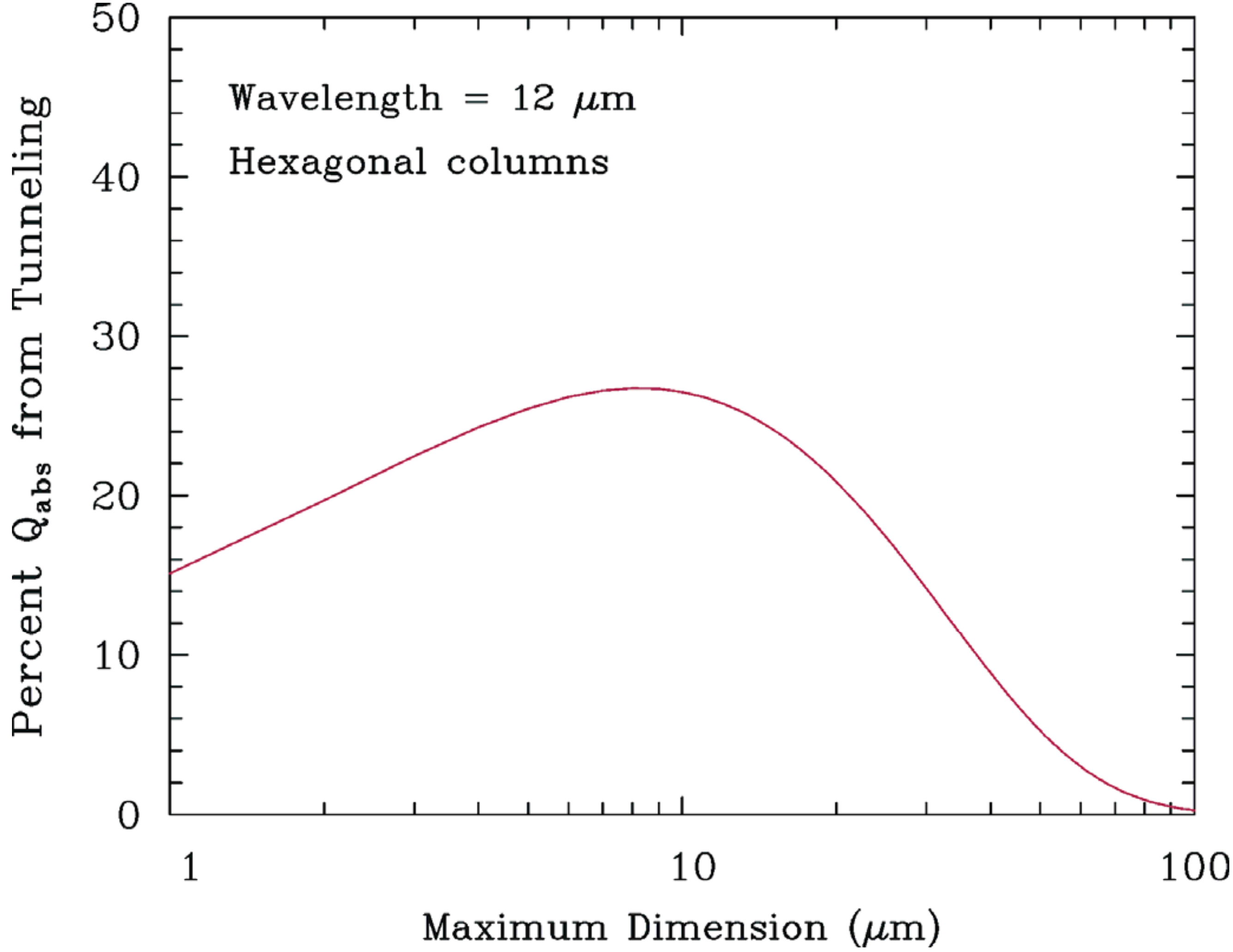
Tunneling Efficiencies for Different Crystal Shapes

(from Mitchell et al. 2006, JAS)

CRYSTAL SHAPE	TUNNELING EFFICIENCIES: Small Mode of SD, D = 14 to 20 µm	Large Mode Mean of SD, D = 53 µm	Large Mode Mean of SD, D = 170 µm
Aggregate	0.35	0.30	0.15
Bullet Rosette	0.70	0.40	0.15
Hex. Column	0.90	0.65	0.40
Hollow Column	0.70	0.50	0.15
Hex. Plate	0.60	0.15	0.00
Droxtal	1.00	0.80	0.40

Red circles indicate typical crystal shapes found in the small or large mode.
Efficiencies are one reason tunneling is mostly manifested in the small mode.

Figure 1.2: Size dependence of tunneling for single ice crystals



Why is tunneling important ?

- The tunneling signal is the emissivity difference between 12 and 11 μm wavelength (for ice). This difference is attributed to n_r which has a minimum value near 11 μm but is substantial near 12 μm.
- Tunneling contributions to τ_{abs} can reach 20% when particle size is less than 60 μm.
- Thus, absorption of radiation by photon tunneling affects the small mode of the PSD but not the large mode, making thermal emission due to tunneling an ideal signal for detecting small ice crystals.

Figure 2: Absorption Efficiencies for a Bimodal Size Distribution

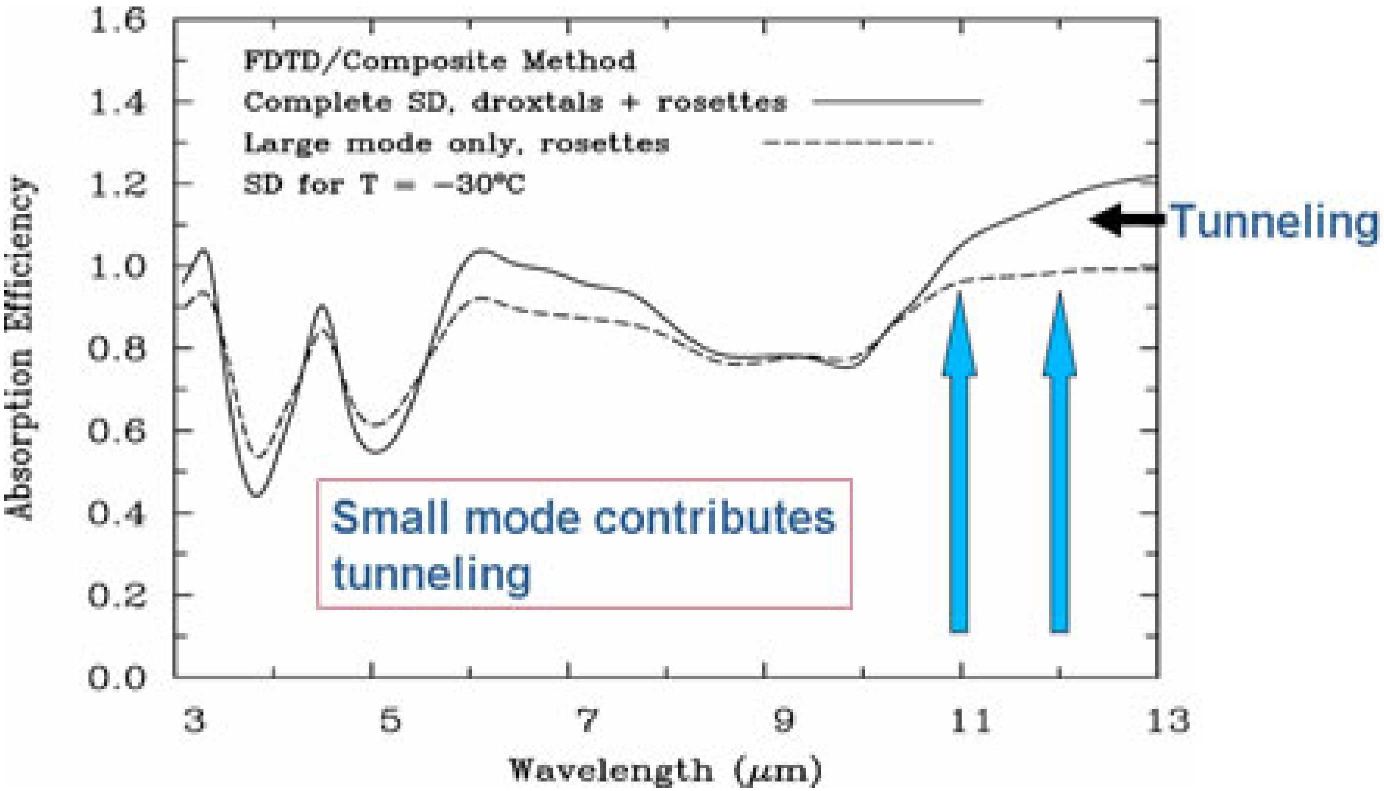
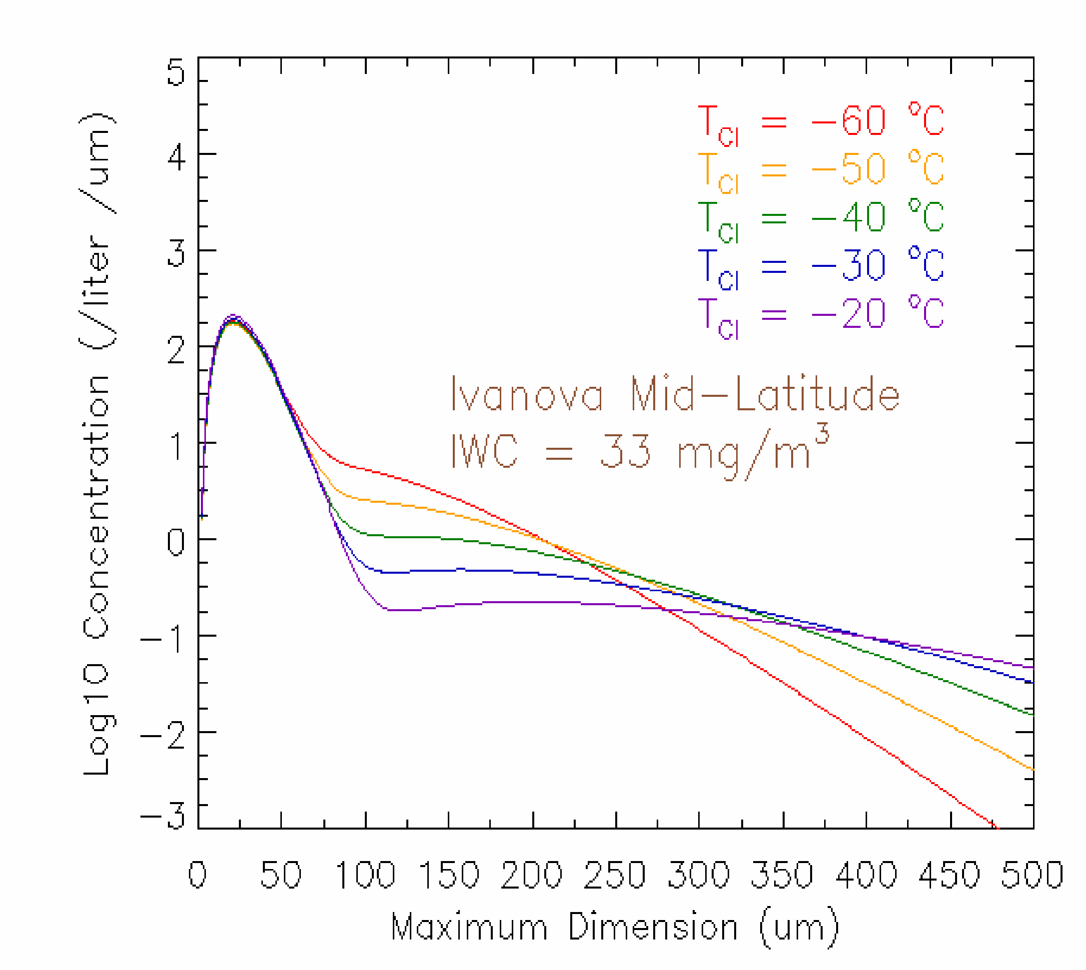
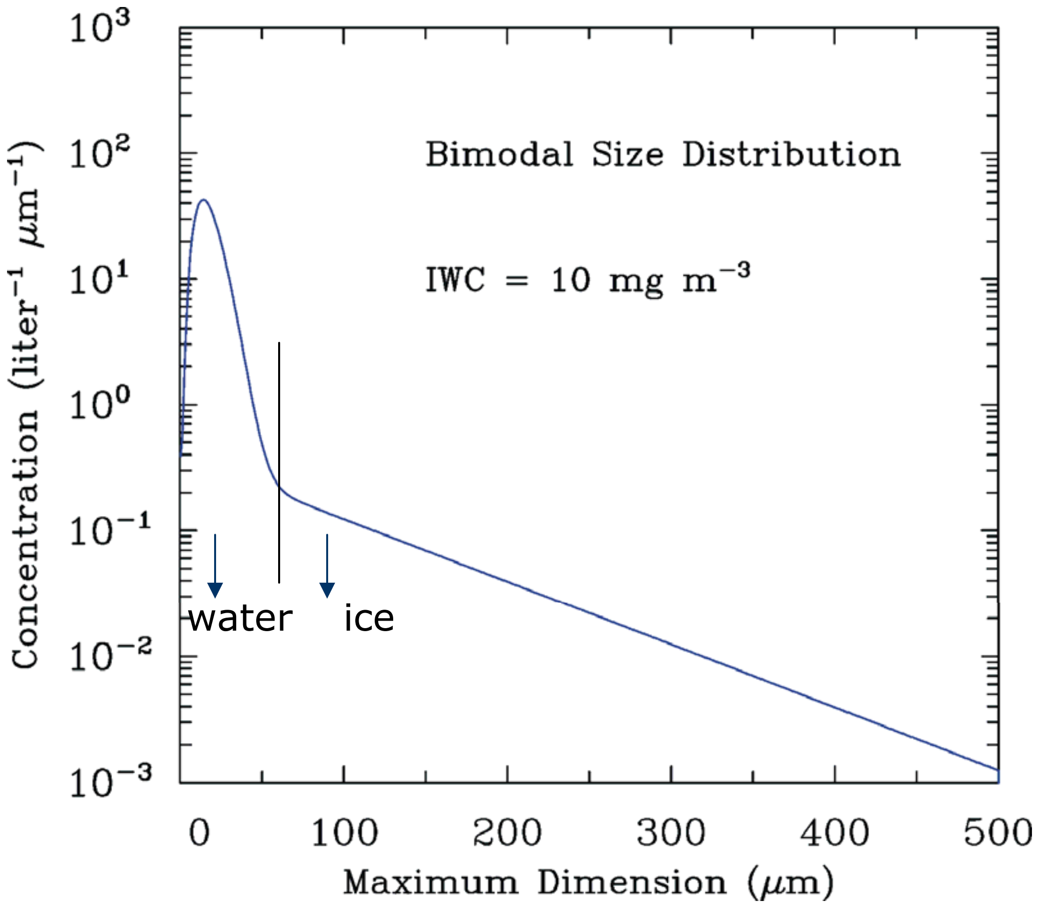


Figure 3. Ivanova mid-latitude scheme



Examples of bimodal size distributions based on measurements from mid-latitude cirrus clouds (Ivanova et al. 2001).

Size Distribution Scheme



Method for Estimating Small Crystal Amounts

1. Begin with ground based retrievals of cloud temperature and emissivity (ε) at 11 and 12 μm wavelength channels from the AERI.

2. Use the retrieved cloud temperature to estimate the PSD mean size $\bar{D}$ and dispersion (ν) for large and small mode. Difference between the solid and dashed curves result primarily from differences in the contribution of the PSD small mode to the IWC. This also determines effective diameter, D_e. Note that the large mode $\bar{D}$ and ν have little effect on above curves.

3. Locate the retrieved Δε and the ε(11 μm) by (1) incrementing the modeled IWP to increase ε(11 μm) and (2) incrementing the small mode IWC, which elevates the curve.

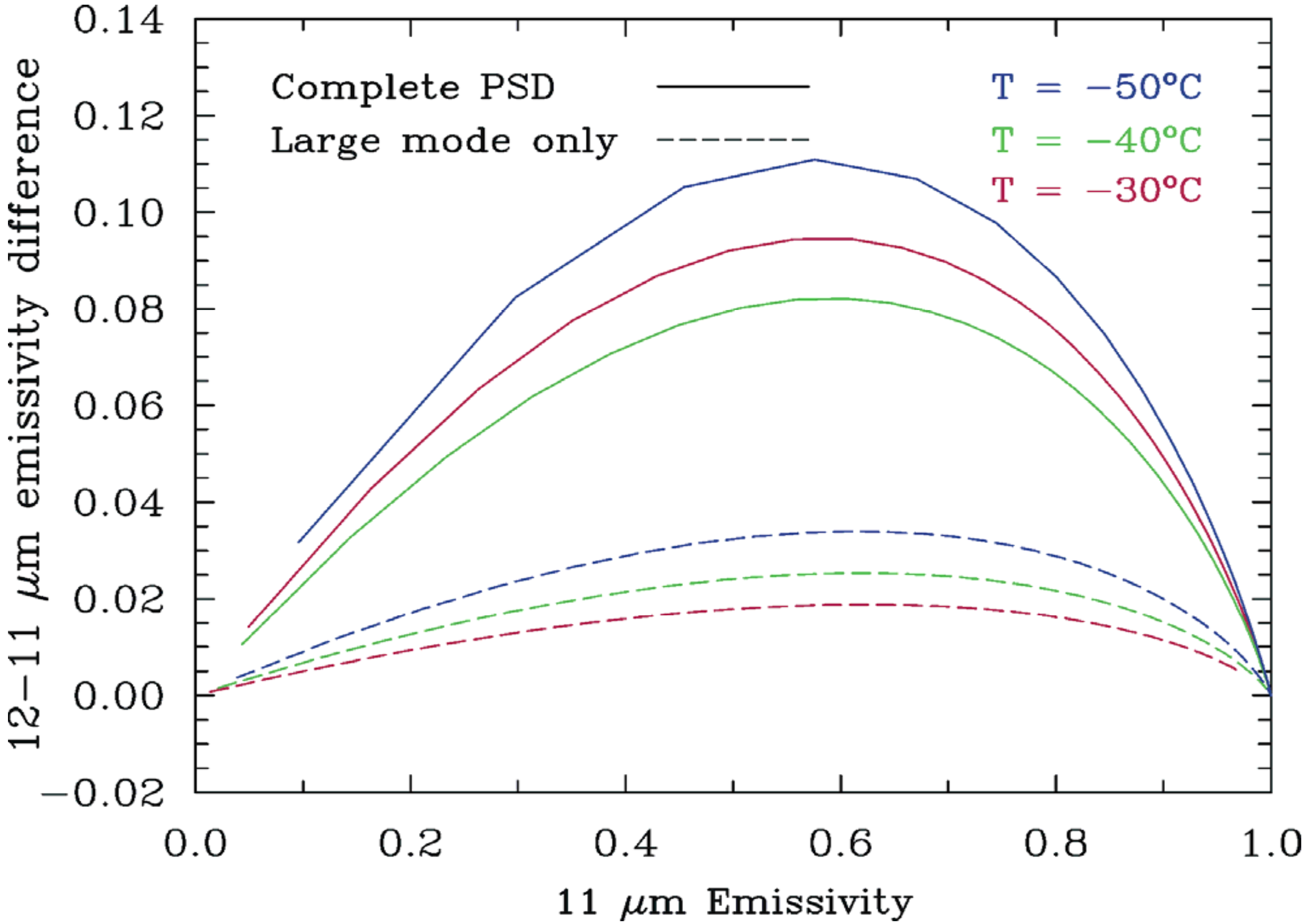
Method for Estimating Small Crystal Amounts
- continued -

4. If all IWC is in the small mode and retrieved Δε and ε(11 μm) is still not located, then decrease small mode $\bar{D}$ to locate them.

5. If the retrieved point lies below the "large mode only" curve (e.g. a dashed curve), then systematically increase $\bar{D}$ for large mode until a match is obtained. Negative Δε values correspond to maximum allowed large mode $\bar{D}$ values.

6. This methodology retrieves IWP, D_e, the small-to-large mode ice crystal concentration ratio, and the ice particle concentration for a given IWC. It also estimates the complete PSD (even when it is bimodal).

Figure 4. Method for Estimating Small Ice Crystal or Cloud Droplet Concentrations



Case Study Analysis (Oct 17th, 2004) MPACE - Barrow, Alaska

- Retrieval algorithm uses the Ivanova et al. (2001) PSD scheme for mid-latitude synoptic cirrus, but will soon be replaced with a PSD scheme developed from M-PACE PSD data
- AERI measurements are used to indicate concentration of small ice crystals relative to large ice crystals
- AODs are obtained at clouds for three wavelengths (12.19 μm, 11.09 μm and 8.73 μm)
- Visible OD is limited to values less than 4.5 (to prevent emissivity saturation) and greater than 0.5
- This retrieval methodology developed by Dr. Mitchell enables us to retrieve the small-to-large mode ice crystal concentration ratio, the ice crystal concentration for a given IWC, the IWP and D_{eff}. However, this assumes that the cloud contains negligible liquid water.
- An AOD ratio above 1.1 suggests presence of liquid water in the cloud (Giraud et al. 1997, 2001).

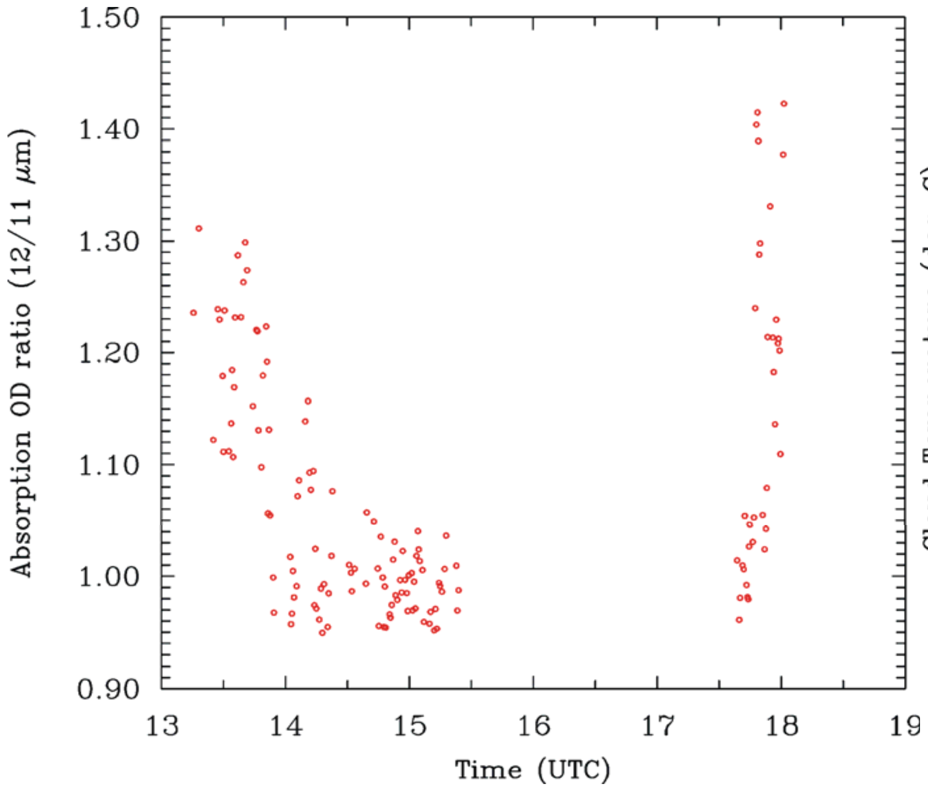


Figure 5. Ratio of the absorption optical depth between 12 μm and 11 μm as a function of hour of the day (UTC).

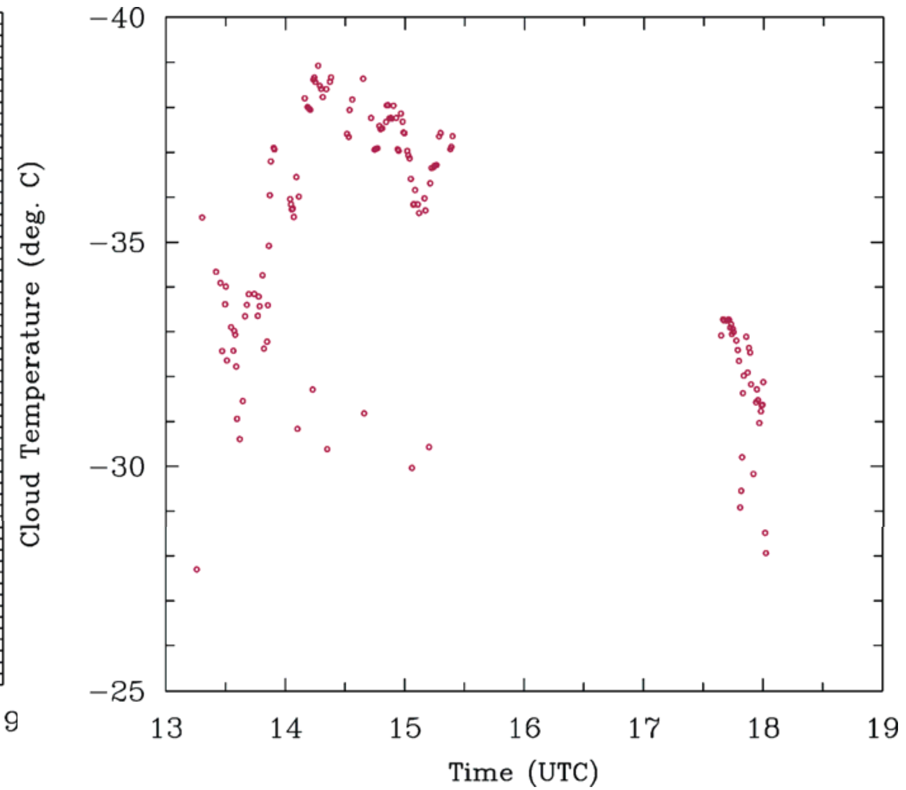


Figure 6. Cloud temperature (° C) versus the hour of the day in UTC.

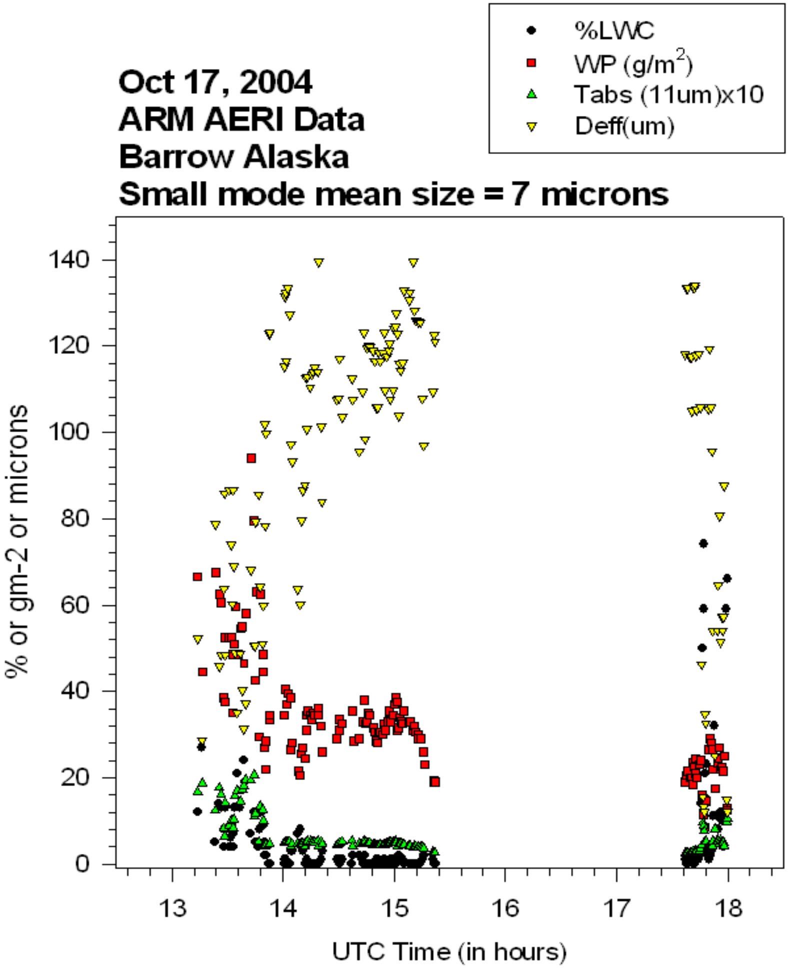


Figure 7. Retrieval results for M-PACE case study of 17th October, 2004.

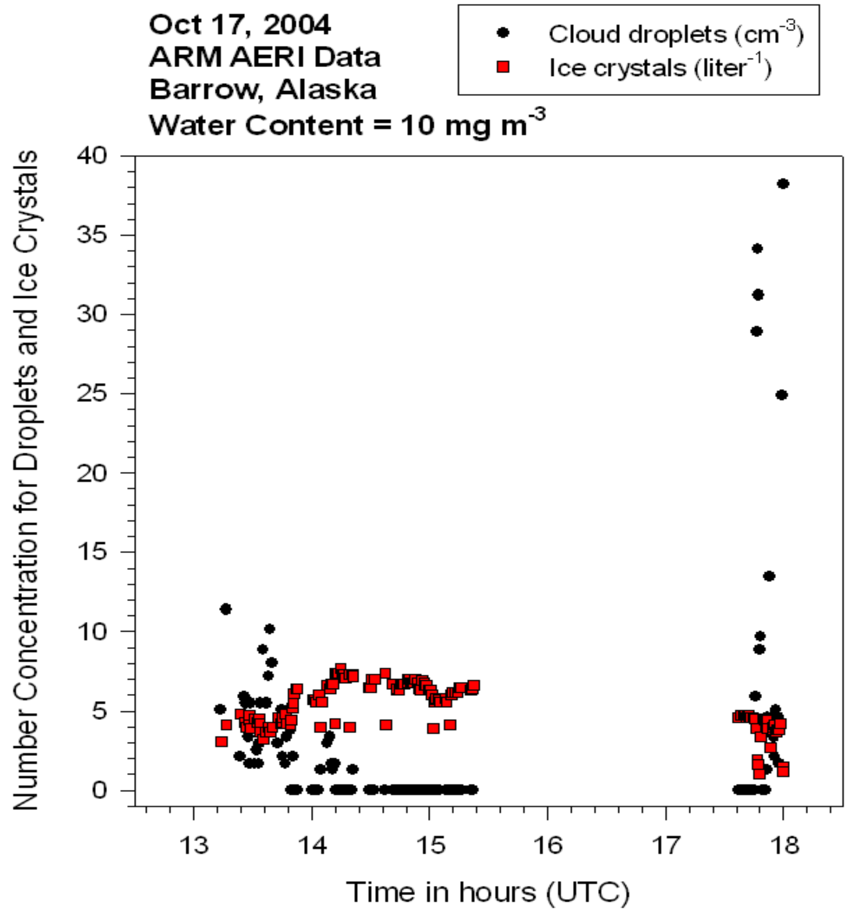


Figure 8. Retrieved cloud droplet and ice crystal number concentrations assuming a total water content (ice + liquid) of 10 mg m^{-3}.

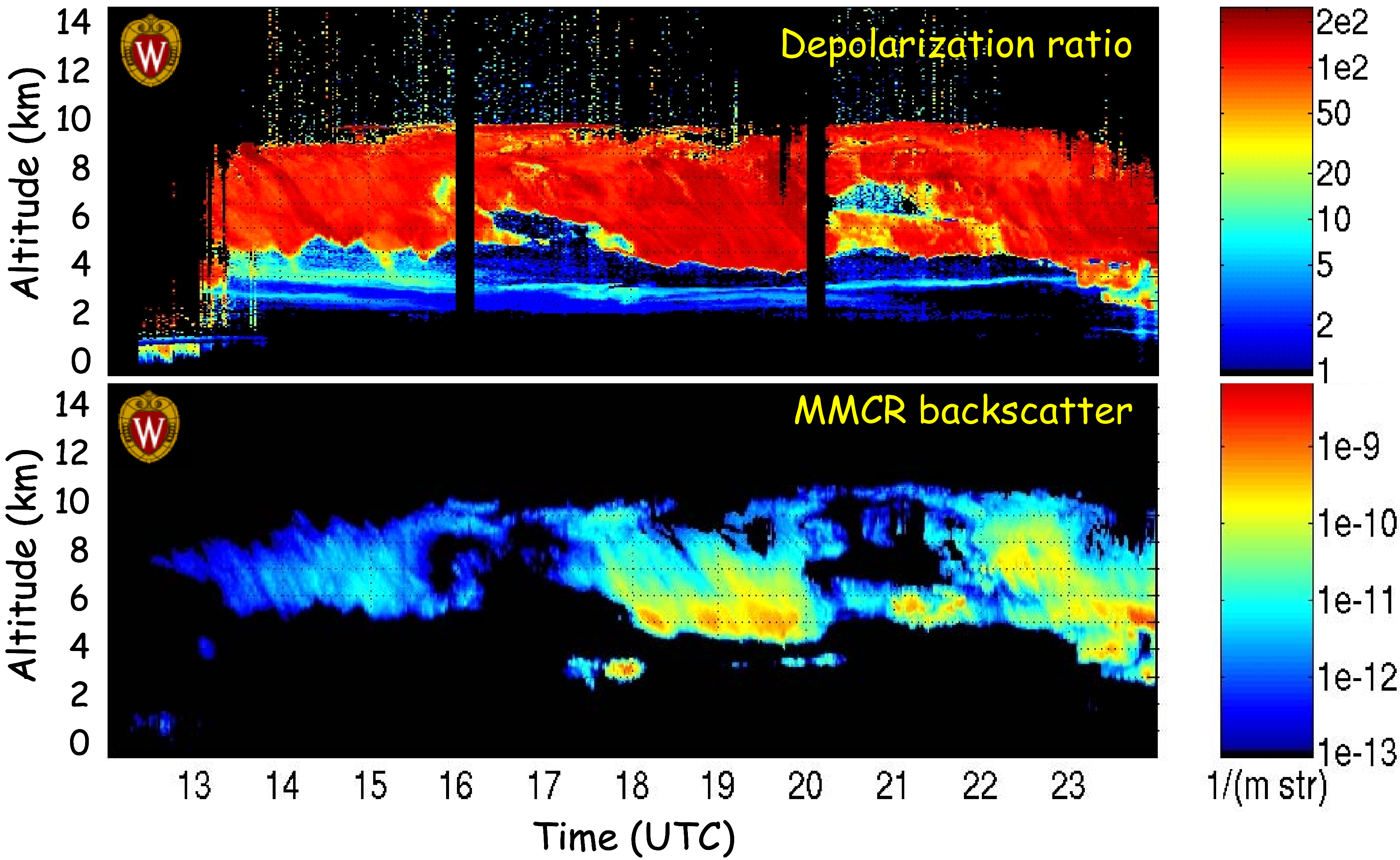


Figure 9. Lidar depolarization ratios and MMCR backscatter for the M-PACE 17 October case study at Barrow, Alaska, courtesy of Ed Eloranta (Univ. of Madison, WI).

Summary

1. AOD ratios in Fig. 5 and the radiance-weighted cloud temperatures in Fig. 6 suggest the presence of liquid water in Arctic cirrus clouds.

2. Retrievals using a new satellite remote sensing methodology suggest that a pronounced PSD small mode is often a measurement artifact and that the small mode when present is mainly comprised of liquid water. Therefore, this retrieval algorithm is modified to interpret all condensate in the small mode as liquid water.

3. Cloud retrievals are sensitive to what one assumes for D_{sm}. Based on measurements in mixed phase clouds, we assume D_{sm} = 7 μm. Increasing D_{sm} from 7 to 10 μm can increase the retrieved LWC by a factor of 3 and decrease the retrieved WP and D_{eff} by 40% and 32%, respectively. This is due to the transition from area dependent absorption to mass dependent absorption (as droplet size decreases for D < 10 μm).

Summary continued ....

4. When the retrieval algorithm is changed 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.

5. When the LWC is negligible (glaciated clouds), the AERI radiances indicate monomodal PSDs with ice particle concentrations of 4-7 $liter^{-1}$. These retrieved ice particle concentrations appear consistent with known ice nucleation processes.

6. High lidar depolarization ratios indicate the dominance of ice phase, consistent with our results.

THANK YOU!!

QUESTIONS?