Lidar observations of tropical high-altitude cirrus clouds: Results from dual wavelength Raman lidar measurements during the ALBATROSS campaign 1996

G. Beyerle[a,b], H.-J. Schafer[b], O. Schrems[b],
R. Neuber[b], P. Rairoux[b], and L S. McDermid[a]

[a] Jet Propulsion Laboratory, California Institute of Technology,
Wrightwood, California 92397 USA

[b] Alfred Wegener Institute for Polar and Marine Research,
D-27515 Bremerhaven and D-14401 Potsdam Germany

ABSTRACT

Results from dual wavelength Raman lidar observations of tropical high-altitude cirrus clouds are reported. Based on 107 hours of night-time measurements cirrus clouds were present in more than 50% of the observations at latitudes between 23,5”S and 23.5°N and altitudes between 11 and 16 km. Volume depolarization is found to be a sensitive parameter for the detection of subvisible cloud layers. Using Mie scattering calculations estimates of the ice water content are derived.

Keywords: Raman lidar, aerosols, cirrus clouds

1. INTRODUCTION

It is well known from satellite observations that cirrus clouds form an ubiquitous layer at tropical latitudes.[1,2] These clouds are believed to play an important role in the radiation budget of the earth atmosphere. Furthermore, because of upward transport of air across the tropical tropopause into the stratosphere the presence of tropical cirrus clouds influences the stratospheric water content .[3-5]

Here, we present first results from lidar observations of tropical high-altitude cirrus clouds above the Atlantic ocean during the ALBATROSS campaign (Atmospheric chemistry and lidar studies above the Atlantic ocean related to ozone and other trace gases in the tropo- and stratosphere) in October-November 1996. The measurements were performed with a mobile aerosol Raman lidar aboard the German research vessel “POLARSTERN” on a cruise from Bremerhaven, Germany to Punta Quills, Argentina.

2. INSTRUMENTATION AND DATA REDUCTION

The lidar instrument transmits simultaneously at wavelengths of 355 and 532 nm. Elastic and inelastic components of the backscattered light (Rayleigh- and Mie-scattering, vibrational Raman-scattering on molecular nitrogen) are detected, Additionally, the cross-polarized signals at 355 and 532 nm are recorded. Currently the instrument operates during night-time only. Further technical details can be found in Schafer et al.[6]

After applying background and saturation corrections to the raw signals the backscatter ratio $R = 1 + \beta_A/\beta_M$ is derived by dividing the Rayleigh and corresponding Raman profile and normalizing to unity at an aerosol-free altitude range between 18 and 22 km. Here, $\beta_{A,M}$ denote the aerosol and molecular backscatter coefficient, respectively. Similarly, volume depolarization $\delta = \beta^{\perp}/\beta^{\parallel}$ is calculated by forming the ratio of the signals in the cross- and

For further information- G.B. (correspondence): Email: beyerle@tmf.jpl.nasa.gov; Telephone: +1 (617) 249-6176; Fax: +1 (619) 249-5392; I. S.M.: Email: mcdermid@tmf.jpl.nasa.gov; Telephone: +1 (617) 249-4262; Fax: +1 (619) 249-5392; R.N.: Email: neuber@awi-potsdam.de; Telephone: +49 (331) 288-2129; Fax: +49 (331) 288-2137; P.R.: Email: rairoux@awi-potsdam.de; Telephone: +49 (331) 2S8-2129; Fax: +49 (331) 288-2137; J. S.: Email: schafer@awi-bremerhaven.de; Telephone: +49 (471) 4S31-247; Fax: +49 (471) 4831-425; 0. S.: Email: otto_schrems@awi-bremerhaven.de; Telephone: +49 (471) 4831 -4S0; Fax: +49 (471) 4831-425;

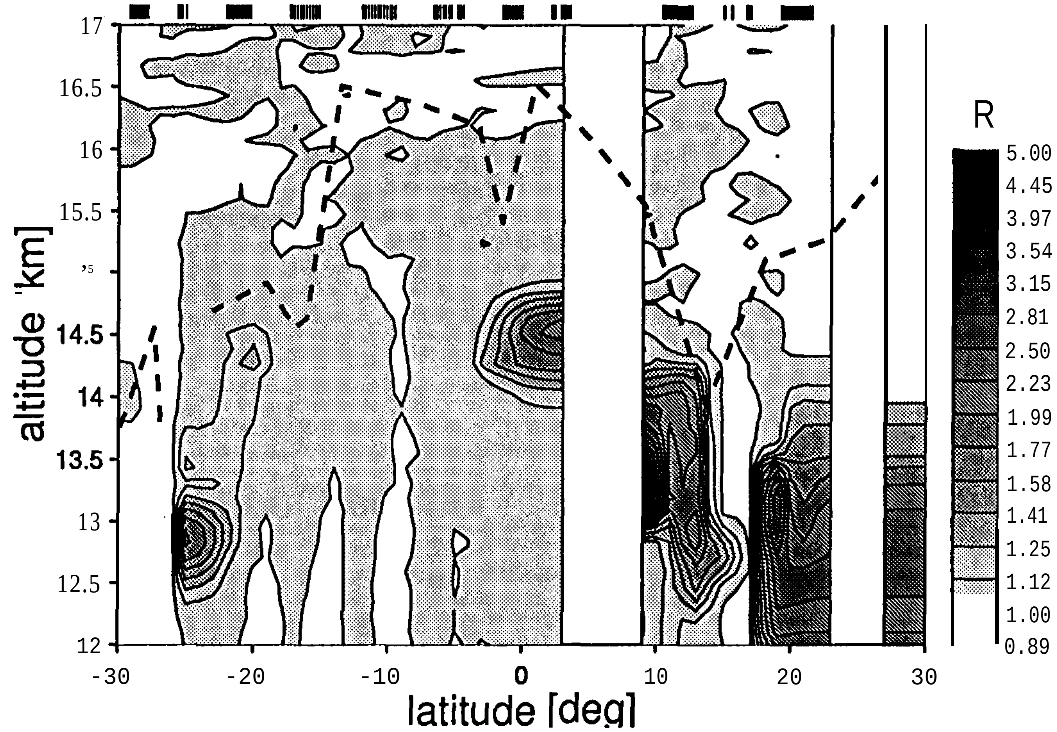

Figure 1. The altitude dependence of backscatter ratio at a wavelength of 355 nm as a function of latitude. Also given is the tropopause altitude (broken line). Bars above the figure show the measurement periods.

aligned-polarization channels and normalizing to 0.014. The superscripts ⊥,|| refer to cross- and aligned-polarization, respectively. The cloud optical thickness between altitudes z_b and z_t is given by

$$\tau = L \int_{z_b}^{z_t} dz\, \beta_A(z) .$$

Here, L denotes the ratio of aerosol extinction and backscatter coefficient.

3. RESULTS AND DISCUSSION

During the campaign lidar measurements were performed on the Atlantic ocean between 35°N and 45"S. In the following we restrict the discussion on the tropical and subtropical observations (30°N-300S). Based on 12288 shot averages (about 7 minutes) a total of 632 lidar profiles were obtained within this latitude range.

The altitude dependence of backscatter ratio and volume depolarization at a wavelength of 355 nm as a function of latitude is shown in Figures 1 and 2, respectively. The altitude of the tropopause (broken line) is obtained from daily serological soundings. Frequently several distinct layers were found within the cirrus cloud with the highest layers reaching the tropopause. High values of R and δ were observed close to the *ITCZ* at 8"N. There is no indication for the presence of cirrus clouds in the lower stratosphere.

Comparison between Figure 1 and 2 suggests that volume depolarization is a sensitive indicator for the detection of subvisible cirrus clouds. Enhanced values of δ which occasionally exceeded 30% are caused by scattering on nonspherical cirrus ice particles whereas for molecular scattering $\delta = 1.4\%$.[7] In the tropics (23.5 °S–23.50N) we find in 53% out of 475 profiles maximum volume depolarizations exceeding 5% within the altitude range 11–16 km. In the subtropics (23.5-30°S and 23.5–30°N) this percentage reduces to 18% based on 157 profiles. Frequently, enhanced values of δ indicated the presence of cirrus which were invisible to the unaided eye. Assuming that $\delta > 5\%$ indicates

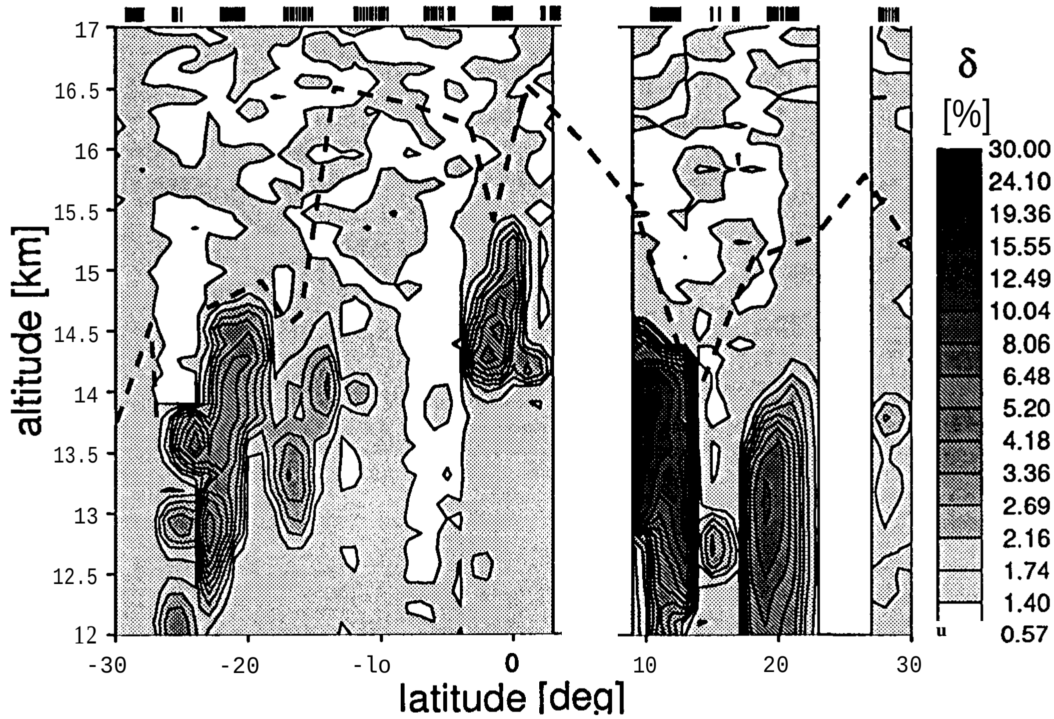

Figure 2. The altitude dependence of volume depolarization at 355 nm as a function of latitude. Also given is the tropopause altitude (broken line). Bars above the figure show the measurement periods.

the presence of a cirrus layer we find that 38% of the observed clouds had an optical thickness of less than 0.03 at 355 nm.

Based on the ratio of aerosol backscatter coefficients at 355 and 532 nm an estimate of the particle sizes were derived within the framework of Mie scattering theory. For the refractive indices of water ice at 355 and 532 nm $1.325 + i\,3.76 \cdot 10^{-9}$ and $1.312 + i\,3.11 \cdot 10^{-9}$ are used, respectively.[8] As Mie theory is valid for spherical particles only measurements with an aerosol depolarization $\delta_A < 0.3$ are included. The resulting ice water content (I WC) as a function of temperature T is shown in Figure 3. Here, a mass density of ice $\rho = 0.78$ g/cm^3 is assumed.[9] The full line shows the result of the linear fit, $IWC = \exp(-29 + 0.063\ \mathrm{K}^{-1} \cdot T)$ g/m^3. The broken line is a parameterization from Suzuki et al.[10]

4. ACKNOWLEDGEMENTS

The help and support by the crew of "POLARSTERN" during the ALBATROSS campaign is gratefully acknowledged. We thank R. Weller and J. Gräser for providing the radio sonde data. The lidar instrument was designed and built by OHB System Bremen, Germany in co-operation with GKSS Forschungszentrum Geesthacht, Germany and Alfred Wegener Institute, Bremerhaven and Potsdam, Germany. We gratefully acknowledge financial support for this project by Deutsche Bundesstiftung Umwelt, Germany. G. B. thanks the National Research Council for the award of an associateship. Part of the work described here was performed at the Jet Propulsion Laboratory, California Institute of Technology, through an agreement with the National Aeronautics and Space Administration.

REFERENCES

1. C. Prabhakara, R. S. Fraser, G. Dalu, M. C. Wu, R. J. Curran, and T. Styles, "Thin cirrus clouds: Seasonal distribution over oceans deduced from Nimbus-4 IRIS," *J. Appl. Meteorol.* *27*, pp. 379-399, 1988.

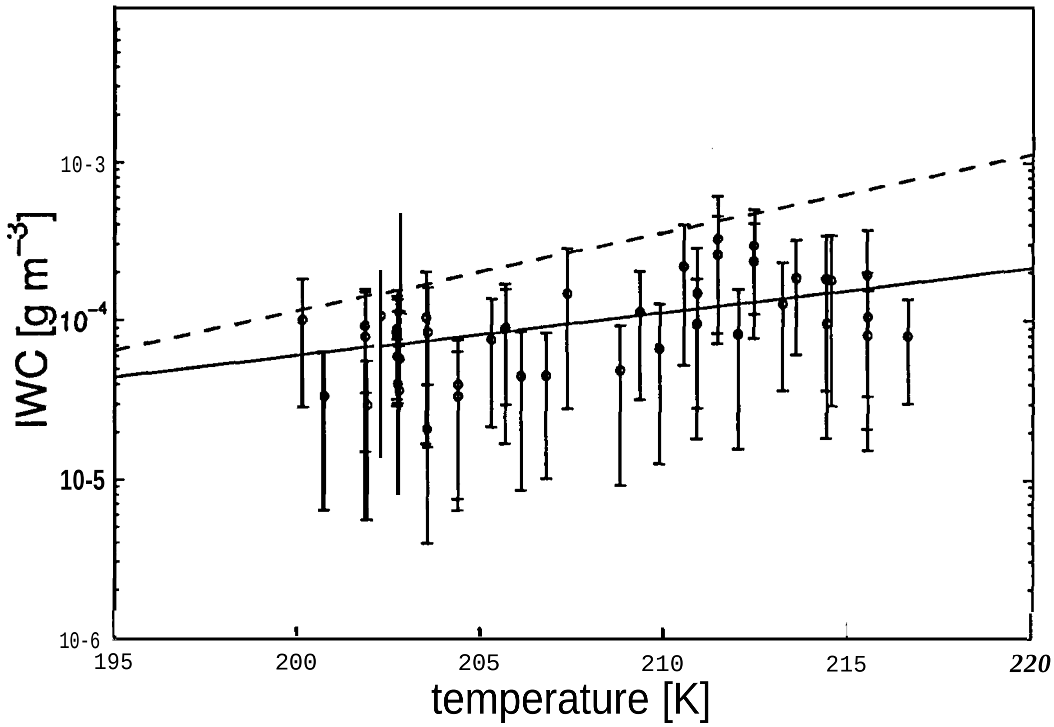

Figure 3. Ice water content (IWC) aa a function of temperature. Also shown area linear fit through the data (full line) and a parameterization by Suzuki et al. (broken line).

2. P.-H. Wang, M. P. McCormick, L. R. Poole, W. P. Chu, G. K. Yue, G. S. Kent, and K. M. Skeens, "Tropical high cloud characteristics derived from SAGE H extinction measurements," *Atmospheric Research* 34, pp. 53-83, 1994.
3. B. E. Potter and J. R. Holton, "The role of monsoon convection in the dehydration of the lower tropical stratosphere," *J. Atmos. Sci. 52(8),* pp. 1034-1050, 1995.
4. E. J. Jensen, O. B. Toon, L. Pfister, and H. B. Selkirk, "Dehydration of the upper troposphere and lower stratosphere by subvisible cirrus clouds near the tropical tropopause," *Geophys. Res. Lett. 23(8),* pp. 825-828, 1996.
5. E. J. Jensen, O. B. Toon, H. B. Selkirk, J. D. Spinhirne, and M. R, Schoeberl, "On the formation and persistence of subvisible cirrus clouds near the tropical tropopause," *J. Geophys. Res.* 101(D16), pp. 21361-21375,1996.
6. H.-J. Schafer, O. Schrems, G. Beyerle, B. Hofer, W. Mildner, F. A. Theopold, W. Lahmann, C. Weitkamp, and M. Steinbach, "A modular and mobile multi-purpose lidar system for observation of tropospheric and stratospheric aerosols," *SPIE EurOpto series 2581,* pp. 128-136, 1995.
7. A. T. Young, "Revised depolarization correction for atmospheric extinction," *Appl. Opt. 19(20),* pp. 3427-3428, 1980.
8. S. G. Warren, "Optical constants of ice from the ultraviolet to the microwave," *Appl. Opt.* 23(8), pp. 1206-1225, 1984.
9. A. J. Heymsfield, "Ice crystal terminal velocities," *J. Atmos. Sci. 29,* pp. 1348-1357, 1972.
10. T. Suzuki, M. Tanaka, and T. Nakajima, "The microphysical feedback of cirrus cloud in climatic change," *J. Met. Sot. Japan 71(6),* pp. 701-713, 1993.