Comparison of cirrus cloud properties in the northern and southern hemisphere on the basis of lidar measurements.

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ABSTRACT: Cirrus cloud measurements have been performed during the INCA field campaigns in Punta Arenas/Chile (53.12°S, 70.88°W) and in Prestwick/Scotland (55.51°N, 4.60°W) in each hemisphere's fall in the year 2000. From lidar backscatter profiles at 532 nm and 355 nm the optical depth (OD) of the clouds is retrieved as well as base and top altitude of the clouds, the color index and the depolarization. Cloud layers with optical depths covering more than 3 orders of magnitude have been detected by the lidar, with a high share (35%) of subvisual cirrus at both sites. Differences in the results from the southern and the northern hemisphere are found in the lidar ratio and the depolarization behavior. While there is a large natural variability in cirrus properties, our results indicate a tendency towards bigger particles and columns in the southern hemisphere compared to smaller particles and small crystal plates in the northern hemisphere.

1 INTRODUCTION

The Mobile Aerosol Raman Lidar (MARL) of the Alfred Wegener Institute is a mobile backscatter lidar which was already operated during several field campaigns at various locations as well as aboard the German research vessel Polarstern to measure aerosol and clouds in the upper troposphere and lower stratosphere. In 2000, two field-experiments have been conducted within the European INCA 2000-project (Interhemispheric differences in cirrus cloud properties by anthropogenic emissions). The first one took place in the midlatitudes of the southern hemisphere (Punta Arenas/Chile, 53.12°S, 70.88°W) and the second campaign followed in September 2000 in Prestwick/Scotland (55.51°N, 4.60°W). The main objective of these investigations was to collect Lidar data of cirrus clouds from clean (Punta Arenas) and polluted (Prestwick) areas and to analyze this data in respect to differences that might be caused by air traffic or other anthropogenic emissions. During the four weeks of the campaigns, about 80 hours of Lidar measurements were gathered at each location, covering different types of cirrus clouds as well as background aerosols. A comparison of the two datasets reveals similarities as well as differences in the measured cirrus cloud properties.

2 CLOUD DETECTION BY LIDAR

MARL (<u>M</u>obile <u>A</u>erosol <u>R</u>aman <u>L</u>idar) is a backscatter Lidar based on a linear polarized Nd:YAG Laser with 30 Hz repetition rate and 200 mJ pulse energy (@532 nm). The detection unit uses a 1.1 m cassegrain telescope and a multichannel polychromator which detects backscattered light at 532 nm and 355 nm, both separated in parallel and perpendicular polarization (with respect to the lasers linear polarisation). Furthermore, the system detects light backscattered from N_2 molecules with a Raman shift (607 and 387nm). The Raman signals allow the direct measurement of cloud and aerosol extinction. The system is capable for day- and nighttime operation, except for the Raman channels.

To detect clouds in the upper troposphere, the backscattered light is analyzed with respect to peaks that result from enhanced backscattering from cloud particles. Every atmospheric feature is included in the analysis, which creates a significant enhancement in the backscatter signal according to the following definition:

$$S(h) = \frac{d}{dh} \frac{P(h)}{P_{Ray}(h)} > 3\sigma \quad (1)$$

where P(h) is the measured lidar backscatter signal and $P_{Ray}(h)$ is a simulated lidar signal from a purely molecular atmosphere. σ is the standard deviation of S(h) calculated from Poisson-statistics of the signal count rates. The cloud base is the first altitude starting from 4 km that satisfies criterion (1). The cloud top height is defined as the altitude where S(h) is back to zero and the integral of S(h) is greater than zero. Whether every feature that creates such a signal is a cloud in the traditional meaning of this word needs to be discussed, however, here we call these atmospheric features clouds. Since our definition is based on the increasing slope of the backscatter signal instead of the total cloud backscatter, there is no lower detection limit in terms of the optical depth. In fact, this method is very sensitive and thin cloud with an optical depth of 10^{-3} can easily be detected in simulations. When using the perpendicular channel as P(h) in eq. (1), the sensitivity of this method is even increased by about a factor of 10 in the case of depolarizing clouds like cirrus.

Besides cloud base and top height the optical depth, the depolarization and wavelengths dependence of the backscatter coefficient (color index) of the cloud can be inferred from the lidar data. Our analysis is based on the mean value of these quantities taken over one cloud layer as defined by the definition given above.

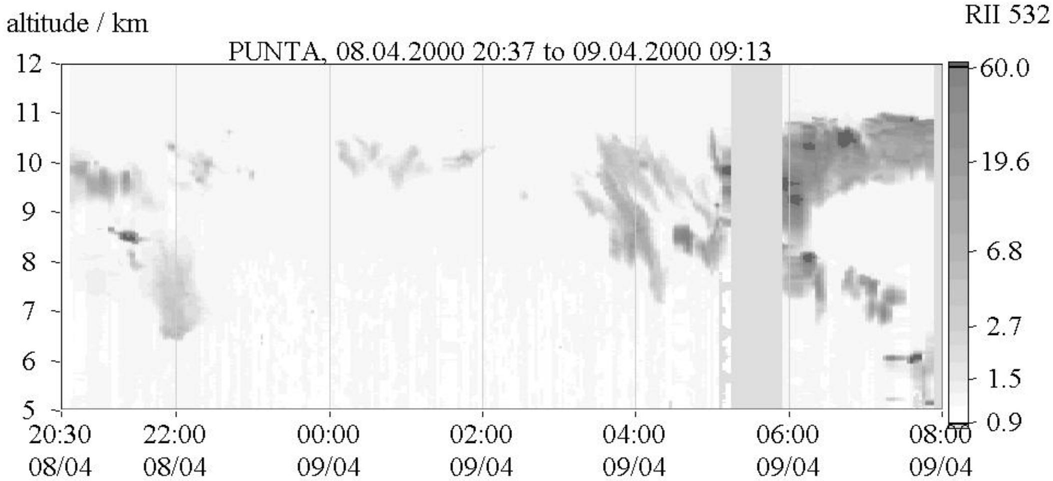


Fig. 1 Lidar measurements of cirrus clouds in Punta Arenas on April 4th 2000. Plotted is the backscatter ratio as a function of time (UT) and altitude. Between 00:00 and 02:00 thin, subvisual cirrus were detected, at an altitude of around 10 km.

3 RESULTS

The ability of our lidar system to detect very thin clouds allow to study the properties of these so-called subvisual cirrus (Sassen et al., 1989) in comparison with visible cirrus clouds. It has been reported earlier (Immler and Schrems, 2002), that during both campaigns a considerable part of subvisual cirrus have been detected. In both, northern (NH) and the southern hemispheric (SH) campaigns, about 35% of the total detected clouds were subvisual.
The 'color' in terms of the color index

$$CI = \frac{\ln(\beta_{532})}{\ln(\beta_{355})} \cdot \frac{\ln(355)}{\ln(532)} \quad (2)$$

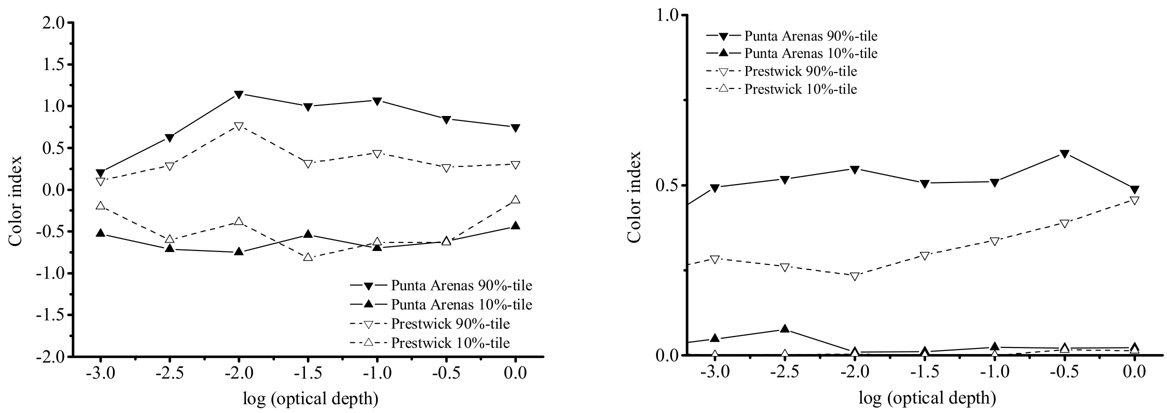
of this thin clouds is predominantly close to zero independent of the optical depth and the location of the campaign (Fig.2). This indicates that the particles of the detected cloud layers are rather large (r_{eff} > 3 µm) and give the cloud a white color. This could be understood as a good definition for cirrus clouds from the lidar perspective, since most aerosol types have a color index greater than 0.5 with the exception of Saharan dust, which exhibits a color index clearly below zero (Sasano and

Browell, 1989). Together with the depolarization data (Fig. 2b) our data suggest that the great majority of the particle layers detected by the lidar in the upper troposphere are ice clouds, including those with an optical depth in the subvisual range.

The tendency towards higher values of the color index in the SH data (Punta Arenas) of Fig. 2a might be caused by the orography of the site where a mountain range to the west regularly induced lee waves in which cirrus were formed. The larger vertical wind speed within the lee-waves generates smaller cirrus particles (Gayet et al., 2002).

The depolarization that was measured in Punta Arenas tended to be larger than the one measured in Prestwick. This discrepancy between the NH and the SH data of the depolarization behavior is higher in the subvisual range. Since the color index and the depolarization are in general anti-correlated the highly depolarizing clouds refer to another fraction of the observed clouds than the ones with the large color index discussed above. These clouds have zero or slightly negative color indices.

For clouds in the visible range, the optical depth can be calculated directly from the lidar signals. Provided that the lidar ratio, i.e. the ratio between the extinction and the backscatter coefficient is constant throughout the cloud, this measurement allows the determination of the lidar ratio. The results are shown in Figure 3. In the NH the measured lidar ratios at 532 nm form a rather narrow distribution around 21 sr with a standard deviation of 7 sr. Values above 30 sr are rarely measured. This is different in the southern hemispheric where about 50% of the data are values above 30 sr.



a b

Fig.2 10% and 90% quantiles of the color index and the depolarization (right) as a function of the optical depth

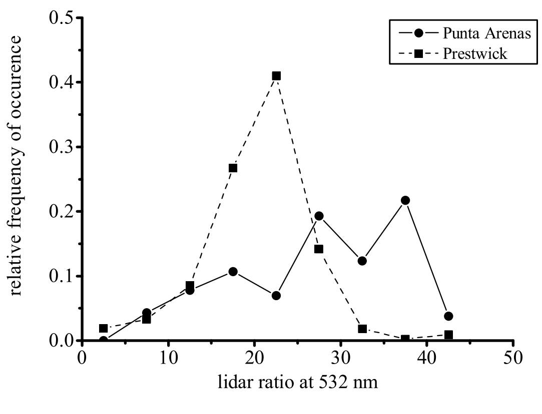


Fig. 3: Relative frequency of occurrence of the lidar ratio of cirrus clouds determined with the lidar at the NH and SH locations.

4 CONCLUSIONS

The interpretation of lidar data of cirrus clouds in terms of properties of the cloud particles is not a straight forward task. Not only is the theoretical treatment of the scattering process difficult and time consuming, it is furthermore complicated by the fact that cirrus can contain particles of various sizes and shapes. However, an interesting approach has recently been developed by Reichardt et al. (2002) who uses the ray tracing technique to interpret the correlations of the depolarization and lidar ratio that were found in their measurements. It is shown that hexagonal columns depolarize more than plates while the lidar ratio is primarily a function of the aspect ratio (= length divided by width of the particle), particles with a stronger asphericity show a higher lidar ratio. While small particles tend to have an aspect ratio close to one, the aspect ratio will commonly differ significantly from unity for large particles. Thus, the lidar ratio is associated with particle size.

Based on this considerations, one may conclude from the lidar ratios measured in our study (Fig.3) that the particles of the clouds in the SH, visible and subvisible, tend to be larger and therefore have a higher lidar ratio, than the ones measured in the NH. Furthermore, the depolarization indicates a higher share of column-like particles in the southern hemisphere, while the northern hemispheric cirrus seem to be dominated by plates. This is most clearly the case for subvisual cirrus since in the SH, where a significantly larger fraction of subvisual clouds show high depolarization than in the NH (Fig. 2b).

However, it has to be noted that the extraction of microphysical information from lidar data is an underdetermined problem and that other explanations based on different types of particles are conceivable and could lead to different conclusions. Also, the limited size of our data base restricts our ability to draw general conclusions for cirrus properties in the northern and the southern hemisphere. One thing however that is save to conclude is, that there is a large natural variability in cirrus properties in both, northern and southern hemisphere, which is expressed by the wide range of optical depth and depolarization ratios of cirrus clouds determined by the lidar.

A detailed study of contrails and cirrus in the midlatitudes is currently being conducted with our lidar in Lindenberg (near Berlin/Germany), where radiosondes and sky cameras allow for a detailed characterization of the clouds and the meteorological condition under which they appear.

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