A NOVEL RADIOSONDE PAYLOAD TO STUDY UPPER TROPOSPHERIC / LOWER STRATOSPHERIC AEROSOL AND CLOUDS

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1. INTRODUCTION

Dehydration mechanisms driven by the formation of visible and subvisible cirrus clouds determine the atmospheric water vapor budget and thus the chemical and radiative properties of the upper troposphere and the stratosphere. In contrast to previous understanding recent in situ observations have revealed high supersaturation with respect to ice of several 10% occurring not only in clear air surrounding cirrus clouds but also inside the cirrus themselves, and apparently also in large interconnected regions where they cannot be explained easily in terms of local upwelling. It is not well understood how such supersaturations, if not caused by instrumental artifacts, can be maintained within clouds exposing large ice surface areas to the water vapor. Precise and frequent measurements of cirrus properties and relative humidity using independent instrumentation are required to obtain a better understanding of dehydration processes and of their influence on the global atmospheric radiation budget.

To further investigate these findings a radiosonde payload was developed that is launched regularly on meteorological sounding balloons from Zurich and Payerne since early 2008. A pTu sonde along with the «SnowWhite» frost point hygrometer (meteolabor SRS-C34, night type) is supplemented by the new Compact Optical Backscatter AerosoL Detector (COBALD). This lightweight (500 g including power supply) and cost-effective sensor applies high power LEDs to measure optical backscatter at wavelengths centered around 455 and 870 nm. We demonstrate the potential of the new COBALD sonde for the characterization and understanding of cirrus nucleation and growth. The sonde observations provide particle surface area densities vis-à-vis relative humidity in the clouds.

2. INSTRUMENT DESCRIPTION

(a) PRESENT STATUS OF INSTRUMENT. Backscatter sondes are a valuable tool to characterize in-situ aerosol or cloud particles on balloon soundings. The lightweight balloon sonde COBALD (Compact Optical Backscatter AerosoL Detector) was designed and tested at our institute (IACETH) recently. It is based on similar principles as the sonde of Rosen and Kjome [1991] which has been used extensively in field studies. The new sonde development was initiated in close consultation with Jim Rosen and Norm Kjome. Their original design, even in a downscaled version, does not meet the weight restrictions of the operational sounding payloads in many countries including Switzerland. Table 1 lists some technical properties of COBLAD.

(b) OPTICS. COBALD applies two high-power LEDs. Rated to 250 mW optical power each, the total light utilizable on average for the backscatter measurement is comparable in magnitude to that of the flashtube sonde (Rosen and Kjome, 1991). The operation scheme chosen for COBALD is depicted in Figure 1. The emitted light is collimated to cones of less than 4° beam divergence (HWHM). The backscatter is collected by a fast lens (25 mm aperture with 18 mm focal length)

Table 1: The backscatter sonde employed within this package has following properties.

Feature	Expected specification	Remark
backscatter intensity dynamic range	40dB	covers range from aerosols (0.1 ppb cond.) to thick anvil outflow (100 ppm ice)
detectable RH relative to ice	20 - 200 %	lower and upper limit determined by SnowWhite single Peltier stage
weight of backscatter sonde including power supply	540 g	suited for piggyback in many applications
weight of entire ensemble incl. SnowWhite and pT sonde	< 1700 g	for operational service
time resolution backscatter	1 Hz	digital transmission via pTu-sonde data stream

and focused onto a silicon detector yielding a field of view of ±6° oriented into the same direction as the LED emission. With a geometric separation of 3 cm limited by the optical-apertures a good overlap between the emission and reception fields of view is established at a distance greater than 0.5 m from the sonde.

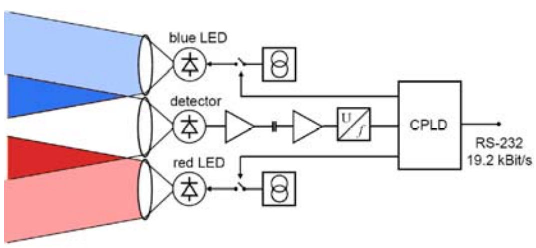

Figure 1: Operation scheme of the backscatter sonde.

In wavelength the emission is confined to $\Delta\lambda_{½}$ = 20 nm around 455 nm in the blue and to $\Delta\lambda_{½}$ = 50 nm around 870 nm in the red optical channel and continuous in time. The wavelength characteristics, together with the high LED current to light conversion efficiency, is advantageous for lowering power consumption and weight. The continuous beam, however, demands special means for data acquisition in order to discern the backscattered light from background and noise sources. In addition, high dynamic range is required in backscatter measurements in order to adequately resolve the molecular Rayleigh scattering which is used as a reference, to provide sufficient headroom for the aerosol scattering on top of the Rayleigh scattering, and to cover the pressure span of an approximate factor 50 encountered during a balloon sounding.

(c) ELECTRONIC CONFIGURATION. To meet these requirements the LED emissions are chopped with a duty cycle of 50 % and a phase sensitive (lock-in) detection scheme is applied to retrieve the backscattered light signal. The modulation of the two LEDs is 90° out of phase so that both optical channels are carried on the same frequency of 300 Hz. Adequate dynamic range and low signal offset are assured by frequency conversion of the detector signal through a highly linear synchronous circuit with subsequent digital implementation of the phase sensitive detection scheme inside a complex programmable logic device (CPLD) that directly communicates to the monitoring computer or the sonde telemetry through a standard RS-232 interface.

The electrical noise of the first amplifier stage following the detector limits the minimum detectable optical power to 200 fW (red channel) at the given 1 Hz bandwidth. This corresponds to a fraction of 10^{-12} of the power emitted by the LED. Daylight saturates the first amplifier stage which has to be DC coupled to the detector photodiode in order to obtain the described signal-to-noise performance. Thus, only nighttime measurements are carried out. This is common for backscatter sondes and no serious limitation since also the SnowWhite sensor is best operated at nighttime to obtain high quality data.

(d) SIGNAL TREATMENT. Backscatter sonde signals obtained at the optical wavelength λ are usually expressed as backscatter ratios T_λ (the ratio of the aerosol to the molecular (Rayleigh) scattering intensity) or as aerosol backscatter ratios B_λ (the ratio of the particle backscatter to the Rayleigh backscatter intensity), where $T_\lambda = B_\lambda - 1$. Particle

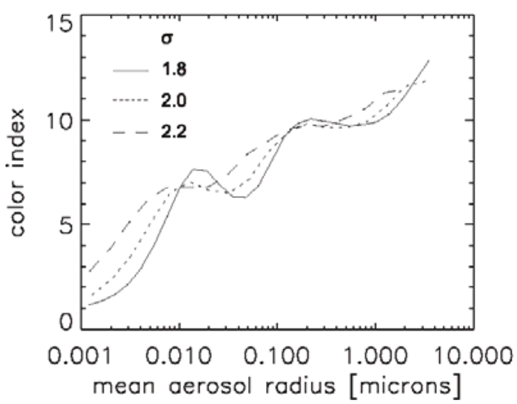

Figure 2: Color index. The color index of a lognormal aerosol distribution as measured by COBALD. The aerosol is assumed to have a refraction index of 1.45. The calculations were carried out for lognormal aerosol distributions with mean radius given on the x-axis and a spread σ indicated by the different lines. All lines will approximate the color index of 15 for larger particles.

size information can be retrieved from the ratio B_{870} / B_{455} which we, following the convention of Rosen and coworkers, refer to as color index *CI*. The *CI* = 1 limit is reached for purely molecular Rayleigh backscatter, whereas for large particles *CI* converges towards 15, since the the aerosol scattering for both probing wavelengths equal and the Rayleigh scattering ratio is 15 (λ^{-4}).

Figure 2 presents the color index dependence on mean radius and spread of lognormal particle distributions. It reveals that a mean aerosol radius of approx. 5 µm can be quantified at maximum with the probing wavelengths used. Above this level it can only be stated that the particle radius must be larger than this limit. For narrow aerosol distributions (σ ≤ 2) radius retrieval may not be unique due to the non monotonic dependence. Still, total particle surface area density can be determined for arbitrarily large particles with the help of the backscatter intensity, provided this measure is robustly characterized and the signal remains within the instrumental dynamic range.

4. FIRST BALLOON FLIGHT OF THE BACKSCATTER SONDE

The COBALD sonde had its premier flight in the late evening of 15 February 2007. The night from 15 to 16 February 2007 was selected because the weather forecast indicated a relatively clear and thus cool night with weak wind. Both parameters were important to have a relaxed premier launch avoid passing through thick low level clouds that could contaminate the sonde optics. The radiative cooling and winterly conditions further let suppose the growth of cirrus clouds.

Two units, orientated to opposite directions were flown hosted by a modified pT-sonde of Meteolabor using GPS data interface to transmit the backscatter sondes' signals. This implied removal of the GPS unit for this flight. At a later stage we intend to use the interface for a combined transmission of the CO-

BALD and GPS telemetry. We chose to fly with two COBALD sondes to be able to intercompare and hence learn about design issues. Figure 3 shows a scatter plot of the two sondes' blue channel

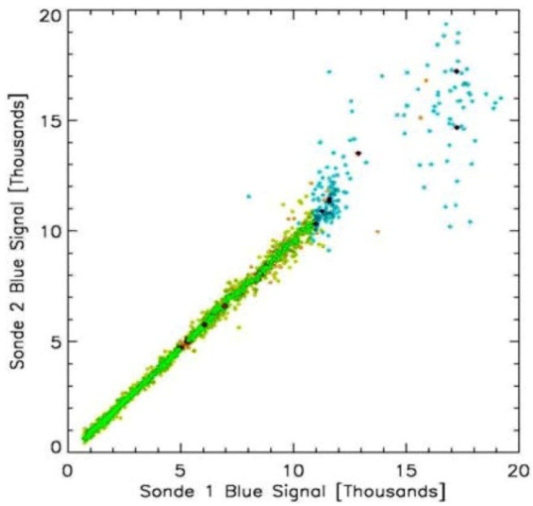

Figure 3: Correlation of the blue channels. Thin light points: unscaled one-second raw data; thick dark points: 100 m altitude averages. Blue colors: planetary boundary layer; red colors: cirrus between 9.2 and 9.8 km altitude; green colors: other altitudes.

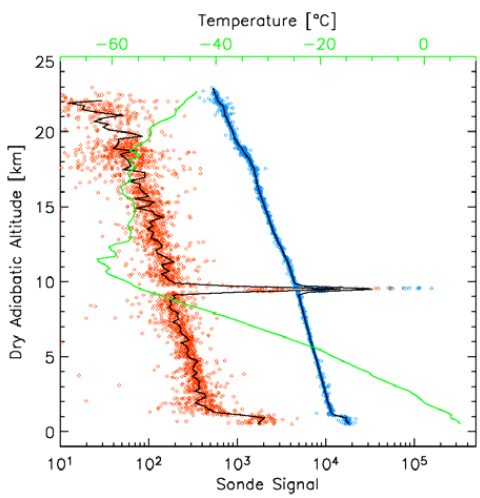

Figure 4: The temperature profile is provided in green. It shows the raw data of the 455 nm (blue) and 870 nm (red) channels. The black lines denote averages over 200 m altitude bins.

data. The correlation is excellent outside the boundary layer (green colors). Due to the higher spatial variability of the aerosol in the planetary boundary layer (blue colors) the correlation is smaller for the two sondes probing opposite directions. The two sondes gave almost identical results.

Figure 4 shows altitude profiles from the first flight. Temperature and pressure data served to calculate the dry adiabatic pressure altitude. Temperature data is superimposed in green on both panels indicating a location of the tropopause near 12 km.

Figure 5 provides estimated aerosol backscatter data together with the deduced color index at expanded altitude scale around the cirrus cloud. A signal increase of more than two orders of magnitude is observed in the 455-nm channel, the maximum cirrus signal at 870 nm exceeds that of the aerosol level by almost three orders of magnitude.

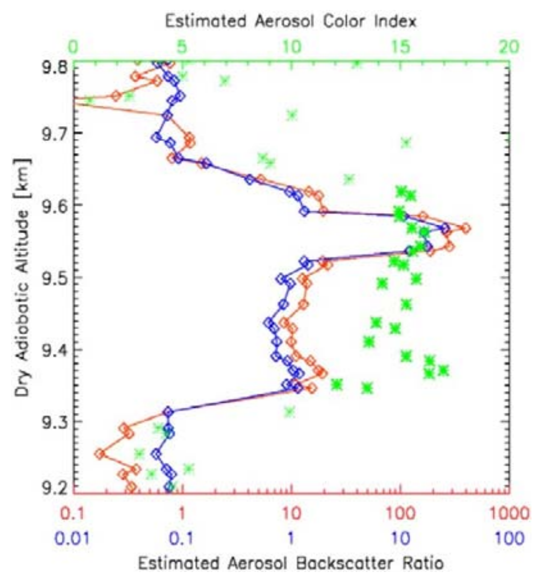

Figure 5: Cirrus cloud. Data integrated over 1 s. The color index (defined as the ratio of the red over blue aerosol backscatter ratios) is given by green symbols. Bold symbols indicate color index values found inside the cloud.

Figure 5 also confirms that both channels are below the saturation limit of 3 x 10^5 signal units. The color index of approximately 15 found inside the cirrus, illustrated as bold symbols, indicates that the particle mean radius exceeds the 5 µm limit that the instrument can resolve according to Figure 2. With the accompanying increase of aerosol backscatter signal, however, cirrus clouds can clearly be discerned from (large) aerosol particles. This is of key importance to examine the occurrence of supersaturation in clear sky or cirrus cloud conditions.

5. CONCLUSION

First observations with COBALD show the new backscatter sonde can robustly provide parameters of the aerosol and hydro particle size distributions in the troposphere (resolving the boundary layer) and stratosphere. Combined with a pTu sonde and an accurate hygrometer (SnowWhite proposed) it will give new insight into the water vapor budget and cloud-physical processes especially in cirrus clouds.

Due to the small weight of the backscatter sonde, the sonde can be launched with ordinary pTu-sondes. It will be possible to use this sonde extensively in future monitoring and research programs or international services (though with the present version only for nighttime measurements). Indeed, a main part of the planned outreach activities will aim at reaching widespread distribution of this new development.

Through an attractive pricing and the widespread deployment a new climatology of cirrus clouds, their cloud particle densities and sizes and the relative humidity in and around midlatitude cirrus clouds can be derived from regular measurements.

References

Rosen JM, Kjome NT, Appl. Opt., 30 (12): 1552-1561, 1991