Polar mesosphere temperature observations by lidar and falling sphere at 78° N

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Abstract. Temperature profiles at mesopause altitudes were obtained by a potassium lidar at 78°N (Spitsbergen) in 2001. Almost all measurements were taken under full daylight condition. At the same location a set of temperature profiles were obtained by rocket borne techniques (`falling spheres') within the ROMA campaign (Rocket borne Observations in the Middle Atmosphere) from mid July to mid September 2001. In this paper we demonstrate for a simultaneous observation on August 28 that the temperatures of both methods are in good agreement. Similar good agreement exists for the seasonal variation of temperatures throughout the entire ROMA campaign. Lidar measurements before the ROMA campaign show that the lowest temperatures of ~120 K occur at the beginning of July at 89 km.

1. Introduction

Studying the thermal structure of the Earth's upper atmosphere by lidar has improved our understanding of the physical and chemical processes in the mesopause region. For example, the discovery of the two level mesopause has been explored by lidar measurements and has modified our understanding of the energy budget of the upper atmosphere [*von Zahn et al., 1996, She and von Zahn, 1998, Berger and von Zahn, 1999*]. At latitudes higher than 69° N the data base is very sparse due to experimental and geographical constraints. In particular no data are available of the summer mesopause at these high latitudes. The knowledge of the thermal structure in the summer mesopause region with a precision of a few Kelvin is crucial for our understanding of phenomena like NLCs (noctilucent clouds) and PMSEs (polar mesosphere summer echoes) [*Lübken et al., 1996, Hervig et al., 2001*]. Accurate temperature observations with high altitude resolution and good seasonal coverage are needed. In the past lidar techniques were not suitable for this demand due to permanent daylight conditions in summer at polar latitudes which lead to very high solar background. With the adoption of the FADOF (Faraday anomalous dispersion optical filter) technique for daylight observations [*Fricke-Begemann et al., 2002*] it has become possible to perform such temperature measurements. The same lidar can simultaneously detect NLC. Here we report about lidar temperatures obtained from June 12 to October 6, 2001 at Spitsbergen, 78° N. The launch of 24 falling spheres (FS) at the same location during the ROMA campaign, 2001 [*Lübken and Müllemann, 2003*] enables us to compare lidar temperatures with the well established FS technique. Together with observations of NLC by lidar and PMSE by radar a unique data set about the Artic mesopause region was obtained. Further results are described elsewhere [*Höffner et al., 2003, Lübken et al., 2004, Lübken and Höffner, 2004*].

2. Experimental Configuration

The mobile potassium temperature lidar introduced by *von Zahn and Höffner [1996*] is designed to measure atmospheric temperatures by profiling the potassium layer between 80 km and 105 km altitude. The lidar is based on a seeded narrowband alexandrite ring laser scanning the Doppler broadened $K(D_1)$ resonance line at 770 nm. At Spitsbergen the laser was operated at 38 Hz and 160 mJ per pulse. A newly developed FADOF [*Fricke-Begemann et al., 2002*] together with the implementation of an avalanche photo diode improved the instrument performance significantly and allows full daylight operation. At the peak of the potassium layer a statistical uncertainty of a few K after 1 h temporal and 1 km vertical integration is achieved. The data acquisition operates with a time and altitude resolution of 2 minutes and 200 m, respectively. This allows to use very small time and/or altitude resolutions. The statistical uncertainty depends strongly on solar elevation angle, weather conditions and potassium density. Under ideal conditions reliable temperatures can be obtained in a few minutes with statistical uncertainties still within a few Kelvin. At polar latitudes such conditions are seldom. In particular the background rises often due to thin and nearly invisible cirrus clouds. In polar summer the determination of temperatures below 90 km is complicated by Mie scattering which is caused by ice particles. We have determined the Mie signal from the backscatter signal at the wings of the resonance line.

The systematic error of the lidar without daylight capability was estimated to 3 K [*von Zahn and Höffner, 1996*]. The influence of the FADOF on resonance scattering causes a shift of less than 0.5 K [*Fricke-Begemann et al., 2002*]. For the calculation of accurate resonance temperatures the Rayleigh signal at ~40 km is in general used to correct for the wavelength dependent sensitivity of the instrument. If this effect is not taken into account a temperature bias of up to 10 K can occur depending on the temperature at the normalization altitude. In cases with high background it has been found that the alternative approach of normalizing the resonance signals to the number of laser pulses at each wavelength is the preferable method [*Höffner and Fricke-Begemann, 2005*]. Apart from temperature measurements the lidar operation and data processing is used to detect systematic discrepancies between the observed and theoretical spectrum which are caused by technical limitations or atmospheric conditions. Thorough investigations of these deviations have led to a temperature correction of up to 5 K depending on measurement conditions.

3. Observation

In May 2001 the K lidar was installed on a plateau (450 m) close to Longyearbyen at 78°14' N, 15°23' E on the site of Svalsat (Svalbard Satellite Station). Temperature measurements were performed from June 12 to October 6, 2001. Altogether 276 hours of observations during 50 days were achieved. As part of the ROMA campaign several meteorological rockets were launched from July 16 to September 14. Temperature measurements were made by the 'falling sphere' (FS) technique which is described elsewhere [*Schmidlin, 1991*, *Lübken et al., 1994*]. A total of 24 temperature profiles from approximately 92 km to 55 km were obtained [*Lübken and Müllemann, 2003*]. The location of the lidar was only ~3 km from the launcher and approximately 60 km from the atmospheric region probed by the falling sphere.

Falling spheres measure densities and horizontal winds. Temperature profiles are obtained by integrating the density profile which requires an unknown 'start temperature' T_0 at the uppermost altitude. This temperature is usually taken from models which introduces large uncertainty. Therefore, mean lidar temperatures were used for T_0 during the ROMA campaign. This introduces some similarities between FS and K lidar temperatures at the top of the FS profile. A temperature comparison is still reasonable because the FS temperature becomes more and more independent on T_0 with decreasing altitudes (see below). There are 5 simultaneous measurements. Two more FS flights took place only a few hours prior to a period of lidar measurements. In this paper we focus on a single comparison when the measurement conditions for the K lidar were good.

In Figure 1 we show a temperature profile of FS flight ROFS19 launched at 21:48 UT on 28. August 2001, and lidar temperatures measured in a short period around the rocket launch. We have shifted the integration period for the lidar data by 4 minutes to account for the difference between rocket launch and the time when the sphere actually probes the atmosphere. We will show later that strong temperature variations are present which makes it necessary to chose a time bin as close as possible to the FS measurement. The start temperature for the FS data analysis was taken from the lidar measurements at an altitude of 93.5 km. This explains the close similarity of both data sets at the top of the FS profile. To demonstrate the influence of different T_0 on the FS results we have also used T_0 ±10 K (gray area in Figure 1). The variation of ±10 K at 93.5 km leads to a bias of ±4 K at 90 km and only ±0.8 K at 85 km. This demonstrates that the influence of T_0 is still noticeable at 90 km whereas it has basically disappeared below 85 km.

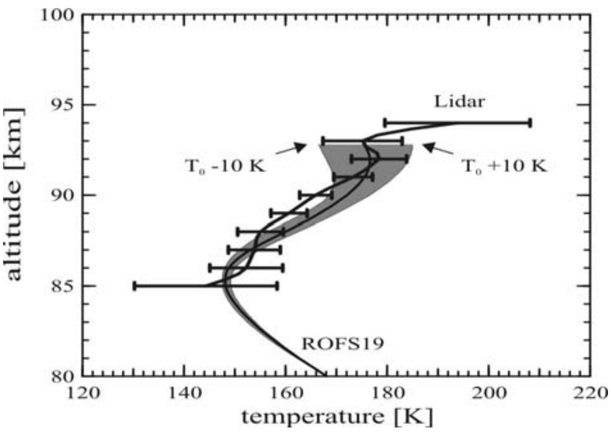

Figure 1: Simultaneously measured temperatures by FS (ROFS19) and lidar. The lidar profile was integrated over 5 minutes between 21:50 and 21:55 UT. The FS was launched at 21:48 UT but temperatures at mesopause altitudes have been measured ~ 4 min later.

During flight ROFS19 the low solar elevation (~ -2°) and high potassium densities (~80 atoms/cm^3) allow the calculation of lidar temperatures with low statistical uncertainties for time periods as small as 5 minutes. Despite this short integration time the statistical uncertainty is only ±4 K at 90 km altitude, increasing towards the bottom and top of the profile. To extend the profile to somewhat higher and lower altitudes we have allowed statistical uncertainties of up to ±15 K in Figure 1. The temperature profiles shown in Figure 1 are in good agreement at all altitudes. A part of the small differences may be of geophysical origin caused by the horizontal distance of ~60 km. We have tentatively increased the integration time to reduce statistical uncertainties. However, this declines the agreement with the FS profile because of natural variability.

In Figure 2 we demonstrate the importance of applying a small integration time. At 88 km a strong wave with approximately 1.5 hour period is clearly visible and appears well above statistical uncertainties (gray area). Shortly before the FS measurement a variation of 25 K in less than one hour occurred. A detailed comparison with FS therefore requires small integration times.

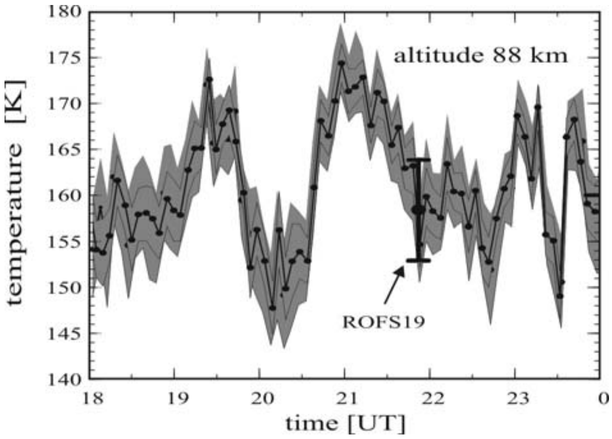

Figure 2: Lidar temperatures (line) with 5 min resolution and statistical uncertainties (gray area) at 88 km altitude. For comparison the FS temperature with error bar (ROFS19) is indicated at 21:52 UT.

The temperatures shown in Figure 2 are only a section of the lidar observations at this particular day and give an impression of the dynamic situation at mesopause altitudes. Figure 3 shows the deviation from the mean temperature for the complete data set. It is obvious that an ensemble of waves is always present changing the temperature quickly in space and time. A similar chaotic situation is also found for the potassium densities (not shown here).

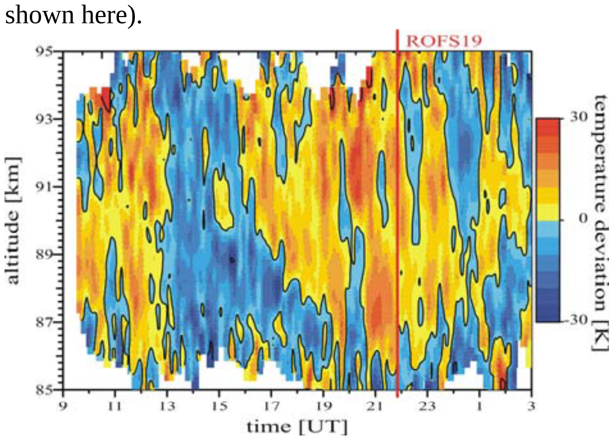

Figure 3: Temperature deviation from the mean observed by lidar on August, 28/29, 2001. The launch time of the falling sphere ROFS19 is indicated.

We have also compared the seasonal variation of temperatures as deduced from FS and K lidar, respectively. In Figure 4 we show temperatures from both techniques at two different altitudes. As can be seen from this Figure the mean seasonal temperature variation throughout the entire ROMA campaign is very similar in both data sets (the lidar data gap in August was caused by a period of bad weather from August 12-26). Note that the measurements of both instruments were performed at different days.

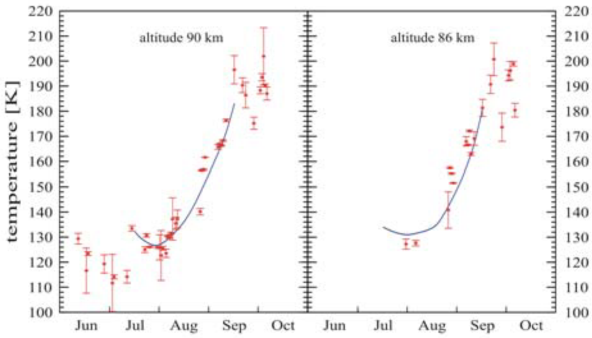

Figure 4: Comparison of FS temperatures (line) and lidar temperatures (dots with error bars) at 90 km altitude (left panel) and 86 km altitude (right panel).

At 90 km altitude (left panel) the lowest temperatures of less than 120 K occur at the end of June/begin of July, i. e. before the ROMA campaign had started. At the beginning of ROMA (mid July) temperatures have already increased by approximately 10 K. Similar differences occur at lower altitudes (right panel). At 86 km the FS is nearly independent on T_0. However, due to the influence of ice particles on the potassium layer [*Lübken and Höffner, 2004*] lidar temperatures at this altitude are only available from the end of July. As mentioned before the additional Mie background below ~90 km complicates the temperature deviation and results in larger uncertainties. Nevertheless the temperatures from FS and lidar are still in good agreement. A similar good agreement is found at all altitudes where data overlap.

We take the good agreement shown in Figure 4 as an indication of the reliability of the K lidar (and FS) technique even if we take the T_0 effect into account (see above). We note that the mesopause temperature of 130 K as deduced from FS [*see Lübken and Müllemann, 2003*] has been obtained during a comparable warm period and is most likely not representative for the coldest period in summer, which has occurred approximately during four weeks in June and July.

Figure 5 presents the seasonal variation of K lidar temperatures taking into account all measurements in 2001. Temperatures were derived by integrating all photon-count profiles obtained during each day. Temperatures with statistical uncertainties larger than 12 K have not been used for calculating the mean. A Hanning filter with a width of 4 km in altitude and 31 days in time has been applied for further smoothing. Compared to mid latitudes the potassium layer at 78° N is very narrow in June and July and allows only temperature measurements between 89 and 97 km. Due to the narrow potassium layer we can hardly observe the low summer mesopause in this period. In June and July the mesopause is located slightly below 90 km altitude with a temperature close to 120 K [*Höffner et al., 2003*].

During the transition period from summer to winter the temperature profiles are nearly isothermal. At the altitude of the summer mesopause (89 km) temperature rises rapidly in August and September from ~130 K to ~190 K. This corresponds to an increase of ~ 1 K per day.

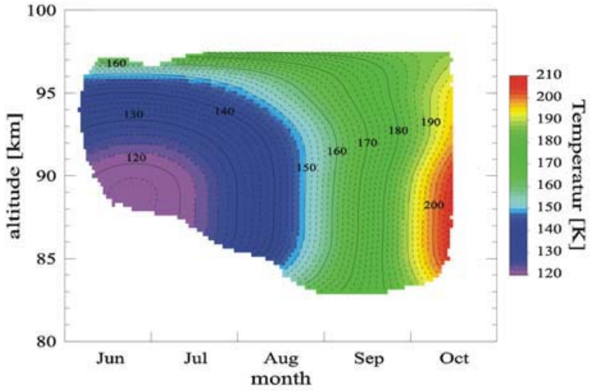

Figure 5: Mean temperatures of 2001 as obtained by potassium lidar at 78° N. The data are smoothed with a Hanning filter of 4 km and 31 days.

4. Conclusion

Using 50 days (276 hours) of lidar observations in 2001 we have derived the seasonal variation of temperatures in the Arctic mesopause region. Our measurements clearly show a rapid transition in mesopause temperatures from summer to winter similar to mid and low latitudes. The summer mesopause is located at 89 km altitude with temperatures close to 120 K during the coldest period in June/July. A comparison with temperatures from falling spheres shows good agreement.

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