A NEW SYSTEM FOR AUTOMATIC BEAM STABILISATION OF THE ALOMAR RMR-LIDAR AT ANDOYA IN NORTHERN NORWAY

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ABSTRACT

We have developed an automated beam stabilisation system for the ALOMAR RMR-lidar to guarantee a full overlap of the field-of-view (FOV) of our telescopes and the laser beams even during long measurements and for all operating conditions of the lidar. The technical realisation as well as the image processing involved is presented here. Some examples are given for the excellent performance of the system that reaches a precision better than 10 μrad and allows us to decrease the FOV and thus increase the instrument sensitivity under sunlit conditions. Additionally, we present the results of simulations for the effect of incomplete focusing in the near-field of the telescopes which limits the reduction of the FOV that is feasible without limiting the usable height range of the instrument.

Key words: automation, beam stabilisation, CCD camera, lidar, overlap function.

1. INTRODUCTION

The ALOMAR Rayleigh/Mie/Raman-lidar at Andøya in Northern Norway (69.3° N, 16.0° E) is a state-of-the-art twin lidar system using two 1.8 m diameter telescopes with a small field-of-view (FOV) of 180 μrad (which corresponds to 18 m at 100 km height) to operate under sunlit conditions. It is used to measure temperature profiles in the stratosphere and mesosphere (Hübner 1998; Fiedler et al. 1999), polar stratospheric clouds (Mehrtens 1998) and noctilucent clouds (Baumgarten 2001; Fiedler et al. 2003). A detailed description of the whole system can be found in von Zahn et al. (2000).

The telescopes can be tilted up to 30° off-zenith between north and west for the North-West-Telescope (NWT) and between south and east for the South-East-Telescope (SET). Our power lasers have a divergence of less than 100 μrad (i.d. 10 m at 100 km height) (Fiedler & von Cossart 1999) after expanding the beam to a diameter of 20 cm. The laser beams are guided each by three beam guiding mirrors (BGMs) from the laser room to the top of the telescopes to transmit the beam coaxially to the viewing direction for all tilting angles of the telescopes as illustrated in figure 1.

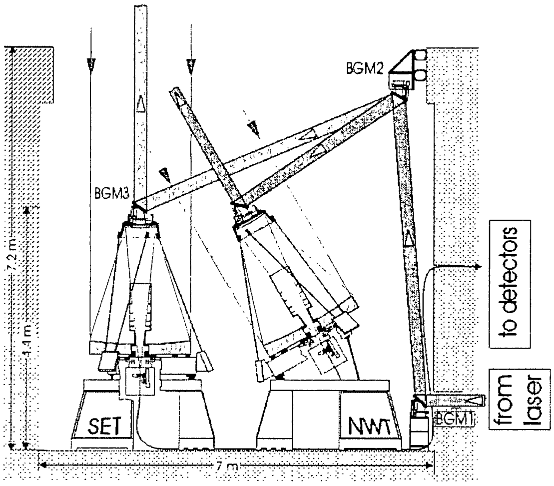

Figure 1. The laser beams are guided each by three beam guiding mirrors (BGMs) from the laser room to the telescopes to transmit the laser beams coaxially to the viewing direction of the telescope.

Changing temperature conditions during the measurements in the telescope hall e.g. due to a change of the weather conditions or varying solar position lead to changes in the beam pointing relative to the required stability given by the difference of FOV and beam divergence of only about 80 μrad (8 m at 100 km height). Figure 2 shows the change of the beam pointing during two days in 1998 in the upper part and the temperature change in the lower part. During these two days, a thermal deformation of the transceivers was corrected by the beam stabilisation system. Roughly 100 μrad per centigrade temperature change had to be corrected.

The system is routinely used to derive temperature profiles from the stratosphere up into the mesosphere (during sunlit conditions) and up to the mesopause

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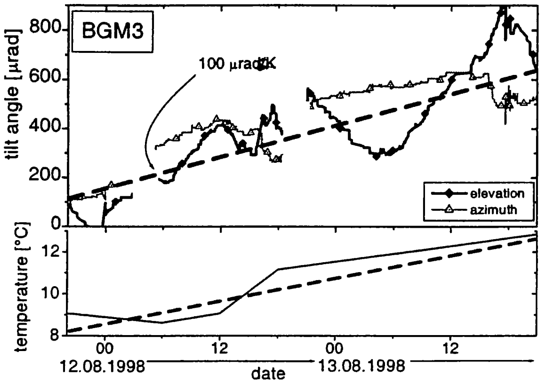


Figure 2. Change of the optimal position of the BGM3 mirror as a function of the temperature in the telescope hall.

region (during nighttime) by integration of the observed relative density profile. This method needs a full overlap of the FOV and the laser beam over the entire altitude range at all times to sound the temperature. An automatic beam stabilisation system (BSS) was developed to keep the emitted laser beam always inside the FOV on which we report in this article.

In section 2 we present the the influence of incomplete focusing. The description of the BSS is divided into the technical and optical design (section 3) and the performance of the system (section 4).

2. SIMULATIONS OF THE TELESCOPE NEAR-FIELD

A large telescope with a focal length of 8345 mm as used in our lidar system is subject to certain restrictions in the focusing because the lower part of the measurement height range of 15 km to 100 km still lies in the near-field of the telescopes. This implies that the echo of the laser beam at the image plane defined by the position of the collecting fibre is blurred due to defocusing. The range of full overlap is optimised by varying the position of the fibre leading to the detectors with respect to the focal point of the telescope. The effect grows larger as the FOV of the receiving system decreases. For details see Baumgarten (2001). As the overlap gets incomplete due to defocusing, also the derived temperatures deviate from the true temperatures. The resulting overlap functions for two different laser divergences are shown in figure 3 together with the impact on the derived temperatures. Tests with both laser systems have shown the laser divergence to be less than 100 μrad.

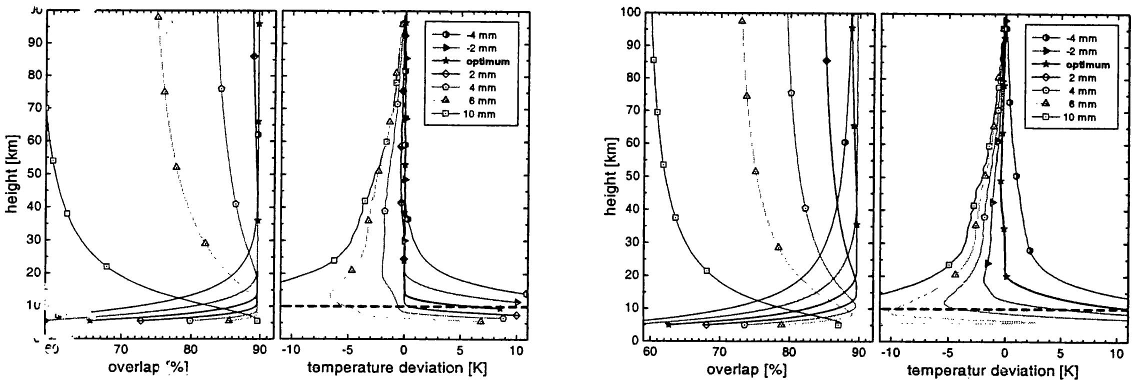
The FOV and thus the background noise level from scattered sunlight is determined by the diameter of the fibre used to guide the light from the focal point of the telescopes to the detectors. By choosing a smaller fibre, the FOV – and hence the background noise – is decreased. A lower background level enhances the sensitivity of the lidar system which is especially helpful in summer to improve the measurements of noctilucent clouds in the mesopause region. But as we decrease the FOV of the receiving system, we need a more stable pointing of the laser beam to still ensure full overlap at all heights. This improvement of the pointing stability is achieved with the automated BSS.

Table 1. Specifications of the transceiver and the beam stabilisation system.

Laser beams (after beam widening)	
beam diameter	200mm
beam divergence	< 100 μrad
pulse rate	30 Hz
Telescopes (Cassegrain design)	
diameter primary mirror	1.8 m
focal length	8345 mm
field-of-view (FOV)	180 μrad
off-zenith tilt angle	$\leq 30°$
azimuth range	2× 90°
BSS camera	
resolution	768 x 576 monochrome
exposure time	2 μsec
exposure delay	6 μsec
acquisition rate	30 Hz
BGM3 mirror mount	
two motorised axis (azimuth, elevation)	
resolution	$\approx$ 10 μrad

3. TECHNICAL AND OPTICAL DESIGN

The technical parameters important for the BSS are described in table 1. The technical realisation is sketched in figure 4. A pick-off mirror in the focal box guides de-focused light from the first few kilometres onto a camera. The image taken by this camera is digitised by a frame-grabber and an image processing programme is analysing the images to find the position of the laser beam on the CCD chip. This information is transmitted to the telescope control computer using the local network. The telescope control computer analyses the messages to identify useful beam spot positions that are not compromised by Mie scatter from clouds. This step is very important to avoid that multiple scattering by inhomogeneous low altitude clouds leads to wrong corrections. Once a position is classified as good, a number of them are averaged and the averaged position is compared to a target position determined during the alignment of



(a) 100 μrad divergence

(b) 150 μrad divergence

Figure 3. Effect of the defocusing of the telescopes for different values of the laser divergence and different fibre positions in the focal point relative to the optimum position ($\Delta f>0$: focused to the near-field, $\Delta f<0$: focused to the far-field). Left: Overlap (10 % of the primary mirror area is covered by the secondary mirror); right: Temperature deviation induced by altitude dependent vignetting of the molecular Rayleigh backscatter.

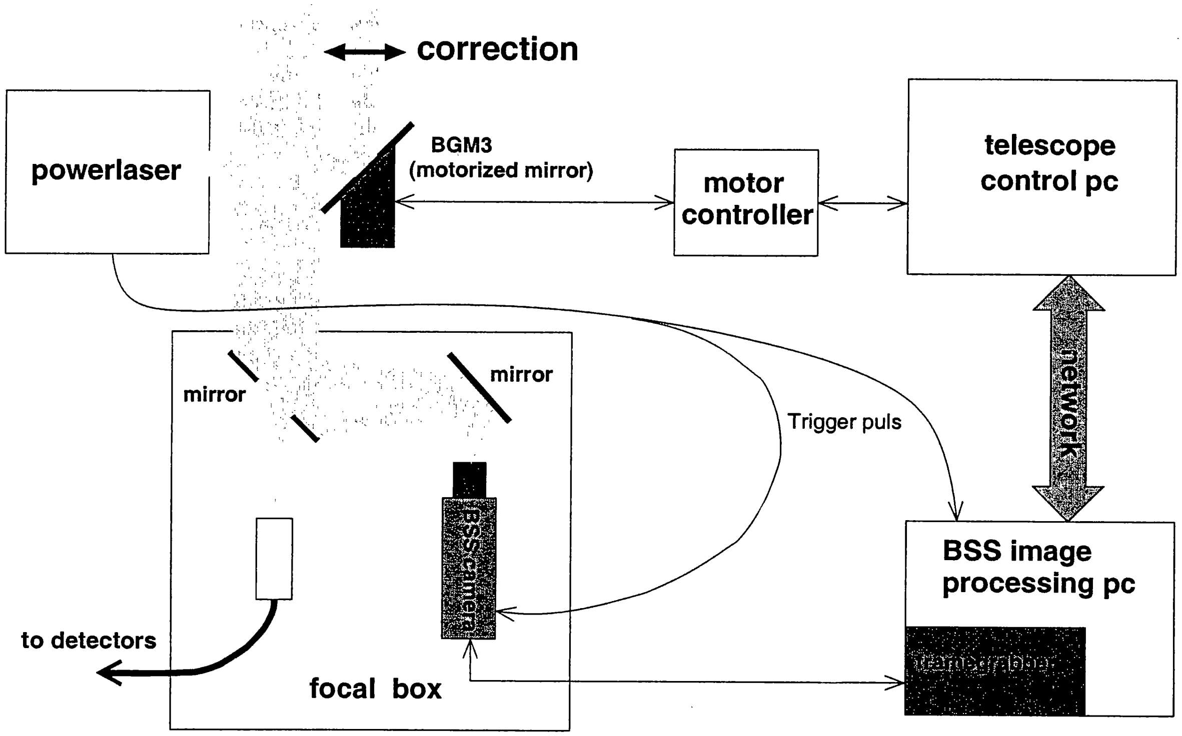


Figure 4. Schematic drawing of the beam stabilisation system. The control loop consists of the passive analyser part (BSS camera, BSS image processing pc) and the active control of the beam direction with the motorised mirror BGM3.

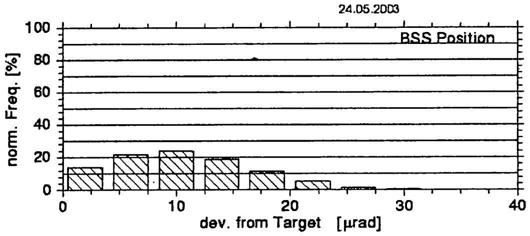


Figure 5. Histogram of the deviations from the optimum target position. Our BSS reaches a mean deviation of 10 μrad which allows us to decrease the FOV during summer from 180 μrad to 120 μrad to gain instrument sensitivity for noctilucent cloud measurements.

the telescope structure. The computed difference is then translated into steps for the mirror motors and the uppermost BGM3 is moved (thereby closing the control loop).

Recently we have upgraded the existing BSS (Wagner 2000) to speed up the control loop allowing to compensate for beam fluctuations on shorter time scales. The new system installed in January 2003 now is capable of capturing and analysing the images at the full 30 Hz repetition rate of the lasers. Together with minor changes of the algorithm for the image processing, this improved the performance of the BSS considerably.

4. PERFORMANCE

While testing the improved system, we found that we had to carefully adjust the parameters of the control loop (like number of averaged positions, limits for detecting bad positions and a proportionality factor for the size of the correction applied to the BGM3 motor axis) to avoid resonances of the control loop. This is especially important during measurements with marginal weather conditions, i.d. broken clouds, cirrus bands or when fog patches drift through the beam.

The performance of the BSS is analysed automatically after each measurement run and archived on a web-server to allow for easy inspection and control of the performance of the BSS. The parameter that best describes the quality of the BSS is the mean deviation from the target position. A histogram of the deviations from the target is shown in figure 5. It shows a mean deviation of less than 10 μrad. Considering the mechanical resolution of the BGM3 mirror drive of around 10 μrad, a perfect control loop with immediate response would achieve a mean deviation of not less than 5 μrad. So the performance of the upgraded BSS is very close to its theoretical limits.

5. CONCLUSIONS

We have developed an automated beam stabilisation system for a Rayleigh lidar that uses a CCD camera to analyse the echo from the first few kilometres in order to keep the laser beam permanently inside the field-of-view (FOV) of the telescopes. Thereby guaranteeing that the signal received during the measurement interval is not compromised by the BSS. The mean stability of the beam pointing is better than 10 μrad corresponding to a mean deviation of the beam at 100 km height of less than 1 m.

Simulations have shown that this stability of the beam direction allows us to decrease the FOV from the current 180 μrad to 120 μrad by changing from a 1.5 mm fibre to a 1 mm fibre without loosing much signal due to defocusing in the near-field of the telescope. Such a reduction of the FOV results in a lower background caused by scatter sunlight under sunlit conditions and thus increases the sensitivity of the system considerably under daylight conditions. While helping to extend the usable range for temperature measurements, this increased sensitivity is especially useful for detecting weak noctilucent clouds and to improve our ability for multi-wavelength measurements of these clouds.

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