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Implementation of a daylight receiver in the ALOMAR ozone lidar

Final report

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1 Introduction

The stratospheric ozone DIAL (Differential Absorption Lidar) at the Arctic Lidar Observatory for Middle Atmosphere Research (ALOMAR, Andøya, 69.28ºN, 16.01ºE) started operation in December 1994. Due to the Arctic location of the site, measurements at ALOMAR are well suited for validation of satellites with polar orbits. In the first years the lidar had no operational daylight capability, and due to the Arctic location no measurements were possible from about May 10th to July 30th. In this period the solar elevation angle exceeds -2 degrees 24 hours a day. To greatly improve the use of the system, in July 1998 a new daylight receiver module was installed. The European Space Agency (ESA) agreed to cover approximately 30 % of the costs for the implementation of this detector. Additional funding was provided by the Norwegian Space Centre, the Norwegian Industrial and Regional Developement Fund, the Andøya Rocket Range (ARR), the Norwegian Institute for Air Research (NILU), and the Norwegian Defence Research Establishment (FFI). With this upgrade, lidar measurements of high quality can be performed at any time of the day and the year at ALOMAR. This report briefly describes the ozone lidar daylight system and discusses its current state. Recent ozone measurements and first satellite validation results will be presented.

2 The ozone lidar at ALOMAR

The stratospheric ozone DIAL at ALOMAR (69.28ºN,16.01ºE) is jointly run by FFI, NILU and the Andøya Rocket Range. It started operation in December 1994. The daylight detection system was installed in late May 1998. The technical details of the lidar are summarized in Table 1a and 1b.

The lidar transmitter is based on a XeCl Excimer laser, emitting radiation at 308 nm, and a H_2-filled Raman cell, converting ca. 15 % of the laser radiation into radiation at 353 nm. Both wavelengths are emitted vertically into the atmosphere. Due to differences in ozone absorption at 308 nm and 353 nm (DIAL technique), from the backcattered signals range resolved ozone densities between 9 and maximal 50 km altitude (daytime: 2 hour-average, ca. 36 km, at best: 42 km) can be derived (typical 1 hour averages). The receiver consists of a 1 m Newtonian telescope, an optical/electronical 2 channel-detector and a data aqusition system. A mechanical filter wheel is used to protect the photomultipliers against the intense return signals from lower altitudes. Measurements are performed sequentially with typical chopper altitudes of 7, 12, and 18 km (8, 14 km during daylight), using neutral density filter with optical density (OD) 2, 1, and no filter (OD 1, 0 during daylight), respectively. The standard altitude resolution used is 97.433 m, the single file acquisition duration is about 5 minutes (2.5 minutes). Raw data are stored in ASCII-format. On a routine base ozone, backscatter ratios,

densities and temperatures are calculated as daily averages. The ozone data are stored in NASA Ames format. Higher time resolutions or e.g. PSC analysis is performed during atmospheric interesting events.On-line raw-data profiles, and quasi-online analysed data can be found under:
http://alomar.rocketrange.no/alomar-lidar.html.

Table 1a: ALOMAR DIAL system, laser characteristis and detection details.

Laser		
Type	Excimer, XeCl	
Manufacturer/Model	Lambda Physics LPX 150T	
Wavelengths	353.2, 307.95, 308.2 nm	
Frequency of Pulses	200 ± 5 Hz	
Length of Pulses	28 ns	
Energy of Pulse	~150 mJ (127 mJ at 308 nm, 20 mJ at 353.2 nm)	
Laser pulse line width	3 pm	
Divergence	≤ 0.15 mrad (after 3x expansion)	
Telescope & Detector		
Diameter	1 m	
Focal length	2.45 m	
Field of View	0.4 mrad (daylight)	0.5 mrad (night)
Half-power bandwidth of interference filter		
307.97 nm	0.51 nm (day)	2 nm (night)
353.01 nm	0.51 nm (day)	2 nm (night)
Etalon system (daylight system)		
307.97 nm	Low res.: FWHM = 17.5 pm, OPD = 75 μm	
353.01 nm	Low res.: FWHM = 20.3 pm, OPD = 116 μm	
	High res.: FWHM = 7.07 pm, OPD = 311.8 μm	
Transmissivity of Filters		
at 308 nm	IF: ~25 %, LRE: 8 %	
at 353 nm	IF: ~ 40 %, LRE: 10 %, HRE: 10 %	

Table 1b: ALOMAR DIAL system, acquisition details.

Acquisition	
Photodetectors at 308, 353 nm	Thorn EMI 9893Q/350
Quantum efficiency of PM	~22 % @ 350 nm
Amplifier	Phillips Model 770
Discriminator	Phillips Model 704
Dual channel counter board	Model FDC-700M, Optech
Maximum count rate	500 MHz
Maximum height resolution	30 m (200 ns)
Total number of bins	1000 bins

3 The daylight receiver

In June 1998 the daylight system for the ALOMAR Ozone lidar was delivered by Hovemere Ltd (UK). First test measurements took place on June 5, 1998.The daylight system is based on capacitance-stabilised Fabry-Perot etalons (FPE), a double FPE (because of the higher atmospheric background) in the 353 nm channel and a single in the 308 nm optical path, all implemented in a temperature-controlled, N_2-filled, sealed container. During night-time the light is directed into photomultipliers by-passing the etalon system (PMT 3 and 4). Figure 1 illustrates the set-up of the receiving system.

In September 1998, an intermediate status report for the daytime receiver system concluded that at the time of the report, the system was not in an acceptable shape. The reason was that the transmittance of the etalon system was a factor of 10 to 100 below the specifications given by the manufacturer. Reliable ozone profiles could not be derived under those circumstances. Since then, major efforts have been made by the systems owners to improve the instruments, so that finally also during daytime high quality ozone density profiles can be derived up to 36 km altitude (ca. 42 km under optimal conditions at low solar angles).

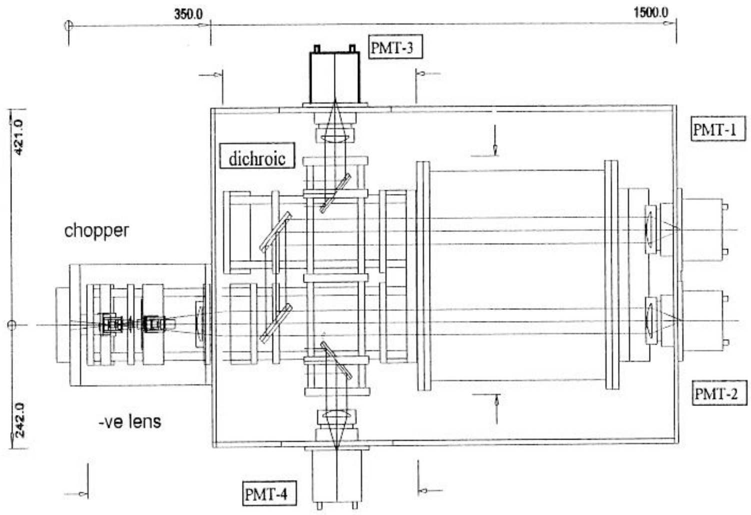

Figure 1: Drawing of the daylight detection system (by Howermere Ltd., UK). Its a two channel detection system based on capacitance-stabilised etalons (a single etalon in the 308 nm channel, a double etalon system in the 353 nm channel). During night time the light is divided into at the side mounted photomultipliers by-passing the etalon system.

4 Instrumental performance

The quality of a lidar measurement depends on instrumental as well as atmospheric factors. Atmospheric aerosols, clouds and moisture attenuate the signal and may reduce the maximum altitude of the estimated ozone density profile. Instrumental factors are e.g. due to optical de-alignments or degradation of laser gas mixtures or optics. In Figure 2 signal-to-noise ratios (SNR) for summer time (May - July) measurements in 2000, 2001 and 2002 as a function of solar elevation angle are shown. Despite the large scatter resulting from above described effects, the improvement since summer 2000 (green values) can be clearly seen. Already during summer 2001 the SNR was higher compared to the year before. Additional efforts led 2002 to better results in particular at high solar zenith angles.

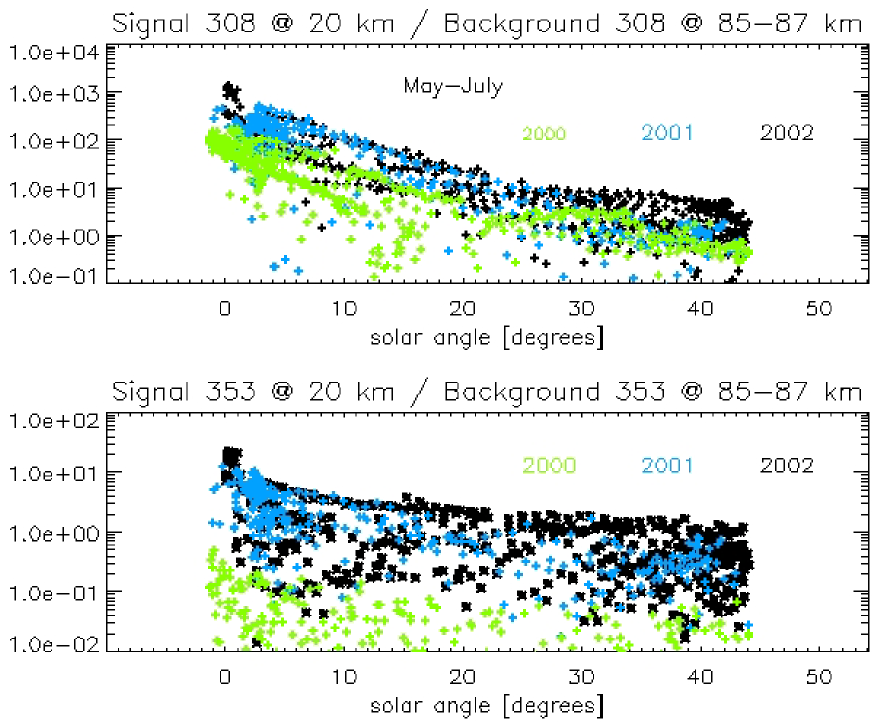

Figure 2: Signal-to-noise ratio for summer time (May - July) measurements in 2000, 2001 and 2002 as a function of solar elevation angle.

5 Ozone density profiles

Ozone density profiles are calculated using an algorithm developed by G. Hansen, NILU. It is based on the standard Differential Lidar equation for ozone (e.g. Steinbrecht, 1994). The a-priori knowledge of the atmospheric reference density profile is taken from the ECMWF data at the nearest grid- and time point (69.75°N, 15.75°E) or, if available, from radiosondes (at ALOMAR, Kiruna or Sodankylä). In few cases with too low SNR at 353 nm above e.g. 28 km, this channel is replaced by the ECMWF density profile to extend the maximum altitude of the derived ozone density profile. Three typical ozone profiles, measured at different solar elevation angles, are shown in Figure 3.

a. April 30, 2002, 10.26 – 13.04 UT(solar elevation 35^{o} – 30^{o})
b. May 23, 2002, 15.17 – 20.42 UT (solar elevation: 28^{o} – 4^{o})
c. October 30, 2002, 20.23 – 22.39 UT (night time system)

The maximum altitude of the ozone density profile reached with the daylight system is about 36 km, under optimal instrumental conditions and low solar elevation at present values as high as 42 km might be reached (about 2 hour averages). For comparison: night-time measurements have an upper limit of about 50 km altitude (typical 1 hour averages).

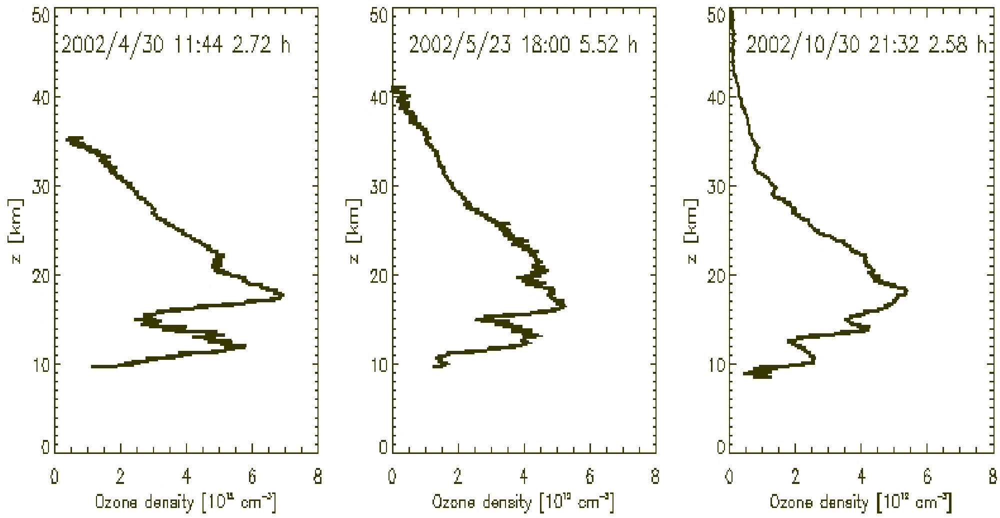

Figure 3: Ozone density profile from a. April 4, 2002; b: May 23, 2002; c: October, 30, 2002.

Figure 3 gives a list of ozone density profiles, measured with the ALOMAR ozone DIAL since September, 8, 2002, are summarized. Day- as well as night time measurements are included. Most of the data are analysed and uploaded to the CalVal database at NILU and thereby usable for ENVISAT validation.

6 Satellite validation

Figure 4 shows the total ozone column at the ALOMAR facility in 2002. The typical seasonal cycle can be seen. Shown are groundbased measurements from the ozone lidar and a multi-channel UV filter instrument (GUV), which is part of the Norwegian ozone and UV monitoring network, and the total ozone column calculated from GOME with the TM3-DAM operational assimilation model of the Royal Netherlands Meteorological Institute (KNMI), which is available on the Internet. While the day-to-weeks variability is similar in the three data sets, it seems as if the assimilated data are systematically lower by 10 to 20 DU than the ground-based data throughout most of the year.

Table 2: List of ozone density profiles measured by the ozone lidar at ALOMAR between September and 20 December 2002.

Date	day-light system	night-time setup
08. Sept.	10:51 UT (2.4 h)	-
14.	09:35 UT (1.9 h)	-
19.	11:13 UT (4.4 h)	21:03 UT (1.1 h)
20.	X	20:24 UT (1.8 h)
21.	X	20:10 UT (1.9 h)
22.	10:22 UT (1.7 h)	-
30.	11:12 UT (2.3 h)	22:50 UT (1.8 h)
03. Oct.	14:18 UT (2.1 h)	-
04.	-	18:56 UT (0.9 h)
05.	13:47 UT (2.3 h)	-
07.	-	18:26 UT (2.1 h)
08.	8:23 UT (3.2 h)	-
09.	9:23 UT (4.4 h)	-
10.	9:34 UT (5.6 h)	18:42 UT (1.9 h)
12.	X	-
13.	X	19:37 UT (2.2 h)
14.	X	-
21.	X	X
23.	8:16 UT (2.0 h)	-
30.	-	21:32 UT (2.5 h)
31.	X	19:42 UT (3.1 h)
07. Nov.	11:57 UT (5.0 h)	18:15 UT (2.0 h)
08.	-	21:04 UT (2.1 h)
10.	-	16:42 UT (1.6 h)
11.	X	18:16 UT (3.1 h)
12.	8:29 UT (0.7 h)	-
13.	-	18:15 UT (1.9 h)
14.	-	17:55 UT (1.9 h)
15.	-	16:44 UT (2.0 h)
20.	10:11 UT (3.3 h)	-
21.	10:39 UT (5.9 h)	16:36 UT (1.2 h)
22.	-	15:13 UT (1.6 h)
24.	-	15:07 UT (2.3 h)
30.	-	15:49 UT (2.8 h)
01. Dec.		21:30 UT (5.3 h)
02.	16:03 UT (3.8 h)	21:18 UT (2.4 h)
03.	X	16:58 UT (4.9 h)
04.	-	16:18 UT (3.8 h)
04.	-	20:53 UT (1.4 h)
05.	-	15:46 UT (3.0 h)
07.	-	16:17 UT (4.8 h)
16.	-	08:12 UT (1.3 h)

X: data available, not uploaded to CalVal database

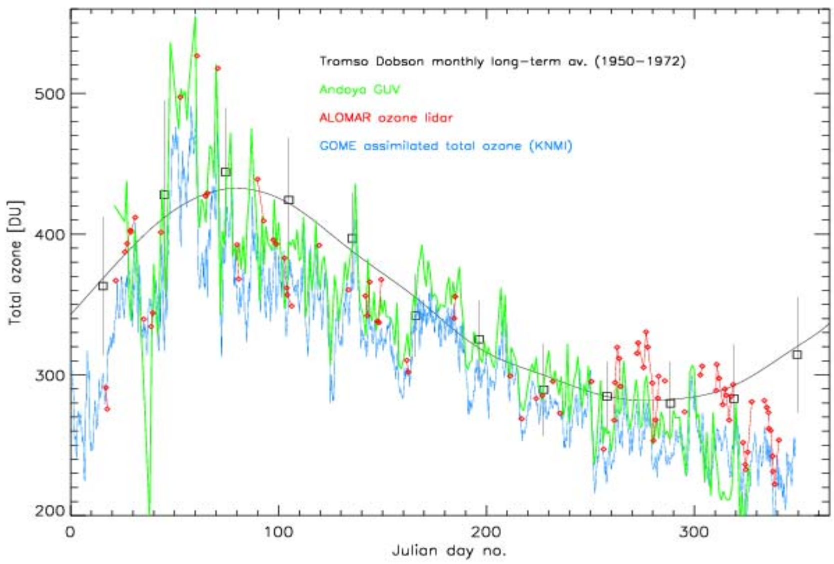

Figure 4: Total ozone column at the ALOMAR facility in 2002. The red diamonds are data derived from the ozone lidar measurements. The green line shows data from a multi-channel UV filter instrument (GUV) which is part of the Norwegian ozone and UV monitoring network. The thin blue line denotes total ozone calculated from GOME with the TM3-DAM operational assimilation model of the Royal Netherlands Meteorological Institute (KNMI), which is available on the Internet.

Recently preliminary results have been presented at the ENVISAT Calibration/Validation workshop at ESRIN, December, 9-14th, 2002. Figure 5 shows a comparison of ALOMAR lidar ozone profiles and MIPAS O_3 Meteo-products. Six MIPAS O_3 measurements with 3 degrees in longitude and latitude, and maximal 10 hours difference to the lidar data, between the 7 and 14 November, 2002 are compared to the lidar data (using pressure as altitude scale due to the known pointing miss-alignment of MIPAS corrected on November, 13th). Though being due to the limited number of satellite data, the comparison shows good agreement between the ALOMAR lidar and MIPAS data above 100 hPa.

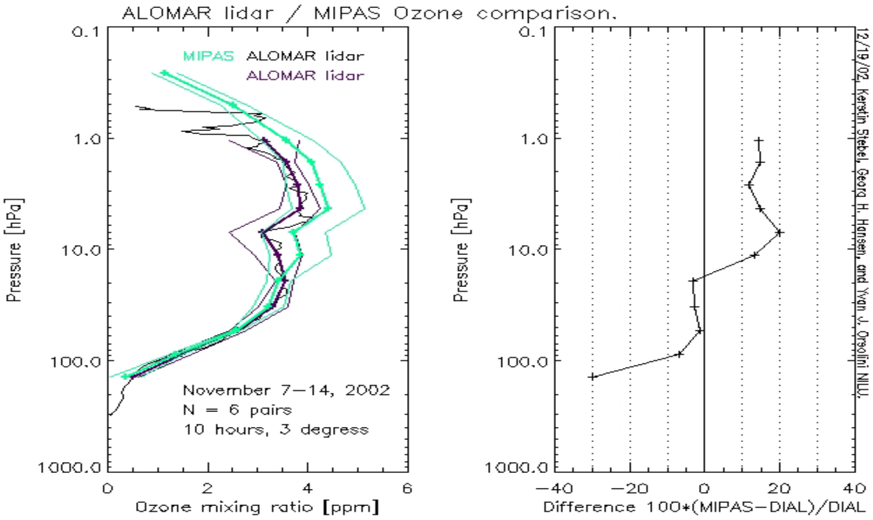

Figure 5: Comparison of ALOMAR lidar ozone profiles and MIPAS data derived from the Meteo-products. Shown are a mean high resolution lidar profile (black, thin line), the to the grid of MIPAS data interpolated mean lidar profile plus standard deviation (dark violet), and the MIPAS ozone data. 6 pairs of collocation (with 3 degrees in longitude and latitude, and maximal 10 hours difference) between the 7 and 14 November are shown.

7 Conclusion and outlook

The daylight system for the ozone lidar at ALOMAR, which has been partly financed by ESA, greatly improved the capability of the ozone DIAL system. With this upgrade, lidar measurements of high quality can be performed at any time of the day and the year. Reliable ozone density profiles can be measured during full daylight conditions up to a maximum altitude of 36 km (optimal conditions: 42 km) from less than 2 hours of continuous measurements (nightime: the maximum altitude is ca. 50 km, about 1 hour averages). So far there have been about 130 measurement occasions in 2002, more than half of which were daylight measurements. This enables the station to be well suited ground reference site for validation of satellites with polar orbits. As the lidar system is also capable of measuring polar stratospheric clouds (PSCs), which recently also have been reported by e.g. MIPAS on ENVISAT, a validation of cloud top heights could be a possible extension of our validation activities.

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ABSTRACT
During summer 1998 the stratospheric ozone DIAL (Differential Absorption Lidar) at the Arctic Lidar Observatory for Middle Atmosphere Research (ALOMAR, Andøya, 69.28ºN, 16.01ºE) has been equipped with a daylight receiver, which partly has been financed by the European Space Agency (ESA). This report briefly describes the ozone lidar daylight system and discusses its current state. Recent ozone measurements and first satellite validation results are presented. Nowadays, lidar measurements of high quality can be performed at any time of the day and the year at ALOMAR. Reliable ozone density profiles can be measured during full daylight conditions up to a maximum altitude of 36 km (optimal conditions: 42 km) from less than 2 hours of continuous measurements (night-time: the maximum altitude is ca. 50 km, about 1 hour averages). This enables the station to be a well-suited ground reference site for validation of satellites with polar orbits

NORWEGIAN TITLE

KEYWORDS		
Ozone lidar	Daylight detector	Satellite validation

ABSTRACT (in Norwegian)
I løpet av sommeren 1998 har den stratosfæriske ozon DIAL (Differential Absorption Lidar) ved ALOMAR (Andøya, 69.28^{o} N, 16.01^{o} E) blitt utstyrt med en dagslysmottaker som delvis har blitt finansiert av Europen Space Agency (ESA). Denne rapporten beskriver kort ozon lidar dagslys-systemet og diskuterer dets nåværende status. Nyere ozonmålinger og de første satelitt validerings resultater presenteres også. Nå kan lidar- målinger av høy kvalitet utføres uansett tid av døgnet og året ved ALOMAR. Pålitelige ozontetthetsprofiler kan bestemmes ved fullt dagslys opp til en maksimal høyde på 36 km (optimale forhold: 42 km) ut fra mindre enn 2 timer med kontinuerlige målinger (nattestid er maksimunshøyden 50 km, gjennomsnitt på 1 time). Dette gjør ALOMAR til en godt egnet bakkereferanse-stasjon for validering av satelitter med polart omløp.

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