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THE LIDAR STATION IN L'AQUILA : SETUP FOR THE EUROPEAN POLAR CAMPAIGN

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Abstract. A progress report of Ozone Lidar Station in L'Aquila (SLAQ) is presented. We extensively describe the experimental system and the recent upgrading; details about inversion of data are also given. We show some preliminary ozone profiles which have been obtained at SLAQ and these measurements are discussed within the algorithm validation. In conclusion the data validation for the use in trajectory data analysis is also discussed.

INTRODUCTION

Nowadays the LIDAR and its implementation in DIAL technique are well established both from technical and data analysis point of view (Papayannis et al, 1990 and Godin et al., 1989). Because the occurrence of more and more sophisticated models has pointed out the necessity of larger monitoring programs, it is obvious the importance of setting up a local station which could continuously perform high quality atmospheric measurements whose use spans from validation and calibration intercomparison campaigns (i.e. with satellite) to analysis of local trends. This paper would be an operative progress report of the SLAQ, and we outline the main technical features and the measurements programs which are going to be operative (Rizi et al, 1990). All these aspects will be discussed within the preliminary results obtained in the earlier part of 1990's summer and we take a small space to describe some of our results on the analysis of DIAL data. Then following the technical specifications of experimental system, we will be able to discuss the DIAL algorithm, and after showing the first measurements we briefly try to report preliminary results on data manipulation (Rizi et al., 1990).

SLAQ EXPERIMENTAL SYSTEM

The SLAQ is located 42^0N, 13^0E at 800m on sea level, in Preturo near L'Aquila. A schematic picture of the ozone lidar system operating in SLAQ is reported in Fig.1. We separately discuss the transmitter and the receiver.

The transmitter system

The active part of the transmitter system is an excimer laser produced by LAMBDA PHYSIK (model EMG 150 MCS). This is a laser with two laser cavities which simultaneously produces the emission of two laser pulses of different wavelengths: $\lambda_{on} = 308$ nm with XeCl gas mixture and $\lambda_{off} = 352$ nm with XeF.

No spectral selection are made in the laser cavities so that the emitted spectrum of the laser includes three lines near λ_{on} and some structure due to impurities in λ_{off} spectra. In Fig.2 the laser spectra recorded by a high-resolution spectrometer is shown. The technical details of the laser are summarized in Tab.1.

The use of dichroic mirrors allows the simultaneously transmission in atmosphere of the two wavelength so it is possible to sample the same air parcel of the backscattering medium.

To reduce the divergence of the transmitted laser beams, in order to illuminate a region of the atmosphere included in the field of view of the detector system, we use a collimator telescope whose details are in Tab.2. This collimator reduce the divergence ten time lower ($\propto$ 0.2mrad).

The receiver

The backscattered signal is collected by a 1 m telescope in Cassegrain configuration. The equivalent focal length of the two mirrors combination is 10m (for details see Tab.2). A mechanical chopper is used to eliminate the saturation of the photomultiplier induced by the lower layers of the atmosphere. The blades of the chopper are synchronized with the emission of the laser pulse so that the photomultiplier window is obscured for a time corresponding to the exclusion of the signal backscattered by the lower atmosphere (from 0 to $\approx$ 10km).

To detect the backscattered signals we use a configuration of two photomultipliers and a dichroic mirror to separate the signals induced by the two wavelengths. The photomultipliers produce a current proportional to the incident radiation on their photocatodes. These pulses, analyzed with a counting data acquisition system are stored on magnetic diskettes via a personal computer. A presummation of the

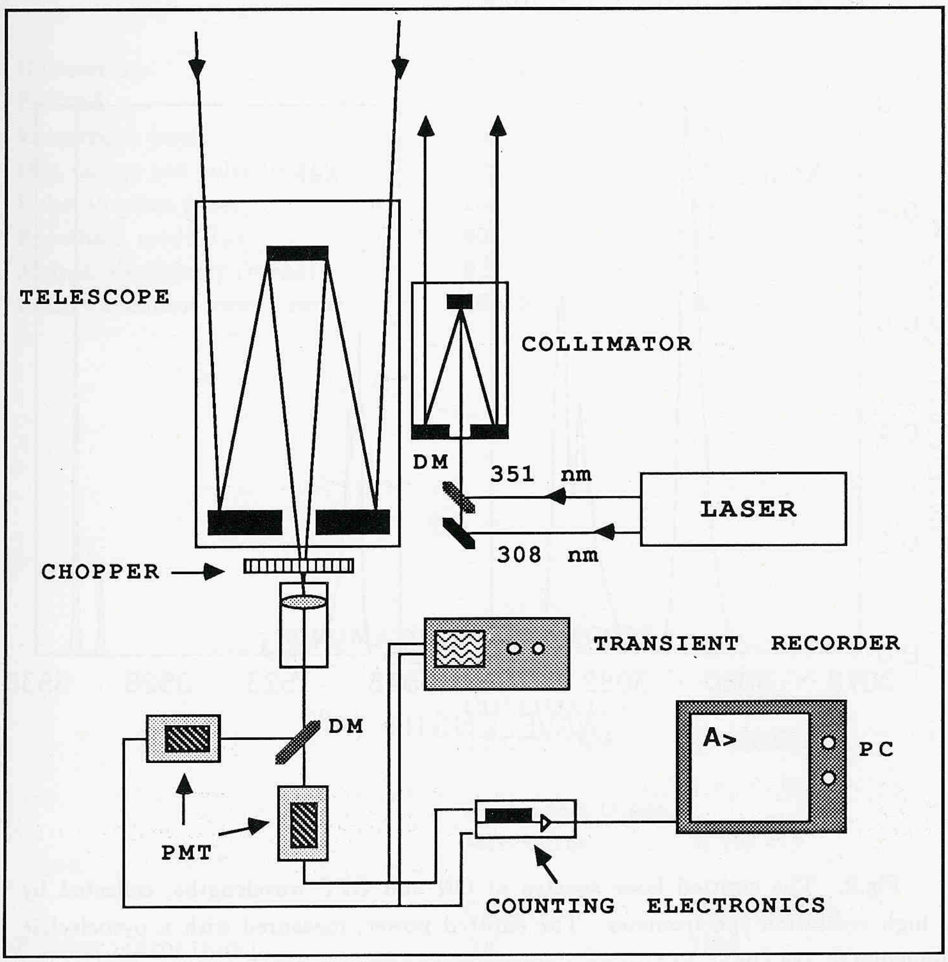

Fig.1. A schematic picture of ozone DIAL in SLAQ

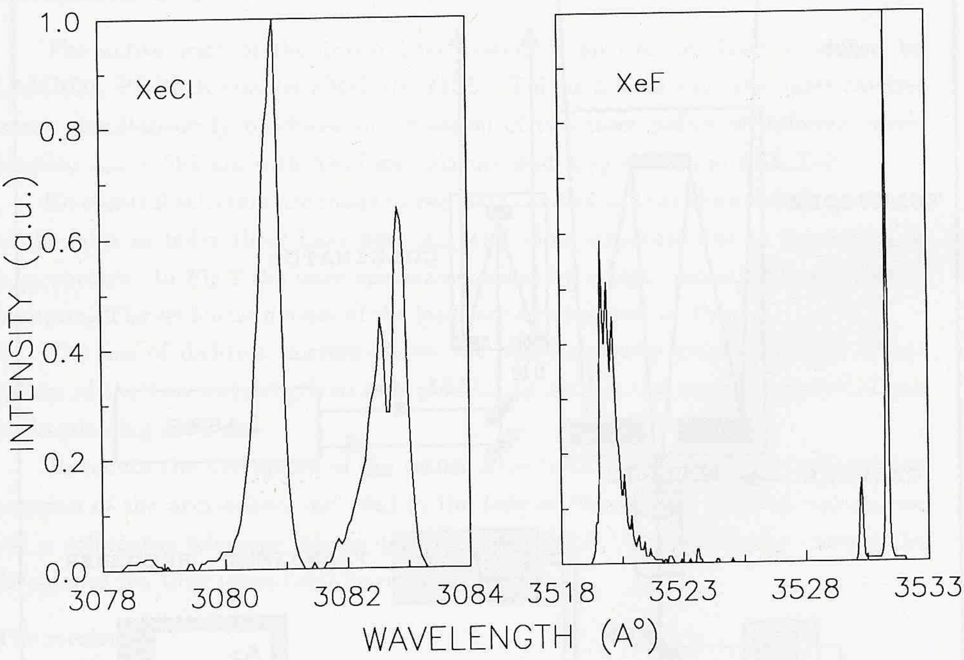

Fig.2. The emitted laser spectra at ON and OFF wavelengths, collected by a high resolution spectrometer. The emitted power, measured with a pyroelectric Joulemeter, are about $P(\lambda_{ON}) = 120$mJ and $P(\lambda_{OFF}) = 75$mJ.

Tab.1

EXCIMER LASER

	LAMBDA PHYSIK EMG 150 MSC	
Gas mixture	$XeCl$	XeF
Emitted		
Wavelength $[nm]$	308	351
Max energy per pulse (mJ)	120	75
Pulse duration $(nsec)$	20	15
Repetition rate (Hz)	80	80
Angular divergency $(mrad)$	0.2	0.2
Beam dimension $(mm \times mm)$	20×5	20×5

Tab. 2

COLLIMATOR and TELESCOPE

	COLLIMATOR TELESCOPE	RECEIVER TELESCOPE
	Costruzioni Ottico Meccaniche	MARCON
	Cassegrain	Configuration
Primary mirror (mm)	200	1000
Total focal length (mm)	3000	10000

return signals is made to reduce the volume of the stored data. The experimental parameters (acquisition time, altitude resolution, etc...) are fixed into an acquisition multichannel scaler program.

Another method for acquisition of the return laser signals is performed by using a transient waveform recorder to check the signals in real time.

LIDAR EQUATION AND DIAL TECHNIQUE

Lidar measurements of vertical ozone distribution are based on the DIfferential Absorbtion Lidar technique (DIAL: see Fig.3) which requires the use of two simultaneously transmitted wavelengths. Two laser pulses of different wavelength are transmitted in the atmosphere and, owing to their different absorbtion, the backscattered signals provide information about the vertical ozone distribution. In SLAQ the ozone measurements are made in the Hartley-Huggins bands of ozone spectra using the two wavelength before specified.

The usual lidar equation (Measures, 1984) is:

$$N(\lambda, R) = N_l(\lambda)\Delta R\frac{A}{R^2}\eta\eta_{\prime}\beta(\lambda, R)e^{(-2\tau(\lambda,R))} \quad (1)$$

where:

$N(\lambda, R)$ is the total number of backscattered photons at wavelength λ from the air cell at range R and of thickness ΔR;

$N_l(\lambda)$ is the number of emitted photons by the laser at wavelength λ;

$\beta(\lambda, R)$ is the atmospheric backscattering coefficient at wavelength λ and range R;

ΔR is the thickness of the range cell corresponding to a time gate interval of $\frac{2\Delta R}{C}$ generally larger then the pulse duration τ_l;

A is the receiver area;

$\eta, \eta\prime$ are the optical efficiencies of the transmitter-receiver system (assumed independent by the range and wavelength);

$\tau(\lambda, R)$ = integrated atmospheric optical thickness at range R and wavelength λ;

The atmospheric optical thickness could be written as:

$$\tau(\lambda, R) = \tau_{O_3}(\lambda, R) + \tau_e(\lambda, R) \quad (2)$$

where $\tau_e(\lambda, R)$ is the integrated optical thickness excluding ozone absorption and

$$\tau_{O_3}(\lambda, R) = \int_0^R \sigma^{O_3}(\lambda)n_{O_3}(R)dR \quad (3)$$

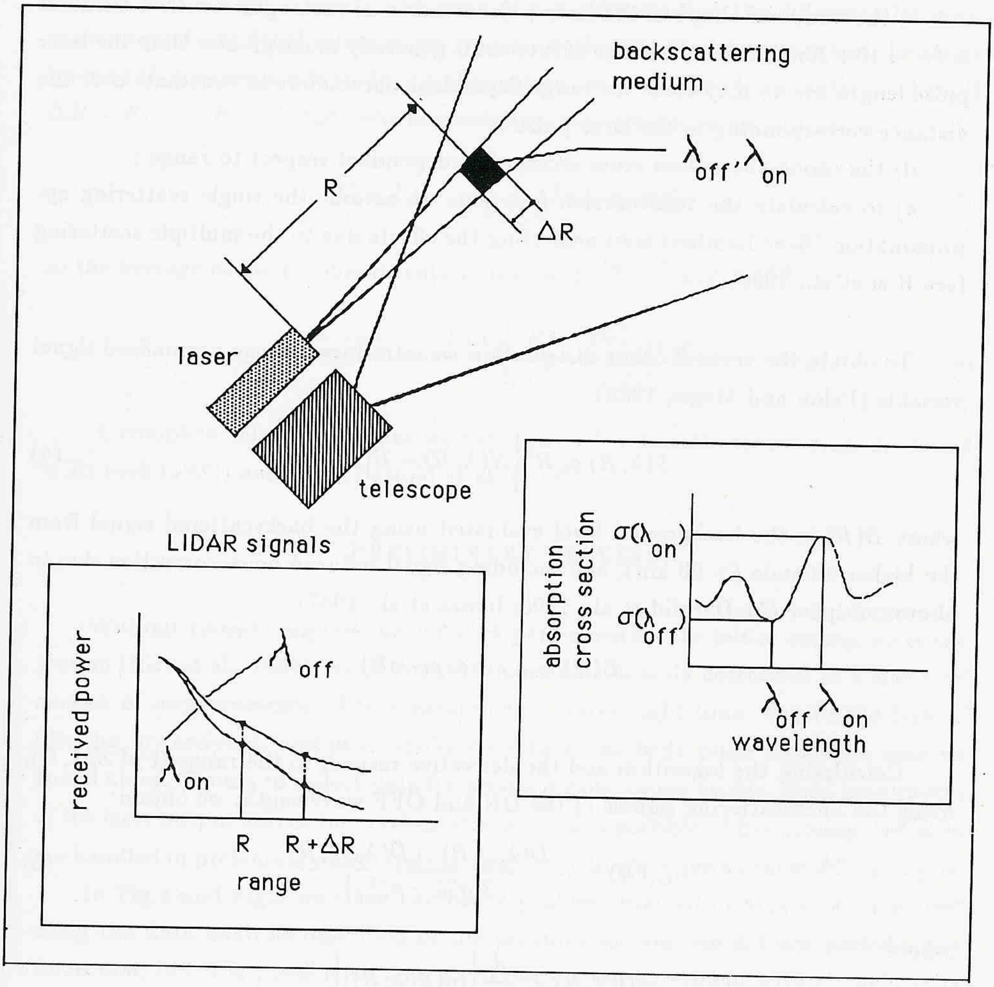

Fig.3. DIfferential Absorption Lidar principle (Adapted from Browel,1989).

is the integrated optical thickness due to the ozone absorption with $\sigma^{O_3}(\lambda)$ absorption cross section and $n_{O_3}(R)$ ozone number density. The Eq.1 is validated with the following approximations (Measures, 1984):

a) the transmitted wavelength coincides with the observed one;

b) the backscattering medium, at range R, is considered homogeneous;

c) the temporal shape of the laser pulse is taken as rectangular with a duration τ_l ($\tau_l \approx 10 \div 20$ns); since the range of interest is generally much greater than the laser pulse length $c\tau_l$ we may treat the range dependent parameters as constants over the distance corresponding to the laser pulse ;

d) the ozone absorption cross section is independent respect to range ;

e) to calculate the transmission functions we assume the single scattering approximation (Beer-Lambert law) neglecting the effects due to the multiple scattering (see Rizi et al., 1990).

To obtain the vertical ozone distribution we introduce a range normalized signal variable (Pelon and Megie, 1982):

$$S(\lambda, R) \propto R^2 \left[N(\lambda, R) - B(R) \right] \tag{4}$$

where $B(R)$ is the background level evaluated using the backscattered signal from the higher altitude ($>$ 90 km), and including signal induced noise correction due to photomultiplier (McDermid et al., 1990; Iikura et al., 1987):

$$B(R) = a + b\, exp(-cR)$$

Calculating the logarithm and the derivative respect to the range R of $S(\lambda, R)$, using the backscattering signals of the ON and OFF wavelength, we obtain:

$$n_{O_3}(R) = -\frac{D(\lambda_{on}, R) - D(\lambda_{off}, R)}{2(\sigma_{on}^{o_3} - \sigma_{off}^{o_3})} \tag{5}$$

where

$$D(\lambda, R) = \frac{d}{dR}\left[ln(S(\lambda, R)) \right]$$

with $\lambda = \lambda_{on}, \lambda_{off}$ and $\sigma_{on}^{O_3}$,$\sigma_{off}^{O_3}$ are respectively the ozone absorption cross section for λ_{on} and λ_{off}.

In the usual derivation of the DIAL method one considers that the wavelength variations of $\beta(\lambda, R)$ and $\tau^e(\lambda, R)$ between λ_{on} and λ_{off} contribute only to the systematic error even if the contribute of $\tau^e(\lambda, R)$, mainly given by Rayleigh and Mie (aerosols) scattering, is not negligible in the lower atmosphere.

To calculate the derivative $D(\lambda, R)$ the signal corresponding to $2n+1$ channels between (R_{j-n}, R_{j+n}) is fitted to a first-order polynomial function as

$$S(\lambda_i, R_j) = a_{ij} R_j + b_{ij} \tag{6}$$

using a least square method. The value of n is taken so that the difference between experimental and fitted values is less than twice the standard deviation and the range interval that corresponds to $2n+1$ channels is the new altitude resolution. Then, if $\Delta R = R_{j-n} - R_{j+n}$ is the vertical resolution, the average value $\overline{D(\lambda, R)}$ is :

$$\overline{D(\lambda, R)} = \frac{1}{\Delta R} \int_{\Delta R} D(\lambda, R_j) dR_j \tag{7}$$

so the average ozone number density in the range $\frac{R-\Delta R}{2}$ and $\frac{R+\Delta R}{2}$ is :

$$\overline{n_{O_3}(R)} = -\frac{\overline{D(\lambda_{on}, R)} - \overline{D(\lambda_{off}, R)}}{2(\sigma_{on}^{O_3} - \sigma_{off}^{O_3})} \tag{8}$$

A complete valuation of that we have called "systematic error" could be found in Browell (1989) and in McDermid et al. (1990).

PRELIMINARY RESULTS

Without considering the huge of work performed for the initial setting up of the system (Rizi et al., 1990), we outline the operations directly correlated to a standard session of measurements. The measurements starts night-time, due to the lack of filtering in receiving, and in clear-sky conditions; at 10Hz pulse repetition rate we spend about 2 hours to collect data for producing one ozone profile. Real time checks of the laser output and of the receiver status are also possible. After storing, the data are handled in preliminary form (formatting, etc.) to allow the suitable data analysis.

In Fig.4 and Fig.5 we show two ozone profiles obtained in May and June 1990 using the data analysis described in the previous section; we did not perform any correction, but it is possible to note a relatively good agreement with Umkehr data provided by Istituto di Fisica dell'Atmosfera del Consiglio Nazionale delle Ricerche in Rome (100Km apart from SLAQ).

It is obvious that these comparisons are not the best chance to validate our system, therefore we are going to look for facilities which could allow in situ measurements.

We do not discuss in detail the data analysis because we are developing a new algorithm which take into account diffuse flux.

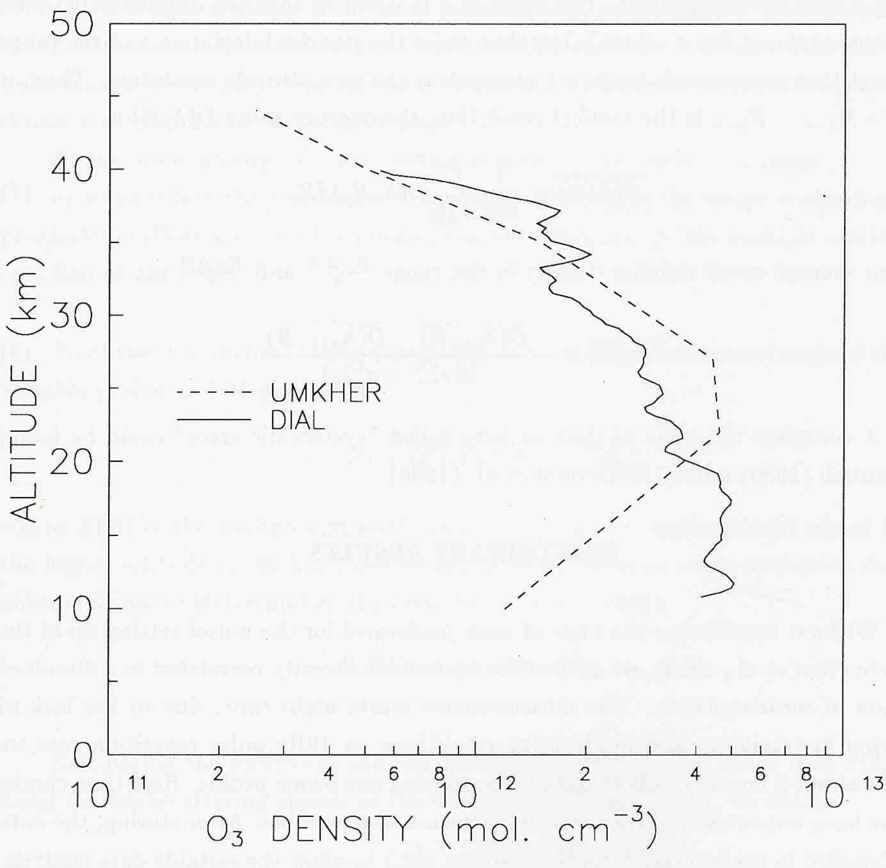

Fig.4. A ozone profile collected in preliminary operation of SLAQ ozone DIAL system, May 1990. The profile are compared with a Umkehr profile obtained in Rome (by I.F.A.). The figure is self explaining.

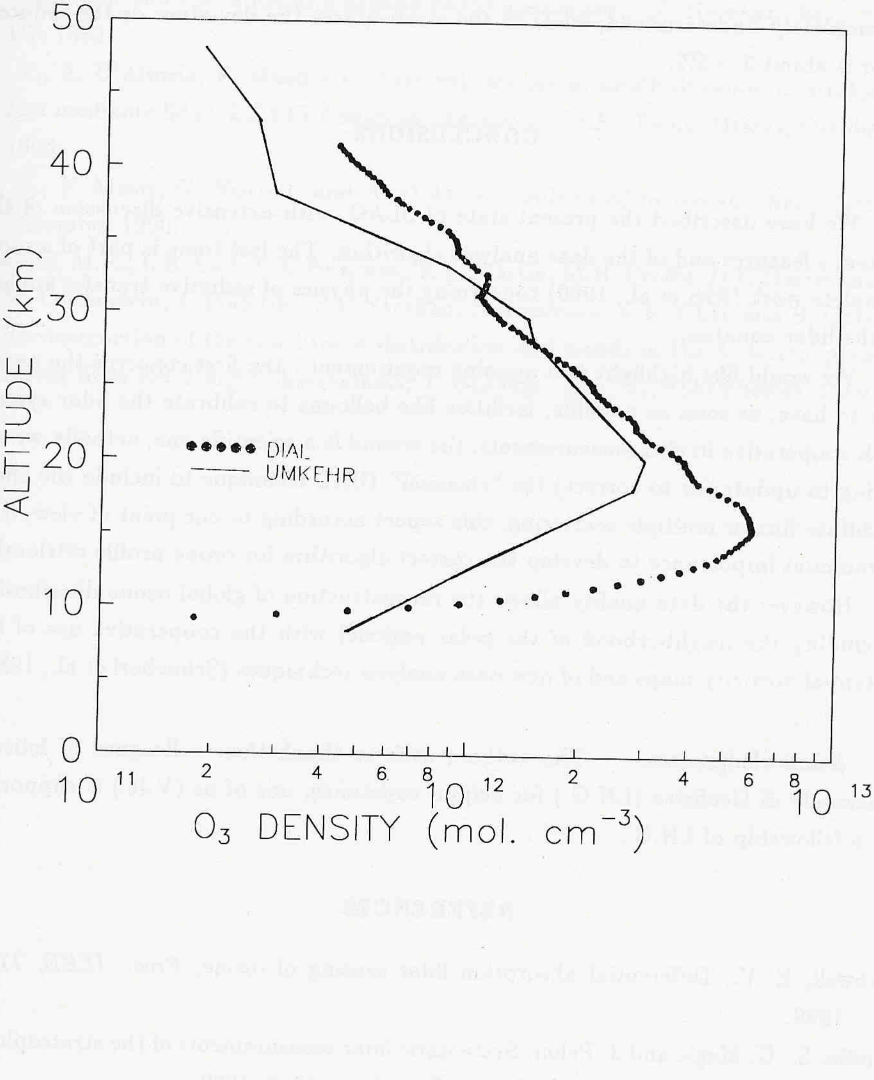

Fig.5. An ozone profile obtained the night of June 30, 1990. It is show a comparison as in Fig.4. Note the better quality of data in respect of Fig.4, due to longer acquisition.

About this new method, our preliminary results (Rizi et al., 1990) show that, neglecting the Rayleigh multiple scattering corrections in UV range (i.e. the wavelengths used in ozone DIAL) or neglecting completely the Rayleigh diffuse flux as the use of Beer-Lambert law in Eq.(1) involves *(this is not the Rayleigh extinction correction !)*, the ozone profile are inferred with very large error: the tropospheric ozone is completely undetermined, while in the stratosphere the deviation or the induced error is about $3 - 5\%$.

CONCLUSIONS

We have described the present state of SLAQ, with extensive discussion of the system's features and of the data analysis algorithm. The last topic is part of a more complete work (Rizi et al., 1990) concerning the physics of radiative transfer applied to the lidar equation.

We would like highlight two pressing requirement : the first concerns the necessity to have, as soon as possible, facilities like balloons to calibrate the lidar system with cooperative in situ measurements; the second is a scientific one, actually we are trying to update (or to correct) the "classical" DIAL technique to include the effect of diffuse flux or multiple scattering, this aspect according to our point of view, is of paramount importance to develop the correct algorithm for ozone profile retrieval.

However the data quality allows the reconstruction of global ozone distribution (including the neighborhood of the polar regions) with the cooperative use of the potential vorticity maps and of new data analysis techniques (Schoeberl et al., 1989).

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