Name of research institute or organization:

École Polytechnique Fédérale de Lausanne (EPFL)

Title of project:

Study of atmospheric ozone by a LIDAR

Project leader and team:

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Project description:

Tropospheric ozone is a climate relevant greenhouse gas, as well, as an atmospheric pollutant. Its abundance in the troposphere is governed mainly by photochemical production due to the anthropogenic pollution at surface level, and the influx of stratospheric air masses. Precise model simulations and measurements are needed to assess the exact impact of these sources onto the total tropospheric ozone content. In the latter case, vertical tropospheric ozone profiles are commonly obtained from in situ balloon-borne measurements. These routine observations are performed with a frequency of maximum several measurements per week and are, therefore, incapable of resolving fast changes in the tropospheric ozone concentration. However, vertical ozone profiles with good accuracy and temporal and spatial resolutions suitable for studying fast tropospheric changes have been produced for decades using remote sensing by means of the ozone UV differential absorption lidar (DIAL) technique.
The main goals of the project aimed to address some of the unresolved problems of the ozone origin and evolution in the upper troposphere and the lower stratosphere and were:

- to develop an UV DIAL for observation of vertical distribution of tropospheric ozone in the free troposphere and the tropopause region
- to perform experimental measurements of vertical ozone profiles in the high troposphere and the tropopause in order to assess the ability of the lidar to observe fast variations in the vertical ozone distribution caused by stratosphere-troposphere exchange, long range transport, and advection from the boundary layer
- to assess the feasibility of systematic ozone lidar observations from Jungfraujoch

The lidar design started in 2005 but was interrupted several times because of serious damages to the laser. The lidar design is presented in more details in the previous reports, therefore, here we will present a brief summary. The lidar transmitter is based on a commercial, fourth harmonic Nd:YAG laser. The ON (284 nm) and OFF (304 nm) DIAL wavelengths are produced by stimulated Raman scattering in high-pressure nitrogen. The receiver uses the existing at HARSJ 76 cm Cassegrain telescope. Spectral separation of the backscattered DIAL wavelengths is carried out by a polychromator based on an imaging diffraction grating. The entire DIAL detection unit is integrated, for reasons of simplicity, into the existing long-range multi-wavelength polychromator box, optically coupled at the Cassegrain telescope's rear end.

With the current design the ozone UV DIAL system provides hourly-averaged ozone profiles reaching from 6 to 12km ASL with a vertical resolution better than 400m at 6 km and 1000m at 12 km ASL. The relative error of the profiles is kept lower than 10 % at 12 km ASL.

During 2009 a series of measurements were taken with the lidar. As a first step of the experiment, the lidar profiles were compared to balloon borne ozone profiles taken by ECC sondes. The sondes were launched by the Swiss Meteorological Institute from Payerne (lat. 46; 49 N, long. 6; 56 E, ASL), situated at approx. 80 km NE of the HARSJ.

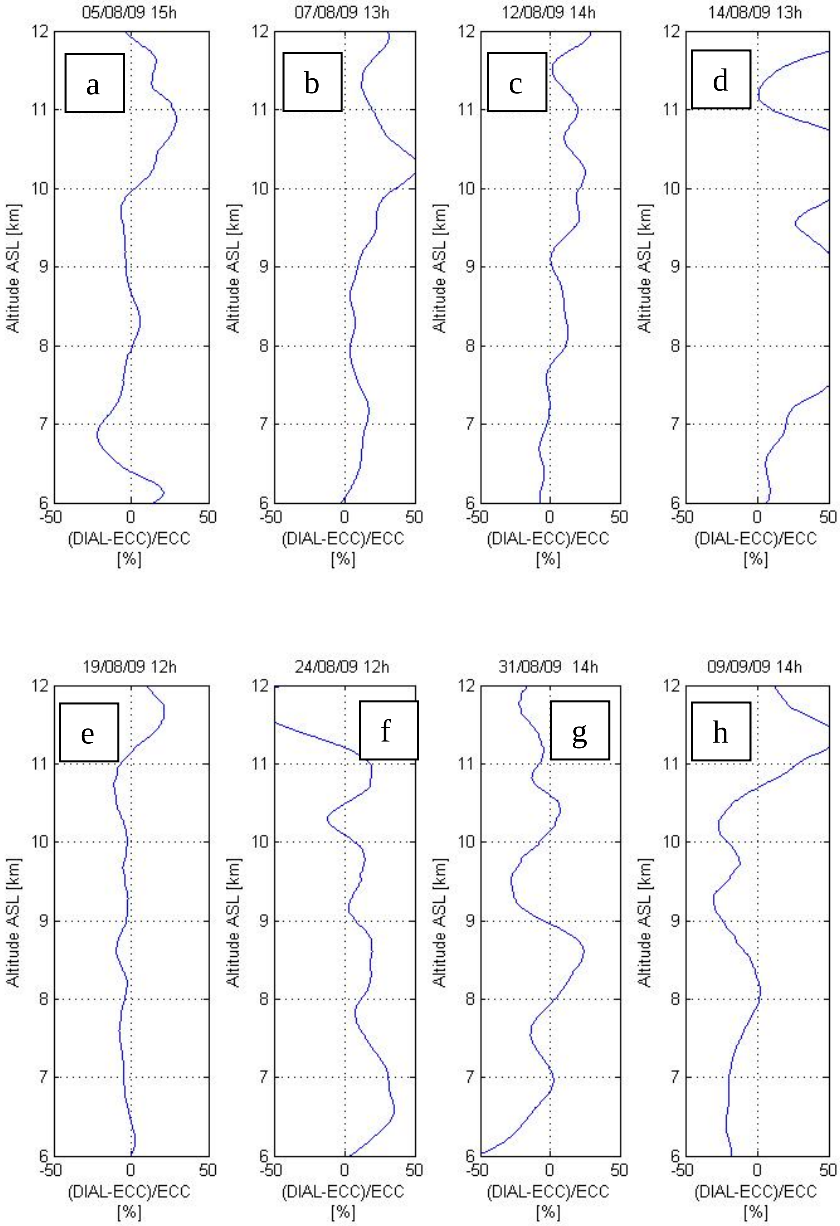

Fig.1 Relative difference between the lidar and the ECC measurements (DIAL-ECC/ECC) for 8 days in August and September. Note the good correlation in stable (high pressure) conditions, panel c and e, and increased difference in unstable conditions (passing front)- panel d

The lidar and the sonde measurements were taken quasi simultaneously. The relative differences between the lidar and the sonde were found to be lower than 20% in a horizontally homogeneous atmosphere Fig.1. The two measurements compare best in horizontally homogeneous atmosphere (panels c and e in the figure), and differ with more than 50% in unstable weather conditions as in panel d. This behavior can be easily explained by the distance between the two measurements.
The intercomparison shows that the lidar is able to reproduce accurately ozone vertical distribution. Intercomparison with vertical profiles taken in the vicinity of HARSJ by an airplane-borne UV photometer confirmed the performance of the lidar.
Time series with duration of up to 21 hours were taken in order to study the time evolution of tropospheric events characterized by elevated ozone concentrations. As a result of these measurements three events, demonstrating different processes have been identified. The lidar measurements were compared to ECC data when possible and to the prediction of the mesoscale model EURAD.

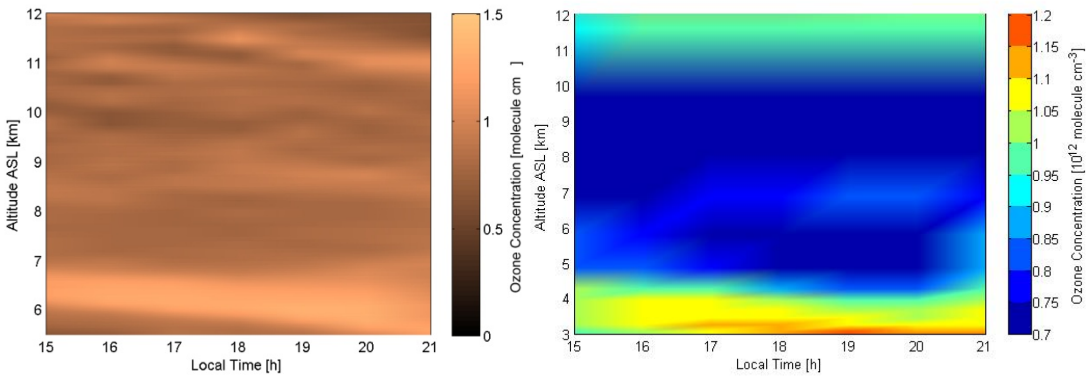

Fig. 2
Left panel Ozone concentration time series, note the elevated ozone concentration between 6 and 7 km.
Right panel EURAD predictions, the predicted ozone layer has slightly different temporal behavior. The predicted high ozone concentration at 3.6 km was measured by an ozone monitor from the NABEL network.

In the first case, an ozone layer with elevated ozone concentration was observed in the 6 to 7 km ASL range. The lower than 10% relative humidity, measured by a meteorological sonde, and the time evolution of this layer allowed us to determine its stratospheric origin. The lidar observations are in a good agreement with the EURAD atmospheric model predictions as seen from Fig.2. The model predictions at 3.6 km also agree with the elevated ozone concentrations measured by the UV -photometer of the NABEL network at HARSJ.
The evolution of an ozone-enriched layer in the tropopause region (1-12 km) was followed for 21 hours during the second case study. The time evolution, the ECC data, and the EURAD model predictions suggest the possibility of a short, reversible filamentation process developing at the tropopause altitudes. The measurements and the model prediction are shown in Fig. 3.

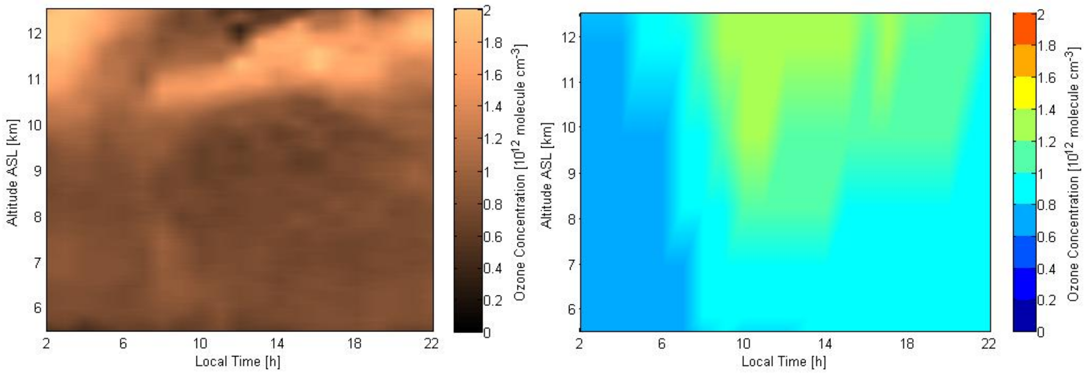

Fig. 3
Left panel Short reversible filamentation measured by the lidar at the tropopause height (10-11 km).
Right panel EURAD prediction – the model predicts shorter and deeper penetration in the troposphere.

The measurements of the third event were made according to a prediction of stratosphere- troposphere events forecasted by a dynamical model developed at ETHZ. A short leaving enhancement of the ozone concentration has been observed at an altitude of about 9.5 km as seen from Fig.4. . There are two possible explanations for this event. The first one could be a short-living reversible STE event as predicted. The relatively high relative humidity (> 20%) however does not support unambiguously this hypothesis. Another possible explanation is a long-range transport of ozone and ozone-precursors-reach air from the forest fires in the Athens region in August. This hypothesis is supported by back-trajectory results from the HISPLIT model as shown in Fig. 5. The absence or very low aerosol content in the ozone-rich layer however does not support this idea. The available information, however, does not allow to make a definite conclusion.

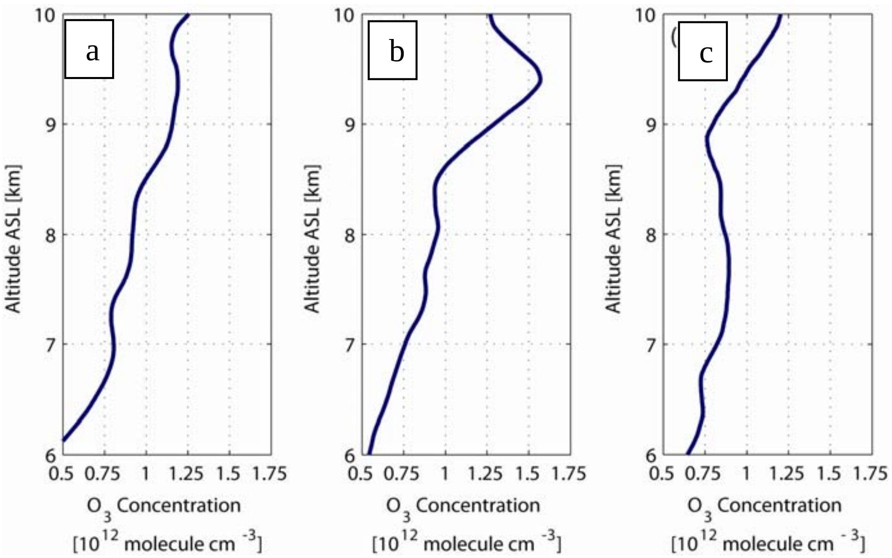

Fig. 4 Consecutive ozone profiles measured at 10.30 h (a), 12.30 h (b), and 15.30 h (c). Note the short-living ozone-rich layer at 9.5 km.

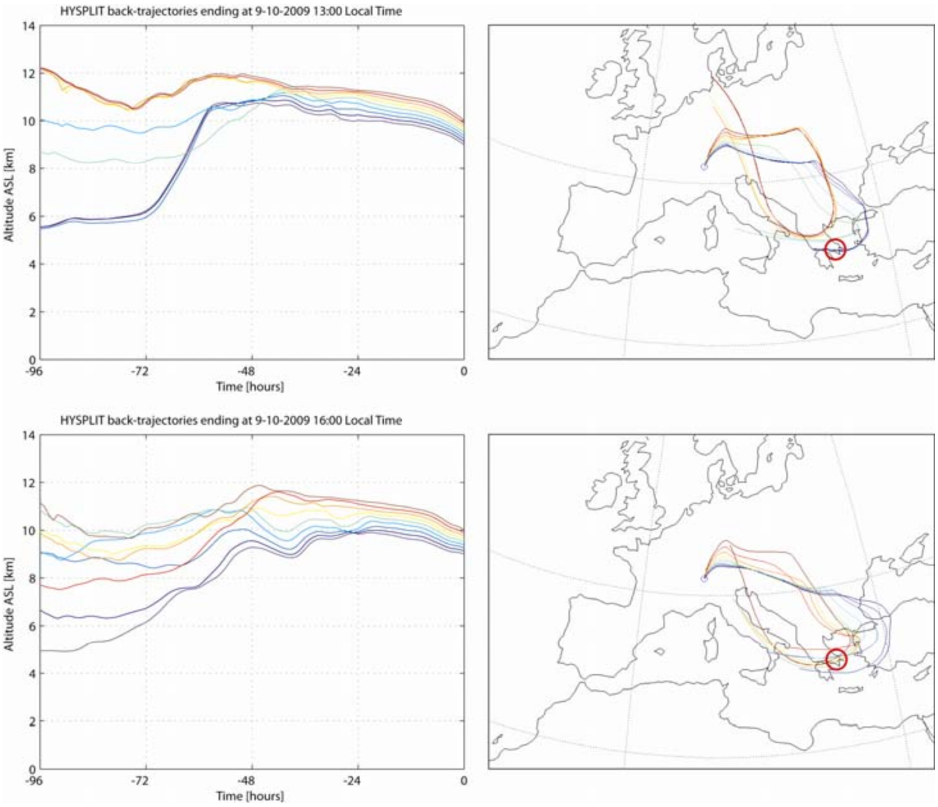

Fig. 5 HISPLIT back-trajectories *Upper row* Arrival at HARSJ at 13 h. Note the trajectories starting at 5.8 km above the Athens region. *Lower panel* Arrival at 16 h.

In conclusion we would like to point out that the lidar has been built successfully and has shown the ability to observe fast variation in vertical ozone distribution with high accuracy and precision. In combination with additional water vapor and temperature lidar observations and supported by model forecasting the lidar could become a powerful tool for improving our understanding of the upper troposphere lower stratosphere processes. To allow future systematic observations however, the lidar will need an essential upgrade to resolve the problems related to the long preparation time, and the limited by technical reasons time of observation related to the use of the astronomical telescope of HARSJ.

Key words:

Differential Absorption Lidar, Tropospheric Ozone, High Altitude Research Station Jungfraujoch, Climate Change, Stratosphere Troposphere Exchange, Long-Range Ozone Transport

Internet data bases:

http://eflum.epfl.ch/

Collaborating partners/networks:

EARLINET – European Aerosol Research Lidar NETwork
Federal Office of Meteorology and Climatology - MeteoSwiss
Institute of Atmospheric Optics – Tomsk, Russia

Scientific publications and public outreach 2008:

Conference papers

Bartlome, M., V. Simeonov, M. Parlange, and H. van den Bergh (2009), Development of an Ozone UV DIAL System at the High Altitude Research, Station Jungfraujoch. Geophysical Research Abstracts, Vol. **11**, EGU2009-8618-1, EGU General Assembly 2009, Vienna, Austria, April 19-24, 2009.

Bartlome, M., V. Simeonov, M. Parlange, and H. van den Bergh (2009) Development of an Ozone UV DIAL System at the High Altitude Research, Station Jungfraujoch. 5th Workshop on Lidar Measurements in Latin America, Buenos Aires, Argentina, November 30 - December 3, 2009.

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