

# Sampling of STE events over Payerne, Switzerland in Spring 2023, by Raman lidar and ozonesondes

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**Abstract:** We present two case studies of long-range transport of stratospheric ozone in the troposphere and of tropospheric ozone photochemically produced by forest fires in Germany, Canada and USA, over the Aerological station of MeteoSuisse, at Payerne, Switzerland, during Spring 2023. The ozone measurements were supported by collocated water vapor Raman lidar measurements and ozone radiosoundings.

## 1. Introduction

Ozone plays a significant role in the tropospheric chemistry as the major precursor of the hydroxyl radicals (OH), which in turn are the primary removal agents for most of the atmospheric pollutants [1]. In addition, ozone as a greenhouse gas influences the radiative balance of the troposphere and consequently the climate change [2]. Moreover, high ozone levels over urban areas contribute to the formation of photochemical smog causing health problems to humans and plants [3]. In this paper we present measurements of tropospheric ozone profiles obtained over the Aerological station of MeteoSuisse at Payerne (Switzerland) during Spring 2023. We focus on two case studies of long-range transport of stratospheric ozone in the troposphere and of tropospheric ozone photochemically produced by wild forest fires in Germany, Canada and USA. The ozone measurements were supported by water vapor Raman lidar measurements and ozone radiosoundings.

## 2. Instrumentation

The MeteoSuisse Aerological station at Payerne is fully equipped with a large suite of in situ and remote sensing meteorological and aerological instrumentation. The station is part of GCOS Reference Upper Air Network (GRUAN). Ozone radiosoundings are performed systematically three times per week in conjunction with automatic profiling of aerosol, temperature and water vapor as obtained by the Raman Lidar for Meteorological Observation

(RALMO) system. RALMO is based on a pulsed Nd:YAG laser emitting at 355 nm with a repetition rate of 30 Hz. The laser beam has a divergence of 0.1 mrad. The system runs during daytime and nighttime providing vertical profiles up to the upper troposphere and the lower stratosphere [4].

RALMO detects elastic lidar signals at 355 nm, as well as N<sub>2</sub>-Raman lidar signals at 387 nm and H<sub>2</sub>O-Raman signals 407 nm. The aerosol optical properties obtained include the backscatter and extinction coefficients. The water vapor mixing ratio profiles and the relative humidity profiles are provided during day and night with a 30 min temporal resolution [5].

The ozonesoundings are based on radiosondes using balloons on which are attached small chemical cells where a chemical reaction between ozone (O<sub>3</sub>) and potassium iodide (KI) molecules occurs, and the measured current is directly proportional to the ozone mixing ratio [6].

## 3. Methodology

To sample stratospheric-tropospheric exchange (STE) events in the troposphere, collocated vertical profiles of ozone and relative humidity are required; to this end an STE event is observed when dry stratospheric air masses (very low relative humidity values) coincide with local ozone maxima, while in the case of long-range transport of photochemically

produced ozone, high ozone peaks have to coincide with increased aerosol presence as shown by high values of the aerosol backscatter coefficients [7,8].

#### 4. Results and discussion

##### 3.1 Case study 10 May 2023

A stratospheric-tropospheric exchange (STE) event was captured over the Payerne site on 10 May 2023. In Figure 1 we present the vertical profiles of the relative humidity (%) (left) and the ozone mixing ratio (ppbv) (right), obtained by a local ozonesounding at 12:00 UTC.



Figure 1 (a) Vertical profile of relative humidity (5) and (b) ozone mixing ratio (ppbv), obtained by ozonesounding over Payerne on 10 May 2023 at 12:00 UTC.

In this Figure the presence of stratospheric air mass layers can be identified directly based on criteria like concurrent elevated ozone concentration values with low relative humidity aloft [7,8]. Indeed, dry air masses were detected between 4-6 and 8-9 km height asl. (cf. Fig. 1a) with concurrent increased levels of O<sub>3</sub> (52 and over 60 ppbv) observed at 5.5-6.5 and 8.5-9.0 km asl., respectively (cf. Fig. 1b), indicating the arrival of a STE event over Payerne on 10 May 2023, at 12:00 UTC.

To verify the hypothesis of the STE event, a 120-hours air mass backward trajectory analysis performed, showed that the air masses arriving on that day (10 May 2023) at 5.5 km (yellow line) and 8-9 km height (magenta and light blue lines, respectively), over Payerne at 12:00 UTC (cf. Fig. 2) originated from the lower stratosphere at ~10 km height over N.

Alaska (magenta line) and the Polar circle (blue line).

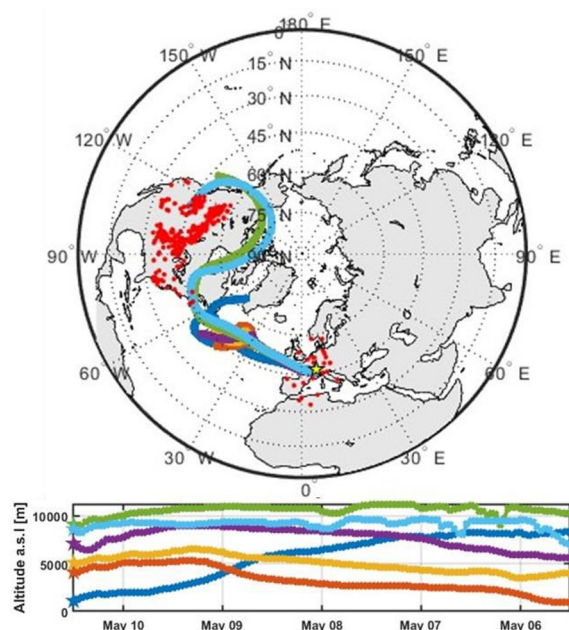


Figure 2. 120-hours air mass backward trajectories ending over Payerne at 12:00 UTC, 10 May 2023, using the Hysplit model.

To validate further our hypothesis of a STE event, we present in Figure 3 the Isentropic Potential Vorticity (IPV) map on the 320 K surface (8.9 km height a.s.l.), on 10 May 2023 (12:00 UTC).

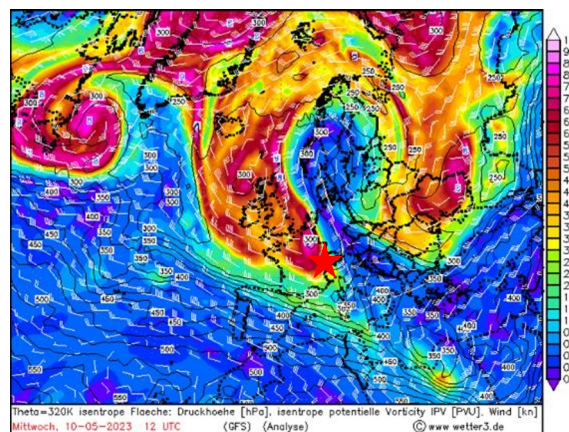


Figure 3. Isentropic potential vorticity (in PV units) map on the 320 K surface over Payerne (indicated by the red star) on 10 May 2023 (12:00 UTC) (source: DWD).

Indeed, in Figure 3 we see that Payerne (indicated by a red star) was located on the eastern flank of a developing cut-off low (COL) system having very high IPV values (IPV>6), a

very clear indication of the arrival of stratospheric air masses over the site at the above height levels.

### 3.2 Case study 12 June 2023

On the 12 June 2023 large-scale fires in Germany, USA, and Canada affected the air quality over Payerne and resulted in a photochemical event in the free troposphere over our measuring site. In situ ground measurements of organic carbon (OC) concentrations carried out at Payerne station (not shown) showed increased values due to the arrival of the smoke particles in the late afternoon hours.

Based on the RALMO and the radiosonde data (cf. Fig. 4a) very humid air masses (RH=50%) are observed between 1.8-2.3 km and very dry ones (RH<2%) are found between 4.0-5.5 and 6.5 km height, on 12 June 2023 at 12:00 UTC.

Therefore, the increased O<sub>3</sub> values (>60 ppbv) below 2.3 km height (cf. Fig. 4b) as well as the correspondingly increased β<sub>aer</sub> values (not shown), correlate very well with the arrival of low tropospheric air masses (below 4 km height) which overpassed the biomass burning areas (rich in aerosols) of Germany and Ukraine (cf. red spots in Fig. 5). This corroborates the arrival of photochemically produced O<sub>3</sub> from the biomass burning areas from Germany and Ukraine over Payerne.

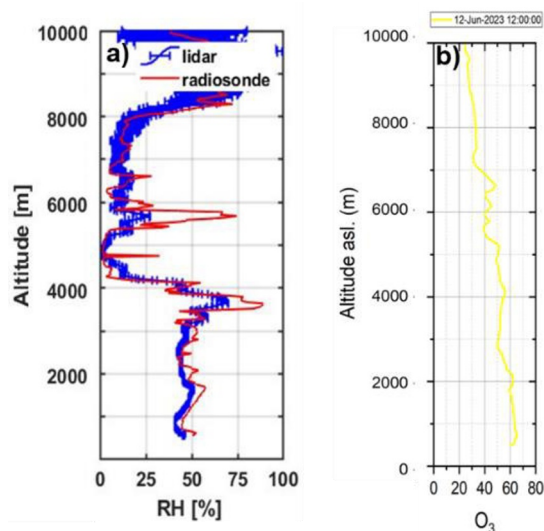


Figure 4. (a) Vertical profiles of relative humidity (%) obtained by RALMO and radiosonde; (b) ozone mixing ratio (ppbv), respectively, obtained over Payerne on 12 June 2023, at 12:00 UTC.

The corresponding locally increased levels of O<sub>3</sub> (Fig. 4b) between 4.0-5.5 and 6.5 km height (50 ppbv) indicate the arrival of very dry stratospheric air masses rich in O<sub>3</sub> at these heights [7,8].

To verify the hypothesis of a STE event, a 240-hours air mass backward trajectory analysis performed for that day for the air masses arriving at 4.0-5.5 and 6.5 km height levels (cf. Fig. 5, yellow and magenta lines, respectively) over Payerne (marked by a yellow star) at 12:00 UTC, originated from the lower stratosphere at ~10 km height over N. Alaska.

To validate further our hypothesis of a STE event, we present in Figure 6 the Isentropic Potential Vorticity (IPV) map on the 320 K surface (6.5 km height a.s.l.) on 12 June 2023 (12:00 UTC). We see in this figure that Payerne (indicated by a yellow star) is located at the far edge of the western flank of a developing cut-off low (COL) system, which indicates that the stratospheric air masses could have been mixed with tropospheric ones. This is further verified by the low IPV values (IPV~1) observed over Payerne that day (cf. Fig. 6).

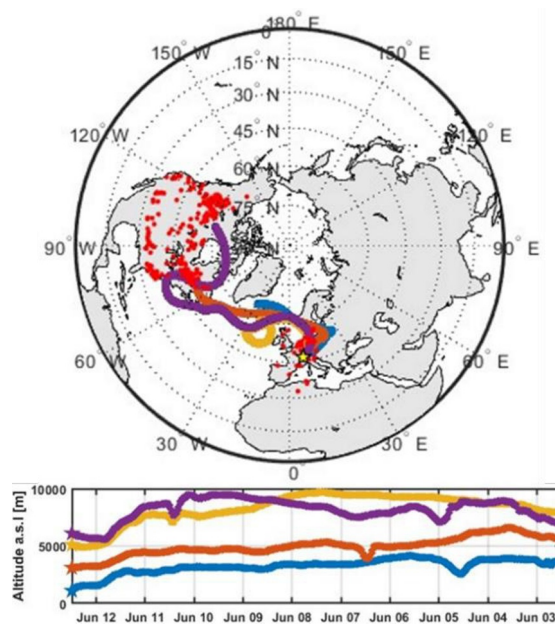


Figure 5. 240-hours air mass backward trajectories ending over Payerne (marked with a yellow star) on 12 June 2023 (12:00 UTC) using the Hysplit model. The red dots refer to wildfire hot spots (MODIS data).

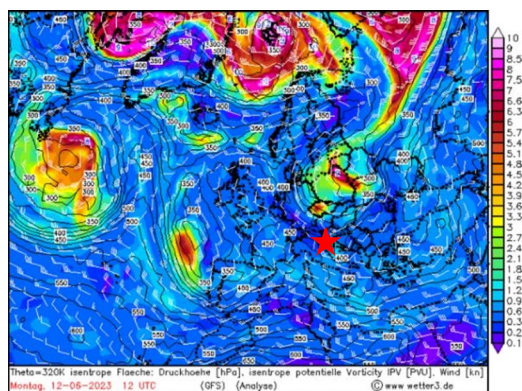


Figure 6. Isentropic potential vorticity map (in PV units) on the 320K surface over Payerne (indicated by a red star) on 12 June 2024 (12:00 UTC) (source: DWD).

## 5. Conclusions

In this paper we showed two cases of long-range transport of stratospheric ozone in the troposphere and of photochemically produced tropospheric ozone by forest fires in Germany, Canada and USA, over Payerne, during Spring 2023. To investigate further the climatological role of ozone in the troposphere, a systematic analysis of ozone and relative humidity profiles has to be performed over large geographical scales, as ozone plays a significant role in the climate change and relevant data still remain limited.

Therefore, feedbacks between water vapor, relative humidity, ozone, temperature, STEs, dynamic and photochemical processes, are of a great importance for the climate change impacts.

## 6. References

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