

33 YEARS OF STRATOSPHERIC AEROSOL MEASUREMENTS AT GARMISCH-PARTENKIRCHEN (1976-2010)

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ABSTRACT

The powerful backscatter lidar at Garmisch-Partenkirchen (Germany) has almost continually delivered backscatter coefficients of the stratospheric aerosol since 1976. The time series is dominated by signals from the particles injected into the stratosphere by major volcanic eruptions, in particular those of El Chichon (Mexico, 1982) and Mt. Pinatubo (Philippines, 1991). The volcanic aerosol disappears within about five years, the removal from the stratosphere being modulated by the phase of the quasi-biennial oscillation. During the long-lasting background period since the late 1990s the stratospheric backscatter coefficients have reached a level even below that observed in the late 1970s. This suggests that the predicted potential influence of the strongly growing air traffic on the stratospheric aerosol loading is very low. Some correlation may be found with strong forest fires. Since 2003 there is some indication of a growing background that is tentatively ascribed to the growing air pollution in East Asia.

1. INTRODUCTION

In 1973, a powerful backscatter lidar was installed in Garmisch-Partenkirchen (Germany). After adding single-photon counting to the analogue detection in 1976 the measurements were extended into the stratosphere. The stratospheric series (Fig. 1) has been carried on until now with just short interruptions mainly caused by technical

problems. A scientific summary for the period 1976-1999 was given by Jäger [1] and, comparing the results for the most important stations performing stratospheric aerosol sounding, by Deshler et al. [2]. The lidar was first operated with a ruby laser (694 nm), since 1991 with a frequency-doubled Nd:YAG laser (532 nm). A 0.52-m-diameter Cassegrain telescope collects the backscattered light. With the laser change in 1991 the lidar was converted into a transportable scanning system that was used for the investigation of the life cycles of contrails [3,4].

In 1991 the system was integrated into the Network for the Detection of Stratospheric Change (NDSC, now: NDACC, Network for the Detection of Atmospheric Composition Change). Since 1998 the lidar has also contributed to the German Lidar Network and the European Aerosol Research Lidar Network (EARLINET).

The series in Fig. 1 may be divided into two sections. The first part, 1976 to 1996, features a number of very strong volcanic eruptions that injected large amounts of particles into the stratosphere. Even the period in the late 1970s was influenced by a strong eruption of the Fuego volcano (Guatemala) in 1974 [2]. From 1997 to 2008 there was a long-lasting background period where the level of stratospheric aerosol reached values even below that before 1980. In this contribution we discuss some of the processes that have kept alive the stratospheric aerosol background during this period.

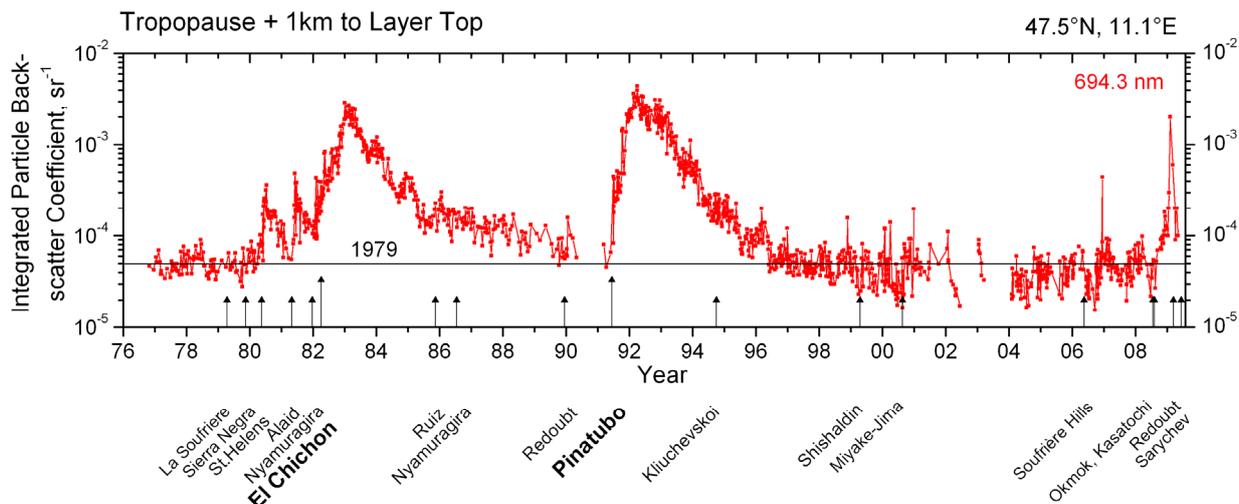


Figure 1. Integrated backscatter coefficient from the lidar measurements at Garmisch-Partenkirchen between 1976 and 2008; the 532-nm measurements since 1991 are converted to 694.3 nm [1].

2. RESULTS 1976-1996

The time series is dominated by signals from the particles injected into the stratosphere by major volcanic eruptions, in particular those of El Chichon (Mexico, 1982) and Mt. Pinatubo (Philippines, 1991). The volcanic aerosol disappears within about five years, the removal from the stratosphere being modulated in phase with the quasi-biennial oscillation [1].

3. RESULTS 1997-2009

During the background phase starting in 1997 the aerosol loading of the stratosphere was rather low (Fig. 1) and exhibited only very short elevated-aerosol events. Some of these events are discussed in the following section. On some days it was even difficult to resolve any aerosol component in the lidar signals received from the stratosphere. As during the volcanic periods a pronounced seasonal cycle is seen, caused by, e. g., the seasonal variation of the tropopause height or vertical exchange across the tropopause.

Starting in 2004, a slight increase of the background aerosol is observed. A similar increase was reported by Hofmann et al. for the stations Mauna Loa and Boulder, but starting already roughly in 2000 [5]. The maximum positive trend at these two stations, 4 to 7 % per year, was found for the altitude range 20-30 km. The authors ascribe this increase to the growing emissions of sulphur dioxide from coal burning, mainly in China, with a pronounced rise since 2000. The reason for the rather long delay between the start of the stratospheric aerosol rise in Ref. 5 and that above Garmisch-Partenkirchen is not fully clear. On one hand there is a shift in latitude which should result in a delayed observation at 47.5° N. On the other hand one would expect a transport time of less than half a year between the two latitudes. Some uncertainty is caused by the two gaps in our data in 2002 and 2003. However, an extrapolation of the data for 2004-2008 to shorter times suggests a start of the rise not earlier than in 2002. Some masking by special events cannot be excluded such as minor volcanic eruptions or the Chisholm fire in 2001 (see Sec. 4).

4. SPECIAL EVENTS

Due to the background period since the late 1990s the influence of less important sources of stratospheric aerosol can be distinguished. One important source could be strong forest fires. In fact, so-called pyro-cumulonimbus (pyroCb) clouds reach the stratosphere and give rise to aerosol observations above the tropopause [6,7].

Two pyroCb events that yielded also plume observations at Garmisch-Partenkirchen were recently studied in an international co-operation [8,9]. The first is the Chisholm fire, initiating a huge burst of smoke that occurred over Northern Canada on May 28, 2001. The intense plume could be followed with TOMS satellite

images (<http://toms.gsfc.nasa.gov/aerosols/aerosols.html>) all the way across the North Atlantic. However, it missed Garmisch-Partenkirchen during the first approach. The plume was observed with some delay during the second half of June and in early July (before a longer interruption of the measurements due to a field campaign). The source region was verified by a three-week backward simulation with the FLEXPART tracer model (N. Spichtinger-Rakowsky, personal communication, 2006). Quite interestingly, a slight positive correlation of the aerosol and the temperature in the profiles of the nearest radiosounding station, München-Oberschleißheim ("Munich"), 100 km roughly to the north, was found. The Chisholm particles gradually filled the lowermost stratosphere in the entire northern hemisphere, as determined from observations with satellites and with NDACC lidar systems [8].

The second pyroCb event studied in detail took place in the Québec province (Canada) in June 1991. The plume was observed with both the NDACC lidar (during the first night hour of July 1, 1991) and the IFU tropospheric ozone lidar (between July 1 and 2, Fig. 2) [10].

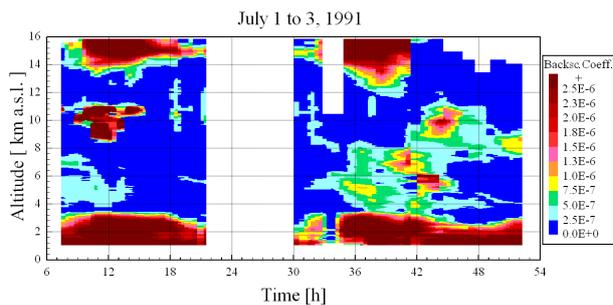


Figure 2. 313-nm backscatter coefficients from measurements of the IFU ozone lidar from July 1 to 3, 1991, showing the intense plume from the Canadian fires between 13 km and more than 16 km; the tropospheric aerosol spikes between 4 and 11 km on July 2 have been ascribed to the Kuwait oil-fire plume advected via the western Atlantic [10]. The time is given in Central European Time (CET = UTC + 1 h), the backscatter coefficient in $\text{m}^{-1} \text{sr}^{-1}$.

The lower-stratospheric plumes had been initially interpreted as the first arrival of Mt.-Pinatubo aerosol over Garmisch-Partenkirchen. We calculated a total of 111 315-h HYSPLIT [11] backward trajectories for this episode, at intervals of three hours, starting at altitudes between 13.5 and 16 km over Garmisch-Partenkirchen. Trajectories from the two relatively strong plumes in Fig. 2 closely overpass the region around Québec City where the fires took place (one example is shown in Fig. 3). All the other trajectories end in regions ranging from the Atlantic Ocean to Central and North America, or the eastern Pacific Ocean. There is almost no chance of any significant overlap with the Pinatubo eruption on June 13, 1991. The very high aerosol signal is due to the direct advection from Canada within just a few days.

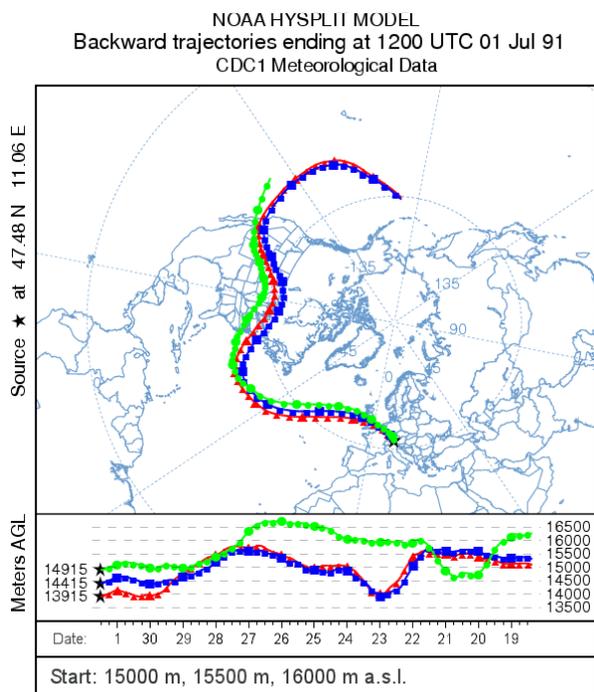


Figure 3. Three of the 315-h backward trajectories, started over Garmisch-Partenkirchen on July 1, 1991, at 13:00 CET; there is a vertical offset (AGL = above ground level, 730 m a.s.l.) due to the crude model orography [12].

An interesting temporary aerosol event was observed in December 2006 (Figs. 1 and 4). Up to 34 km, the stratosphere was loaded with aerosols for a few days. No major volcanic eruption or wild fires could be identified during the two months preceding these observations.

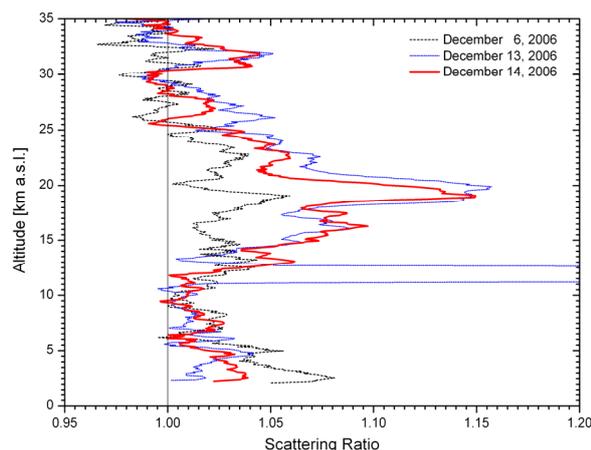


Figure 4. 532-nm scattering ratio for three measurements in December 2006

Since very cold temperatures prevailed in the stratosphere from Novaya Semlya to the Alps and, further to the east, to northern Greece, one could think about a vertically extended polar stratospheric cloud (PSC). How-

ever, the Munich radiosonde showed minimum temperatures of just -70°C (12 to 25 km a.s.l.), not enough for PSC formation. Also the calculated HYSPLIT 315-h backward trajectories did not reach regions with temperatures below -80°C . Further work is planned for determining if a highly delayed arrival of the eruption plume from the Soufrière Hills volcano (Caribbean Sea; May 20, 2006; see Fig. 1), which reached 17 km and stayed in the tropics for some time [13], can explain the observations.

Enhanced integrated backscatter coefficients in a similar distribution, though confined more to lower altitudes, were observed in December 2008 (Fig. 5). Also in this case the temperatures of Munich radiosonde do not reach -80°C , in the altitude range with elevated aerosol below 20 km the values are around -60°C . The trajectories, again, do not show recent arrival from arctic latitudes. As discussed below the observation are best explained by volcanic activity (see below).

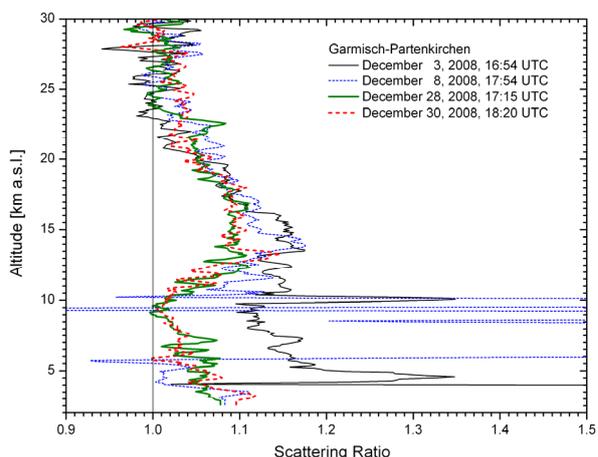


Figure 5. 532-nm scattering ratio for four measurements in December 2008; the elevated aerosol up to about 20 km is very likely due to the Okmok and/or Kasatochi eruptions. The backscatter coefficients continued rising in early 2009 (see Fig. 1), followed by a steep drop until April.

During the years 2008 and 2009 several volcanic eruptions leading to observations of stratospheric aerosol were reported (Okmok, Aleutian Islands, erupting on July 21, 2008; Kasatochi, Alaska, August 7, 2008; Redoubt, Alaska, March 15, 2009; Sarychev, Kuril Islands, June 12, 2009). These plumes resulted in rather confined layers, observed at several European lidar stations. The 2008 plume stayed in a thin layer until September 2008. In October a transition to a wider distribution occurred that continued to be present until the end of the year. Due to a major field campaign [14] and subsequent construction work at IMK-IFU the stratospheric lidar measurements had to be interrupted between May and September 2009. The Sarychev aerosol was, however,

seen in the backscatter data from our water-vapour lidar [15,16] and we plan to fill the summer-2009 gap with the data from this system.

5. CONCLUSIONS

During almost one and a half decades background conditions have prevailed in the stratospheric aerosol. This has sharpened the view on smaller contributions to the aerosol. A small positive trend is seen in the integrated backscatter data between 2004 and 2008. The data for the rest of 2009 and the subsequent years will show how quickly the volcanic influence will settle down to allow us to follow this increasing background longer. In addition, further studies of fire plumes and the December 2006 and December 2008 episodes are planned.

6. ACKNOWLEDGEMENTS

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