In-situ Ozone Observations at Zugspitze (2962 m) from 1978 to 2008

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Zugspitze: 47°N, 11°E, 2962 m asl, at the northern rim of the Alps

Analysis of ozone data (1978 – 2008) with respect to:

- Long-term trend
- Seasonal variations
- Impact of different atmospheric conditions

Focus on differences between earlier and more recent parts of the time series
Overview on the O₃ data structure at Zugspitze (half-hourly mean values, 1996 - 2000).

By short-term variations a range of about 110 ppb is covered.
O$_3$ monthly mean values (1978 – 2008) together with regression curve and long-term trend component

Part 2: 1990 - 2002

Zugspitze (2962 m)
Trend curves for the sites Zugspitze (2962 m) and Wank (1780 m)

Comparisons with the neighbouring Wank summit: Smaller and partly negative growth rates during the 1990s, remarkable agreement in the trend behaviour from 2000 onwards.

Avg:

- ZUG: 1.13 ppb yr\(^{-1}\)
- WNK: 0.98 ppb yr\(^{-1}\)


Part 2: 1990 - 2002


- ZUG: 0.24 ppb yr\(^{-1}\)
- WNK: 0 ppb yr\(^{-1}\)
- 0.55 ppb yr\(^{-1}\)
- 0.79 ppb yr\(^{-1}\)

Instantaneous growth rate = derivate of trend curve
Results of modelling and emission inventories in the literature indicate relationships between NO$_x$ emission trends (increases / reductions) and surface ozone levels.

Strong increase in European NO$_x$ emissions between 1950 and 1980.

Ref., e.g.: Vestreng et al. (2009), Evolution of NO$_x$ emissions in Europe with focus on road transport control measures, Atmos. Chem. Phys., 9, 1503-1520.

Reductions in emissions since the late 1980s.

Filtering of Ozone Data

Based on the parameters:
- relative humidity (RH),
- beryllium-7 ($^7$Be),
- carbon monoxide (CO) [available since 1990]

1. Selection of air masses influenced from the lower stratosphere/upper troposphere:
   "RH < 60 % AND $^7$Be > 85th percentile of the annual data set" (abbreviated $^7$Be(P85)/RH).

2. For dry air affected predominantly by the lower stratosphere/upper troposphere:
   Combined RH criterion requesting: "RH < 60 % AND RH running minimum over 12 hours < 30 %" (abbreviated RH60/30)

3. Relatively unpolluted air: CO < 30-day running median of CO

4. Polluted air: CO > 30-day running median of CO
Growth Rates for Different Atmospheric Conditions

Calculated from the slope of linear regression on selected data sets


1978-1989: Similar rates for different conditions
1990-2002: Highest rates for air from lower stratosphere/upper troposphere


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Contribution of selected condition [%]

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<thead>
<tr>
<th>Condition</th>
<th>Rate(78-89)</th>
<th>Rate(90-02)</th>
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<tr>
<td>All data</td>
<td>14.7</td>
<td>14.2</td>
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<td>night-time</td>
<td>10.6</td>
<td>13.1</td>
</tr>
<tr>
<td>RH&lt;60</td>
<td>23.0</td>
<td>8.8</td>
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<tr>
<td>7Be(P85)/RH</td>
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<td>14.2</td>
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<td>7Be(P65)/RH</td>
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<td>RH60/30</td>
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Comparison of growth rate calculations (1990-2002):
Monthly means & Annual means

Zugspitze: Ozone growth rates (1990 - 2002) from linear regression on monthly and annual means with 95%-confidence limits

Proxy of background trend (?)

Highest rates associated with "clean air" conditions
A different view on the ozone trend

Growth rates from seasonal percentiles: 5th, 25th, 50th, 75th, 95th
Winter = Dec, Jan, Feb; Summer = Jun, Jul, Aug

1978 – 1989: Highest $O_3$ increase associated with highest summer-time concentrations

1990 – 2002: Strongest $O_3$ decrease associated with highest summer-time concentrations
The most recent development – from 6 years only

Growth rates from seasonal percentiles

2003-2008: Winter = Dec, Jan, Feb;

Zugspitze, O3 growth rates

Winter (2003-2008)
Summer (04-05, 07-08)
Seasonal Variations from Different Data Sets
Average seasonal variations:
and with UT/LS data filtering applied
Average seasonal variations:
All data 1990 – 2002, "unpolluted", "polluted"
Average seasonal variations:
all data 1990 – 2002, "unpolluted", "polluted"
Statistics of Data Flags

What does it indicate?

Temporal development of events flagged by the criteria $^7$Be(P85)/RH and RH60/30

1) Annual number of events fulfilling the $^7$Be(P85)/RH criterion: Increase by a factor of 1.23 from 1978 to 2005 (95% confidence level)

Associated data coverage: Increase by a factor of 1.25 (90% c.l.)

→ Average duration of events ≈ constant

2) Annual number of events fulfilling the RH60/30 criterion: Increase by a factor of ≈ 2

Associated data coverage: Increase by a factor of ≈ 2.6

→ Average duration of events has increased (95% c.l.)

Ratio of annual number of events: $n(RH) / n(Be7) \rightarrow$ significant increase (99% c.l.) This means: RH60/30 events have become relatively more frequent than $^7$Be(P85)/RH events.
Ozone at Zugspitze (1978 – 2008)

Summary

- Part of the trend behaviour reflects the development of precursor emissions
- Clean-air data filtering (1990 – 2002): Growth rates are above the all-data value Seasonal variations with pronounced spring maximum
- O$_3$ in polluted air (1990 2002): Rates smaller than the all-data case Seasonal maximum shifted to mid-summer
- Indications of an increasing influence of upper tropospheric air masses on ozone at Zugspitze
Acknowledgements

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