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

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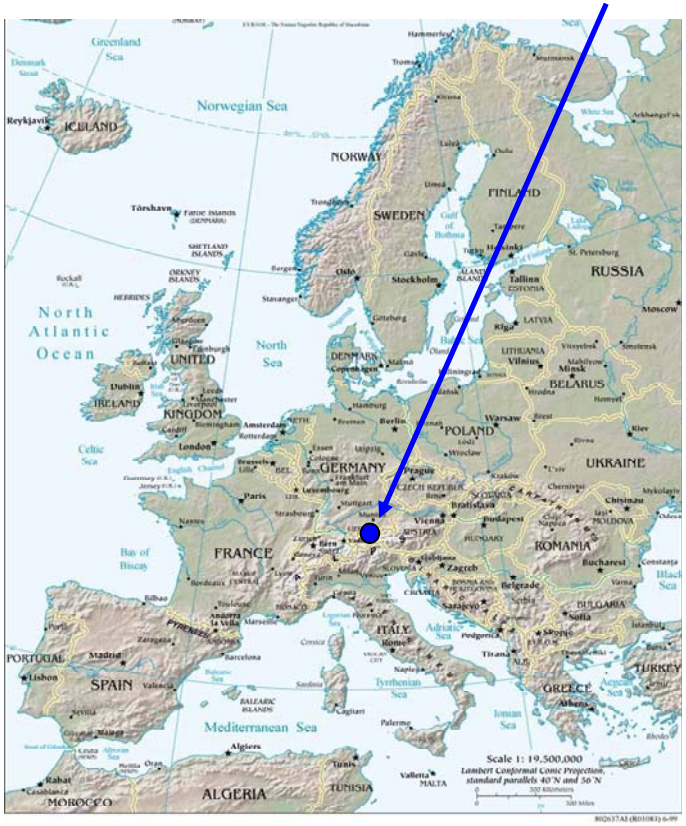
Zugspitze: 47°N, 11°E, 2962 m asl, at the northern rim of the Alps



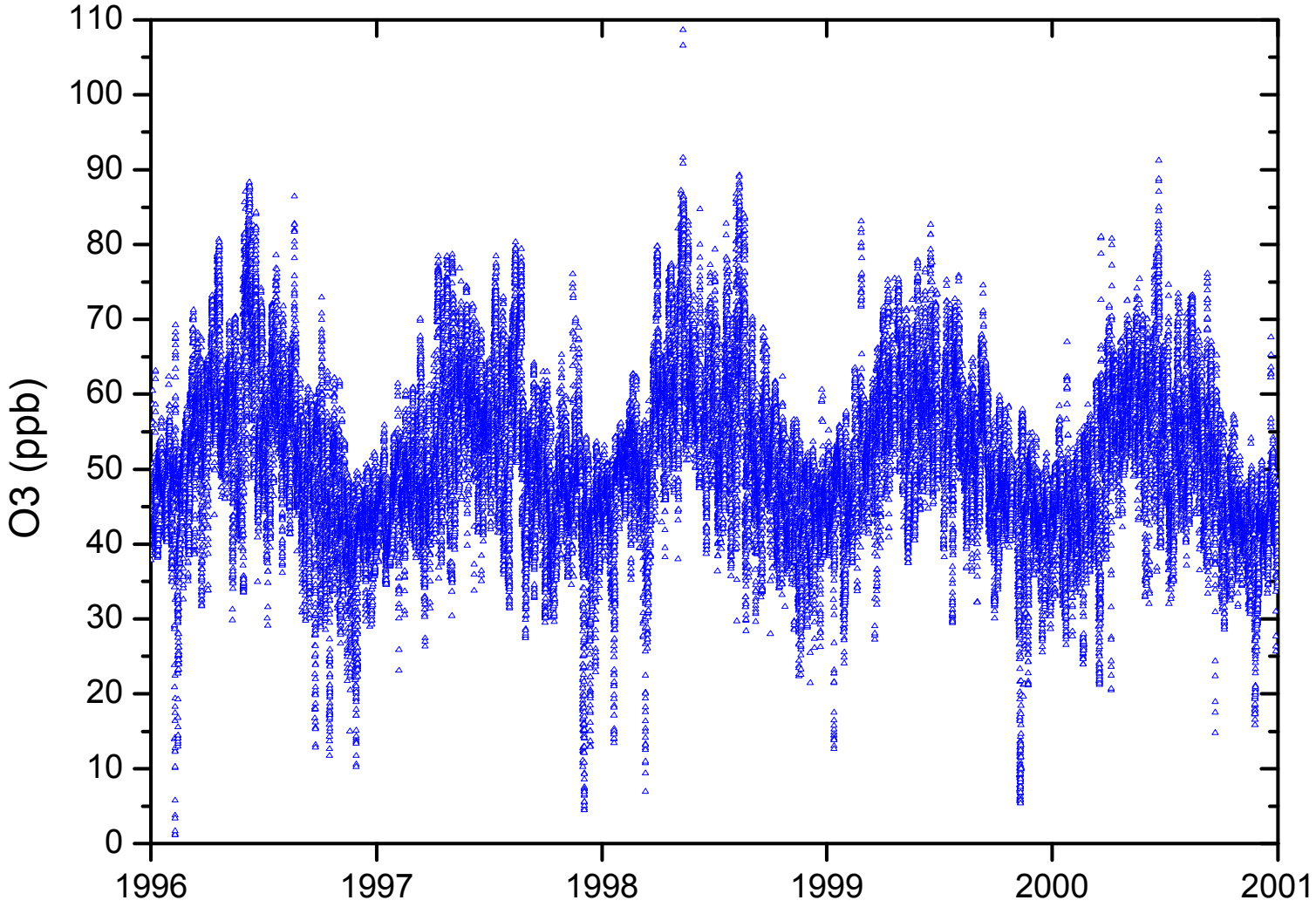
Analysis of ozone data (1978 – 2008) with respect to:

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

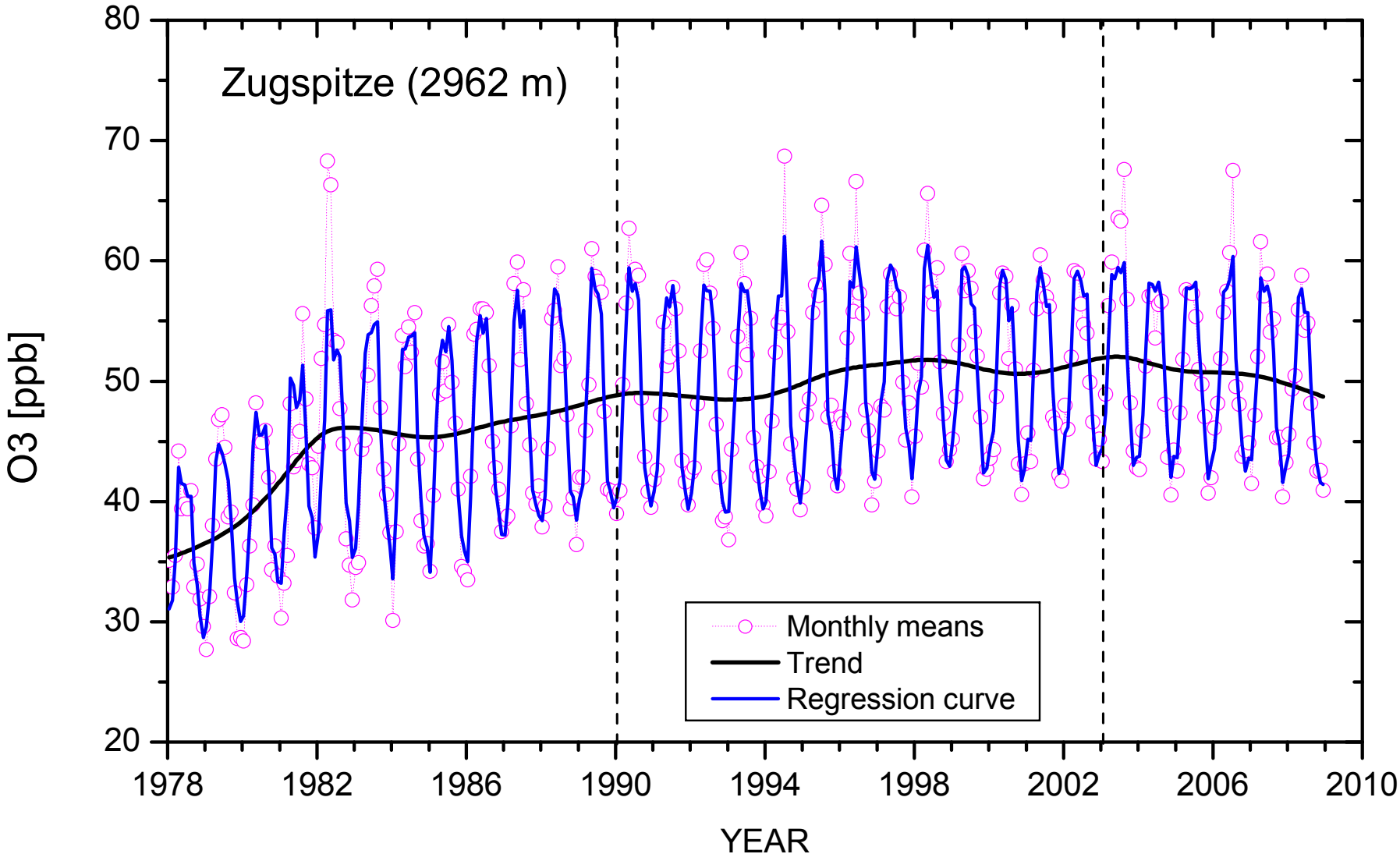
Focus on differences between earlier and more recent parts of the time series

Overview on the O_3 data structure at Zugspitze (half-hourly mean values, 1996 - 2000).

By short-term variations a range of about 110 ppb is covered.



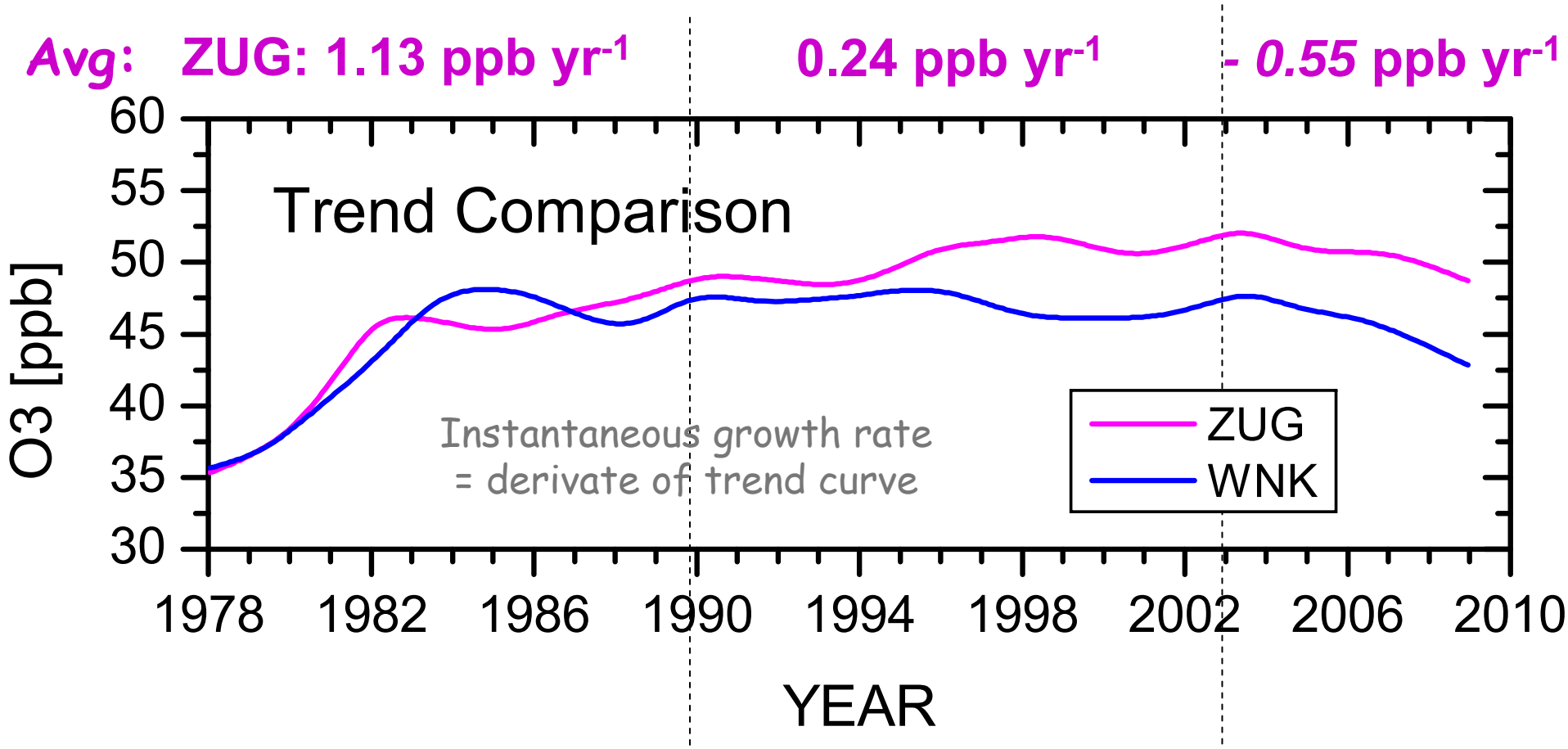
O_3 monthly mean values (1978 – 2008) together with regression curve and long-term trend component



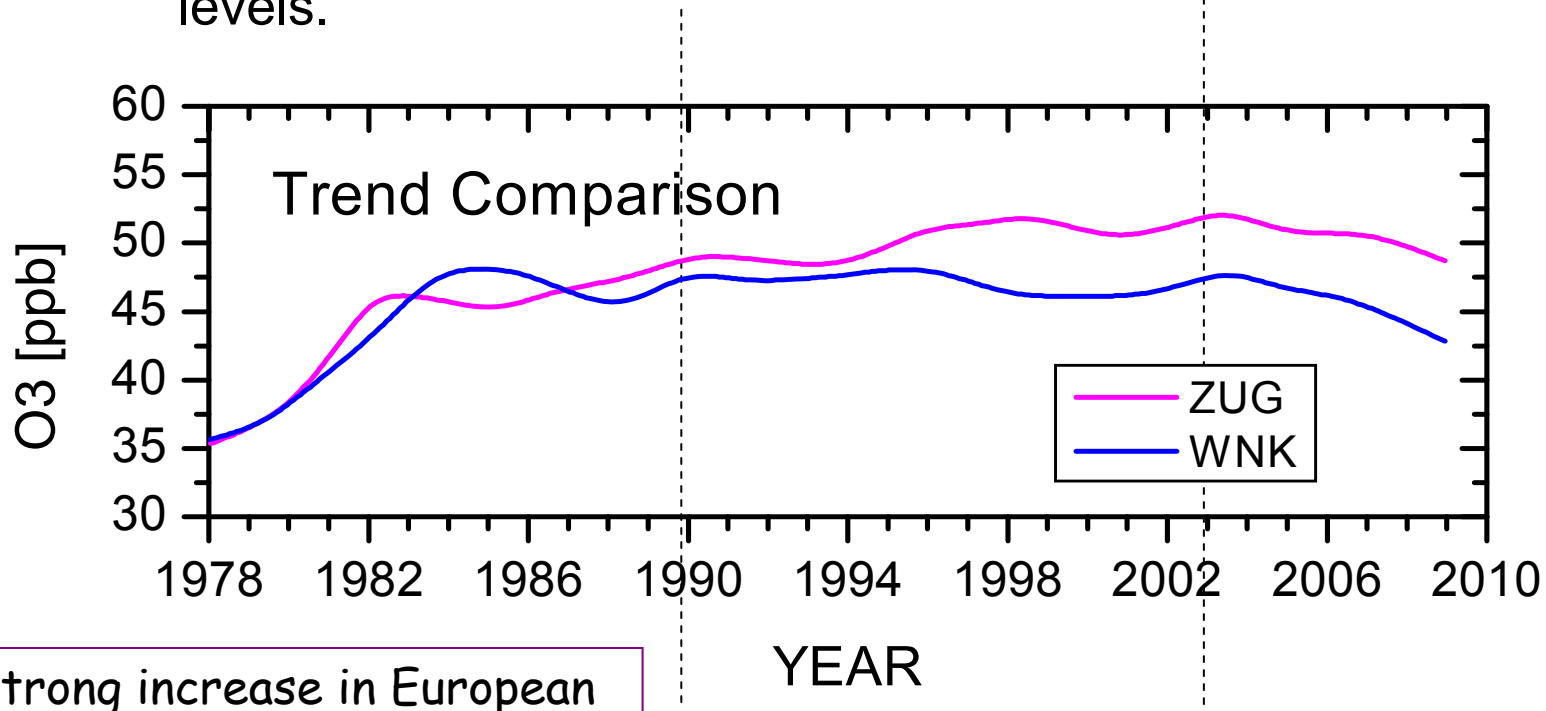
Part 1: 1978 - 1989 **Part 2: 1990 - 2002** **Part 3: 2003 - 2008**

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.



Results of modelling and emission inventories in the literature indicate relationships between NO_x emission trends (increases / reductions) and surface ozone levels.

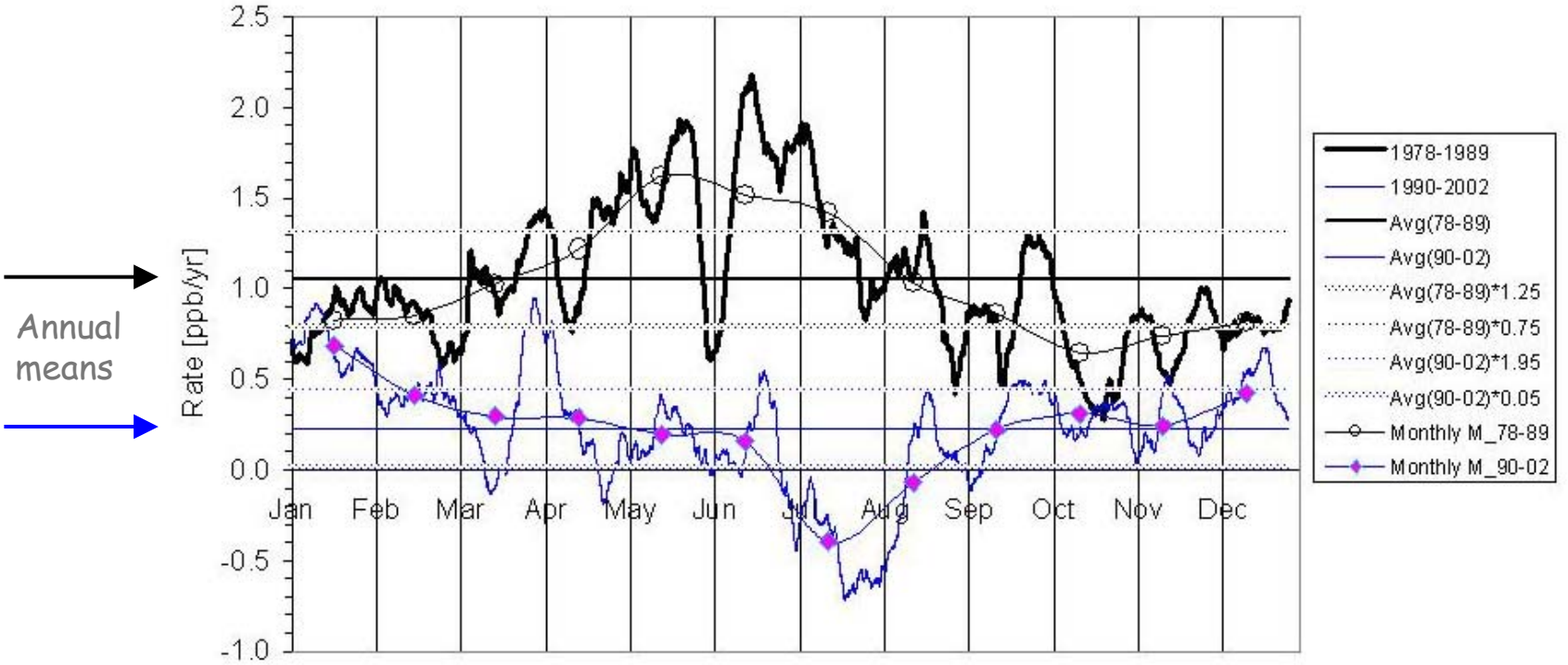


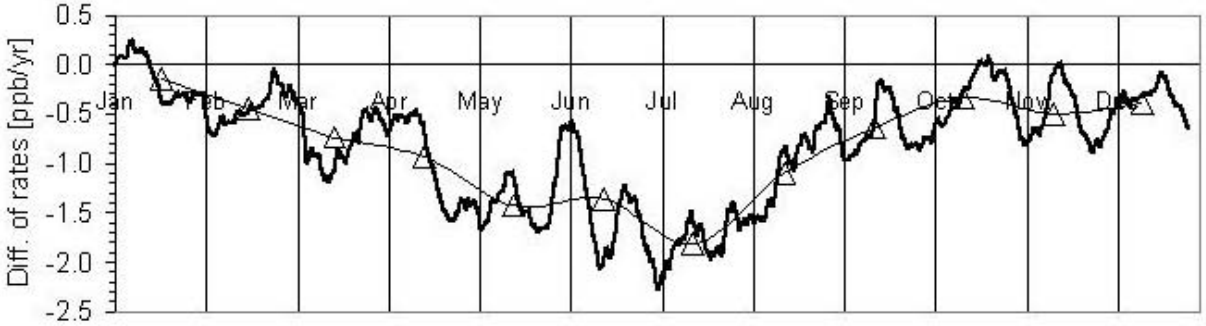
Strong increase in European NOx emissions between 1950 and 1980.

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.

Average O_3 growth rates [ppb yr^{-1}] at 11-day temporal resolution: **1978 - 1989** (without 1982) and **1990 – 2002**, & monthly means





Difference of growth rates, i.e. rate (1990-2002) minus rate (1978-1989).

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

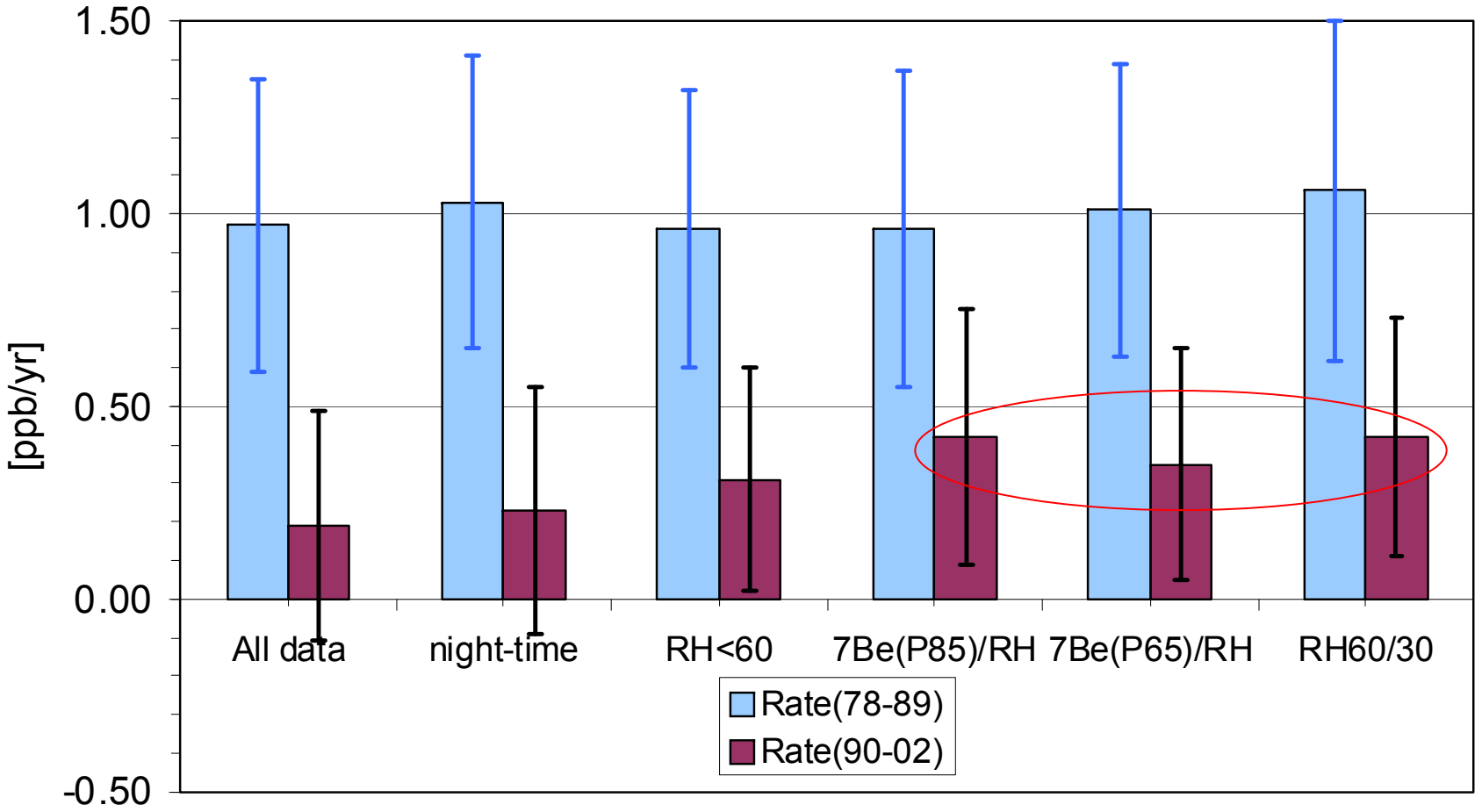
(4) Polluted air: CO > 30-day running median of CO

Growth Rates for Different Atmospheric Conditions

Calculated from the slope of linear regression on selected data sets

Growth rate comparison: 1978-1989 and 1990-2002

Zugspitze: Ozone growth rates [ppb/yr] from linear regression on monthly means with 95%-confidence limits. Periods 1978-1989 & 1990-2002



1978-1989: Similar rates for different conditions

1990-2002: Highest rates for air from lower stratosphere/ upper troposphere

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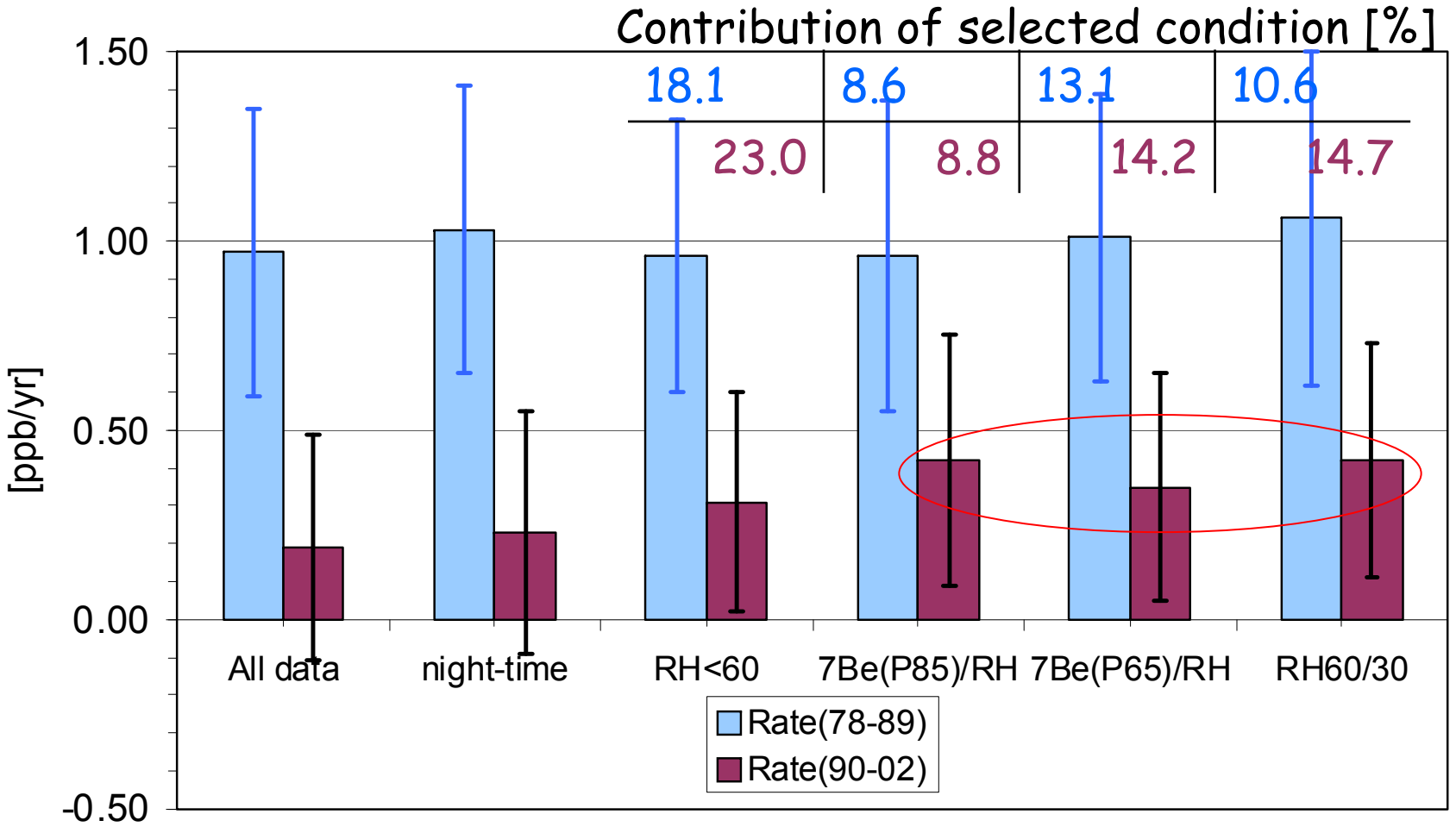

1978-1989: Similar rates for different conditions

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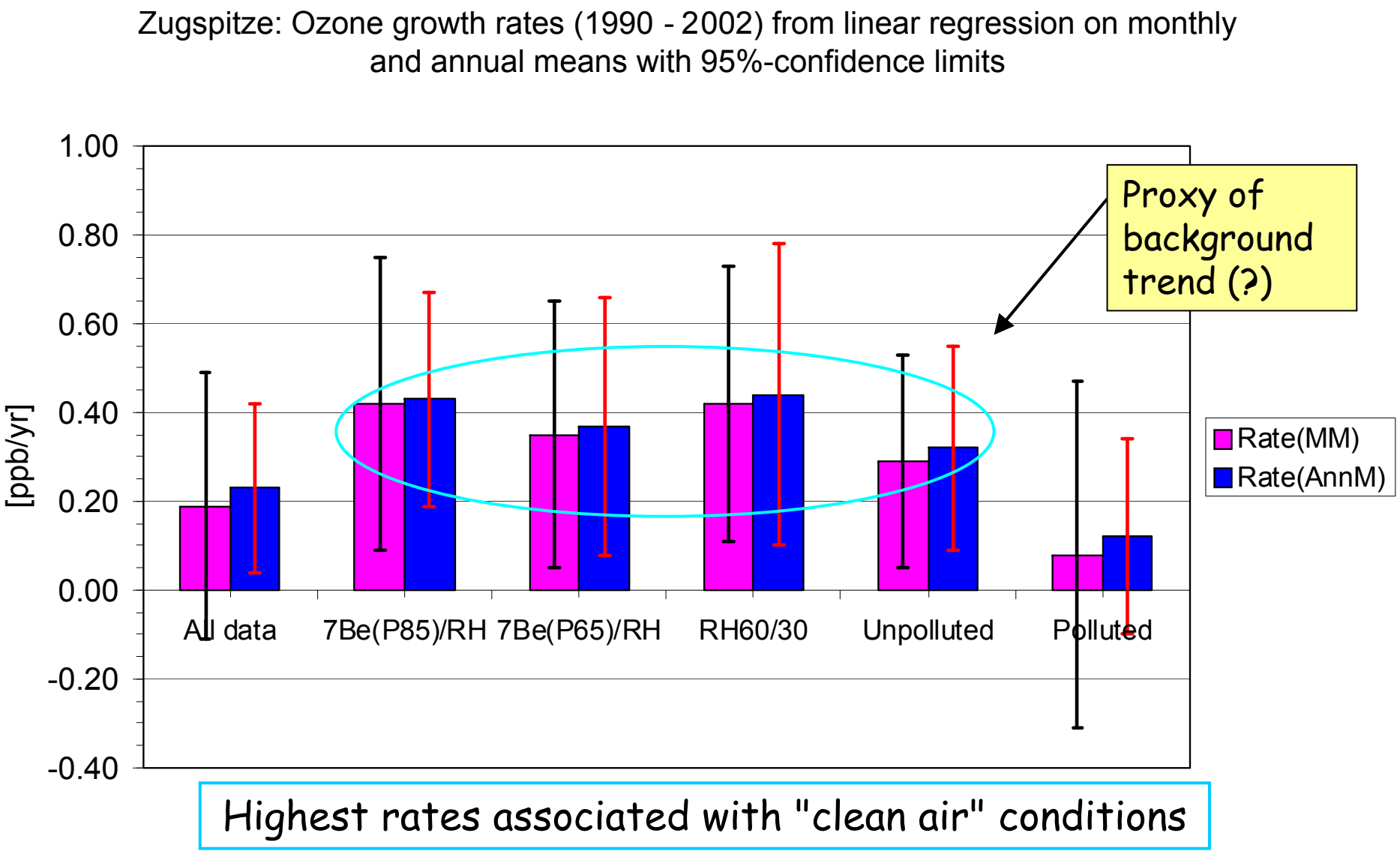
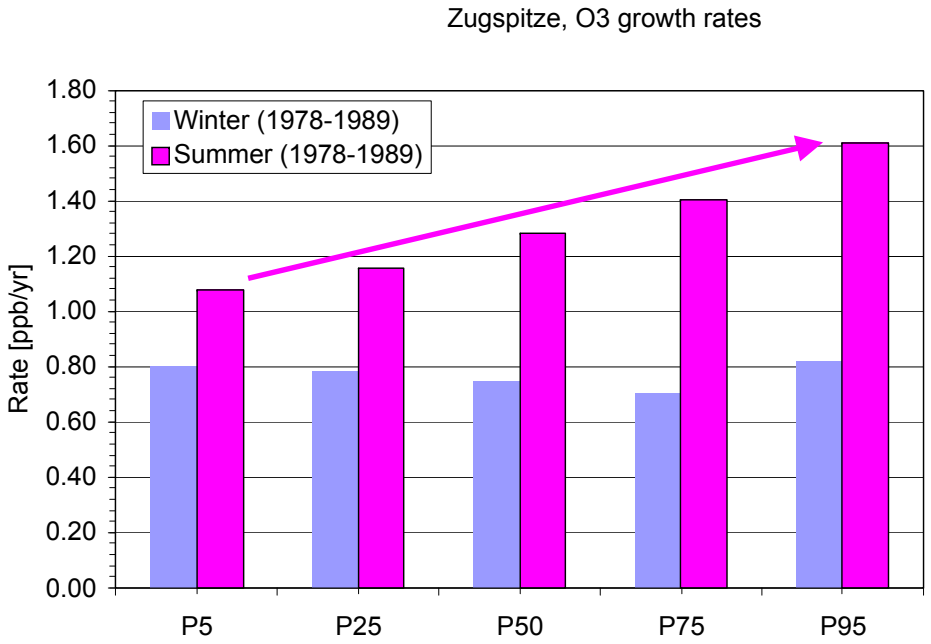
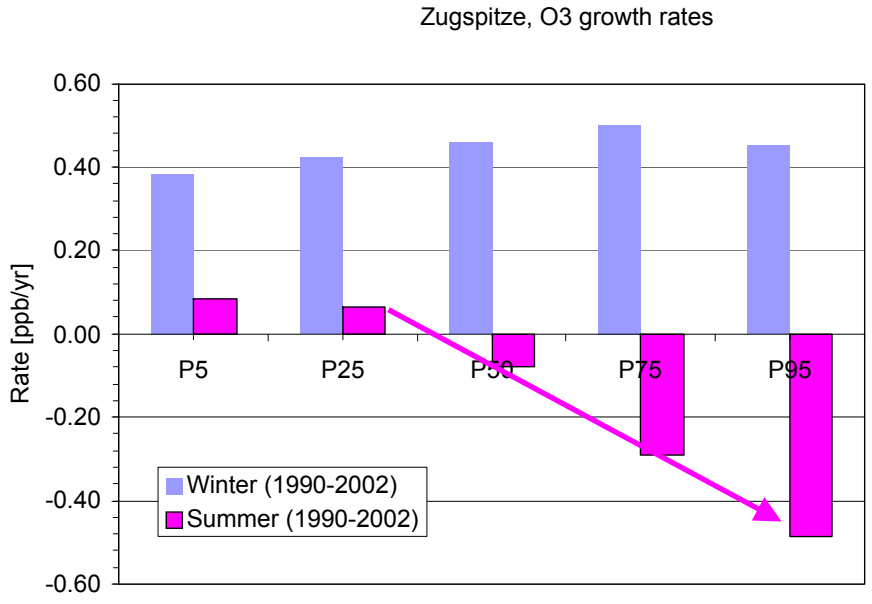
Comparison of growth rate calculations (1990-2002): Monthly means & Annual means



A different view on the ozone trend

Growth rates from seasonal percentiles: 5th, 25th, 50th, 75th, 95th
1978-1989 & 1990-2002
Winter = Dec, Jan, Feb; Summer = Jun, Jul, Aug





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

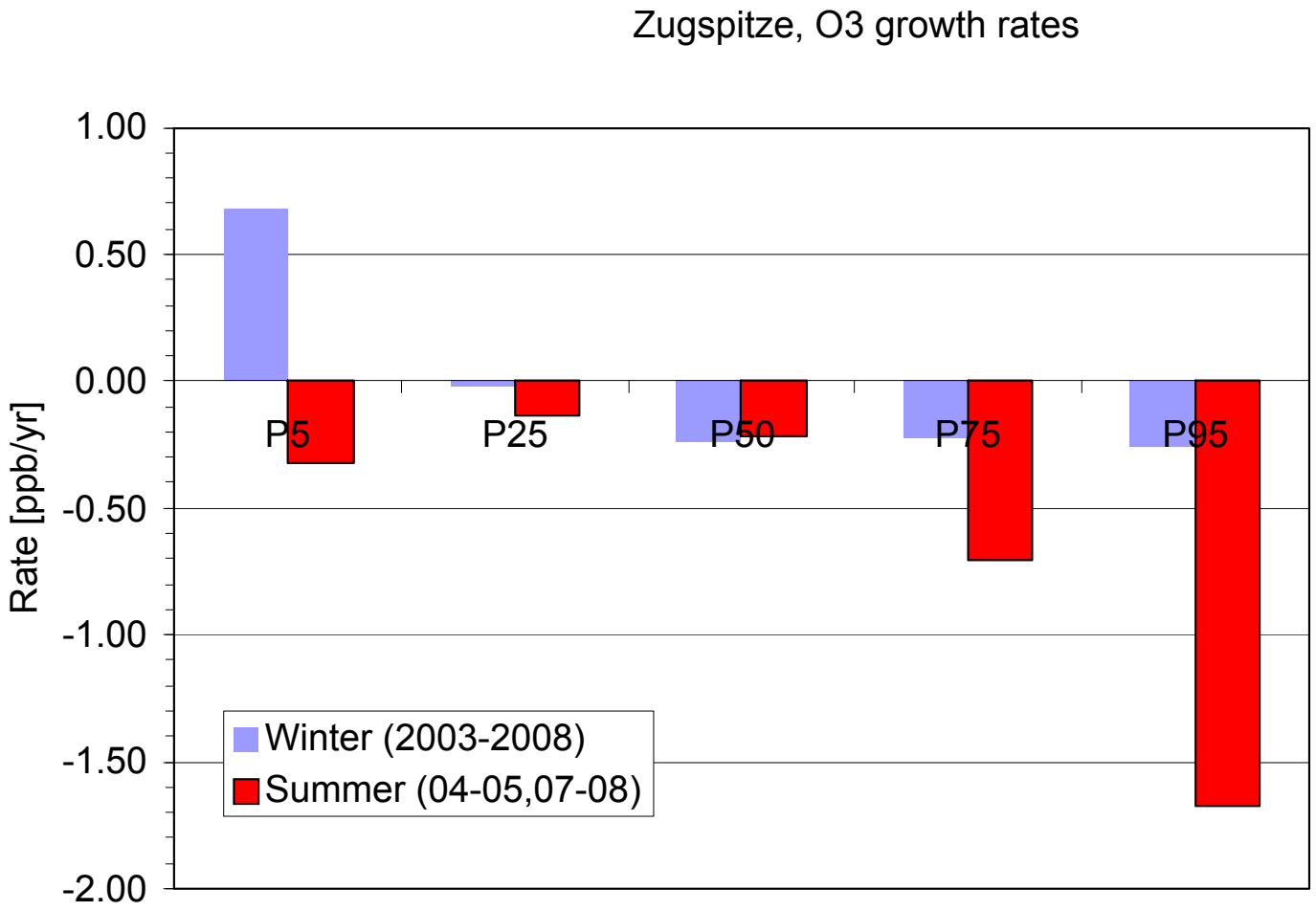
1990 – 2002: Strongest O_3 decrease associated with highest summer-time concentrations

The most recent development – from 6 years only

Growth rates from seasonal percentiles

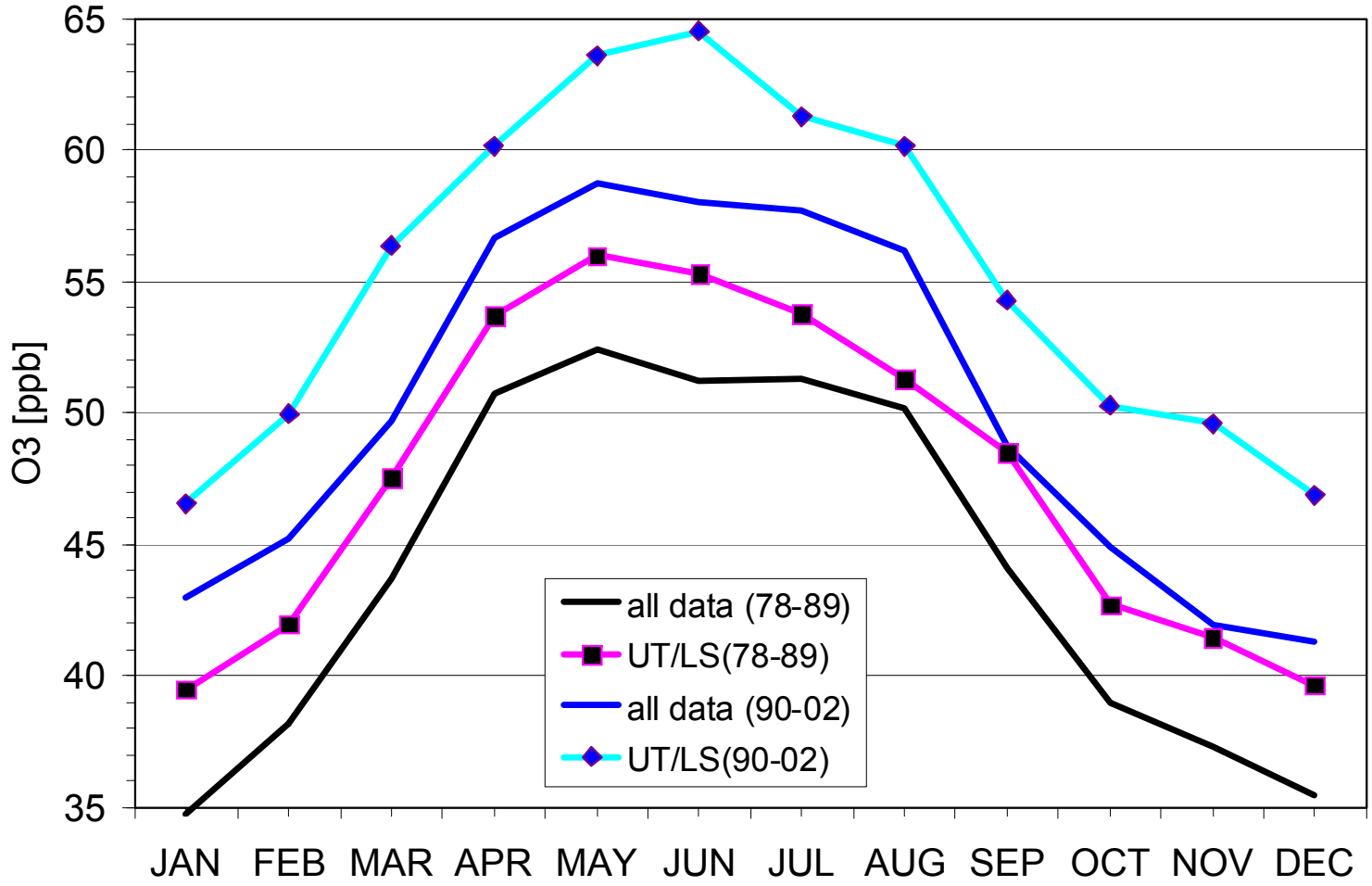
2003-2008: Winter = Dec, Jan, Feb;

2004-2005 & 2007-2008: Summer = Jun, Jul, Aug

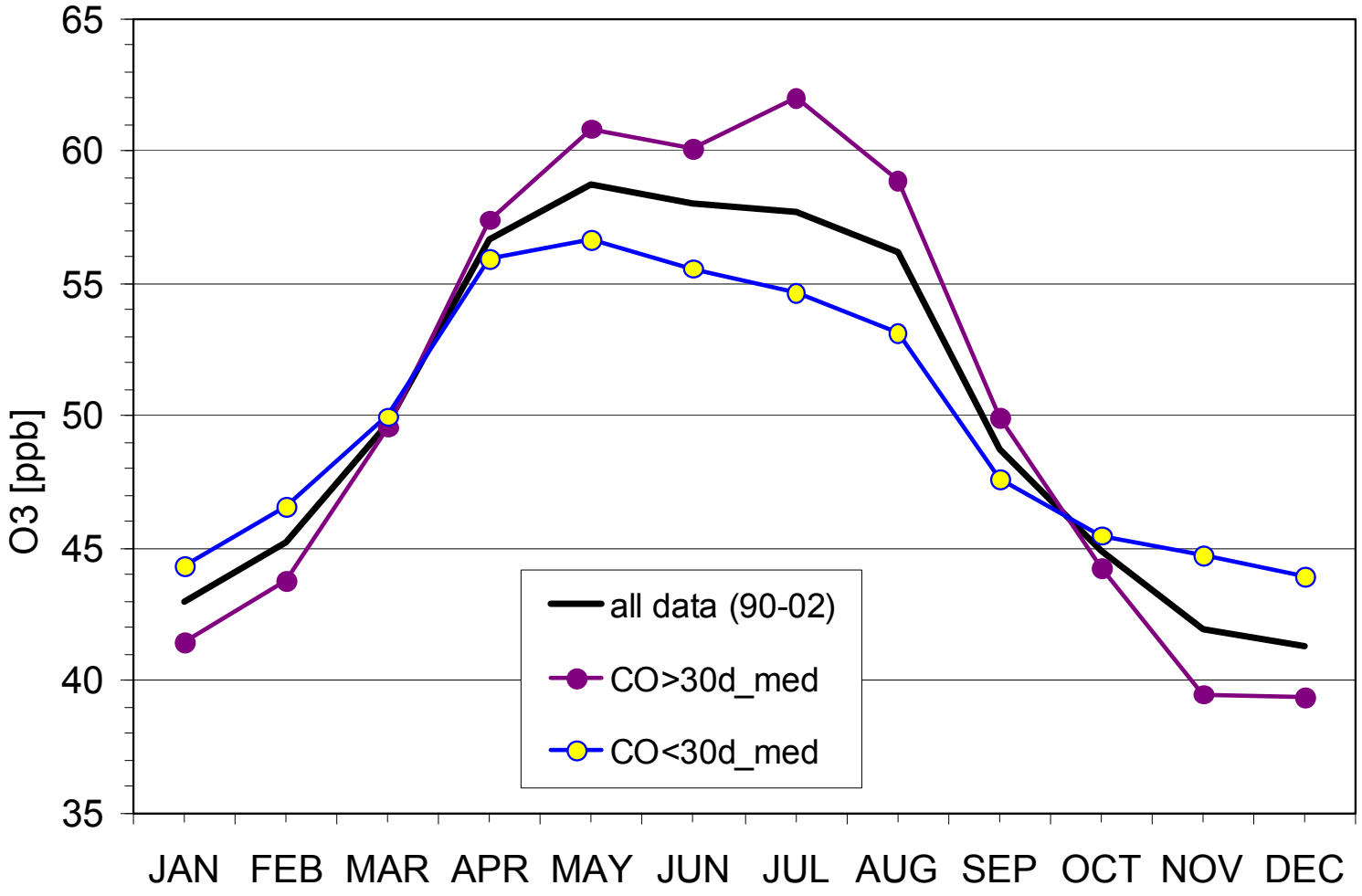


Seasonal Variations from Different Data Sets

Average seasonal variations:
All data **1978 – 1989**, **1990 – 2002**
and with UT/LS data filtering applied



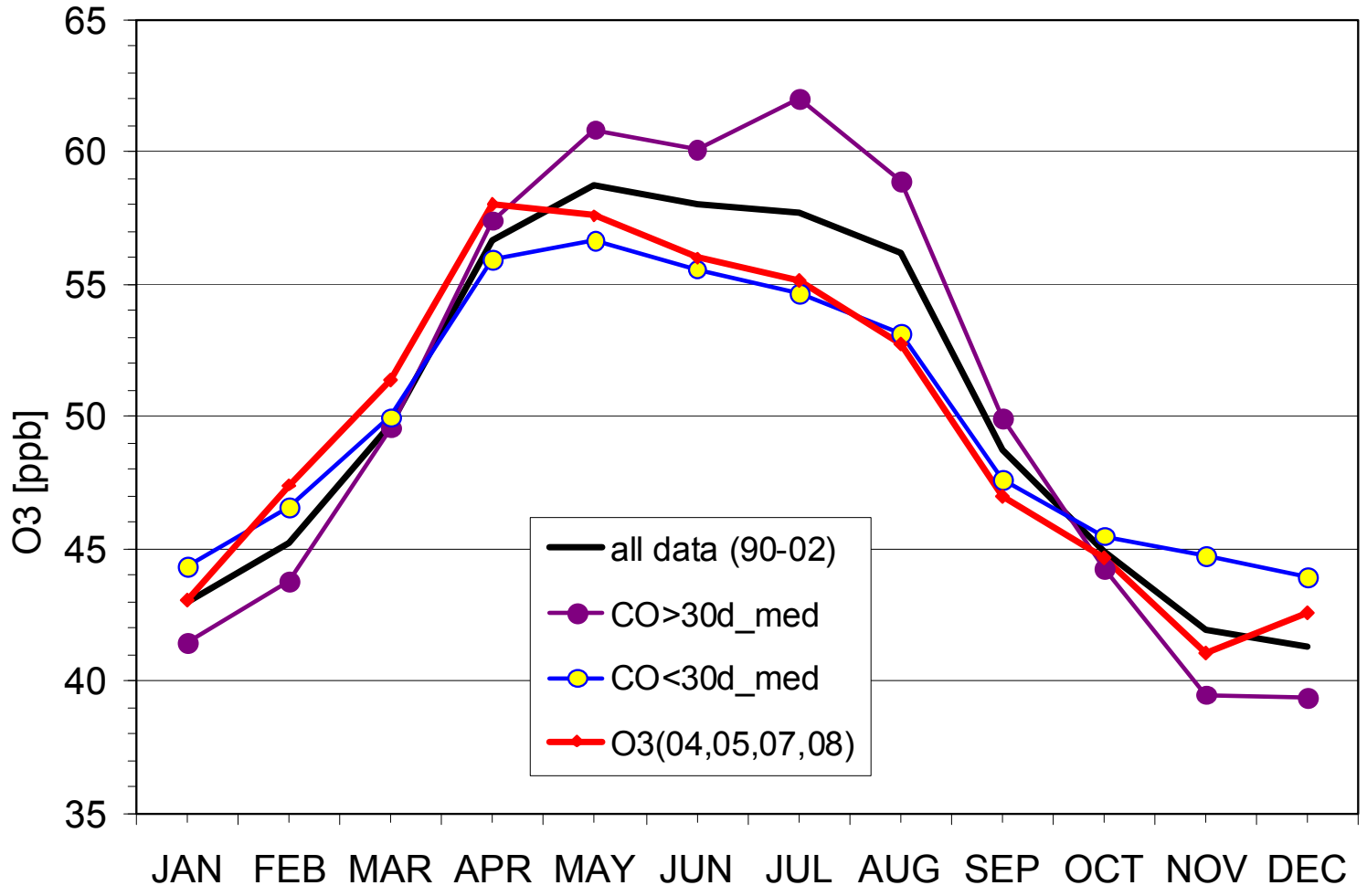
Average seasonal variations:
All data 1990 – 2002, "unpolluted", "polluted"



Average seasonal variations:

all data 1990 – 2002, "unpolluted", "polluted"

all data 2004-2005, 2007-2008



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) → 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

- The time series displays 3 different regimes:
1978 – 1989, 1990 – 2002, 2003 – 2008 with different seasonal dependence of growth rates

- 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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technical support and data processing,
measurements of ^{7}Be,
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discussions,
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From mid-1998 until March 2002 the in-situ ozone instrumentation at the Zugspitze summit was operated by the German Environment Agency (UBA).