Comparison of tropospheric ozone trends from European mountain stations

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History of tropospheric ozone

Tropospheric ozone is a powerful oxidant, harmful for people and animals, and causing damages of agricultural plants and crops. Moreover it is a greenhouse gas. Ozone monitoring over long time periods is important to understand the ozone evolution. Continuous data sets from surface sites are among the most valuable sources to evaluate ozone tropospheric trends. Ozone measured at European mountain sites during the period 1870 - 2004 has increased from ~10 ppb to ~ 50 ppb (Marenco et al., 1994; Chevalier et al., 2007).

Previous studies include Gilge et al., 2010 who compared ozone trends among the highest European mountain stations for the period 1995 – 2007 and related these to changes in CO and NO_2 precursor concentrations. Cui et al., 2011 concentrated on the highest European site Jungfraujoch (1990-2008). Chevalier et al., 2007 documented that 1000-1200 m altitude is a transition level between boundary layer and free-tropospheric ozone. Below that level ozone is increasing faster and has higher variability than above. Tarasova et al., 2009 analyzed and compared ozone trends for Jungfraujoch and Kislovodsk (mountain in Caucasus) for the period 1990-2006.

Motivation

- How similar are ozone records from different sites in one region?
- How representative are ozone concentrations from one site for the Alpine/European region?
- Find robust criteria for model evaluation in ozone time series

This study focuses on mountain sites in Europe, because:

- Moderate to low pollution levels
- Relatively coherent variability because of small influence from local sources and transport from the boundary layer
- Several stations available within a few hundred kilometer radius

Sites characteristics

- High mountain sites - Alps and Pyrenees
- Low mountains – all over Europe
- Altitude range: 572 m – 3580 m
- Max. available period: 1978 - 2009

Site	Abbreviation	Altitude	Country	Organisation	Available data
Jungfraujoch	JFJ	3580 m	Switzerland	WDCGG	1986-2009
Sonnblick	SNB	3105 m	Austria	WDCGG	1990-2009
Zugspitze	ZUG	2962 m	Germany	H.E. Scheel	1978-2009
Monte Cimone	Mon.Cim	2165 m	Italy	WDCGG	1996-2009
Monte Gaza	Mon.Gaz	1601 m	Italy	Airbase	1998-2009
Puy de Dôme	PDD	1465 m	France	PAES	1995-2009
Iraty	Irat	1300 m	France	EMEP	1999-2008
Masenberg	Masen	1170 m	Austria	EMEP	1992-2009
Chaumont	Chaum	1137 m	Switzerland	EMEP	1992-2009
Schmücke	Schmuck	937 m	Germany	EMEP	1991-2009
Donon	Donon	775 m	France	EMEP	1995-2009
Morvan	Morv	620 m	France	EMEP	1999-2009
Simmerath	Simm	572 m	Germany	UBA	1990-2009

1990-2009 (JFJ, SNB, ZUG); 2000-2009 (all stations)

Decadal trends

JFJ, SNB and ZUG show consistent behaviour of their time series. Ozone trends are slightly positive for 1990 - 2009, though significant only for JFJ. Growth rates of annual percentiles show that winter ozone trends are stronger than summer ones.

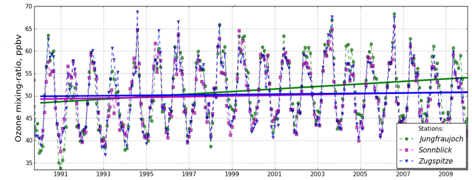
1990-2009

	Slope, ppb/year	Intercept, ppb	Sign.
JFJ	0.283	48.42	+
SNB	0.080	49.26	-
ZUG	0.044	49.88	-

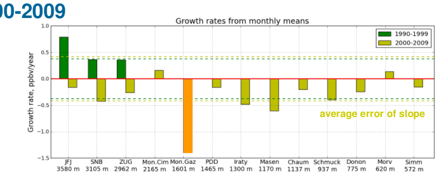
1990-1999 and 2000-2009

	Slope, ppb/year		Significance	
	1990-1999	2000-2009	1990-1999	2000-2009
JFJ	0.794	-0.164	+	-
SNB	0.364	-0.425	-	+
ZUG	0.358	-0.263	-	-

JFJ, SNB and ZUG, 1990-2009

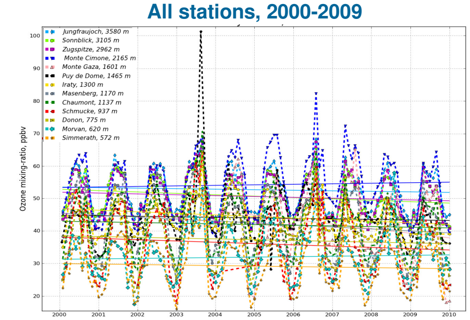


2000-2009



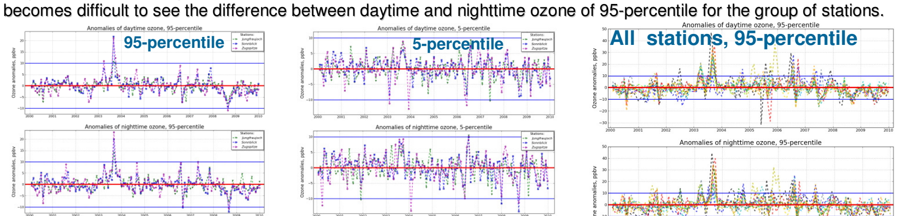
For the period 2000-2009 ozone trends are slightly negative for most of the stations. Only few stations show significant trends. Trends from some individual stations differ more than the average error of the slope. Therefore trend from one arbitrary station cannot be considered representative for the Central European region, but the group of stations appears to yield a robust trend estimate.

All stations, 2000-2009

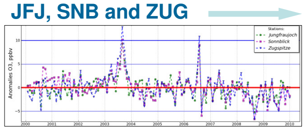


Anomalies of percentiles and monthly means, 2000-2009

95-percentiles of the nighttime data exhibit the most consistent behavior. It is clear for the JFJ, SNB and ZUG, but becomes difficult to see the difference between daytime and nighttime ozone of 95-percentile for the group of stations.



JFJ, SNB and ZUG

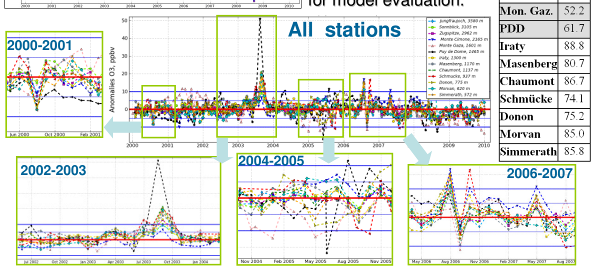


Ozone monthly mean anomalies are very consistent. Differences are between ±5 ppb, which can be a criterion for model evaluation.

Data inside (-5, +5) ppb

Station	P, %
JFJ	95.8
SNB	95.0
ZUG	94.2
Mon. Cim.	82.3
Mon. Gaz.	52.2
PDD	61.7
Iraty	88.8
Masenberg	80.7
Chaumont	86.7
Schmücke	74.1
Donon	75.2
Morvan	85.0
Simmerath	85.8

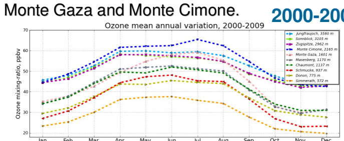
All stations



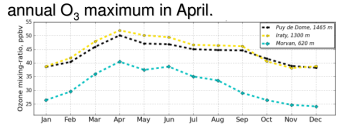
Mean annual variation

JFJ, SNB, ZUG: seasonal amplitudes ~ 15 ppb. Highest seasonal amplitudes ~ 20-25 ppb for Monte Gaza and Monte Cimone.

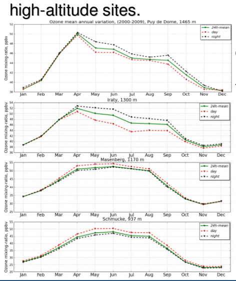
2000-2009



Western sites: Iraty, PDD and Morvan show annual O_3 maximum in April.



Nighttime ozone exceeds daytime ozone for high-altitude sites.



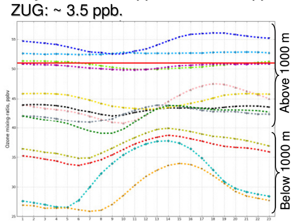
Below 1300 m (Iraty) : daytime ozone is higher than night-time ozone

Day-night amplitudes in July:

JFJ: ~ 1.5 ppb
SNB: ~ 4.3 ppb
ZUG: ~ 3.3 ppb
Mon.Cim. : ~3.3 ppb
Mon.Gaz.: ~ 4.2 ppb
PDD: ~ 1.2 ppb
Iraty: ~ 5.3 ppb

Daily variation

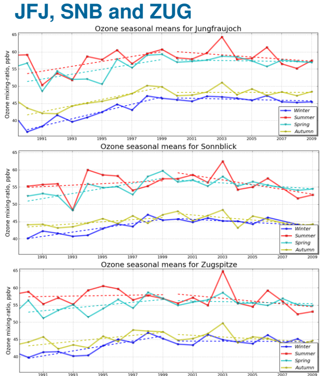
High mountain stations show daytime minimum in summer. The diurnal variability is: JFJ: ~1.5 ppb, SNB: ~ 4.5 ppb, ZUG: ~ 3.5 ppb.



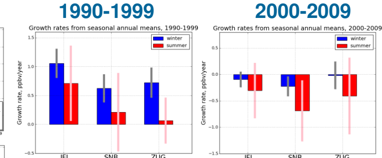
Diurnal ozone cycles vary considerably among all the stations.

Seasonal trends

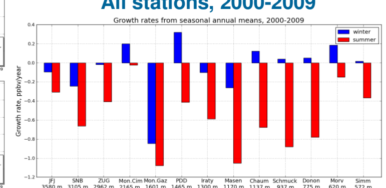
JFJ, SNB and ZUG



1990-1999 **2000-2009**



All stations, 2000-2009



JFJ, SNB and ZUG exhibit consistent behavior of seasonal trends for both periods: 1990 - 1999 and 2000 - 2009. They show common features of elevated (2003, 2006) and reduced (1991, 1993, 1997) summertime averages and lower interannual variability in winter ozone concentrations. Winter ozone trends are much stronger than summer trends for the period 1990 - 1999. For 2000 - 2009 at most of the stations the negative trends of monthly mean ozone concentrations are mostly driven by reductions in summertime ozone.

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