Site Characteristics
Zugspitze summit (ZUG): 47° N, 11° E at the northern rim of the Alps, 2962 m asl.
Time zone UT+1.

THE TIME SERIES OF CARBON MONOXIDE AT ZUGSPITZE (2962 m) FROM 1990 TO 2008

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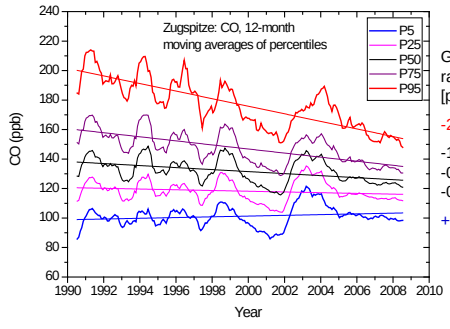
Technical
Different types of instruments have been employed over the years, comprising gas chromatography with HgO reduction detector (Trace Analytical RGD2) and non-dispersive infrared absorption instruments with and without gas filter correlation technique (TEI 48S and Horiba APMA-360, respectively). Usually two instruments were operated in parallel. Since 2004, a vacuum UV fluorescence CO analyzer (Aero Laser AL5001) is serving as the primary instrument. The CO calibration was intercompared within a number of international round-robin experiments.

Goals of the Measurements
Long-term trend and seasonal variations of CO concentrations in the lower troposphere.
Case studies with respect to transport and short-term changes of air mass composition.
Supporting information for the interpretation of in-situ ozone variations (data filtering).

Database and Data Processing
Input data: 1/2-hourly, monthly and annual means
Selected data sets: Monthly percentiles from 5th to 95th (P5, P25, P50, P75, P95); day-time (09-17), night-time (00-05 h), stratospherically influenced.
Two data filters for stratospheric influence:
(1) Combination of ^{7}Be (tracer, data only till 2004) and relative humidity (Be7/RH): *"RH < 60 % AND ^{7}Be > 85th percentile of the annual data set".*
(2) Combination of two RH criteria (RH60/30): *"RH < 60 % AND RH running minimum over 12 hours < 30 %".*

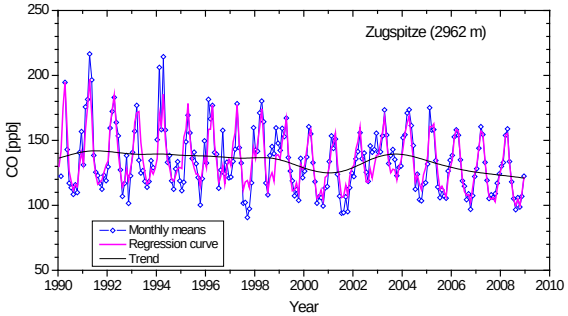
Trend Estimates from Selected Data

12-month moving averages of monthly data and linear fit



Trend comparisons among percentiles: High CO levels as represented by the 95th percentiles (P95) show the strongest decrease (-2.57 ppb yr-1). The 5th percentiles (P5) yield a positive trend of 0.25 ppb yr-1.

Time Series Overview

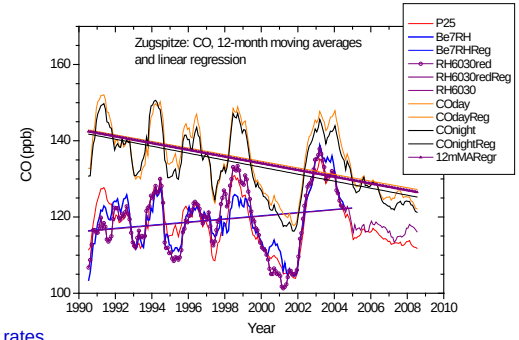


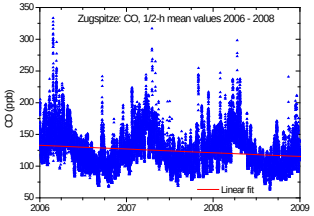
Time Series Overview
Remarkable variations on time scales from hours to years, traceable to processes such as meteorological variability and periods of enhanced northern hemispheric biomass burning. Annual average CO mole fractions (1990 – 2008) between 120 and 148 ppb.
Trend curve shows statistically significant decrease. Average rate −0.84 ppb yr-1 (lin. regr. on monthly means: −0.94 ppb yr-1 , annual means: −0.85 ppb yr-1).
Seasonal component of regression curve indicates a decrease of the peak-to-peak amplitudes. Decrease of high-CO episodes is reflecting reductions of European CO emissions.

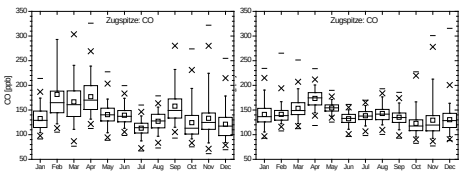
Seasonal Variations
Average seasonal variations with an April maximum and a broad minimum extending from July to October. Peak-to-peak amplitude of 56 ppb (average CO = 134 ppb). Higher p-t-p amplitude of 72 ppb for the period 1991–1994.
Data fulfilling the RH60/30 criterion show average p-t-p amplitude of 42 ppb (average CO = 119 ppb), with monthly differences to the all-data cycle ranging from 11 to 27 ppb.

Trend Estimates from Selected Data
Specific percentiles (95th, 75th, 25th, 5th) reveal strongest CO decrease of the higher CO concentrations. Low-end CO levels (clean air, episodes of subsidence) display no trend or a small positive trend.
Comparisons among selected data sets point to the 25th percentile (of all data) as a proxy for the CO level influenced by upper tropospheric/lower stratospheric air masses.
Differences in magnitude and sign of CO trends from specific subsets of the data are indicative of different developments of the CO concentrations on regional, continental, and hemispheric scales.

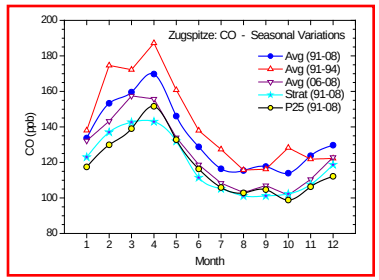
12-month moving averages of monthly data and linear fit



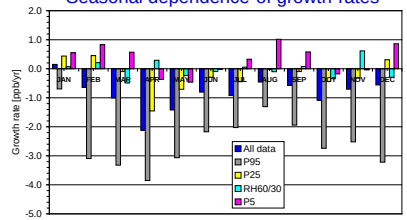




Box and Whisker plots of CO in **1996** and **2003** indicate a change in the monthly concentration distribution. The size of the 25th/75th percentile boxes gives evidence of a reduction of the higher CO concentrations during winter and spring.



Seasonal dependence of growth rates



Upper traces: Day-time (09-17) and night-time (00:05) data together with linear fit and fit of all-data case. Comparable CO decrease [ppb yr-1] for night-time (-0.92), "all data" (-0.88) and day-time (-0.87).

Lower traces: Data filters Be7/RH and RH60/30 yield comparable CO levels (1990-2004), nearly equal trends, and coincidence with 25th percentile CO. Overall mean mole fractions = 119 ppb for all three data sets.

Acknowledgements: Thanks are due to all colleagues involved in the maintenance of instrumentation, calibrations, and data processing over the years. From mid-1998 until March 2002 the trace gas instrumentation at the Zugspitze summit was operated by the German Environment Agency (UBA).

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