Total ozone and Umkehr observations at Hoher Sonnblick 1994–2011:
Climatology and extreme events

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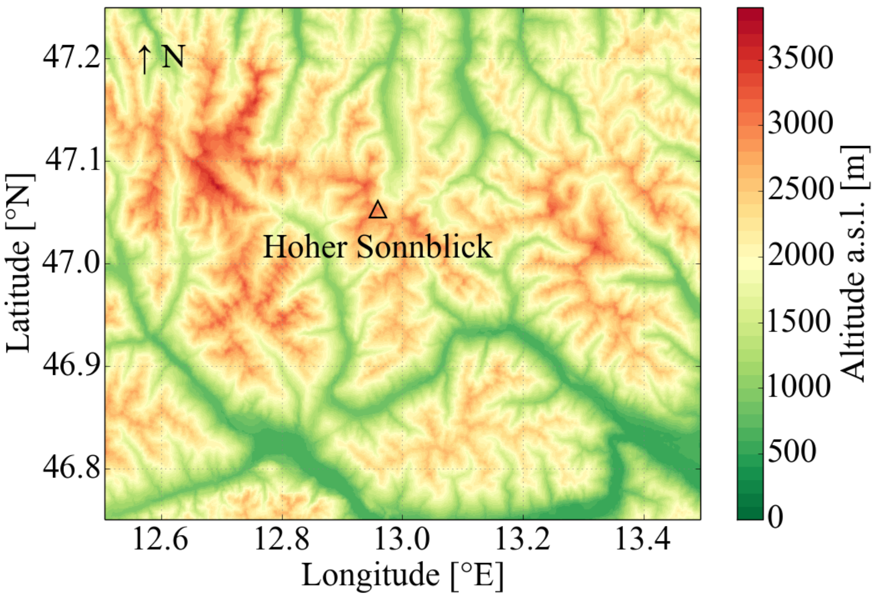
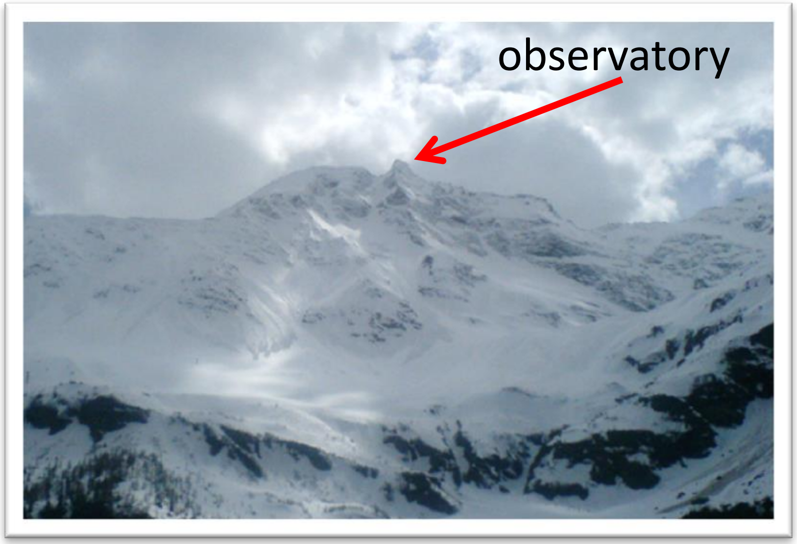
Measurement site and instrumentation





Sonnblick observatory (3106 m)

- elevated altitude
- complex topography
- influence of albedo
    - clouds below the station

- reduced influence of aerosols and pollutants
- monitoring under (relatively) undisturbed conditions, representativ for long-term evolution of stratospheric ozone and solar UV radiation

Measurement site and instrumentation

BREWER MkIV #093 Spectrophotometer

- global spectral UV irradiance (290-325 nm)
- total ozone column
- Umkehr observations
- Aerosol optical depth

- continued measurements since 1994

- regular NIST and PTB traceable calibration

BENTHAM DM150 Spectroradiometer

- global spectral UV irradiance (290-500 nm, 0.5 nm steps)
- increased accuracy (double-monochromator)

- continued observations since 1997

- NDACC affiliated instrument
- regular NIST and PTB traceable calibration

Trend analysis: considerations

- **Trend detection in time series of stratospheric ozone: caveats and pitfalls**

  – complex interaction of governing processes (yearly cycle, hemispheric circulation, …)

  → very high temporal and spatial variability

  → time series may exhibit strong auto-correlation [1]

  – gaps and outliers

  ➢ large portion of data records too short to resiliently estimate trends [1]

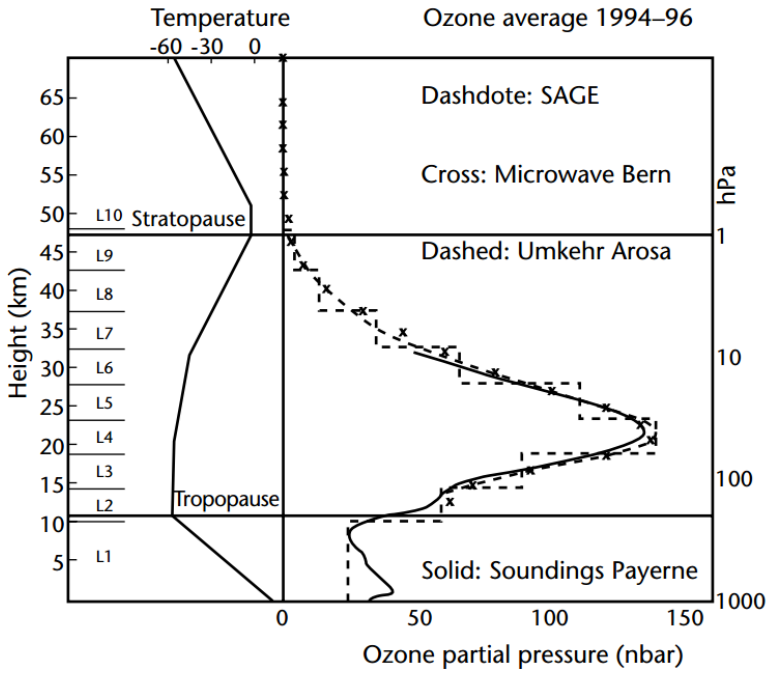
  ➢ statistically significant does not imply physically sound

[1] Weatherhead, E. C., et al. (1998). "Factors affecting the detection of trends: Statistical considerations and applications to environmental data." Journal of Geophysical Research **103**(D14): 17149.

Measuring stratospheric ozone

- **total ozone (TO_3) from direct sun observations**
  - wavelength pair in HARTLEY-HUGGINS-band (strong vs weak ozone absorption)
  - total ozone calculated from differential absorption

Figure: Staehlin et al., ETH Zürich



- **vertical structure of stratospheric ozone („Umkehr“ observations)**
  - observation of zenith radiance at large zenith angles
  - wavelength pair as with TO_3
  - vertical resolution $\Delta z \approx 5$ km (10 km above ground to TOA)

Trends in stratospheric ozone

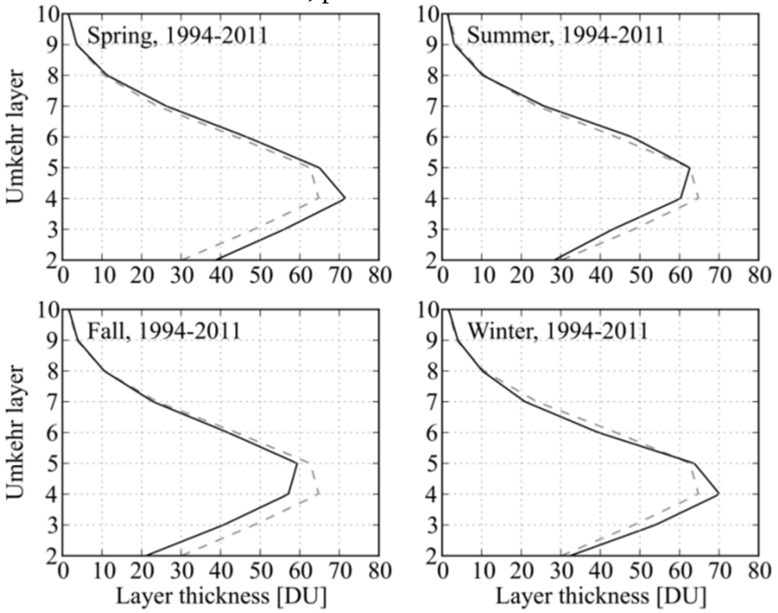
trend in monthly mean anomalies (MMAs)

- of total ozone
- of column depth in individual Umkehr layers

evolution in individual layers of the stratosphere

- allows to draw **conclusions** regarding different influencing parameters on stratospheric ozone
  - 11-year solar cycle
  - chemical ozone destruction
  - atmospheric circulation (NAO, QBO, TP, EP)

Figure: climatological Umkehr profiles at Sonnblick; per season



Results: Trends in stratospheric ozone

trends in upper stratosphere

- **strong influence of ODS** (Ozone Depleting Substances)
- clear signs of **recovery not observed**
- column thickness decreases slightly (not significant) or stagnates
- moderate seasonal variation

trends in lower stratosphere

- strong influence of **atmospheric dynamics**
- significant trends identified
- significant increases over the year
- strongest increases during late winter and spring

explanation

- major portion of stratospheric ozone found in middle and lower stratosphere
  → enhanced influence of atmospheric circulation
- extended dwell time of many ODS in the upper stratosphere

→ ***Impact of chemical ozone destruction***

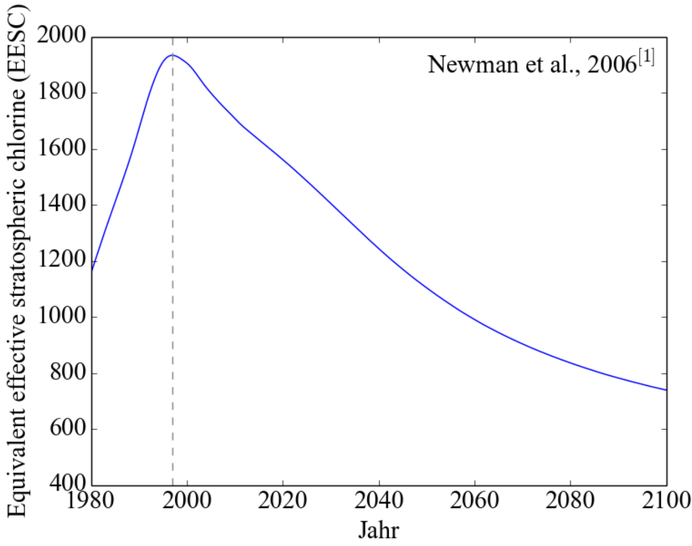
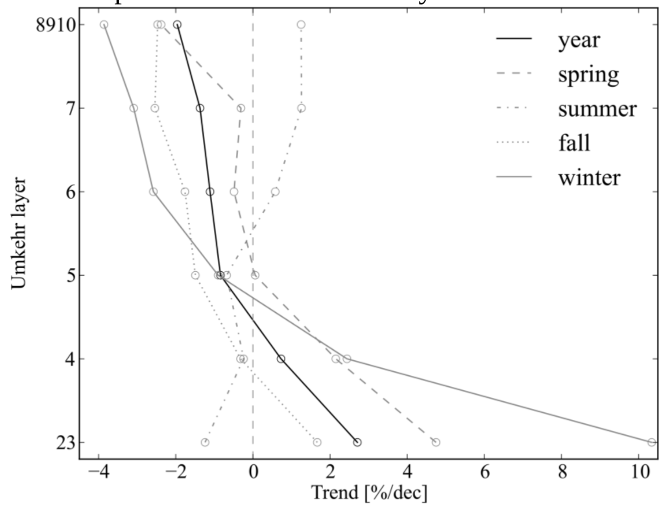


Figure: trends in stratospheric ozone, per season and Umkehr layer



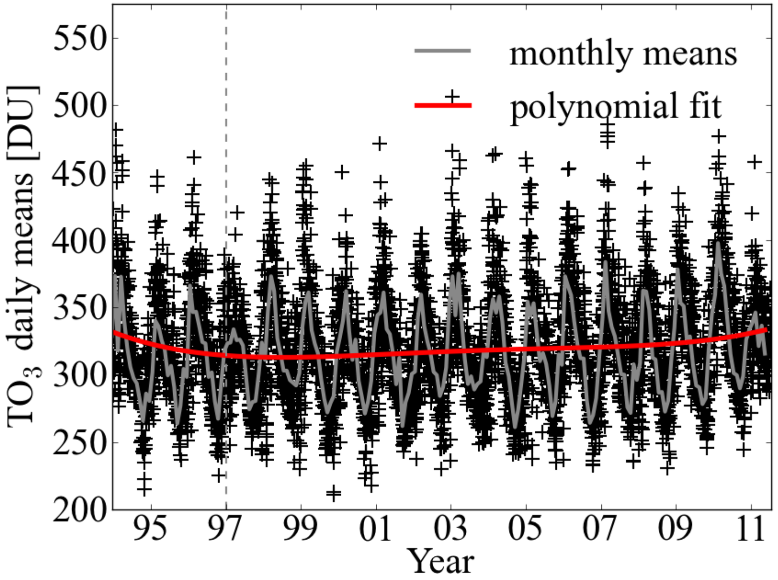
[1] Newman, P. A., E. R. Nash, S. R. Kawa, S. A. Montzka and S. M. Schauffler (2006). "When will the Antarctic ozone hole recover?" Geophys. Res. Let. **33**(12).

Results: Trends in stratospheric ozone

trends in total ozone (1994-2011)

- **strong dependency on chemical ozone destruction**
- significant increase of ≈2 % per decade over the year
- most significant increases during spring (+3.3 %/dec) and winter (+2.3 %/dec), attenuated during summer and fall
- trends enhanced for 1997-2011 → hints at turnaround in ca. 1997

Figure: daily and monthly means of total ozone at Hoher Sonnblick, 1994-2011



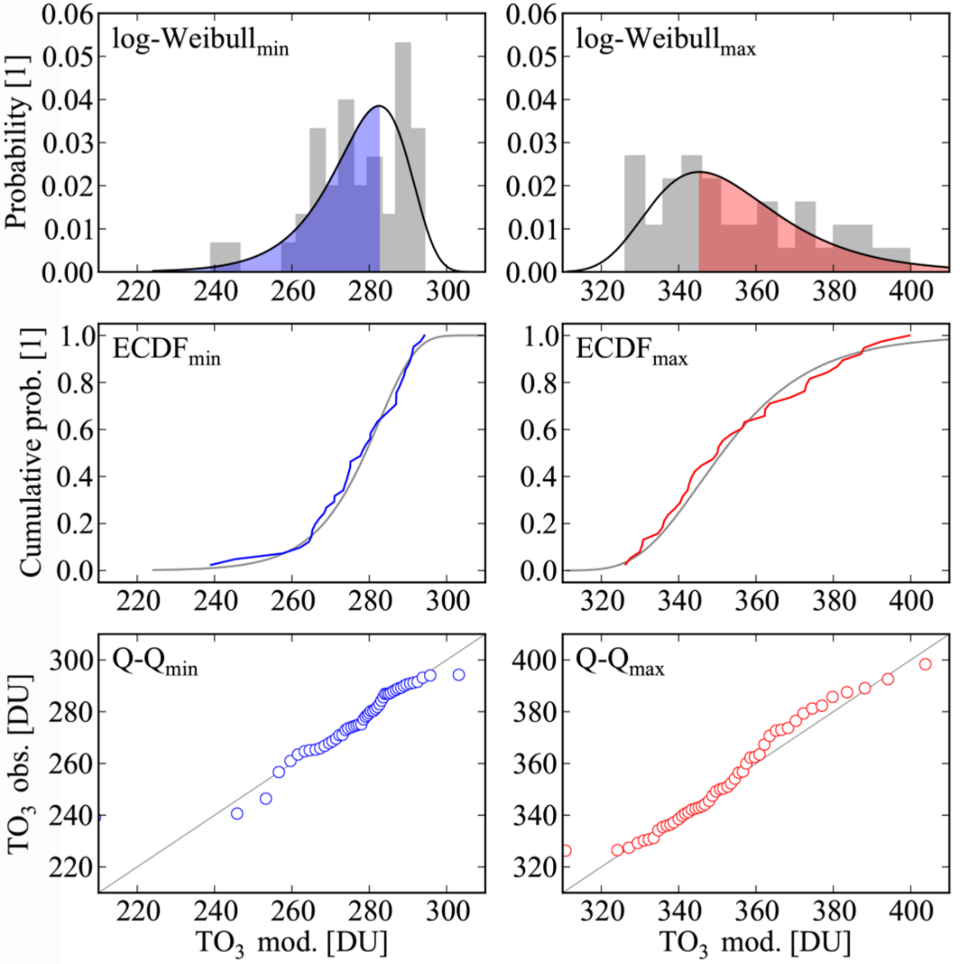
Extreme events in total ozone

- **Challenge: selection / designation of extreme values**
  - finding thresholds for extreme events by fitting extreme-value distributions to observations
  - Detrimental auto-correlation → ***De-Clustering procedure***
  - **de-seasonalization** considering known, non-linear influence parameters (season, 11-year solar cycle, Effective Equivalent Stratospheric Chlorine, …)

$$Y_{L_i}(t) = \mu + A \cdot sin(P \cdot t + \theta) + b \cdot t + \gamma \cdot F_{10.7} + \varepsilon \cdot EESC(t) + R(t)$$

→ ***statistical QA/QC***

Figure: fitting appropriate extreme-value distributions



Extreme events in total ozone

- Absolute frequency of **extreme events with high total ozone** increased

- Absolute frequency of **extreme events with low total ozone** decreased

- no perceivable changes in magnitudes of extreme events

→ ***TO_3 affected through change in number of extreme events***

Abbildung: Monatsmittelwerte des Gesamtozons am Hohen Sonnblick 1994-2011, hohe Extremereignisse in Rot, niedrige Ereignisse in blau

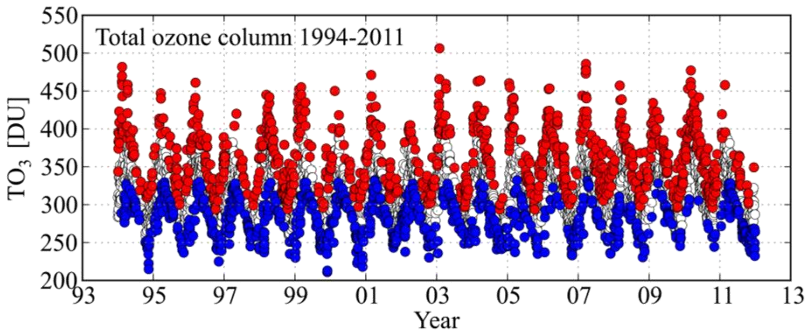
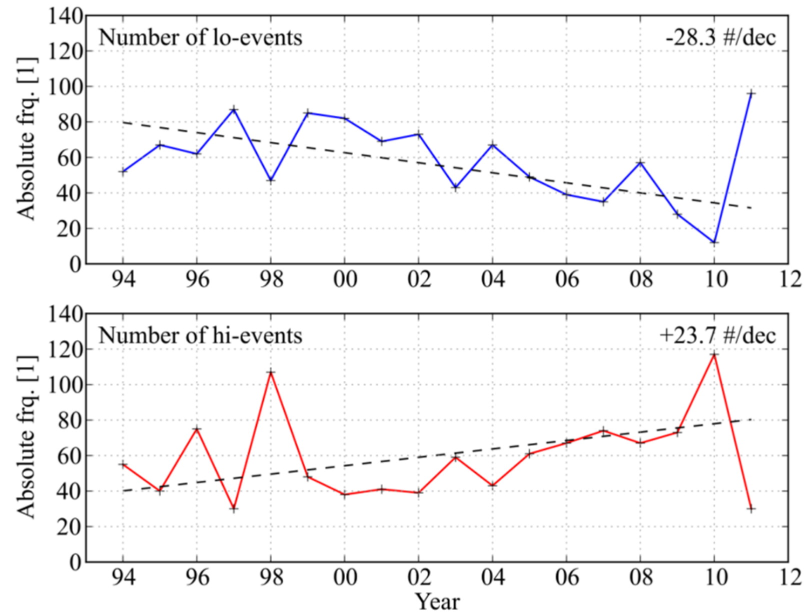
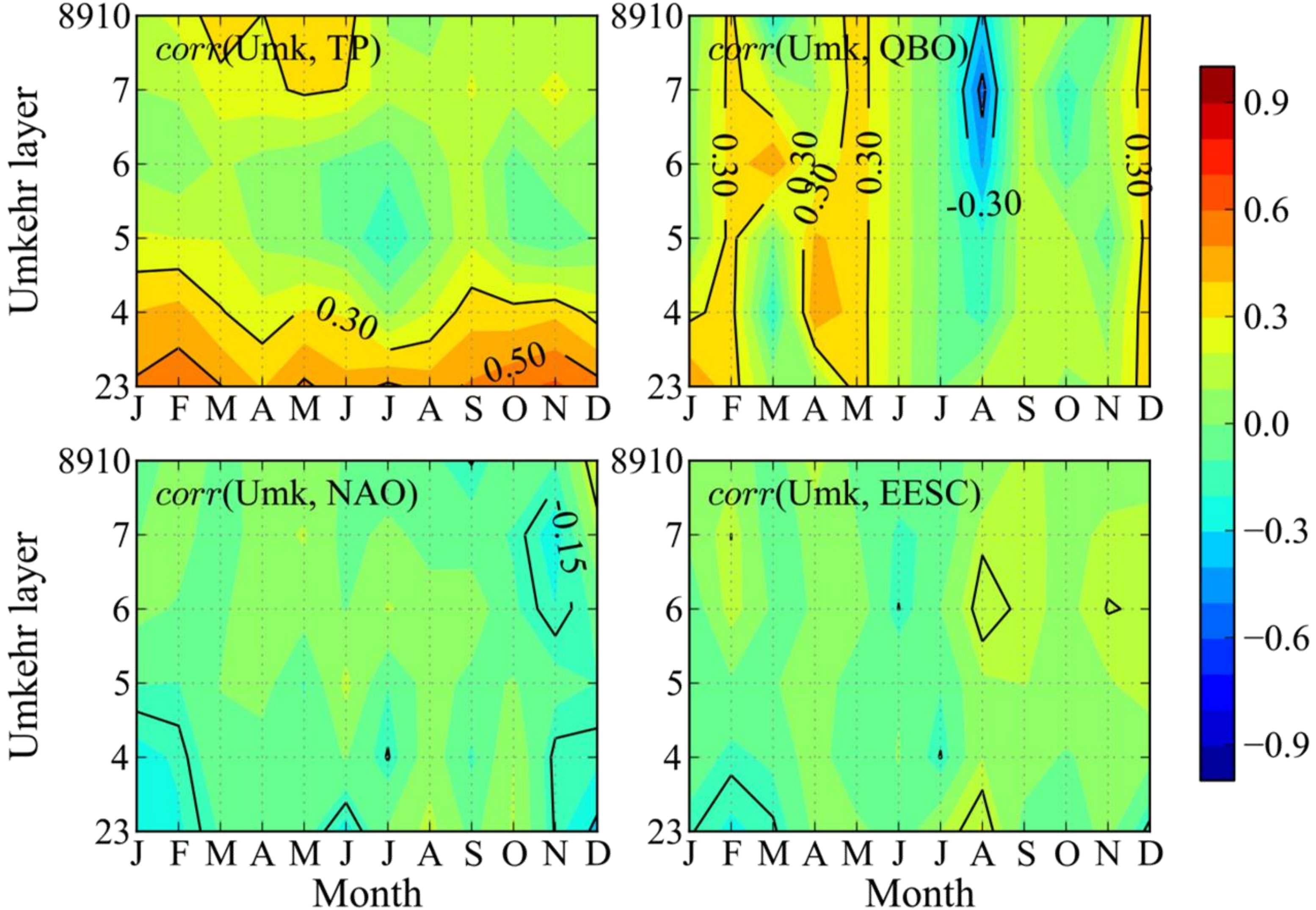


Abbildung: Anzahl der Extremereignisse 1994-2011



O_3 correlation with proxies

Vertical cross-section of correlations with potential proxies and vertically resolved ozone, over the year

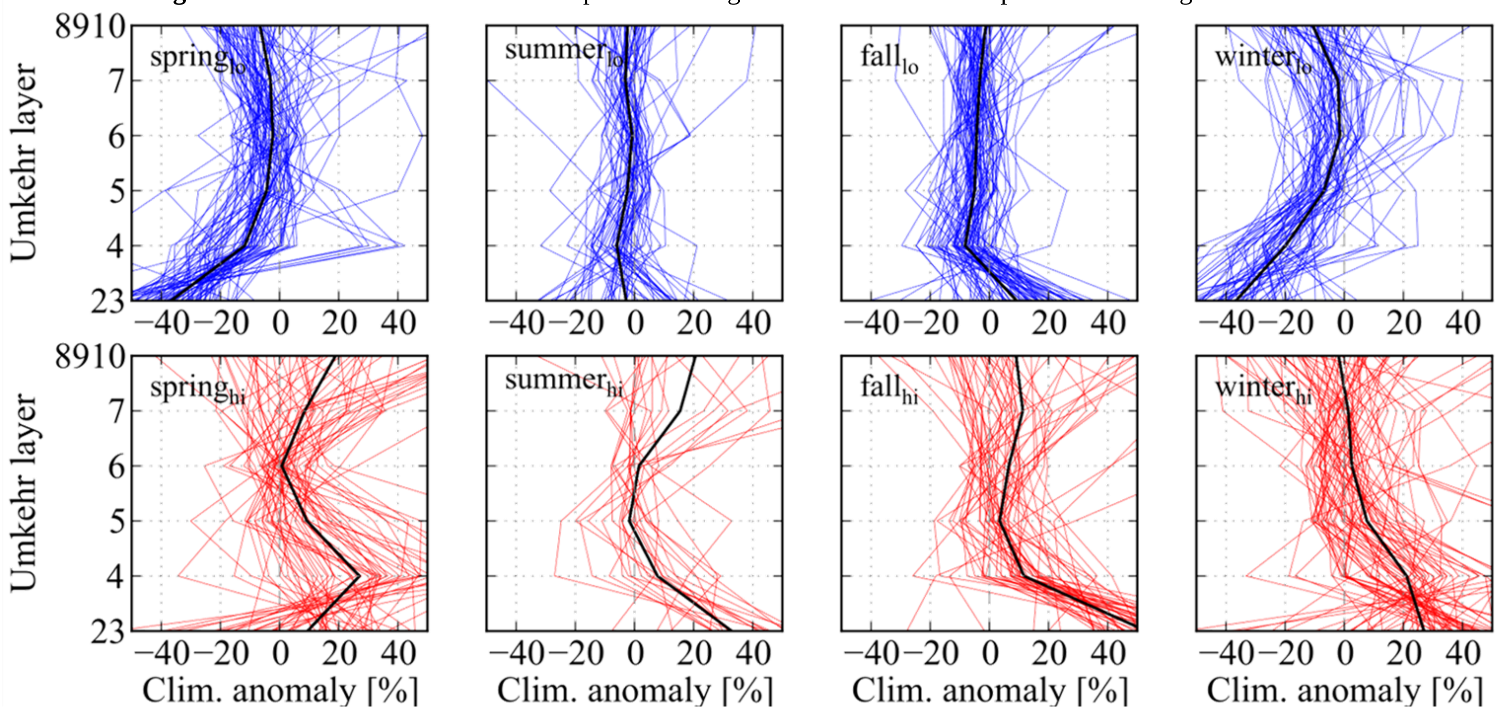


Extreme events in Umkehr profiles

- **extreme low TO_3 events** often composed from strong deficits in lower layers
- deficits in upper layers especially visible during late winter and spring (chemical ozone destruction)
- **extreme high TO_3 events** with contributions from upper stratosphere (advection from tropical latitudes, weaker during summer)

→ ***Hints at significant influence of atmopsheric dynamics to ozone column thickness at Hoher Sonnblick, significant contribution to observed trends***

Figure: Deviations of observed vertival profiles during extreme events with respect to climatological mean values



Conclusion & outlook

- **clear trends in stratospheric ozone since 1997**
  - cannot be clearly attributed to reduction in stratospheric ODS concentrations
  - strong influence of atmospheric dynamics evident in observed stratospheric ozone

- **extreme events in stratospheric ozone**
  - novel method for threshold estimation
  - extreme events often triggered by atmospheric dynamics
  - significant influence on observed trends

- **future evolution of ozone layer still uncertain**
  - concentrations of ODS, substitutes for ODS (EESC)
  - dynamically forced changes in O_3 by hemisperical circulation
  - changes in radiative forcing (WMGHGs, ODS, O_3)

  → **signs and budgets of feedback mechanisms not quantified**

Thank you for you attention