Update on statistical trend analysis of column ozone: Influence of dynamical and chemical processes & Is there a turnaround in the trend of ozone?

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Introduction & Motivation

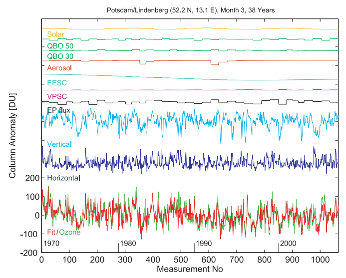
- What causes the trends in ozone column?
- Is ozone depletion the main cause for the trend?
- How important are dynamical changes?
- Is there a statistically significant turnaround in the trend of ozone column as a sign of ozone recovery ("recovery stage ii" of the WMO report)?
- Update on Wohltmann et al. (2005, 2007) and CANDIDOZ EU project (Chemical and dynamical influences on decadal ozone change) (Harris et al., 2008)

Multiple linear regression

- Data time series: Ozone column measurements from Dobson network (WOUDC database)
- Daily data
- 1970-2007
- Explanatory time series: 1 daily proxy (dynamical transport changes) and 6 interannual proxies (EP flux, EESC, VPSC, aerosol, QBO, solar cycle) with constant values in a given month
- 12 separate time series for 12 months of the year, e.g. time series of January consists of the measurements of January 1970 followed by the measurements of January 1971 etc.
- After regression, results are averaged over stations in geographical regions
- Errors consider autocorrelation (AR(1)), spatial correlation of stations and non-equal measurement time spacing
- Trend error additionally includes error due to random trends arising from short-term variability of the time series

Notes

- Daily data to fit INTEQL with lower error bars
- 12 separate monthly time series (in contrast to the usual approach to fit a time series including all months of a year): Avoids systematic errors in fit parameters, no problems in defining cumulative proxies like EP flux, summer months with their lower variability don't get a lower weight in the regression than winter months, the disadvantage of lower significance of results can be compensated by seasonal averaging
- High number of explanatory time series: Avoids systematic errors in fit parameters (if the assumed model is a correct description of ozone variability) at the expense of increasing the statistical error bars. Since systematic errors don't show up in the error bars, this better illustrates the real error of the regression coefficients



Example regression for Potsdam/Lindenberg in March. Green: Measured ozone column anomaly, red: Multiple regression fit. Colored lines explanatory time series multiplied by regression coefficient to give values in DU

Stations

Europe: Arosa (D), Belsk (D), Hohenpeissenberg (D), Hradec Kralove (D), Potsdam (D)/Lindenberg (B), Uccle (D)
North America: Bismarck (D), Boulder (D), Caribou (D), Churchill (D/B), Edmonton (D/B), Goose Bay (D/B), Nashville (D), Toronto (D/B)
Northern Hemisphere: Europe, North America, Sapporo (D), Tateno (D)
Australia: Perth (D), Aspendale/Melbourne (D), Invercargill/Lauder (D)
Antarctica: Syowa (D), Amundsen-Scott (D), Halley Bay (D)

D=Dobson, B=Brewer, / denotes 2 time series merged into one

References

Wohltmann et al.: A process-oriented regression model for column ozone, JGR, 112, D12304, doi:10.1029/2006JD007573, 2007

Wohltmann et al.: Integrated equivalent latitude as a proxy for dynamical changes in ozone column, GRL, 32, L09811, doi:10.1029/2005GL022497, 2005

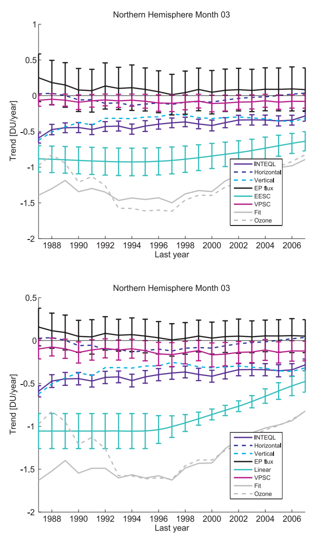
CANDIDOZ overview paper: Harris et al., Ozone trends at northern mid- and high latitudes - a European perspective, Annales Geophysicae, 26, 1207-1220, 2008

Explanatory time series

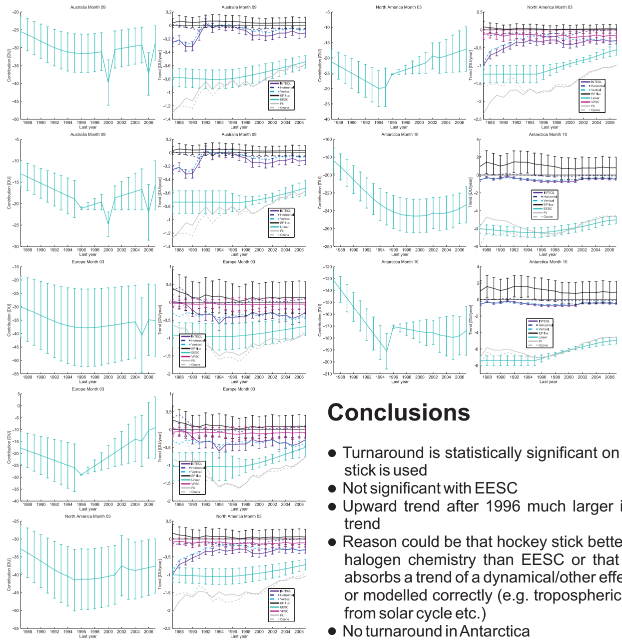
Integrated equivalent latitude (INTEQL)	Dynamical short- and long-term changes by horizontal transport and mass convergence by tropospheric pressure systems	Broken down into horizontal transport and vertical convergence in the plots. See Wohltmann et al. (2005) for details.
EP flux through mid-latitude tropopause	Effects of residual circulation	Integrated over preceding winter of hemisphere From ECMWF ERA-40 and operational data
EESC or	Homogeneous halogen chemistry	Halogen loading: WMO effective equivalent stratospheric chlorine Mean age 3 years, 1.5 years halfwidth (5/2.5 y Antarctica)
Hockey stick trend		2 linear trends from 1970-1995 and 1996-2007
EESC x VPSC	Heterogeneous halogen chemistry	PSC volume from NCEP temperatures
Aerosol backscatter	Volcanic aerosols	Sato index
Solar flux	Solar cycle	10.7 cm flux
Equatorial zonal wind	QBO	2 proxies to account for phase shift (30+50 hPa)

A turnaround in the trend of column ozone?

Contribution of EESC (top) or hockey stick (bottom) proxy to the anomaly in ozone column in March as a function of year. Northern hemisphere. Error bars are 95% confidence intervals.



Evolution of trend from 1970-1987 to 1970-2007 for March in NH. Linear trend fitted to only the part of the fitted explanatory time series from 1970-X, where X is 1987-2007. Fitted explanatory time series is original explanatory time series multiplied by regression coefficients taken from 1970-2007 regression. Gray line is trend of fitted ozone column calculated the same way, dashed gray line trend of observed ozone column. Error bars show 95% confidence intervals. With EESC (top) or hockey stick (bottom).

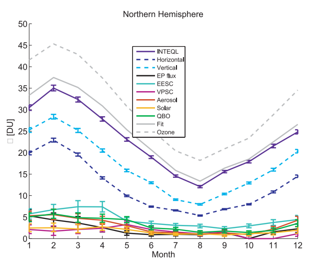


Same as in the large plots for (down from top left) Australia (September), Europe (March), North America (March) and Antarctica (October).

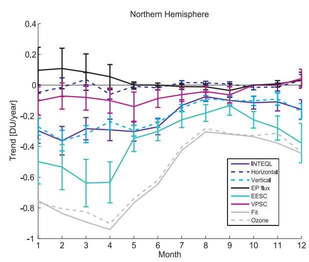
Conclusions

- Turnaround is statistically significant on the 95% level if hockey stick is used
- Not significant with EESC
- Upward trend after 1996 much larger in case of hockey stick trend
- Reason could be that hockey stick better describes the effect of halogen chemistry than EESC or that the hockey stick trend absorbs a trend of a dynamical/other effect that is not considered or modelled correctly (e.g. tropospheric ozone changes, trends from solar cycle etc.)
- No turnaround in Antarctica

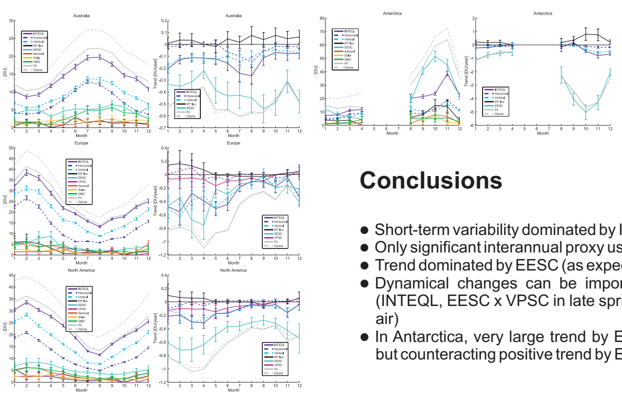
Seasonal cycle of variability and trend



Variability (standard deviation) of the fitted explanatory time series in DU as function of month in NH. Gray line is variability of fitted ozone column, dashed gray line is variability of observed ozone column. Error bars are 95% confidence intervals. With EESC as variable.



Trend of the fitted explanatory time series in DU/year as function of month. Gray line is trend of fitted ozone column, dashed gray line is trend of observed ozone column. Error bars are 95% confidence intervals. Solar cycle, QBO, aerosols omitted in plot but not in regression. With EESC.



Same as in the large plots for Australia, Antarctica, Europe and North America

Conclusions

- Short-term variability dominated by INTEQL
- Only significant interannual proxy usually EESC
- Trend dominated by EESC (as expected, see WMO 2006)
- Dynamical changes can be important contributors to trend (INTEQL, EESC x VPSC in late spring due to dilution of vortex air)
- In Antarctica, very large trend by EESC (up to 22%/decade), but counteracting positive trend by EP flux