Is the ozone layer recovering ?

Johannes Staehelin

Institute for Atmospheric and Climate Science (IACETH), Swiss Federal Institute of Technology Zürich (ETHZ)

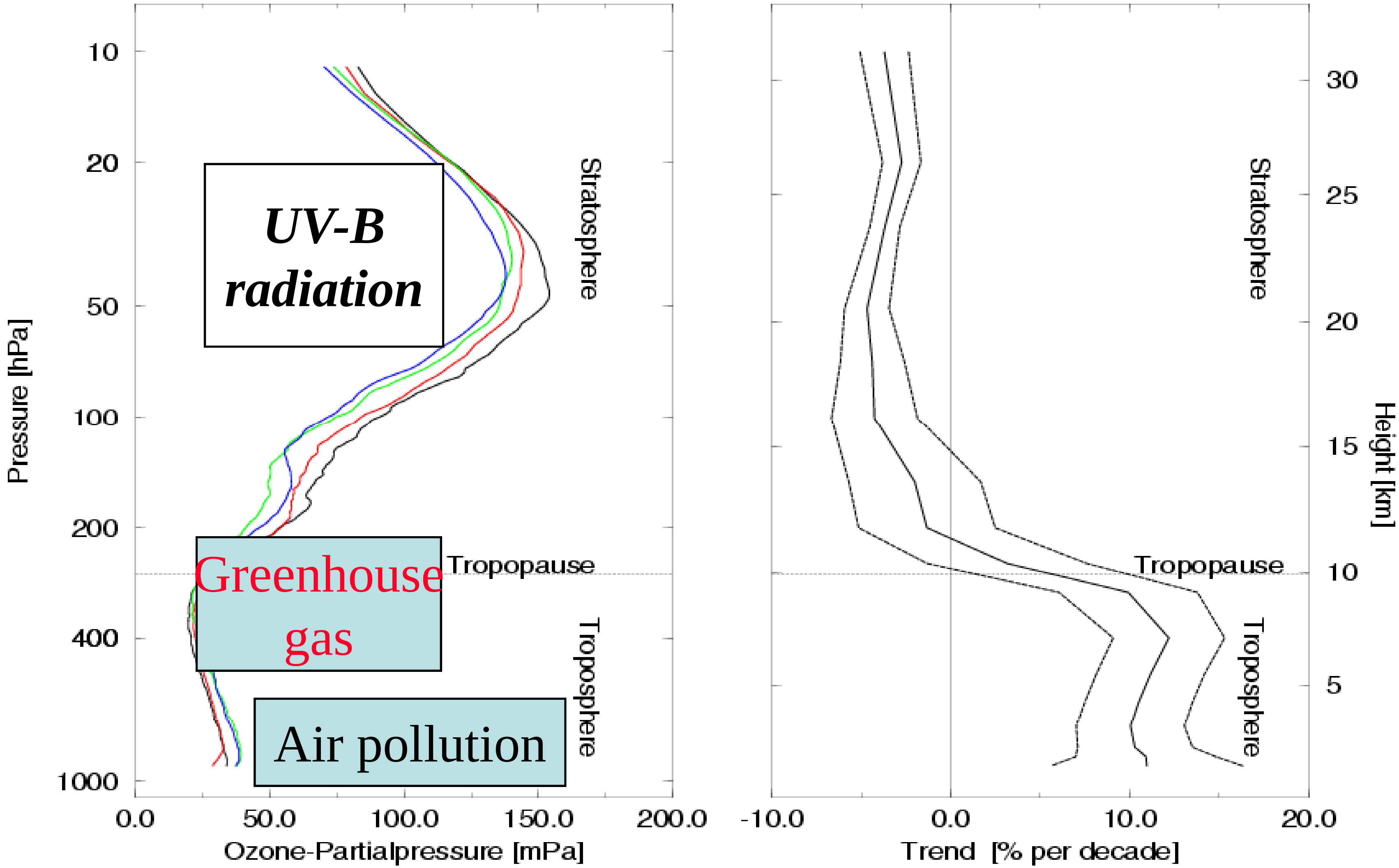
Universitätstrasse 16

CH-8092 Zürich, Switzerland

email:Johannes.Staehelin@env.ethz.ch

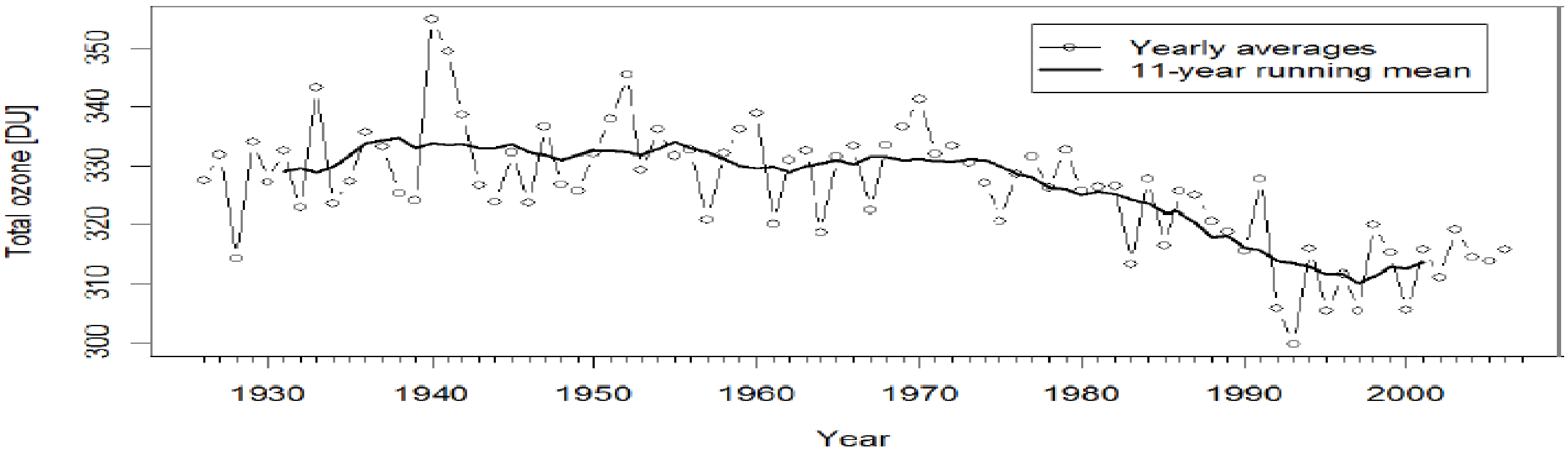
1. Introduction

Measurements of ozone sondes of Payerne (Switzerland). Black: 1970; red: 1980; green: 1990; blue: 2000



Swiss long-term ozone measurements (MeteoSwiss since 1988)

1. Longest total ozone series of the world (Dobson spectrophotomery), homogenised
2. First Umkehr measurements (1930), continuous measurements since 1956
3. Ozone sonde measurements since 1969 (Payerne, Swiss Plateau)



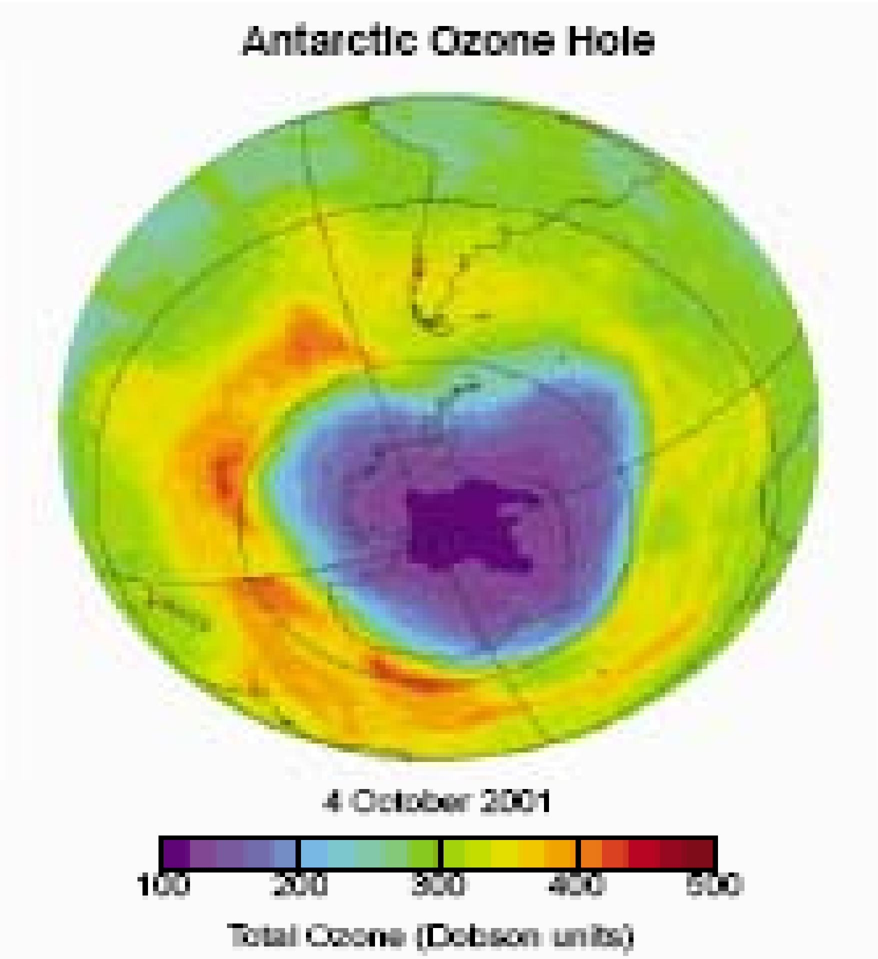
Short history: 1970s

Anthropogenic stratospheric ozone depletion (since early 1970s):

- H. Johnston (1971), P. Crutzen: Ozone depletion by Super Sonic Transport (NO_x) (?)
- R. Stolarski, R.J. Cicerone (1974): Ozone depletion by Chlorine radicals
- M.J. Molina, S. Rowland (1974): Ozone depletion by CFCs

(Ozone Depleting Substances (ODS): CFCs, halones, HFCFCs)

Surprise: Farman et al., 1985:
Descovery of Antarctic Ozone hole



Second part of 1980s

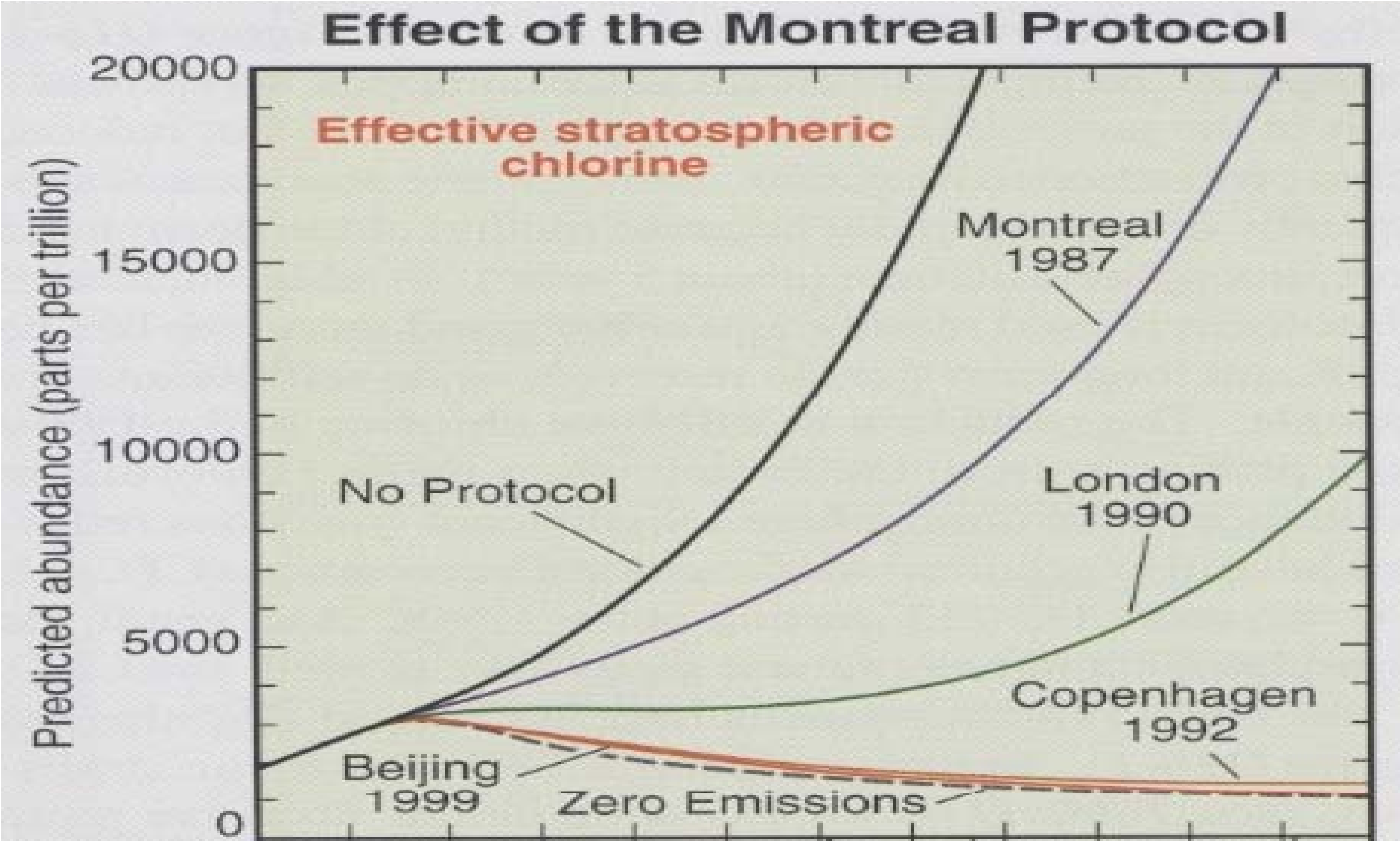
- 1988: Explanation of ozone hole by (anthropogenic) CFCs (halones) (heterogeneous chemistry)
- 1988: Publication of International Ozone Trend Panel Report: Significant decrease in (winter) ozone at Northern midlatitudes (multiple regression analysis)

2. Global Regulation

- 1985: Vienna Convention
- 1987: Montreal Protocol
- Several amendments and adjustments
- Quantity for (chemical) ozone depletion of ODS: **EESC** (Equivalent Effective Stratospheric Chlorine): Weighting over release and ozone depletion of individual ODS

EESC for mid-latitudes

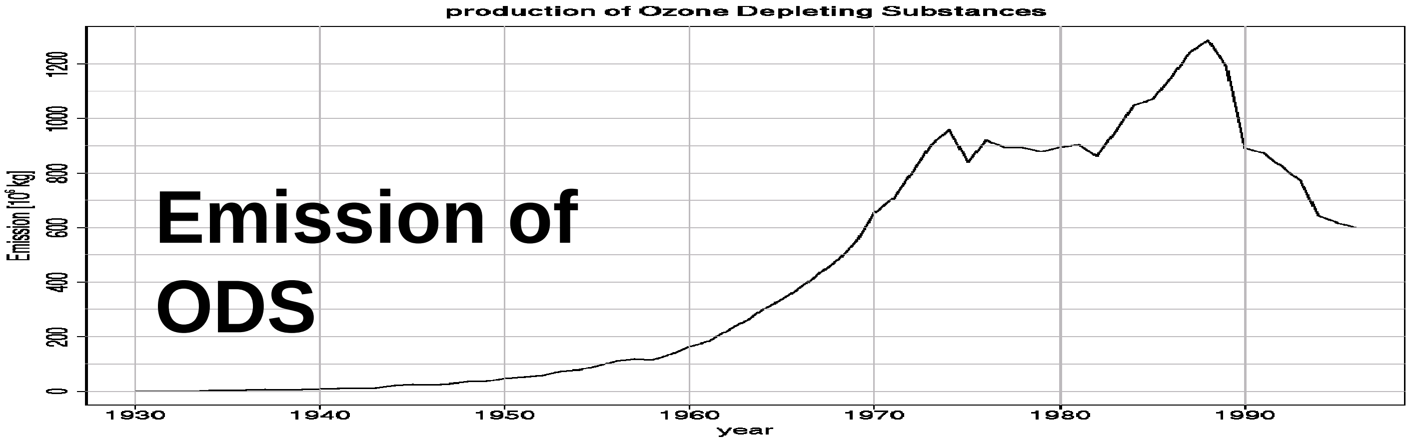
http//:www.wmo.ch/web/arep/reports/ozone_2002/q&as.pdf, Seite Q.29

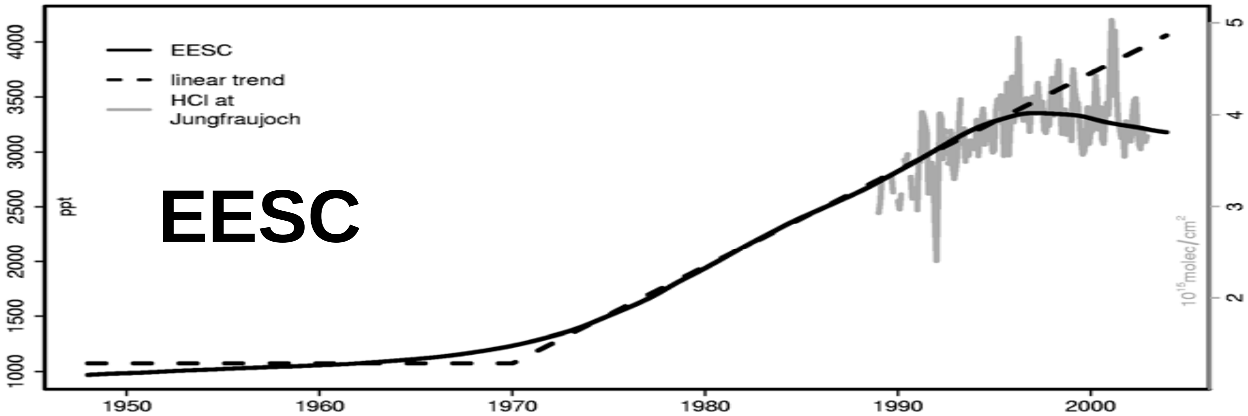


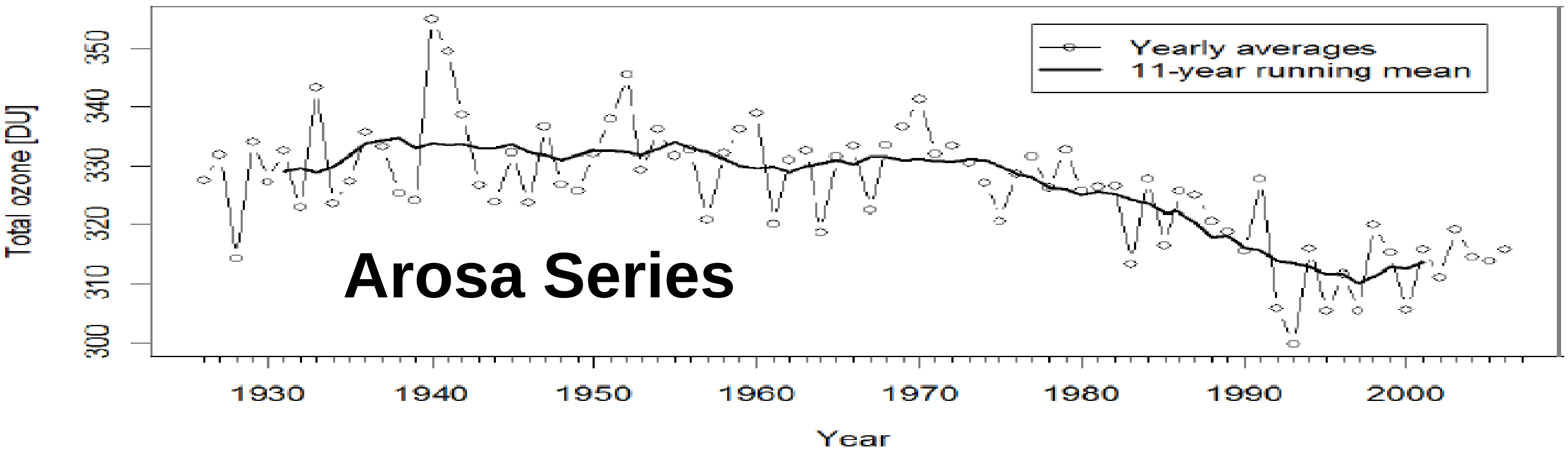
1980 1990 2000 2010 2020 2030 2040 2050 2060 2070 2080 2090 2100

3. Problem of documentation of ozone shield recovery

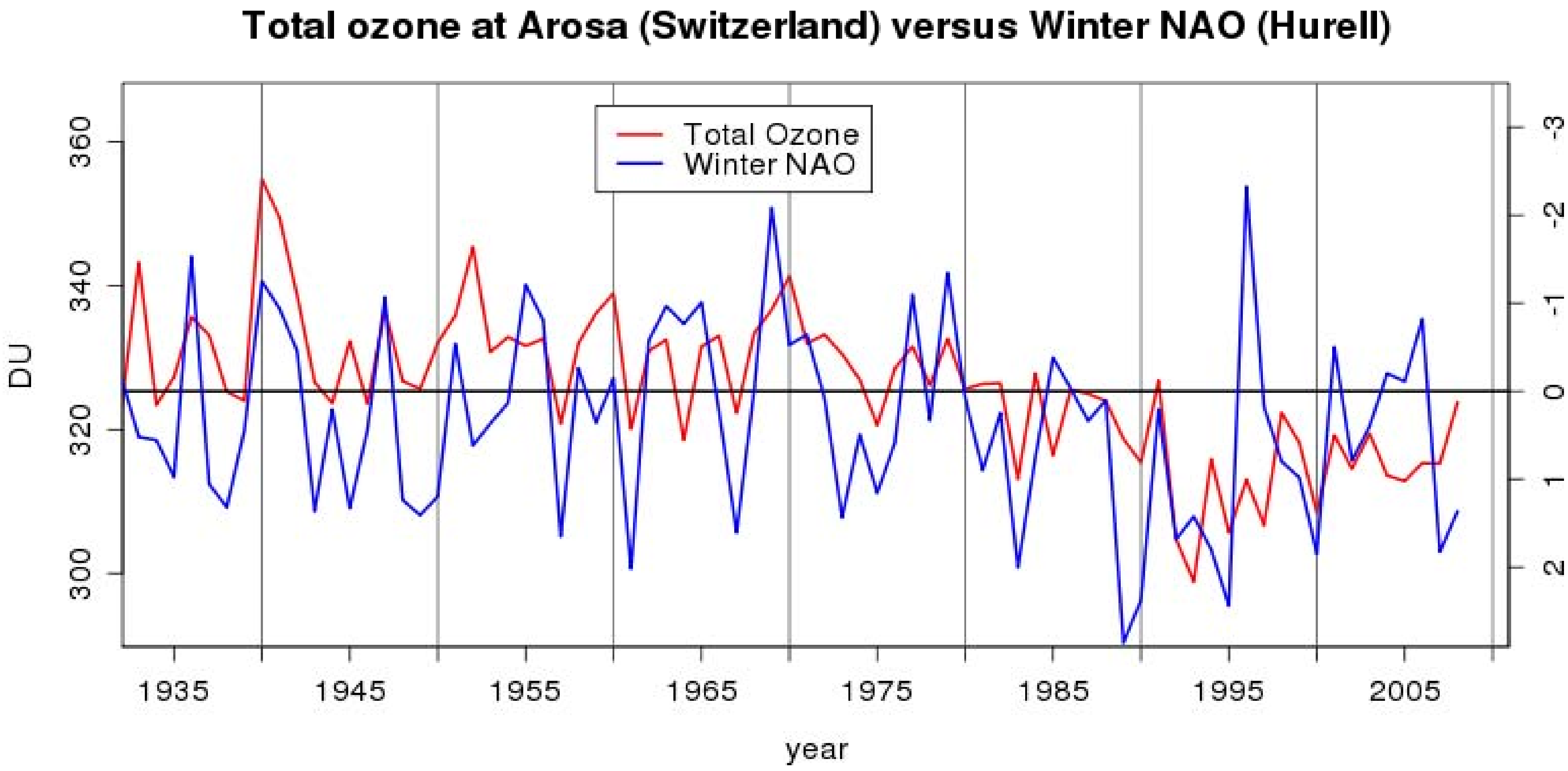
- Illustration by the total ozone series of Arosa: started in 1926 and continued since 1988 by MeteoSwiss:
- Problem: Attribution of ozone evolution to individual processes (in addition to EESC)


production of Ozone Depleting Substances
Emission of ODS
Emission [10^6 kg]
0
200
400
600
800
1000
1200
1930
1940
1950
1960
1970
1980
1990
year


EESC
linear trend
HCl at Jungfraujoch
EESC
ppt
1000
1500
2000
2500
3000
3500
4000
10^15 molec/cm^2
2
3
4
5
1950
1960
1970
1980
1990
2000


Yearly averages
11-year running mean
Arosa Series
Total ozone [DU]
300
310
320
330
340
350
1930
1940
1950
1960
1970
1980
1990
2000
Year

Further processes affecting mid-latitude ozone
- Violent Volcanic eruptions (Pinatubo, June 1991)
- (Long-term) climate Variability: Strong correlation between (NAO(AO index and winter total ozone values at Arosa (Appenzeller et al., 2000, updated by J. Mäder), Brewer Dobson Circ., polar ozone depletion



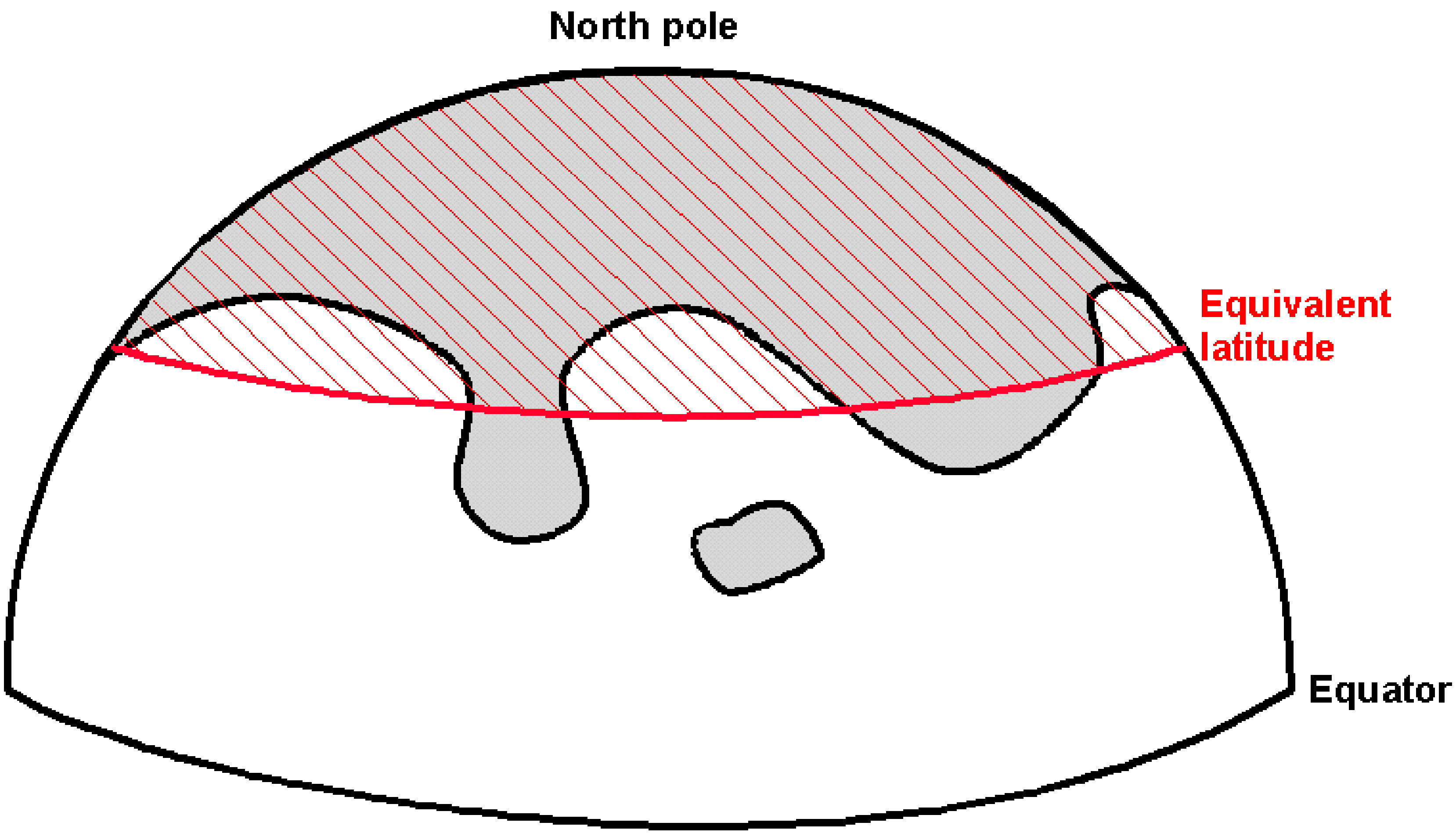
4. CATO ozone data sets

CATO (Candidoz Assimilated Three-dimensional Ozone) (EU-project: CANDIDOZ: Chemical and Dynamical Influences on Decadal Ozone Change): Principle:

- Measurements: Satellite total ozone data (since 1979) of NIWA data set (G. Bodeker): Composite of different satellite total ozone measurements normalized by ground-based Dobson measurements
- Assimilation technique: Kalman filtering
- ECMWF (ERA-40) for PV at 16 pot. temp. levels
- Tropospheric ozone residual susbstracted
- Assimilation technique (PV) not suitable for upper stratospheric ozone: In one version satellite (SBUV) measurements used

(see Brunner et al., J. Geophys Res., 2006)

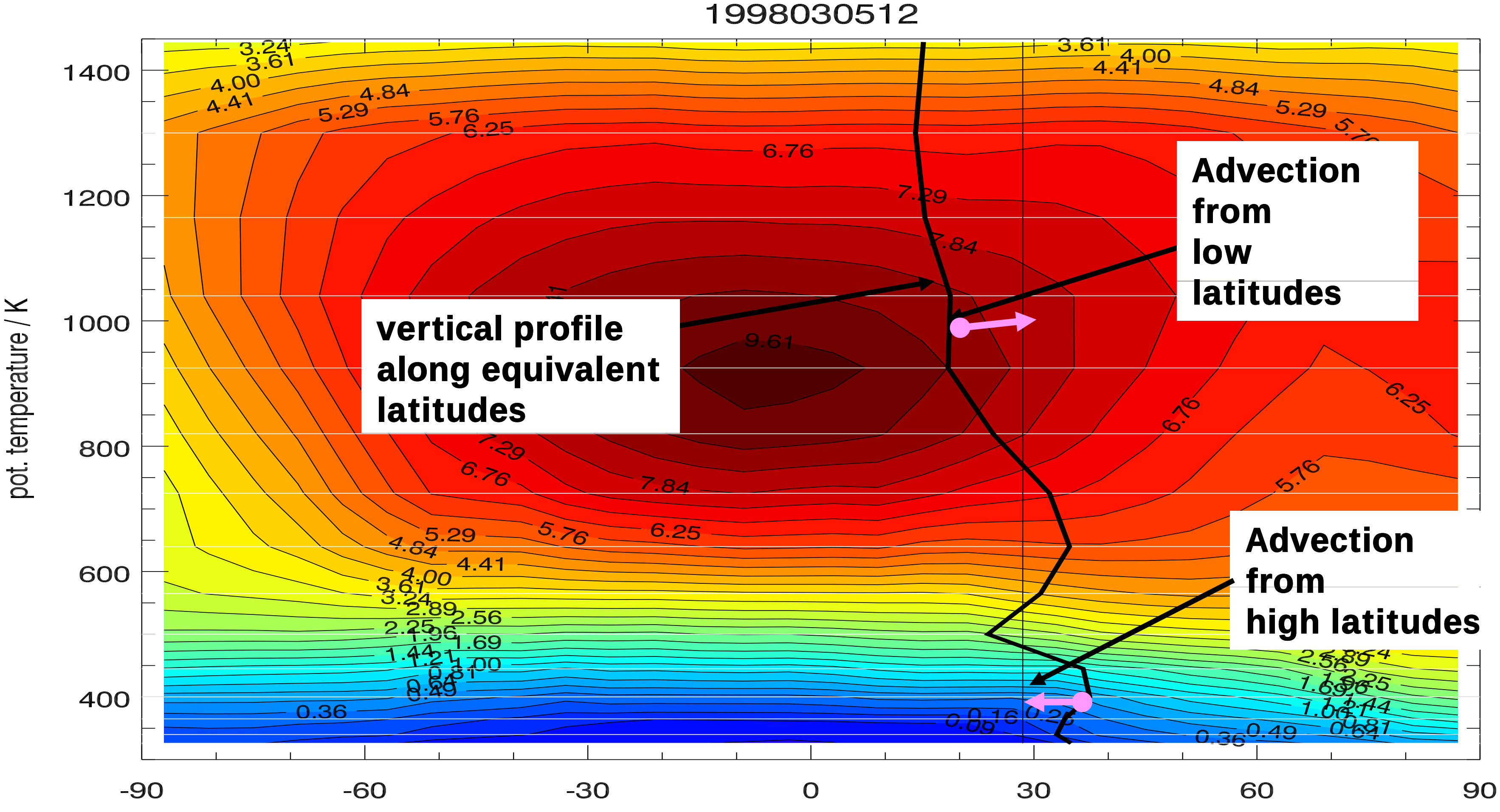
CATO based on equivalent latitude/theta coordinates



A = 2 p (1 – sin f_E) in spherical radian

Reconstruction method

Vertical column in equivalent latitude – θ space



P = tropospheric residual <320 K

$$\Omega(\lambda,\varphi) = \mathrm{P}(\lambda,\varphi) + a \cdot \int_{\theta_0}^{\infty} d\theta \left(-\partial p/\partial\theta\right) \cdot \chi(\varphi_{eq}(\lambda,\varphi,\theta),\theta)$$

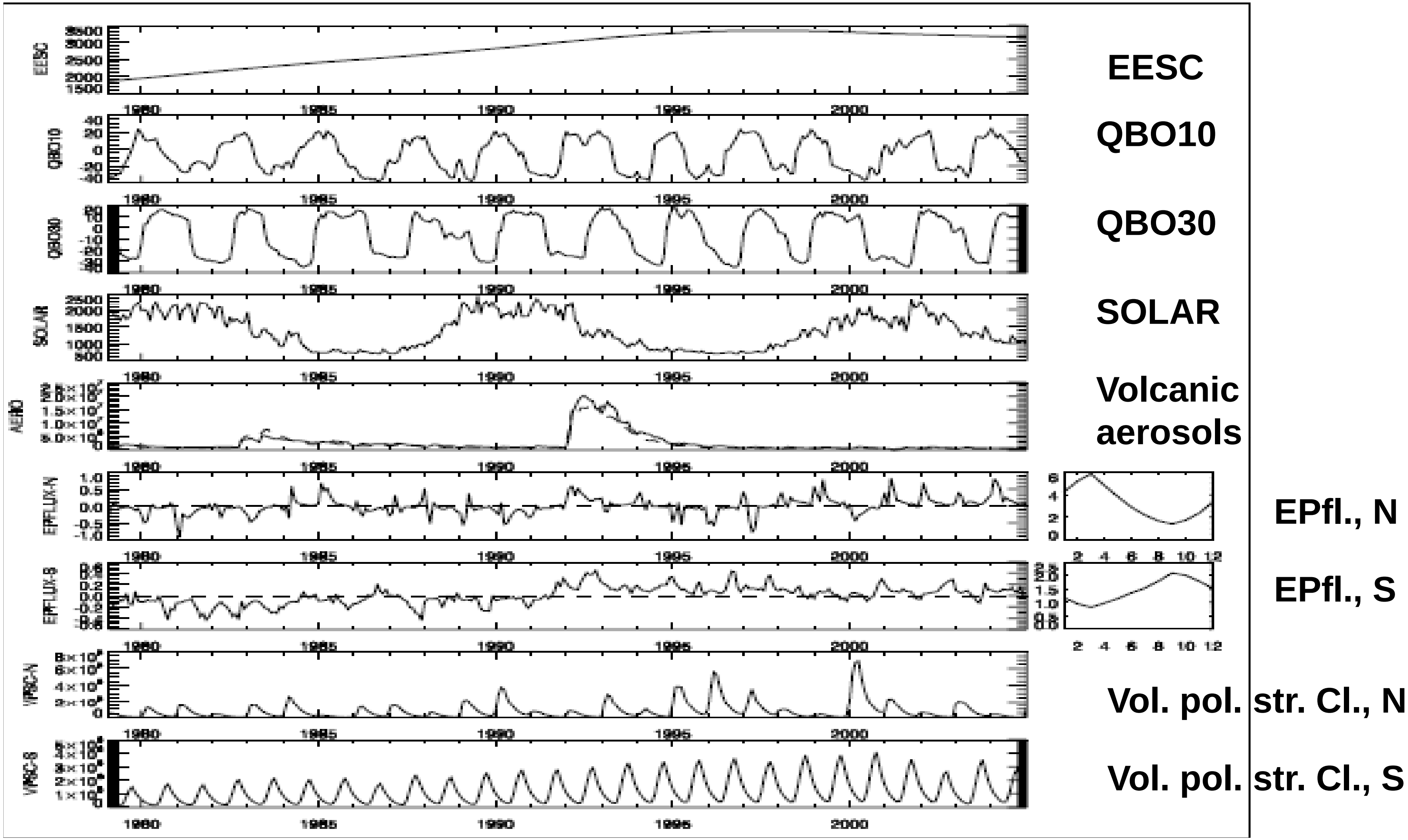
5. Multiple regression analysis of CATO

Multiple linear regression model

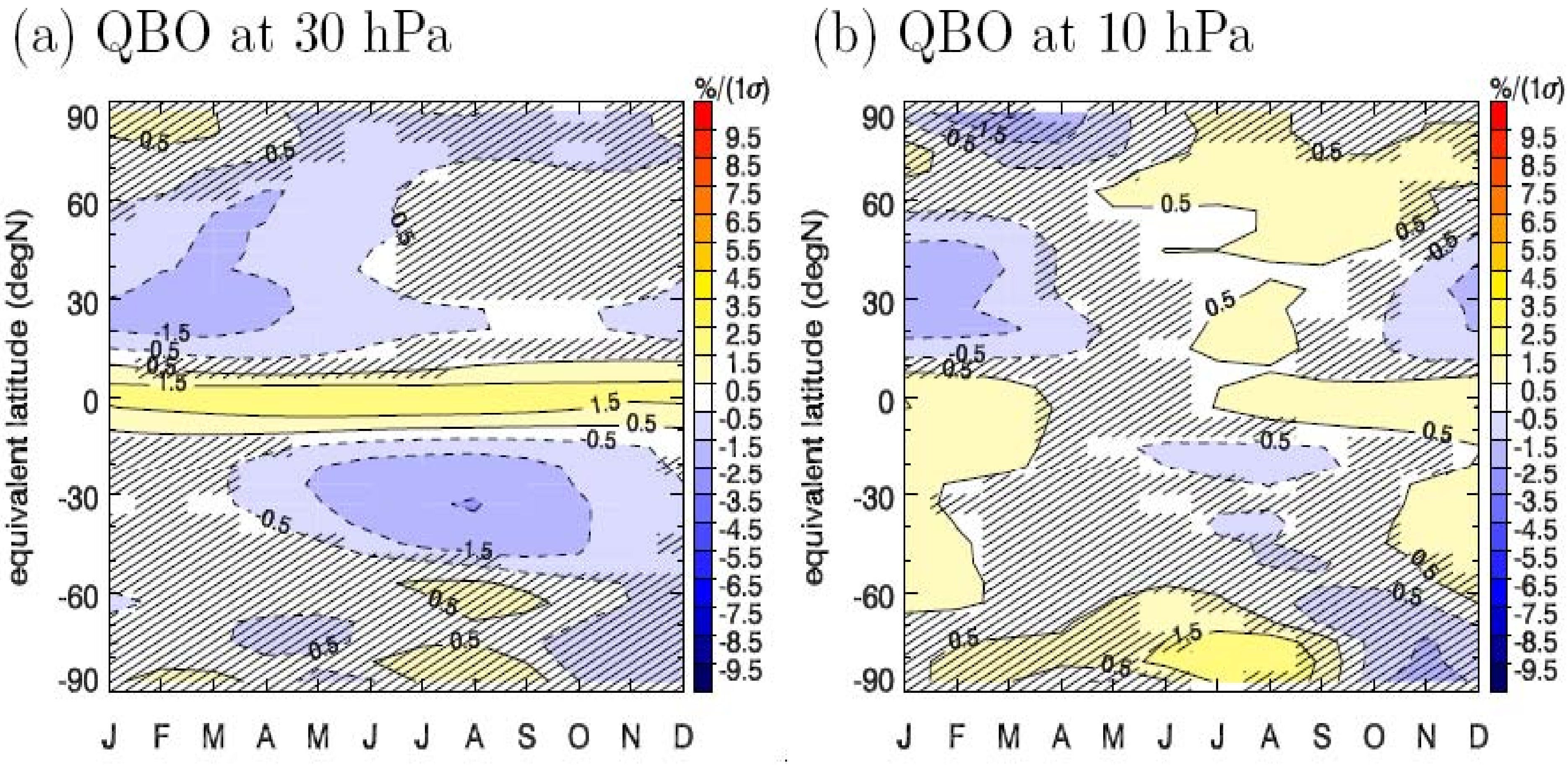
$$Y_t = a + b\,(t) + \Sigma^N c_j X_j(t) + e(t)$$

t: **number of month since start of record (t=1: January 1979)**
Y_t: **Monthly mean total ozone (or ozone partial pressure)**
a: **seasonally varying intercept (offset) of ozone time series**
b: Trend term:Two hockey stick method
(or EESC: **Equivalent effective stratospheric chlorine)**
$c_i X_j(t)$: **time series of expl. Var. *(j= 1,N)*, (seasonally) var. coef**
e(t): **residual variations (not described by model)**
a,b,c: **depend on month of year, described by 12-month and 6-month harmonic series:**
$$cj(t) = cj(1) + \Sigma^2\,(c_{j,2k}\cos(2pkt/12) + c_{j,2k+1}\sin(2pkt/12))$$

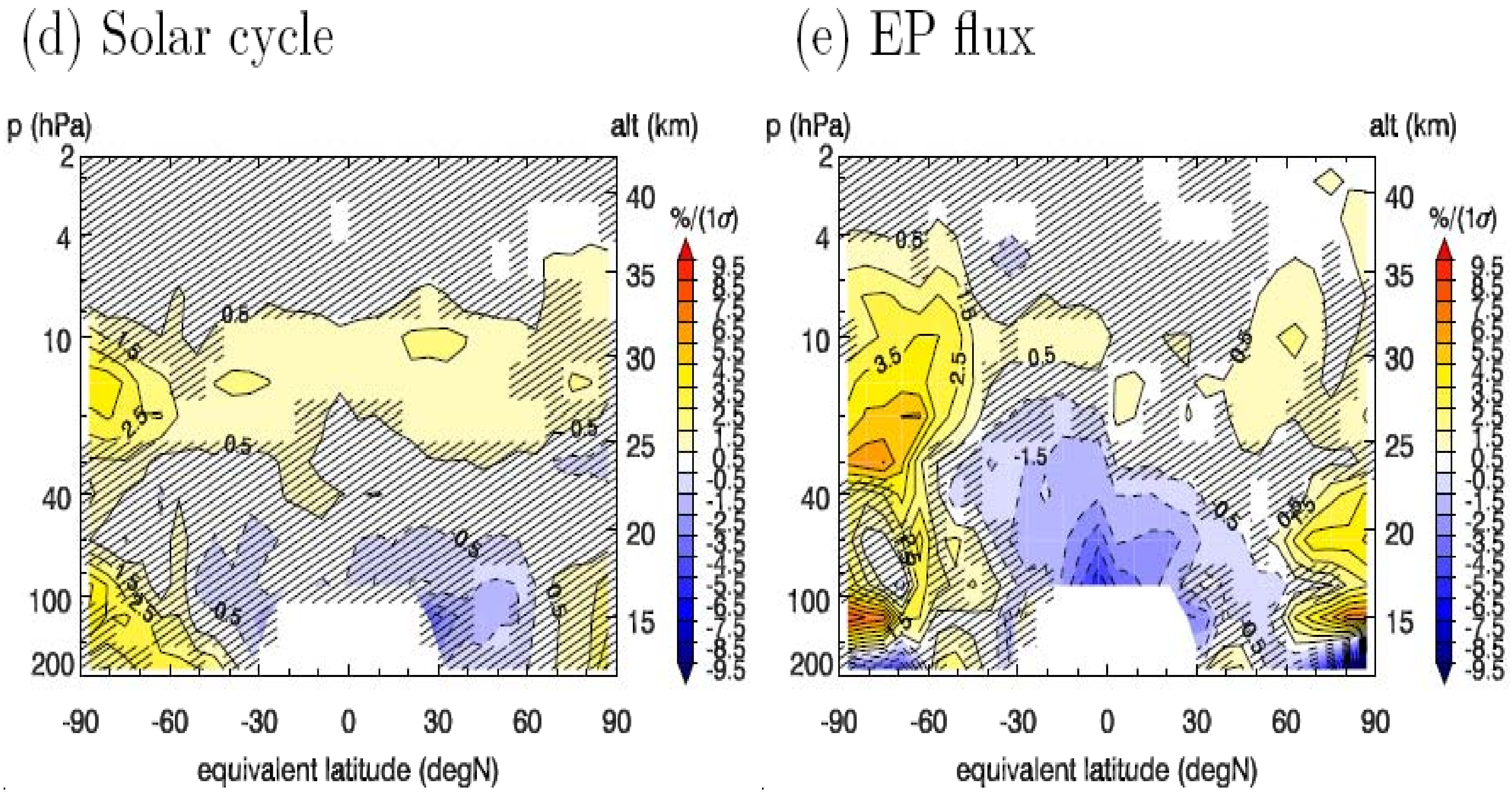
Used explanatory variables:



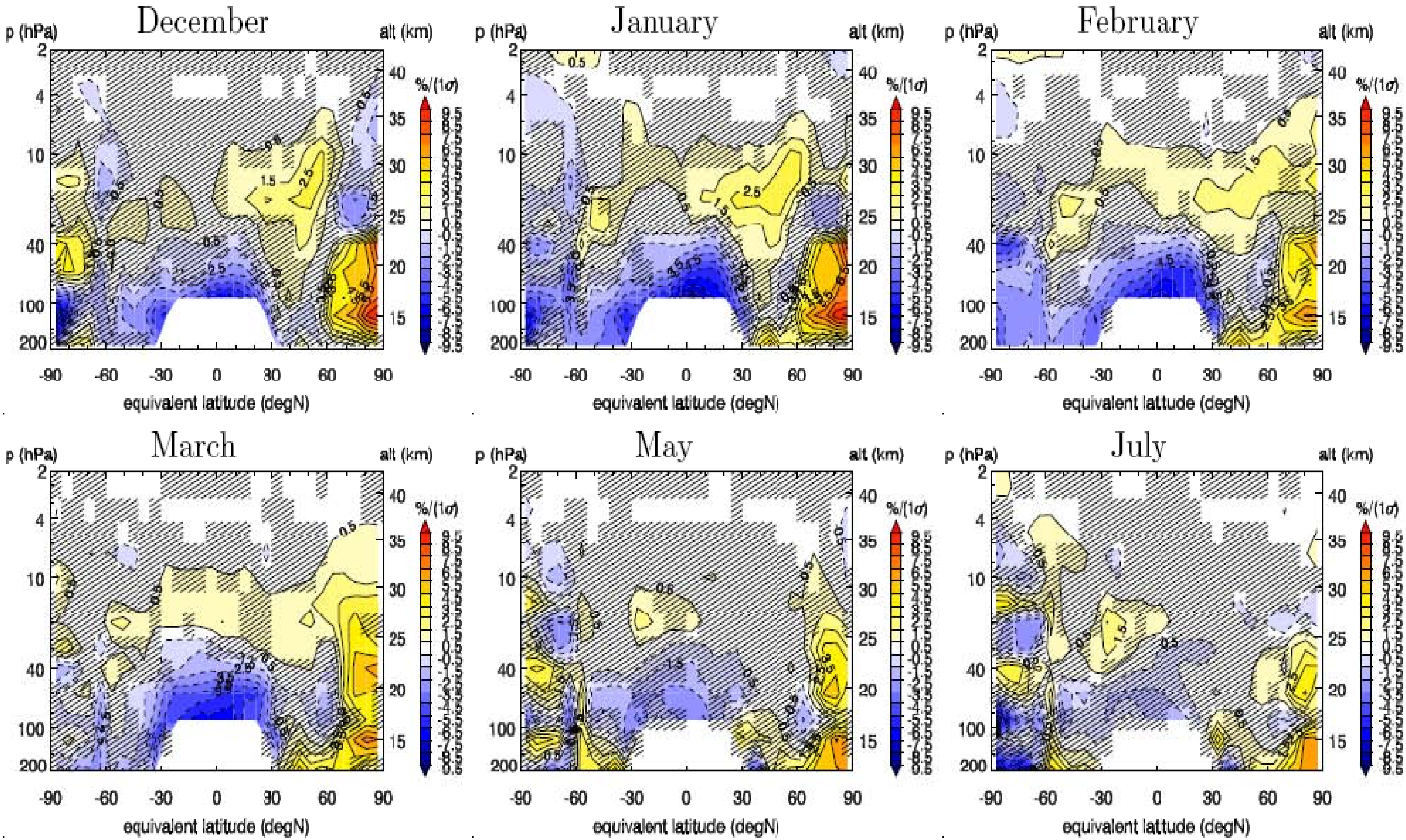
Contribution of QBO(30hPa) and QBO(10hPa) to total ozone variabiability (funct. of season and equiv. latitude): Regression coefficients multiplied by 1σ of each proxy time series and then divided by 1979-2004 mean ozone distribution (% change in tot. O_3 for 1σ increase in proxy)



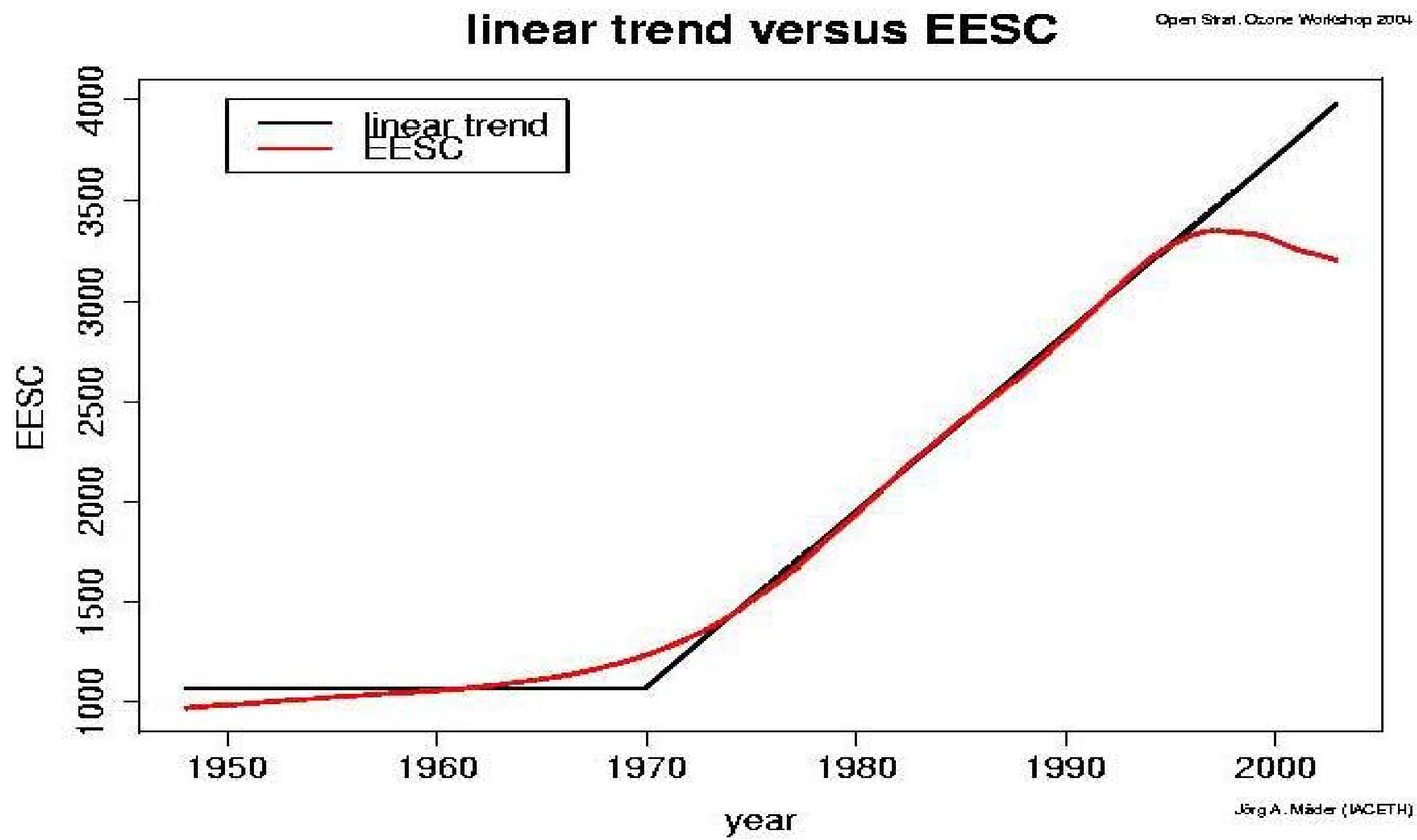
Annual average contribution to variability in ozone partial pressure (altitude/equivalent latitude) (% change in ozone concentration for 1σ increase in proxy)



Sequence of hemispheric EP-flux on global stratospheric ozone distribution



“Turn-around”: Two hockey stick (Reinsel et al., 2005)



Mathematical description (Reinsel et al.)

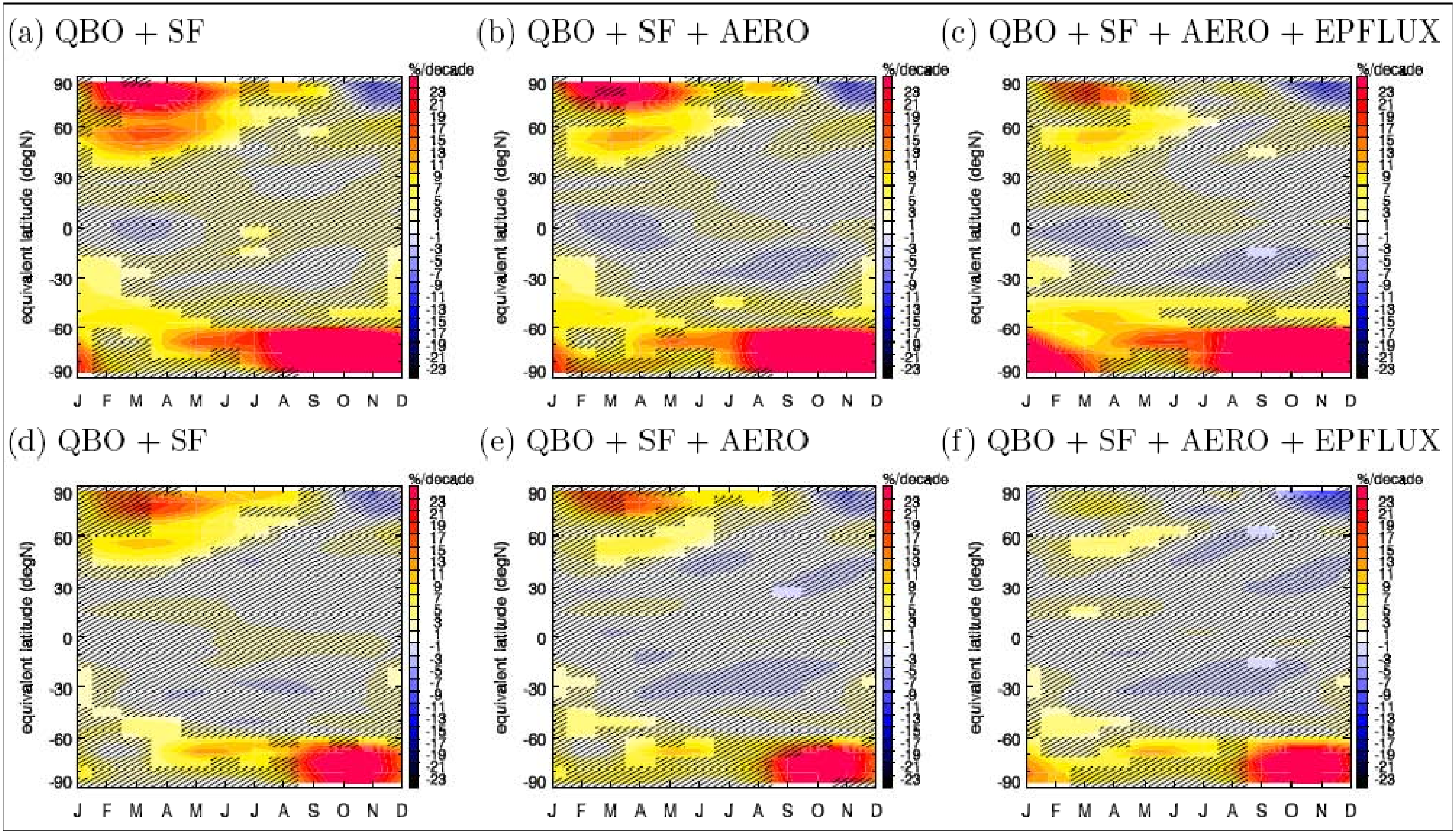
$$\boldsymbol{Y_t = \mu + S_t + \omega_1 X_{1t} + \omega_2 X_{2t} + \ldots.\ \gamma_i Z_{i,t} \ldots + N_t}$$

t: month (1, ..,T), period: 1978-2004
Y_t: Monthly mean total ozone; μ : baseline constant
S_t: Seasonal component (linear fit of sin/cos functions)

ω_1: **linear (decreasing) trend**, beginning at t=0:
effect of ODS
ω_2: **change: linear additional upward trend**,
starting from 1996: ***effect of Montreal Protocol***

$N_t = \rho N_{t-1} + \varepsilon$: autoregressive noise term;
ε: independent random variables

Key results (1979-2004) (a)-(c): Changes in ω; (d)-(f): upward trend



Conclusions from Brunner et al., ACP, 2006

- Equivalent latitude coordinates partially compensate for short term variabilty
- Polar ozone depletion can not be separated from changes in Brewer Dobson circulation
- Results regarding “recovery” depends on used explanatory variables
- Using data until 2004: Only marginal sign of effect of Montreal Protocol regulation

Antartic ozone hole

http://www.wmo.int/web/arep/gawozobull06.html

No indication of recovery: Extent of Antartic ozone depletion depends on meterological cond.

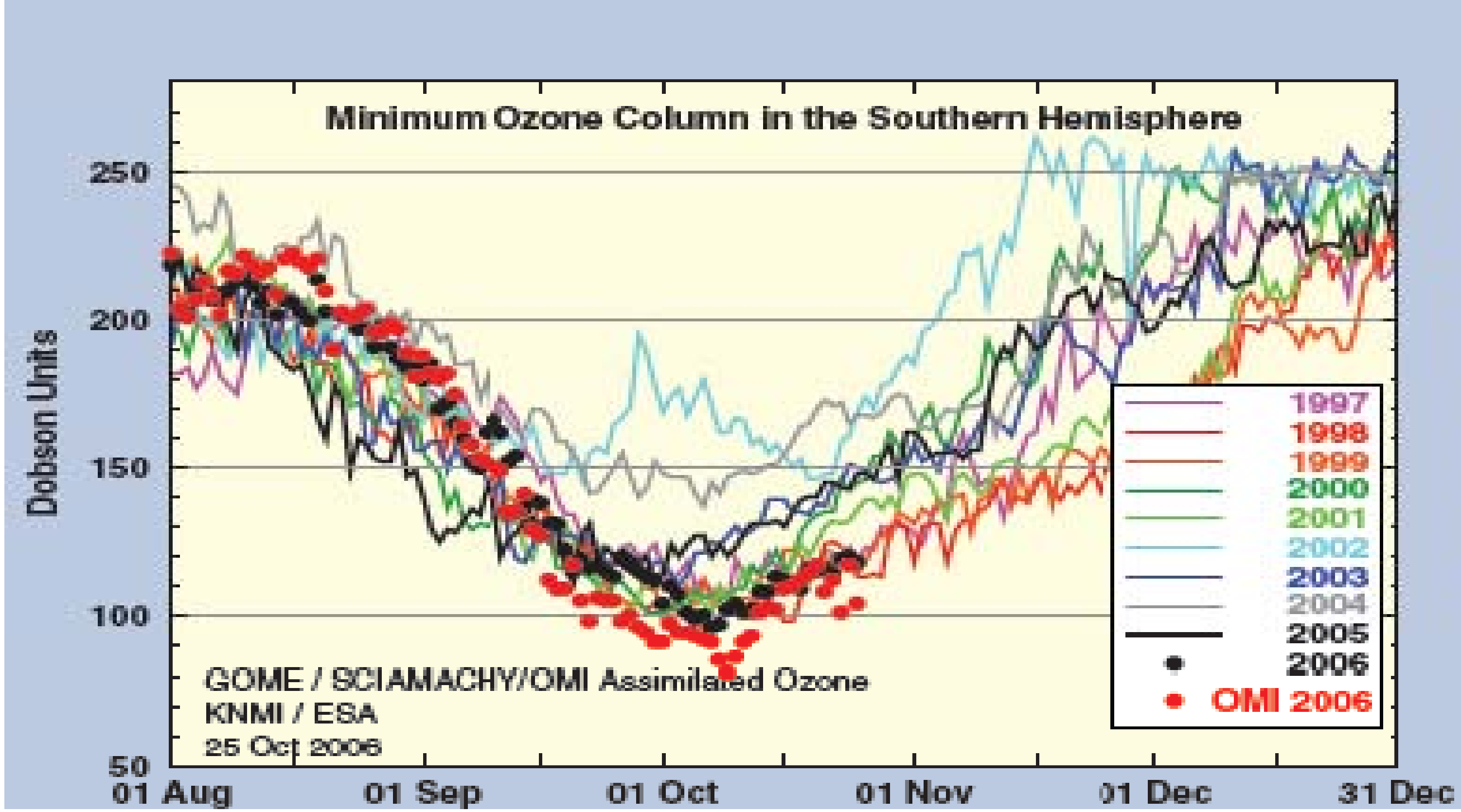


Figure 4. Daily minimum total ozone columns in the Southern Hemisphere as observed by GOME, SCIAMACHY and OMI from 1997 to now. The black dots show the SCIAMACHY observations for 2006. The red dots show the OMI observations for 2006. The SCIAMACHY data now show minimum ozone columns down to 110DU. The OMI data show somewhat lower minimum ozone columns than SCIAMACHY since OMI looks deeper into the vortex and now sees minimum ozone columns around 100DU. The plot is provided by the Netherlands Meteorological Institute (KNMI).

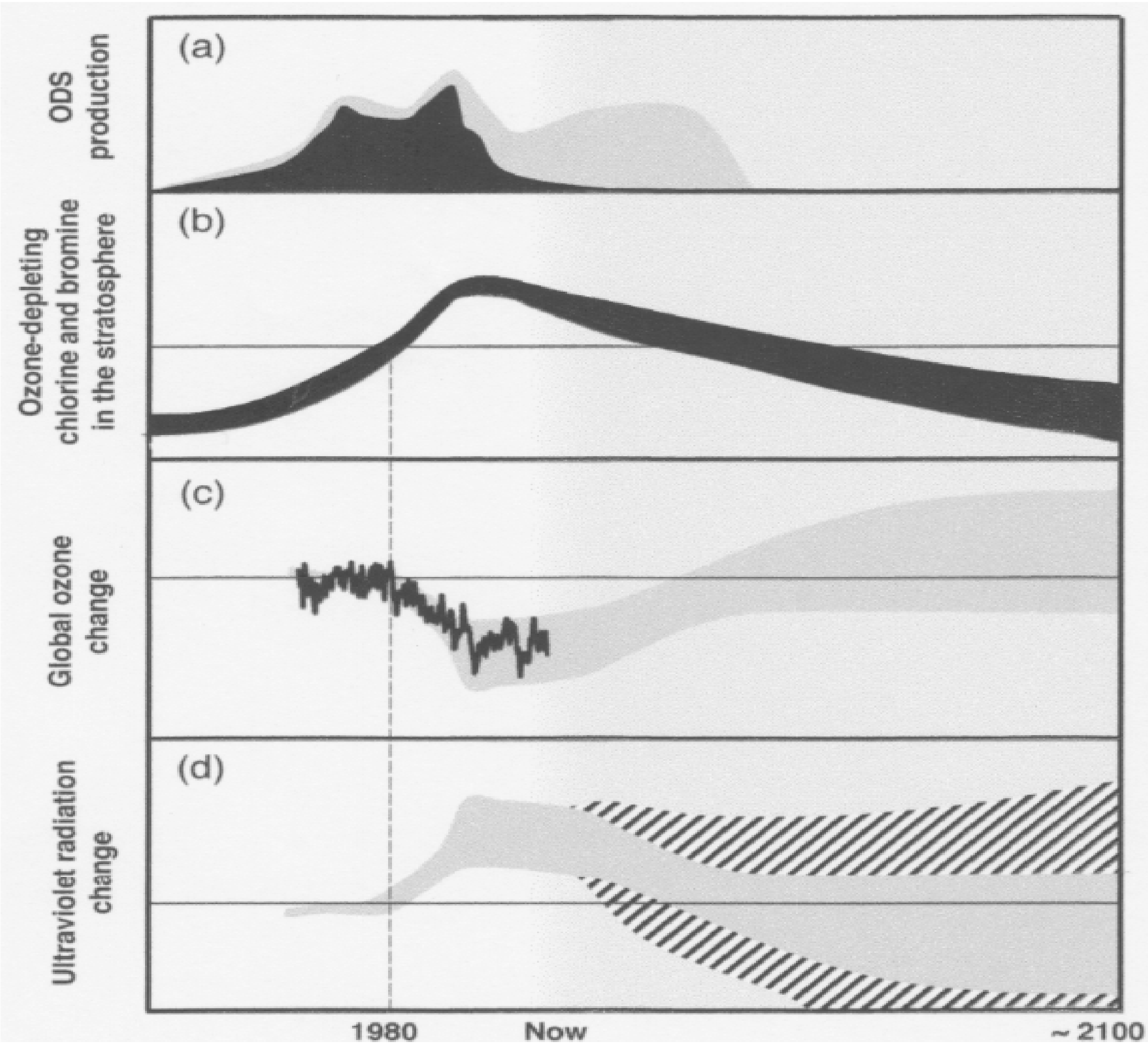
6. Conclusions

- Record low values in 1992, increase since 1993: mainly attributable to Pinatubo eruption (1991) and (long-term) climate variability, etc.
- No signs of revovery of Antartic ozone (in agreement with expectation)
- Attribution of miladtitudinal changes to processes (Montreal Protocol (1987) vs. others) still challening
- Continuation of high quality ground-based and satellite ozone measurements important

7. Expectation

(Executive Summary, Scientific Assessm. of Ozone Depletion: 2006, WMO/UNEP, 18. 8. 2006

(http://www.wmo.int/web/arep/reports/ozone_2006/exec_sum_18aug.pdf)



(a) Produktion of ODS (black: CFCs and halones; grey: HCFCs (used as replacement)

(b) Effect of ODS on midlatitudinal stratospheric ozone (EESC)

(c) Ozone changes 60ºS-60ºN (black: Measurements; grey: numerical modles)

(d) Effect of ozone depletion on erythemal UV (grey according (c), hattched: including additional processes)

(Possible) future development

- Montreal Protocol effective to reduce (anthropogenic) ODS emissions
- Recovery of global ozone layer expected
- Future challenges: Effect of climate change on stratospheric ozone
- “Super recovery” caused by stratospheric temperature decrease ?
- Intensification of Brewer-Dobson circulation ?
- Increased transport of stratospheric ozone to troposphere ? Effect on tropospheric ozone budget ?