# Ozone profile trends from ground-based and satellite data.

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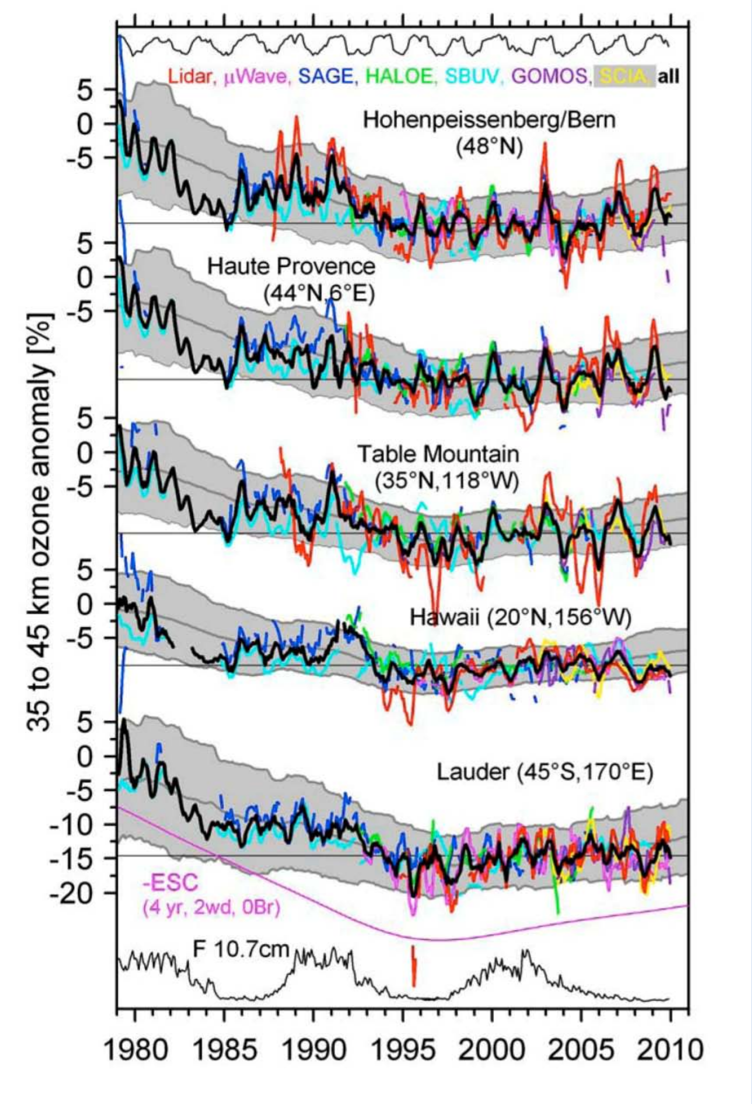
# 2007 WMO Ozone assessment

- **Total column ozone values** (2002-2005 vs pre-1980)
  - **Global** - 3.5%.
  - **NH**, -3.0%, decrease to mid-1990s, increase.
  - **SH**, -5.0%, decrease through 90s, leveled off since 2000.
- **lowermost stratosphere (12 and 15 km)**
  - **NH**, decrease till 1995, relative increase, substantial impact on total ozone column.
  - **SH middle latitude,** no similar increase since 1995
- **upper stratosphere (35-45 km) and lower stratosphere (20-25 km)**
  - declined till 1995, constant since 1995.
  - first stage of recovery (e.g. slowing of ozone decline) has occured.

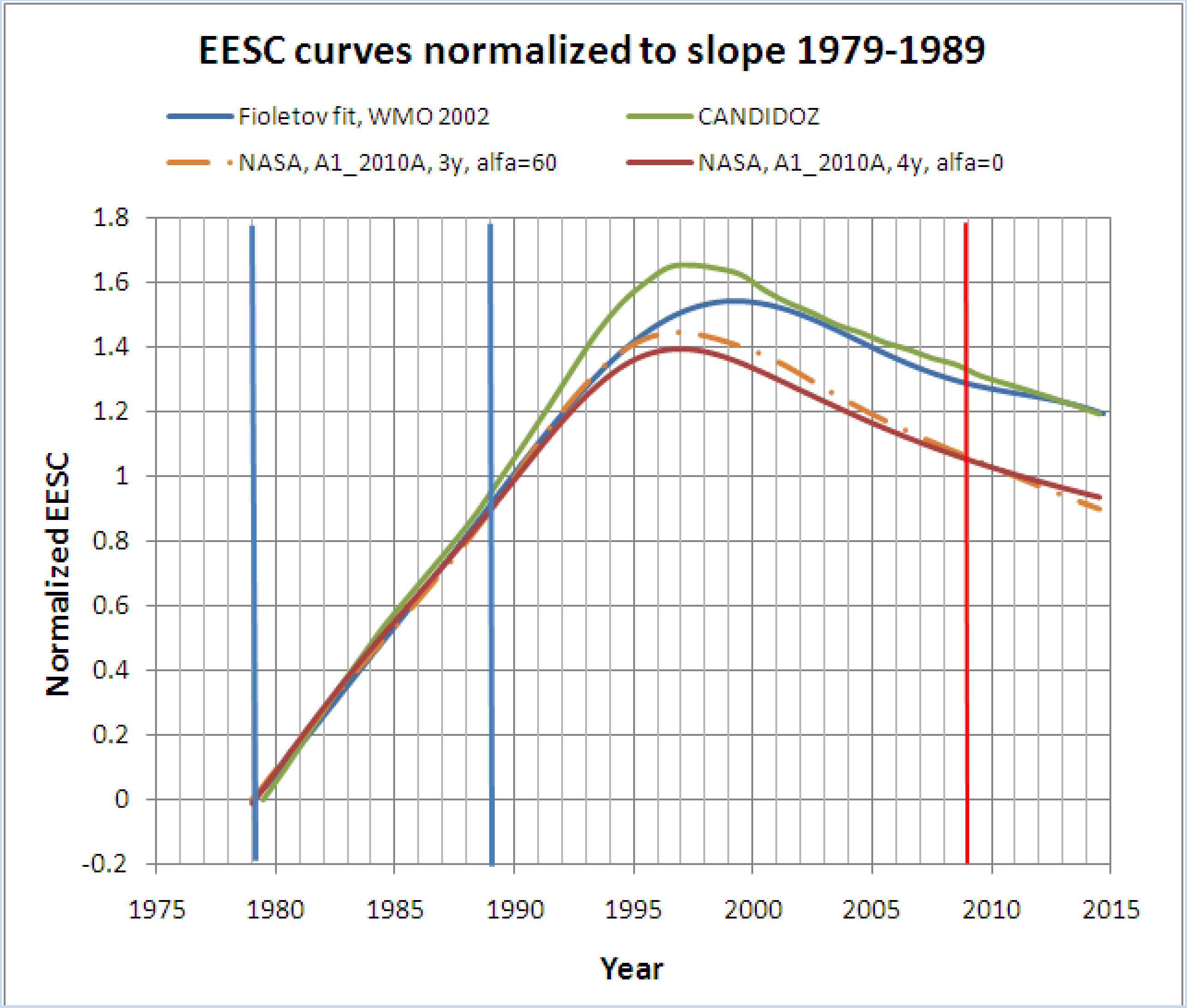
# Upper stratospheric ozone variability [Steinbrecht, et al. (2009)] – natural and ODS changes



# Data Analyses and methods

- PWLT (piece wise linear trend) – two linear trends, turn around in the ODS curve (CFCs) in 1996 -2000.
- EESC (effective equivalent stratospheric chlorine)
  - fractional release of CFC and Halons
  - alpha factor (Bromine).
  - age of air – function of latitude and altitude
  - curve - release values, the age of air spectrum, multiplied by the release rate factor.
- Goddard model (Waugh, D.W., T. M. Hall (2002), Schauffler, S. M., et al (2003), Newman et al. (2006)) , Mid-latitudes
  - **low stratosphere** - 3-years mean age of air
  - **upper stratosphere** - 4 years mean age of air

# EESC curves for upper (above 30 km, 4 years) and lower stratosphere (3 years)



# Data

- Ground based
  - Dobson and Brewer (Column and Umkehr profile in ~5 km layers, smoothed vertical resolution)
  - Sonde sounding (reported in 100 m resolution)
  - Lidar (1 km)
  - FTIR (ground-10 km; 10-18 km; 18-27 km; and 27-42 km)
  - Microwave (2 km)
- Satellite (~ 3 km resolution, smoothed vertically)
  - Merged TOMS, NOAA (/2) SBUV and Aura OMI time series (MOD) (Goddard, S. Frith, R. Stolarski)
  - NIWA (G. Bodecker): TOMS, GOME, SBUV
  - combined SCIAMACHY (2002) and GOME/2 (2006) records (Weber et al., 2007; Loyola et al., 303 2009).
  - SBUV data referenced to SAGE, 1979-2005 (McLinden et al., 2009).

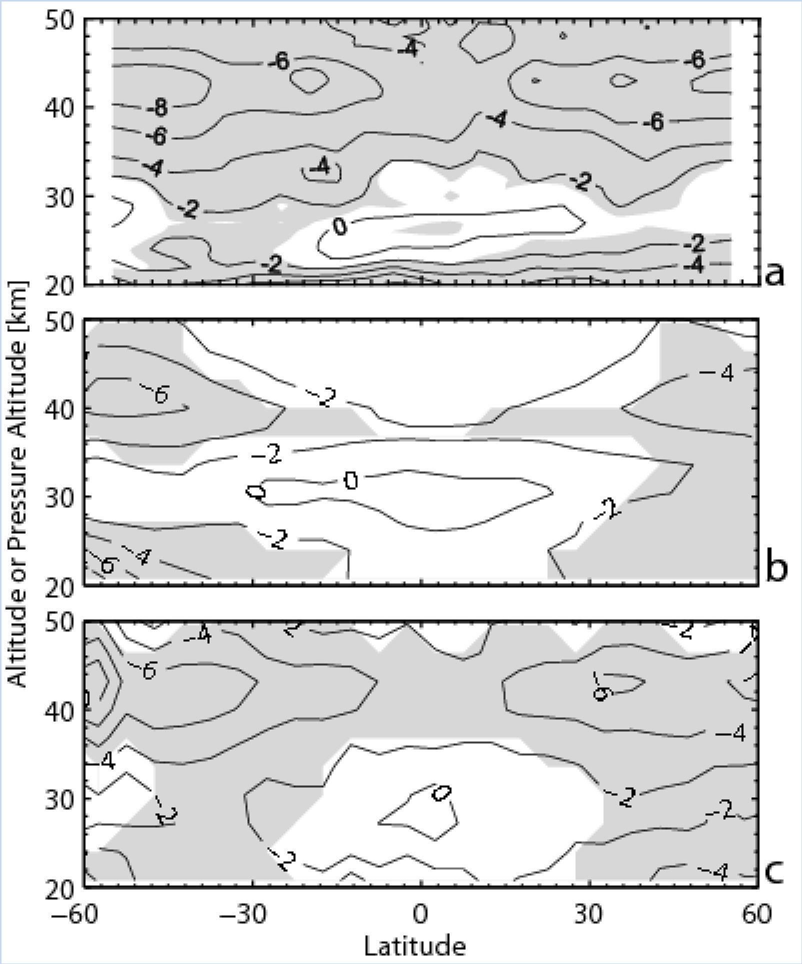
# Total ozone column trends update

- Average - very little change from 2007.
- global 3.5% below 1964-1980.
- Mid-latitude, both NH and SH - stabilize at 3.5% and 6% lower than the pre-1980 average.
- No sign of increase in recent years for global ozone.
- But **statistically significant positive trends** in zonal averages
  - **50°S-50°N -** increase in the tropical belt, low values in the mid-1990s and high due to recent solar activity minimum.
  - **5°S and 30°N** - statistically significant increase from June 1995 to April 2009

# Discussion

- Recent data analyses seem to contradict previous estimates of the number of years required to detect statistically significant ozone trend expected from the decline of ODCs (Weatherhead et al., 2002; Vyushin et al., 2007) – "statistically significant trends will be detected first at southern middle latitudes and it will happen not earlier than in 2015-2020".
- Are there some other mechanisms that might contribute to ozone recovery?
- EESC decrease since the mid-1990s is not a major contributor to the recent increase in ozone (Reinsel et al., 2005; Dhomse et al., 2006; Wohltmann et al., 2007; and Harris et al., 2008).
- How are the total ozone changes distributed vertically and globally?

# Stratospheric ozone trends as a function of latitude from various data sources

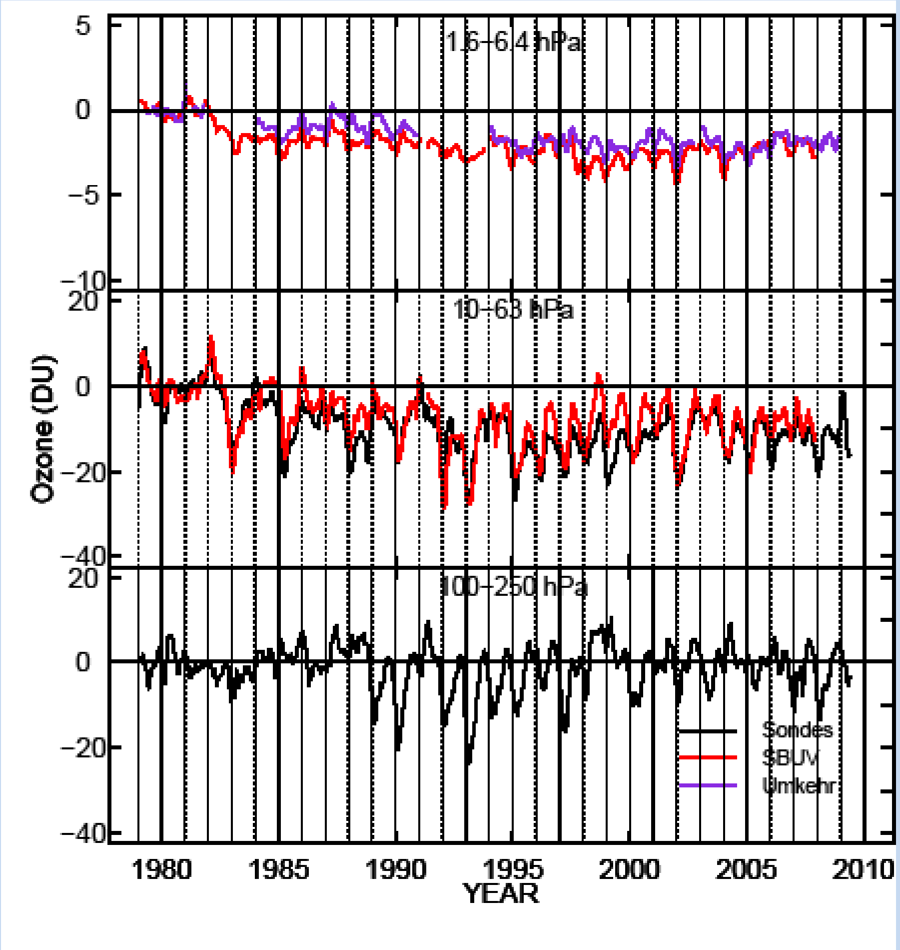


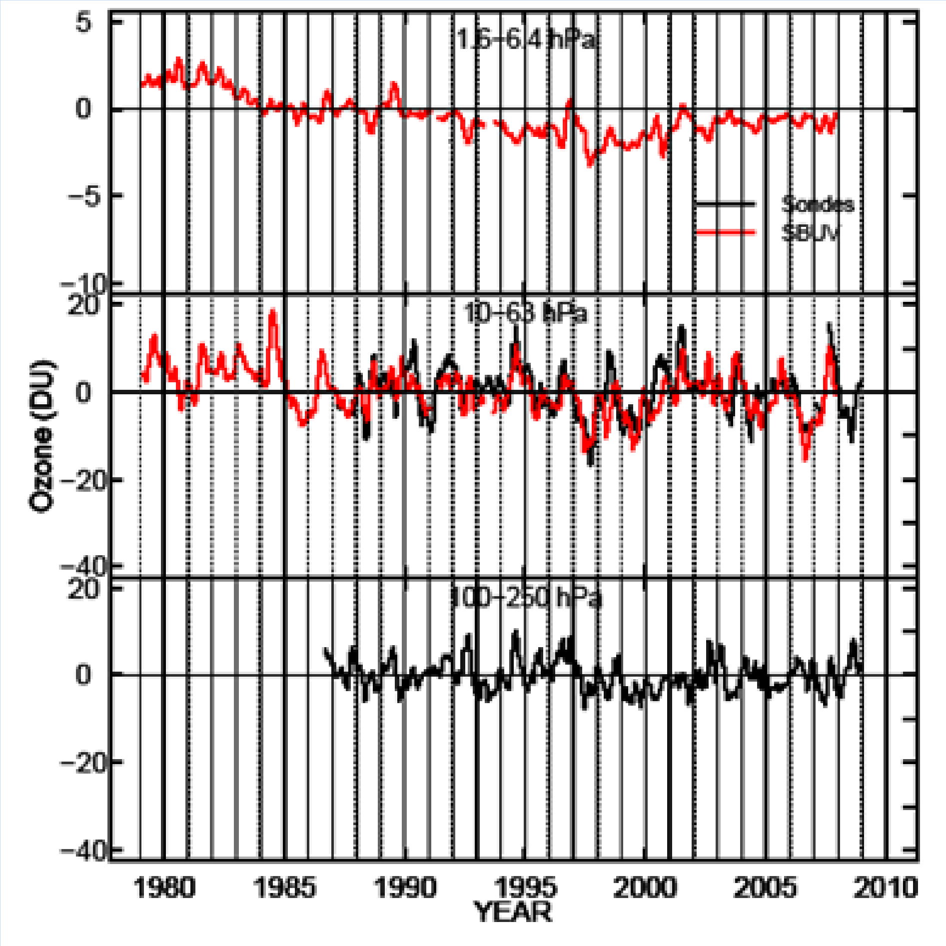

(a) SAGEI+II (Randel and Wu, (2007)

(b) NASA merged SBUV data set

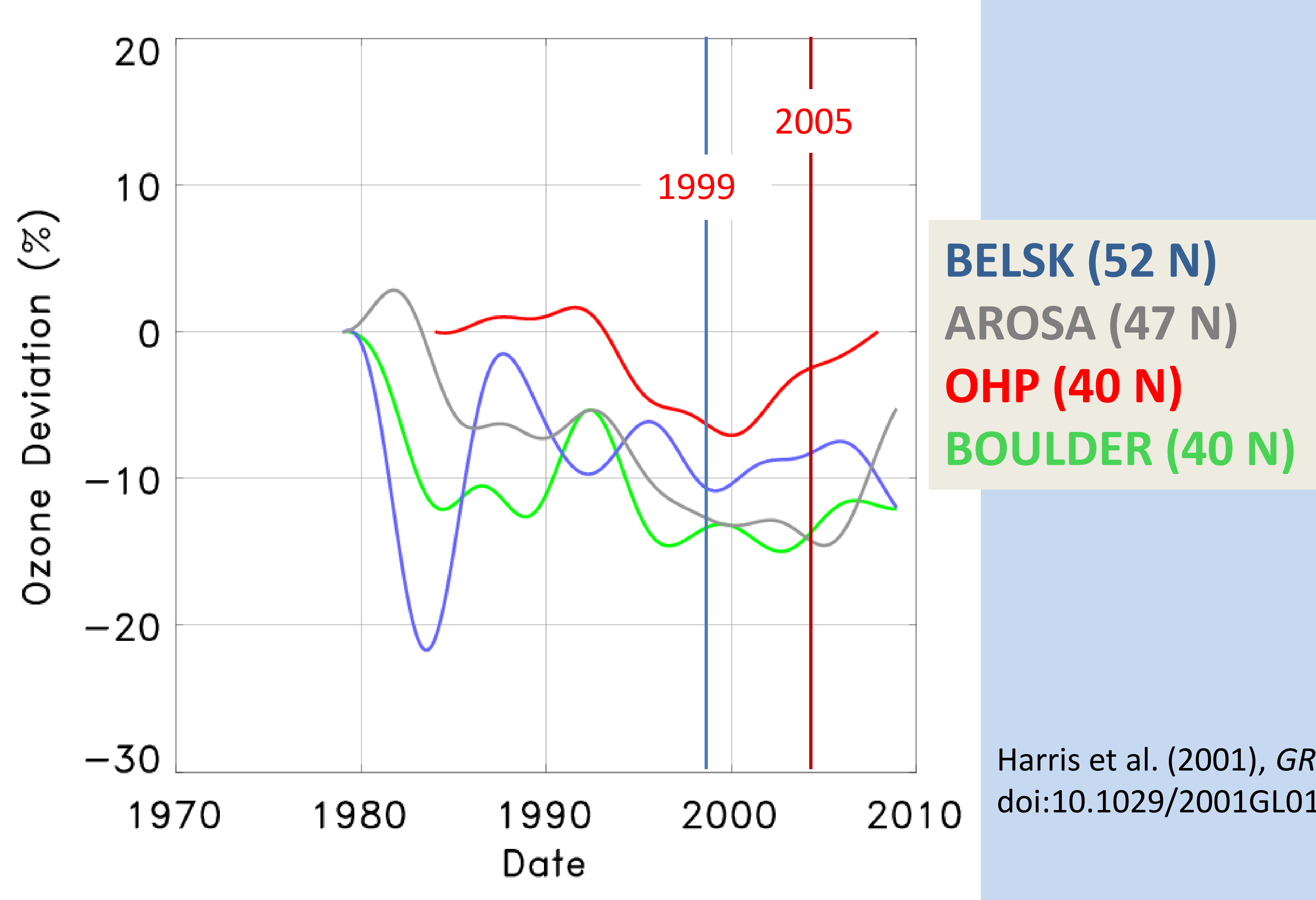
(c) SAGE-corrected SBUV (McLinden et al., 2009

# Time series of ozone data in 3 layers. Europe, NH and Lauder, SH



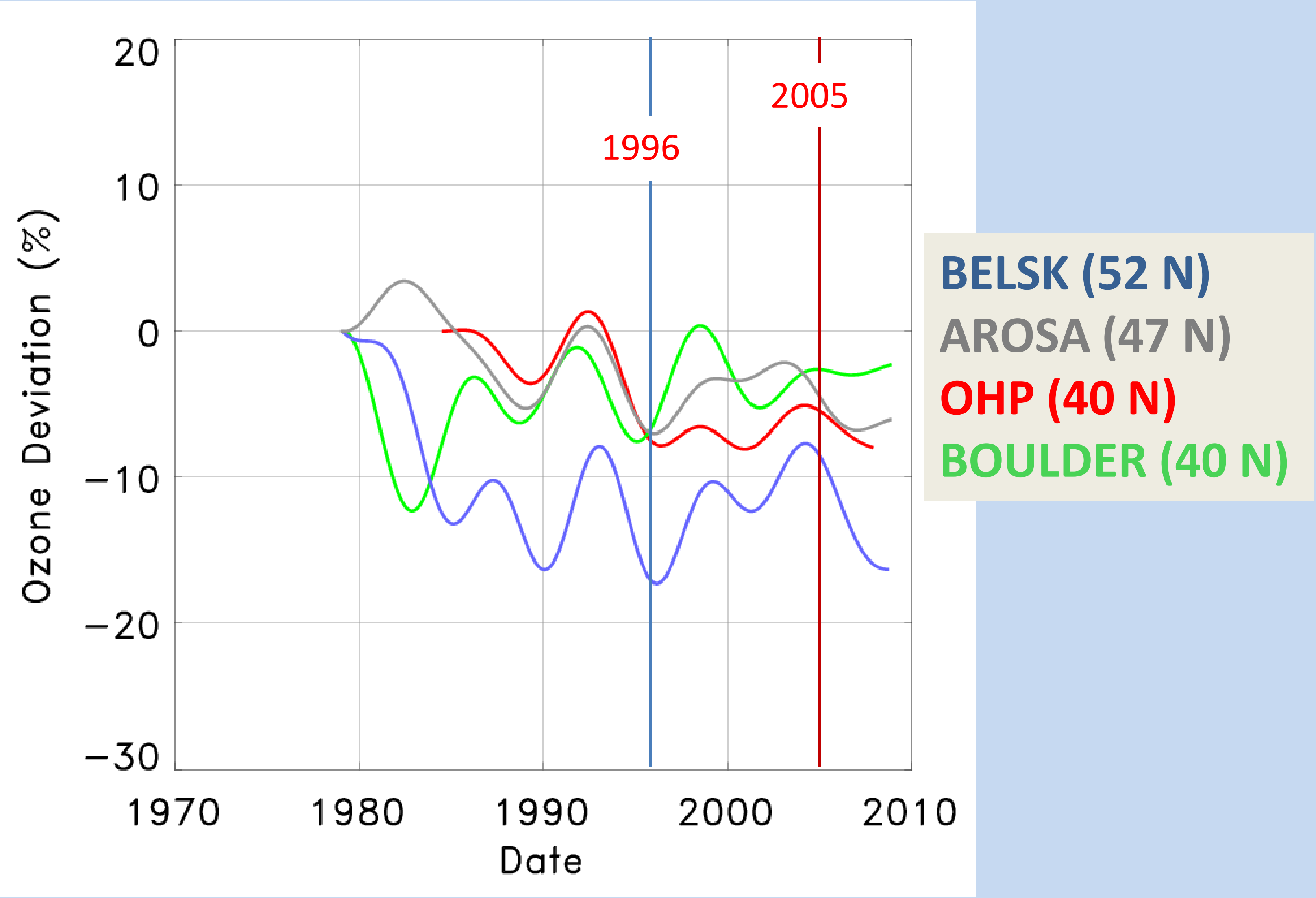



# Ozone tendency, upper stratosphere, Umkehr ozone, 40-45 km, 4-2 hPa

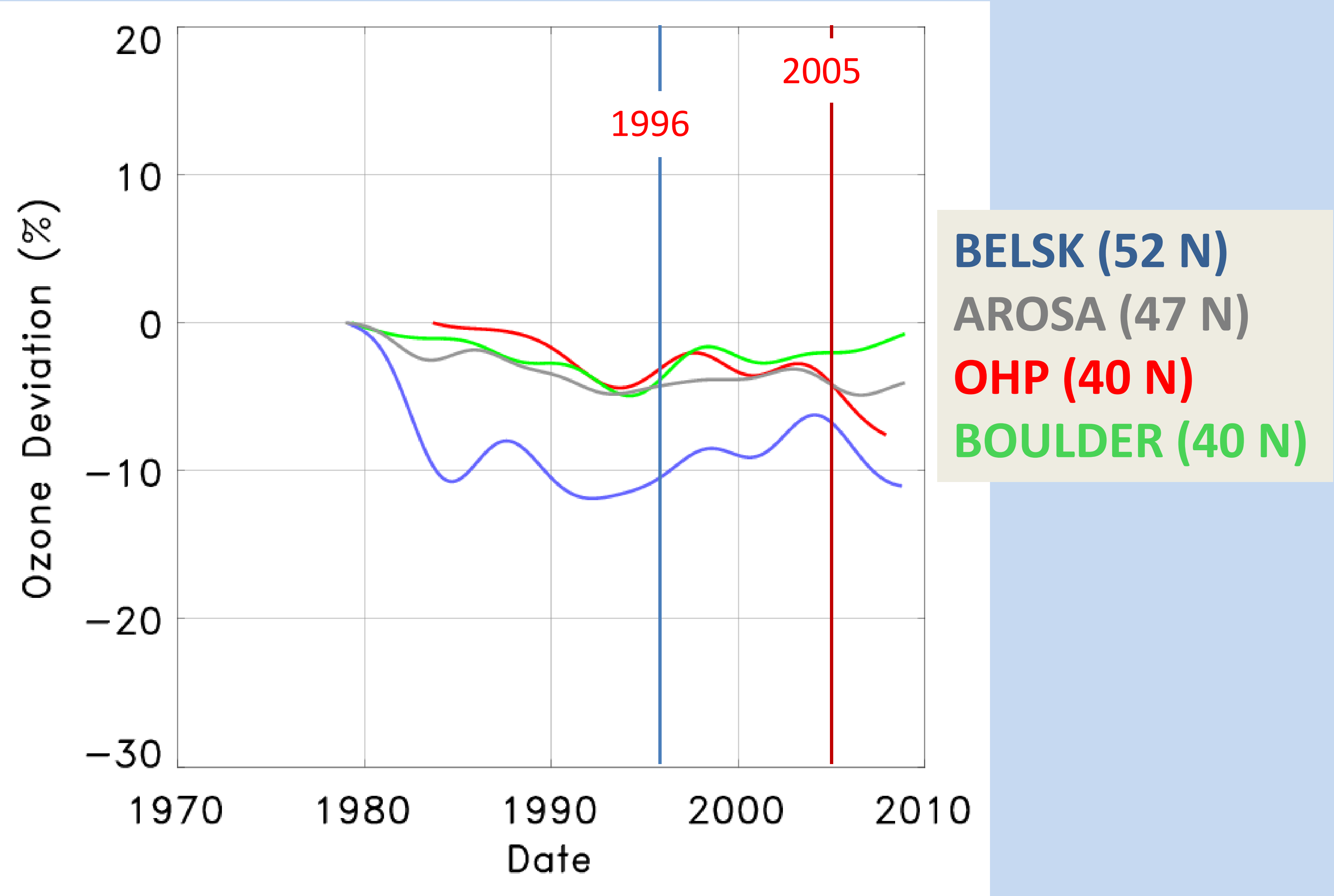



Harris et al. (2001), *GRL*, doi:10.1029/2001GL013501.

# Ozone tendency, lower stratosphere, Umkehr ozone, 15-20 km, 125-63 hPa

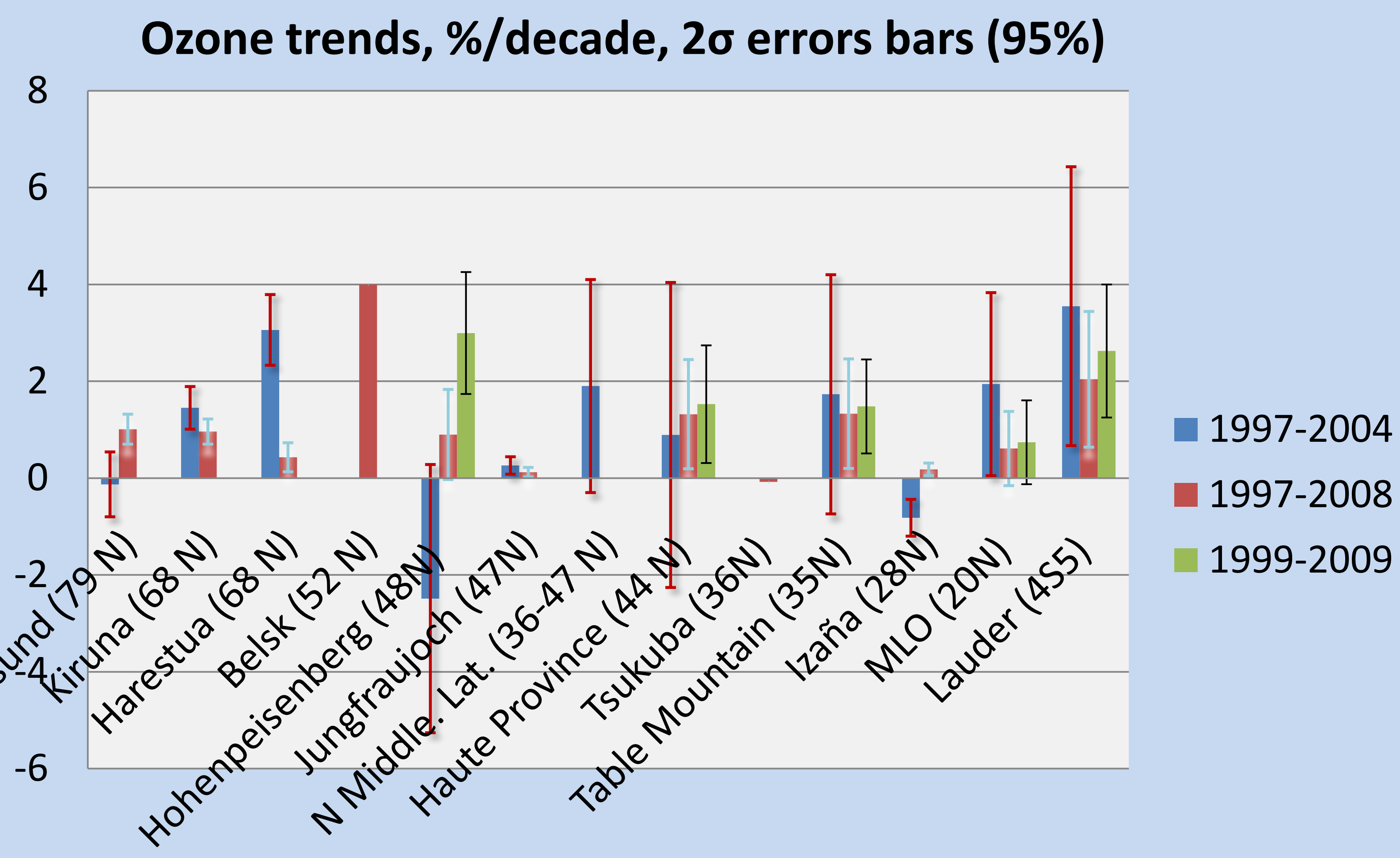


# Ozone tendency, total column

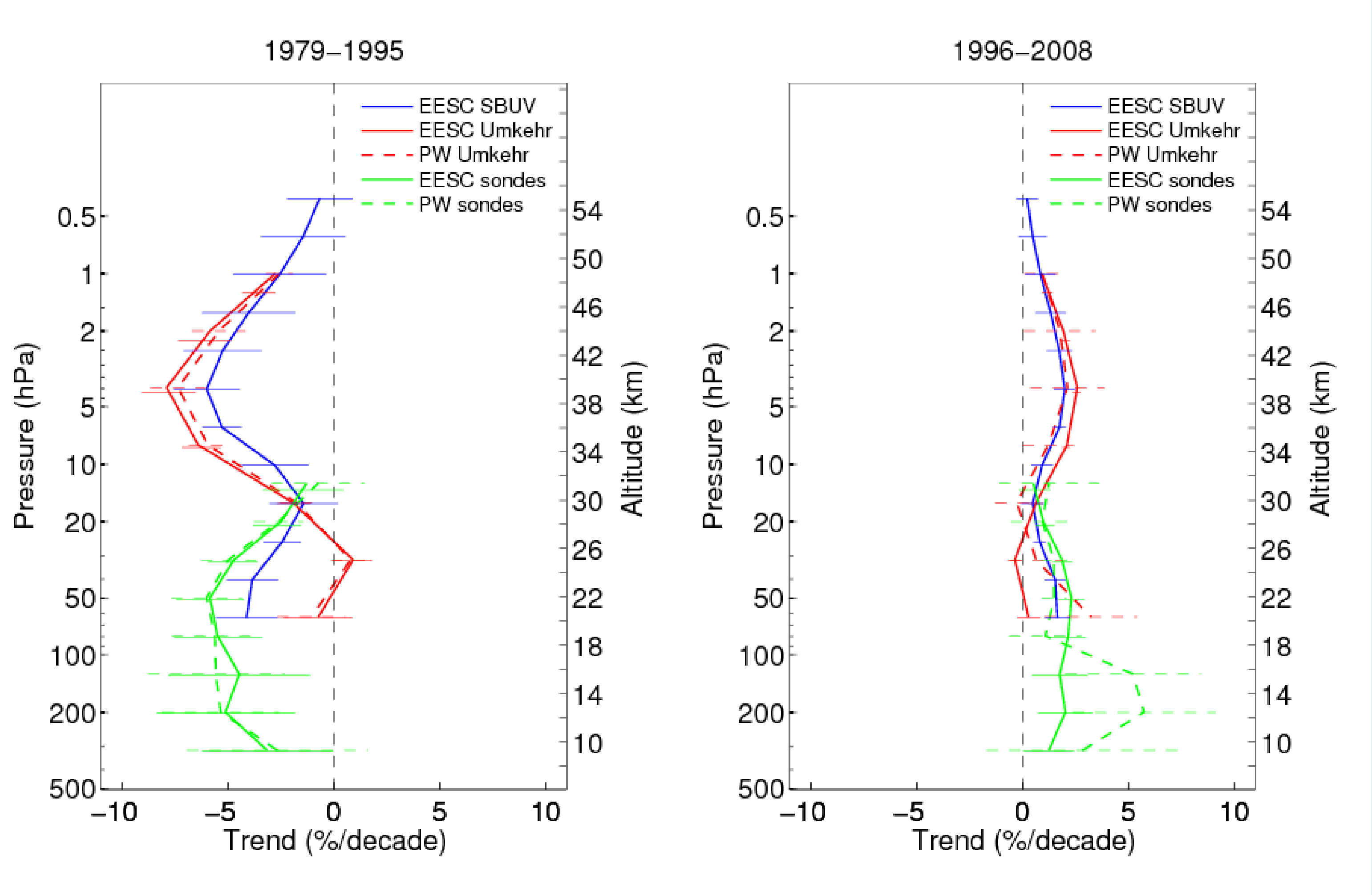


# Upper and middle stratosphere (+4 years)

Lidar + Satellite (35-45 km), FTIR (27-40 km), Umkehr (35-40 km)



# Vertical ozone trends
# *EESC* (EXPECTED rate of ozone recovery) vs. *PWLT* (statistically significant increases in ozone above previous minimum values)



# Conclusions from observations

- Various datasets show some biases, but very similar interannual variations.
- Upper stratosphere (1.6-6.4 hPa)– stabilized ozone levels since 1996, extra-tropical stations show statistically significant increase in ozone levels since 1999, but not in tropics
- Lower and middle stratosphere (10-63  hPa)- stabilized ozone levels, more pronounced over Europe than in the Southern hemisphere.
- Lowermost stratosphere (100-250 hPa) - no significant long term variation.

# Trend analysis results

- Decline in ozone is consistent with 2007 WMO statement.
- Increasing EESC
  - two maxima in the upper (-7%) and lower (-5 %) stratosphere
  - agreement between EESC and PWL trend
- Decreasing EESC
  - positive ozone trends, about 2 % per decade, not significant in the lower stratosphere, 2 sigma significant around 40 km for ground-based
  - discrepancy between EESC and PWL trend analysis in the lowermost stratosphere
- Large positive PWL trends in lowermost stratosphere vs. barely significant EESC trends suggests that ozone increase could be due to other factors (e.g. dynamical processes) than chlorine decline.