Combining height resolved ozone time-series from satellite measurements

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Objectives

- Extension of "historical" stratospheric satellite time-series (SAGE, HALOE, ...) with data from "new generation" of satellites, launched from 2001 onward: Odin, Envisat, ACE, Aura, ...

- Ozone recovery?
- Stratospheric chlorine (Cly, ClOx)?
- Nitrogen family (NOy)?

...

- Water vapour evolution?

Workshop aims

- Satellite data sets suitable for assessing long-term changes? Yes (if long enough)
- Internally consistent? Yes (Odin data sets)
- Evidence for consistency? Comparisons!
- Useful for evaluation of other data sets? Yes
- Can it be used in conjunction with other data set to provide a 20-30 year record? Yes
- Lessons learnt? see summary of this talk ...

Ozone

Ozone depletion from satellites

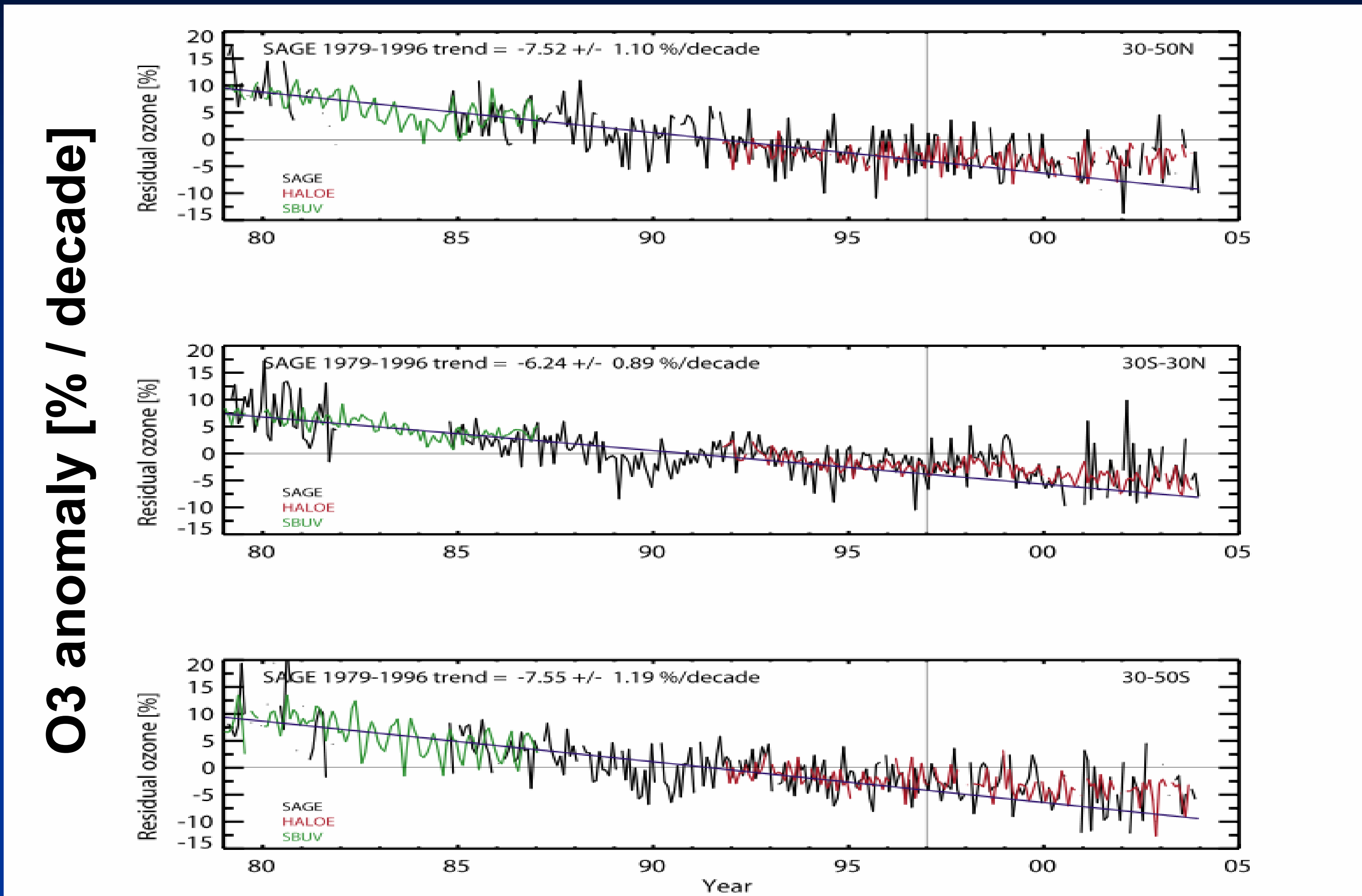


Figure 3. Residuals of the SBUV Nimbus 7 ozone series (green lines) at 35–45 km, (top) 30°–50°N, (middle) 30°S to 30°N, and (bottom) 30°–50°S, respectively. The trend lines are derived from the SAGE residuals (black lines) for 1979–1996. The HALOE residuals are shown by the red lines. These residuals were all obtained using the F10.7cm flux proxy for the removal of the solar cycle effect (as given by N3).

SAGE I+II
1979 - 1997 trend:

-7.5 ± 1.1 %/decade
30-50N

-6.2 ± 0.9 %/decade
30S-30N

-7.6 ± 1.2 %/decade
30-50S

upper stratosphere
35-45km

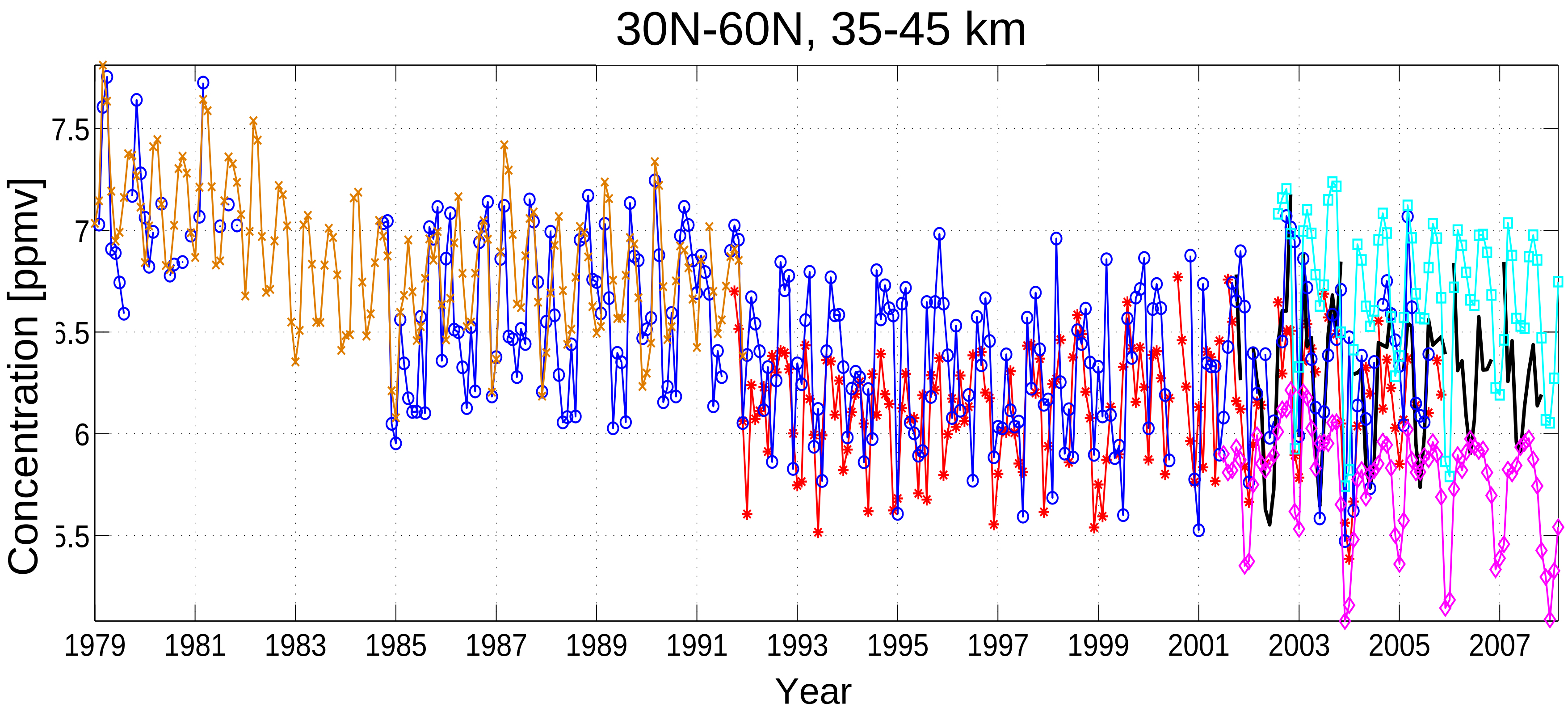
(Cunnold et al, 2004) **HALOE SAGE SBUV/2**

Satellite ozone profile data sets

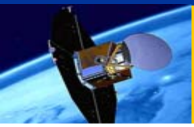
- SBUV	(v8.0)	**1979-1992**	UV/VIS - nadir
- SAGE I + II	(v6.2)	**1979-2005**	UV/VIS - limb
- HALOE	(v19.0)	**1991-2005**	thermal IR - limb
- OSIRIS	(v3.0)	**2001-present**	UV/VIS - limb
- SMR	(v2.1)	**2001-present**	microwave - limb
- SCIAMACHY	(v2.0)	**2002-present**	UV/VIS -limb

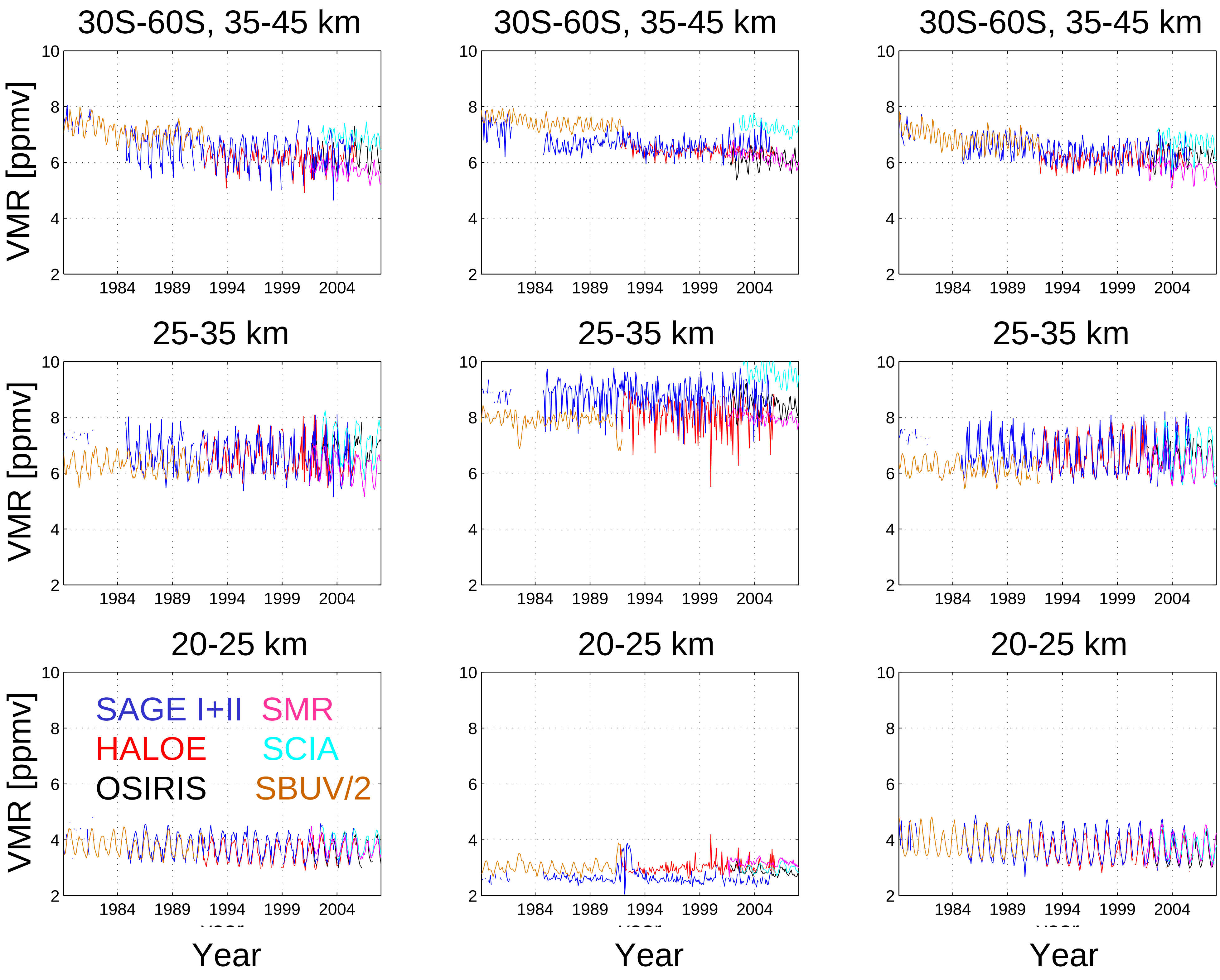
Ozone trend from satellites

Monthly zonal mean ozone - 30N-60N - 35-45km



SAGE I+II HALOE SBUV SMR OSIRIS SCIAMACHY




30S-60S, 35-45 km
30S-60S, 35-45 km
30S-60S, 35-45 km
25-35 km
25-35 km
25-35 km
20-25 km
20-25 km
20-25 km
VMR [ppmv]
VMR [ppmv]
VMR [ppmv]
10
8
6
4
2
1984
1989
1994
1999
2004
SAGE I+II
SMR
HALOE
SCIA
OSIRIS
SBUV/2
Year
Year
Year

Linear regression model

$$O_3(t) = a + b\,t + [\text{Seasonal terms}]$$
$$+ [\text{QBO periodic terms}]$$
$$+ [\text{Solar terms}]$$
$$+ N_t$$

a = constant offset

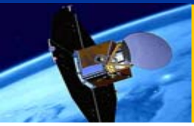
b = linear slope

Seasonal terms = 12 and 6 months

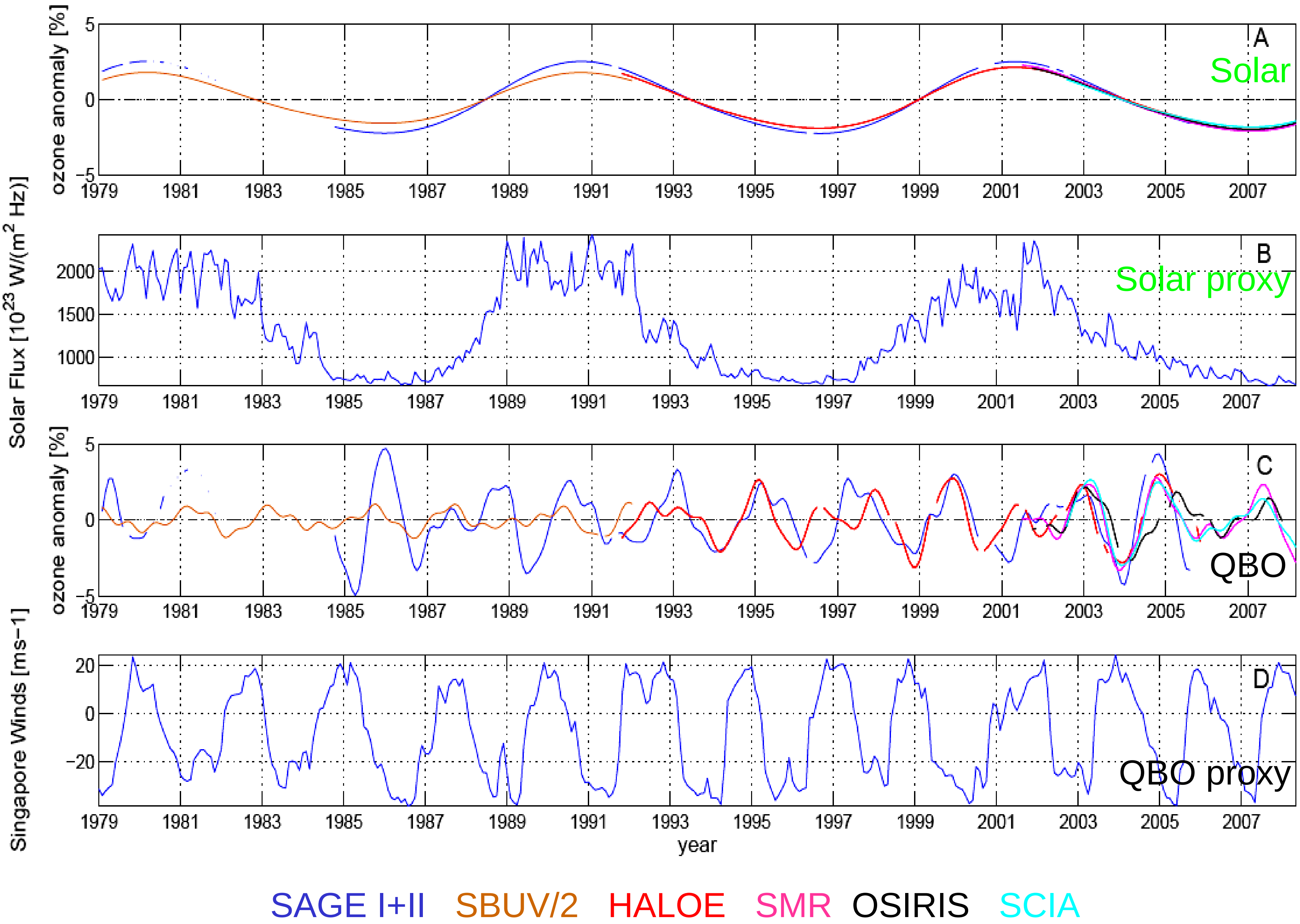
QBO terms = periods between 3 and 30 months
(examined using a FFT model)

Solar terms = 63 and 127 months
(as suggested by Cunnold et al., 2004)

N_t = auto-correlated error term (i.e. remaining residual)



Estimates of QBO and sun related ozone variation, 30–60N, 35-45km



Statistical methods for detection of milestones

(a) "Change in linear trends" method

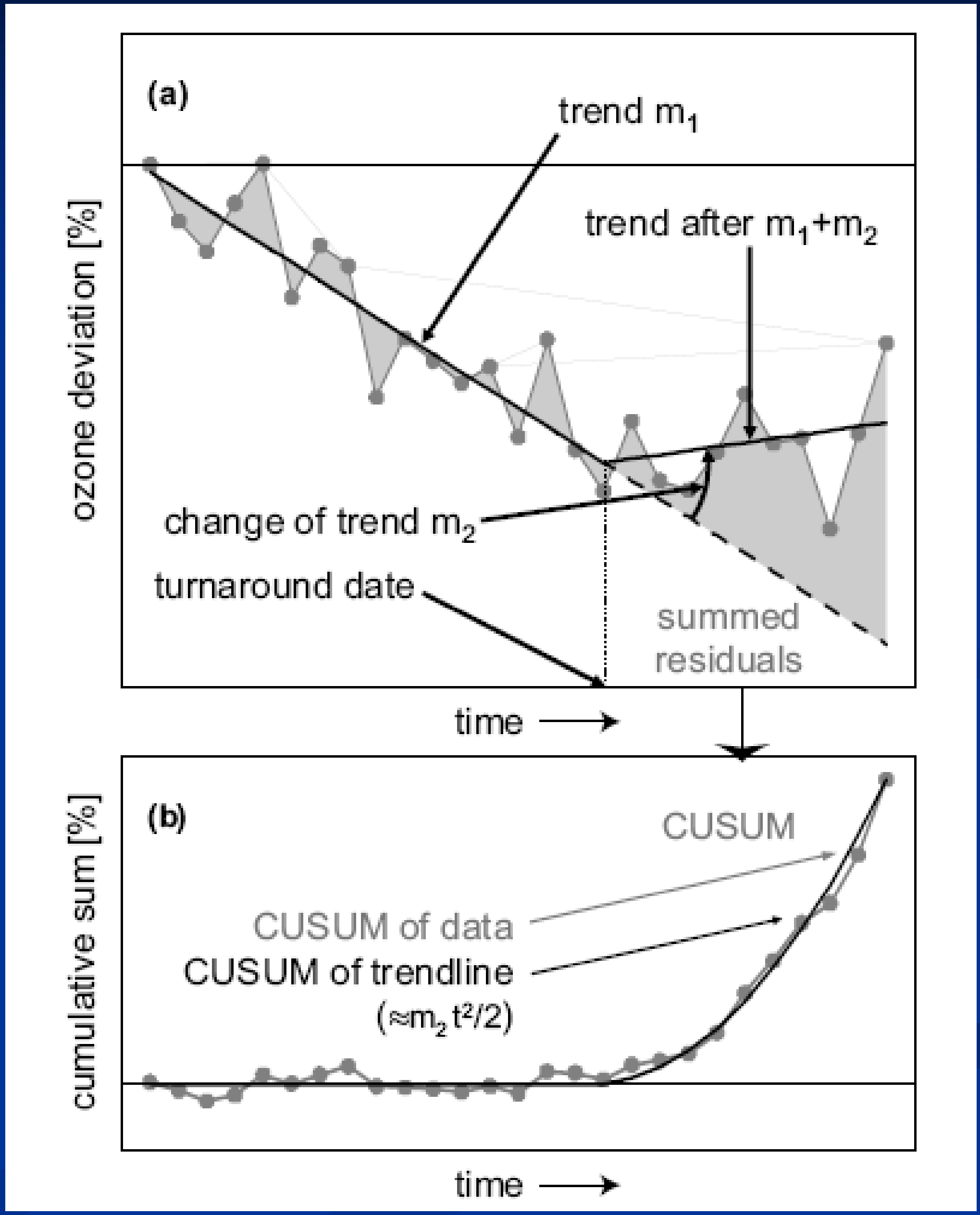
linear trends before and after selected turn-around date

[Reinsel et al., JGR 2002]

(b) "Cumulative sum of residuals" (CUSUM) method

deviation from extrapolated linear trend after selected turn-around date by cumulated sum over residuals

[Reinsel et al., JGR 2002; Newchurch, JGR 2003]



Stratospheric ozone changes: Northern mid-latitudes 30-60N, 35-45km

A. Jones et al., Atmos. Chem. Phys. Discuss., 9, 1157–1209, 2009

SAGE I+II
nir limb occultation

SBUV
uv/vis nadir

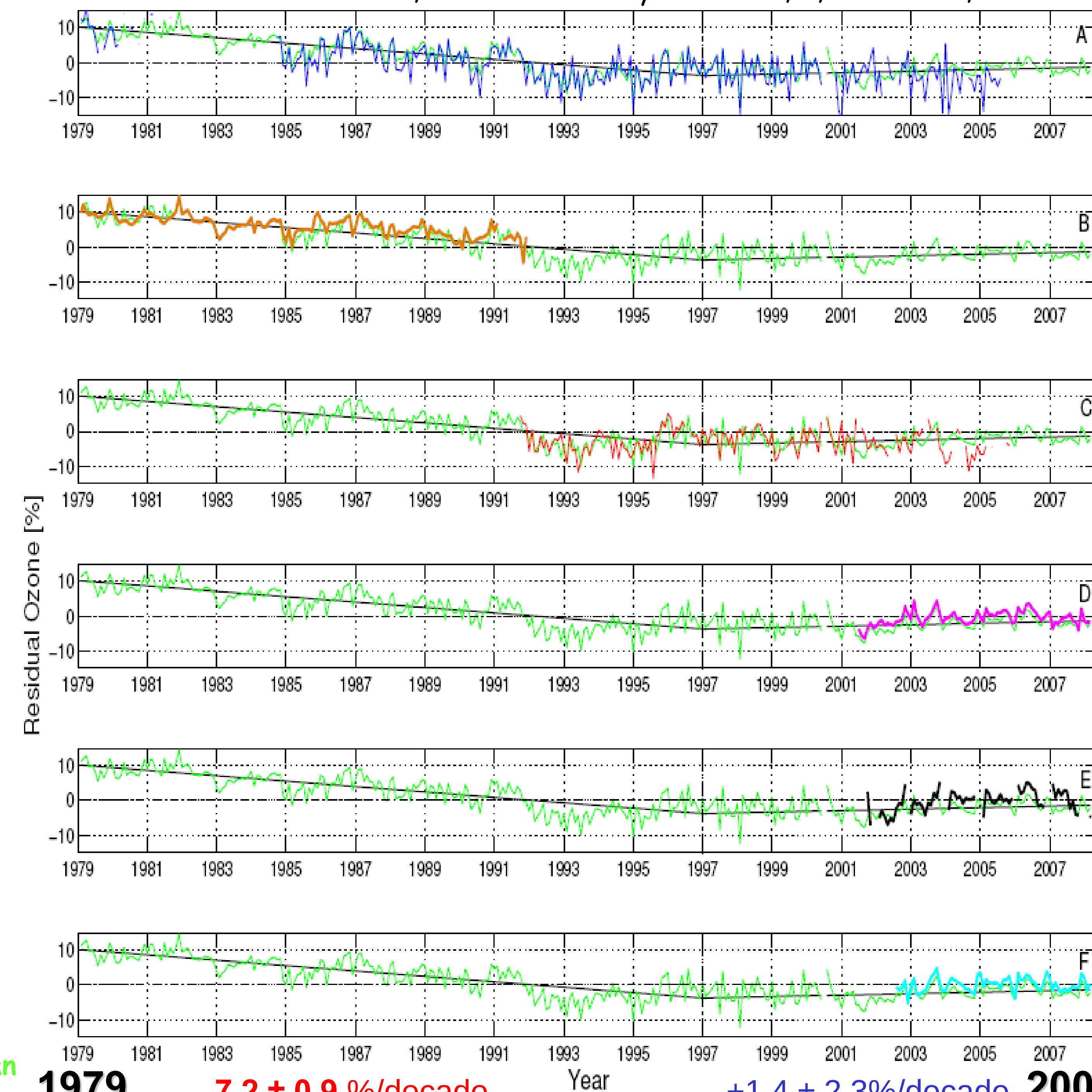
UARS/HALOE
mid-ir limb occultation

Odin/SMR
sub-mm limb emission

Odin/OSIRIS
uv/vis limb scattering

Envisat/Sciamachy
uv/vis limb scattering

green: all instrument weighted mean



1979 -7.2 ± 0.9 %/decade +1.4 ± 2.3%/decade **2008**

Ozone: linear trend estimates

in [% / decade], 2-sigma uncertainties (95% confidence),
assumed "turn-around": 1-Jan-1997

altitude	trend period	SH: 60S-30S	EQ: 30S-30N	NH: 30N-60N
35-45km upper strat.	pre-1997 1997 - 2008	**-7.1 ± 0.9** 0.8 ± 2.1	**-4.1 ± 0.6** -0.5 ± 1.5	**-7.2 ± 0.9** 1.4 ± 2.3
25-35km	pre-1997 1997 - 2008	**-1.5 ± 0.6** **-2.1 ± 1.3**	**0.7 ± 0.5** **-2.7 ± 1.2**	**-3.3 ± 0.7** 0.8 ± 1.5
20-25km lower strat.	pre-1997 1997 - 2008	**-4.4 ± 0.9** -1.0 ± 2.0	0.5 ± 1.0 0.5 ± 2.3	**-3.8 ± 0.8** 0.2 ± 1.9

=> Upper stratospheric ozone: Statistical significant change of trend, but small "recovery" after 1997 not yet significant at 95% confidence level!

Turn-around year ?

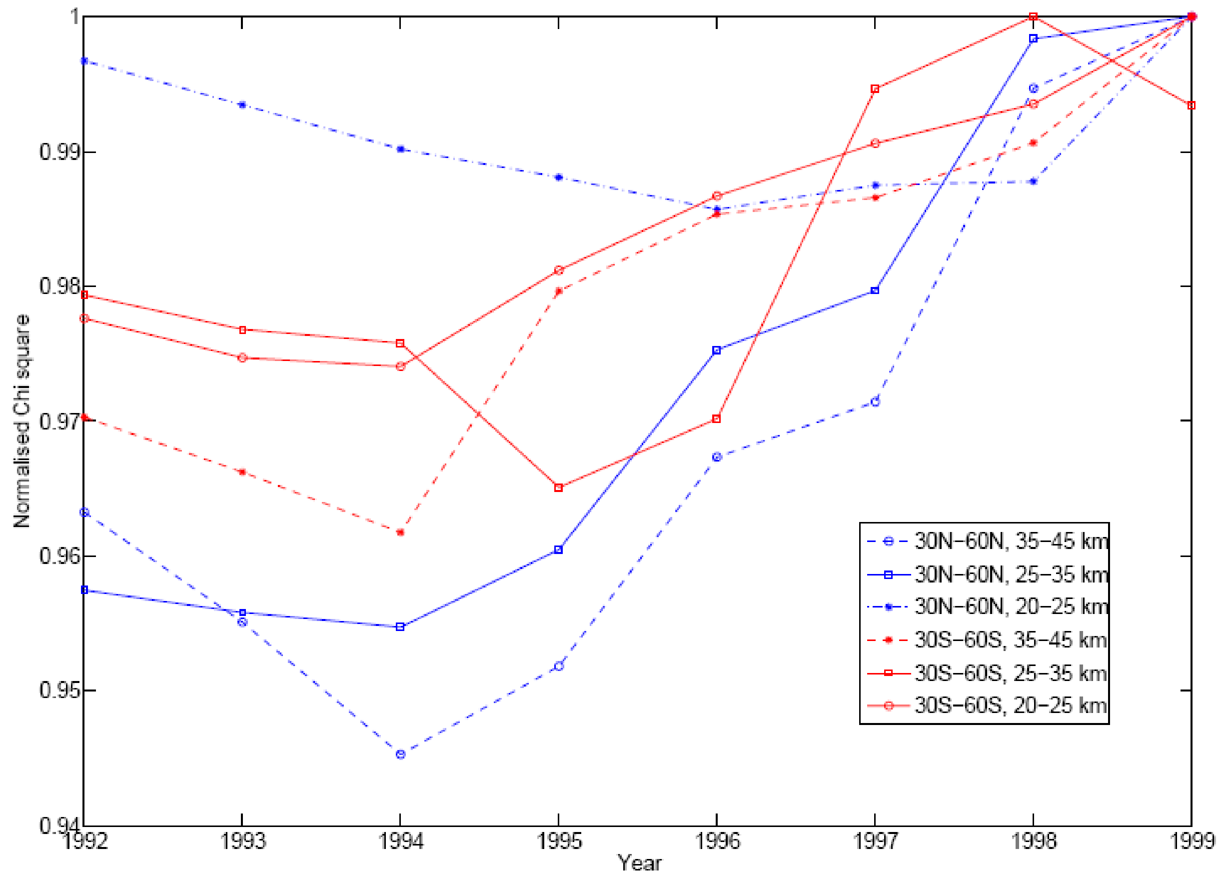


Table 3. Turn around years for each altitude/bin based on minimum χ^2 values rounded to the nearest year. Also shown in brackets are the corresponding trend values up to each turn around date and after. Bold values indicate where the trend value is statistically significant at the two sigma level.

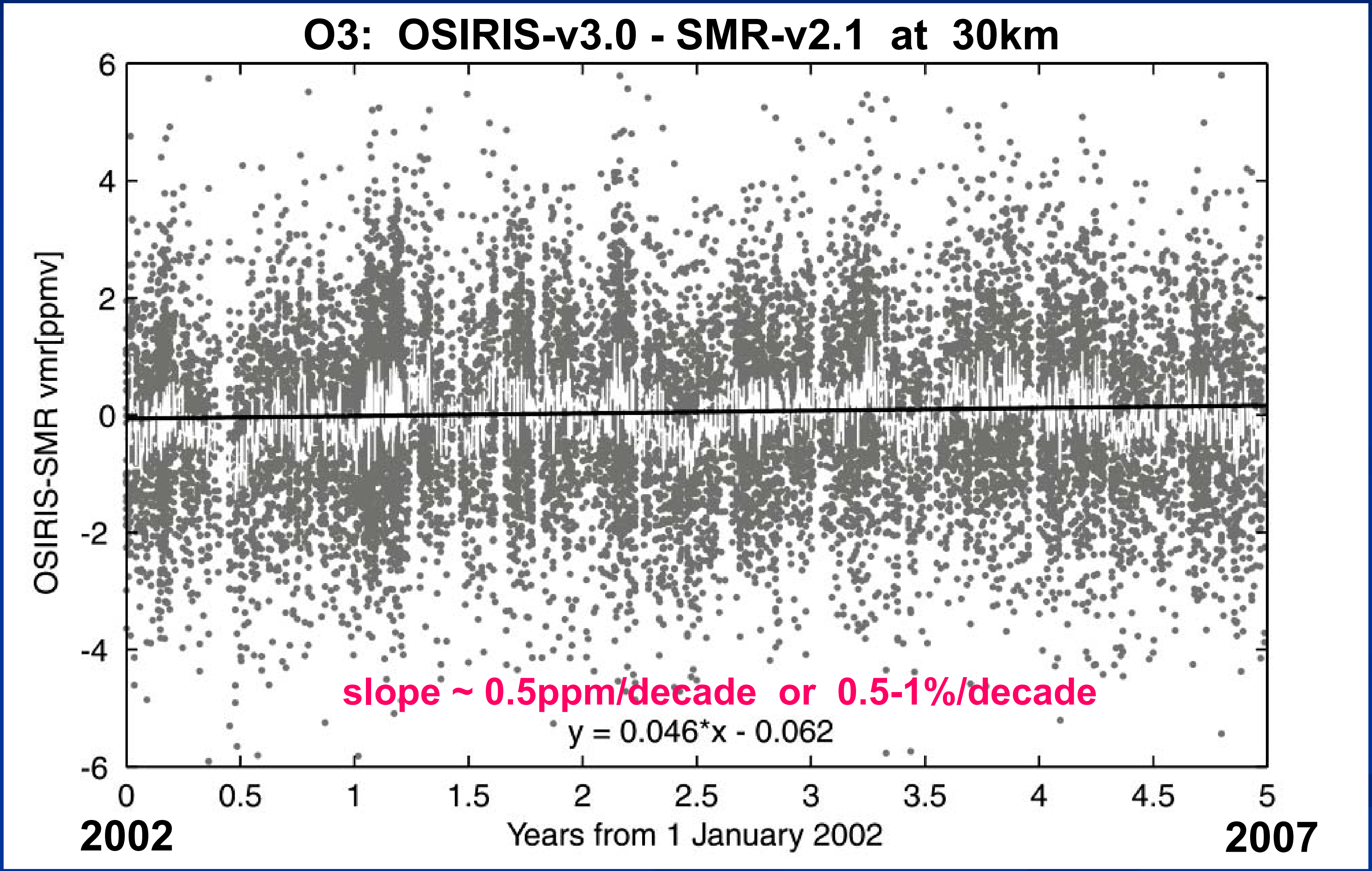
	60 S–30 S	30 N–60 N
20–25 km	1994 (**−5.2±0.9/0.7±1.6**)	1996 (**−3.8±0.9/−0.5±1.8**)
25–35 km	1995 (**−2.0±0.6/−2.0±1.1**)	1994 (**−4.3±0.6/0.4±1.2**)
35–45 km	1994 (**−8.1±0.9 /−0.8±1.6**)	1994 (**−8.3±1.0/−0.5±1.8**)

Instrument drift ?

Table 2. A summary of the instrumental drifts of the six analysed instruments for the nine latitude/altitude bins before and after the break date in 1997. Plus minus values are the two standard deviation uncertainties, where bold values are statistically significant from zero. Drift is defined as the difference between each individual instrument time series and the all instrument average.

Instrument	60 S–30 S			30 S–30 N			30 N–60 N		
	20–25 km	25–35 km	35–45 km	20–25 km	25–35 km	35–45 km	20–25 km	25–35 km	35–45 km
SAGE	−1.4±1.8	1.4±1.5	−0.4±1.4	−2.9±4.2	0.3±1.1	0.2±1.2	−1.1±2.0	0.3±1.4	0.1±1.5
SBUV	−0.7±2.8	−1.7±2.6	−1.3±1.7	−1.5±4.2	0.9±3.8	−0.4±1.4	0.1±3.6	−0.8±2.8	−1.8±1.8
HALOE	−4.8±4.8	**−7.7±6.9**	**−9.3±5.0**	2.2±7.7	1.3±5.7	−2.6−±3.4	−2.9±11.2	−3.6±9.7	**−9.0±7.0**
Instrument drift: Trend – instrument fit (% per decade) prior to 1997									
SAGE	−0.9±4.0	1.8±4.0	1.9±4.4	2.8±4.7	−1.6±2.9	−0.6±3.5	0.2±3.8	1.4±4.3	−1.4±3.4
HALOE	−0.7±3.6	−1.6±4.2	0.6±3.7	−2.2±4.3	−2.3±4.3	−1.7±2.7	1.6±3.3	−0.6±4.6	1.6±3.8
SMR	**6.7±3.6**	**4.5±3.9**	0.8±4.0	**−6.2±3.9**	−1.5±3.0	3.3±4.0	0.1±4.1	2.6±4.1	−0.7±4.7
OSIRIS	**−4.6±4.1**	1.6±4.4	−3.0±5.1	−0.2±4.4	1.1±4.9	−5.0±5.4	**−5.3±3.6**	−0.5±4.1	−3.8±5.3
SCIAMACHY	−1.4±5.2	**4.5±3.6**	1.3±3.7	**−8.9±4.0**	2.7±4.7	**3.3±3.0**	0.2±4.4	2.4±4.5	0.1±4.7
Instrument drift: Trend – instrument fit (% per decade) after 1997									

Internal consistency of Odin/SMR and Odin/OSIRIS ozone data sets



Brohede et al., Can. J. Phys. 85, 1275-1285, 2007

ClO and HCl

Spatio-temporal coverage

solar occultation

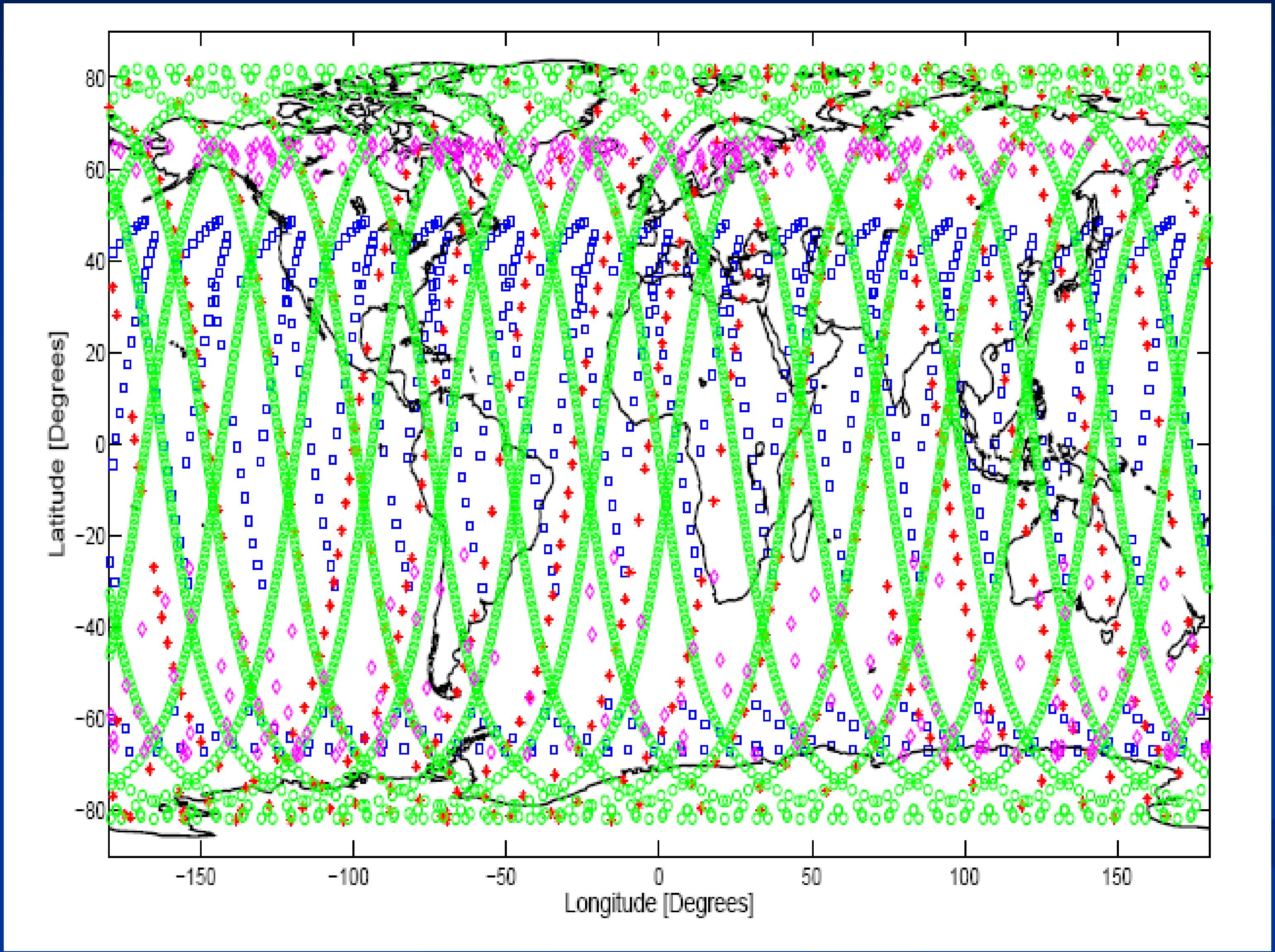
HALOE
January 2005

ACE/FTS
January 2005

thermal emission

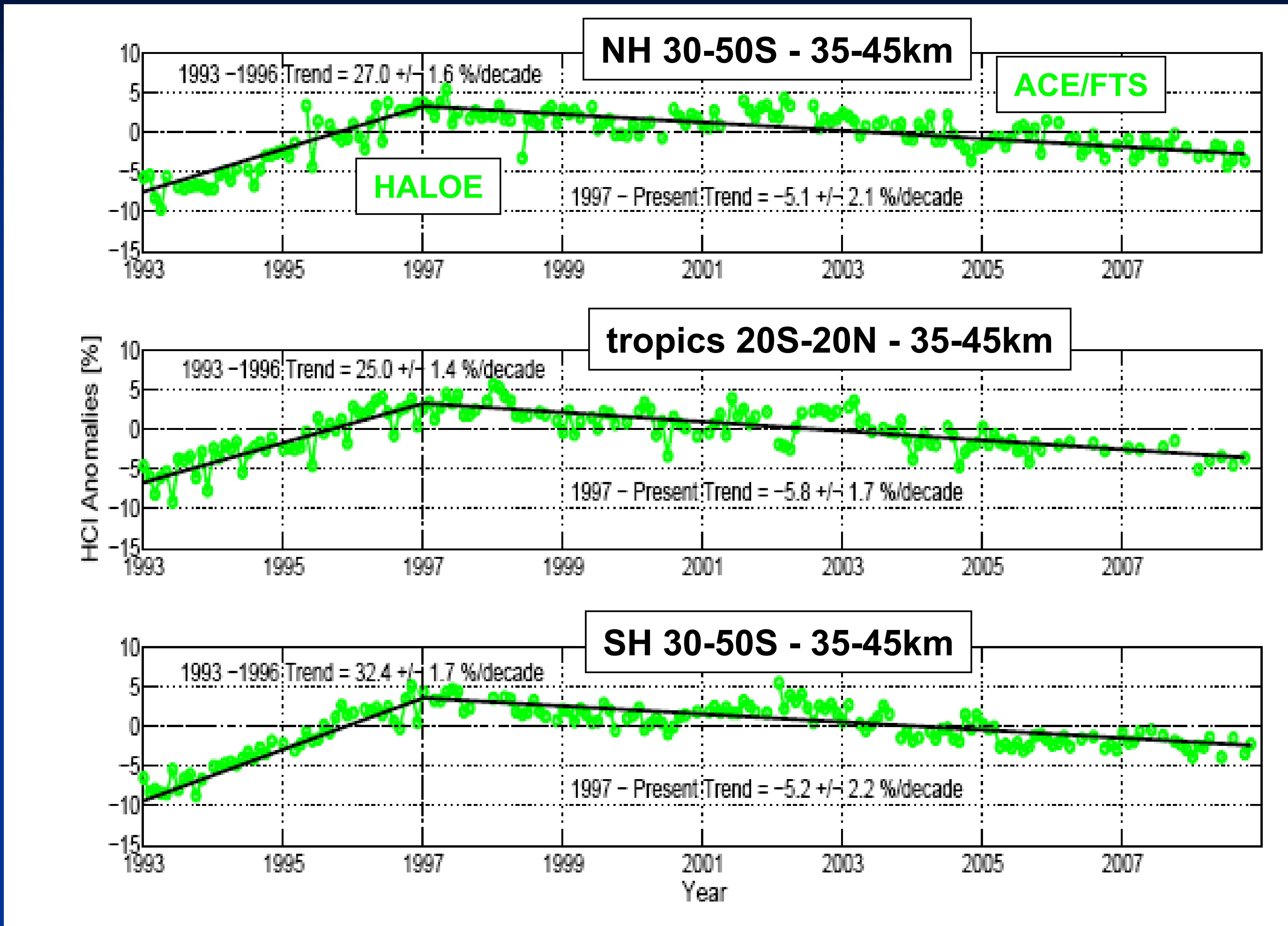
Aura/MLS
1st January 2005

Odin/SMR
1st January 2005



[Jones et al., ACPD 2010, in revision]

HCl trend: HALOE and ACE/FTS



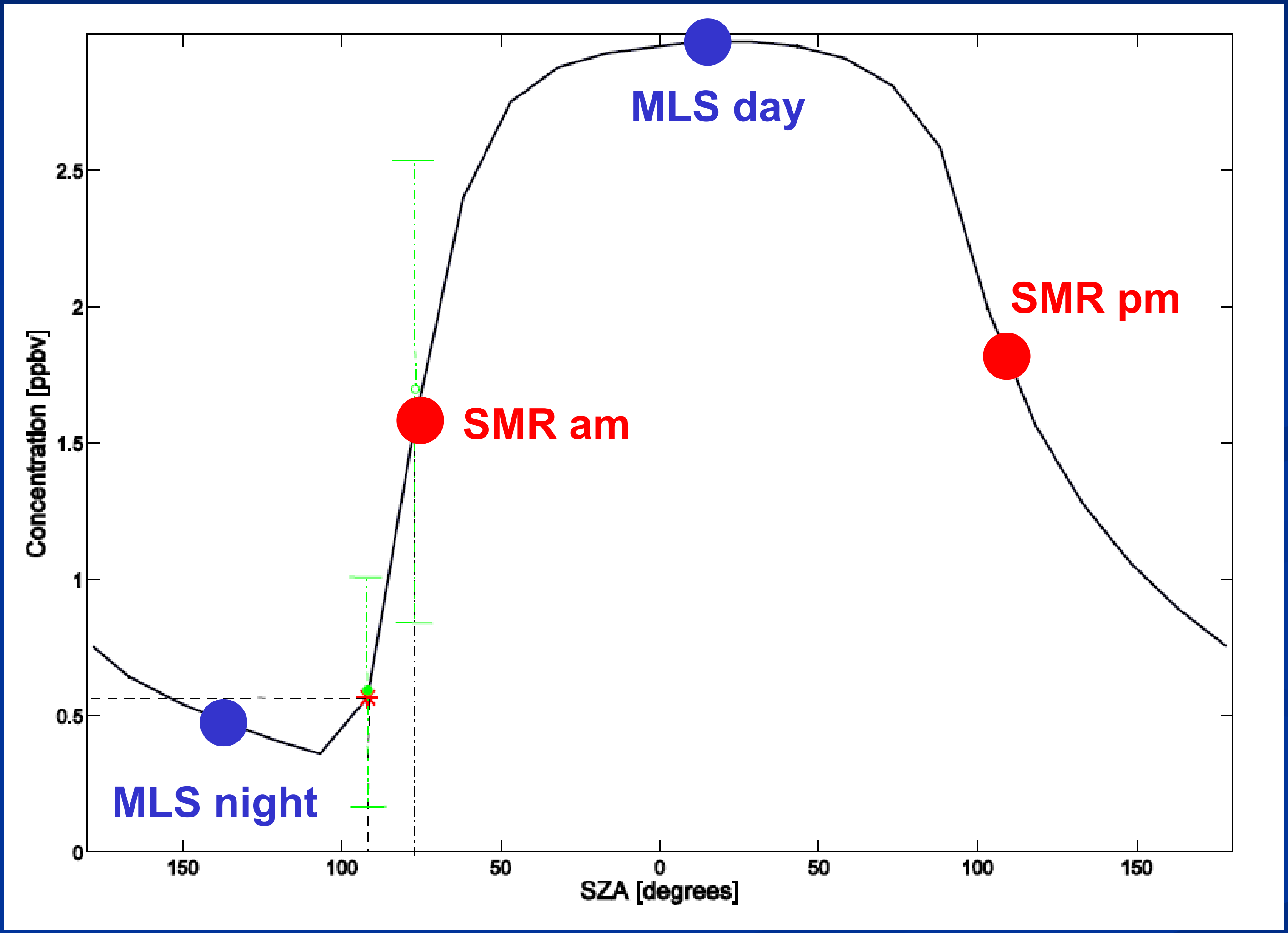
+25-33 %/decade

- 5-6 %/decade

Jones et al., ACPD 2010, in revision

ClO: diurnal variation

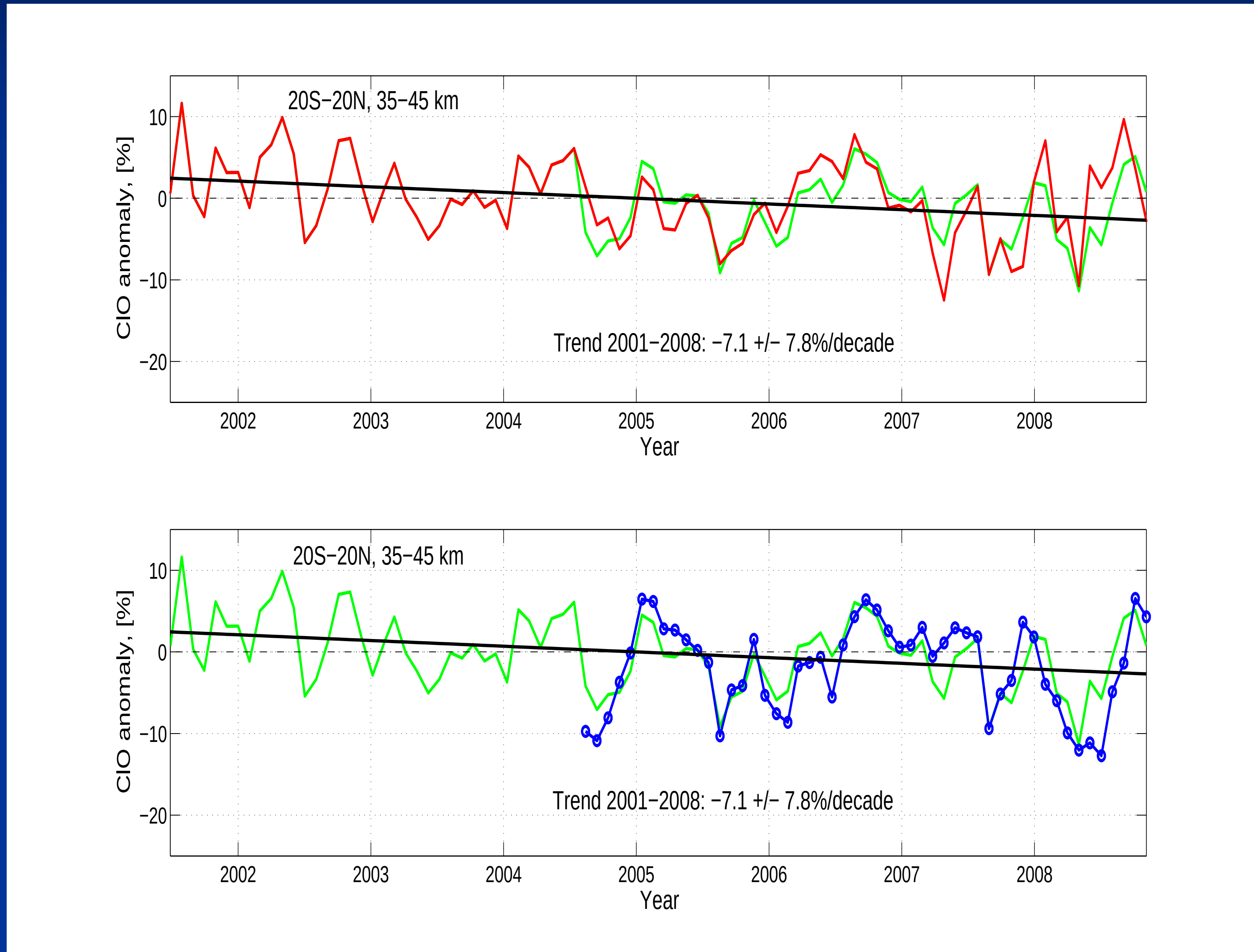
Sun-synchronous orbits: equator crossing MLS ~1:30am/pm, SMR ~6:00am/pm



Scaling factors for local time correction from 1-d model

ClO trend: Odin/SMR and Aura/MLS

equator 20S-20N, upper stratosphere 35-45km,
de-seasonalized and QBO removed, sza corrected to 90°(am)



-7 ± 8% / decade
(not significant at 2-σ)

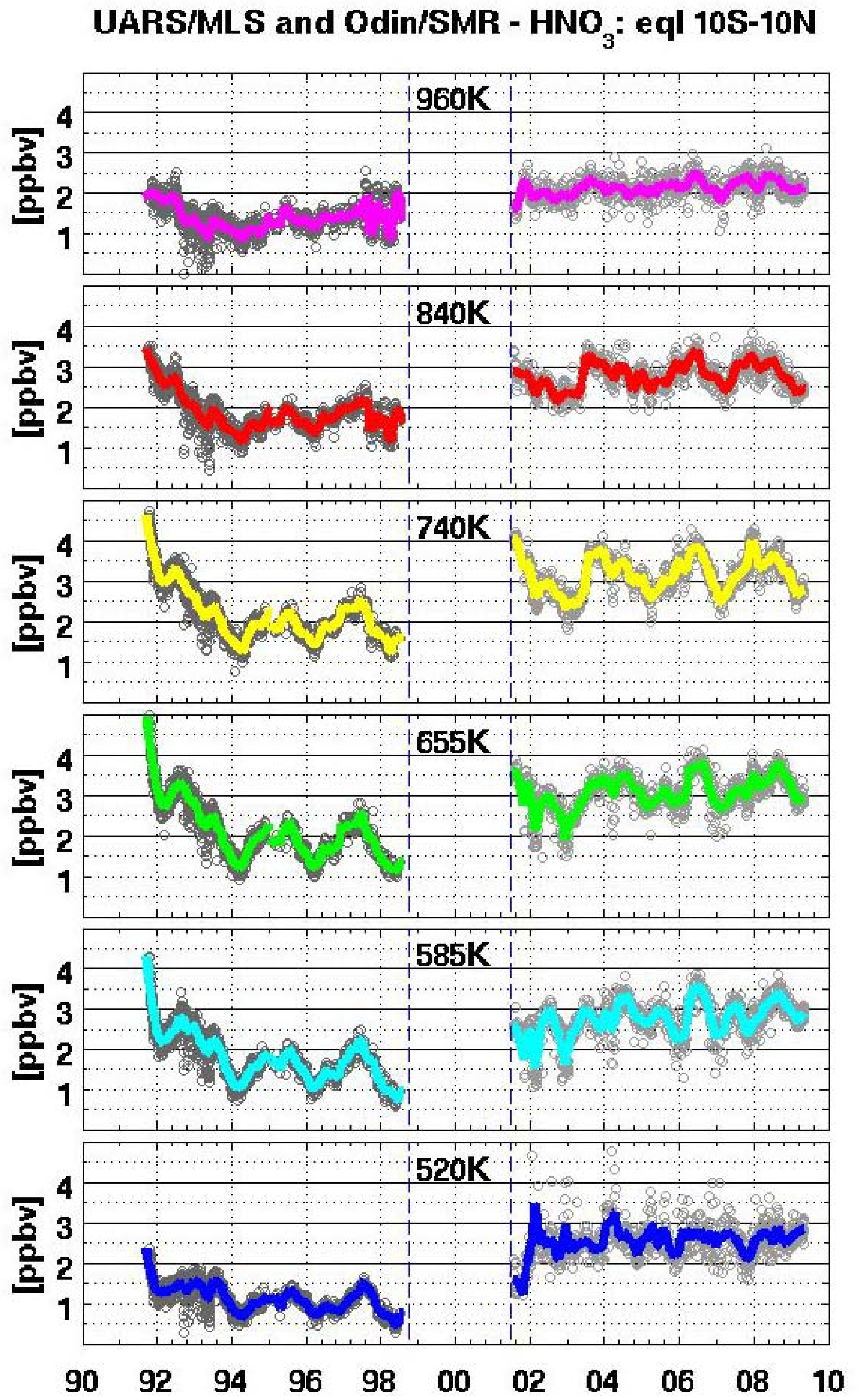
green: all instrument mean

from Jones et al., Ph.D., Chalmers 2009

HNO3

HNO3 evolution: UARS/MLS and Odin/SMR

tropics:
10S-10N
equivalent latitude



UARS/MLS: 1991-1998
Odin/SMR: 2001-2009

Urban et al., ACP-2009 (in press)

Summary (1)

- **Satellite data sets**: "historical" - HALOE, SAGE, SBUV, ...
  "new" - Odin, Envisat, ACE, Aura, ...
- **O3 depletion**: largest decline of ~7%/decade from 1979 until 1997 in upper stratosphere at mid-latitudes. Clear change of trend thereafter, recovery not (yet?) significant with 95% confidence (in 2008).
- **HCl**: HCl increase in upper stratosphere of 25-33% until 1997. Decline thereafter, rate ~5-6%/decade at mid-latitudes.
- **ClO** : -7% intropice for 2001-2008 period (but not significant with 95% confidence).
- **HNO3**: positive trend 1991-2009 or bias of satellite sensors?

Summary (2)

- Combination of satellite time-series:
  - **Required overlap period at least ~1-2 years (better longer!) for bias correction (→ analysis of "anomaly" or weighted mean).**
  - **Use of multiple overlapping time-series allows to detect drifts in individual data sets and during specific periods.**
  - **11yr solar cycle correction requires long data set (→ use of SAGE-I/II 1979-2005).**
  - **Low noise in zonal means from thermal emission and limb scattering techniques due to better spatio-temporal sampling characteristics compared to solar occultation.**
  - **Aerosol sensitivity of short-wave techniques critical (e.g. Pinatubo period to be excluded).**
  - **Correction required for diurnally variable species (higher altitudes).**
  - **Gaps between satellite time-series make combined trend analysis difficult, due to systematic errors in individual time-series (→ combine with data from NDACC or balloon sondes ...).**

Photo: K. Sagi, Göteborg 2010-12-24