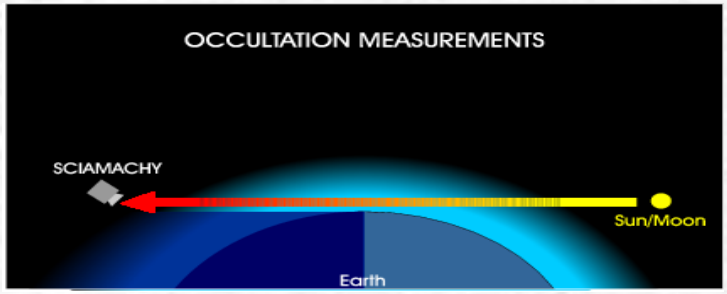
Retrieval of Trace Gas Concentrations from Lunar Occultation Measurements with SCIAMACHY on ENVISAT



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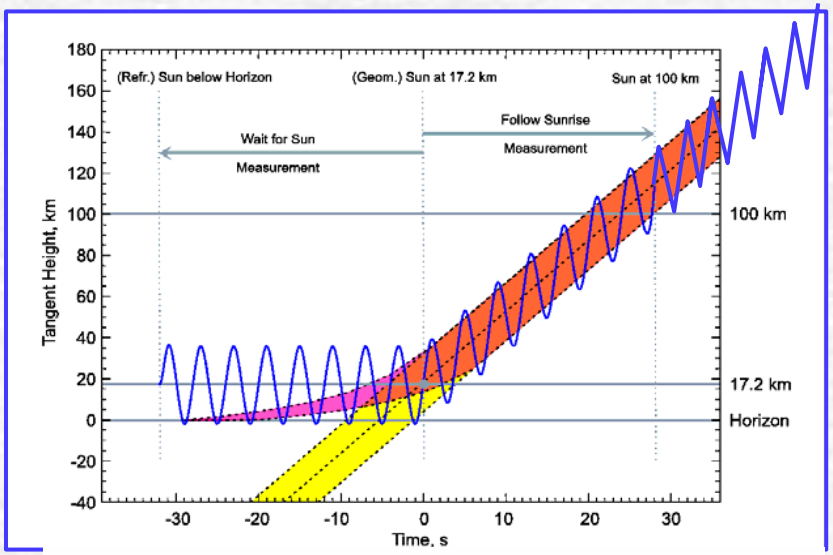
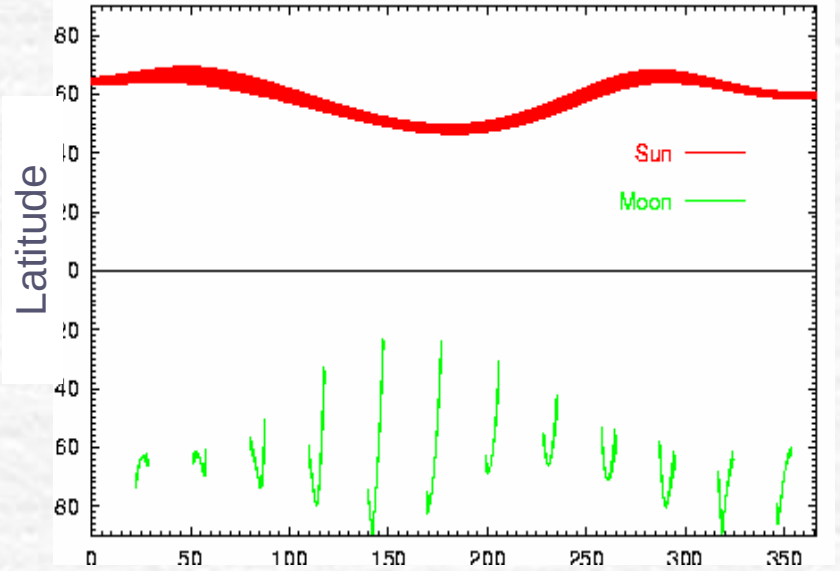
Outline

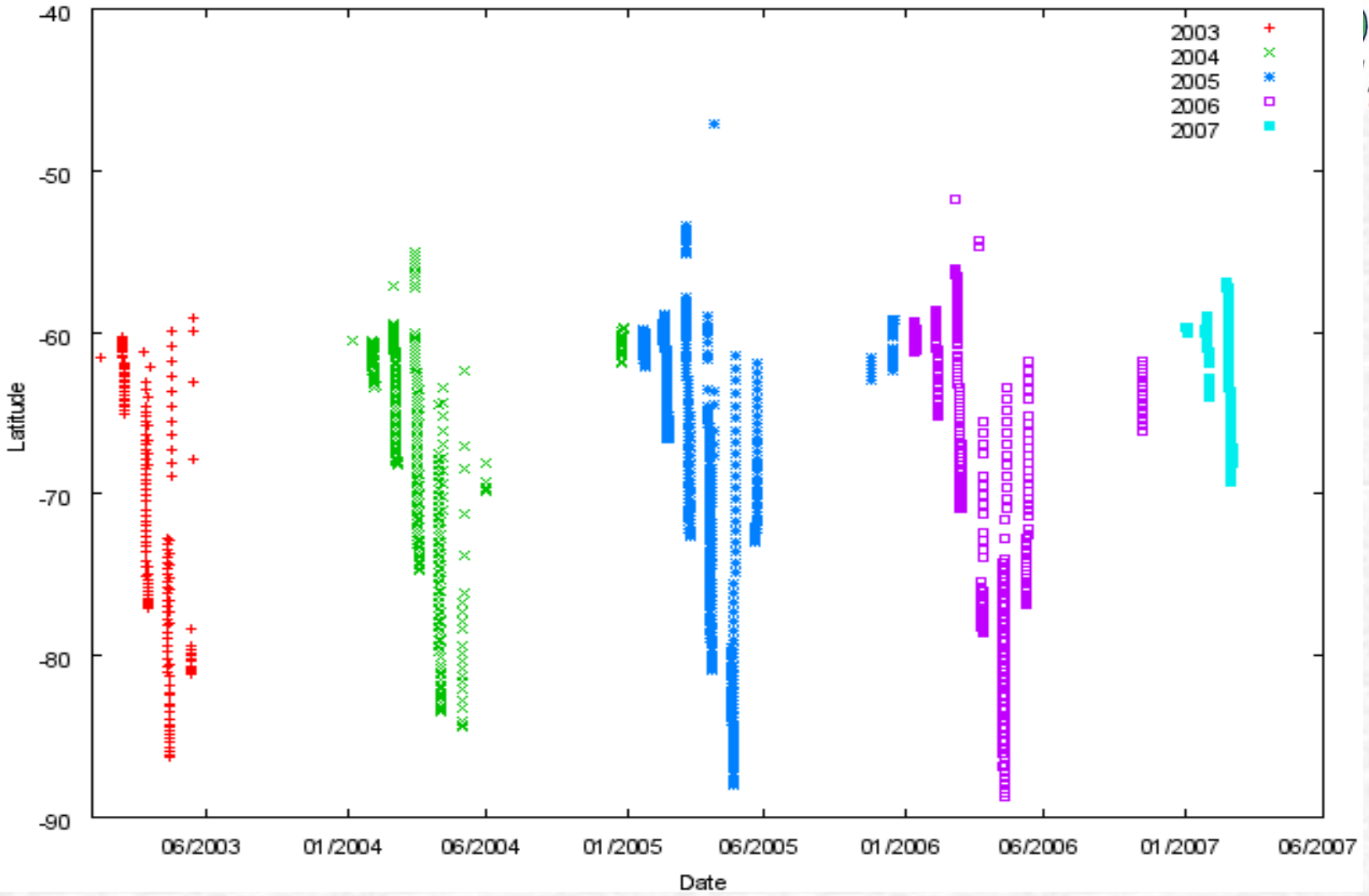
- Occultation with SCIAMACHY
- Nighttime NO_y Chemistry
- Lunar Occultation Retrieval Method
- Major Retrieval and Validation Results
- Summary and Conclusions
- Acknowledgements

Occultation with SCIAMACHY

- **SCIAMACHY**:
  - nadir, limb, lunar+solar occultation
  - imaging spectrometer 240-2400nm
  - 0.2-1.5nm spectral resolution
  - 8 channels
- **Solar occultation (Poster P6)**
  - Sun scanning mode
- Measurements in all orbit (50°N - 70°N)
- **Lunar occultation**
  - Moon pointing mode
  - Performed if moon phase > 0.5
  - Vertical resolution ~2.5km
  - Horizontal resolution 30 X 400 km²
  - Latitudes: 40°S –90°S

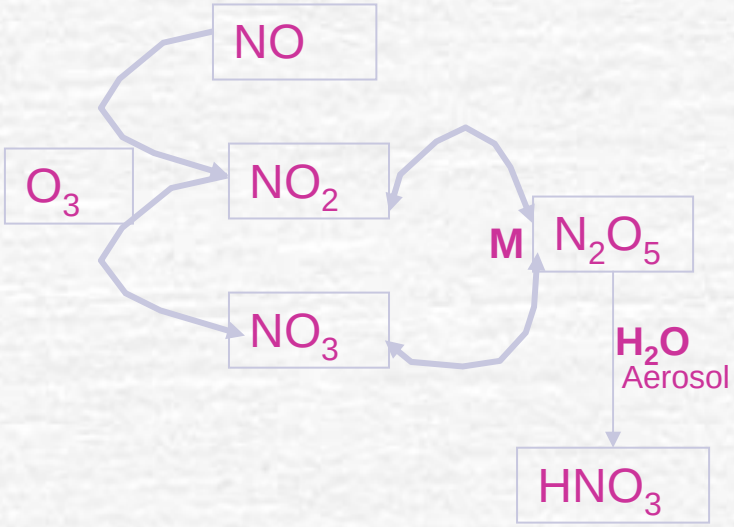






- Measurements are performed 6-8 days in a month and 4-8 month in a year
- Measurements are highly variable
- Most measurements in March, April, and May

Nighttime Stratospheric NO_y Chemistry



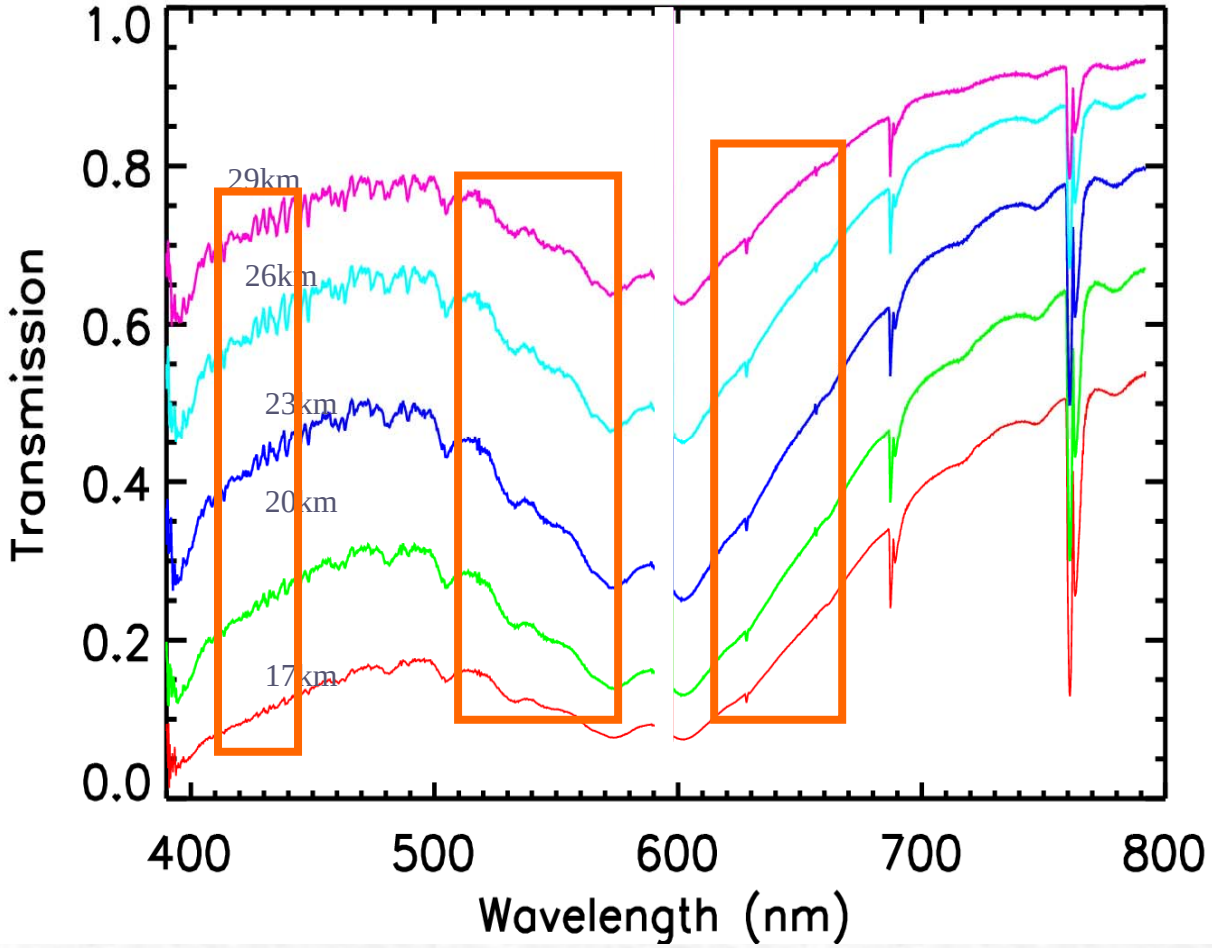
- Nighttime NO_X is in the form of NO_2 and NO_3
- NO_X are important in middle stratosphere ozone chemistry
- Implies long-term trend in stratospheric ozone loss and NO_X budget can be studied by simultaneous measurements ozone, NO_2, and NO_3
- This can be achieved using lunar and stellar occultation methods

Retrieval Method

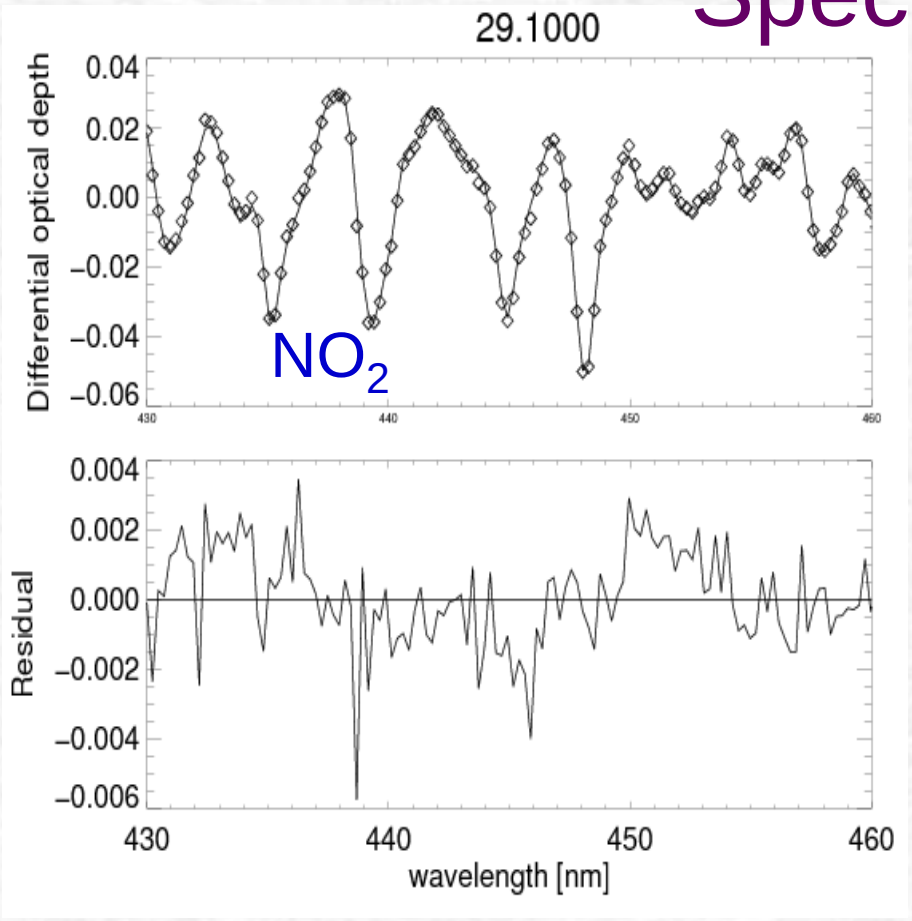
- Forward model : SCIATRAN 2.1
- P,T (ECMWF), a priori trace gases (MPI data base)
- Retrieval: Optimal estimation with Twomey-Tikhonov regularisation
- Using SCIAMACHY data Level 1b version 5.04/6.02
- Retrieved trace gases O_3, NO_2, and NO_3
- Ozone and NO_2 are retrieved simultaneously
- Interfering gases are modelled and fitted (e.g. For NO_3; O_3, O_2 and H_2O are fitted)
- The Differential cross section O_2 and H_2O are calculated using ESFT method (Buchwitz et. al, 2000)

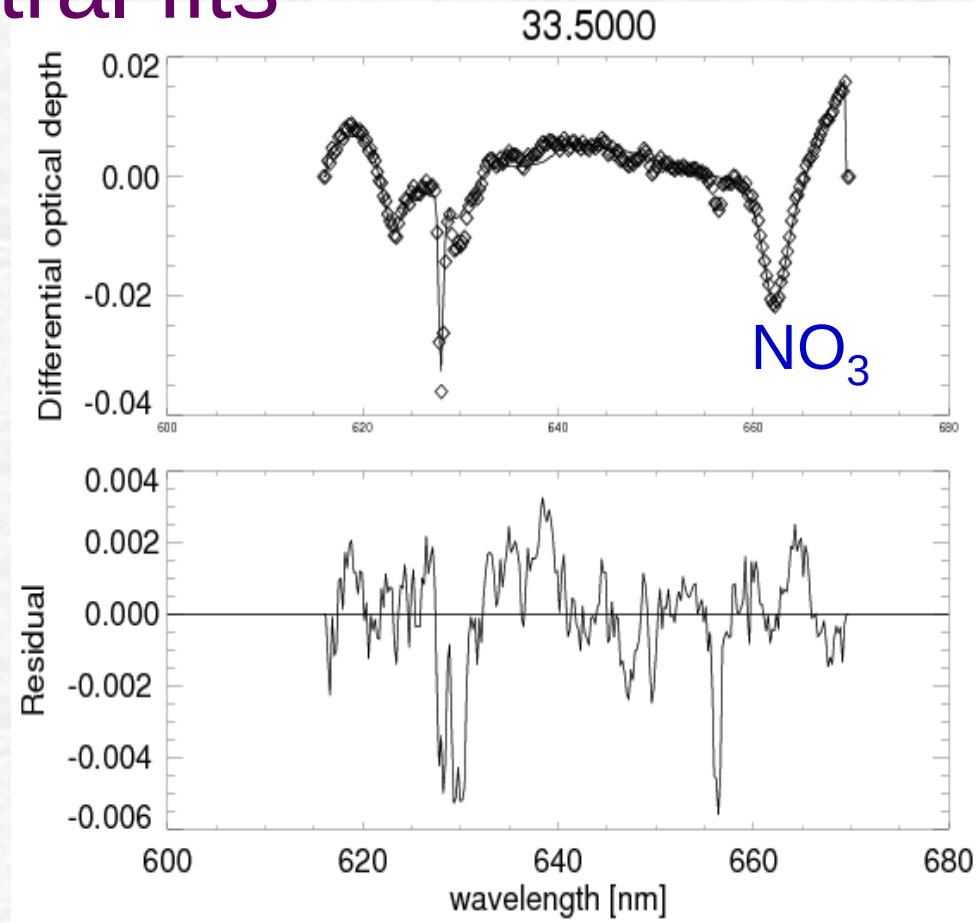
SCIAMACHY Channels 3 and 4 (Lunar Spectra)

- Spectral fitting windows
  - NO_2: 430 – 460 nm
  - O_3: 520 – 580 nm
  - NO_3: 615 – 670 nm



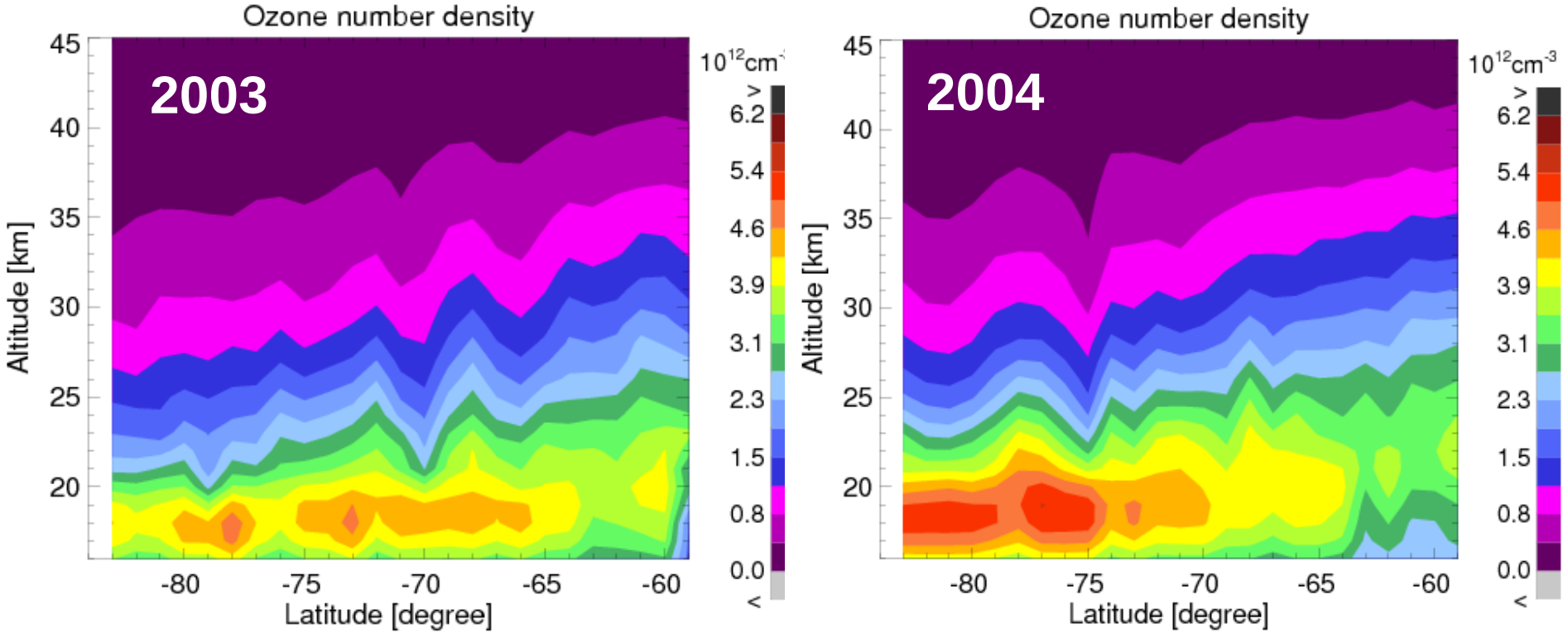
Spectral fits





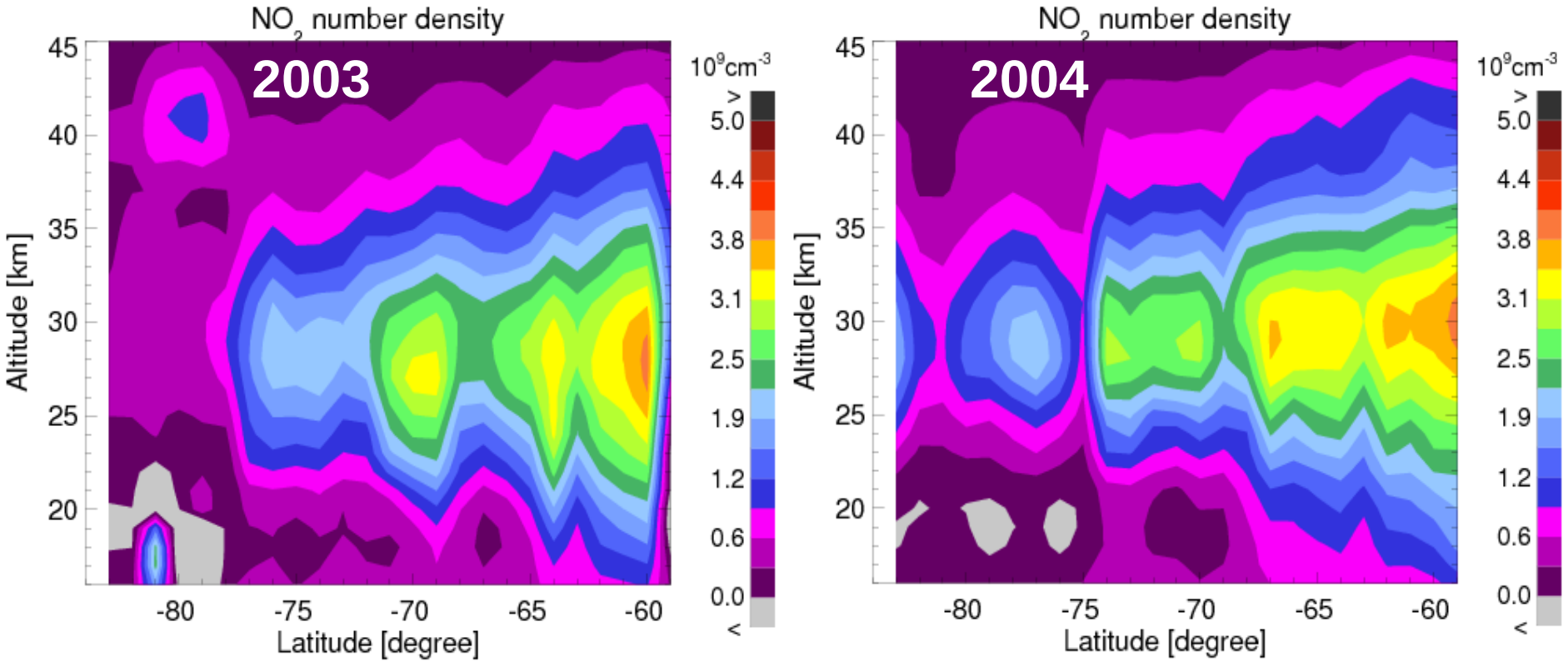
- The diamond points: modelled contribution and solid line measurement contribution
- Very good spectral fits are generally obtained (16-42km for NO_2 and 16-45 for NO_3)
- Spectral residual are less than 0.5%

Retrieval Results: Ozone



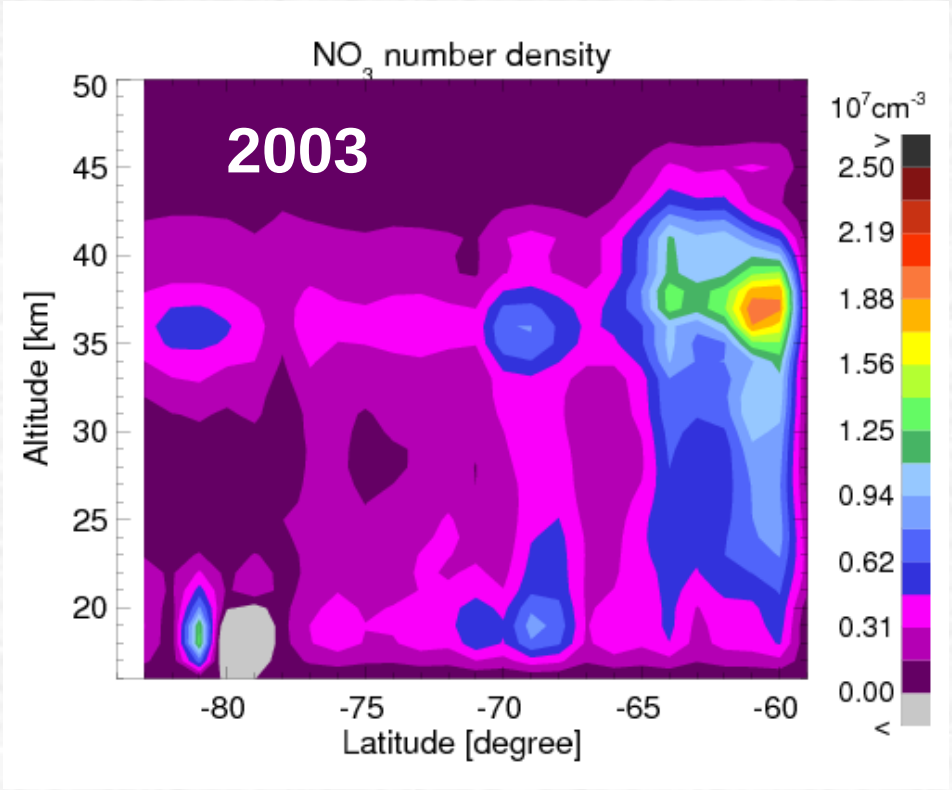
- 2003 results are zonal mean for measurement between March to June
- 2004 results between Dec. to June.

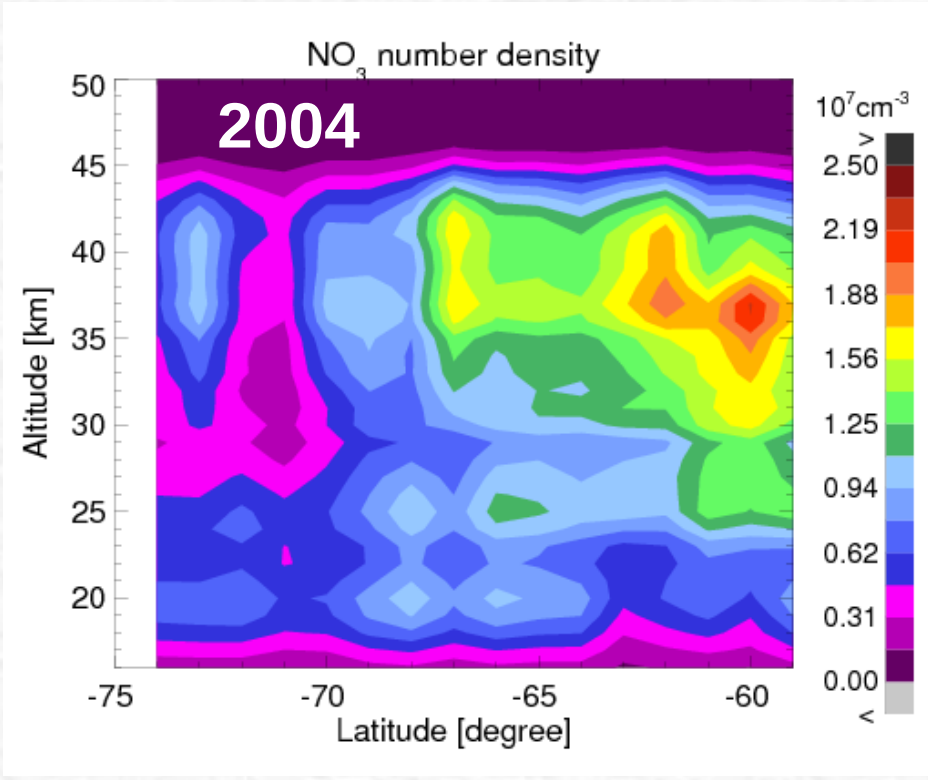
Retrieval Results: NO_2



- 2003 results are zonal mean for measurement between March to June
- 2004 results between Dec. to June.

Retrieval Results: NO_3





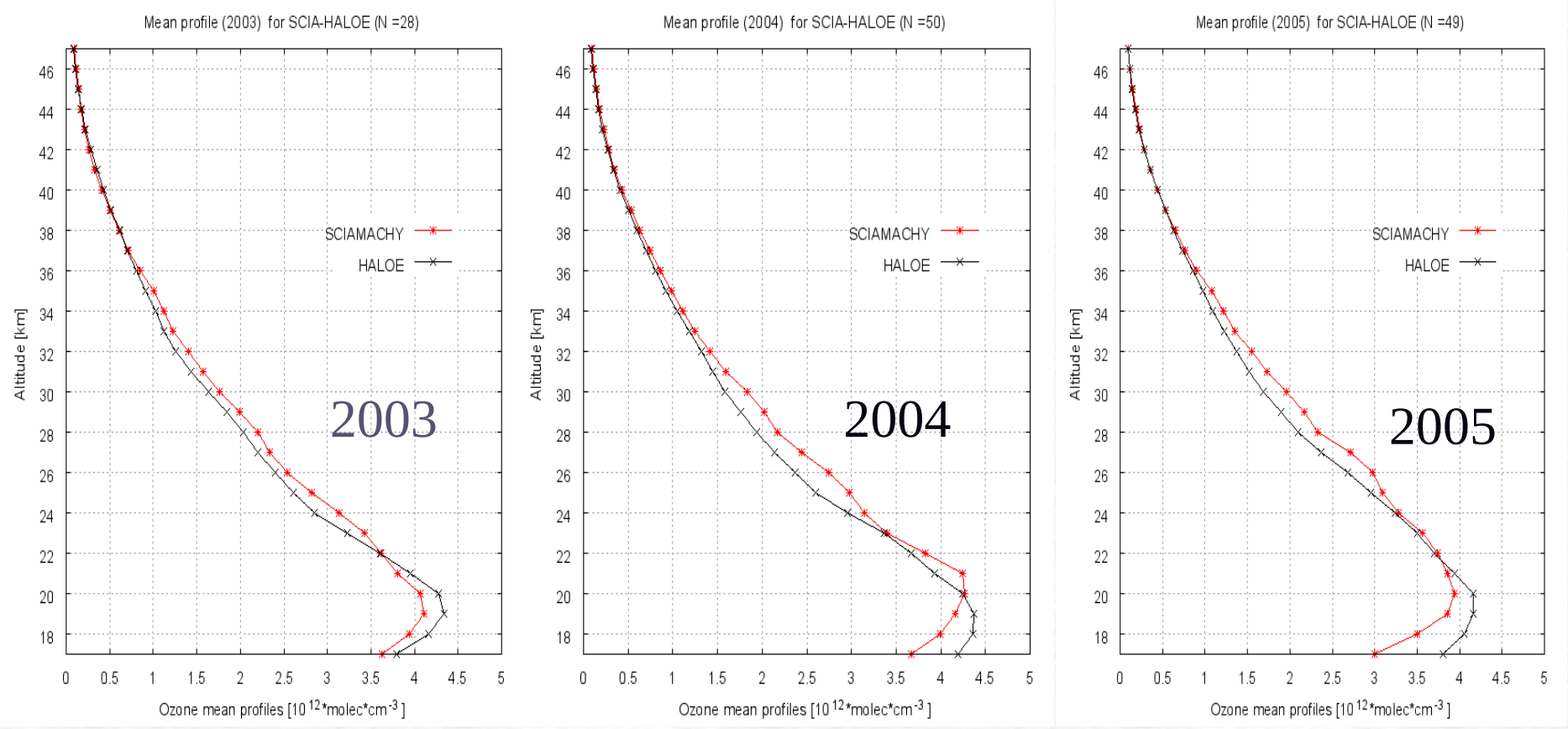
- 2003 results are for measurements between March to June
- 2004 results, Jan. to April.

Validation Results:Ozone and NO_2

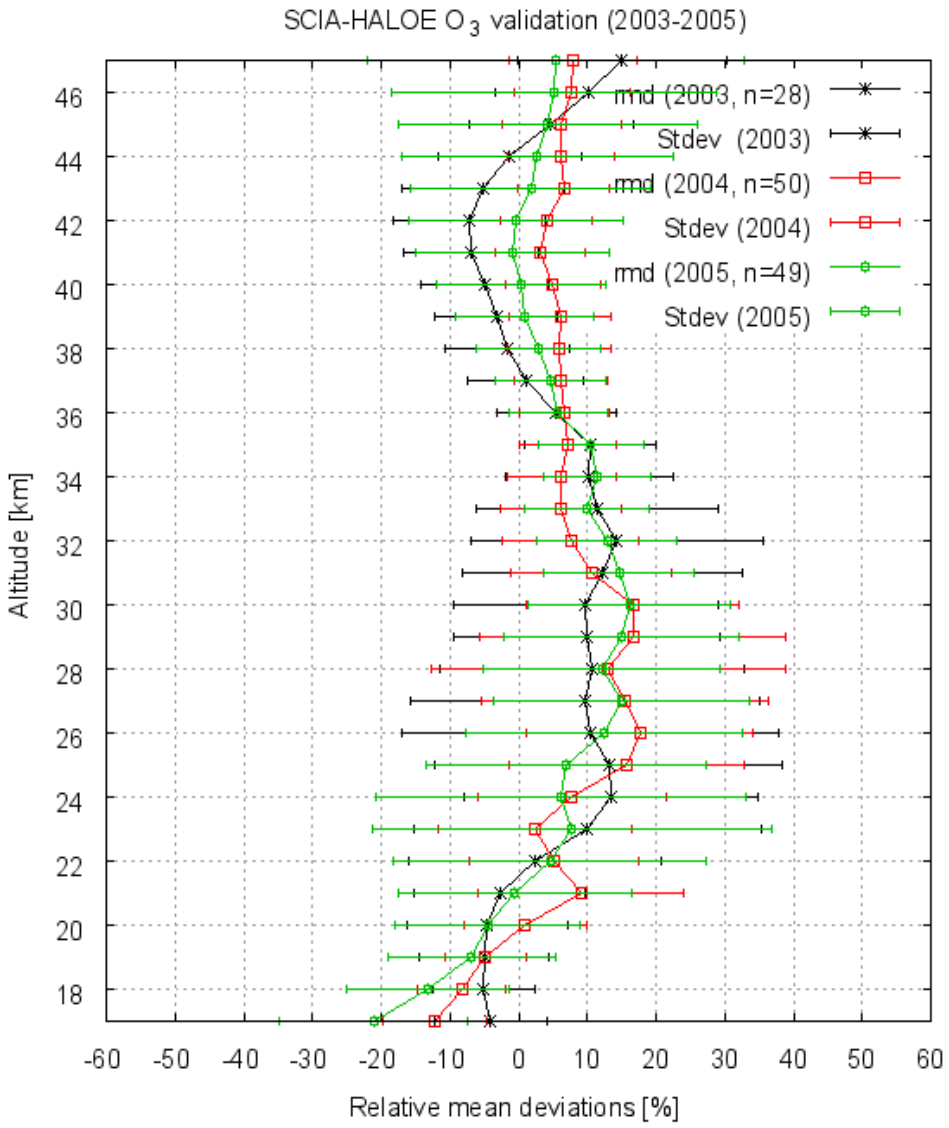
Instruments	max. Dist./time	# NO_2	# O_3	Data quality	Reference
HALOE (v19)	1000 km 12 hrs	65	154	6-12% (25-60 km) 10-15% (25-42km)*	Brühl et al.,1996 Randall et al.,2002

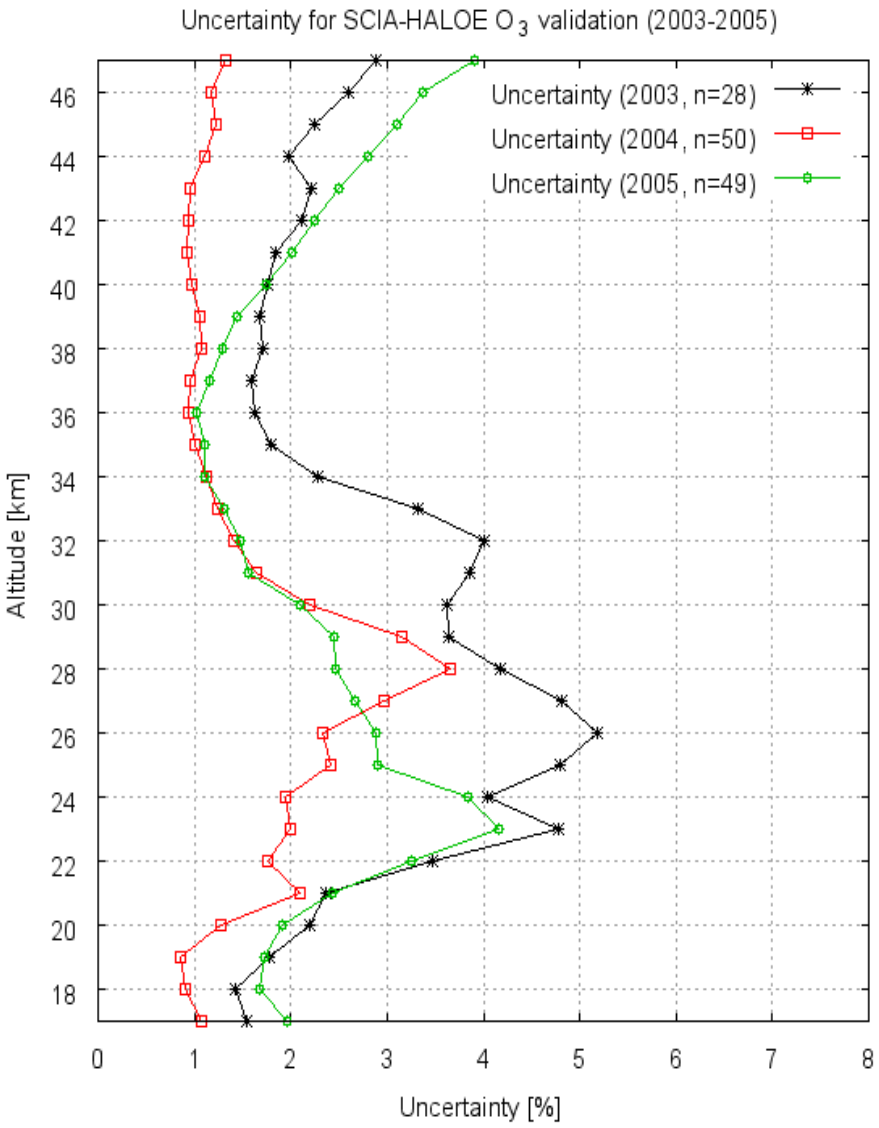
- NO_2 data quality (*)
- NO_2 compared to sunrise measurements of HALOE/SAGEII only
- Coincidences with HALOE are in 2003-2005, SAGE II in 2004 only, and POAM in 2003 and 2004

SCIA-HALOE O_3 Validation



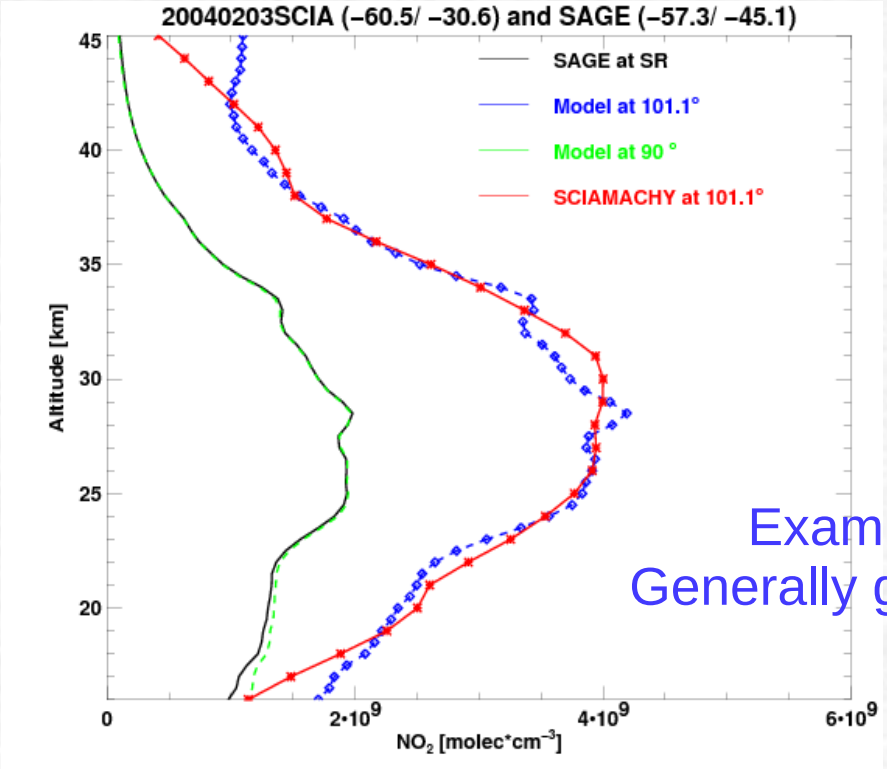
SCIAMACHY results mostly slightly higher

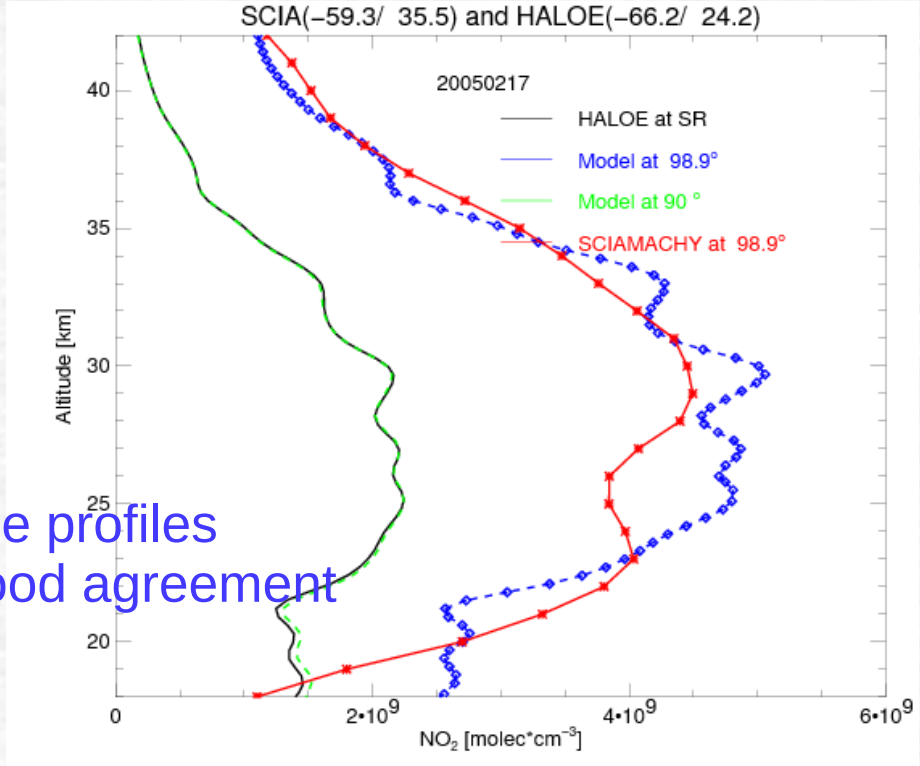




- Very good agreement: The rmd mainly between -5% to +15%
- The rms of bias is 5-25% and uncertainty is 2 - 5%

NO_2 Validation

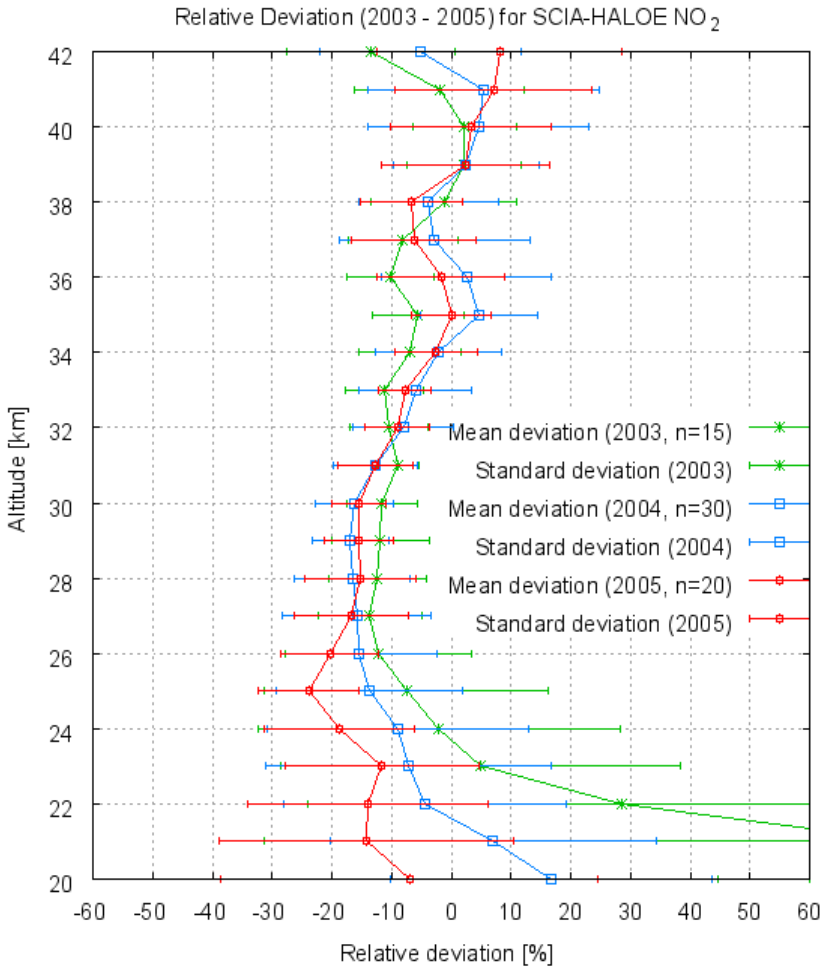


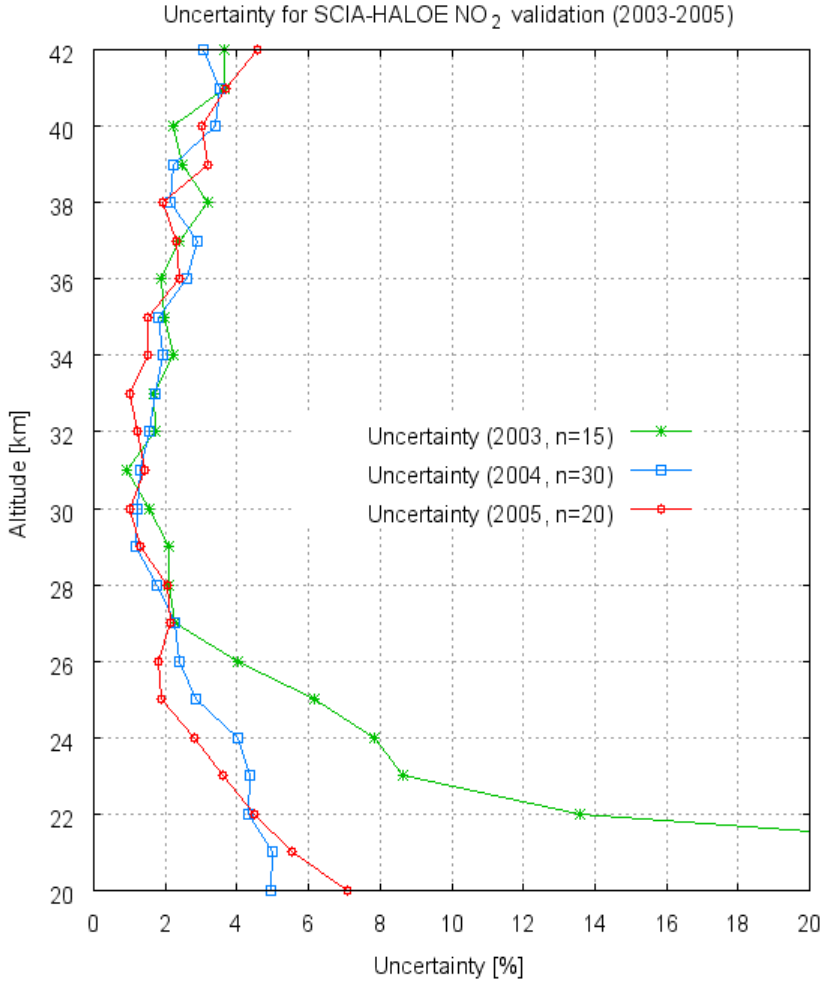


Example profiles
Generally good agreement

- Photochemical correction (Bracher et al. 2005) was applied to scale HALOE/SAGE II results to SCIAMACHY SZA
- The model nighttime error is less than 14%

SCIA-HALOE RESULTS





- The rmd mainly between -20% to +5% between 25 – 40 km
- The rms of bias is 4-16% and uncertainty is 1 - 6%

Summary of validation results

Ozone validation

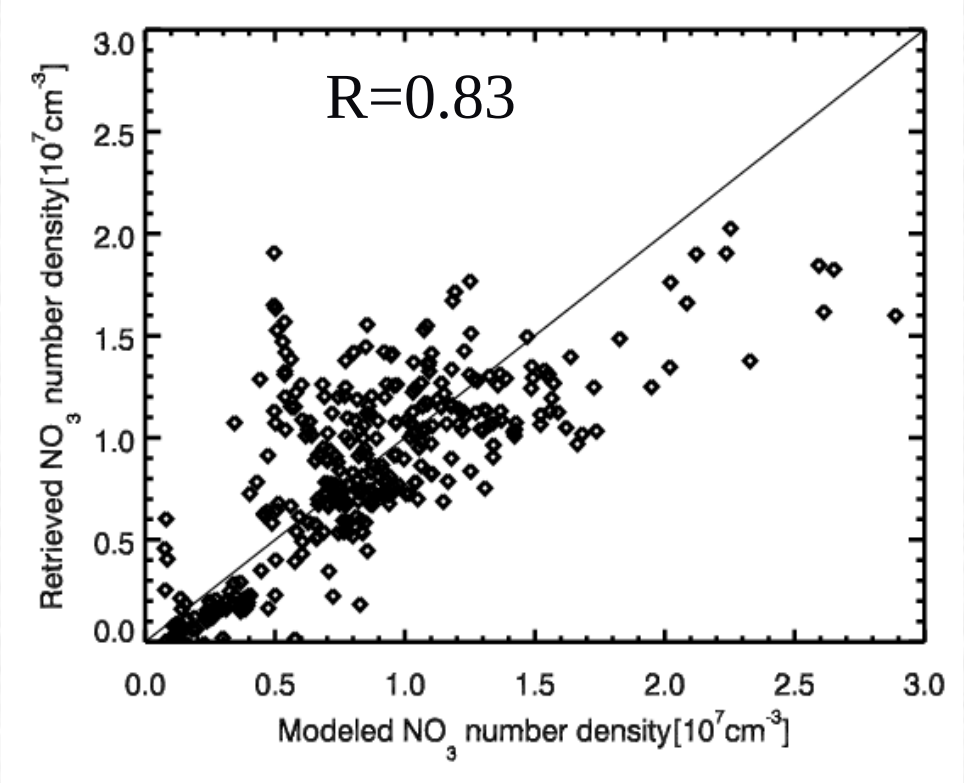
Instruments	rmd (%)	rms(%)	Altitude(km)
HALOE	0 to +15	5 – 25	20 – 45
SAGE II	-15 to +15	6 –20	20 – 45
POAM III	-8 to +2	12 –20	24 – 43

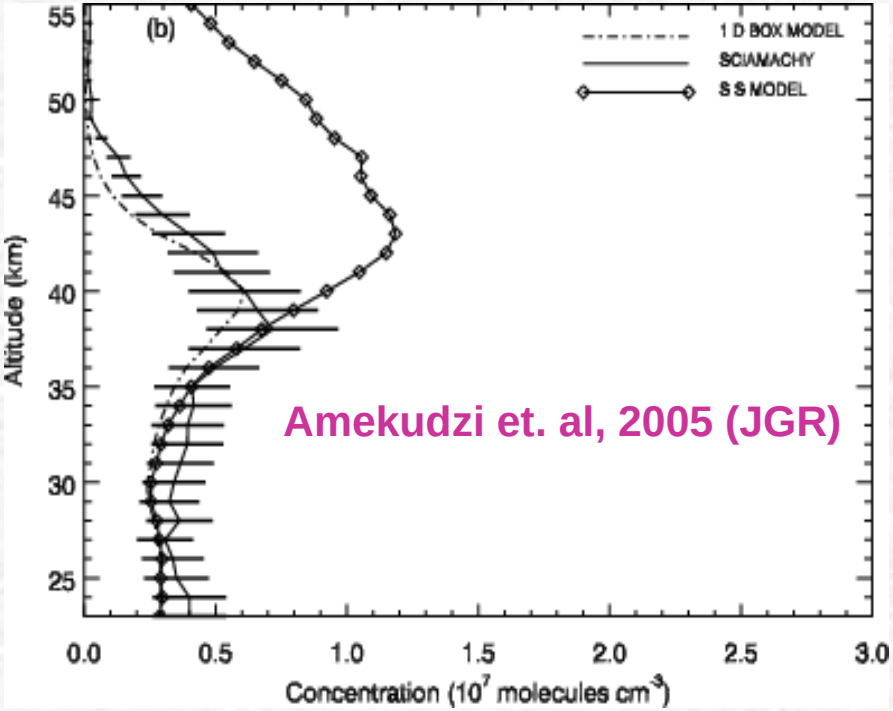
NO_2 validation

Instruments	rmd(%)	rms(%)	Altitude(km)
HALOE	-16 to +3	4 –16	25 – 38
SAGE II	-9 to +7	10 – 17	22 – 39

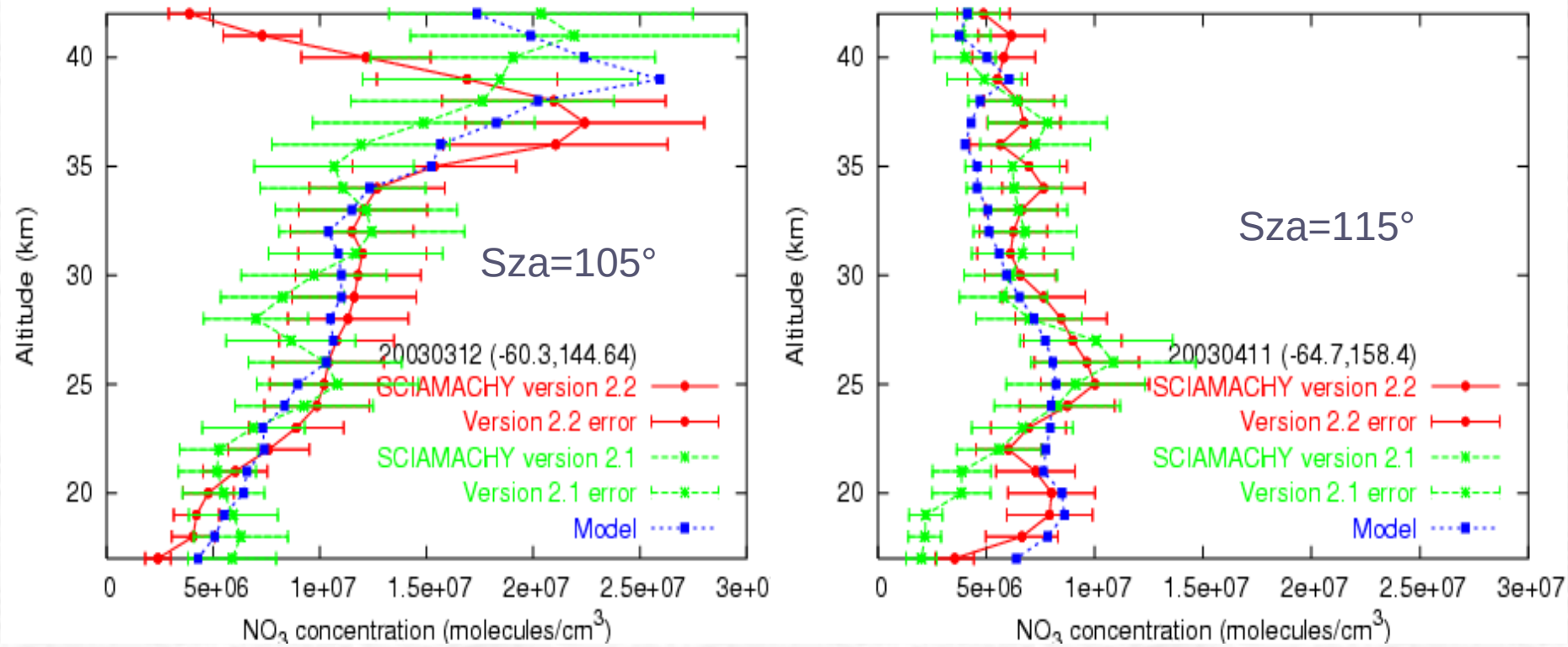
In JASR, Amekudzi et al. 2007

NO_3 Comparisons with model





- NO_3 retrieved compared with simple and full photochemistry model outputs
- The altitude range considered is 22 – 40 km and latitude: 59°S - 65°S



- Current results compared with previous and simple model results
- Error bars: 25% and 35% retrieval errors for v2.2 and 2.1 respectively
- Model assumed steady state condition for NO_3 formation

Summary and Conclusions

- The retrieval results (O_3, NO_2 and NO_3) from SCIAMACHY lunar occultation for 2003 - 2007 are presented.
- The accuray of the retrieved profiles have been verified.
  - O_3 results show very good agreement with the other instruments (HALOE, SAGE II and POAM III) between 22 and 45 km.
  - NO_2 results using photochemical correction model show very good agreement with HALOE and SAGE II instruments (25-42)
  - NO_3 profiles comparisons with model calculations show promising results with accuracy less 30%
- Reprocessing of complete dataset and validation activities are still in progress

Acknowledgements

We are thankful to the following institutions:

- ESA for providing SCIAMACHY level-1 data
- HALOE team at Hampton University and NASA LaRC for providing the HALOE level-2 data
- SAGE II team at NASA LaRC for providing SAGE II data
- German Ministry of Education and Research (BMBF), the DLR-Bonn, Unversity of Bremen and the State of Bremen for funding

Radiative transfer modeling equation for simulated radiance

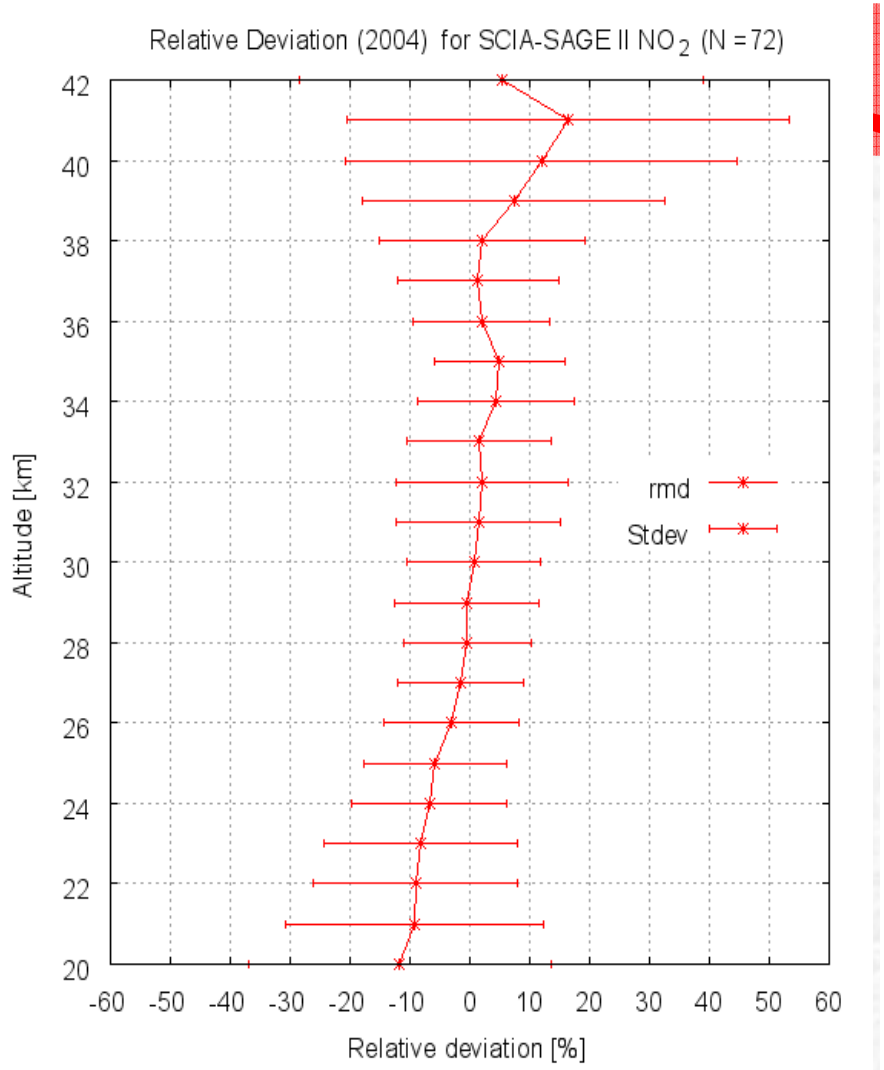
$$Y_s = \int_{\Omega}\int_{\Delta\lambda} I_0 S(\lambda,\lambda')F(\omega)e^{-\tau(h_i,\lambda')}d\lambda' d\omega \qquad (1)$$

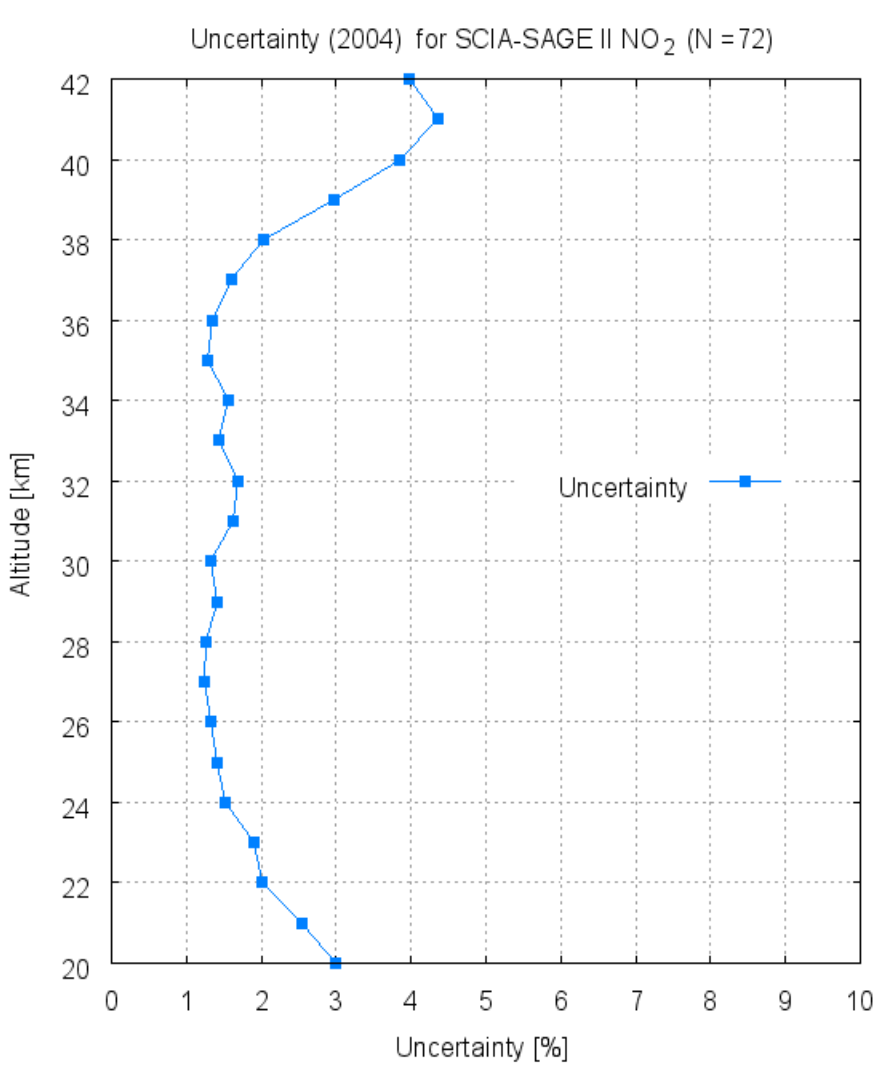
Optimal Estimation equation

$$Y = K(x - x_o) + \varepsilon \qquad (2)$$

Optimal Estimation solution is given as

$$x_{i+1} = x_0 + \left(K_i^T S_y^{-1} K_i + R\right)^{-1} K_i^T S_y^{-1} \left(Y - Y_i + K_i\left(x_i - x_0\right)\right) \qquad (3)$$

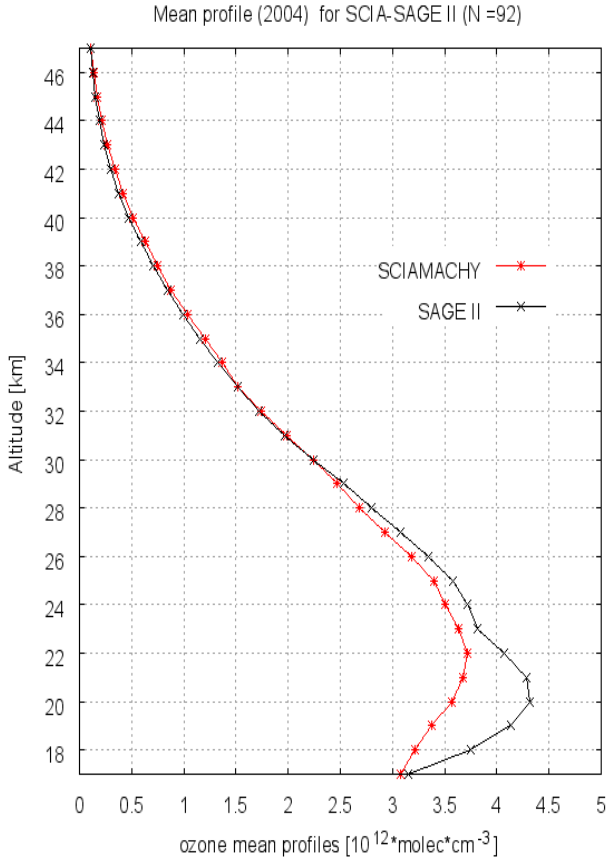


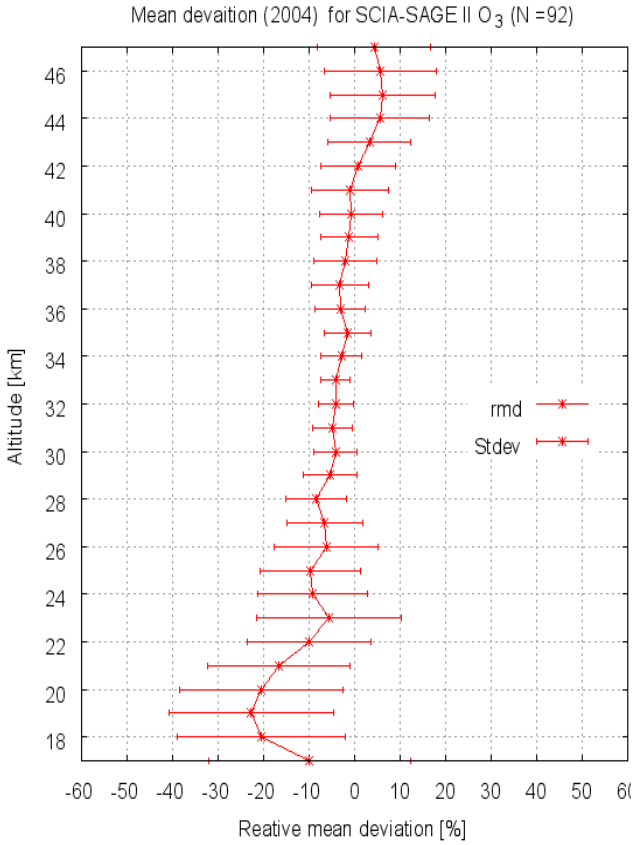


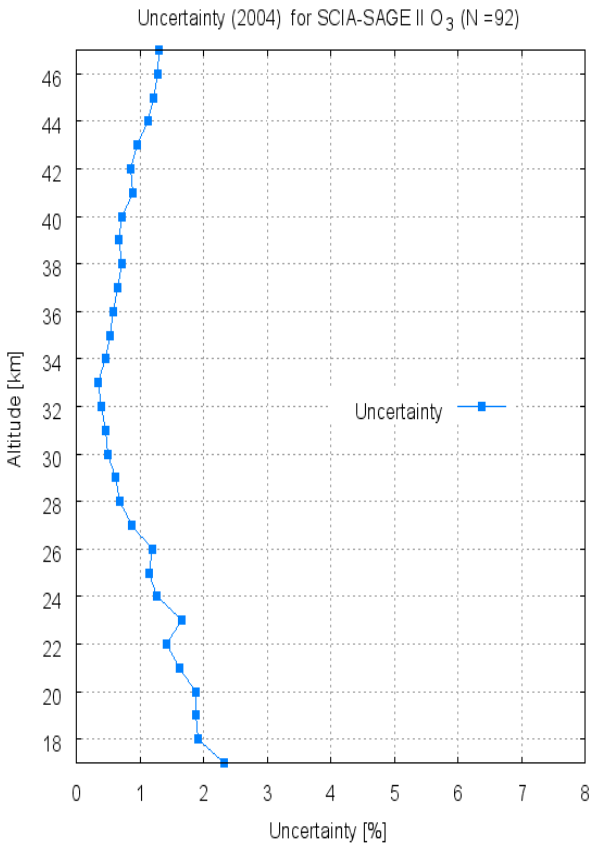
- Very good agreement from 24-38 km with rmd -8% to +4%
- The rms of the bias is 10-14% and uncertainty < 2%

Also in Amekudzi et al. 2007 (JASR)

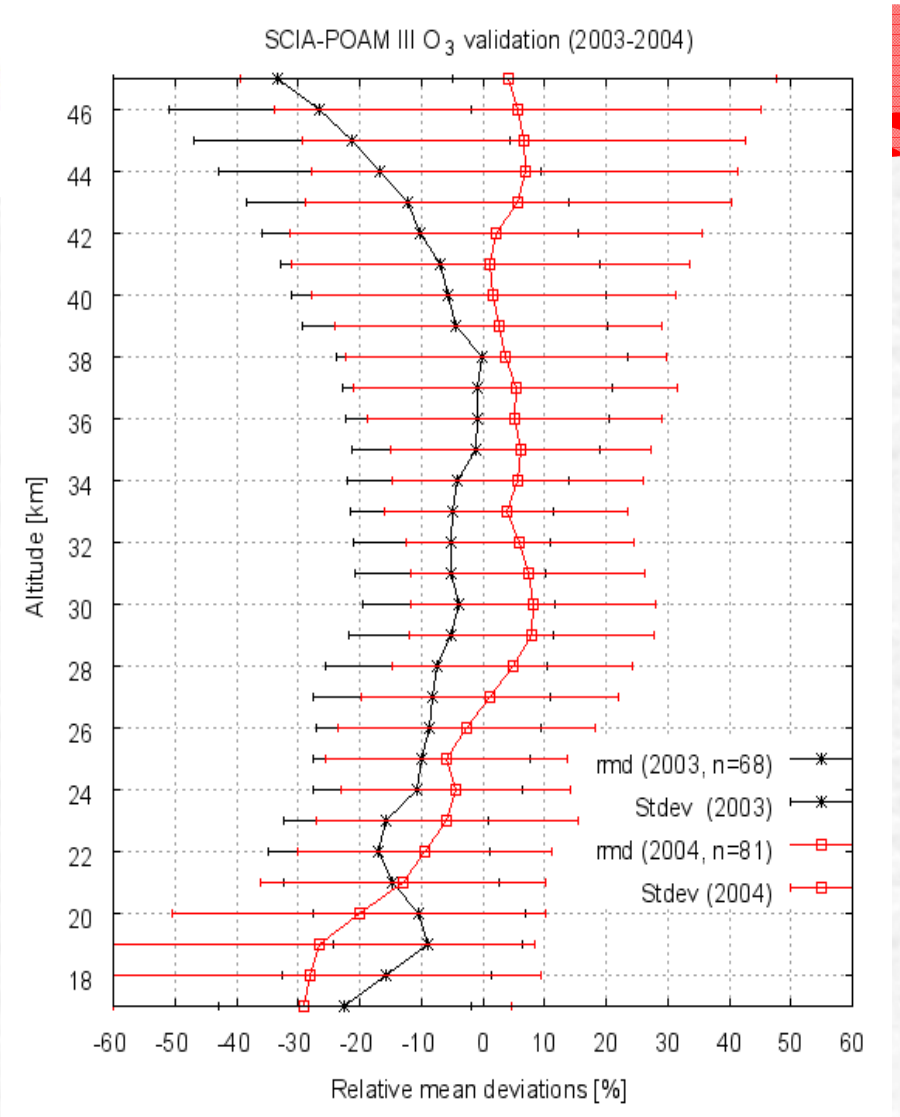
SCIA-SAGE II O_3 Validation

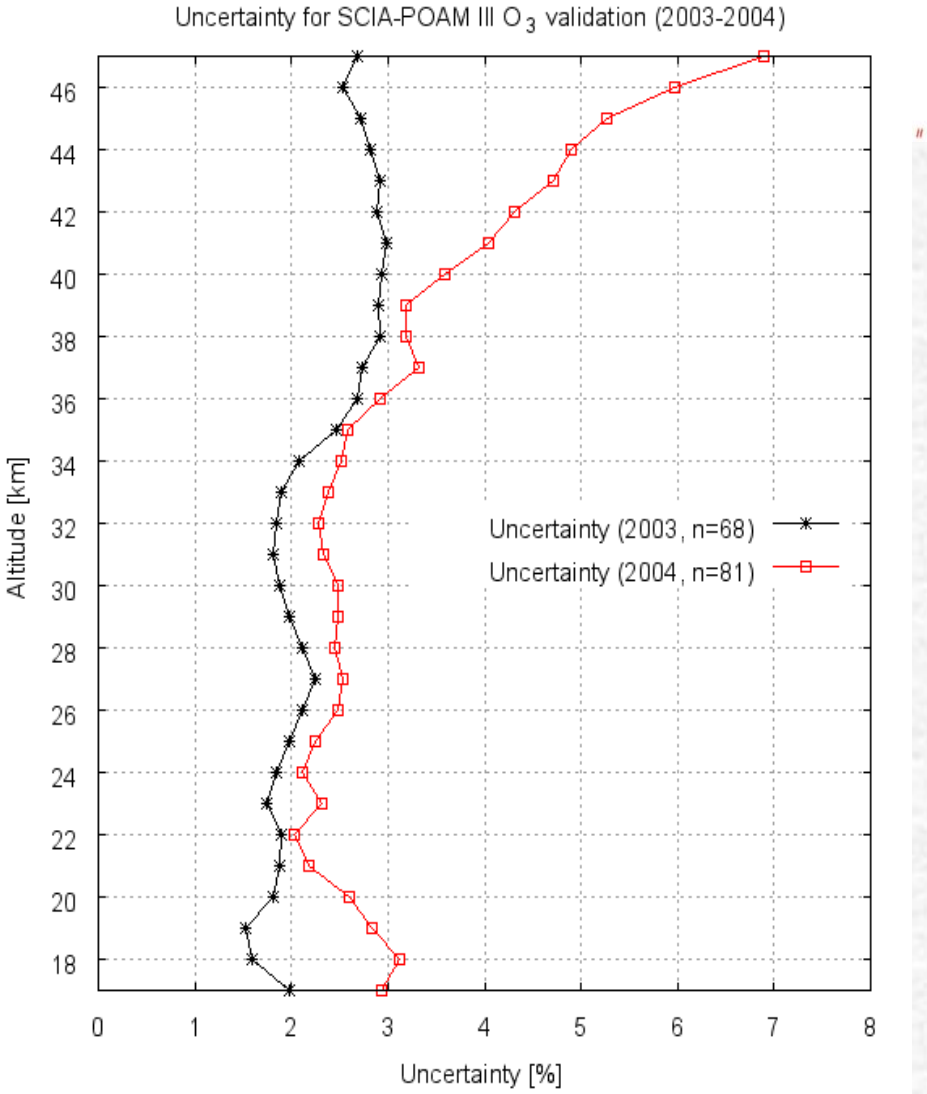






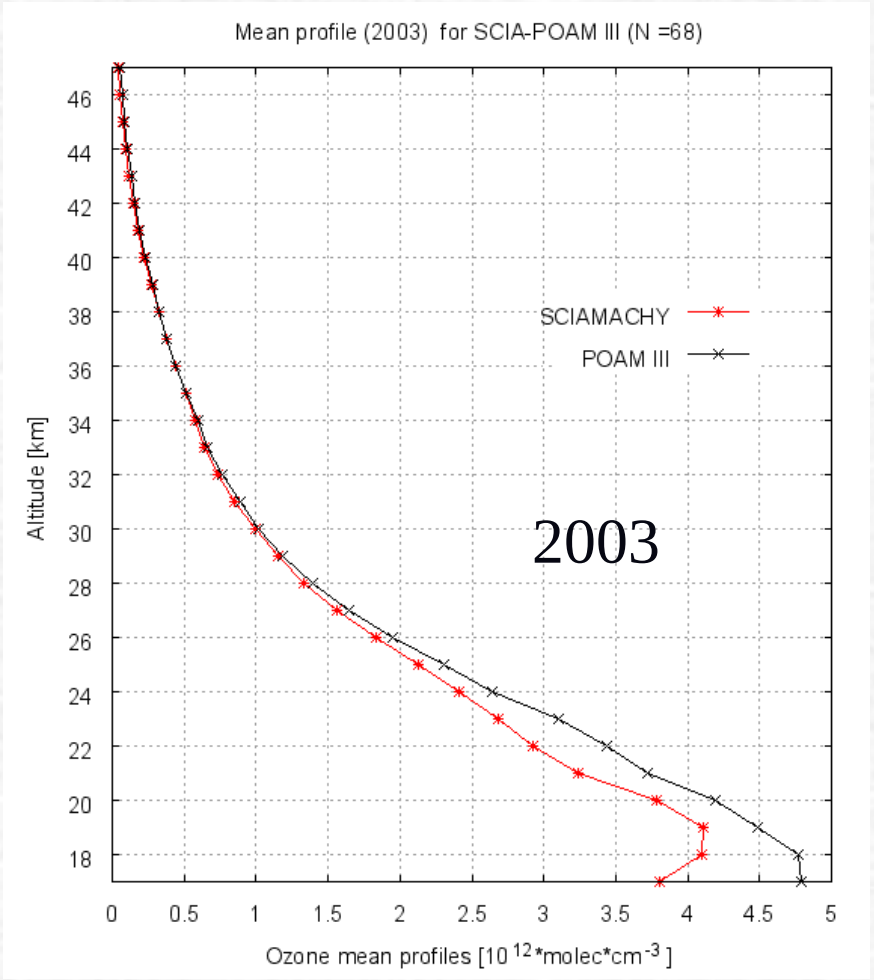
- Very good agreement between 20-45 km with rmd within -15% to 15%
- The rms of bias 6% - 20% and uncertainty < 2%

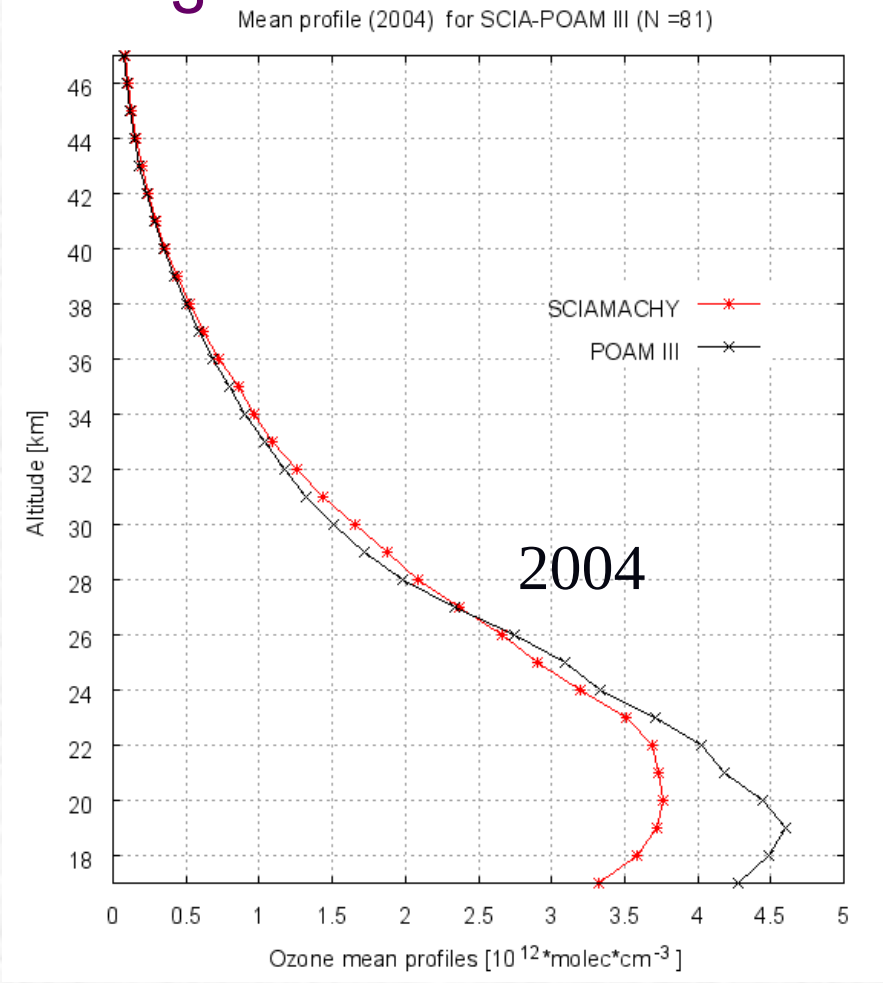




- Very good agreement (24 – 43 km): The rmd -8% to +2%.
- The rms of bias within 12 - 20% and uncertainty < 4%.

SCIA-POAM III O_3 Validation





- SCIA-POAM III mean profiles, general very good agreement