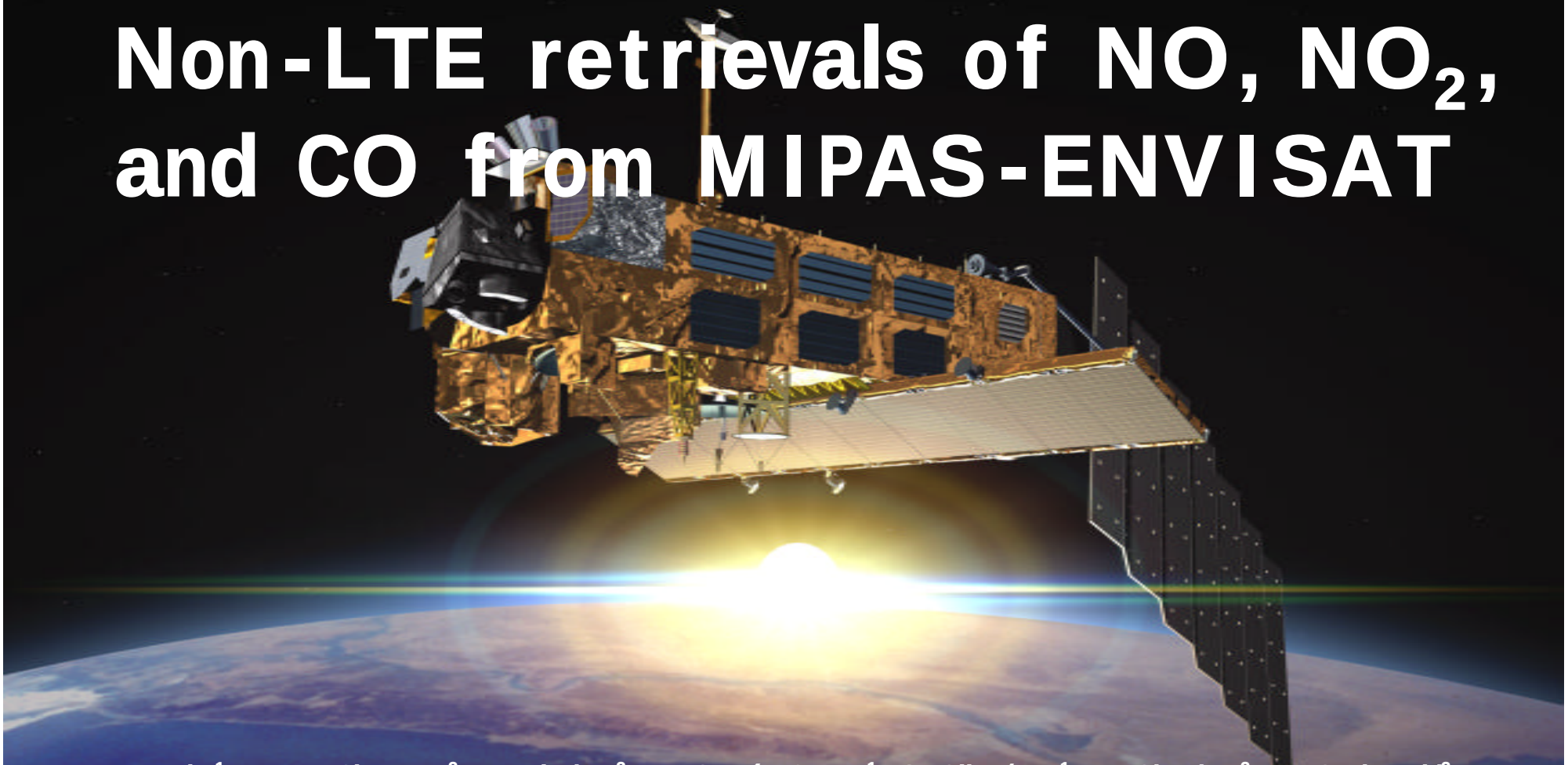
Non-LTE retrievals of NO, NO_2, and CO from MIPAS-ENVISAT



B. Funke[1], T. von Clarmann[2], H. Fischer[2], M. García-Comas[1], S. Gil-López[1], N. Glatthor[2], U. Grabowski[2], M. Höpfner[2], S. Kellmann[2], M. Kiefer[2], A. Linden[2], M. López-Puertas[1], M.Á. López-Valverde[1], G. Mengistu Tsidu[2], M. Milz[2], T. Steck[2], G.P. Stiller[2], D.Y. Wang[2]

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Outline

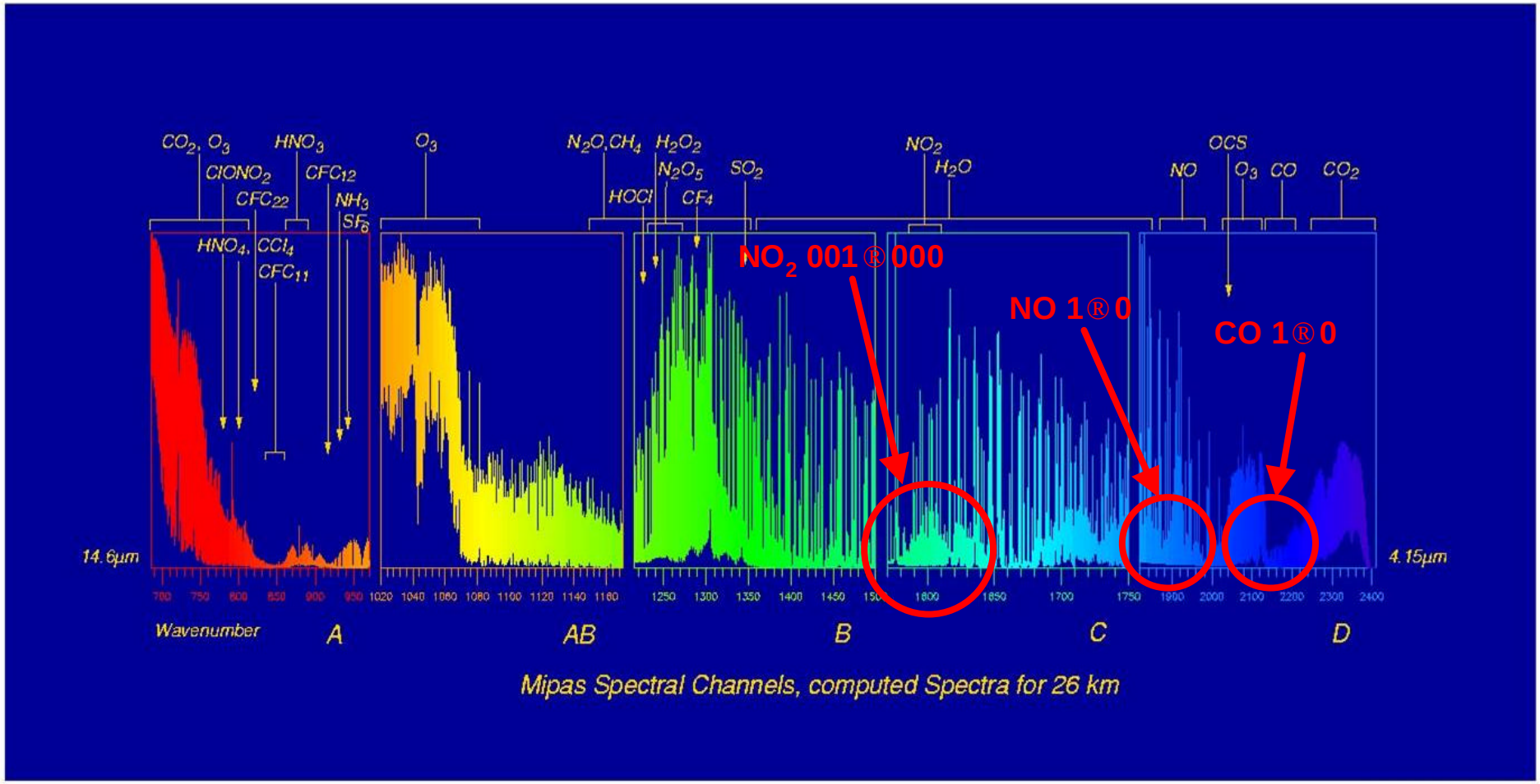
- The non-LTE retrieval scheme
- Retrieval setup & accuracy of data products
- Validation
- Measurements of NO, NO_2, and CO in July, September, and October 2002 (including split-up of S polar vortex at 24-26 September): preliminary results

Scientific objectives

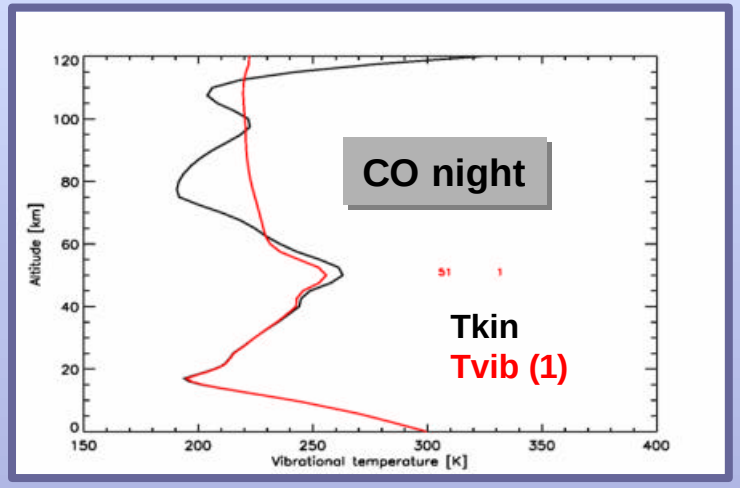
- **Dynamical coupling of stratosphere and mesosphere**
  - Þ **CO**

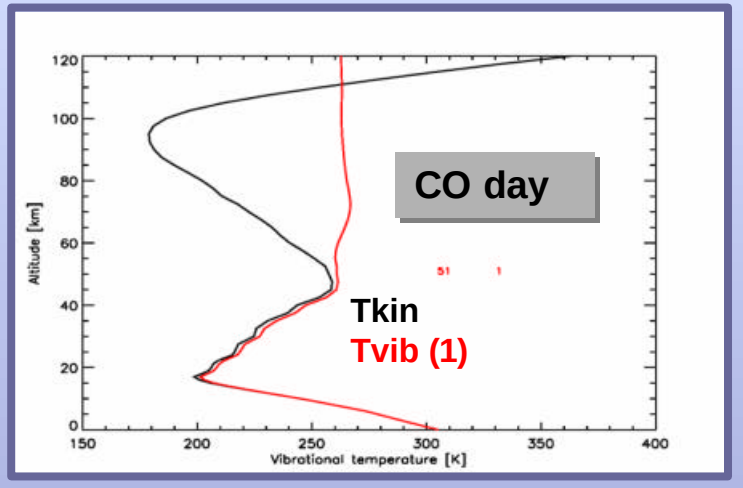
- **Descent of mesospheric/thermospheric NO_x down to stratosphere & implications to stratospheric chemistry**
  - Þ **NO+NO_2, CO**

MIPAS spectral channels

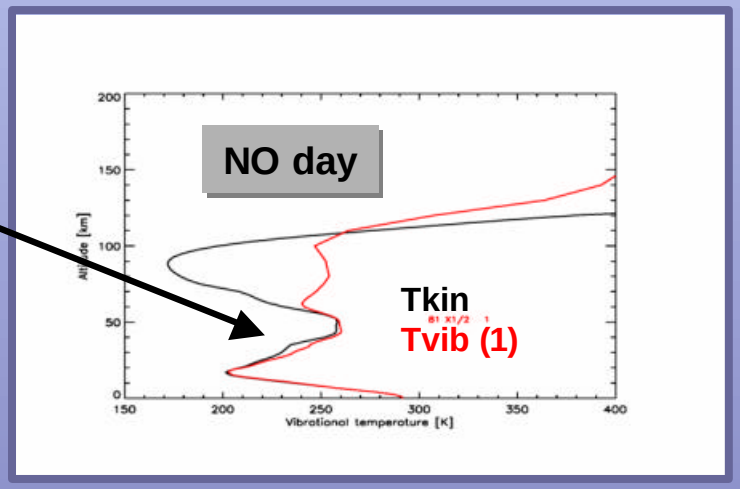


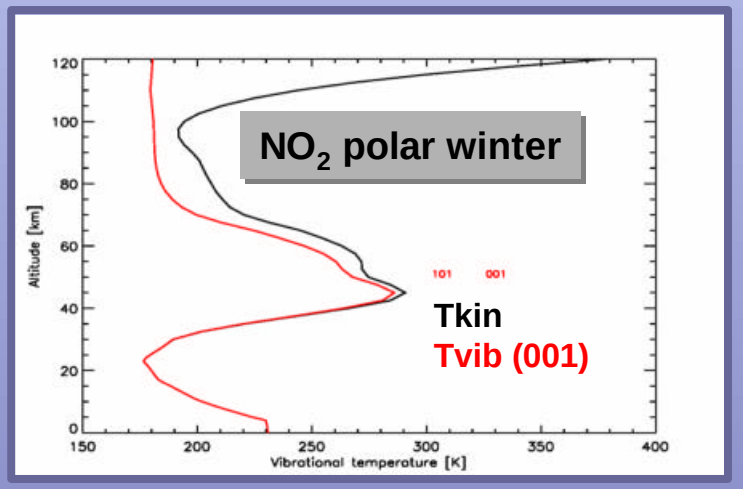
Vibrational temperatures of CO, NO, and NO_2





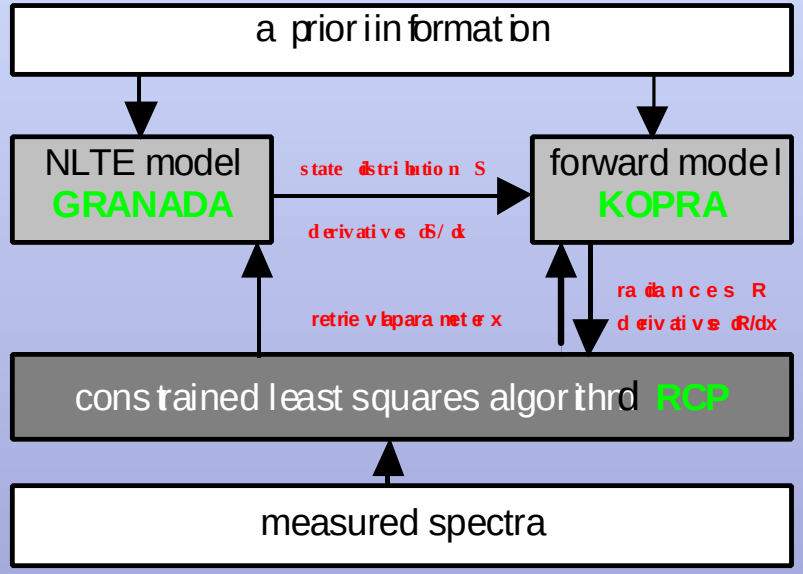
NO_2 + hv





vmr – dependent !!!! …..recursive non-LTE retrieval scheme required

The non-LTE retrieval processor



Forward model: Karlsruhe Optimised and Precise Radiative transferAlogrithm (KOPRA)

- Line-by-line radiative transfer model
- Interface for generic NLTE-model GRANADA
- supports vibrational and rotational non-LTE
- Computes spectra and Jacobians for LTE and non-LTE

Retrieval Control Program (RCP)

- global fit least sqares algorithm + userdefined regularisation

Non-LTE model: Generic RAdiative traNsfer AnD non-LTE population Algoritm (GRANADA)

- Calculation of vibrational and rotational populations and their derivitavies wrt the NLTE retrieval parameters
- Generalized scheme: same algorithm used for populations of CO2,O3, CO, NO, NO2, H2O, OH, etc.
- Userdefined (states and transitions, altitude range, iteration strategies, process definition, etc.)
- Rotational (and spin-orbit) non-LTE
- Line-by-line and line independent radiative transfer (KOPRA)
- Inversion of multilevel steady state equation with the Lambda iteration or Curtis matrix formalisms

Retrieval setup & performance: nominal mode

	CO	NO	NO_2
tangent heights	12 -70 km	20 -70 km	15-70 km
microwindows	2024 - 2217 cm^{-1}	1840 -1920 cm^{-1}	1580 – 1630 cm^{-1}
non-LTE	vibrational	vibrational +rotational	vibrational
retrieval grid	0-120km	0-200 km	0-120 km
regularisation	Tikhonov 1st order	Tikhonov 1st order	Tikhonov 1st order
vertical resolution	10km @ <40 km 7 km @ 40 - 70 km	10km @ 20 km 5 km @ 40 km >50 km @ > 100 km	7 km @ 20 km 4 km @ 40 km
noise error	20 ppb @ 30 km 100 ppb @ 50 km	1-3 ppb in statosphere	0.2-0.8 ppb
systematic error sources	•temperature •ILS •terminator (non-LTE)	•temperature •thermospheric horizontal structure	•temperature •ILS

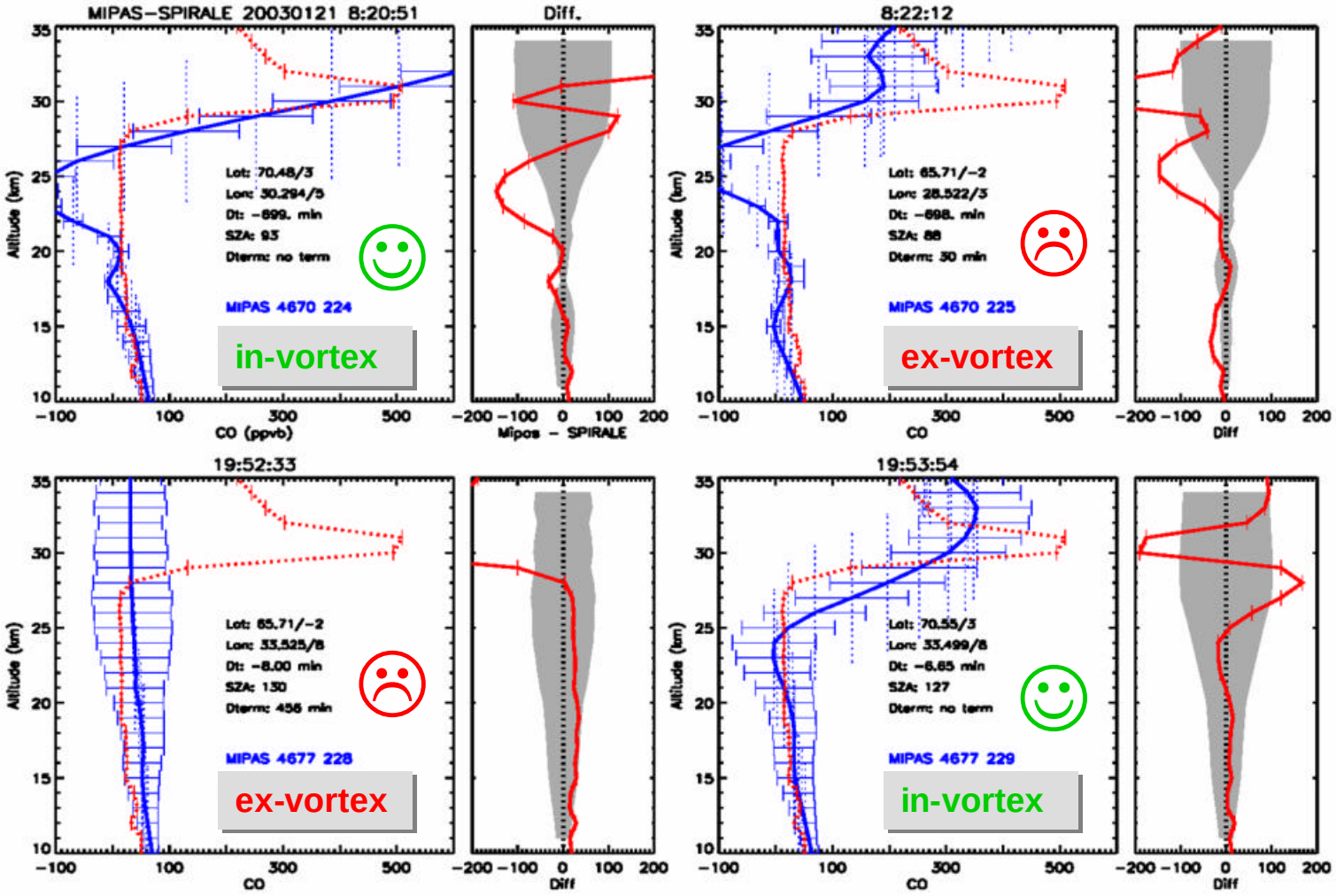
Validation

SPIRALE Þ CO
in situ balloon measurements (1)
Kiruna (68ºN /25ºE), 21/01/2003

MIPAS-B Þ NO_2
Limb emission balloon measurements (2)
Air s/ Ladour (41ºN/0ºE, 45ºN/1ºE), 24/09/2002

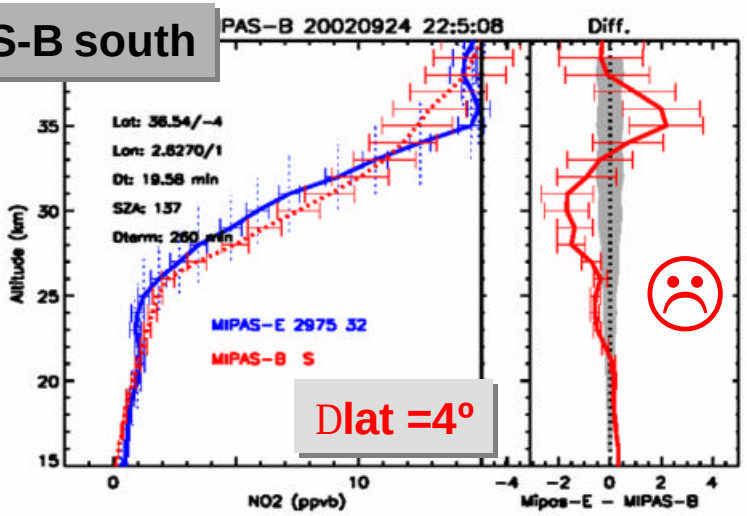
HALOE Þ NO+NO_2
Solar occultation satellite measurements (~ 120 coinc.)
mainly N hemisphere, July – October 2002

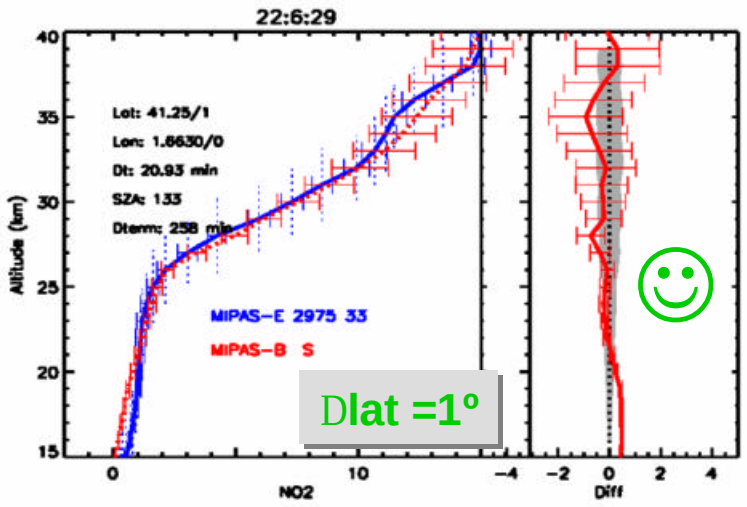
CO validation with SPIRALE (in situ, 1 profile at 67°N)



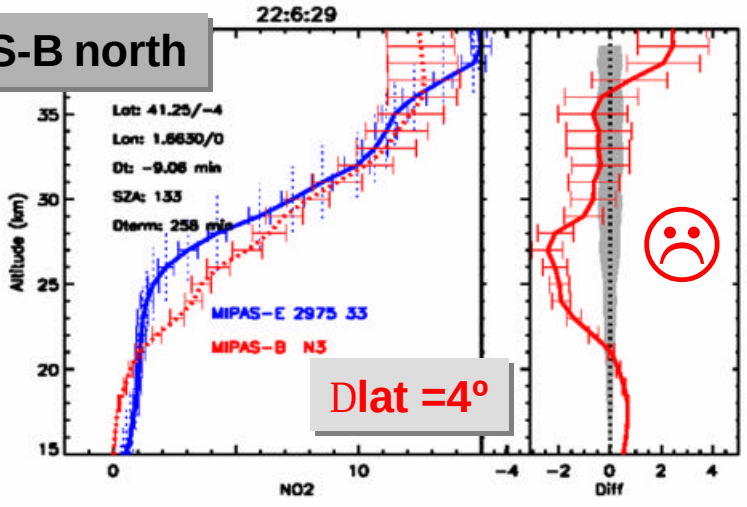
NO_2 validation with MIPAS-B (2 profiles, night)

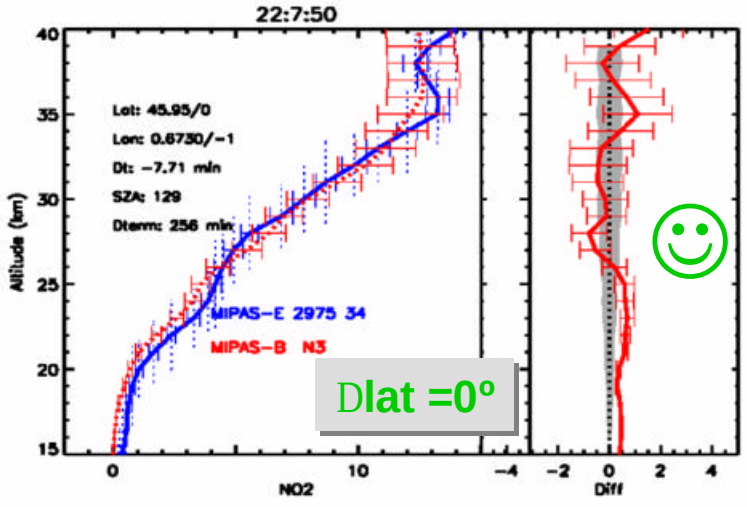
MIPAS-B south



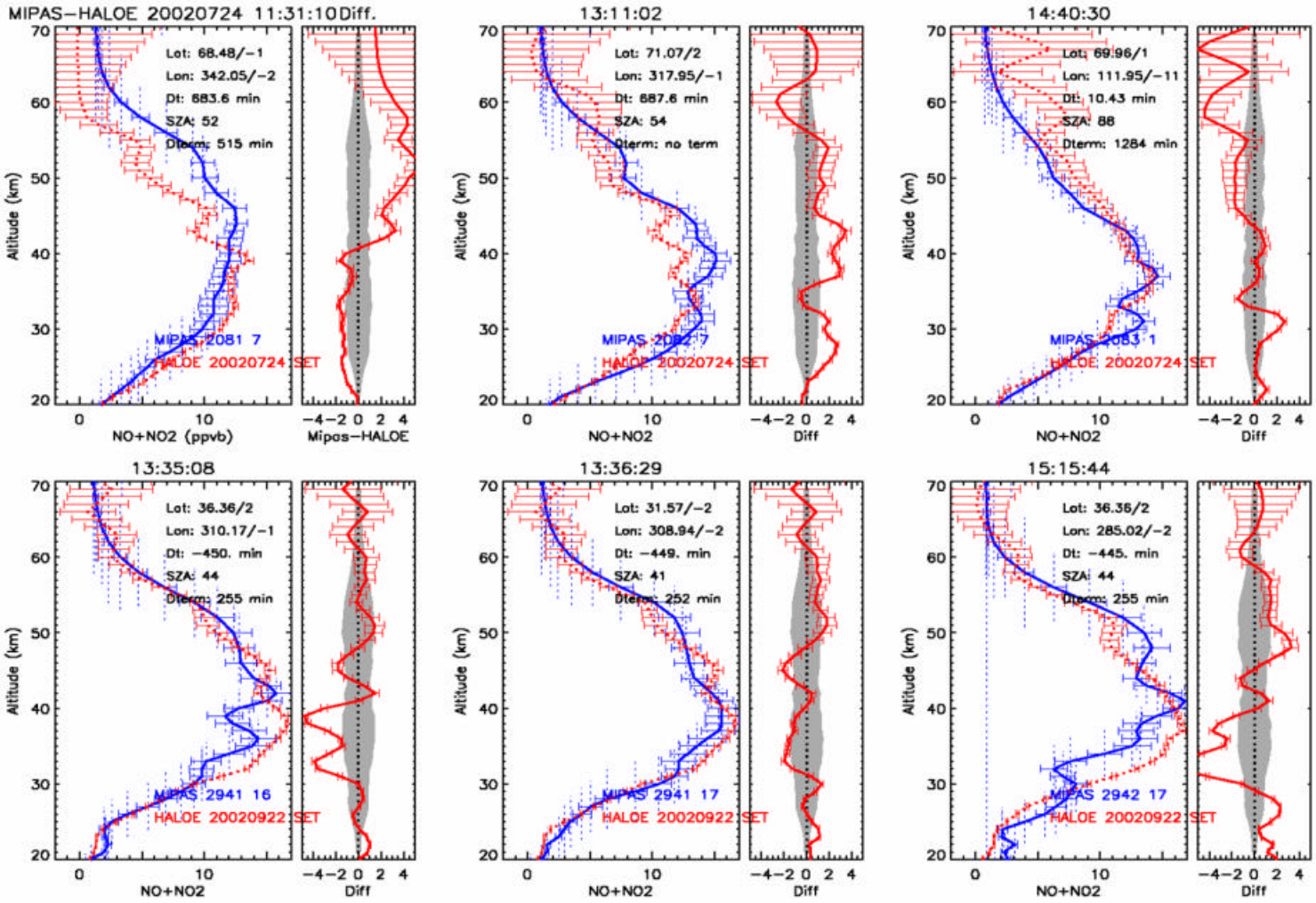


MIPAS-B north



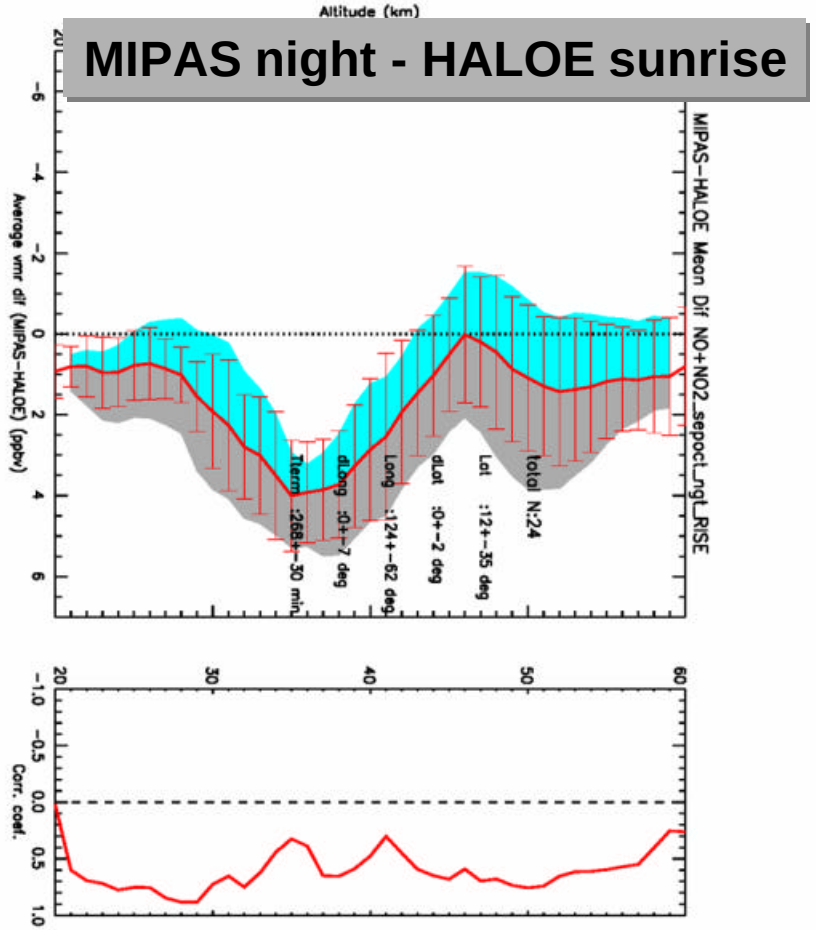


NO_x validation with HALOE (examples)

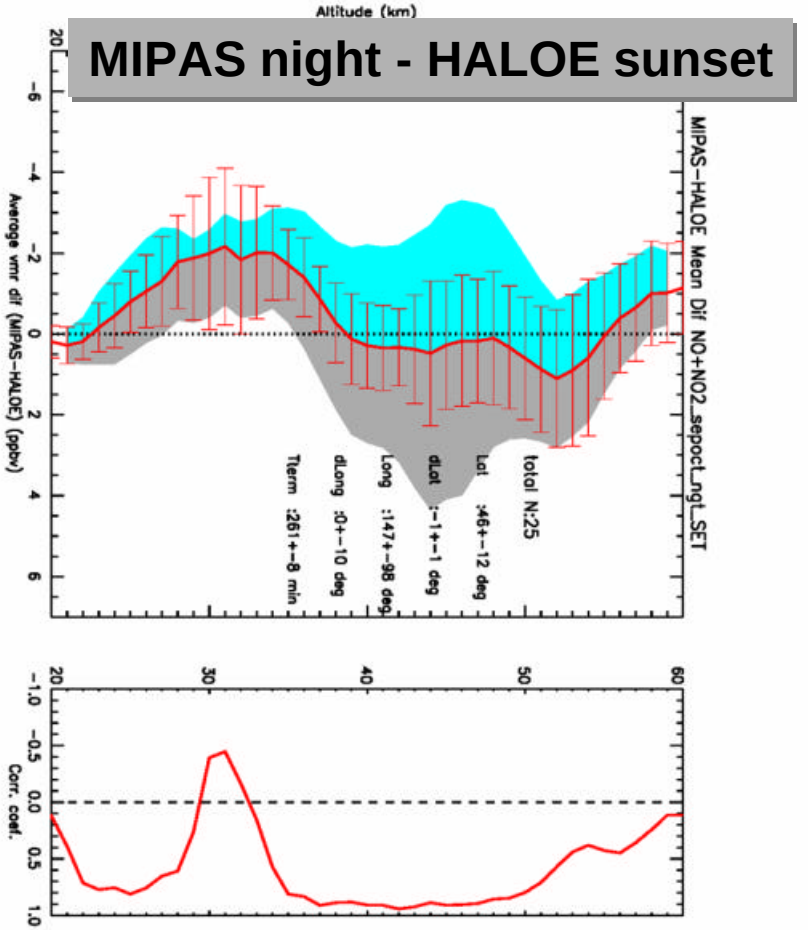


Nighttime NO_x compared to HALOE

MIPAS night - HALOE sunrise



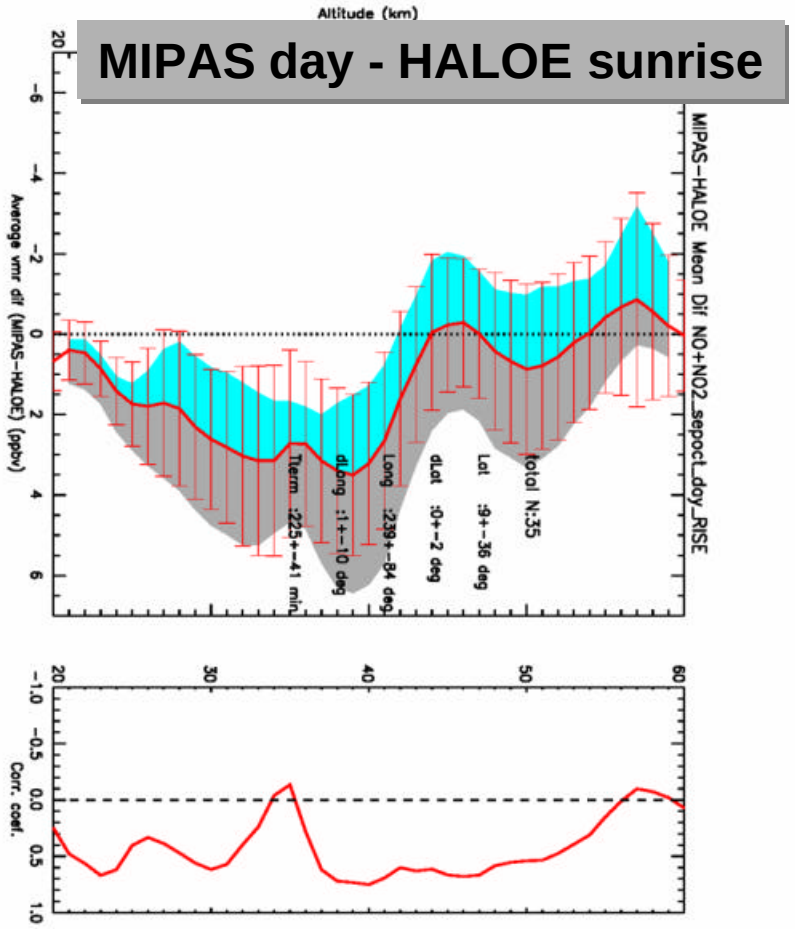
MIPAS night - HALOE sunset



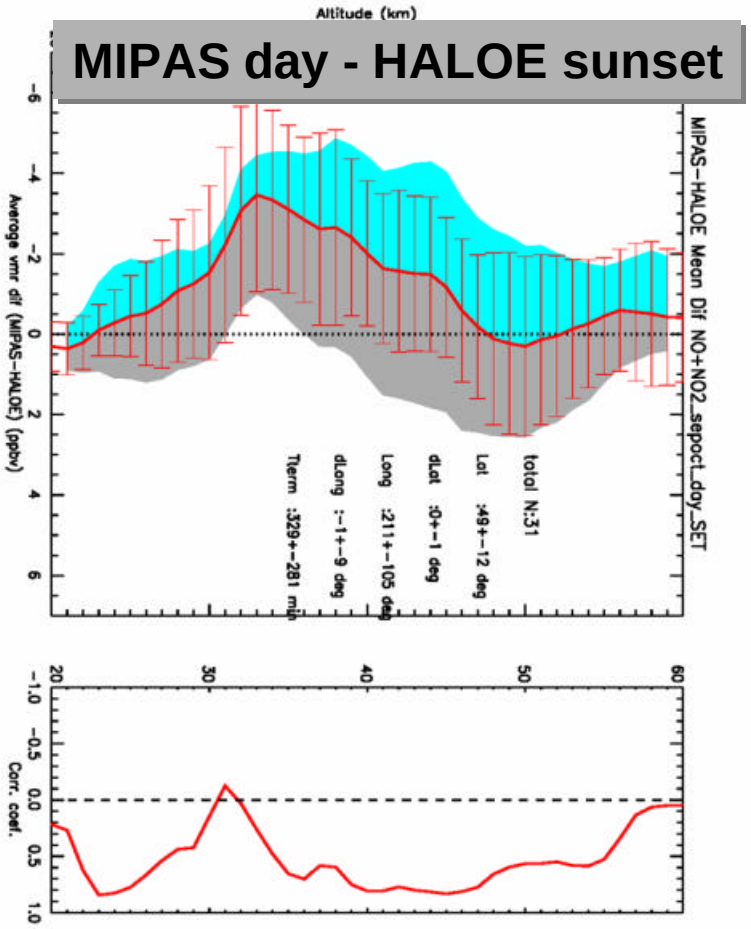
± 3 ppbv difference due to $NO_2 \leftrightarrow N_2O_5$ conversion between sunset and sunrise

Daytime NO_x compared to HALOE

MIPAS day - HALOE sunrise



MIPAS day - HALOE sunset



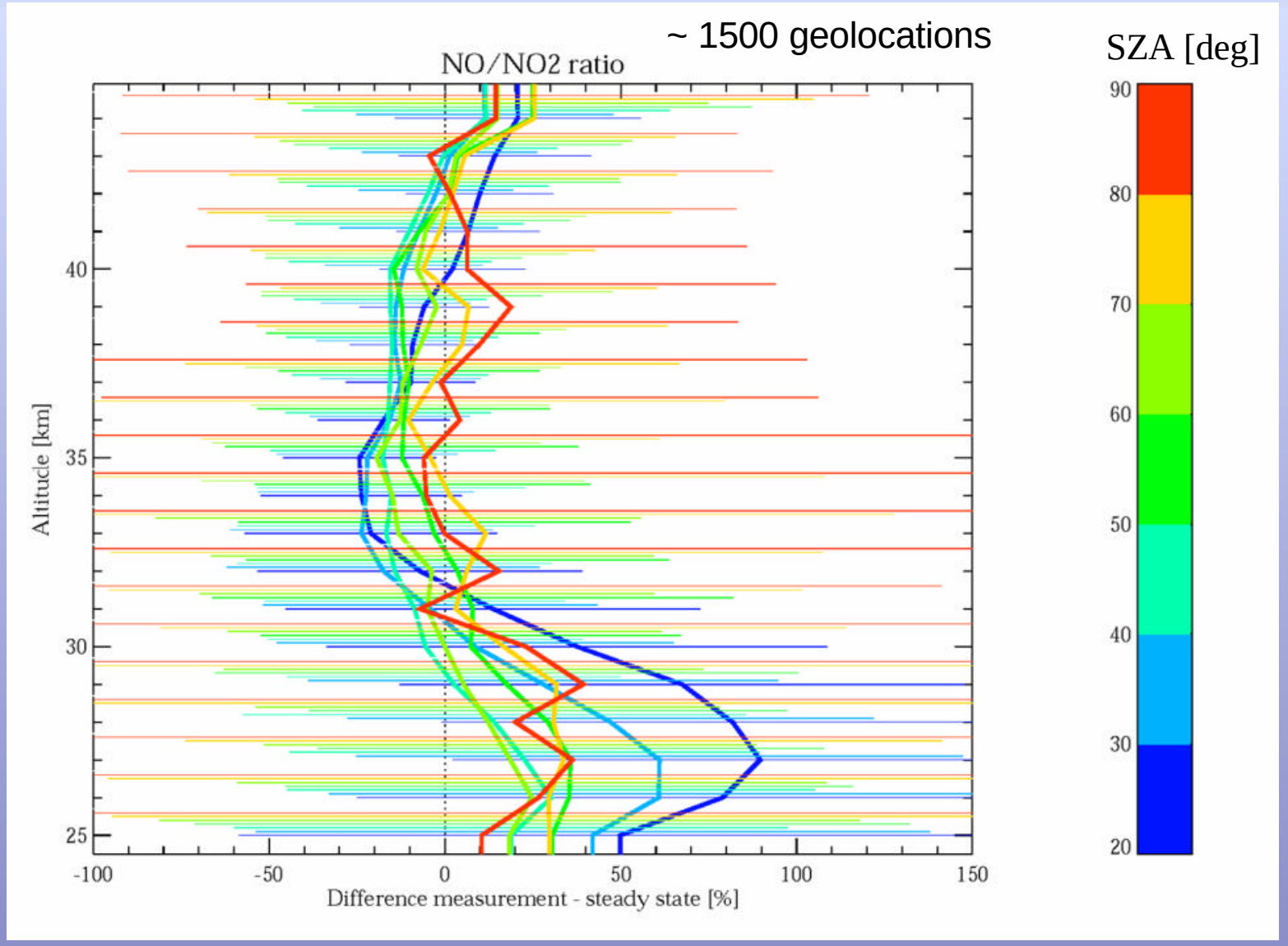
± 3 ppbv difference due to $NO_2 \leftrightarrow N_2O_5$ conversion between sunset and sunrise

Is measured NO and NO_2 consistent with steady state?

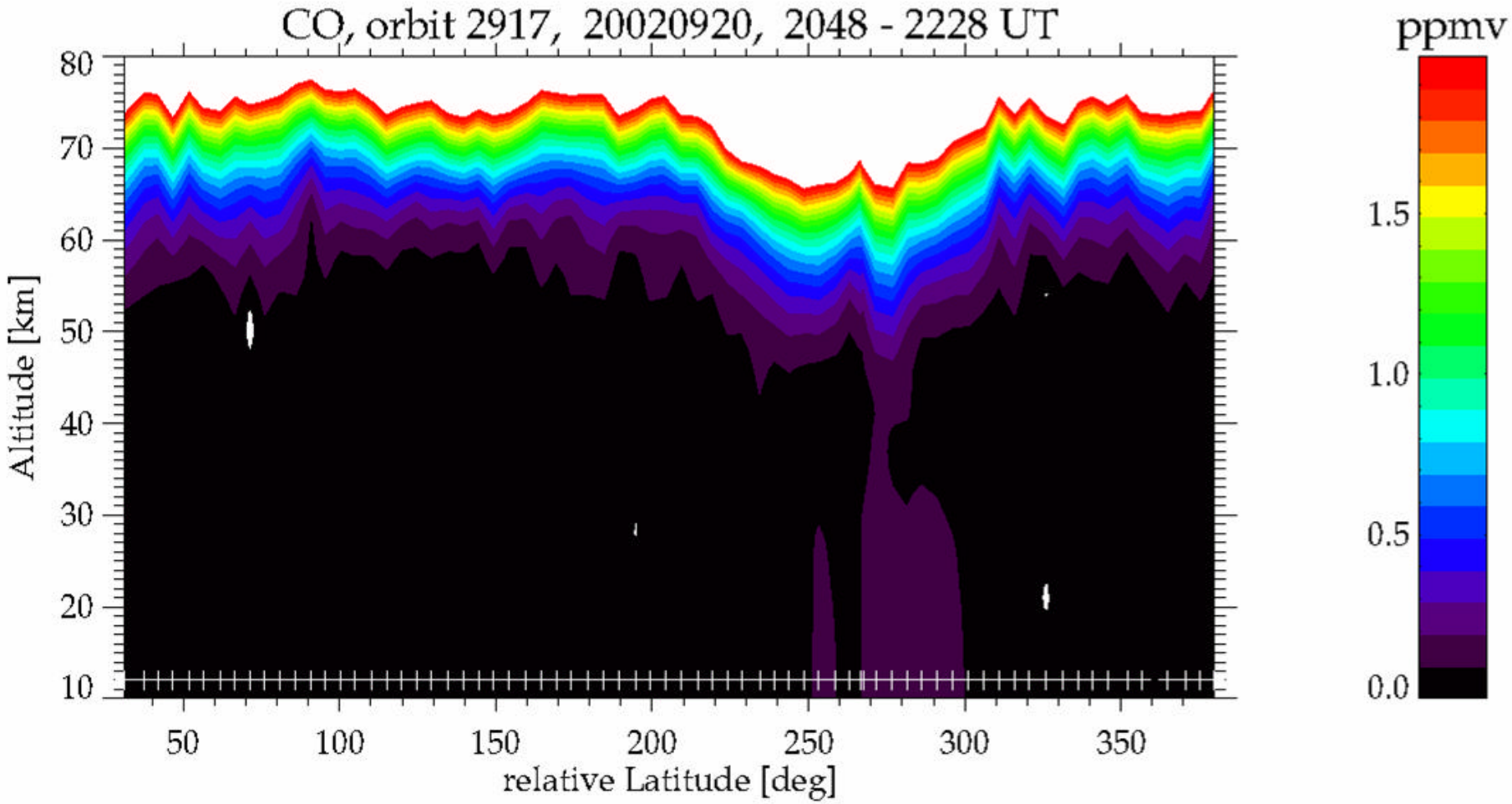
Steady state:

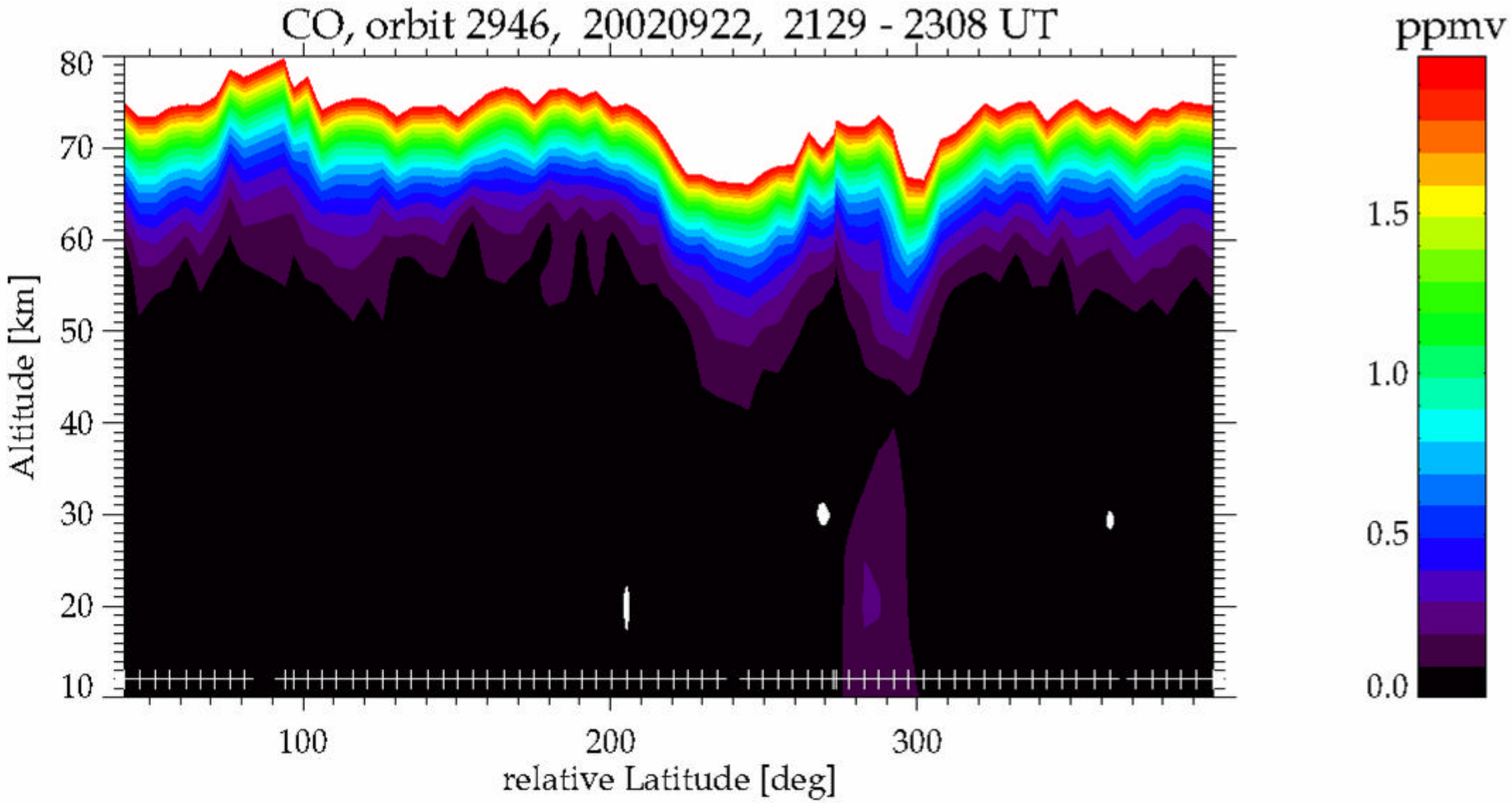
$$\frac{[NO]}{[NO_2]} = \frac{J_{NO_2} + k_{NO_2+O}[O]}{k_{NO+O_3}[O_3] + k_{NO+ClO}[ClO]} \quad \text{with} \quad [O] = \frac{J_{O_3}[O_3]}{k_{O+O_2+M}[O_2][M]}$$

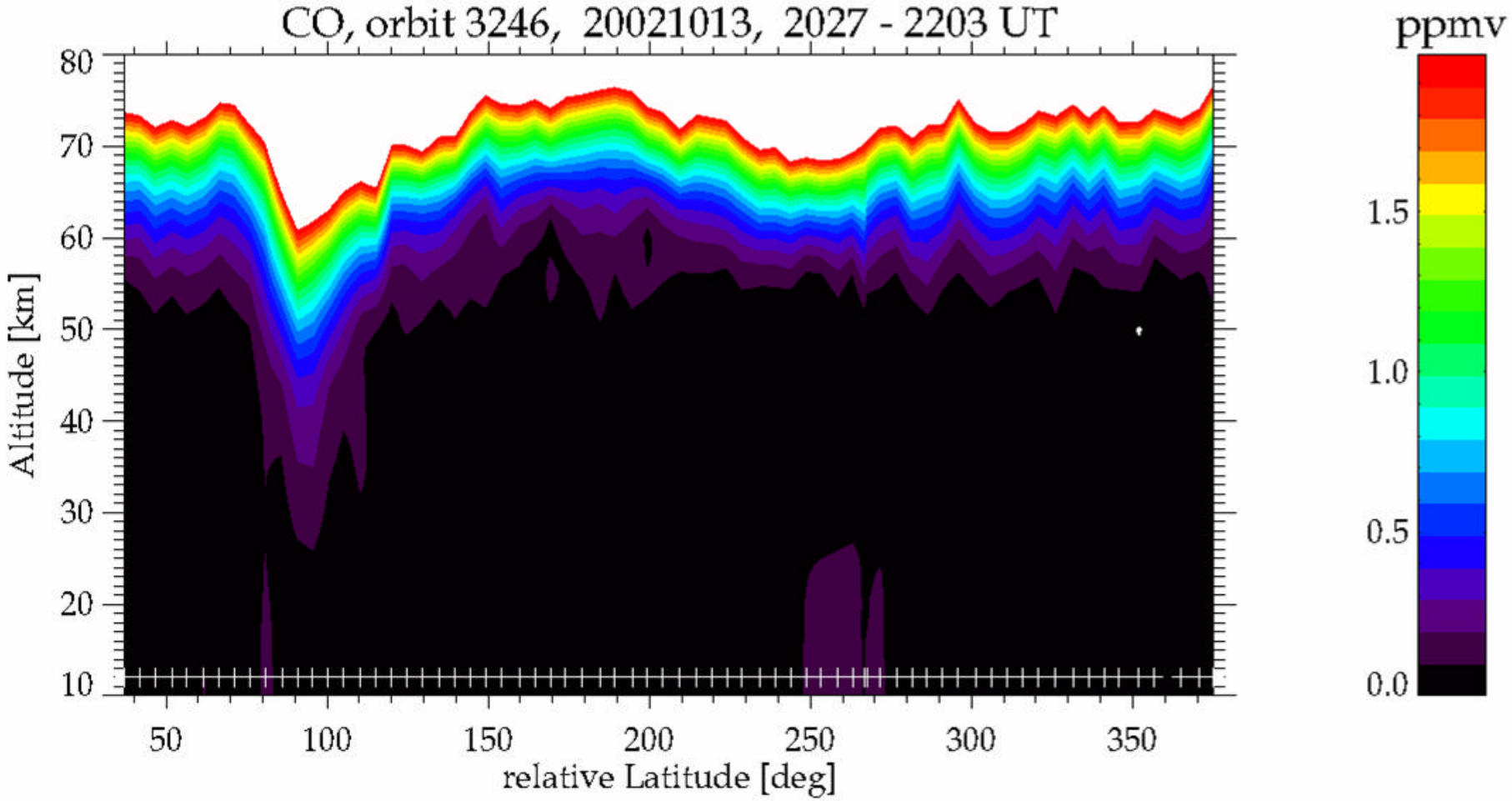
- MIPAS O_3, ClO, p, and T
- Photolysis rates from TUV model


~ 1500 geolocations
NO/NO2 ratio
SZA [deg]
90
80
70
60
50
40
30
20
Altitude [km]
40
35
30
25
-100
-50
0
50
100
150
Difference measurement - steady state [%]

CO measurements


CO, orbit 2917, 20020920, 2048 - 2228 UT
Altitude [km]
80
70
60
50
40
30
20
10
50
100
150
200
250
300
350
relative Latitude [deg]
ppmv
1.5
1.0
0.5
0.0
Npole
Spole

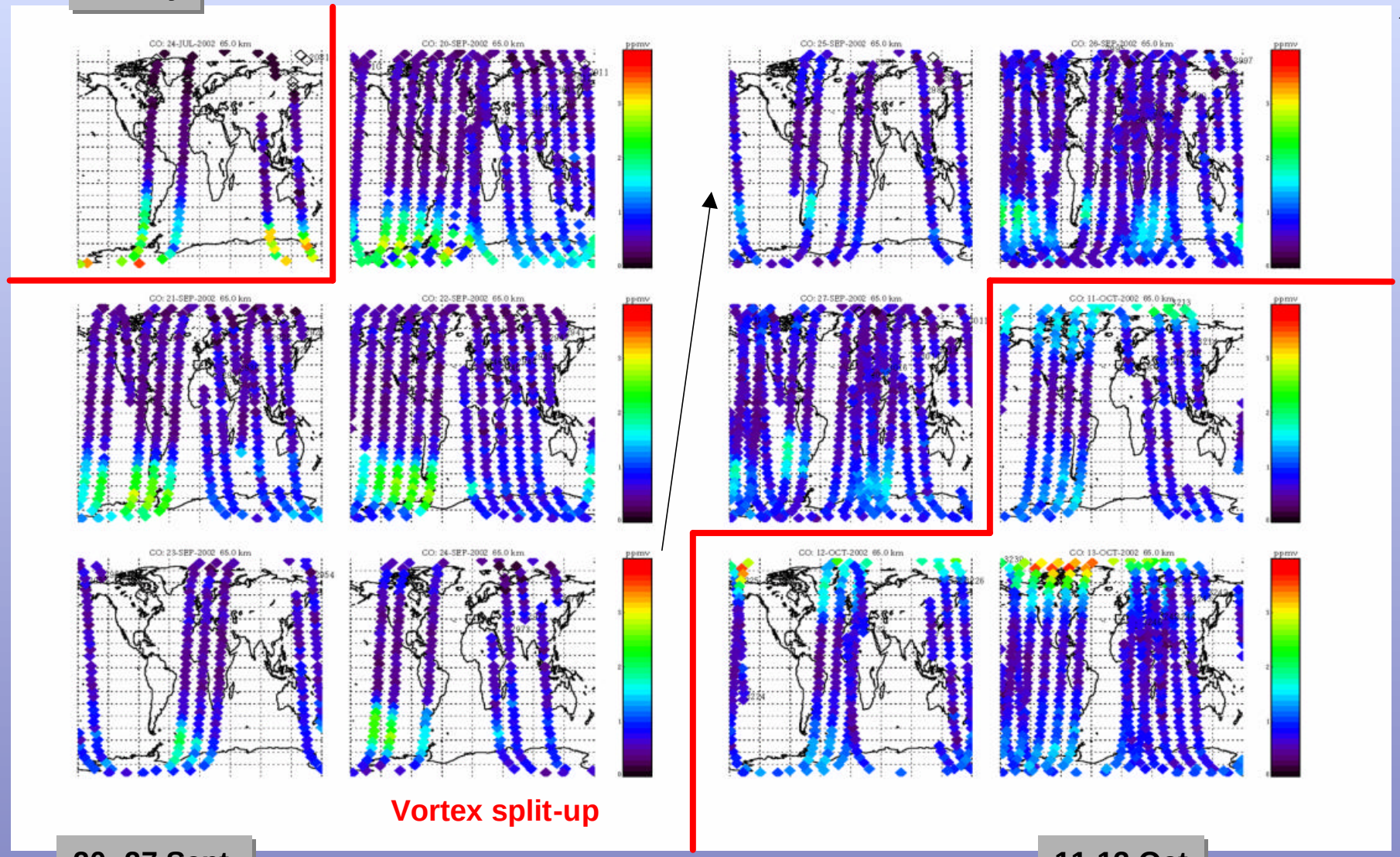

CO, orbit 2946, 20020922, 2129 - 2308 UT
Altitude [km]
80
70
60
50
40
30
20
10
100
200
300
relative Latitude [deg]
ppmv
1.5
1.0
0.5
0.0
Npole
Spole


CO, orbit 3246, 20021013, 2027 - 2203 UT
Altitude [km]
80
70
60
50
40
30
20
10
50
100
150
200
250
300
350
relative Latitude [deg]
ppmv
1.5
1.0
0.5
0.0
Npole
Spole

- **Mesospheric air in stratosphere over South pole.**
- **Turnover of meridional circulation in September/October.**

Mesospheric CO at 65km

24 July

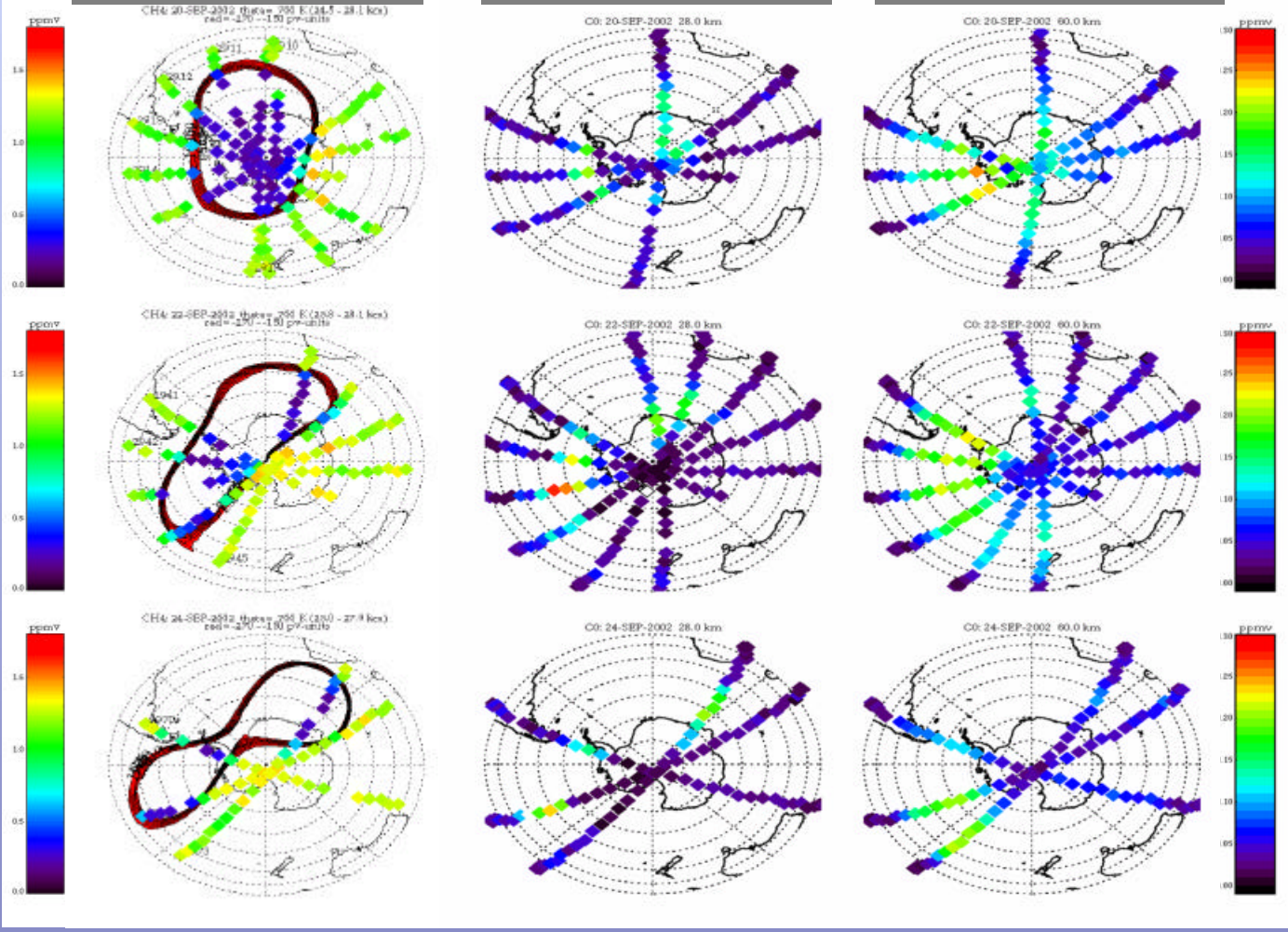


Vortex split-up

20 -27 Sept

11-13 Oct

Comparison of CO, CH_4, and pV

	CH4 @ q=700 K	CO @ 28 km	CO @ 60 km
20 Sept.			
22 Sept.			
24 Sept.			

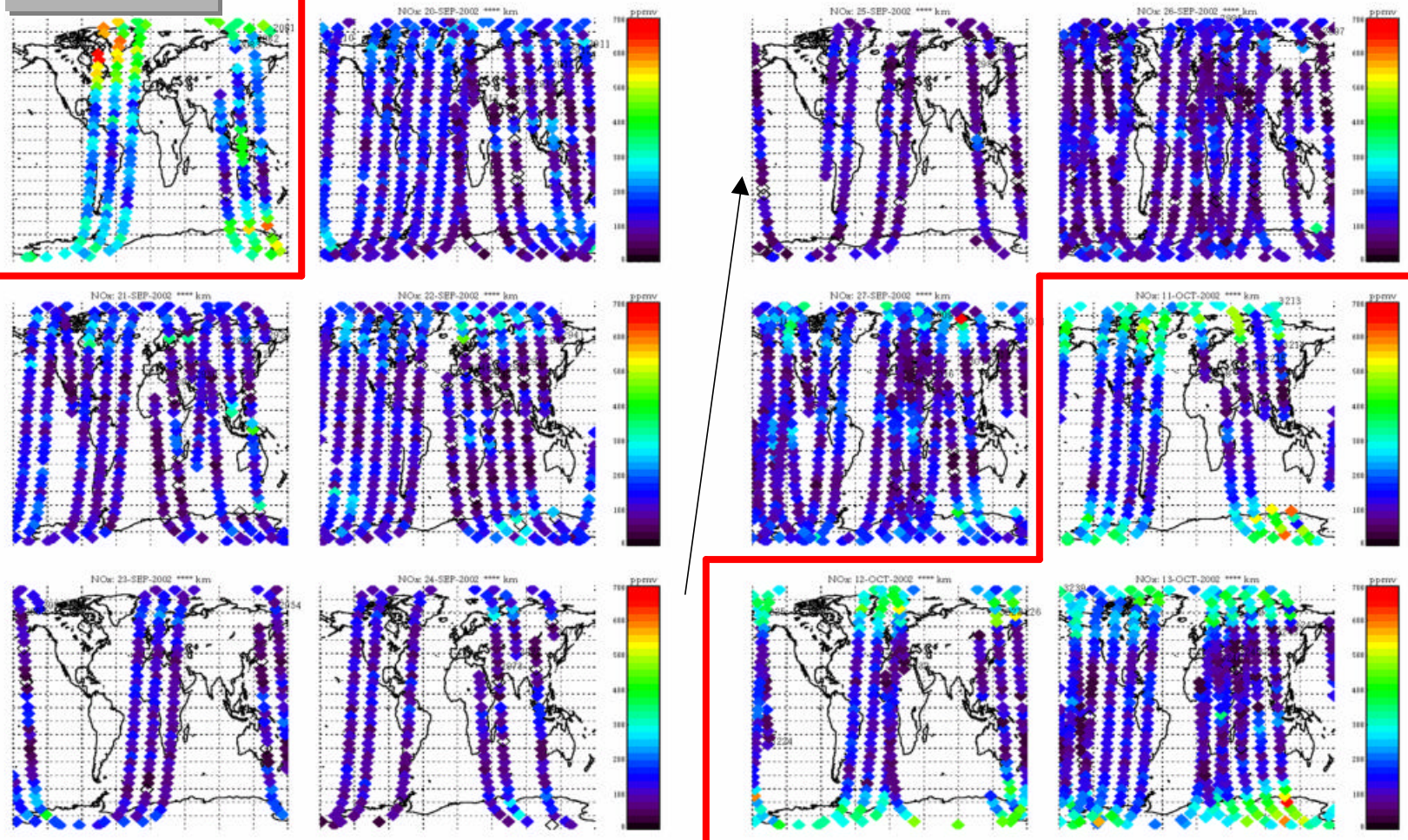
Dynamical connection between stratosphere and mesosphere:

Is turnover of circulation induced by vortex split ?????

NO_x measurements

Thermospheric NO at 120 km

24 July
F10.7 » 210

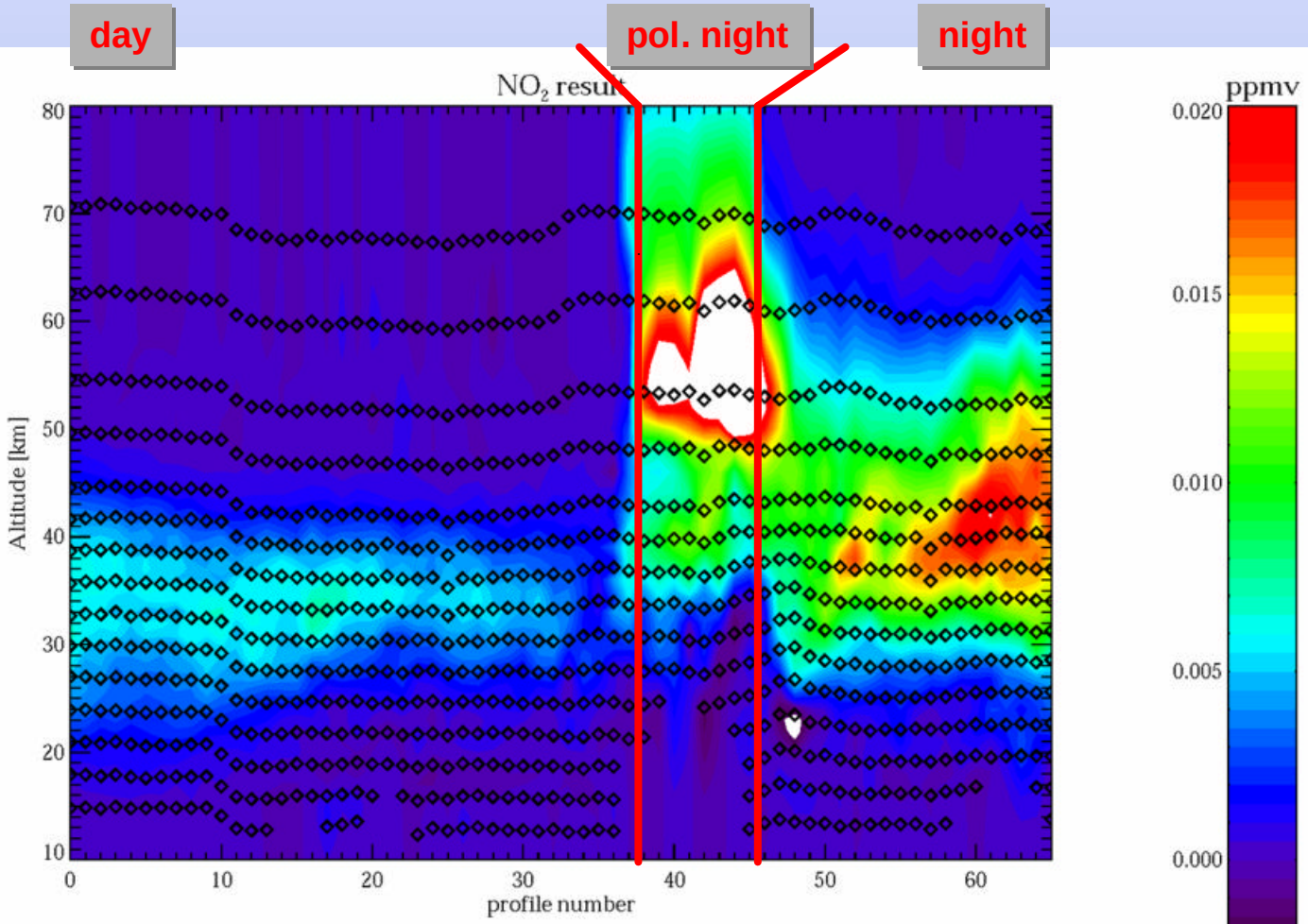


20 -27 Sept
F10.7 » 155

11-13 Oct
F10.7 » 180

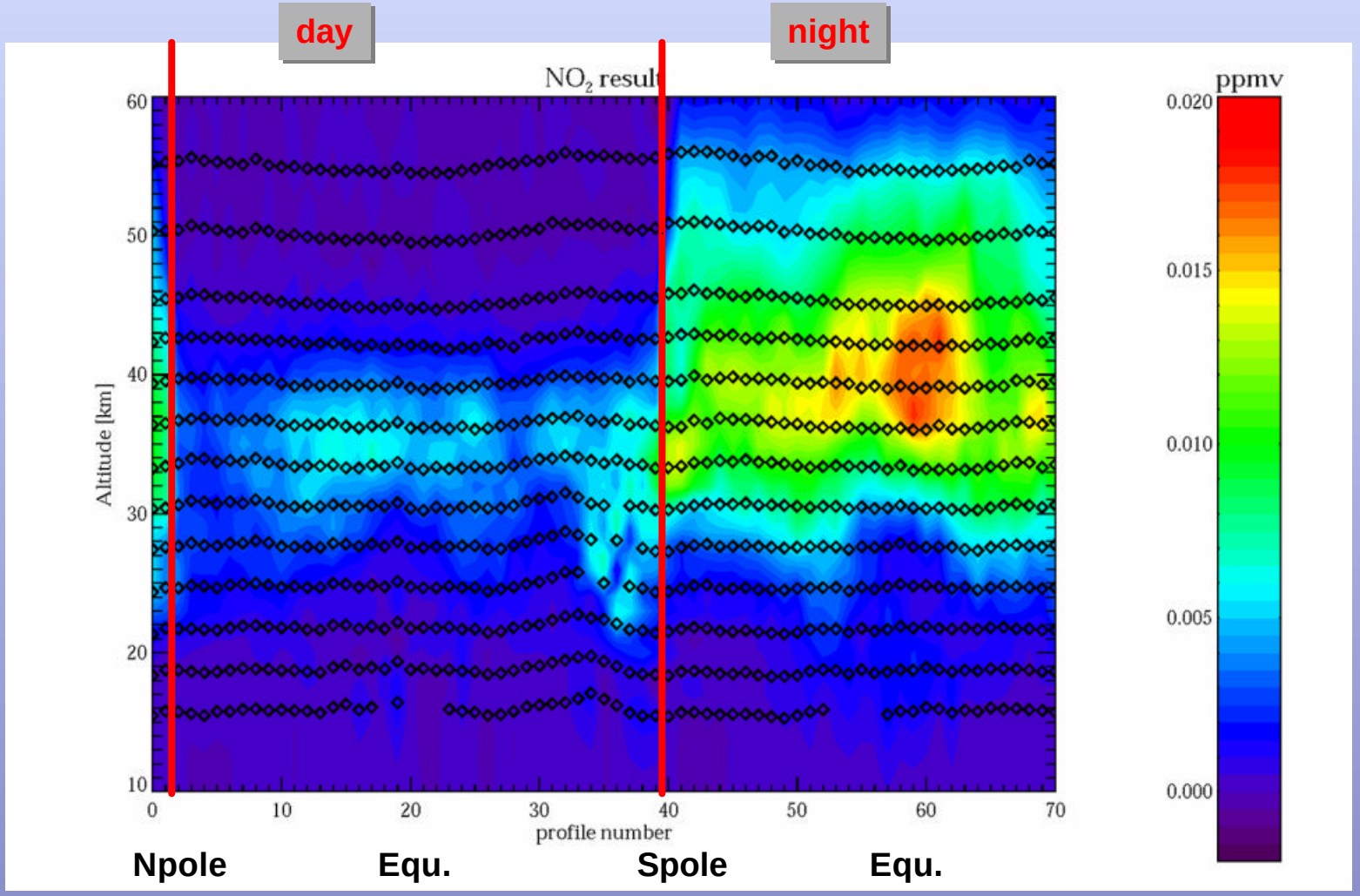
...is thermospheric NOx descending to the stratosphere?

NO_2 measured at 24 July 2003



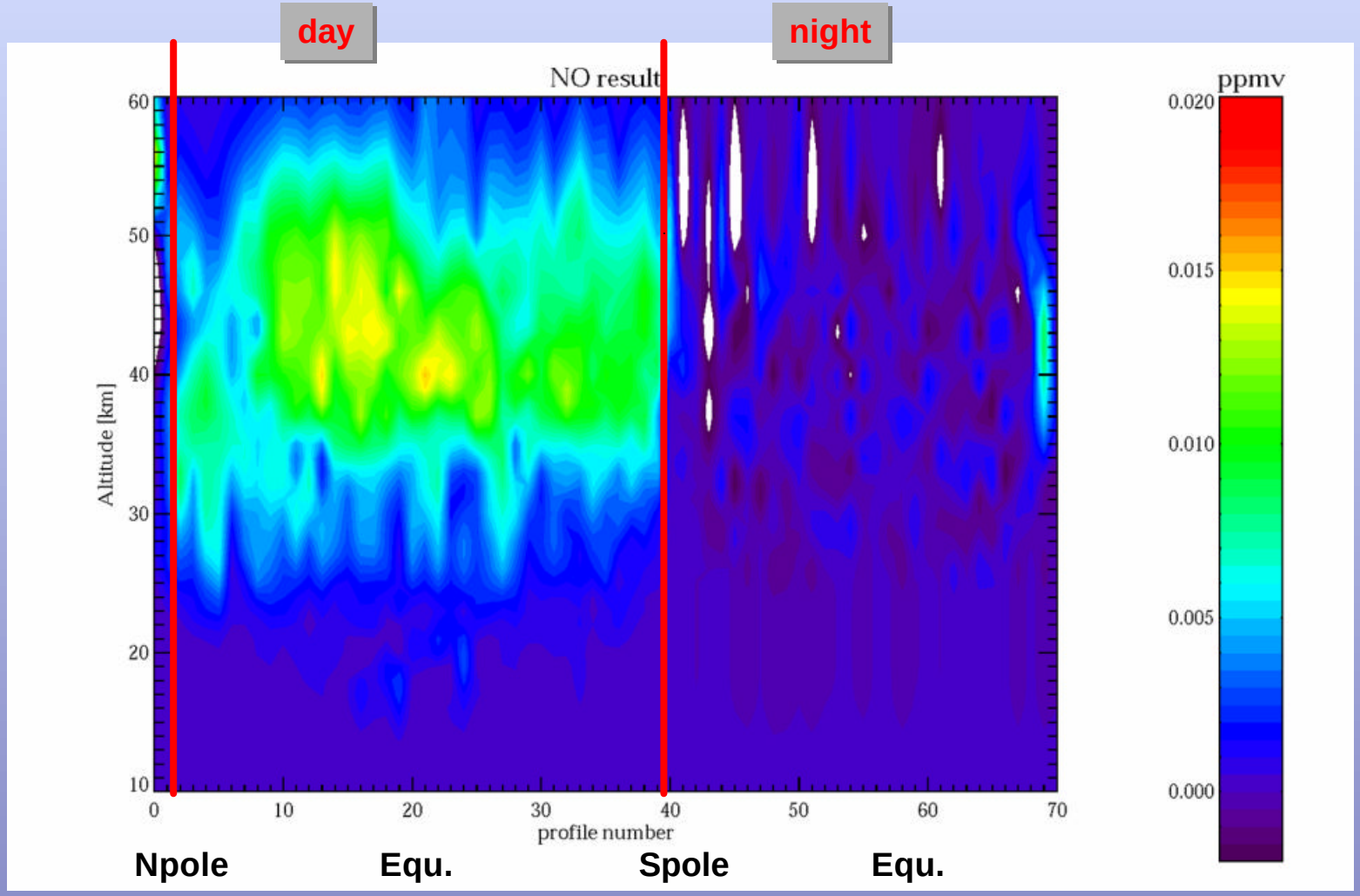
…over 50 ppb NO_2 over the S pole at 60 km !!!!

NO_2 measured at 24 September 2002



... but not in September !!!!

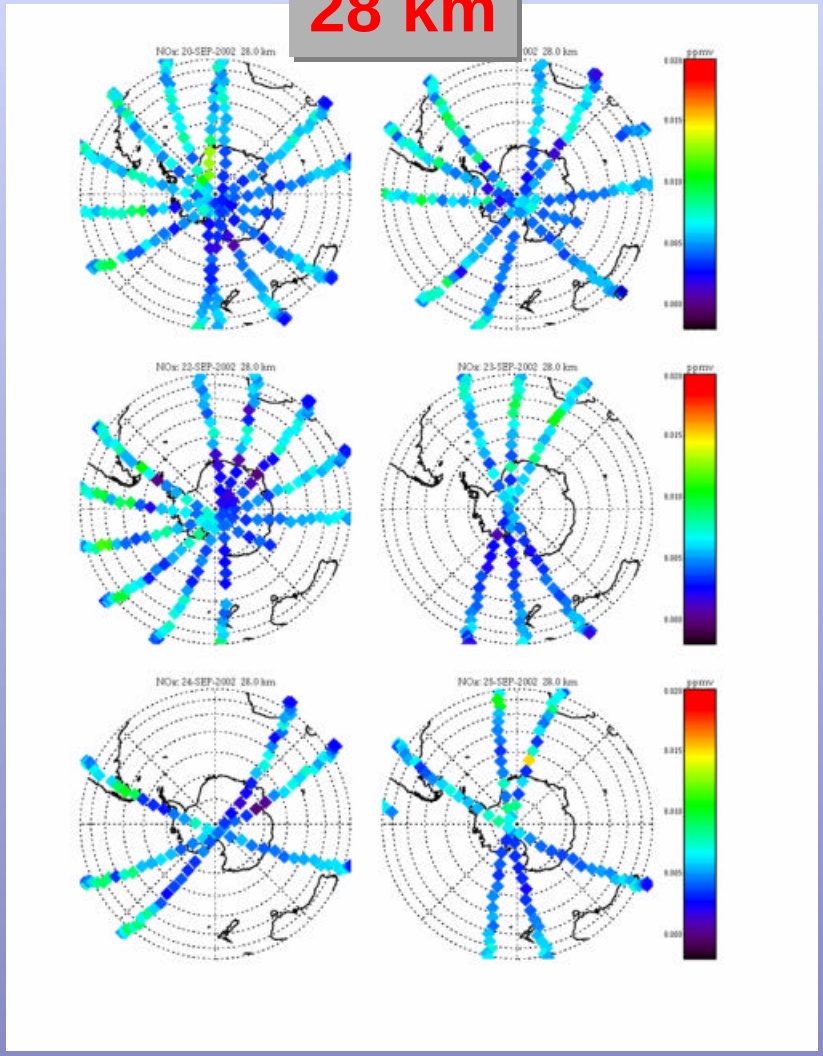
NO measured at 24 September 2002



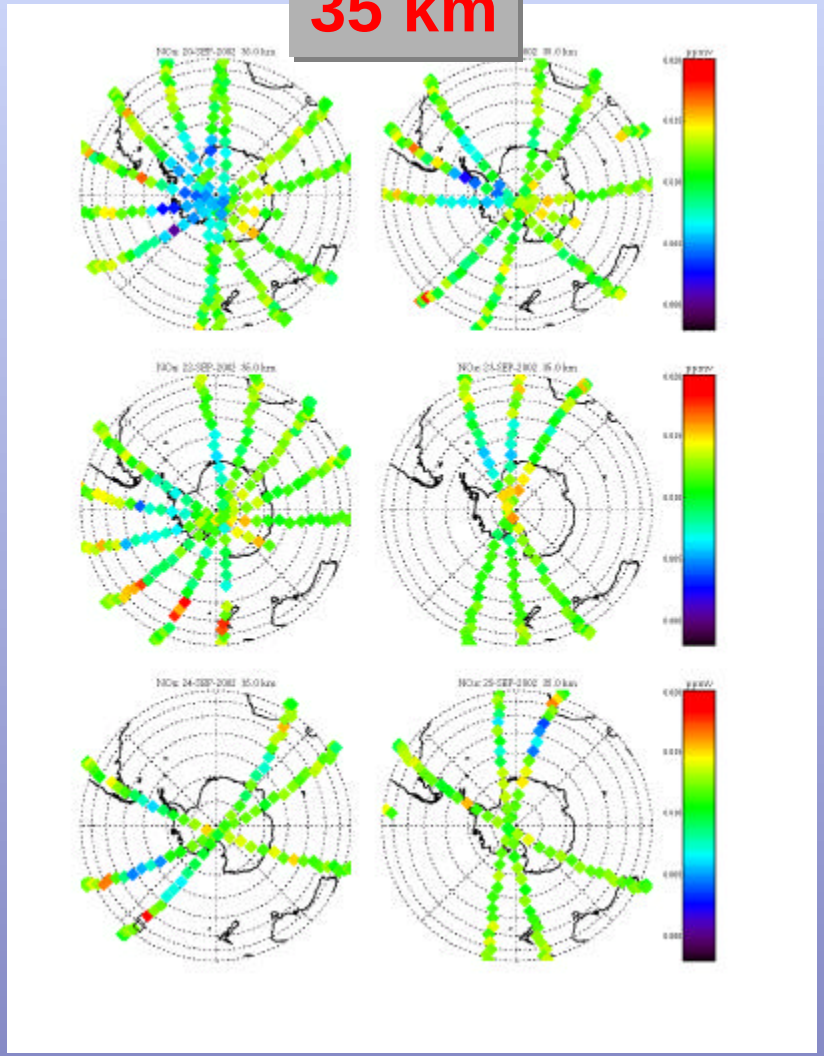
Enhanced stratospheric NO_x transported down from the upper atmosphere can only be detected at polar night, when mesospheric NO photolysis barreer is not active.

NO_x in S Hemisphere in September (20-26/9/2002)

28 km



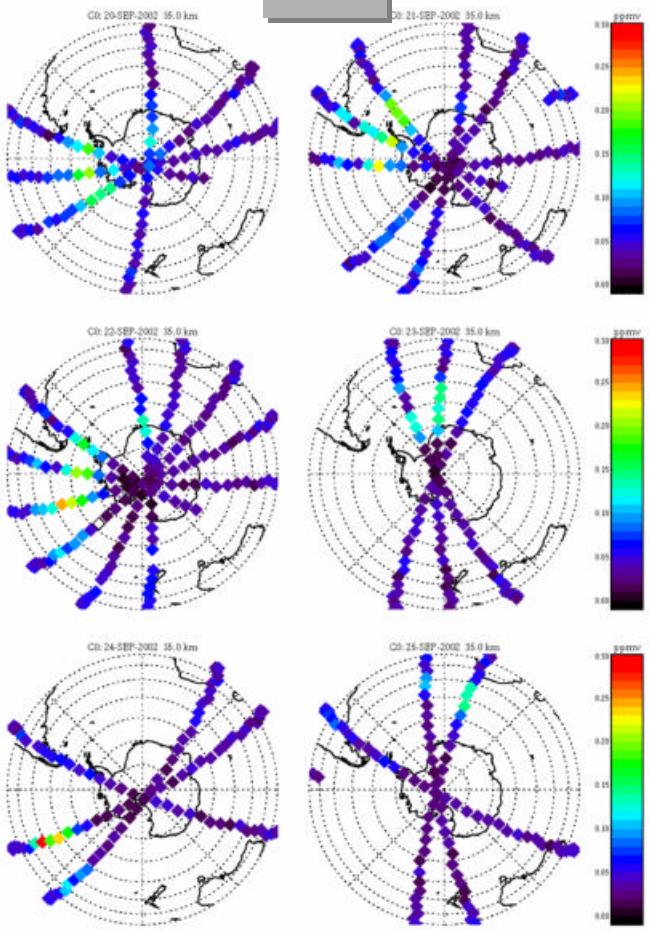
35 km



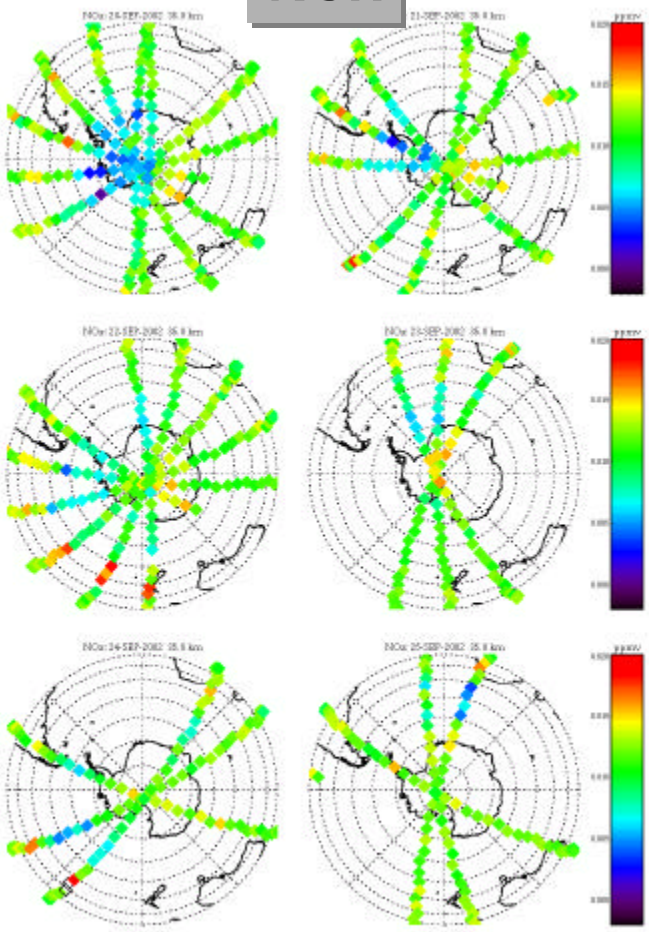
…distribution of NO_x above 30 km is different to below (pronounced minima). Is this mesospheric NO_x??

NO_x and CO in S Hemisphere at 20-26/9/2002

CO



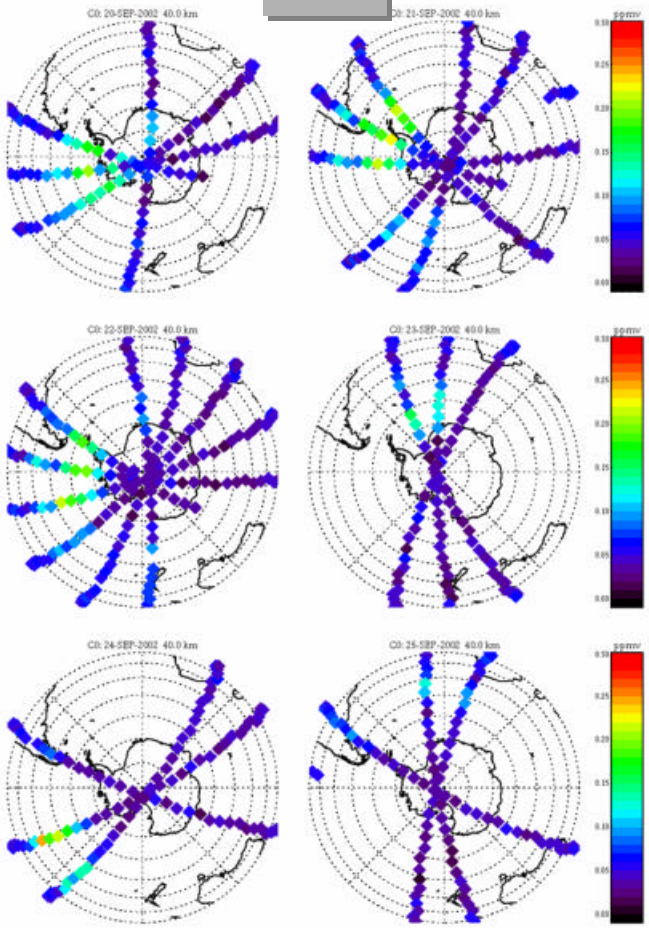
NOx



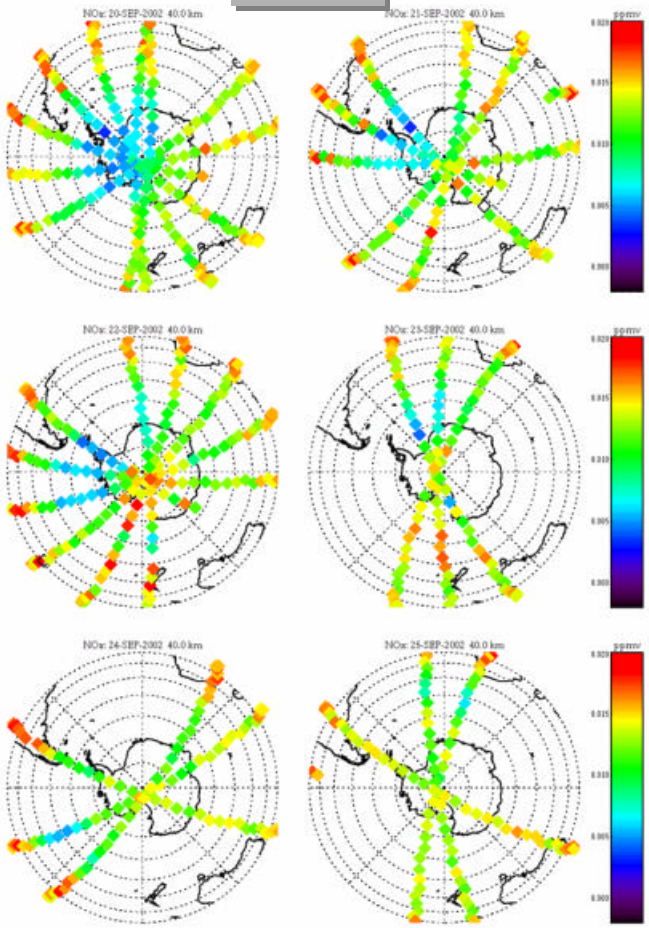
35 km

No_x and CO in S Hemisphere at 20-26/9/2002

CO



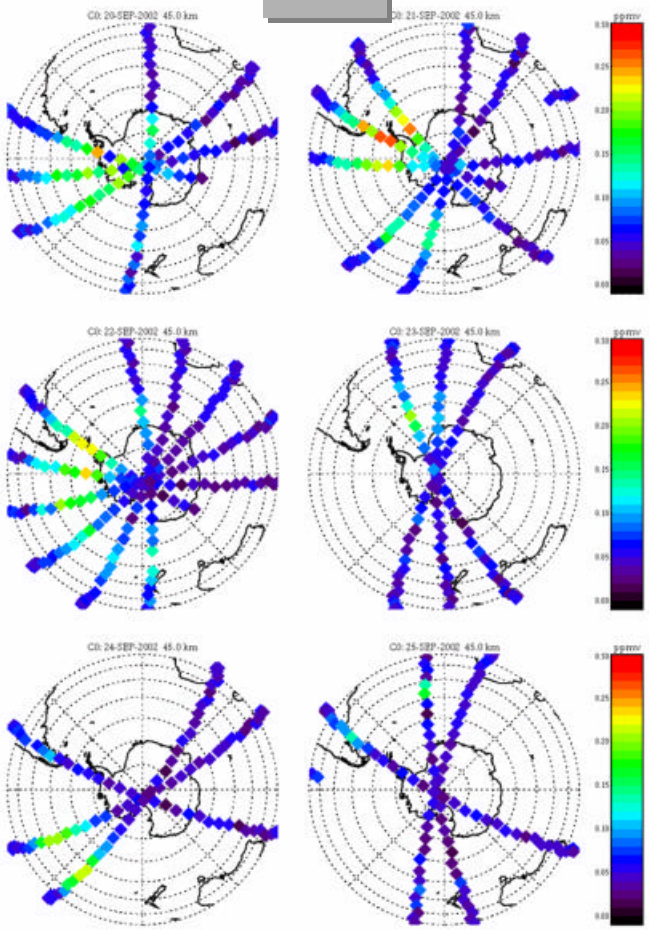
NOx



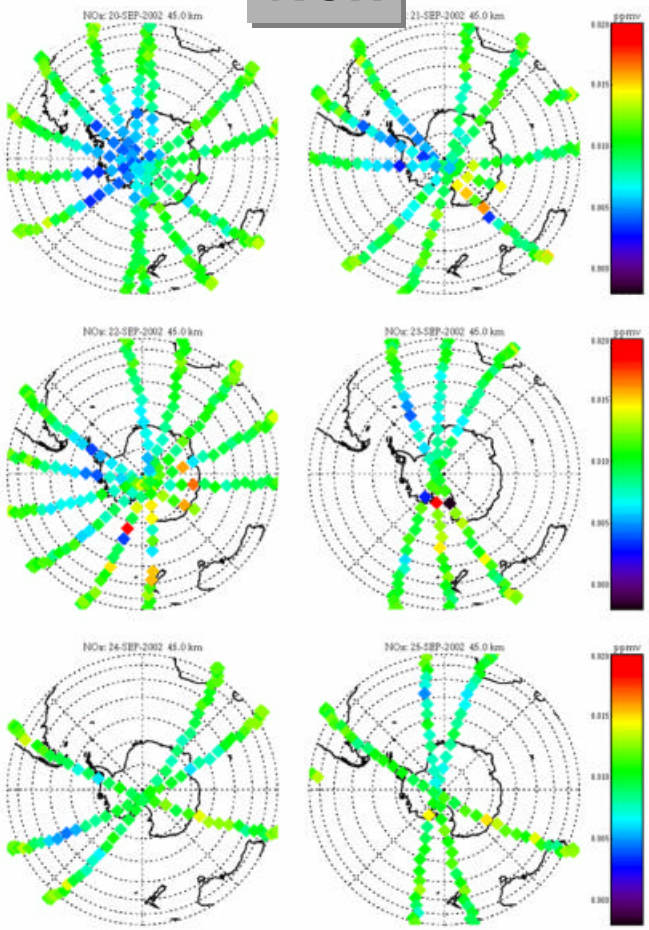
40 km

No_x and CO in S Hemisphere at 20-26/9/2002

CO



NOx



45 km

NO_x vs. CO distributions over South pole give evidence for mesospheric NO_x in upper stratosphere with low vmr's in September.

Conclusions

- non-LTE retrieval processor allows for NO, NO_2, and CO retrieval with high accuracy and vertical resolution.
- Validation: good agreement of MIPAS/SPIRALE CO, MIPAS/MIPAS-B NO_2, and MIPAS/HALOE NO_x.
- Measurements of NO, NO_2, and CO in July - October 2002:
  - ® Dynamical interaction of stratosphere and mesosphere.
  - ® Change of meridional circulation coincides with vortex split !?
  - ® Mesospheric air in stratosphere over South pole.
  - ® HIGH NO_x in upper stratosphere during polar night BUT
  - ® LOW NO_x in upper stratosphere over South pole in Sept.