Retrieval of HNO_3 Vertical Profiles from AIRS Measurements

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Outline

1. Introduction
2. Physical retrieval algorithm
3. Global HNO_3 distribution
4. Comparison HNO3 total amount with ground-based FTIR measurements
5. Comparison HNO3 vertical profiles with balloon-based measurements
6. Summary and future plans for HNO_3 products
7. Status of N_2O retrieval

Satellite Measurements of Nitric Acid (HNO_3)

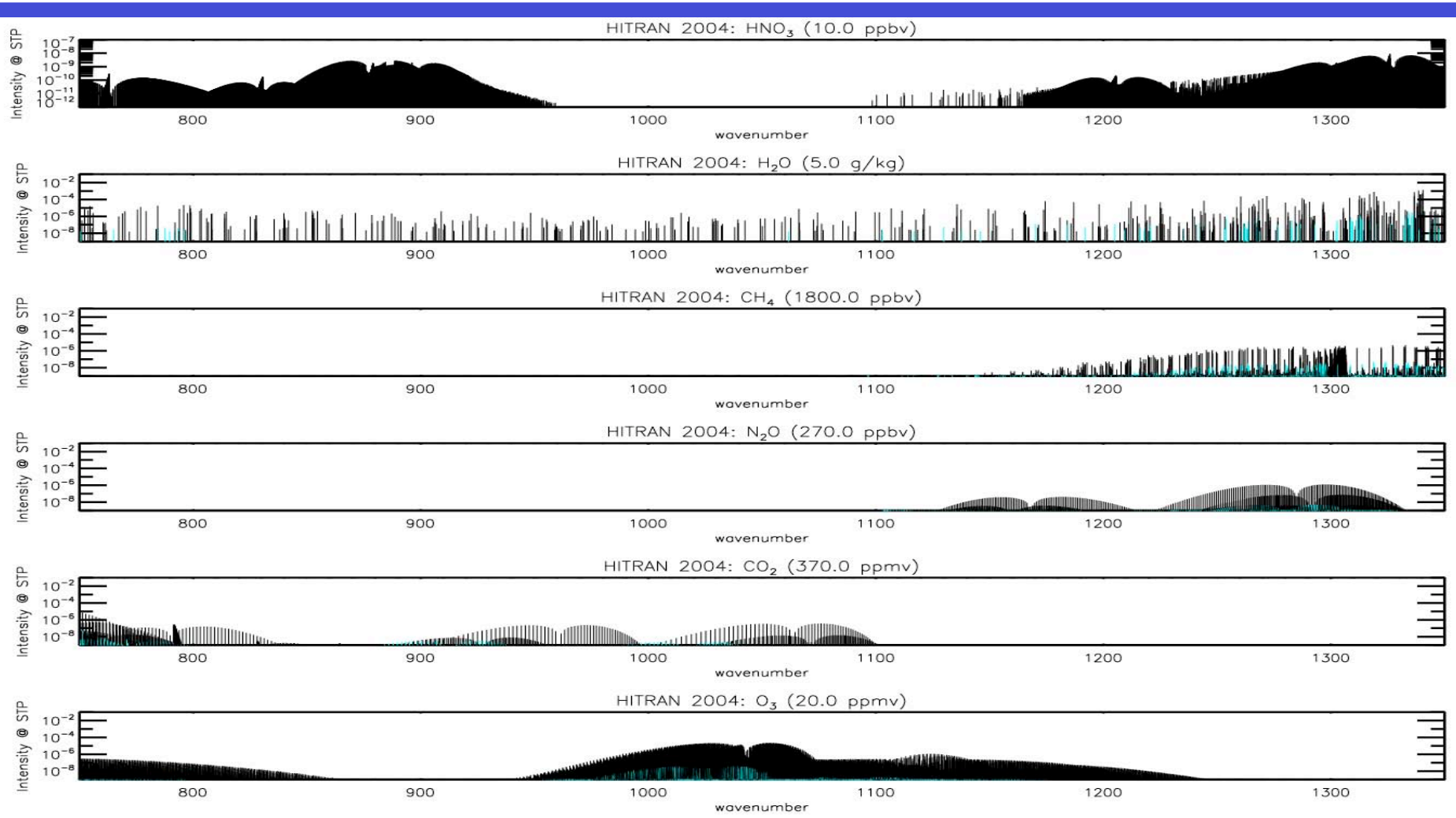
Infrared limb *infrared nadir* *Microwave limb* *millimeter limb*

- LIMS (the Limb Infrared Monitor of the Stratosphere), mounted on the Nimbus 7 satellite.
- CLAES (the Cryogenic Limb Array Etalon Spectrometer) and MLS (Microwave Limb Sounder), onboard the UARS (Upper Atmosphere Research Satellite)
- MLS, HIRDLS (High Resolution Dynamics Limb Sounder) and TES (Tropospheric Emission Spectrometer) on Aura.
- ILAS (the Improved Limb Atmospheric Spectrometer) and IMG (Interferometric Monitor of Greenhouse gases), onboard ADEOS (Advanced Earth Observing Satellite).
- ILAS-II on ADEOS-II.
- SMR (the Sub-Millimetre Radiometer) on Odin
- FTS (the Fourier Transform Spectrometer) on SCISAT-1, also knows as ACE (Atmospheric Chemistry Experiment)
- MIPAS (the Michelson Interferometer for Passive Atmospheric Sounding) onboard the ENVISAT satellite.
- AIRS (the Atmospheric Infrared Sounder) onboard AQUA.

AIRS Science Term Retrieval Algorithm (Susskind et al, 2003) Version 5

- Regularized Least Square fitting approach using cloud clearing radiance (same as $O_3(p)$, CO(p) retrievals).
- Retrieval HNO_3 after cloudy and surface properties, T(p), Q(p), $O_3(P)$ and CO(p) retrievals, but before $CH_4(p)$, $CO_2(p)$ and $N_2O(p)$ retrievals.
- Optimize retrieval algorithm by selection of channel, definition of retrieval functions, usage of first guess, calculation of error covariance matrix and how much damping is used.

HNO_3 has weak lines but more lines per AIRS channel than H_2O and CH_4. N_2O, CO_2 and O_3 are relatively weaker interference species.



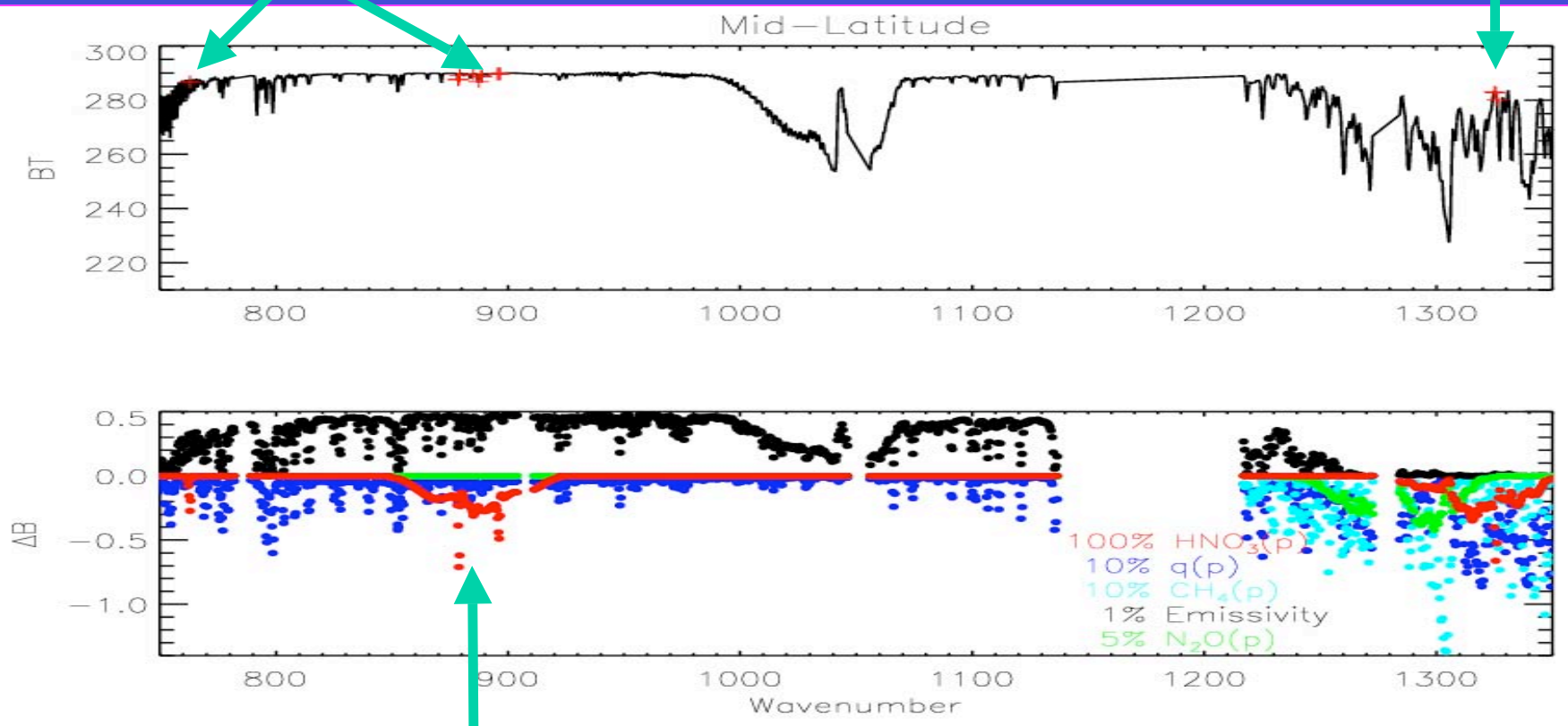
Infrared Line Strength from HITRAN 2004 Database

Sensitivity Analysis of HNO_3 Retrieval

Selection of 14 channels in 760-770 (1), 870-900 (10) and 1320-1330 (3) cm^{-1} (3) spectral regions

less interference from other species

Improve CH_4 retrieval



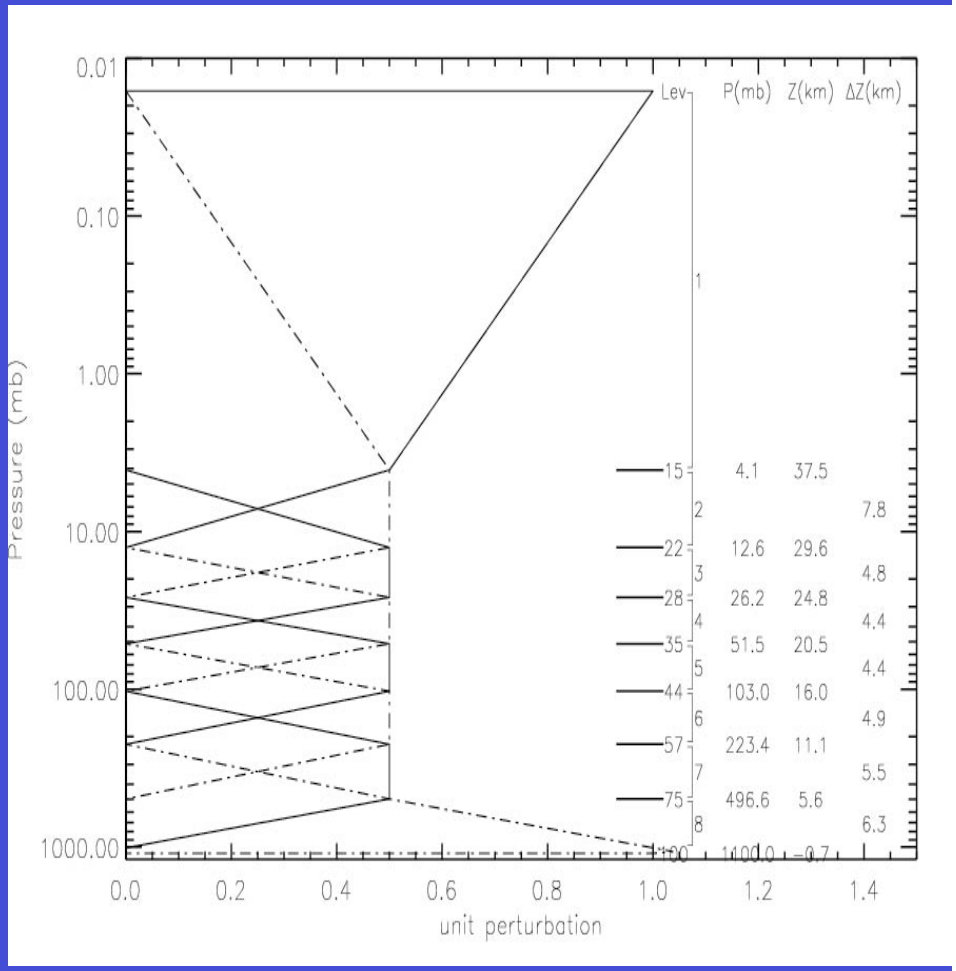
11μm band requires good emissivity (future thought — use ON/OFF line to eliminate sensitivity to surface emissivity).

Retrieval Functions: 8 Vertical Overlapping Trapezoids

Define a reduces state space and acts as a smoothing constraint on the retrieval.

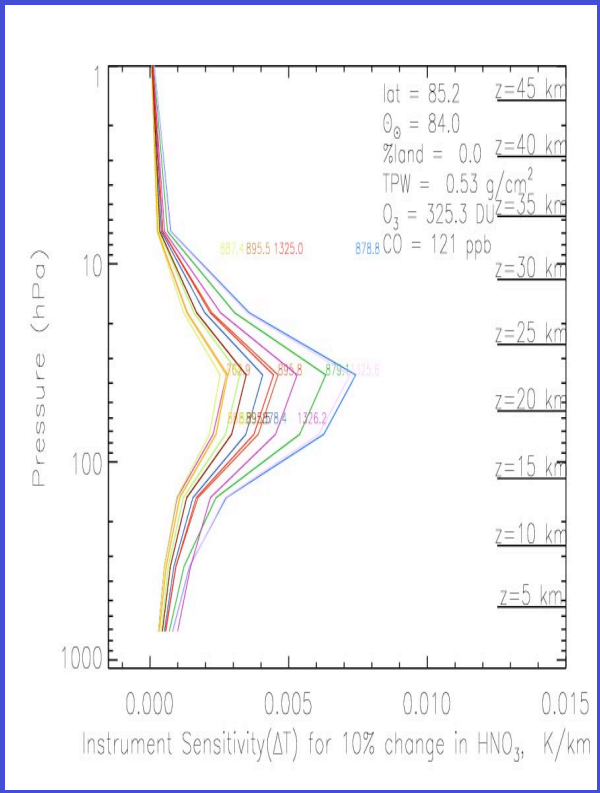
What should consider:

1. HNO_3 natural vertical distribution and temporal and spatial variation.
2. AIRS instrument spectral sensitivity: broad width and most sensitive layer.
3. Mimic the shape of channel kernel functions.

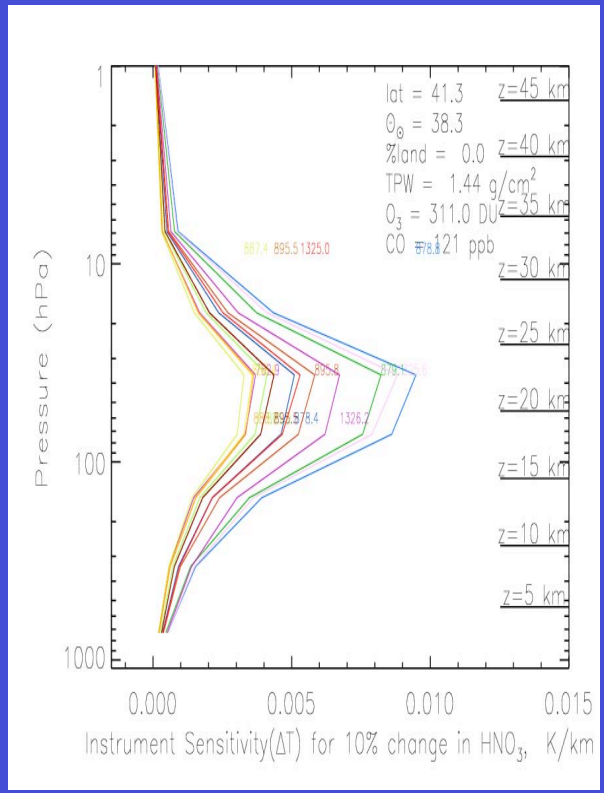


Examples of Channel Kernel Functions: K=dR/dHNO3

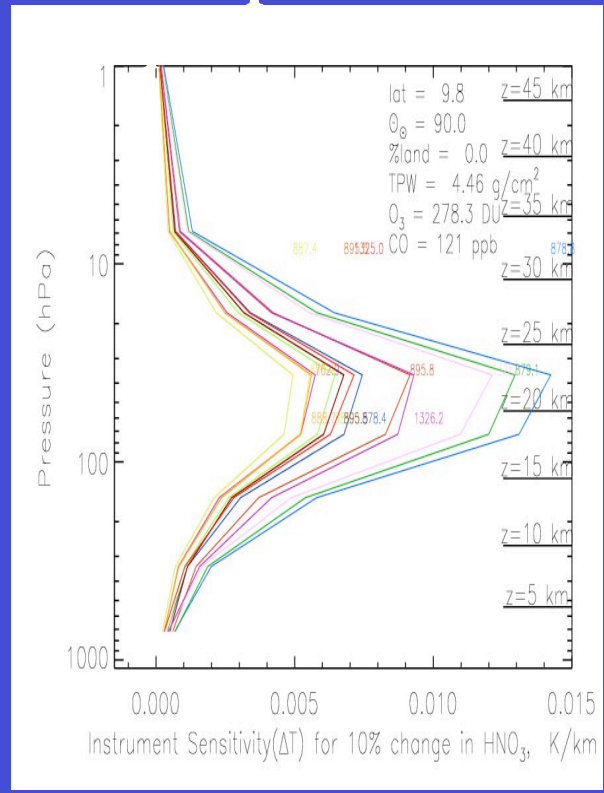
Polar



Mid-latitude



Tropica



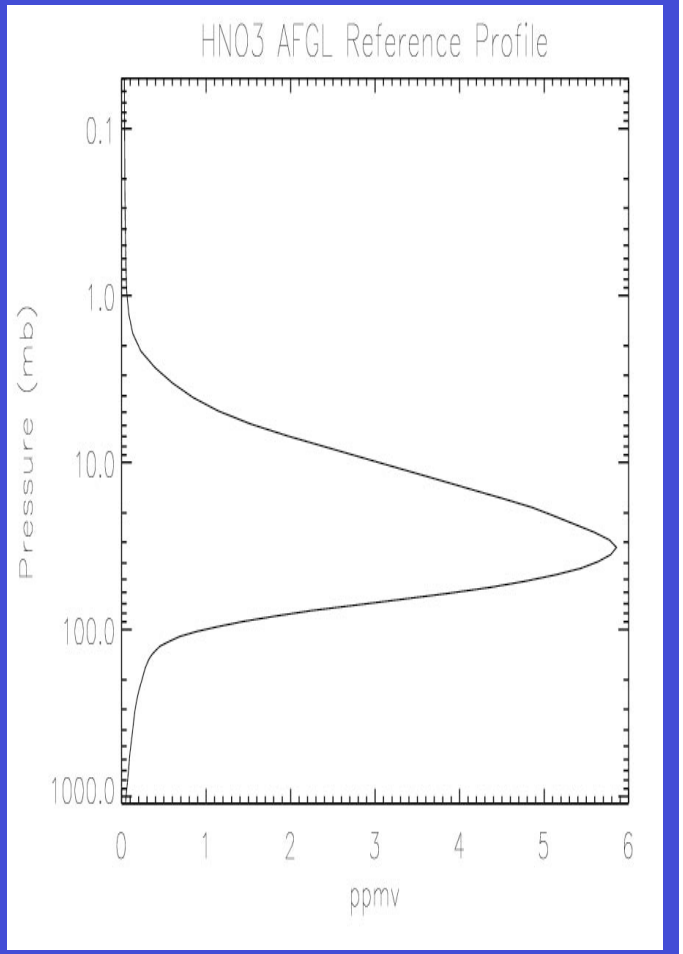
Most sensitive to lower stratosphere. Vertical resolution is 8 kilometers. Channel sensitivity increases with lapse of temperature. No obviously vertical shift as water vapor concentration increases.

First Guess: AFGL standard profile

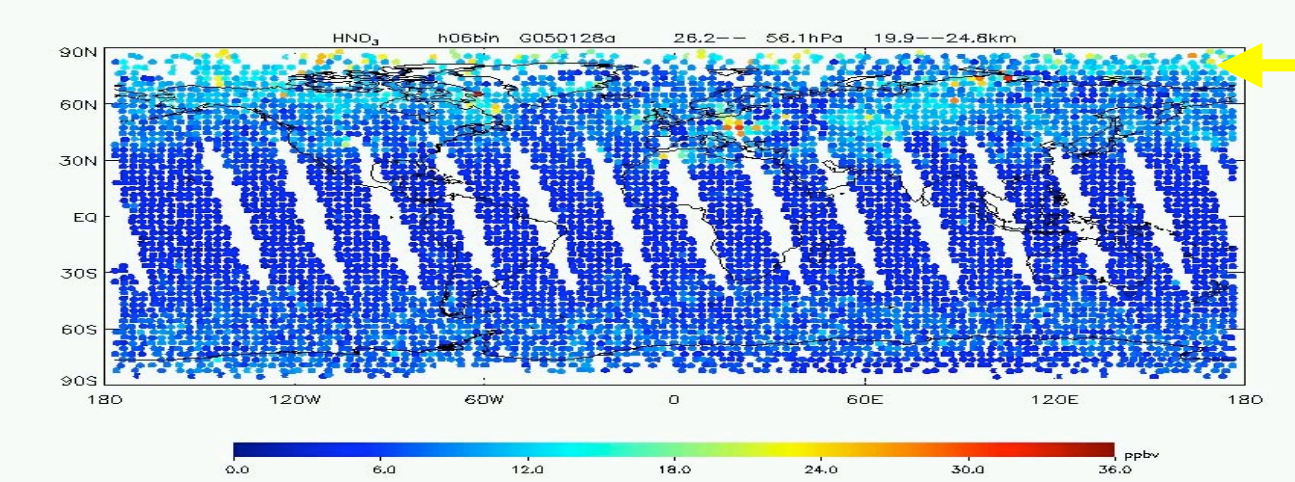
Represent mid-latitude standard HNO_3 profile

Other *a-priori* information:

- Instrument noise and spectrally correlated error of cloud clearing.
- Surface pressure from AVN model.
- Retrieval products of surface skin temperature, surface emissivity, T(p), Q(p), O_3 and CO et al., and error covariance estimated from the uncertainties in skin surface temperature, temperature and moisture profile retrievals.
- CH_4, CO_2 and N_2O first guess.
- And more …

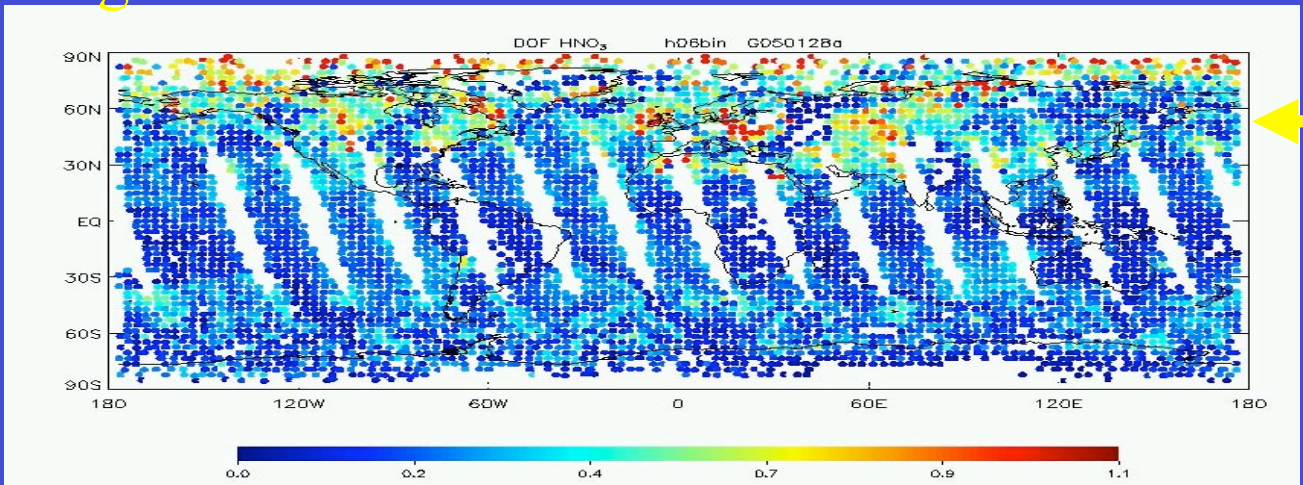


Example global distribution in lower stratosphere (20-25 km) on Jan. 28, 2005



High partial columns in the north high-latitude. Consistent with the distribution of DOF.

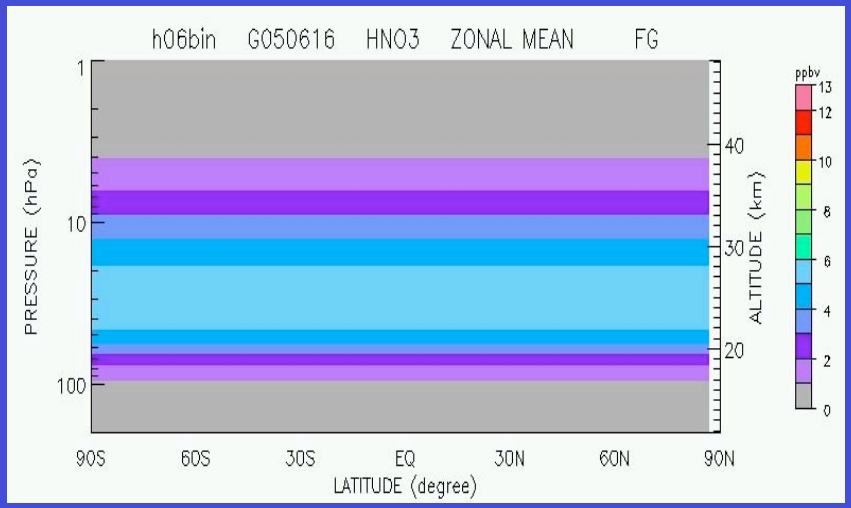
Degree of Freedom



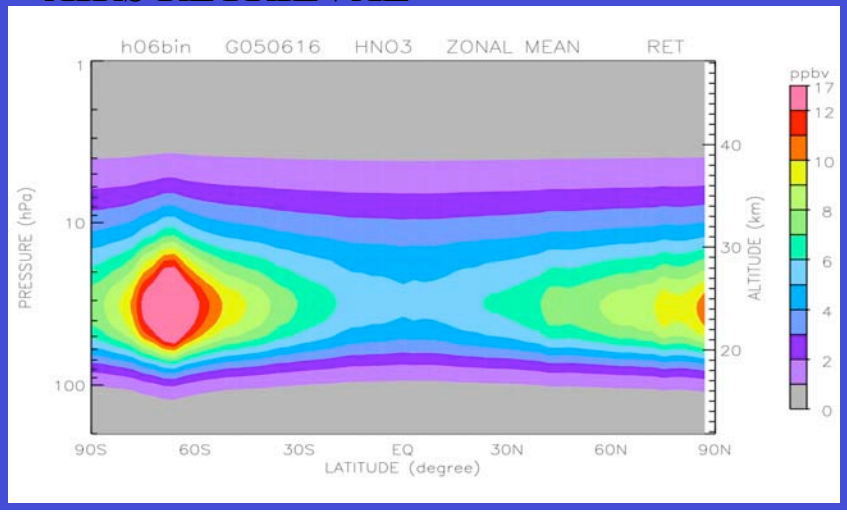
Larger in north high-latitude. AIRS provides at least the lower stratospheric partial columns.

Daily AIRS zonal mean compared with MLS on June 16, 2005

AIRS FIRST GUESS

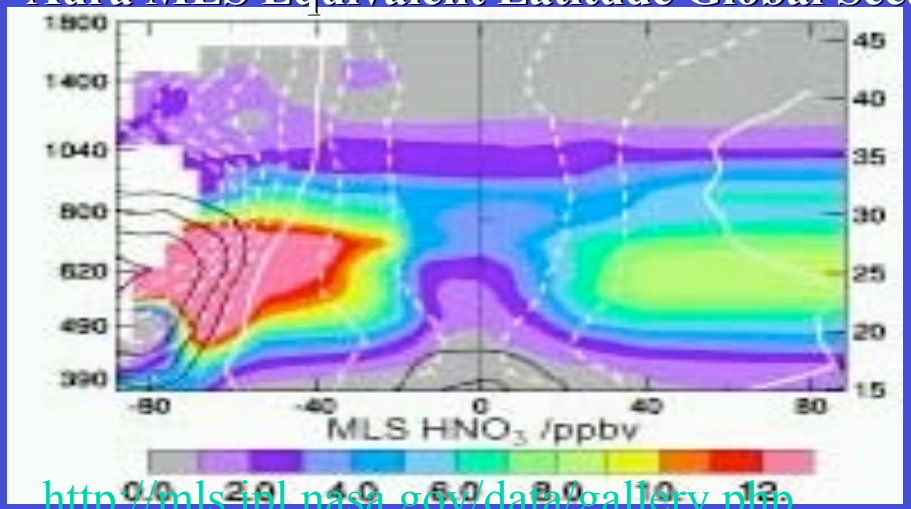


AIRS RETRIEVAL



Latitude structure is determined from AIRS radiance measurements. The value and altitude of peak value is consistent with that of MLS's.

Aura MLS Equivalent Latitude Global Sectio



http://mls.jpl.nasa.gov/data/gallery.php

Comparison of HNO_3 total amount with ground-based FTIR measurements

Data Source: http://www.ndsc.ncep.noaa.gov/

- FTIR (Fourier Transform Infrared Spectroscopy) measurements of daily HNO_3 column abundances at six NDACC (The Network for the Detection of Atmospheric Composition Change) sites.
- Collocation criteria: within the distance of 200 km on the day of *in-suite* observation from full-resolution AIRS level-2 dataset.
- Analysis of relative differences (%)

  DIFF1 = 100(MEAN(AIRS) – FTIR)/FTIR*

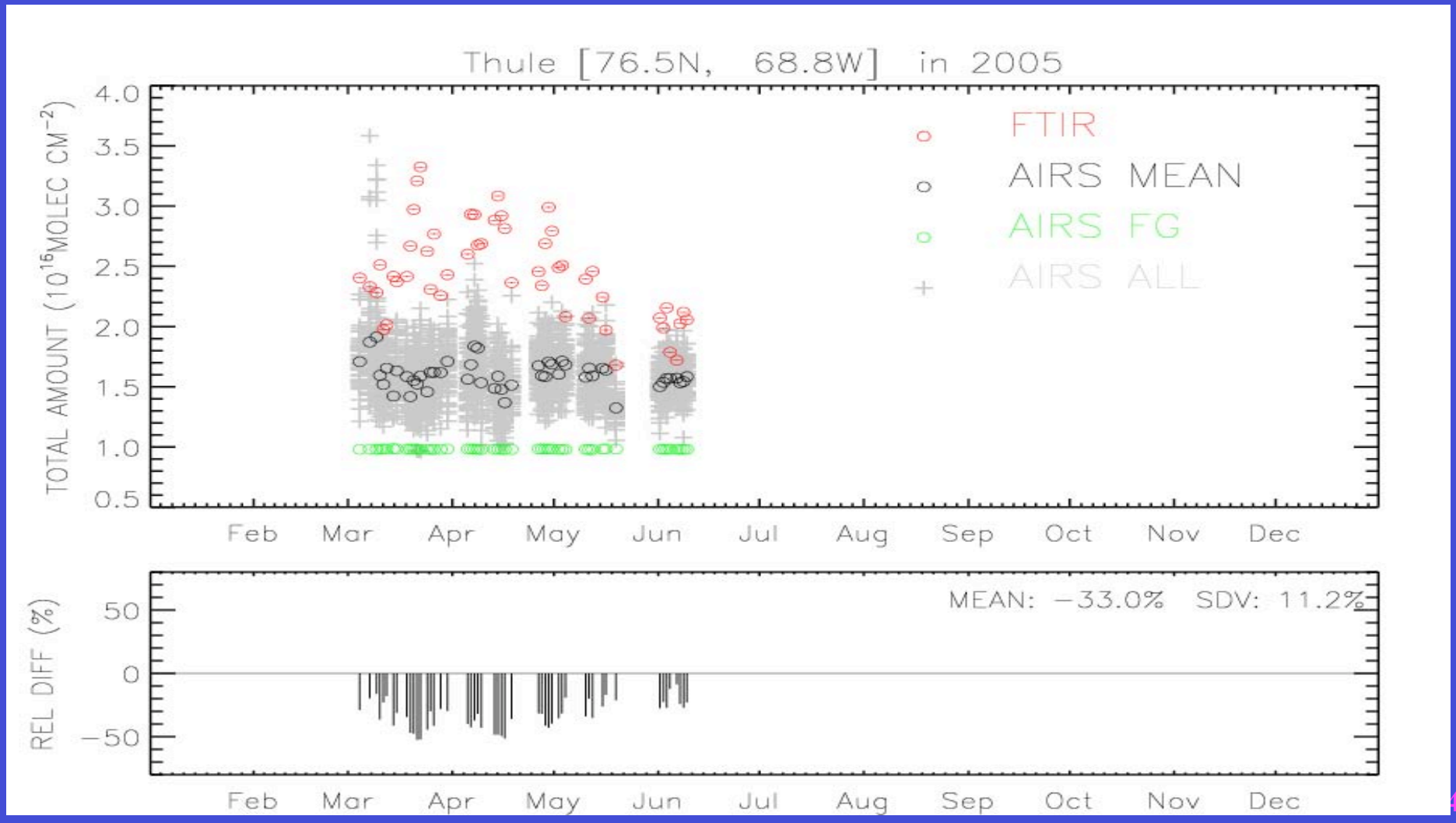
  DIFF2 = 100(CLOSEST(AIRS) – FTIR)/FTIR*

STATION	LOCATION	Data Type	DIFF1 (%) MEAN±STD	DIFF2 (%) MEAN±STD
Thule, Greenland (3006/50)	76.5N, 68.8W	daily average	-33.0±11.2	-33.4±17.7
Kiruna, Sweden (4601/73)	67.8N, 20.4E	daily average	-9.4±13.2	-12.1±15.9
Harestua, Norway (1807/37)	60.2N, 10.8E	daily average	-0.9±20.6	-1.9±26.6
Izana, Canary Islands (4531/85)	28.3N, 16.5W	daily average	44.4±18.2	44.0±18.0
Lauder, New Zealand (4599/163)	45.0S, 169.7E	Individual measurement	5.9±11.8	4.2±14.5
Arrival Height, Antarctica (640/32)	77.8S, 166.6E	Individual measurement	-9.2±18.3	-4.7±20.0

Issues

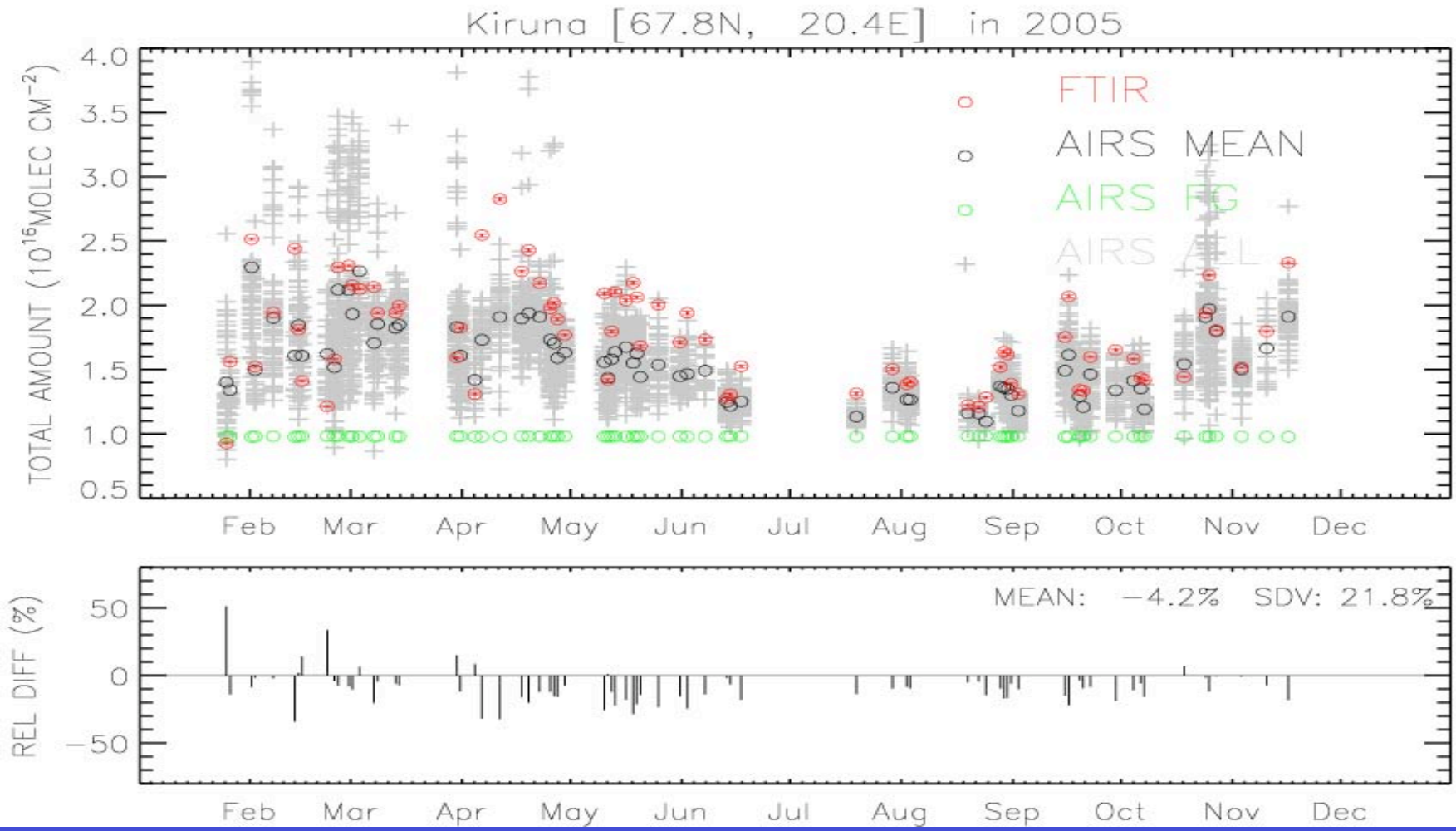
- FTIR observes HNO3 concentration upward from earth surface and senses the total columns (solar occultation approach). AIRS looks downward from space and is most sensitive to HNO3 in strong lapse of temperature (lower stratosphere).
- It is better to apply FTIR averaging kernel to AIRS HNO_3 vertical profiles before calculation of AIRS total amount, if FTIR averaging kernel functions are available.

AIRS did not catch the variation of FTIR observations.

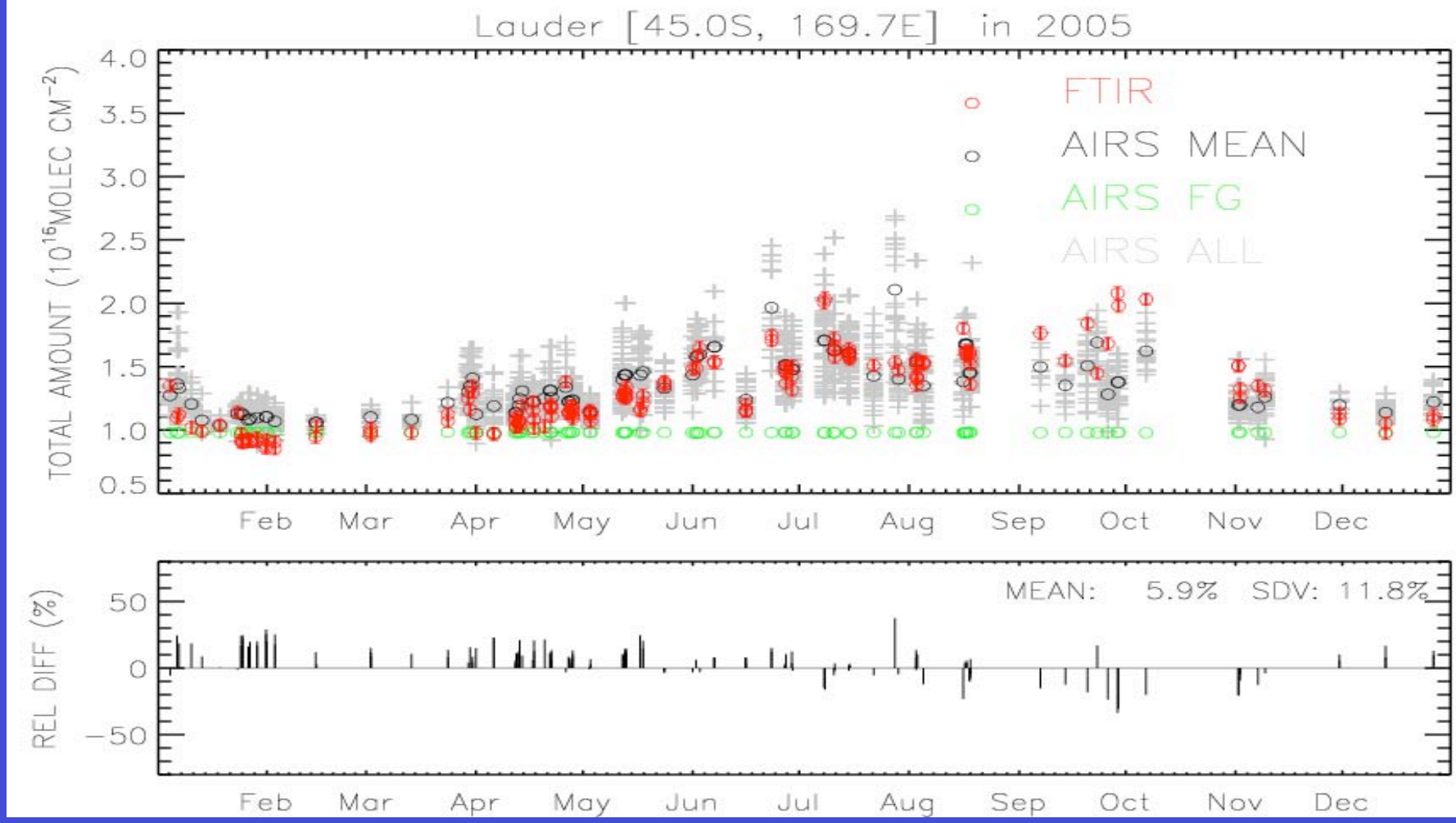


Large horizontal variation in later winter and spring.

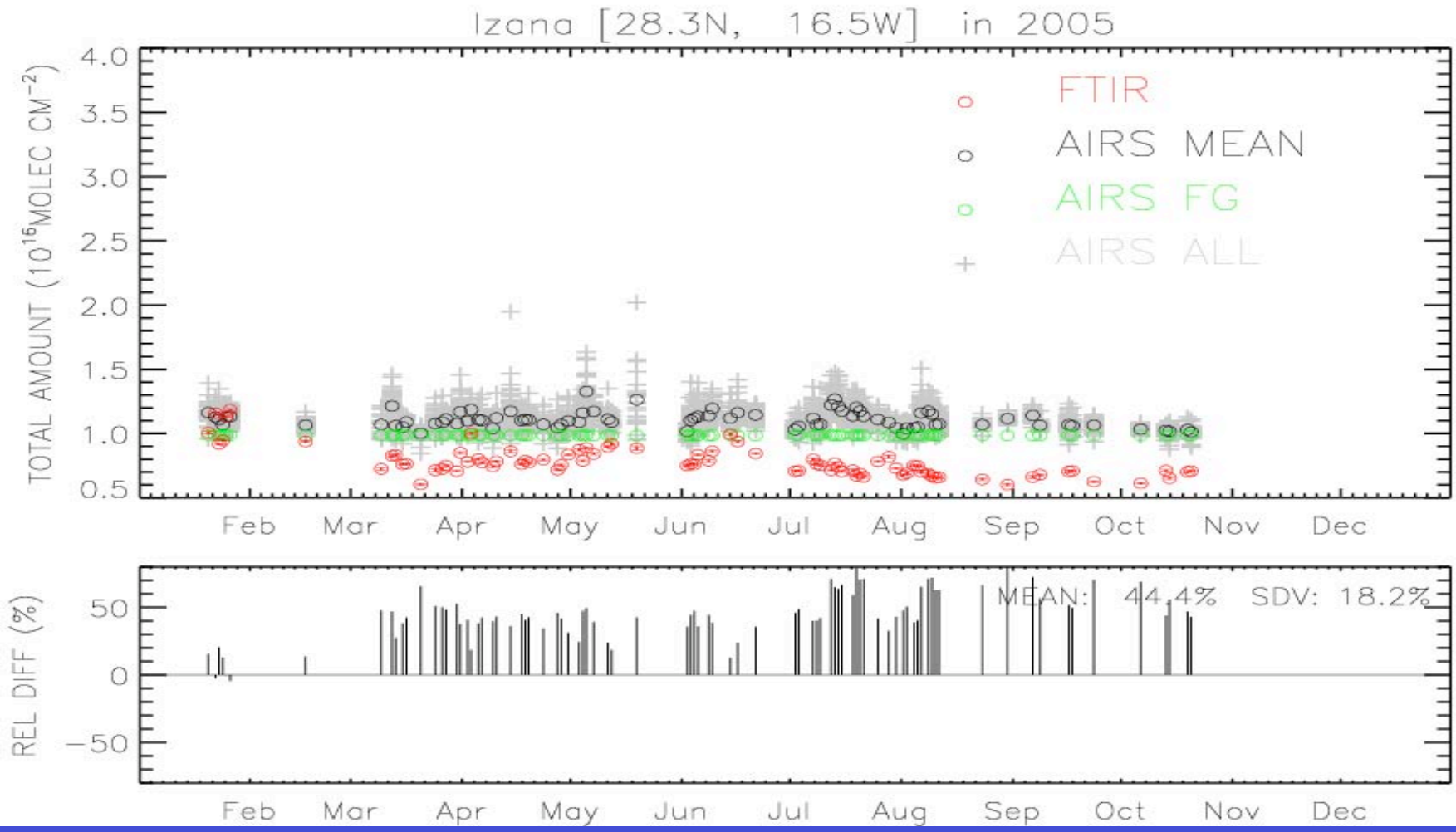
- Near polar vortex boundary.
- May need to consider PV as collocation criteria.



Show the seasonal variation like FTIR observation.



Larger AIRS retrieval bias due to 'sticking to' the a-priori profile (AFGL standard profile).



Comparison of HNO_3 vertical profiles with balloon-borne LPMA, MIPAS.B and SPIRALE measurements

Data source: ENVISAT CAL/VAL Database at NILU/NADIR

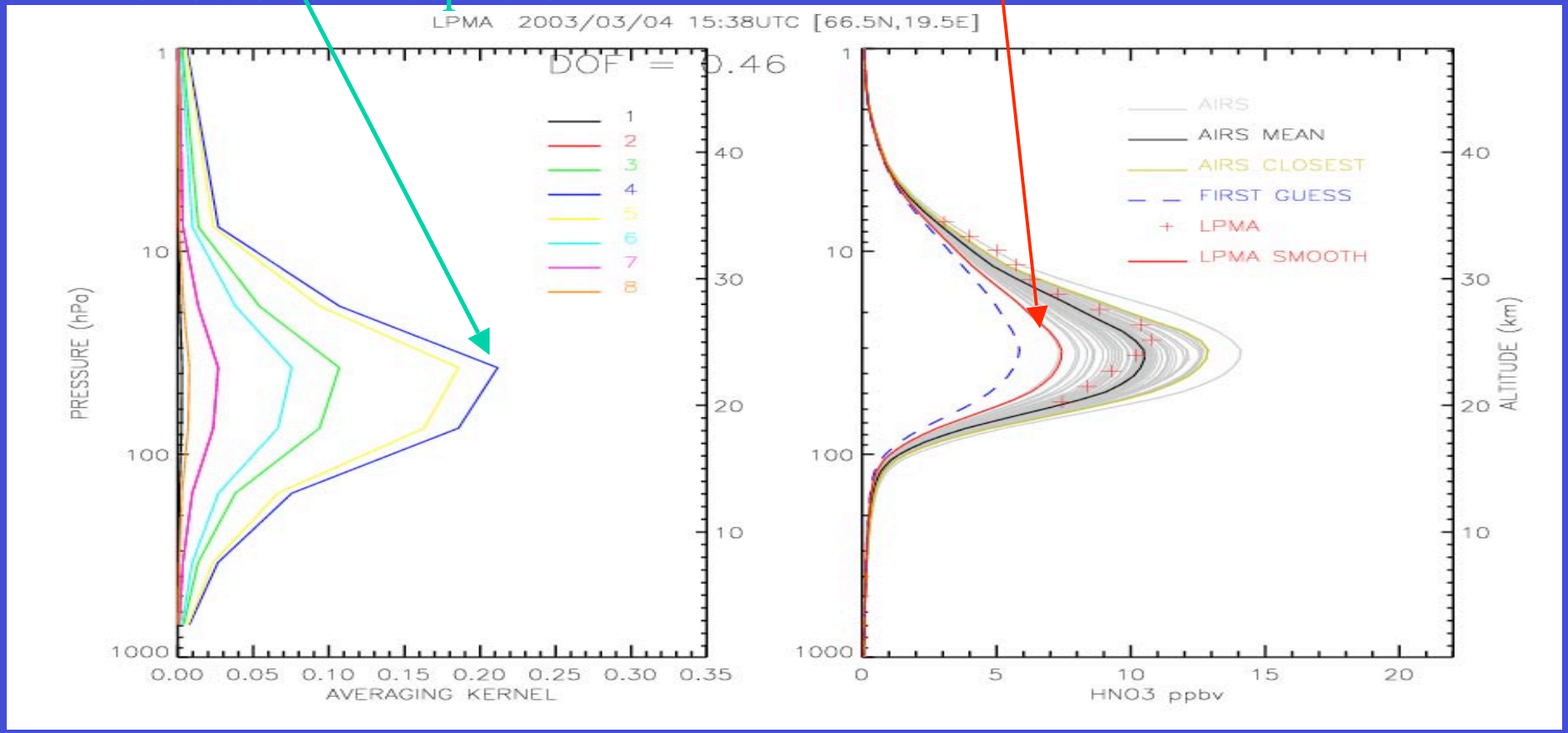
INSTRUMENTS	TIME	VERTICAL RANGE (hPa)	LOCATION	CLOSEST AIRS FOV (No. of collocation)
LPMA	03/04/2003 15:38−16:09 UTC	7.2 − 55.2 (D)	[66.8N, 23.1E] − [66.2N,15.9E] Kiruna, Sweden	27.11 km (56) (-5.83 − -4.18 hr)
MIPAS.B	09/24/2002 21:50−21:57 UTC	3.4 − 307.9 (A)	[37.8N, 1.2E] − [43.3N,0.8E] Aire sur l'Adour, France	25.43 km (36) (4.27 − 4.28 hr)
	09/24/2002 22:13−22:38 UTC	3.9 − 470.6 (A)	[48.9N, 0.5E] − [44.2N, 1.0E] Aire sur l'Adour, France	3.99 km (50) (3.70 − 3.71 hr)
	03/20/2003 20:51−21:07 UTC	7.9 − 215.2 (A)	[65.2N, 11.3E] − [66.7N, 20.8E] Kiruna , Sweden	26.06 km (43) (4.10 − 5.74 hr)
SPIRALE	10/02/2002 07:15−08:37 UTC	7.8 − 208.2 (A)	[43.8N, 0.2E] − [43.6N, 0.1E] Aire sur l'Adour, France	16.74 km (29) (-5.68 − 5.43 hr)
	10/02/2002 09:33−10:39 UTC	9.6 − 140.9 (D)	[43.6N, 0.1E] − [43.7N, 0.2E] Aire sur l'Adour, France	40.46 km (16) (3.27 − 3.28 hr)
	01/21/2003 18:55−21:14 UTC	6.3 − 234.1 (A)	[68.2N, 21.6E] − [67.1N,28.6E] Kiruna , Sweden	1.54 km (24) (4.39 − 4.41 hr)

Collocation criteria: within 200 km and 6 hours from full-resolution AIRS level-2 dataset.

LPMA (Laboratoire de Physique Moleculaire et Applications du CNRS, FTIR solar occultation sounding , Flight LPMA19) **on Mar. 4, 2003**

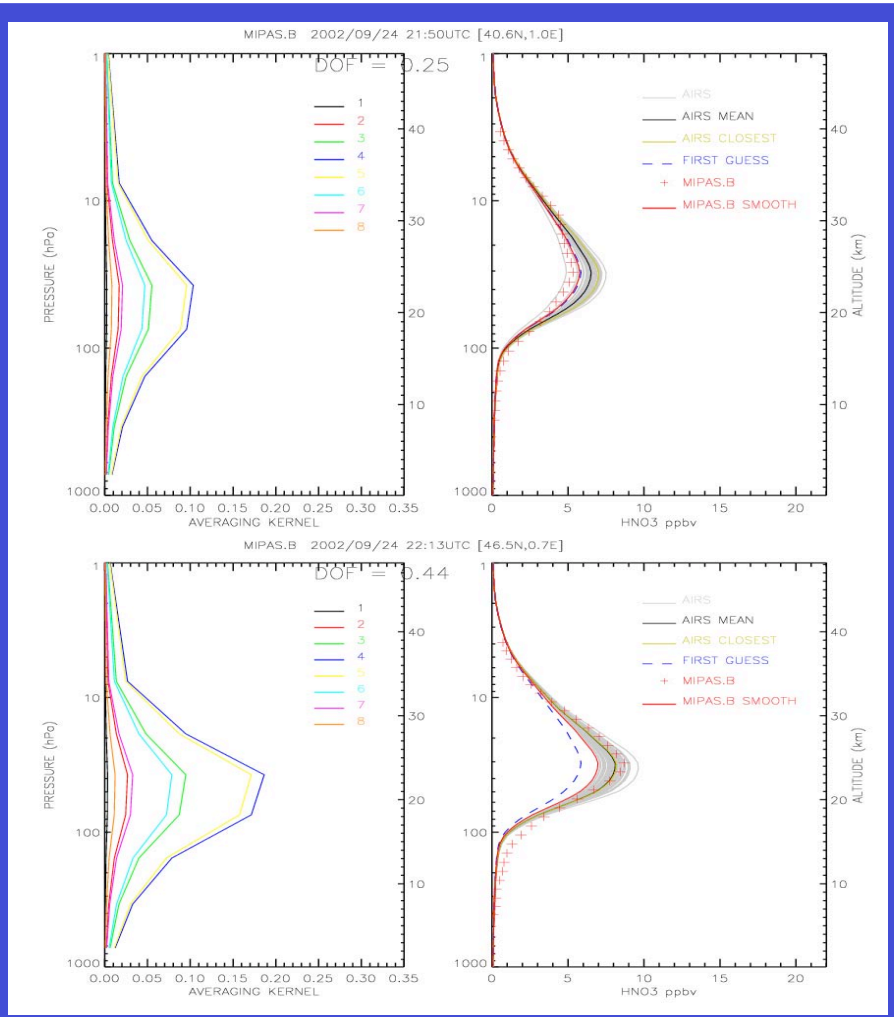
25% of the retrieval is believed at the lower stratosphere

Convolved *in-suite* measurements with AIRS averaging kernel.

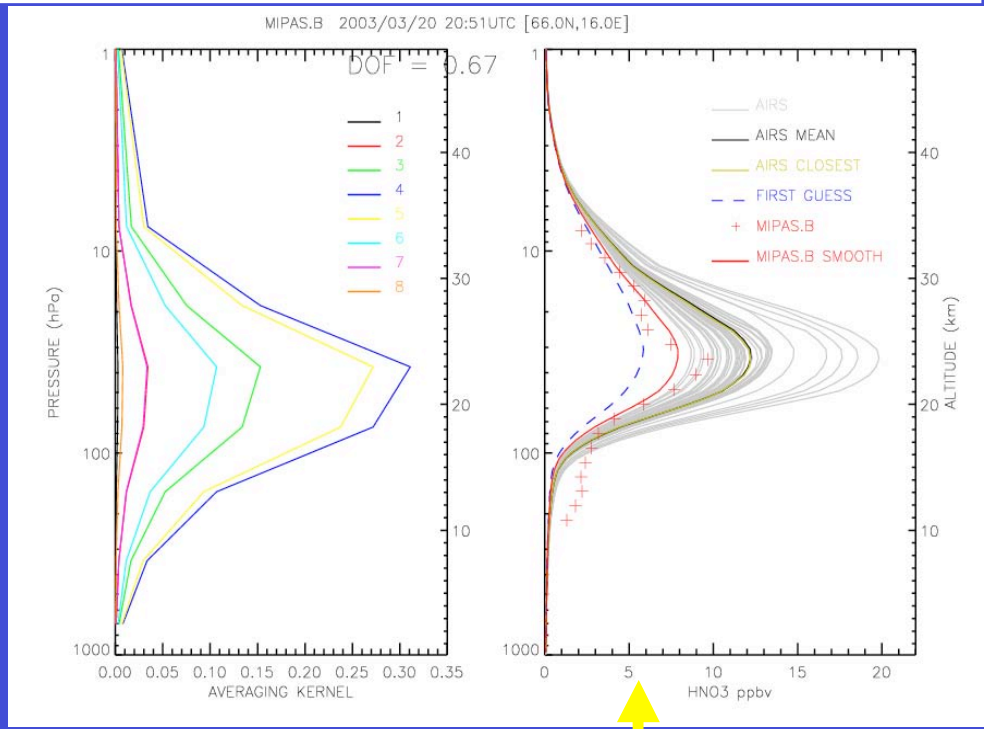


AIRS overestimates about 3 ppbv near the VMR peak and has large horizontal variation.

MIPAS.B (the balloon-borne version of Michelson Interferometer for Passive Atmospheric Sounding) on Sept. 24, 2002 (left panel) and Mar. 20, 2003 (right panel)

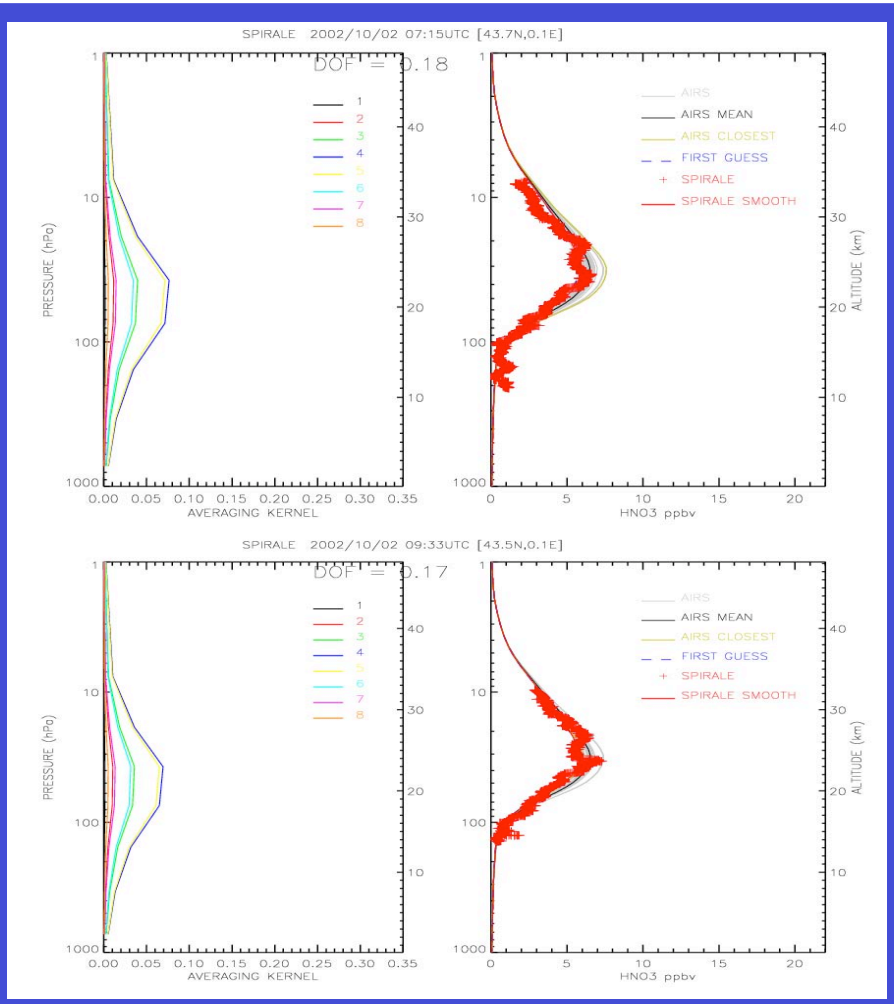


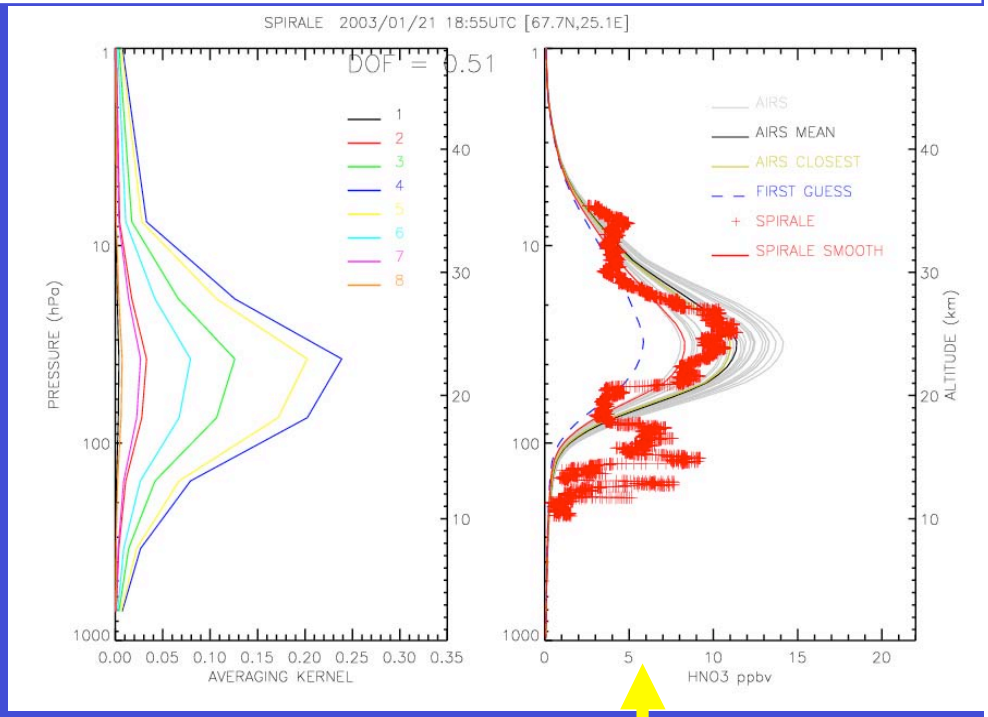
About 1 ppbv difference



Overestimate HNO_3 profiles about 4 ppbv near the peak and has large spatial variation.

SPIRALE (Spectrométre Infra Rouge pour l'étude de l'Atmosphére par diodes Laser Embarquées) on Oct. 2, 2002 (left panel) and Jan. 21, 2003 (right panel)





Overestimate HNO_3 profiles about 3 ppbv near the VMR peak and has large spatial variation.

About 0.5 ppbv difference near the peak

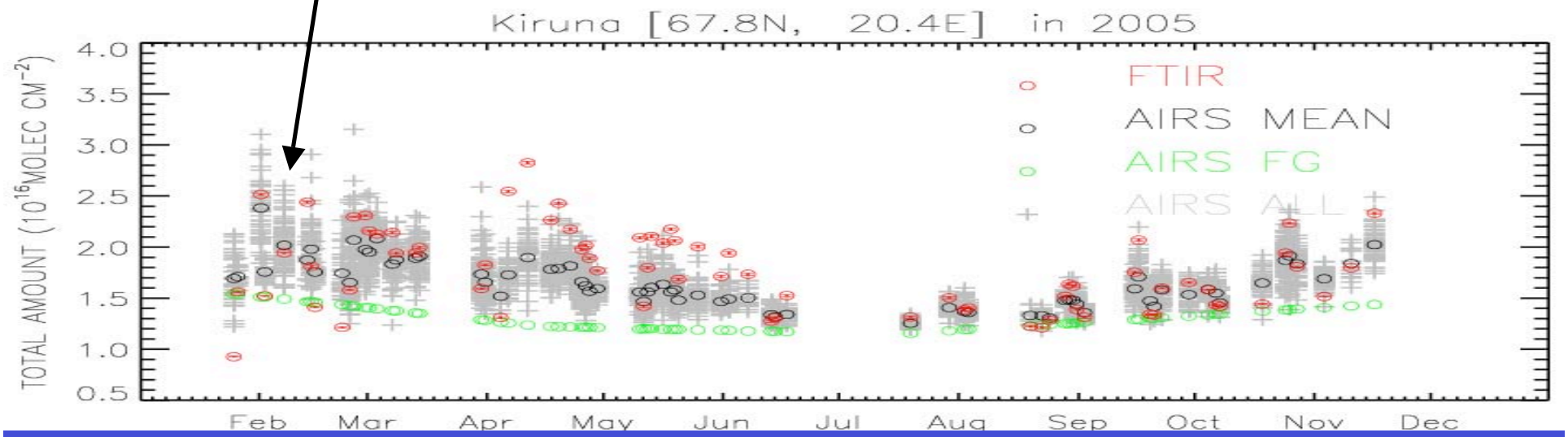
Summary

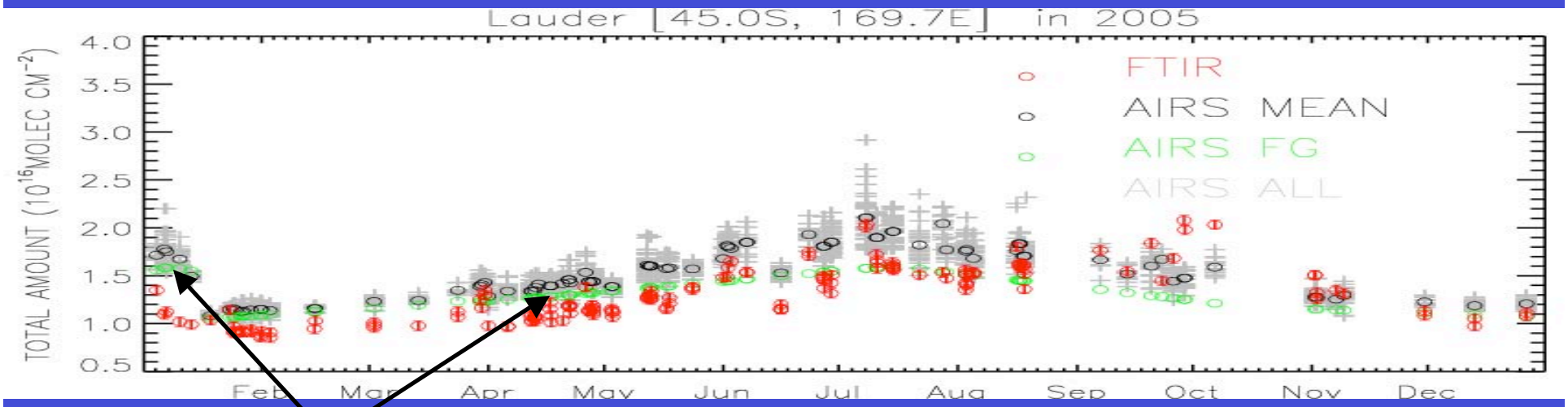
- HNO_3 vertical profile was derived from AIRS channels selected from 760-770, 870-900 and 1320-1330 cm^{-1} spectral regions.
- The DOF of HNO_3 retrieval products is one or less than one, meaning that AIRS at least provides HNO_3 partial columns in the lower stratosphere.
- Total abundances show good agreement with those of FTIR (less than 10% difference between the collocated measurements), excepting the stations at the Greenland and in the tropical (about 30-40%).
- AIRS HNO_3 profiles show good overlapping with balloon-borne mid-latitude measurements and overestimate about 4 ppbv near the VMR peak for the high-latitude observations.

Future Plans

- IASI HNO3 retrieval.
- Characterization and error analysis of HNO_3 products using model simulation.
- Comparison with TES/MLS/HIRDLS measurements.
- Evaluation the interference from water vapour, methane and surface emissivity.
- First guess: latitude and/or seasonal variation. Initial retrievals using climatology as first guess upgrade HNO_3 retrieval in northern high latitude and tropical, but degrade that in southern mid-latitude.

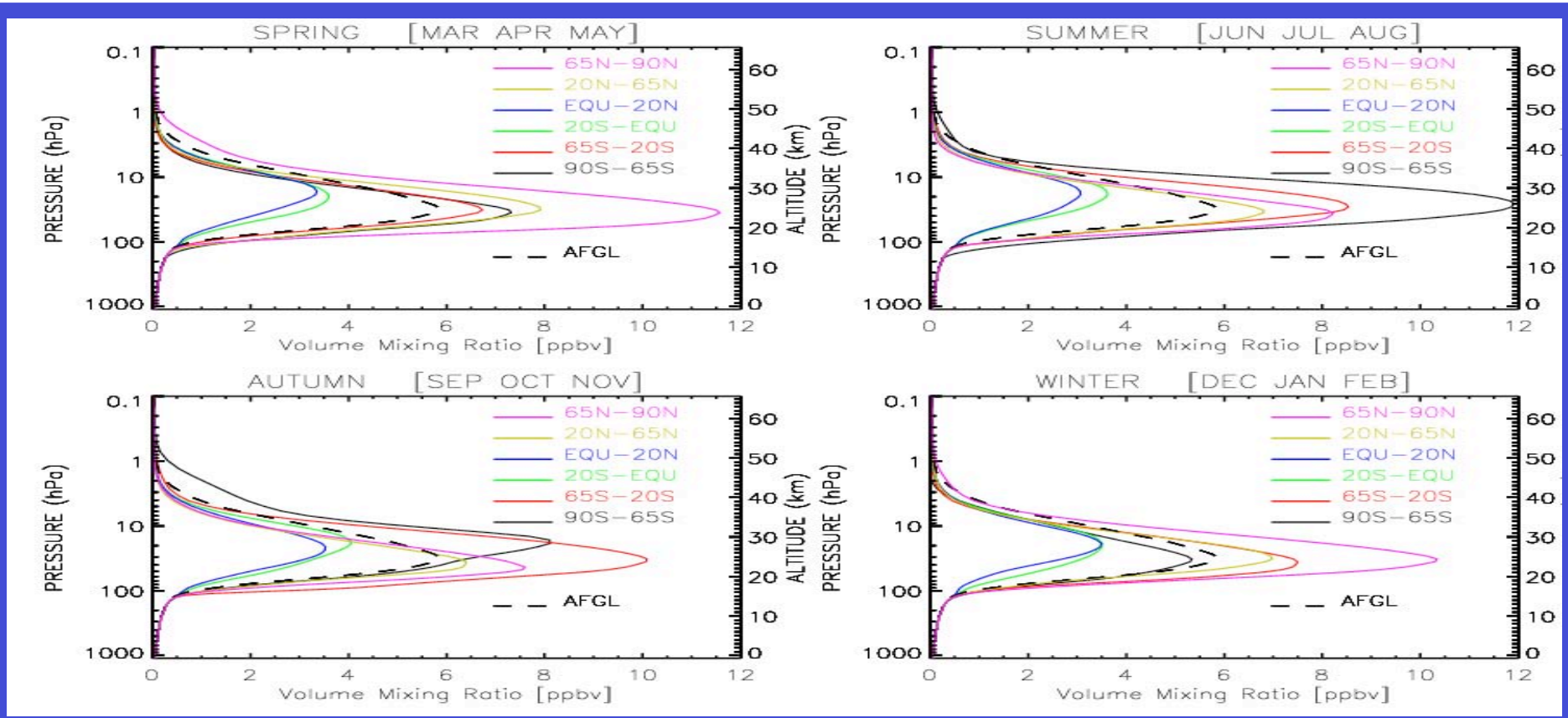
Reduced horizontal variation a lot.





Degraded due to larger first guess was used.

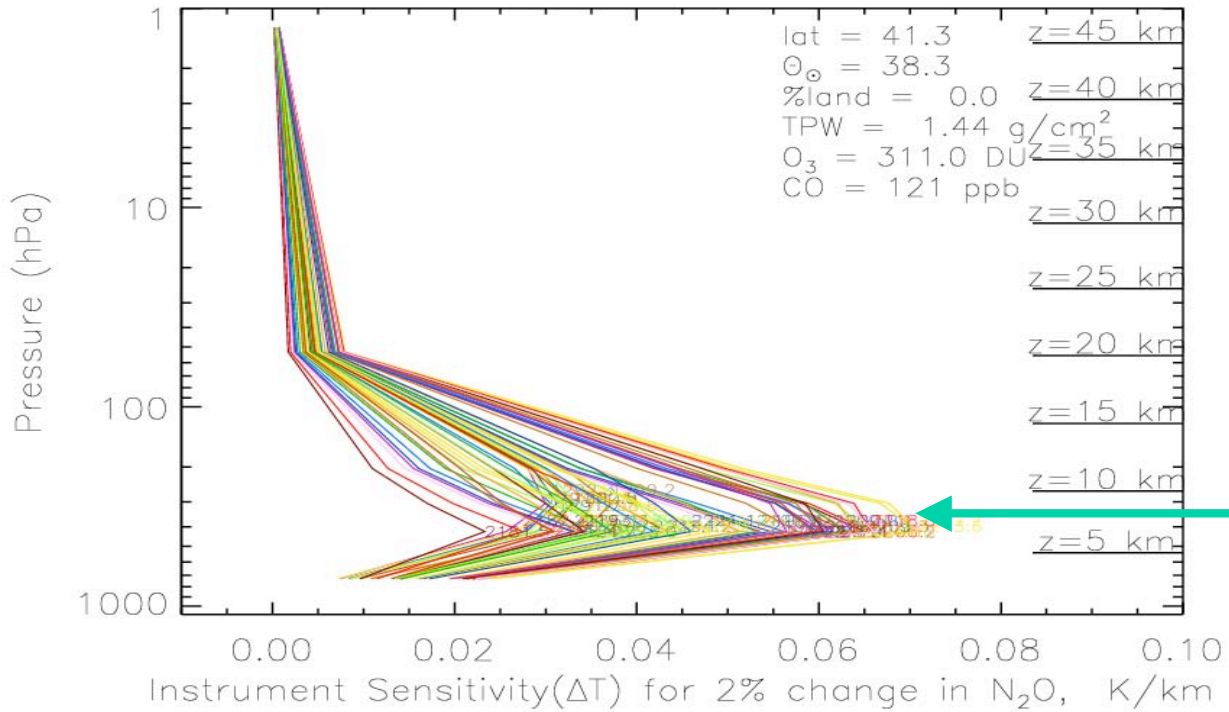
HNO_3 climatology built from CLAES monthly average, using the AFGL reference profile above 5 hPa and below 100 hPa.



CLAES HNO_3 may be 20% larger in the southern hemispheric mid to high latitude data in autumn and early winter for cases where the vmr exceeds ~ 15 ppbv.
(http://daac.gsfc.nasa.gov/guides/GSFC/guide/uars_claes_l3a_dataset.gd.shtml

Status of N_2O Retrieval

- Spectral range: 1250-1315 and 2180-2250 cm^{-1} (58 channels).
- Retrieval functions: 6 overlapping trapezoids.
- Error covariance matrix: uncertainties in surface skin temperature, temperature and water profiles.

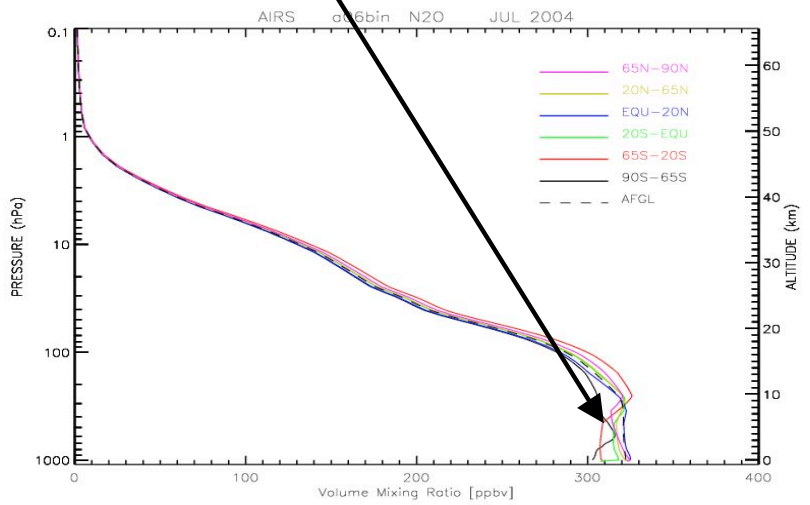


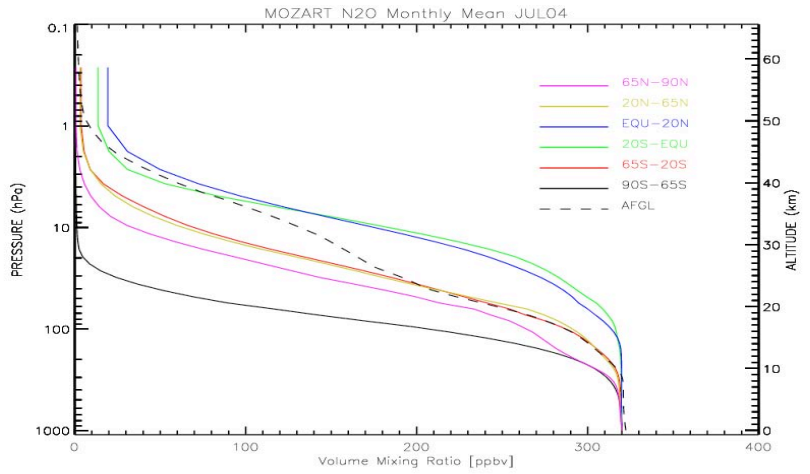
Most sensitive to mid-troposphere

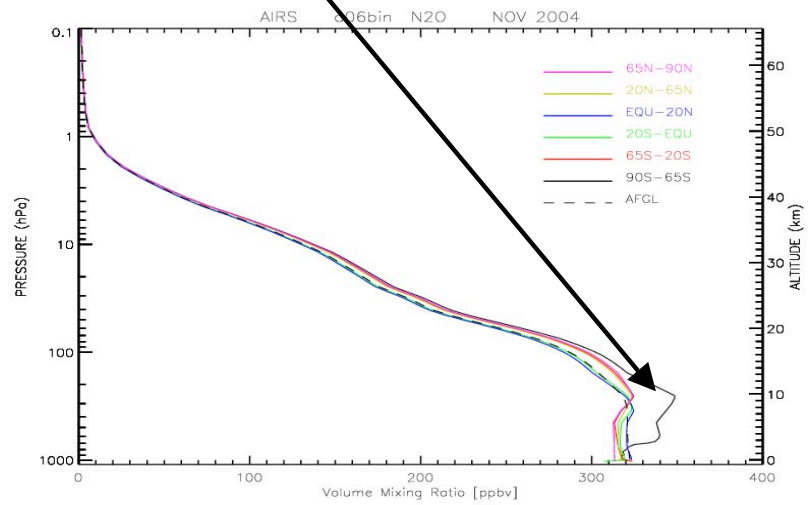
Comparison with MOZART II simulation

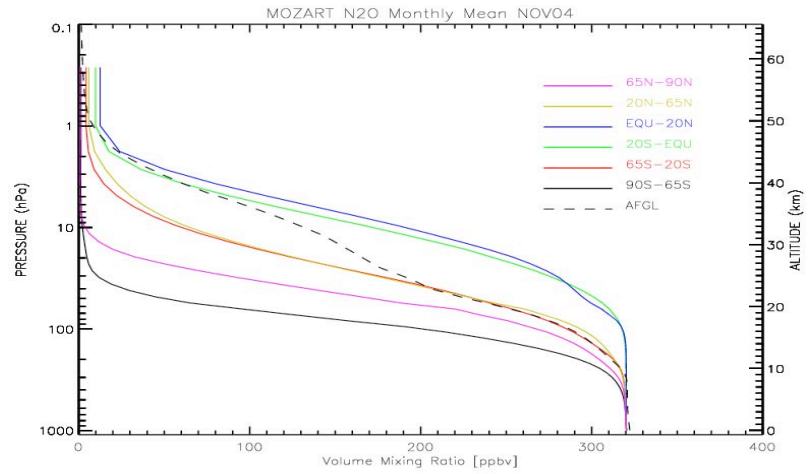
Strong oscillation

Large value in polar region









What to do next …

- Optimize physical retrieval algorithm: selection of channel (add channels in 2520-2600 cm^{-1} spectral region), retrieval functions, damping factor and first guess.
- Validation of N_2O retrievals with aircraft and balloon measurements.
- Compared with other satellite measurements.
- Characterization and error analysis of N_2O products using aircraft and balloon measurements.