The potential of cloud slicing to derive profile information from Nadir looking instruments

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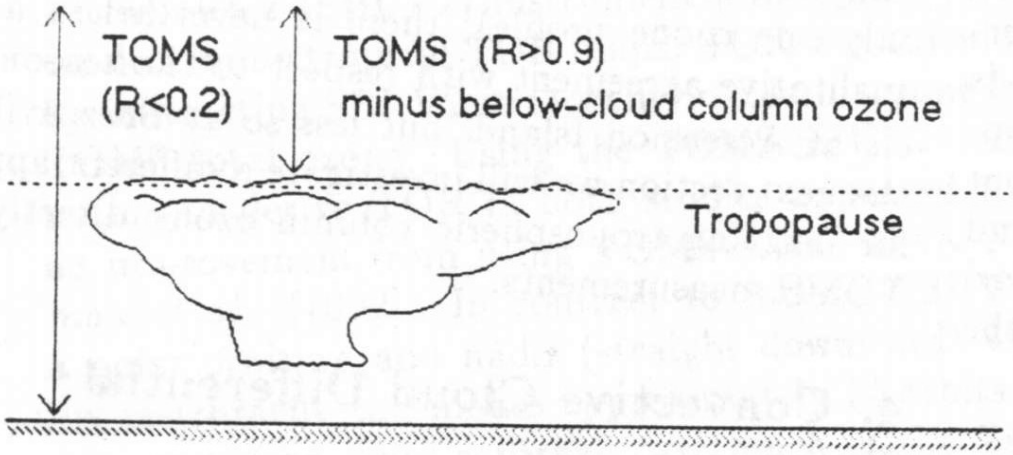
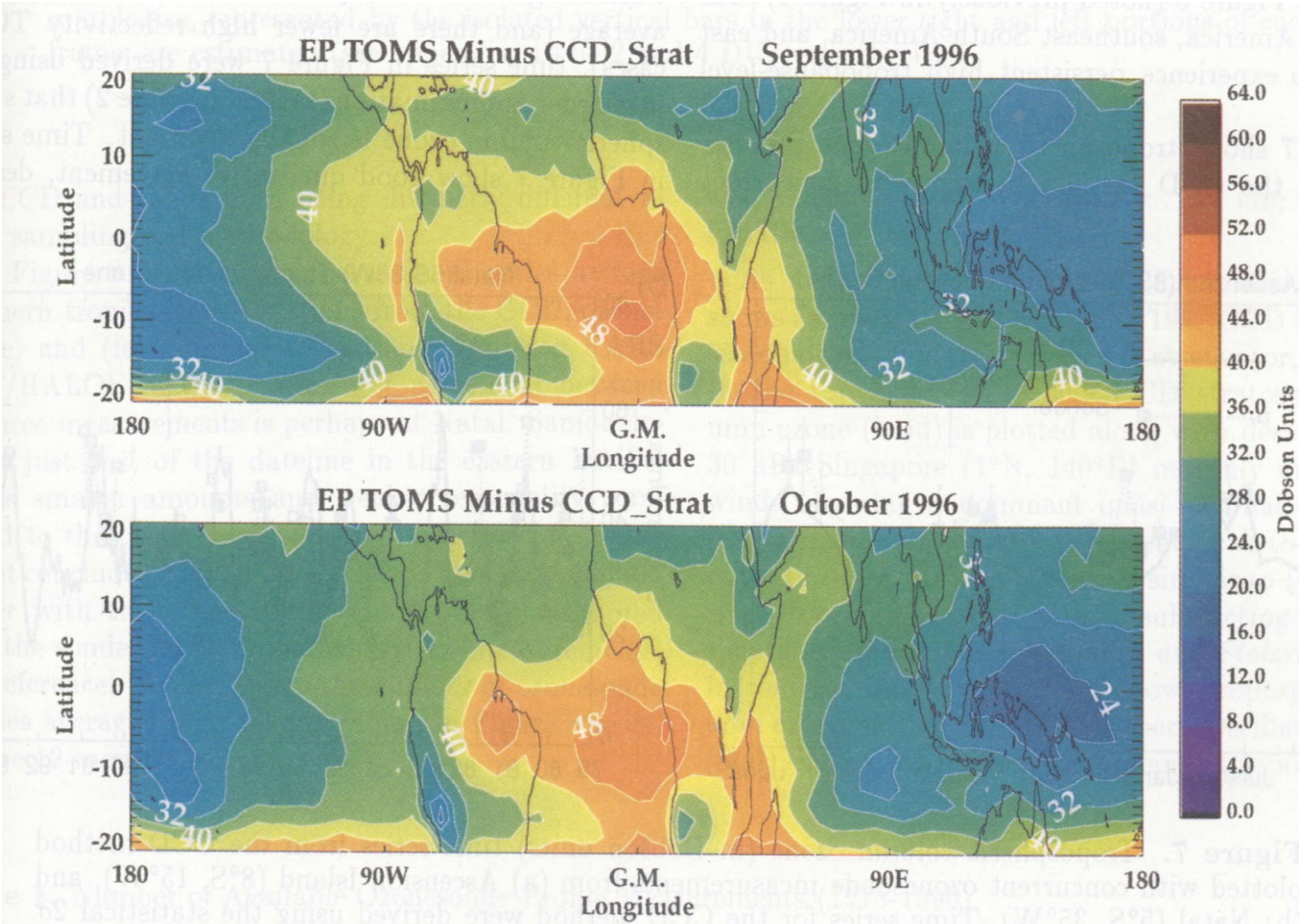
- Pioneering studies (trop. O_3 from TOMS)
- Applications to CO and NO_2 from SCIAMACHY
- Potential of future missions (better spatial coverage and resolution)

Ziemke et al., 1998:

High Clouds Shield the Troposphere

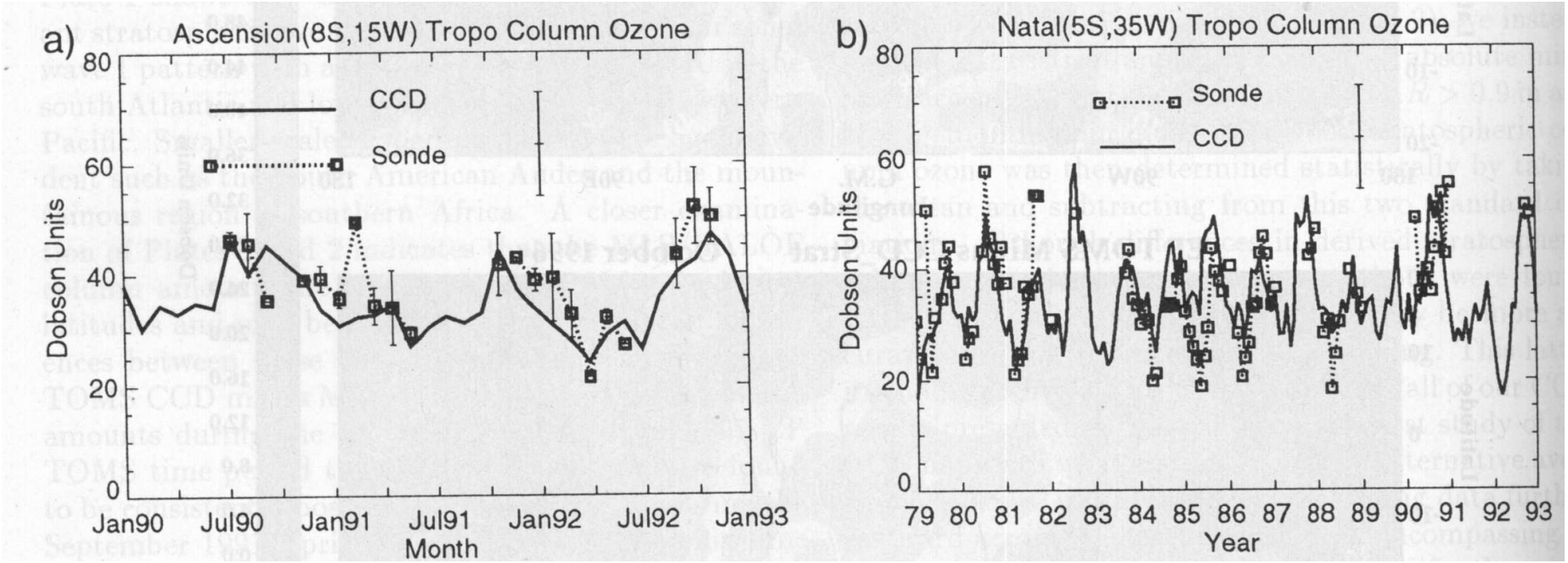
Monthly Distribution of Tropospheric O_3





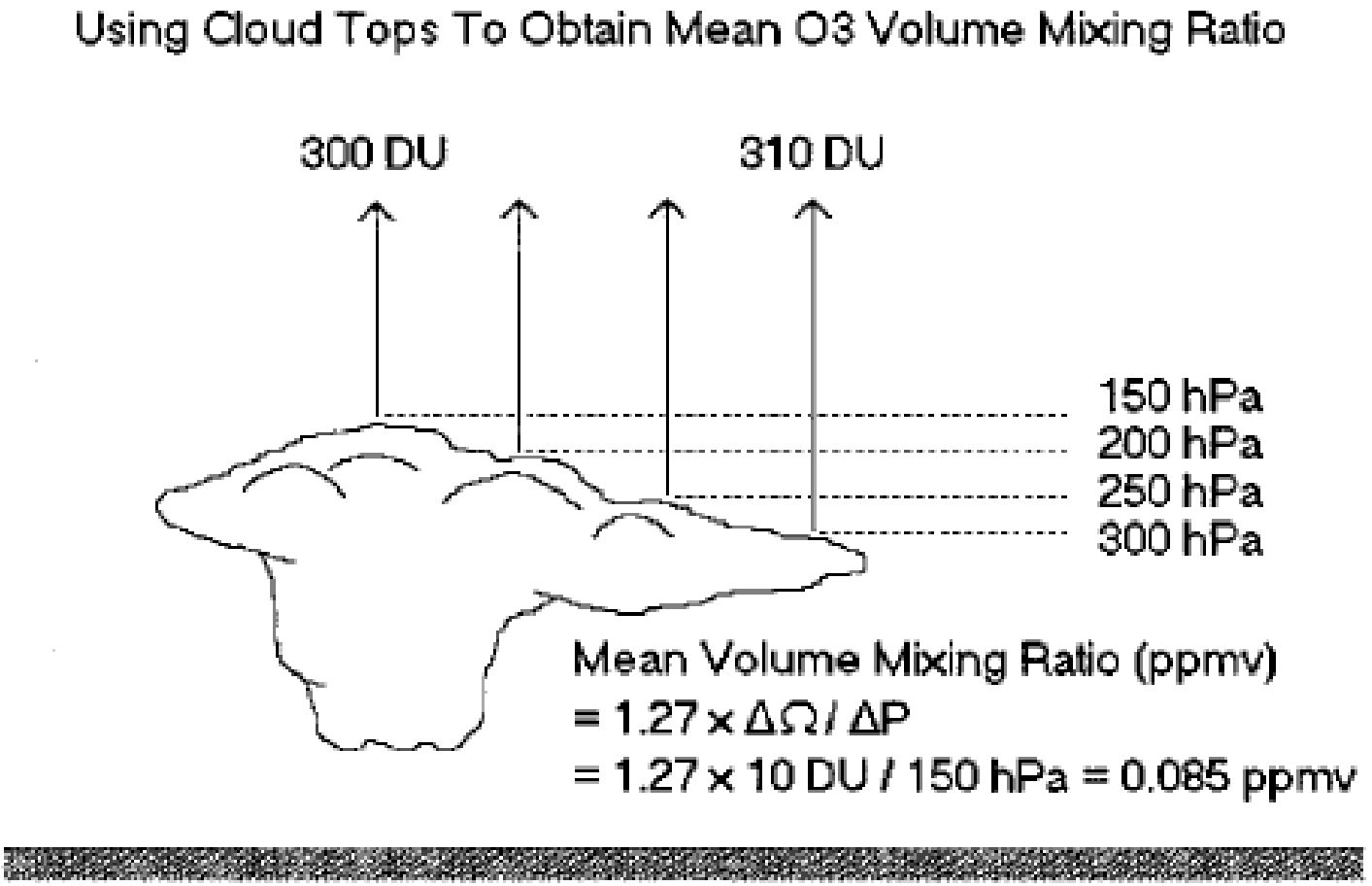
Ziemke et al., 1998:

Time series of tropospheric O_3 at different stations, comparison with ozone sondes



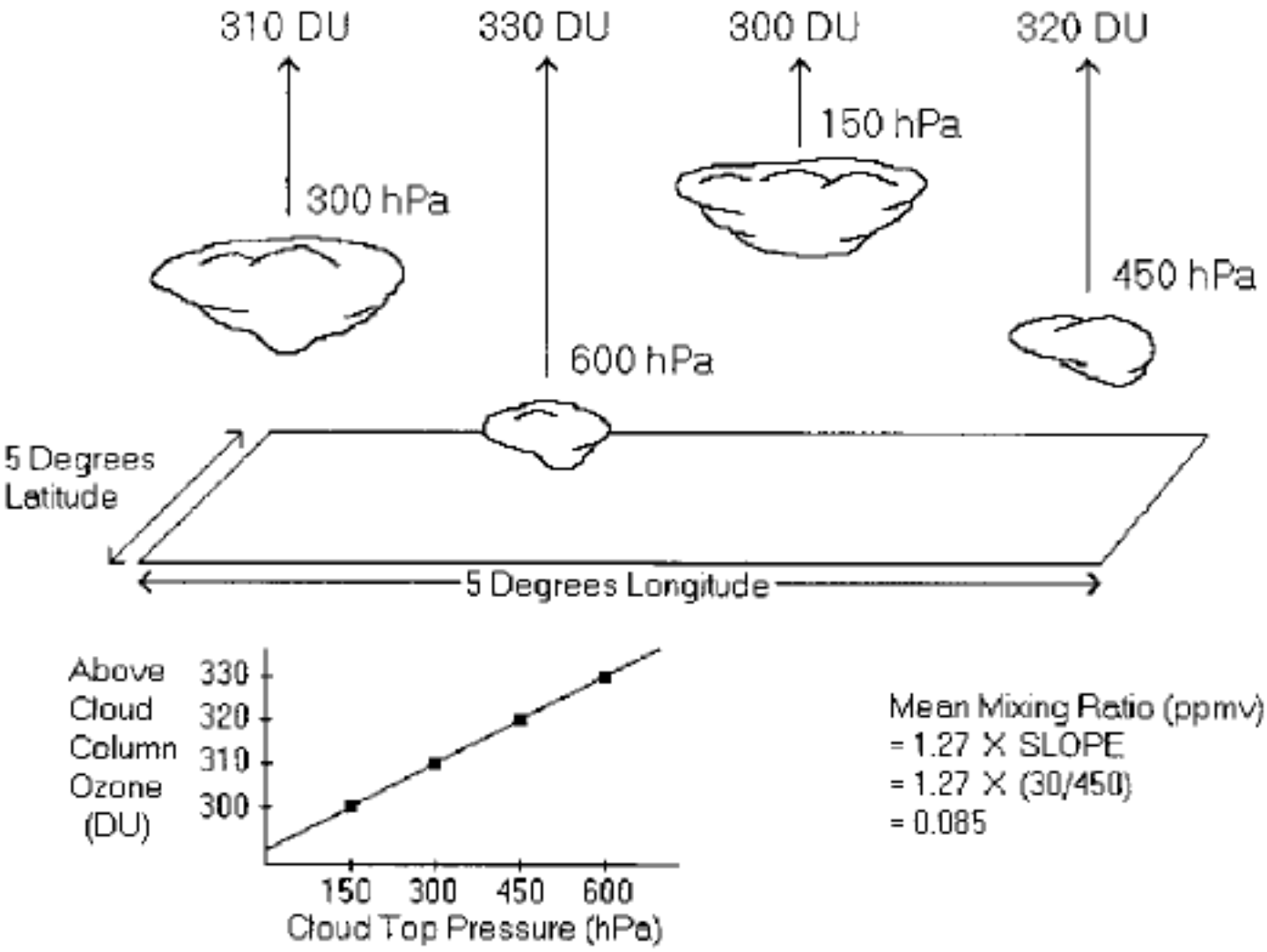
Cloud slicing: use of cloudy measurements with different cloud heights => upper troposphere mixing ratios

Ziemke et al., 2001



Ensemble cloud slicing: use of cloudy measurements with different cloud heights => upper troposphere mixing ratios

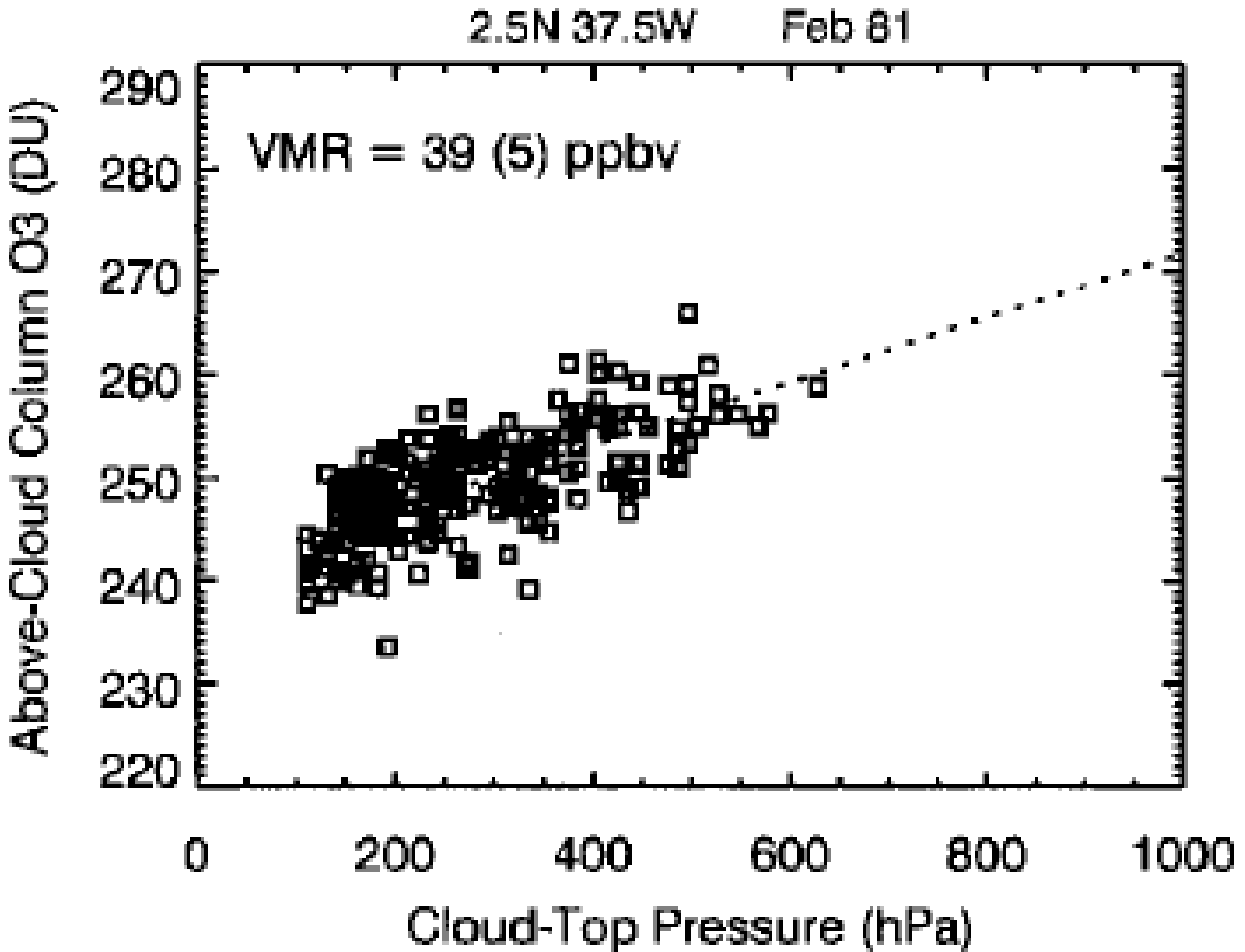
Ziemke et al., 2001



Cloud slicing: use of cloudy measurements with different cloud heights => upper troposphere mixing ratios

Ziemke et al., 2001

Scatter plot for area over the Atlantic



Very successful method - but:

-average values for extended time periods (typically monthly mean values) and large areas

-lifetime of trace gas has to be ‚long' and its abundance should not systemtically depend on the actinic flux

-both cloud heights and trace gas profiles probably systematically depend on meteorology

=> cloud slicing profiles do not represent true average profiles

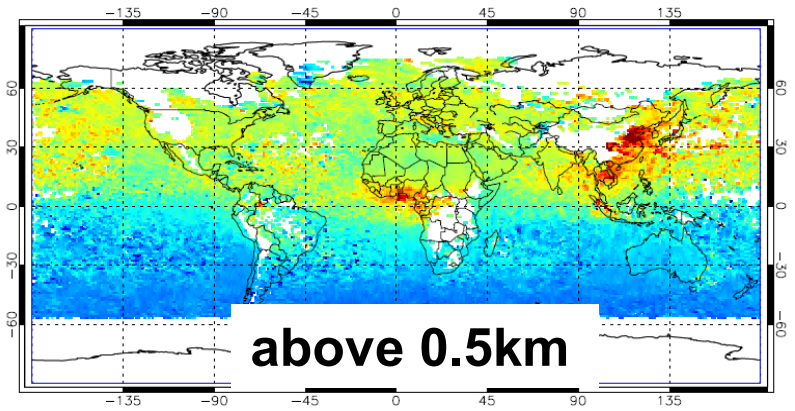
solution: comparison with model results sampled in the same way as the mesurements

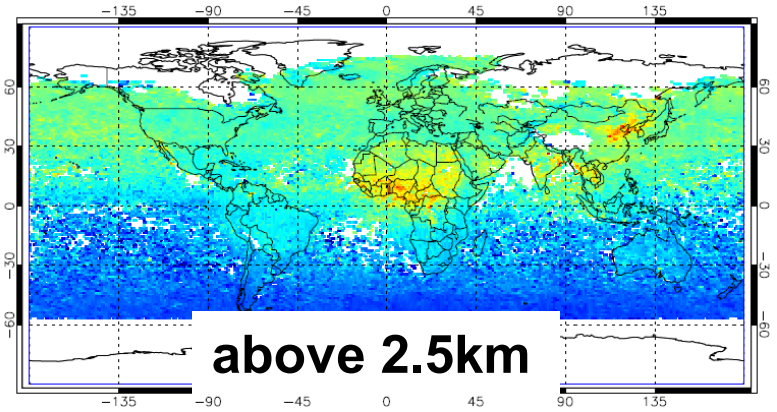
=> Cloud slicing for CO from SCIAMACHY

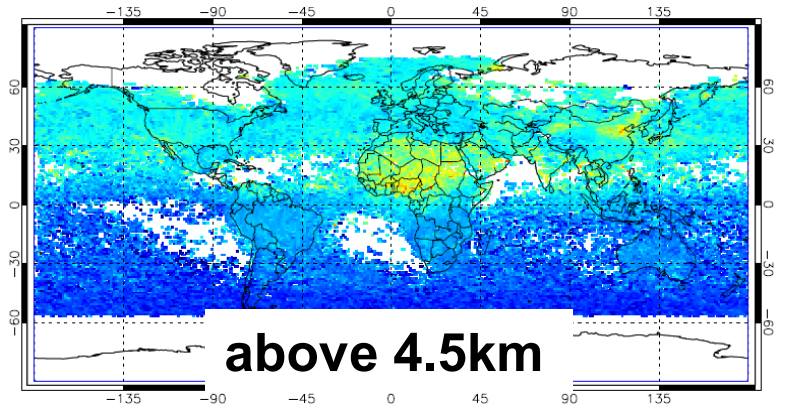
Cloud-Top Pressure (hPa)

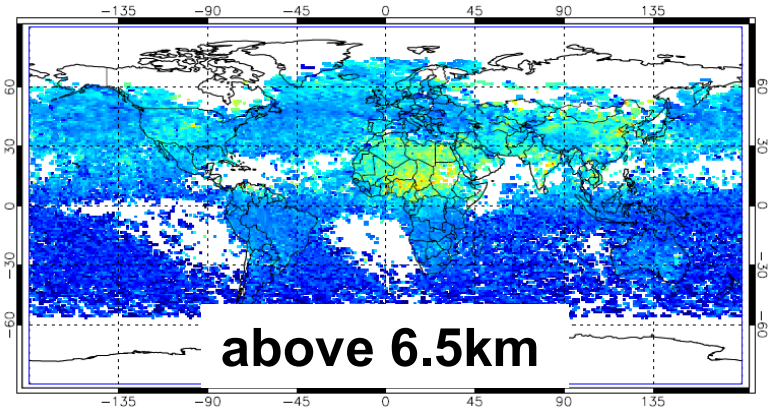
Cloud slicing for SCIAMACH CO measurements
Partial columns for 1 km resolution height grid

Jan. to Mar. of 2003 - 2005

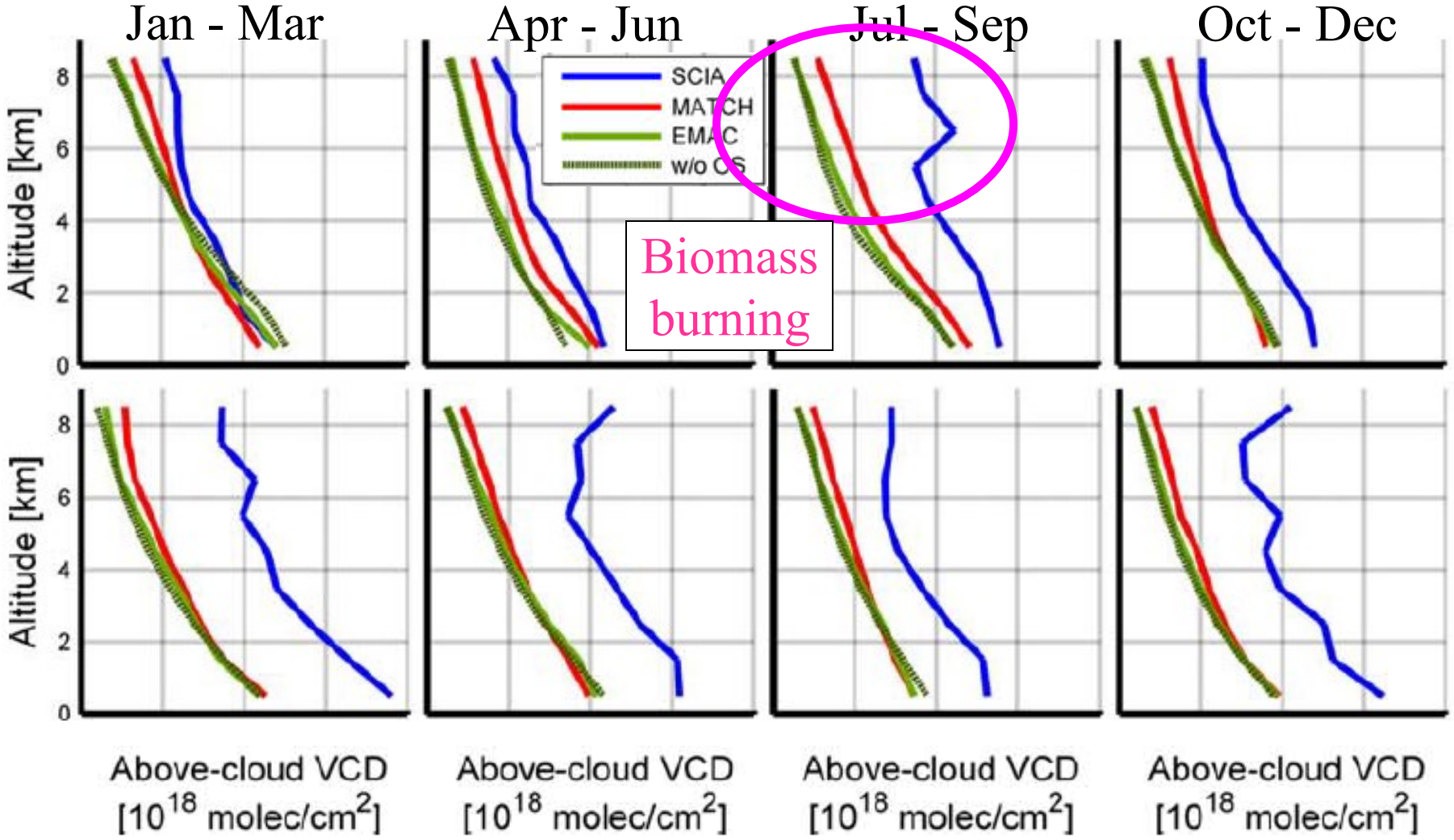








Cheng Liu, MPIC Mainz, ACPD, 2013



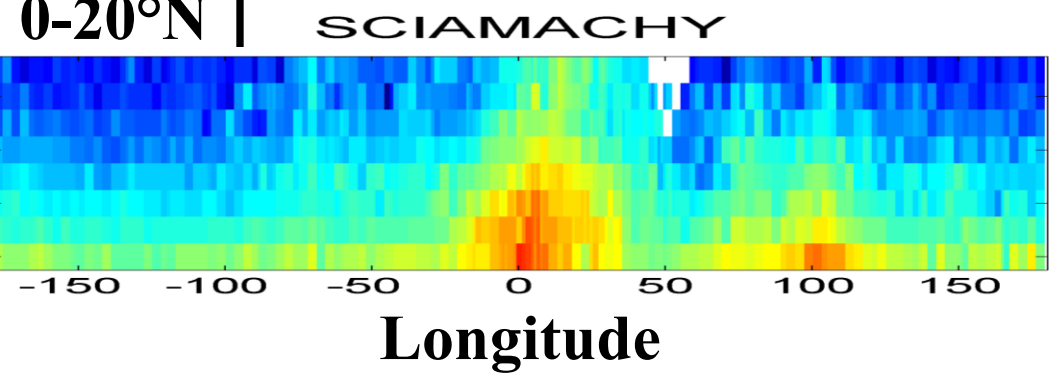
CO partical VCDs from SCIAMACHY observations and model simulations for selected regions. The dark green lines indicate EMAC results without cloud slicing.

Cheng Liu, MPIC Mainz, ACPD, 2013

Jan to Mar 2003~ 2005

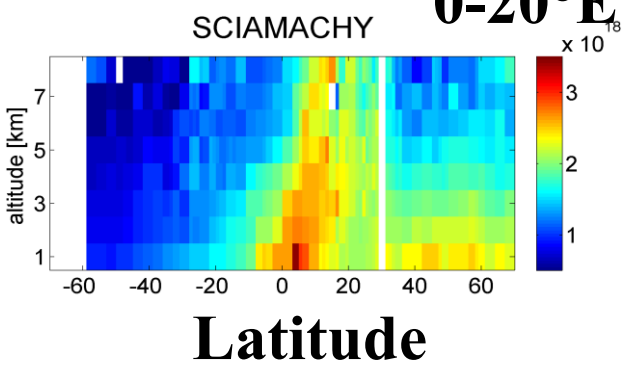
CO total column

0-20°N



Longitude

0-20°E



Latitude

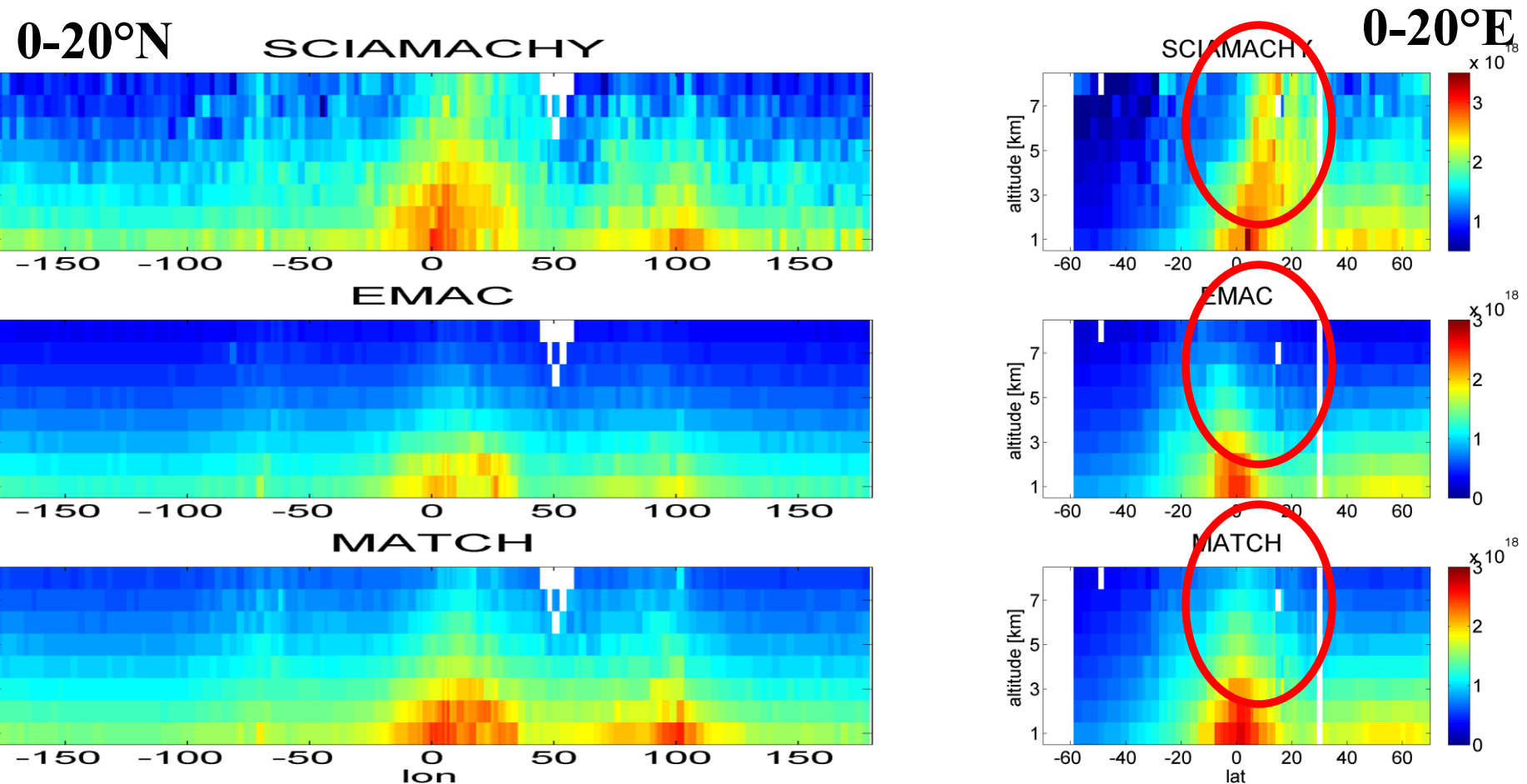
ITCZ is in the south

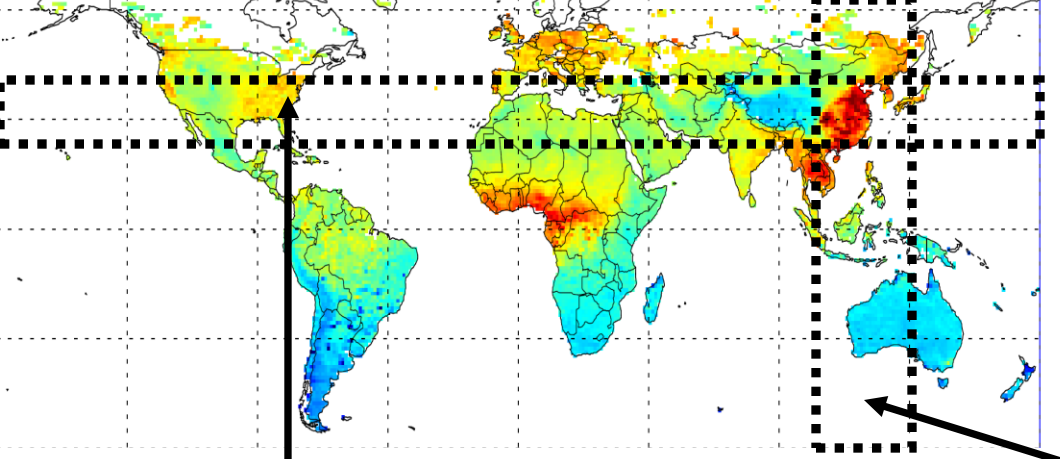
=> CO is transported upwards and to the north

Cheng Liu, MPIC Mainz, ACPD, 2013

Transport patterns are not well represented by the models

Cheng Liu, MPIC
Mainz, ACPD, 2013





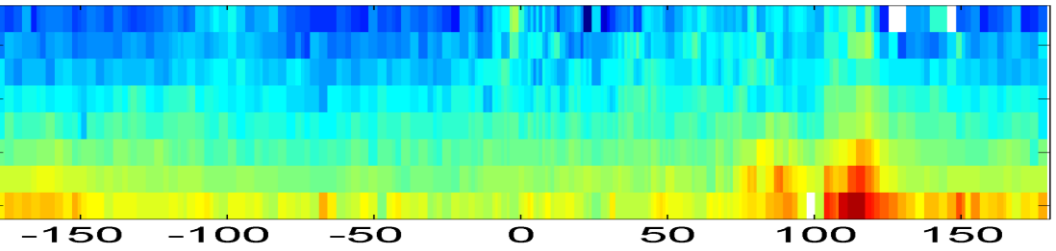
Jan to Mar 2003~ 2005

CO total column

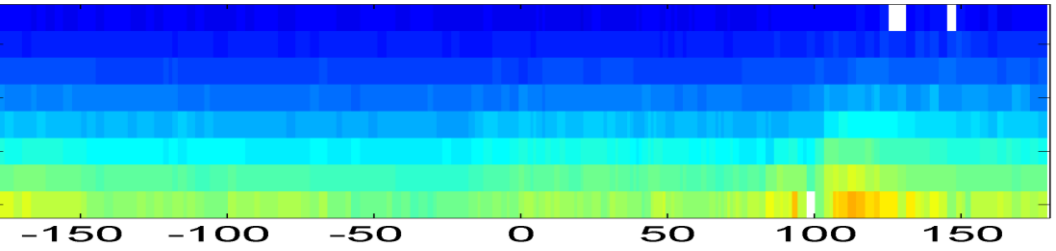
Cheng Liu, MPIC
Mainz, ACPD, 2013

20-40°N

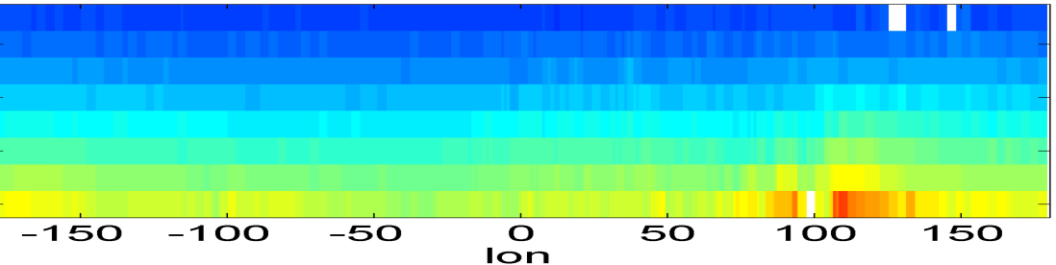
SCIAMACHY



EMAC

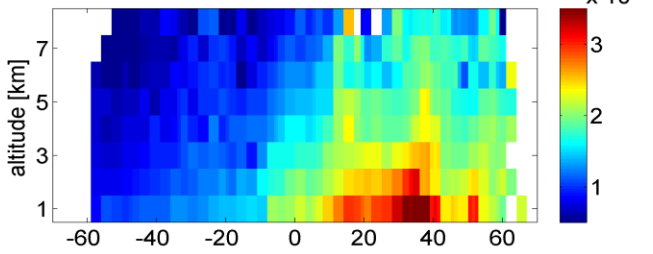


MATCH

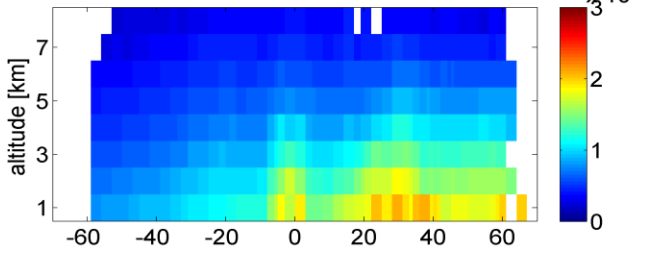


100-120°E

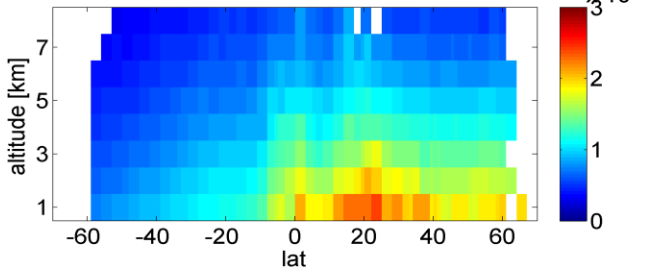
SCIAMACHY



EMAC



MATCH



What about short lived species?

=> Cloud slicing for NO_2 from SCIAMACHY

Additional complications

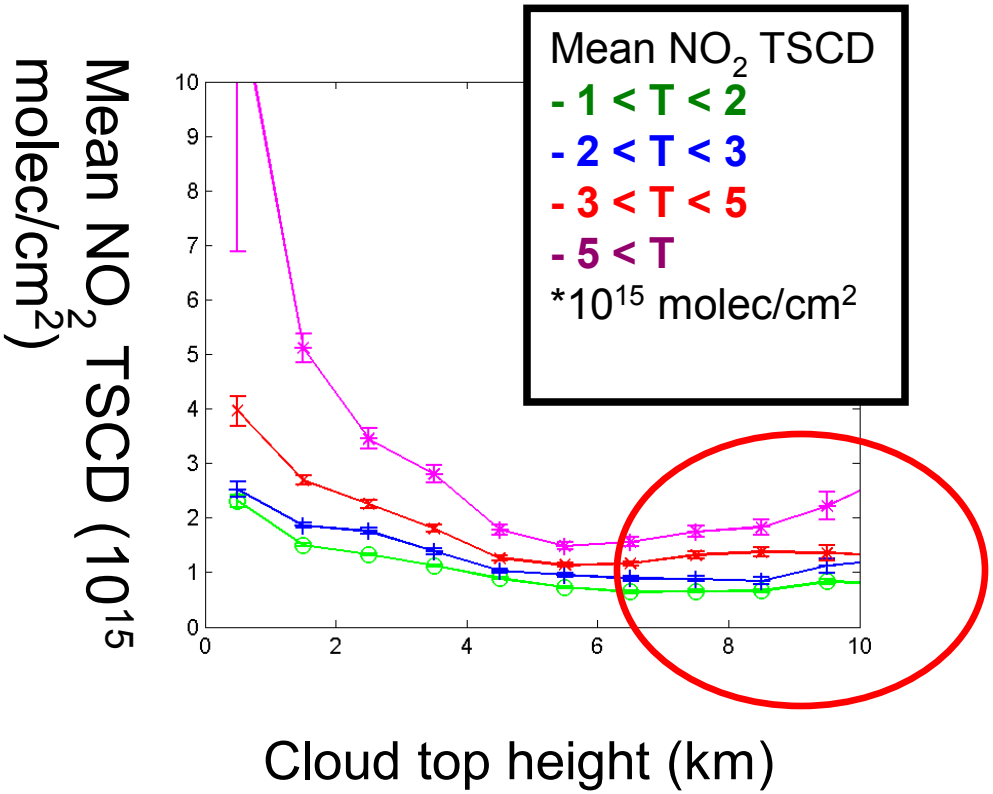
- lifetime is of the order of hours

- partitioning between NO and NO_2 depends on actinic flux

- potential interference with NO_x produced by lightning

Dependency of the tropospheric NO_2 SCD on cloud top height (cloud fraction > 50 %) in Eastern Asia

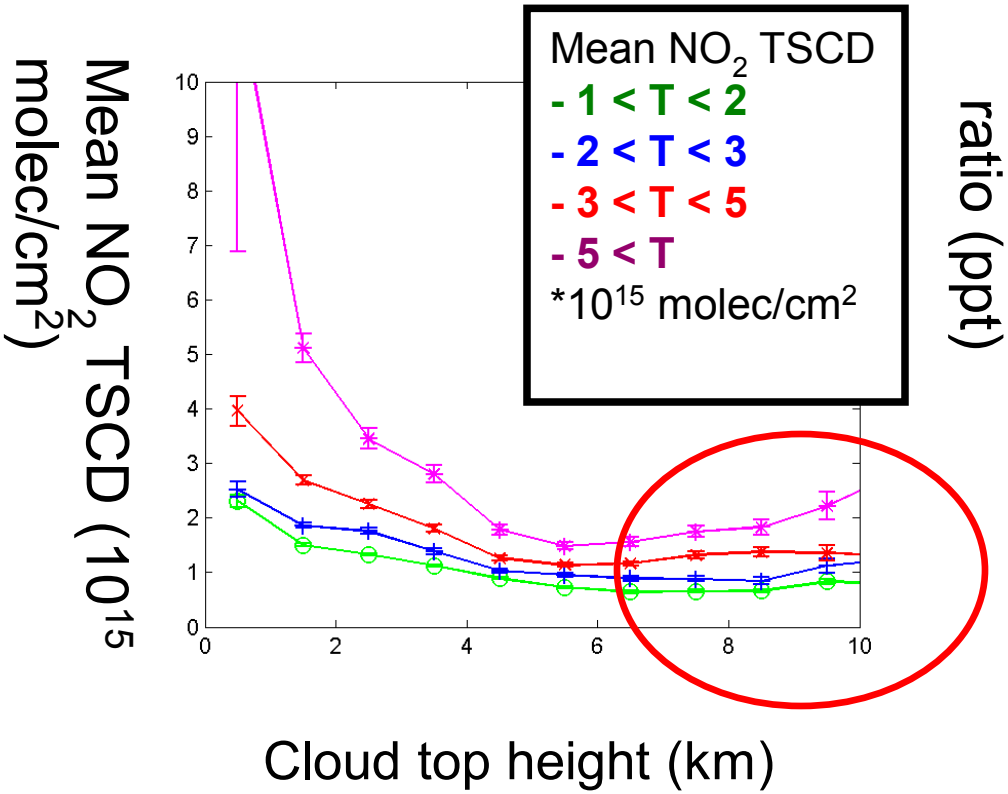
partial NO_2 columns



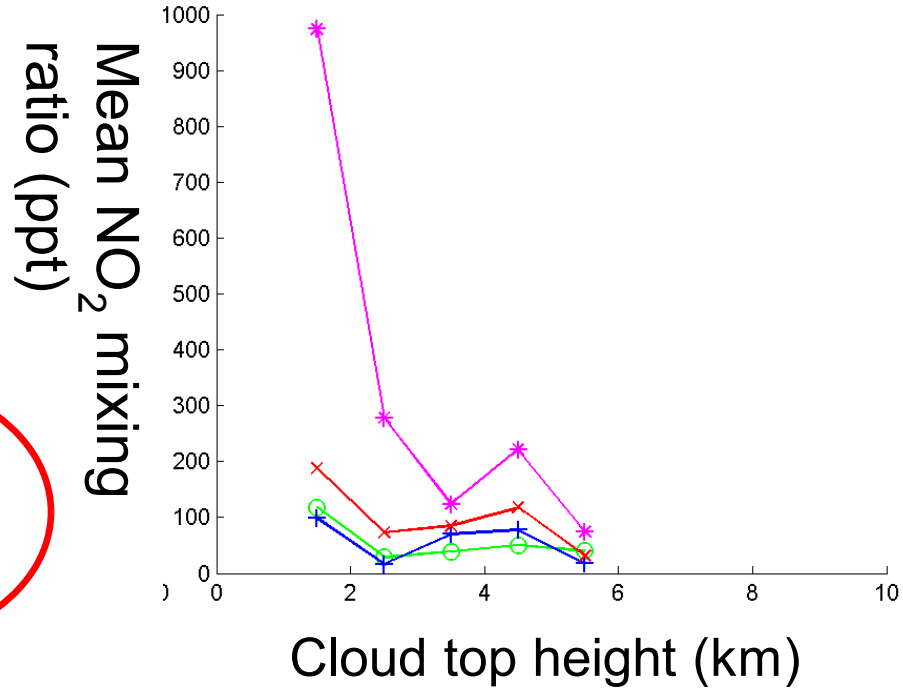
For CTH > 6 km the mean TSCD increases, probably due to convection and lightning NO_x.

Dependency of the tropospheric NO_2 SCD on cloud top height (cloud fraction > 50 %) in Eastern Asia

partial NO_2 columns



derived NO_2 ‚profiles‘

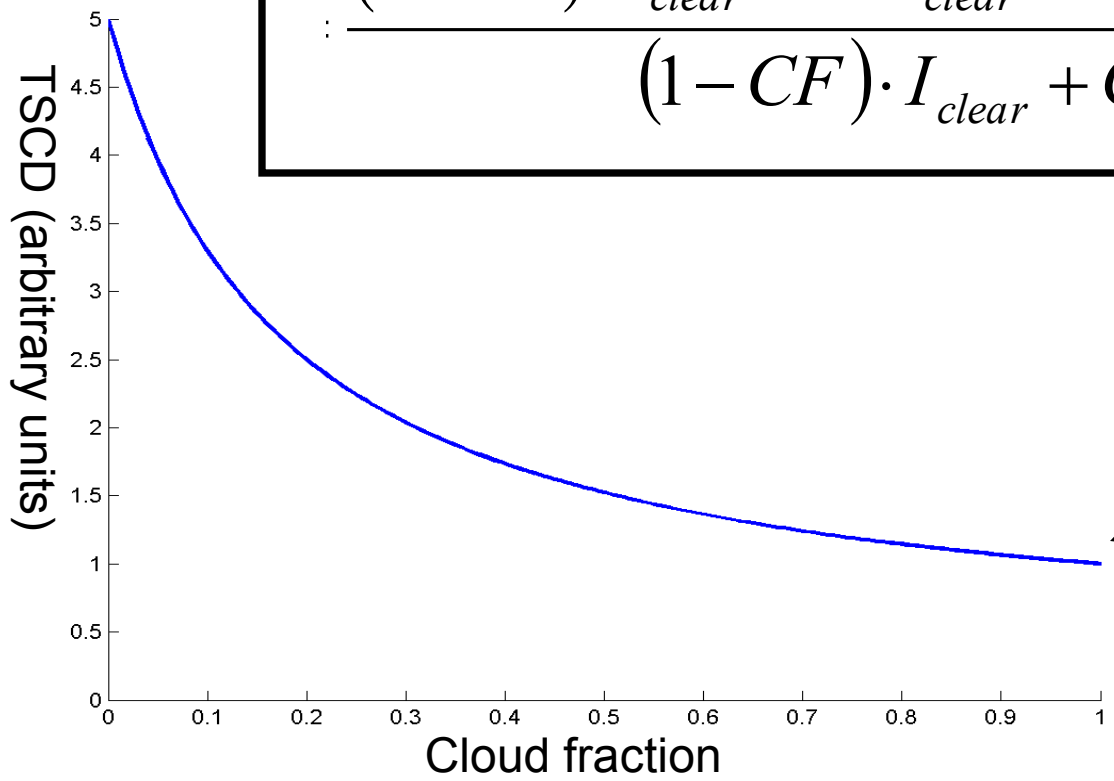


For CTH > 6 km the mean TSCD increases, probably due to convection and lightning NO_x.

Dependency of the tropospheric NO_2 SCD on cloud fraction (CF)

$$SCD(CF) = \underbrace{(1-CF)\cdot I_{clear}\cdot SCD_{clear}}_{clear\ part} + \underbrace{CF\cdot I_{cloudy}\cdot SCD_{cloudy}}_{cloudy\ part} : \left[(1-CF)\cdot I_{clear} + CF\cdot I_{cloudy}\right]$$

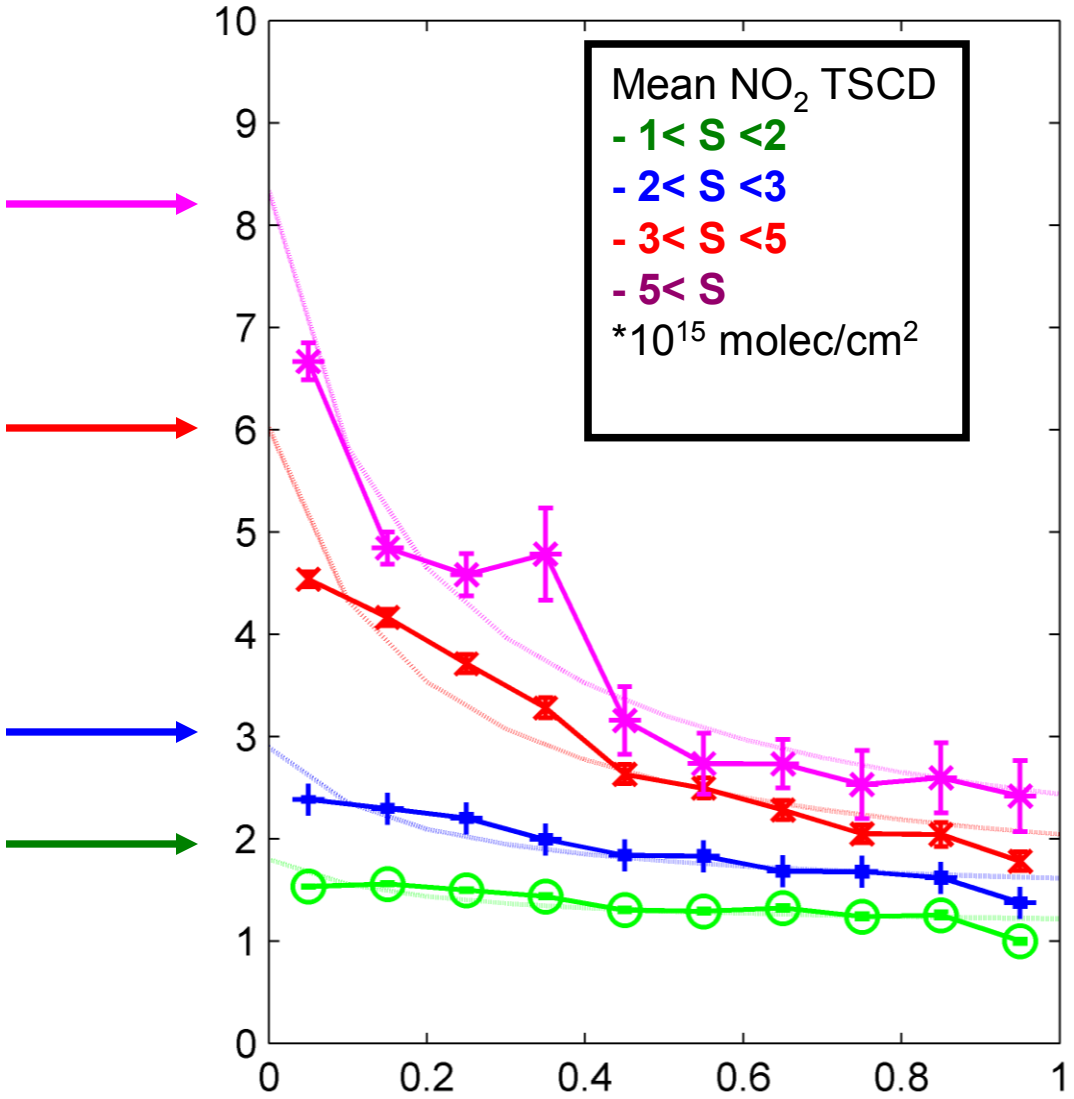
SCD_{clear}



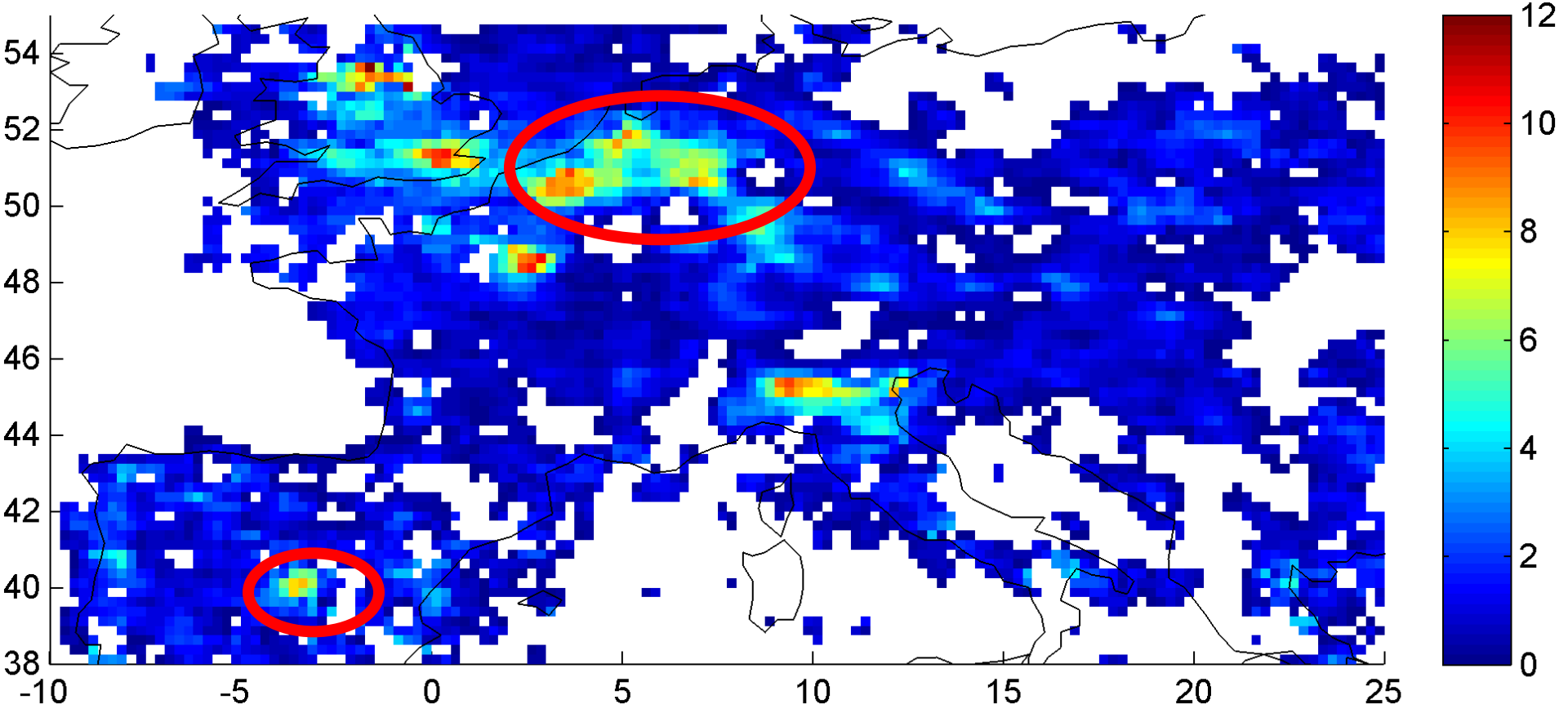
SCD_{cloudy}

Fit of the model function to OMI measurements (over Europe)

With this method, SCD_{clear} can be determined (also SCD_{cloudy})

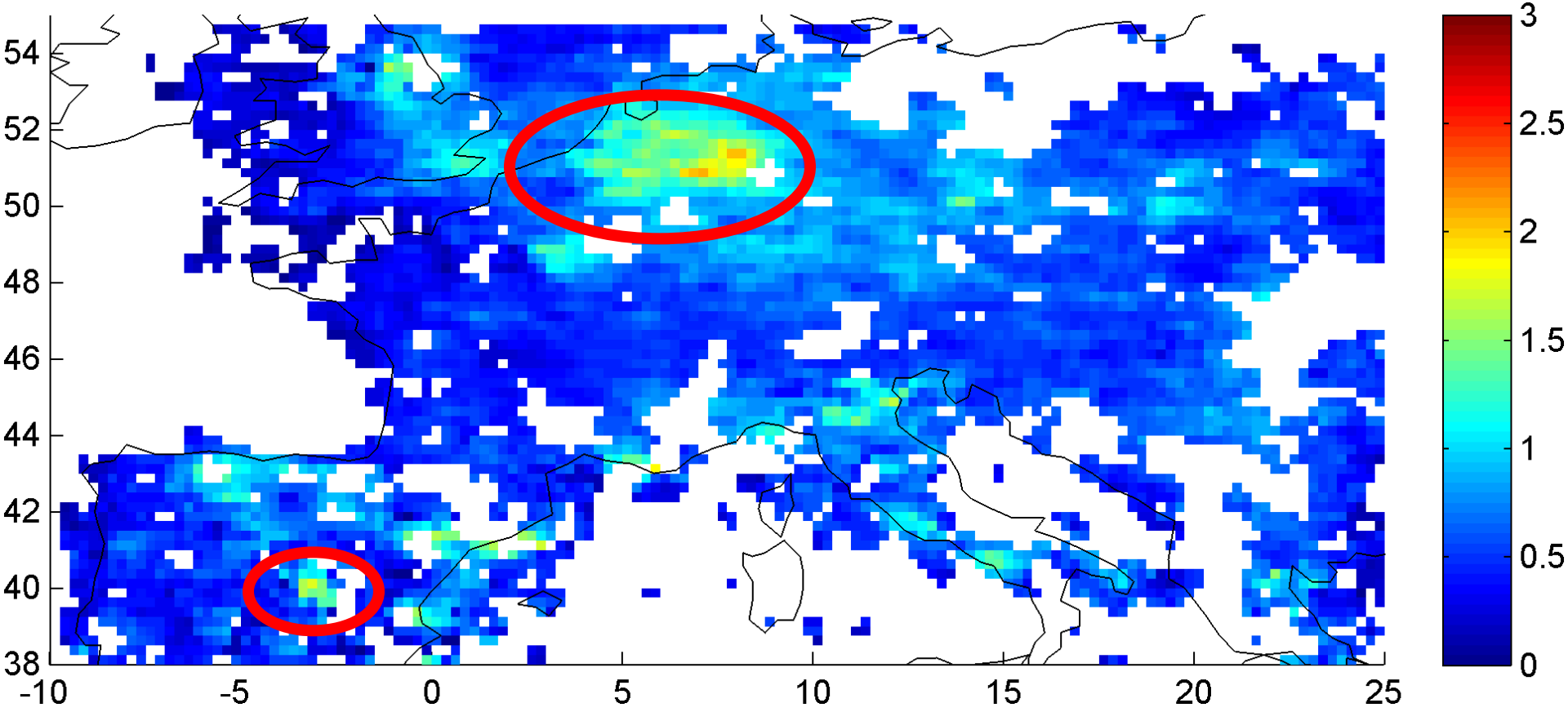


From the derived SCD_{clear} and SCD_{cloudy} partial NO_2 SDCs for selected height ranges can be determined



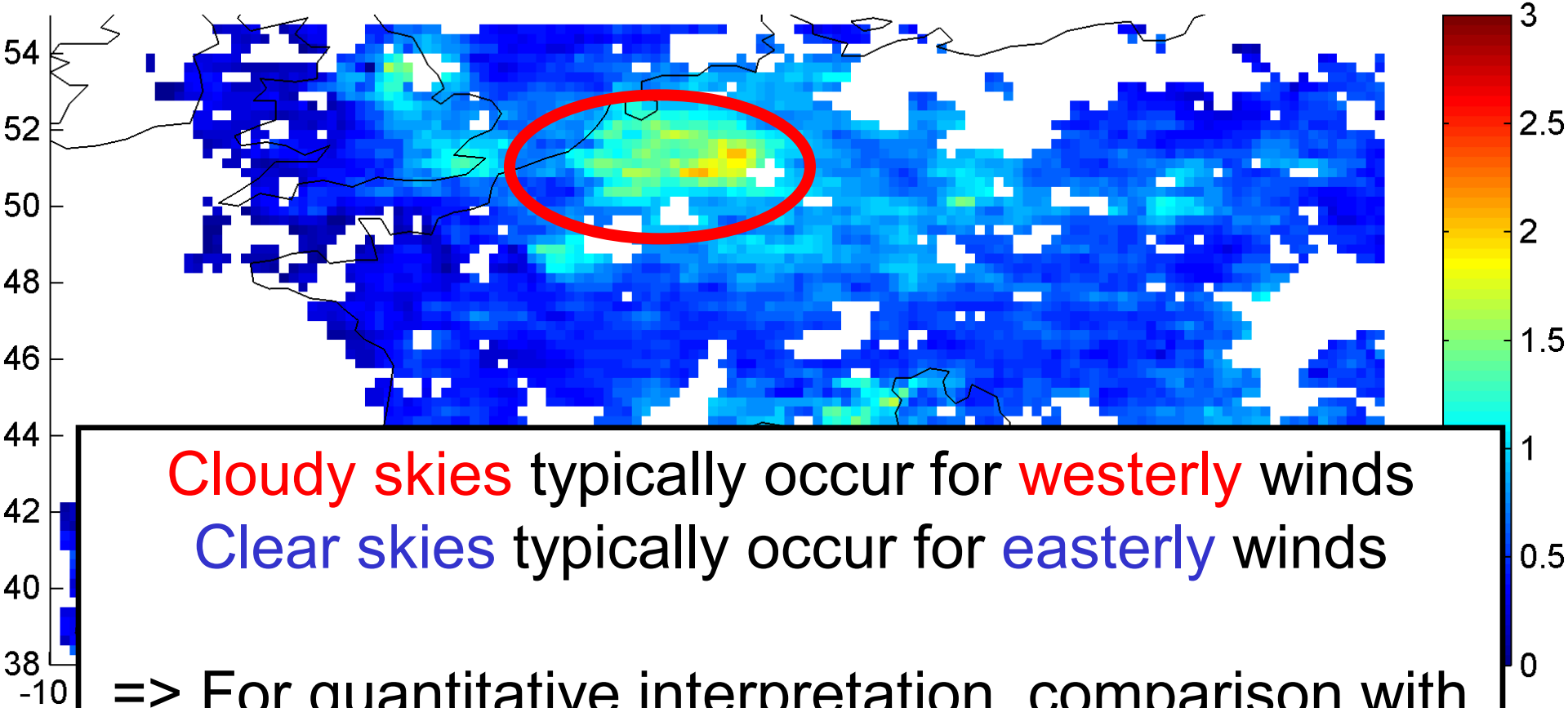
NO_2 VCD for the < 3 km (summer 2003-2007)

From the derived SCD_{clear} and SCD_{cloudy} partial NO_2 SDCs for selected height ranges can be determined



NO_2 VCD for the > 3 km (summer 2003-2007)

From the derived SCD_{clear} and SCD_{cloudy} partial NO_2 SDCs for selected height ranges can be determined



Cloudy skies typically occur for westerly winds

Clear skies typically occur for easterly winds

=> For quantitative interpretation, comparison with models is necessary (including photo-chemistry and ‚high' spatial resolution)

What can new sensors offer?

- TROPOMI (S5p): daily global coverage and high spatial resolution (7 * 7 km²)

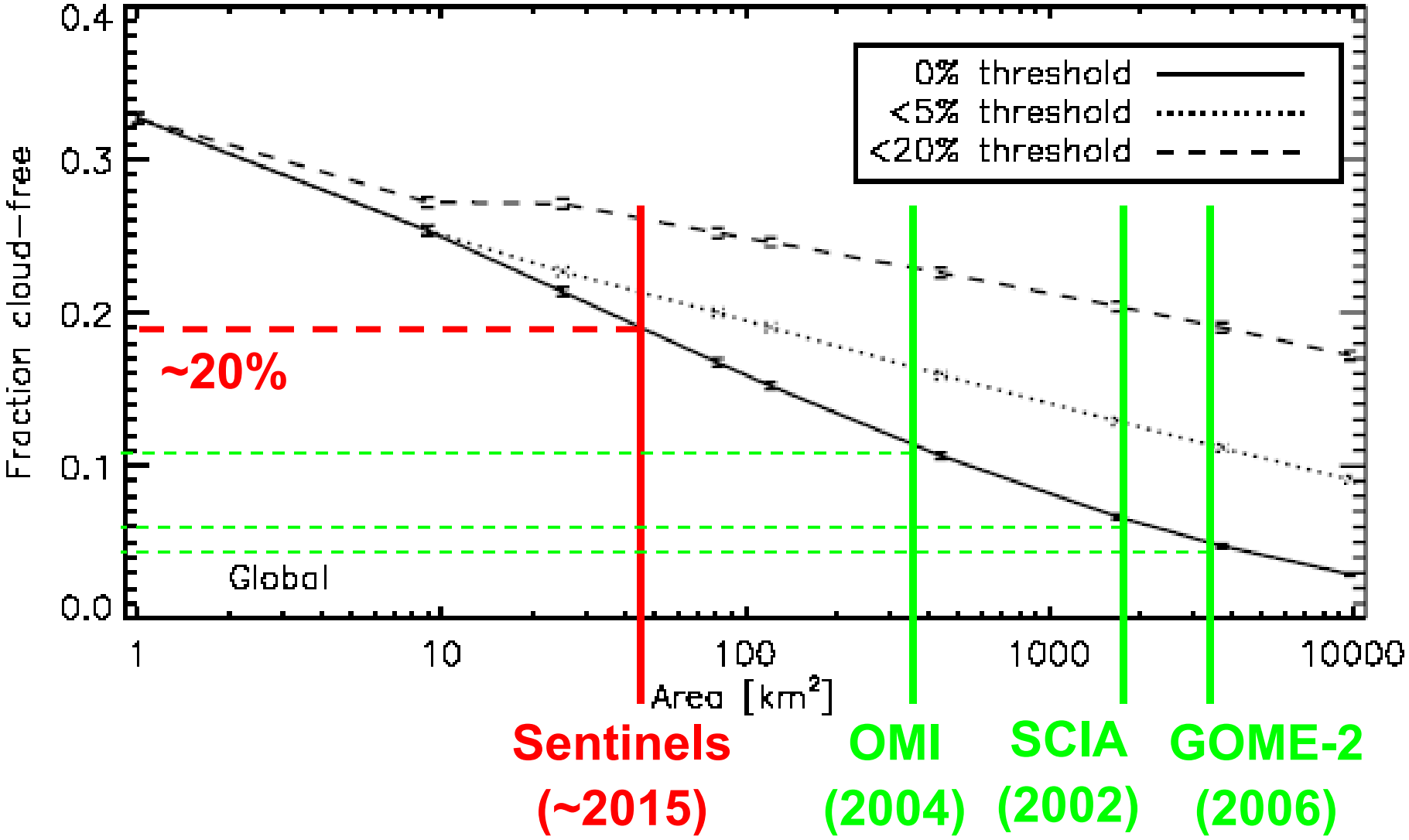
=> more neighbouring measurements in megacity emission plumes

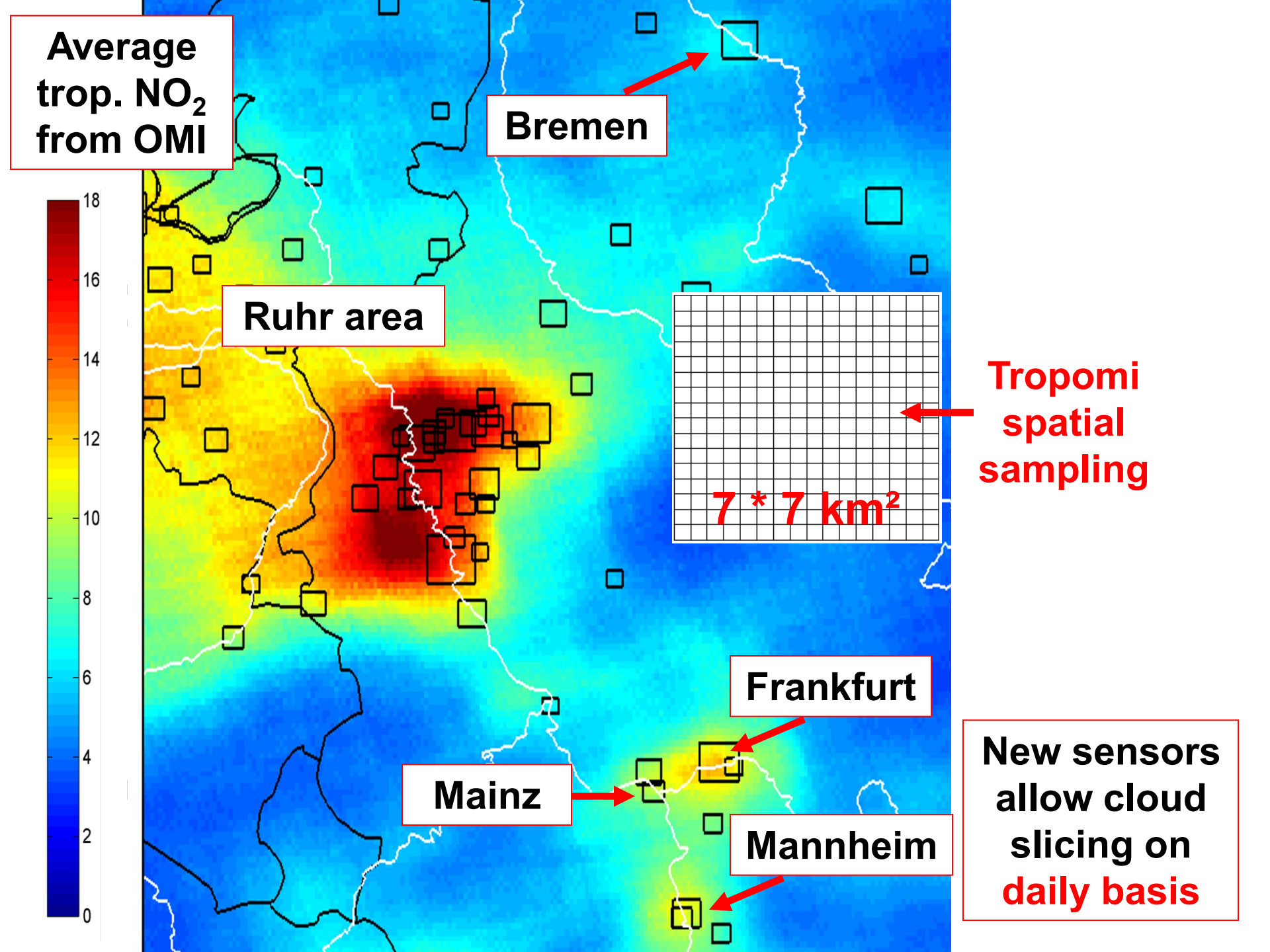
=> higher probability for completely clear and cloudy pixels

=> cloud slicing on a daily basis?

Probability of cloud contamination depending on pixel size

Krijger, J. M., van Weele, M., Aben, I., and Frey, R, ACP, 2007.

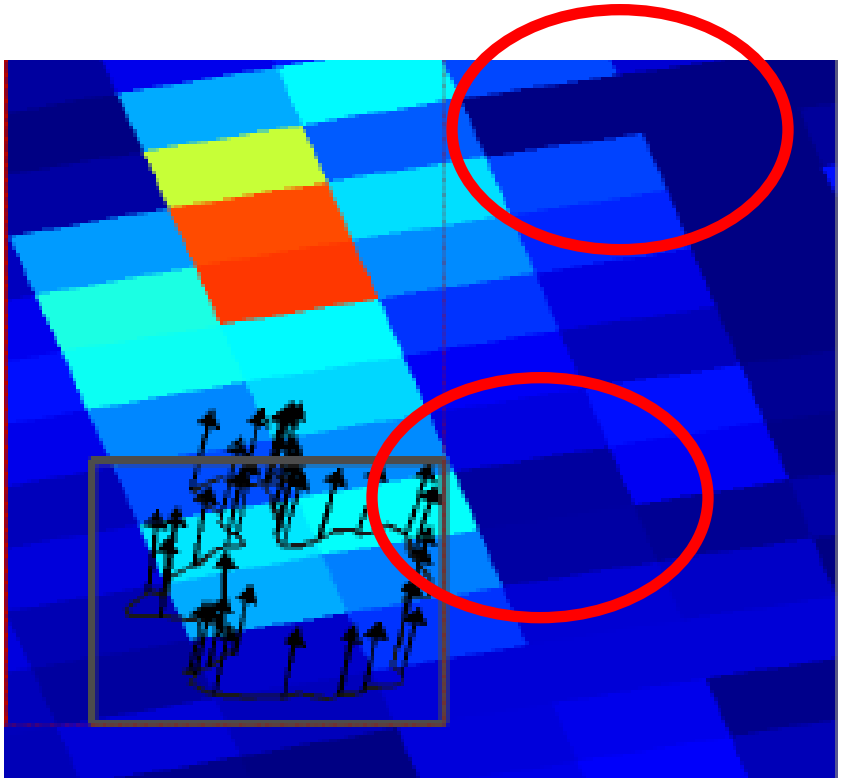


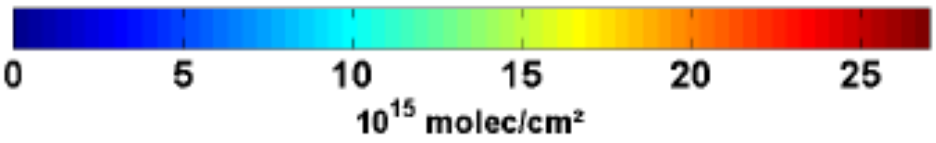

Average trop. NO_2 from OMI
18
16
14
12
10
8
6
4
2
0
Bremen
Ruhr area
7 * 7 km²
Tropomi spatial sampling
Frankfurt
Mainz
Mannheim
New sensors allow cloud slicing on daily basis

Example: OMI observations over Paris, 16.07.2009

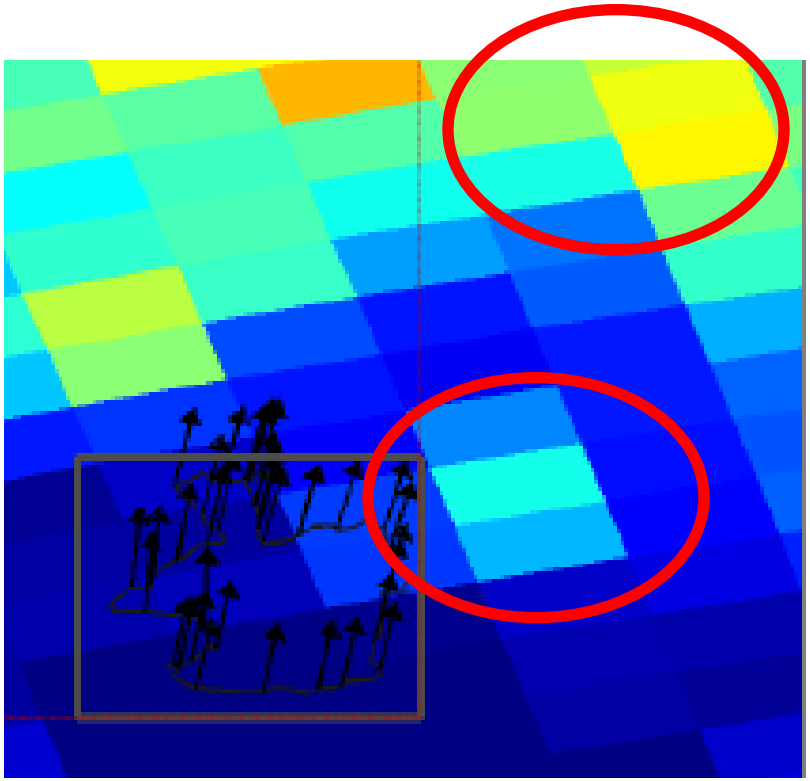
=> often lower NO_2 VCDs are observed for larger cloud fractions

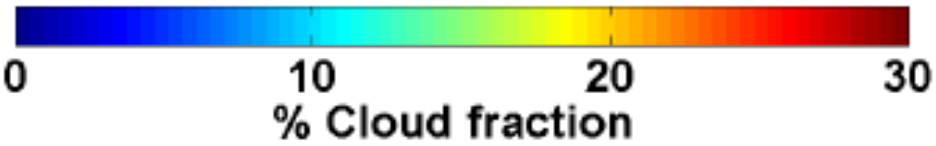
NO_2 VCDs





Cloud fraction





Which clouds are most useful?

=> probably completely clear pixels should be avoided, because:

a) relative uncertainty of cloud properties is large

b) vertical mixing might differ strongly for completely clear and cloudy pixels

=> low clouds are needed to ‚sample' the surface-near profile

=> maybe H_2O observations should be used to derive cloud top height (scale height ~ 2 km)

=> what about man made clouds?

Artificial clouds can cover large parts of a TROPOMI ground pixel

Summary

- cloud slicing from novel sensors has the potential to derive profile information on daily basis

- neighbouring pixels covering central parts of the megacity plumes should be used

- completely clear pixels should be avoided

- cloud top height needs to be retrieved with improved accuracy (use H_2O observations ?)

- photochemical corrections might be needed (simple parameterisations or regional models?)

- dependence of vertical transport on cloud cover should be investigated (simple parameterisations or regional models?)