Improving S5P NO_2 retrievals

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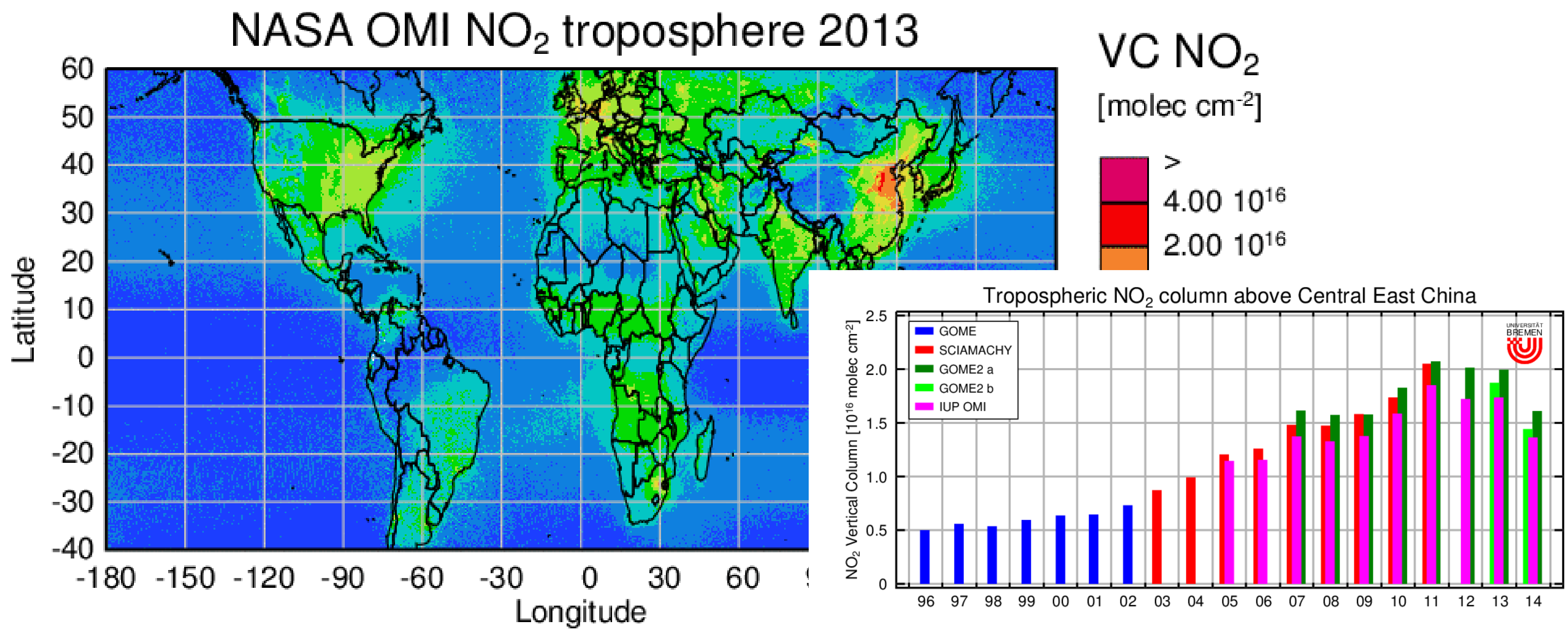
Introduction



- Current instruments provide excellent coverage and spatial detail for NO_2
- They will soon be followed by the TROPOMI / S5P instrument which promises even better performance and spatial resolution

S5P tropospheric NO_2 retrieval is state of the art – so what‘s left to improve?

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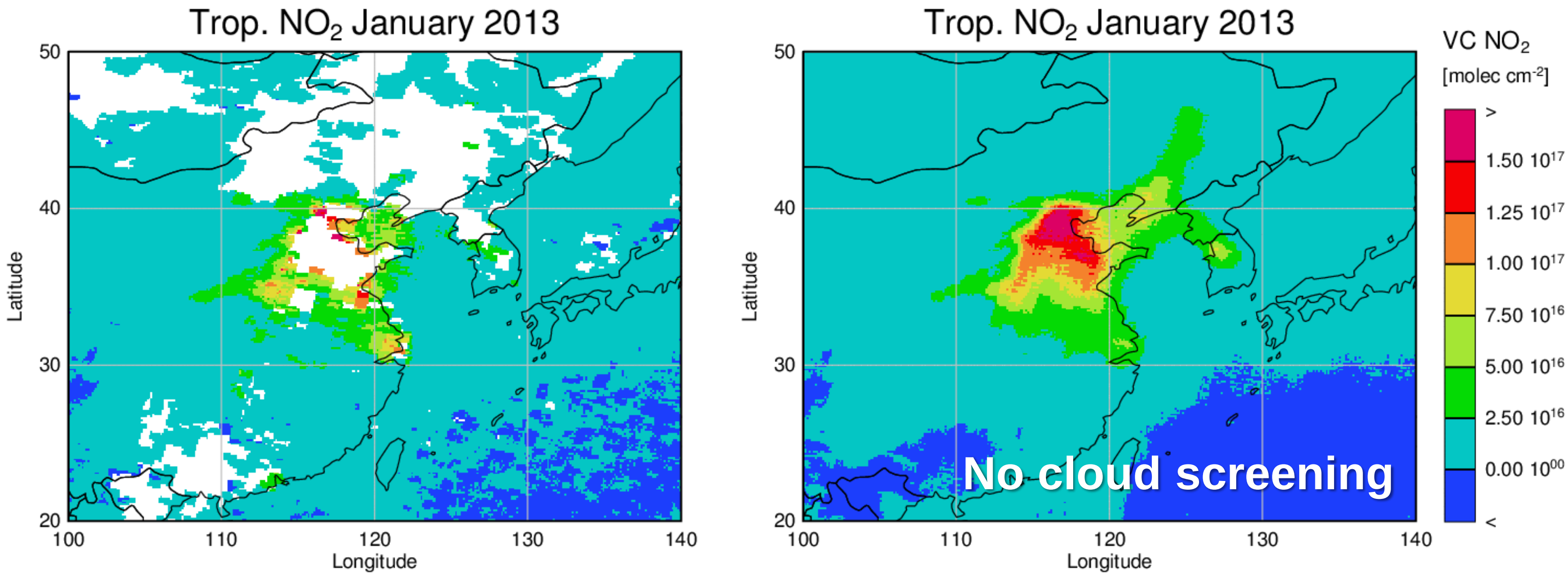
GOME-2A NO_2 above China



- Monthly GOME-2 tropospheric NO_2 data are missing most of the large values
- These were removed by cloud filtering as aerosol was so thick that data were classified as partially cloudy

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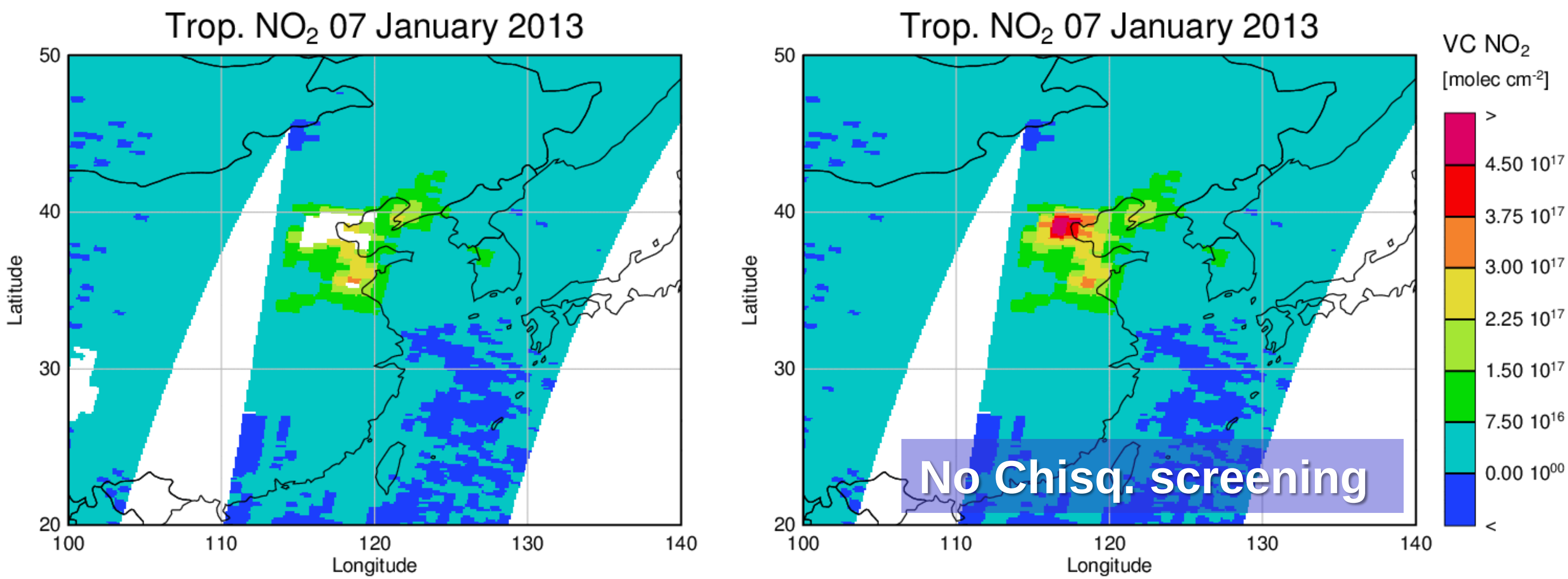
Is it only Aerosols?



- Even without cloud screening, there are data gaps over pollution hot spots on some days
- This is due to quality checking as these fits are poor

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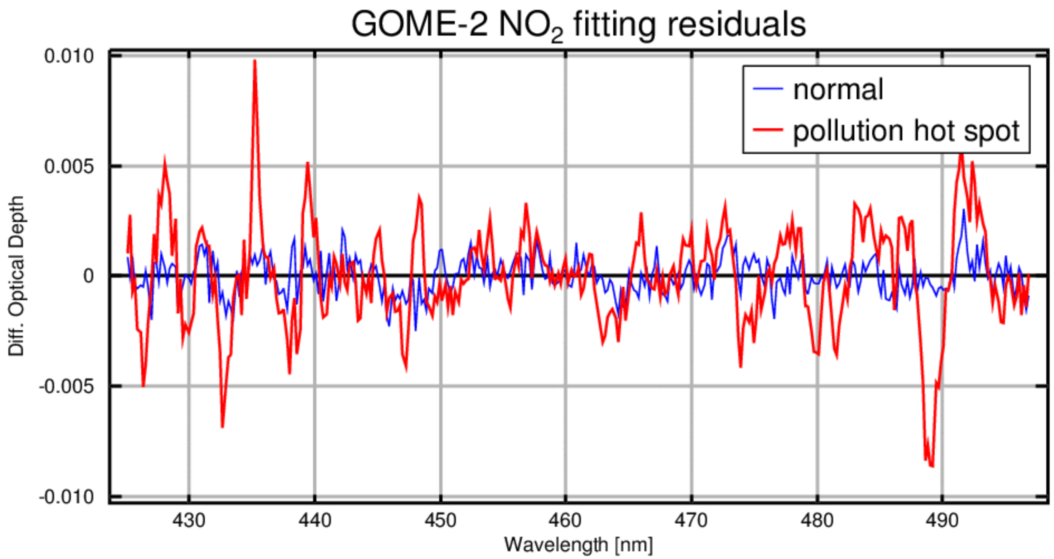
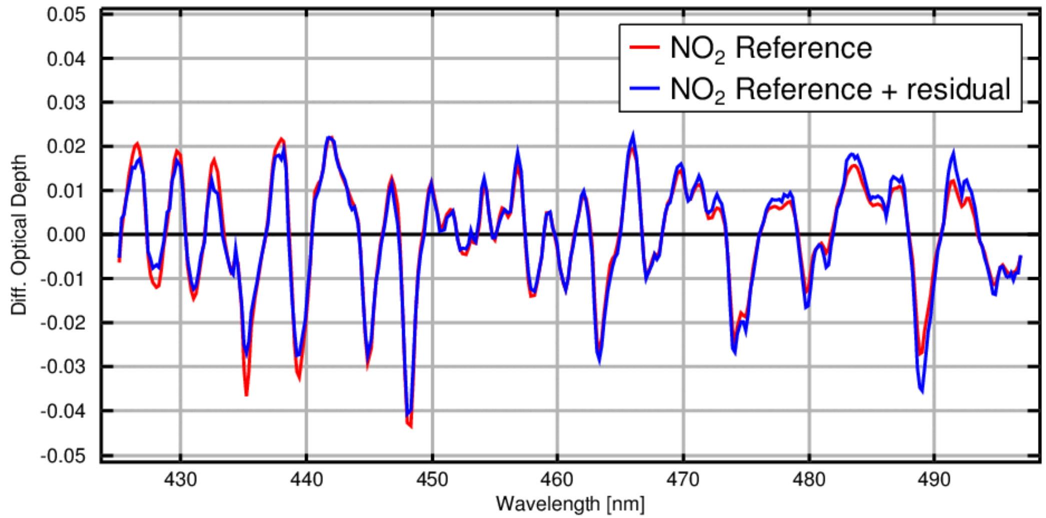
Why are the fits poorer at strong pollution?





- There are large and clearly structured residuals in fits over pollution hot spots
- This is not random noise!

- Comparison to NO_2 cross-sections shows that scaling of NO_2 should change over fitting window

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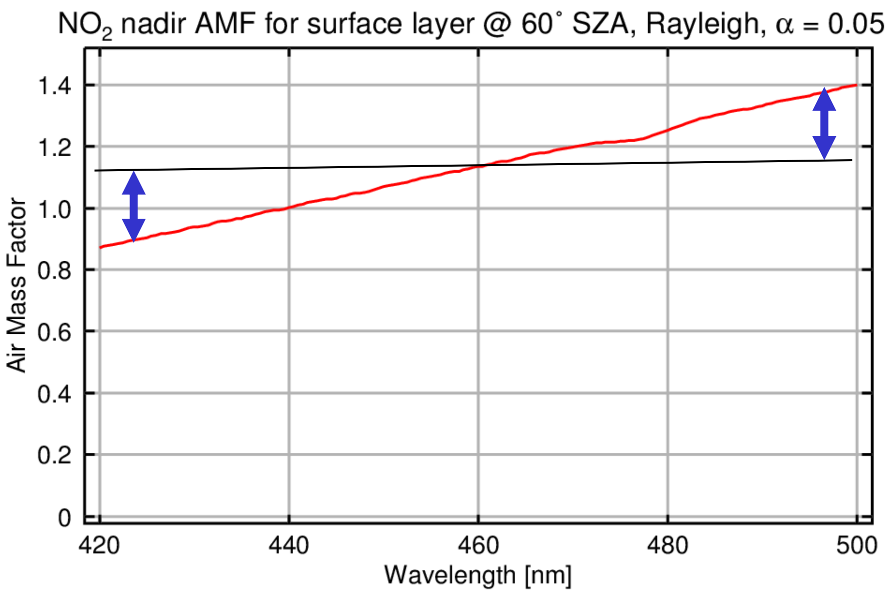
Wavelength dependence of Air Mass Factor



About +/- 20%

- For constant albedo, AMF of NO_2 layer close to the surface increases with wavelength in a Rayleigh atmosphere
- For a surface layer, this can be a significant effect
- With radiative transfer modelling and a formal inversion, this should provide information on the altitude of the NO_2

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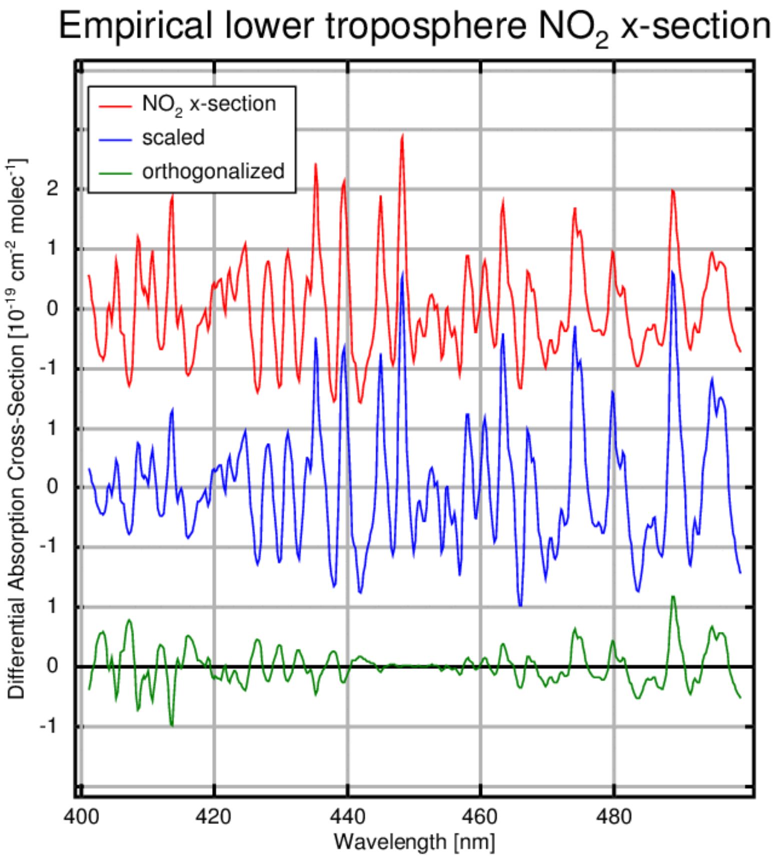
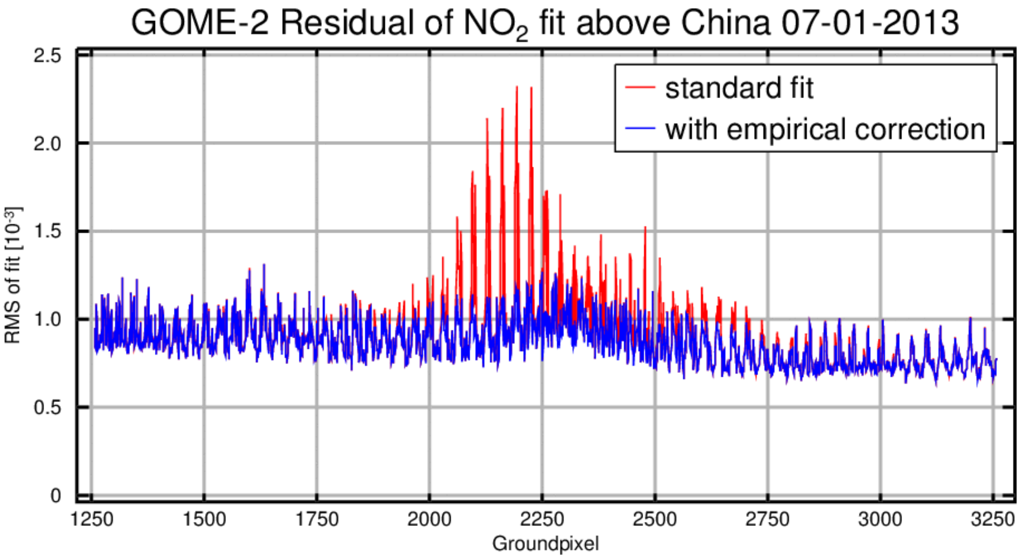
Empirical Approach for $NO_2(\lambda)$



- Take standard NO_2 x-section
- Scale to increase amplitude with wavelength
- Orthogonalise to leave NO_2 columns unchanged



When introduced in the fit, large residuals are fixed

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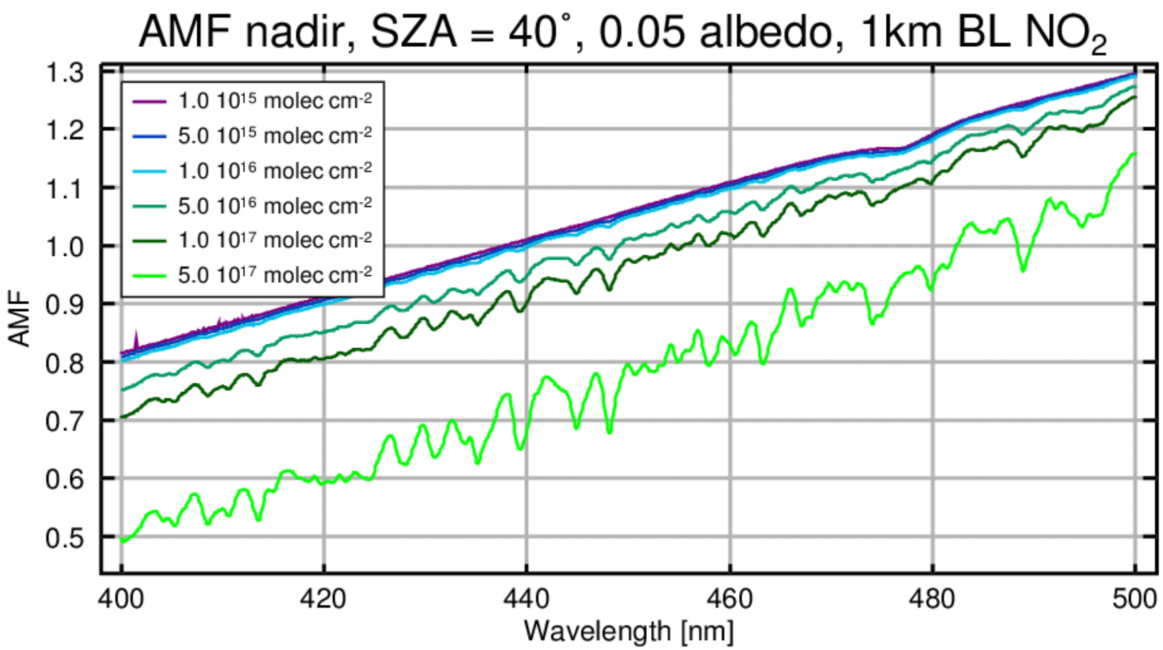
Is this the only problem at large NO_2 columns?

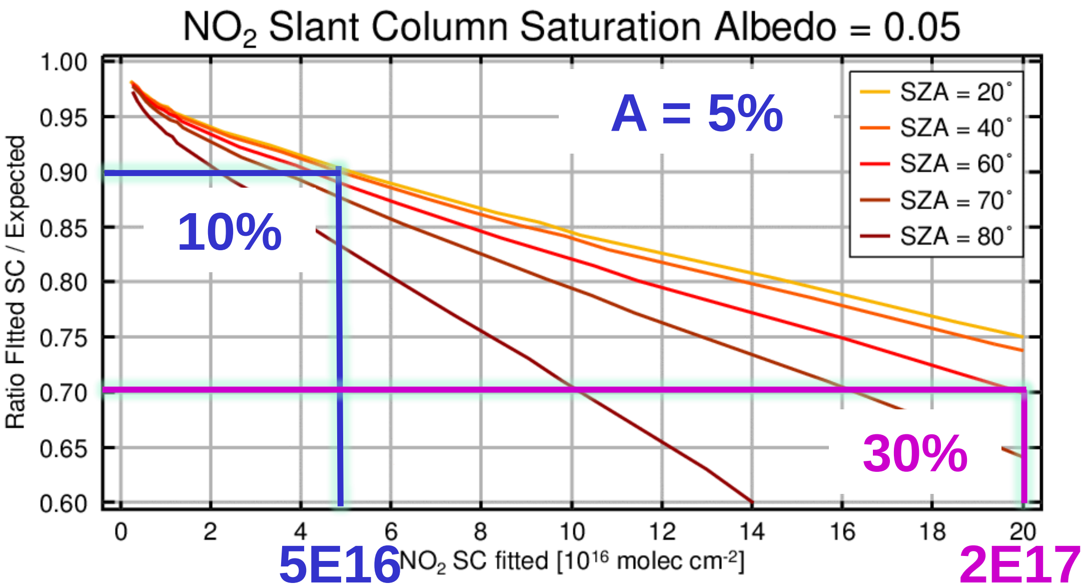
- One of the main DOAS assumptions is, that the light path enhancement (AMF) for a trace gas is independent of its column amount
- For strong absorbers (O_3, SO_2, IR gases) this approximation is not good enough and the change of sensitivity with wavelength needs to be accounted in the fit ("modified“ DOAS)
- NO_2 is generally considered to be a weak absorber, but is that still true for very polluted scenarios?

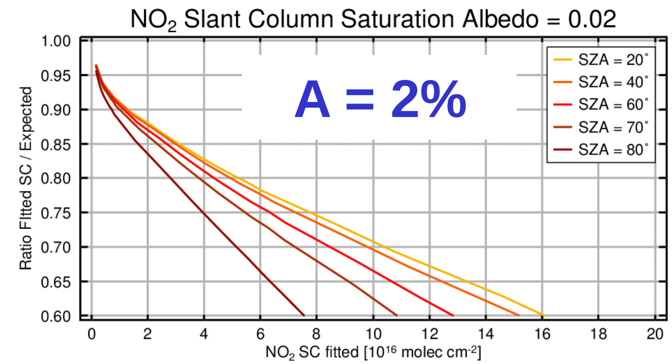
AMF dependence on NO_2 column

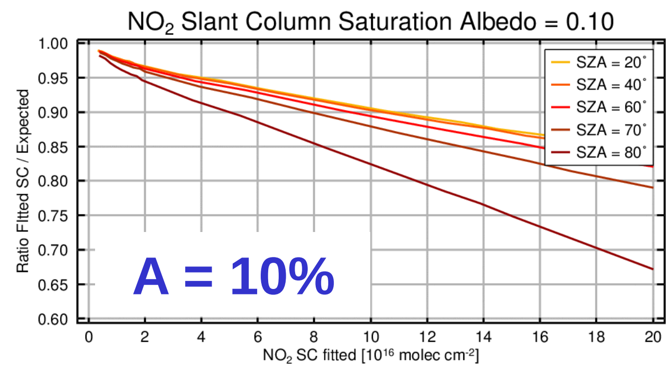


- Up to a vertical column of about 1×10^{16} molec cm^{-2}, small dependence of AMF on NO_2 amount
- For larger columns, the AMF decreases and NO_2 absorption structures appear

AMF dependence on NO_2 column







- Effect on DOAS fit on synthetic data is larger than on AMF alone as both smaller AMF and spectral structures reduce NO_2 columns
- Effect increases with SZA
- Even at a column of 5×10^{16} molec cm^2, the error is > 10%
- Effect decreases with increasing albedo

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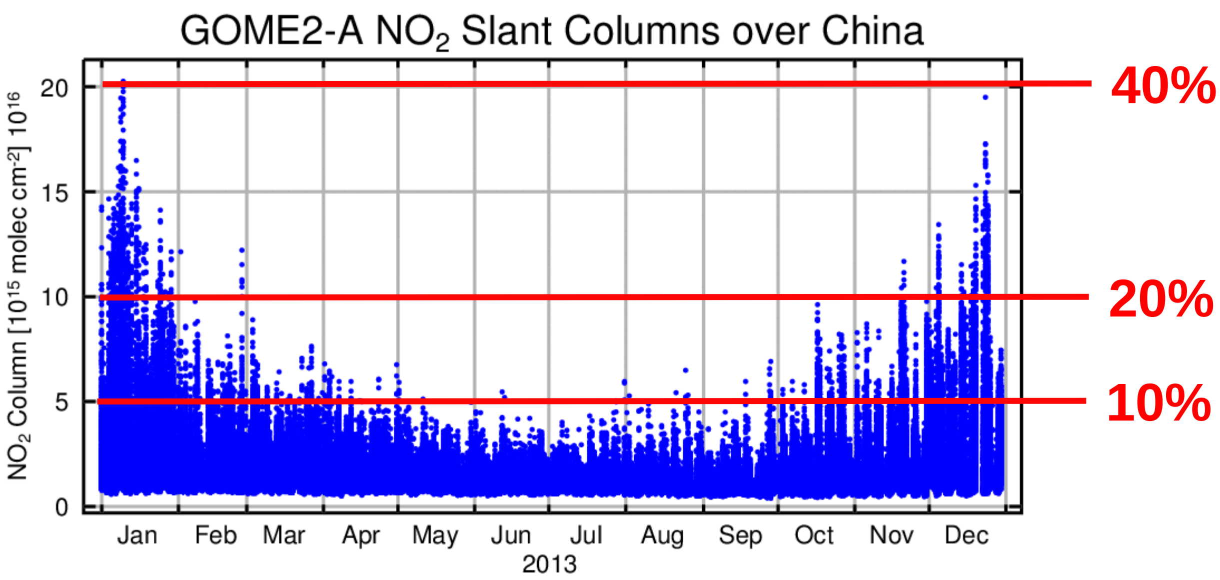
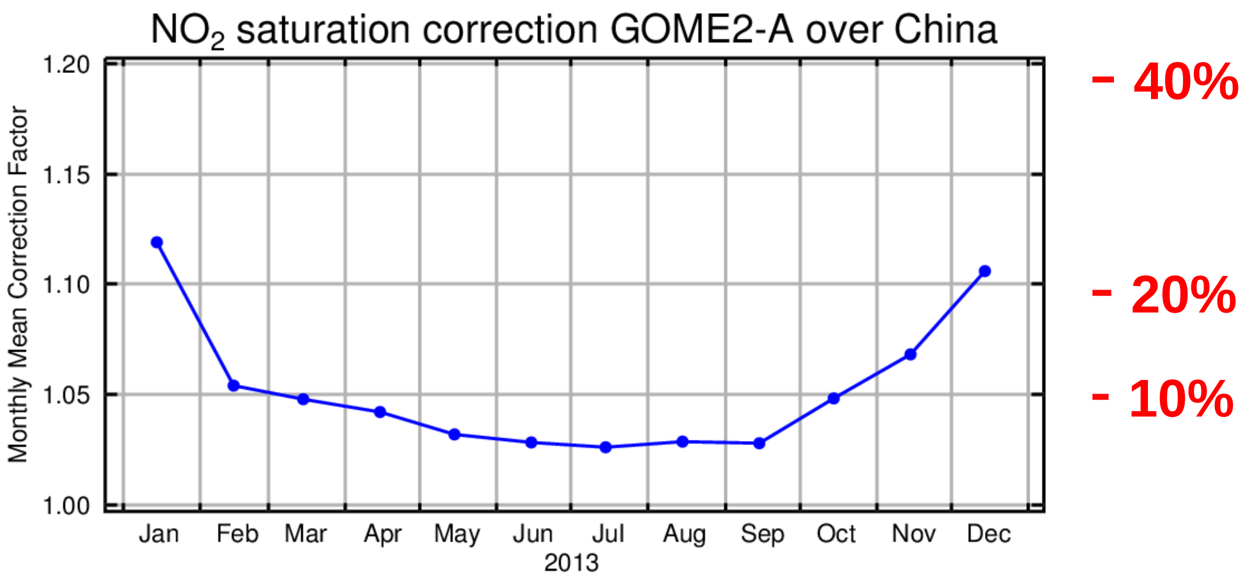
NO_2 saturation on real GOME-2A data



- Many measurements above China are in the saturation range
- Corrections of 5% - 40% need to be applied to individual pixels
- In monthly averages, the effect is still > 10% in January and December
- Real effect is even larger as cloud effects reduce columns but not saturation effects

NO_2 saturation on real GOME-2A data



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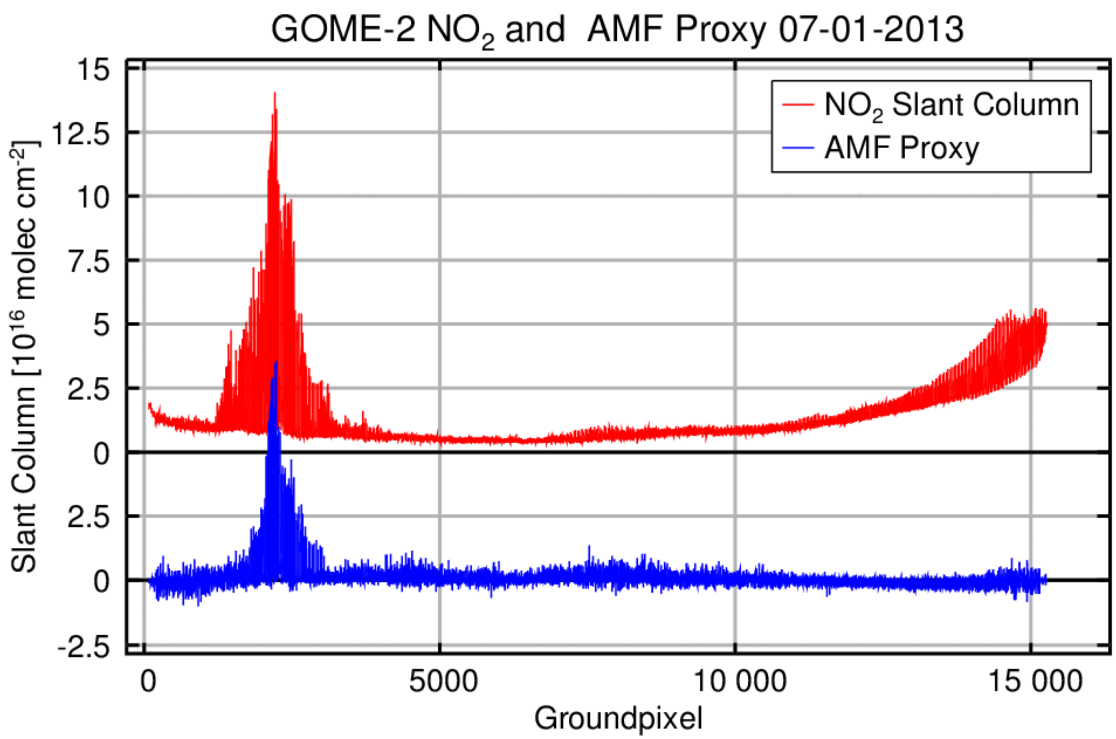
Results Empirical Approach $NO_2(\lambda)$: **GOME-2A**



- The empirical NO_2 AMF proxy is found over the pollution hotspot in China
- It is not found at other locations where the NO_2 slant column is large
- There is some noise in the retrieval of the proxy

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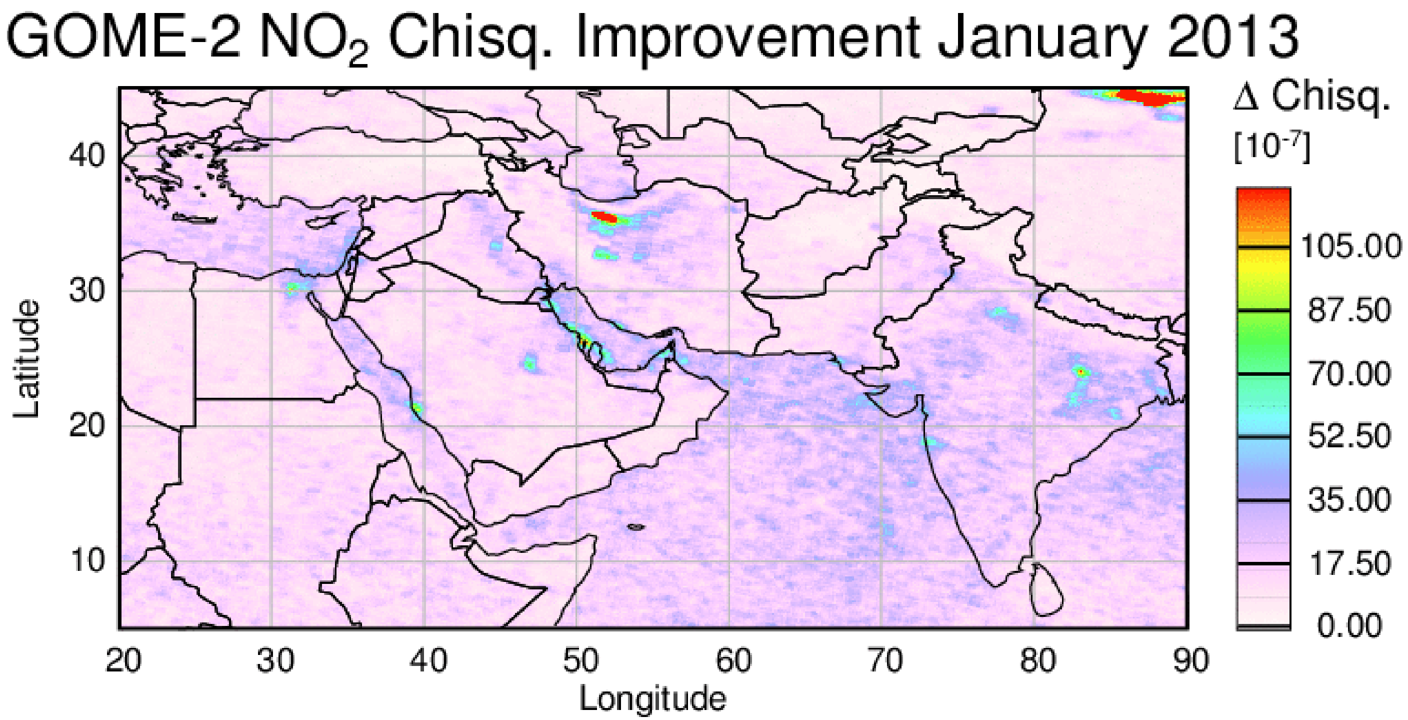
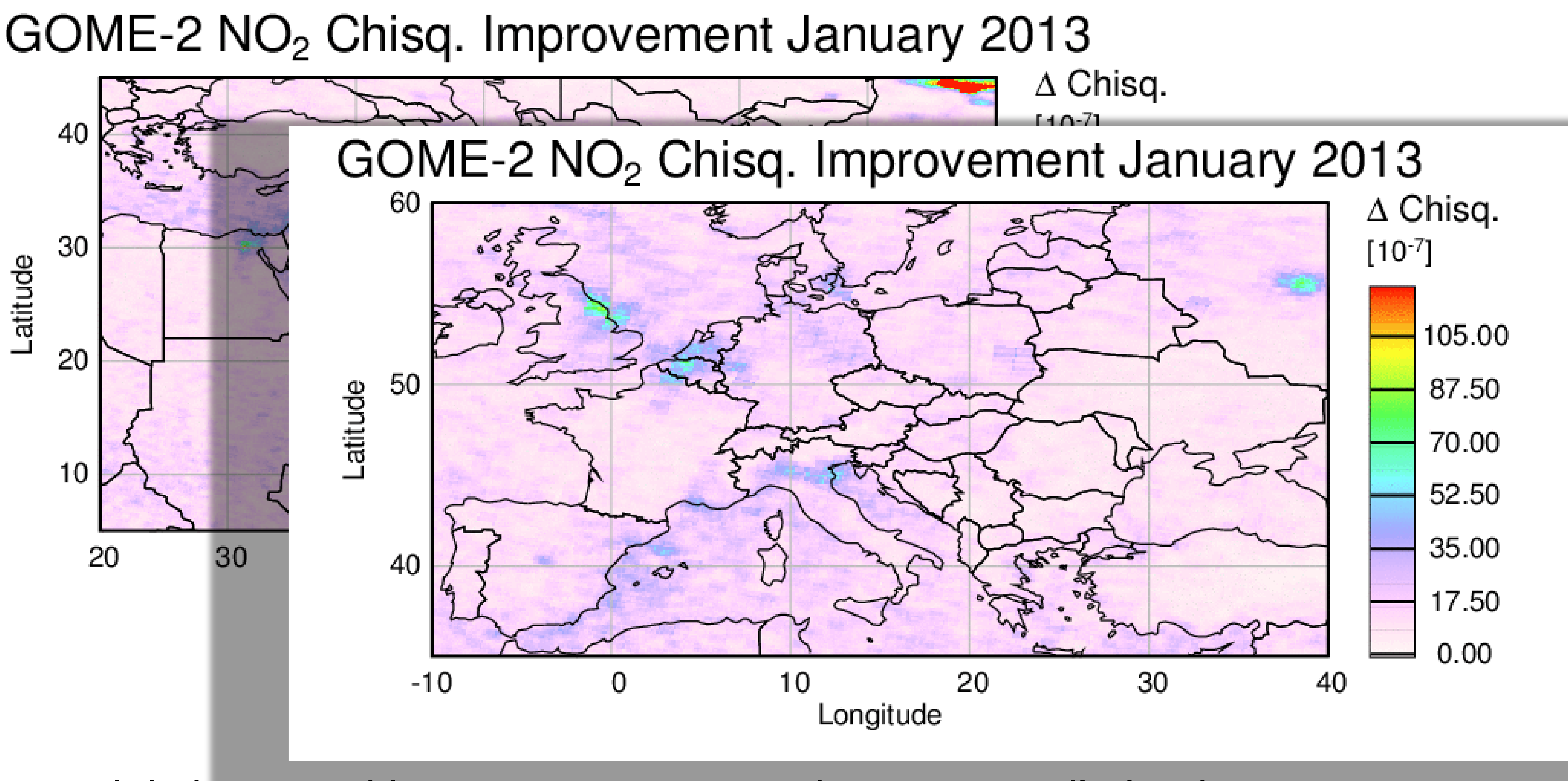
Is there more than China? **GOME-2**



- Fit is improved by AMF proxy everywhere over pollution hotspots

Is there more than China? GOME-2



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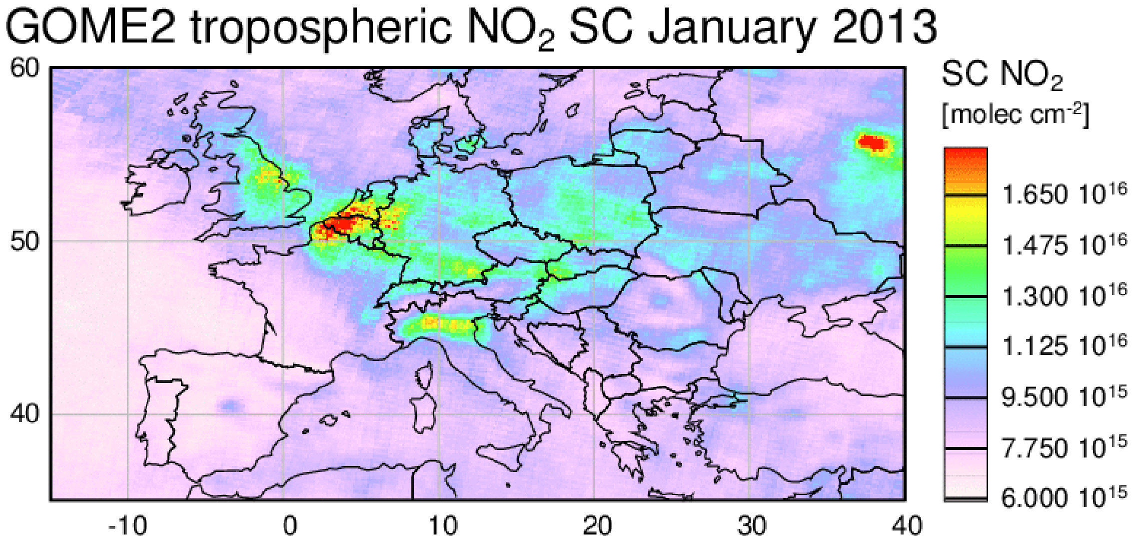
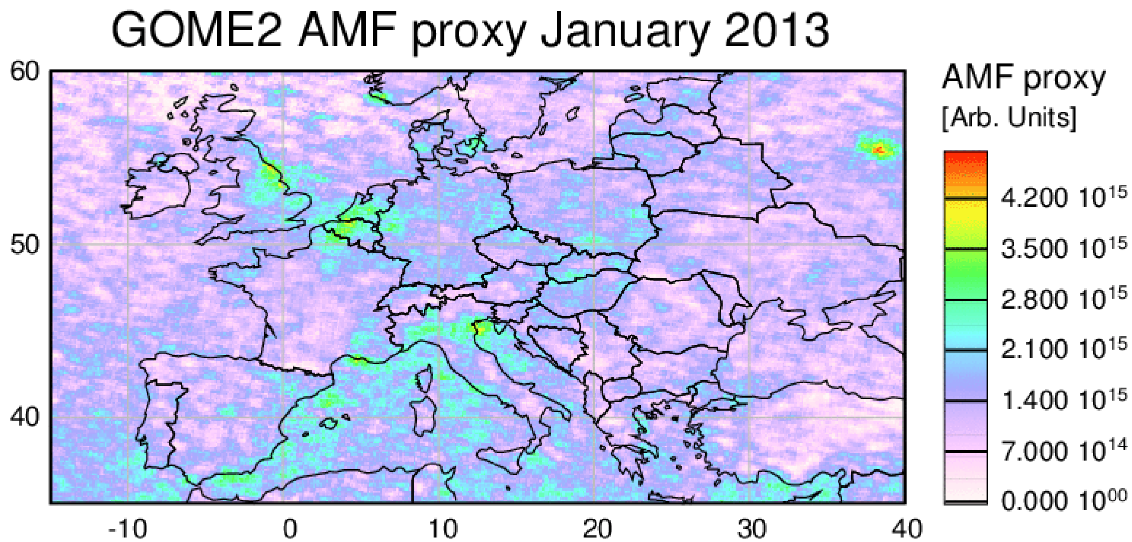
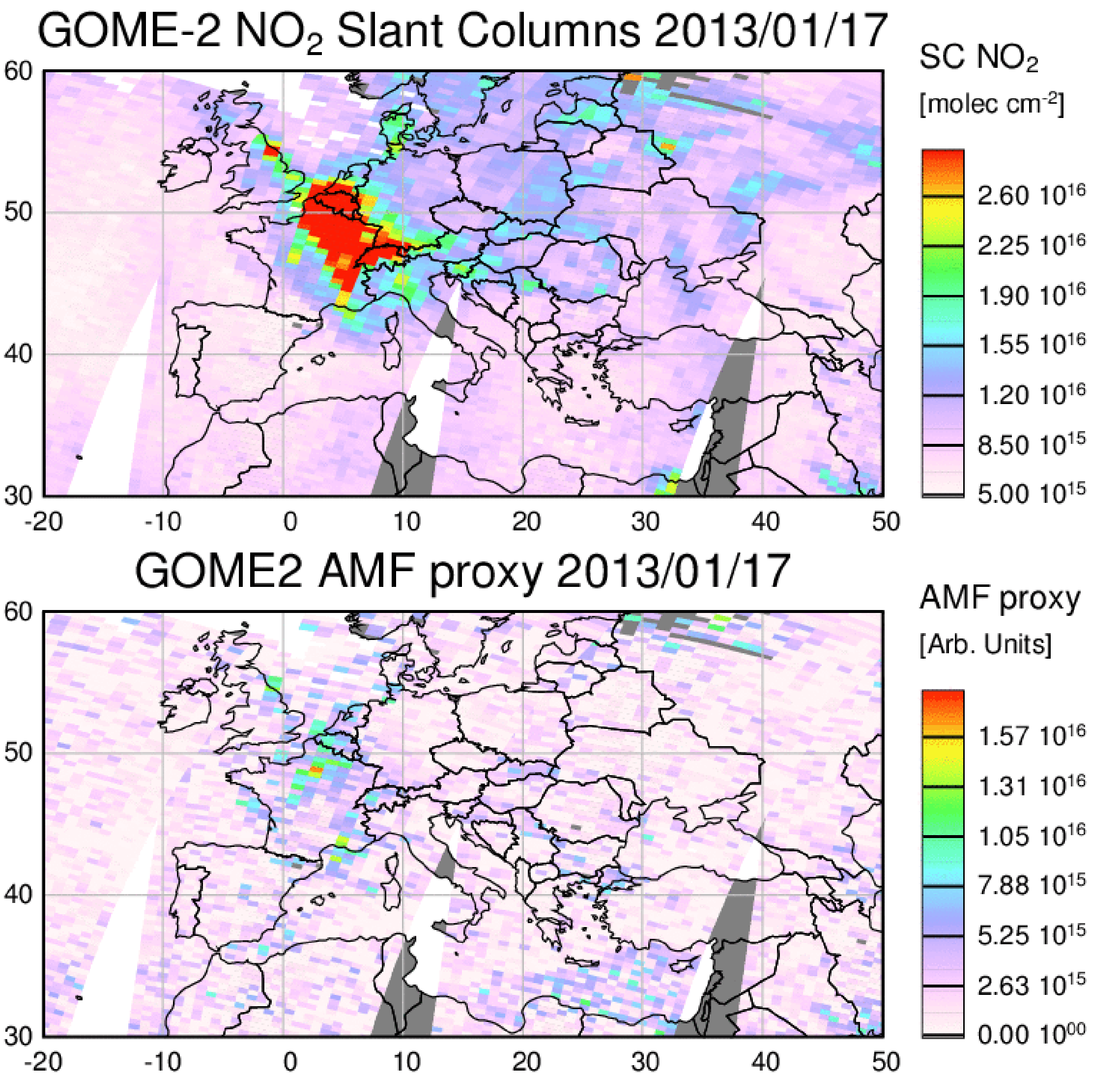
Comparison to NO_2 columns: **GOME-2**





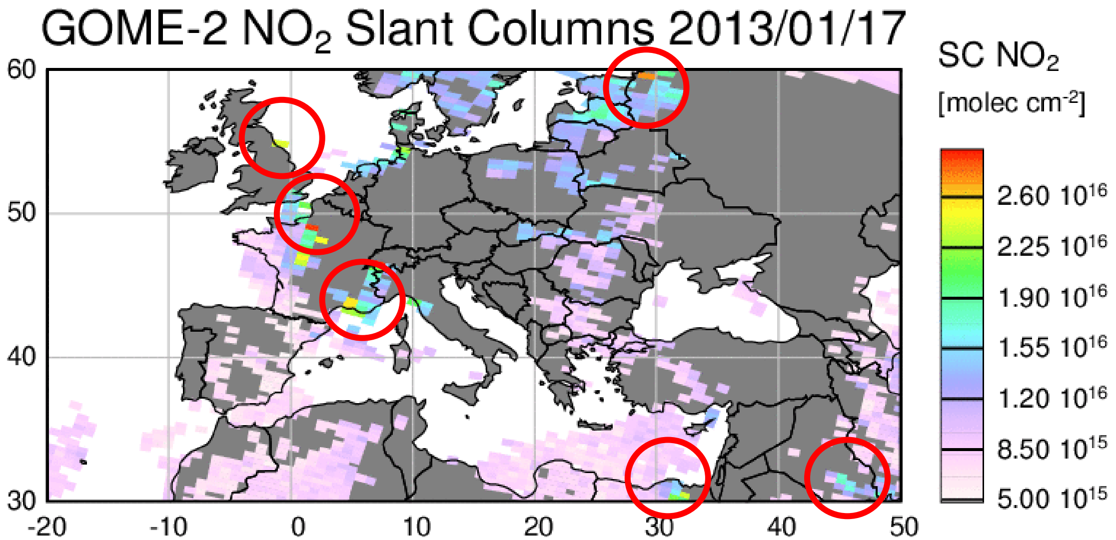
- Overall pattern similar to NO_2 map
- Differences in distributions of maxima
- Artefacts over water
- noise

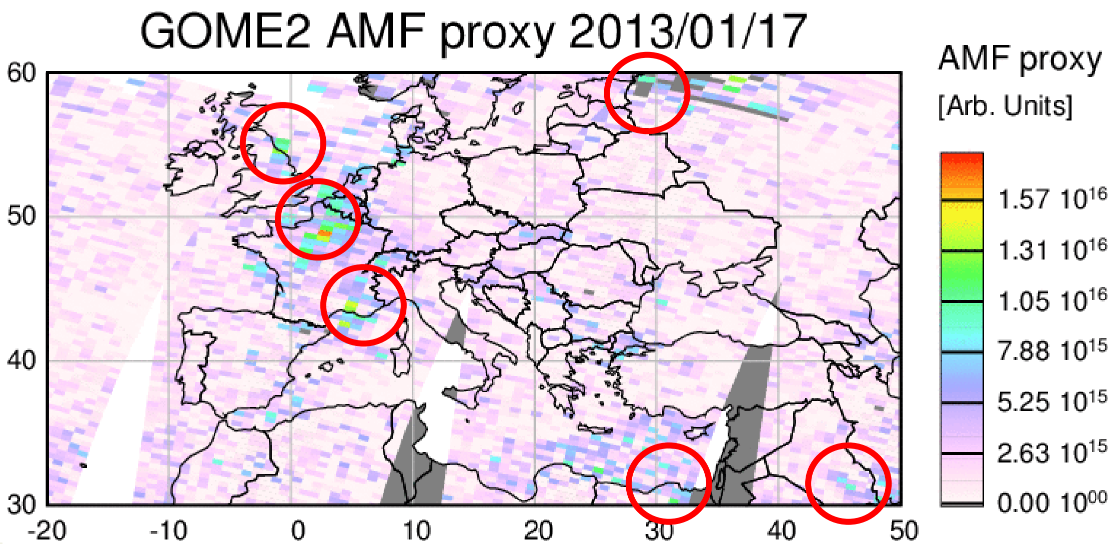
Impact of Clouds: **GOME-2**



- On many days in winter, very large NO_2 slant columns are observed over Europe and the US
- The NO_2 AMF proxy picks up only very few of these signals

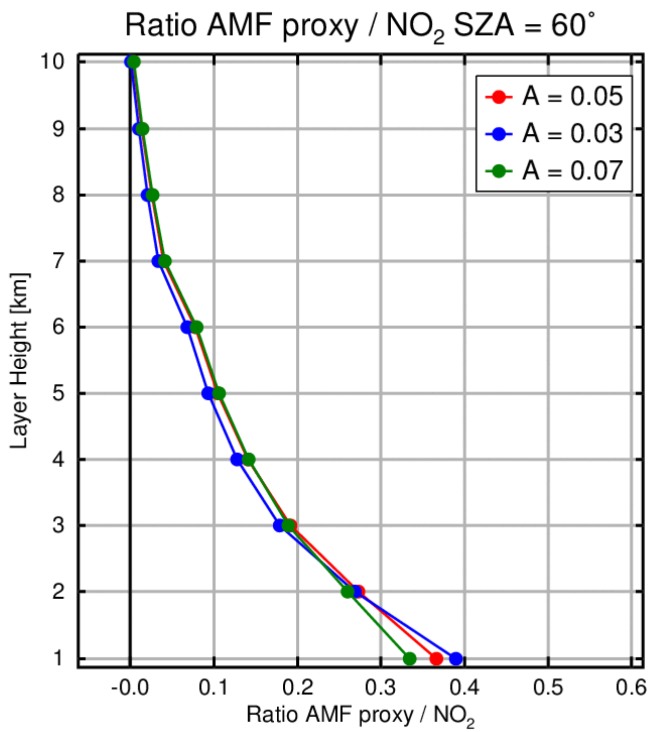
Impact of Clouds: GOME-2





- On many days in winter, very large NO_2 slant columns are observed over Europe and the US
- The NO_2 AMF proxy picks up only very few of these signals
- This is linked to the fact that most of the events are related to cloudy scenes or snow on the surface, resulting in small wavelength dependence

Sensitivity Study for $NO_2(\lambda)$ / NO_2



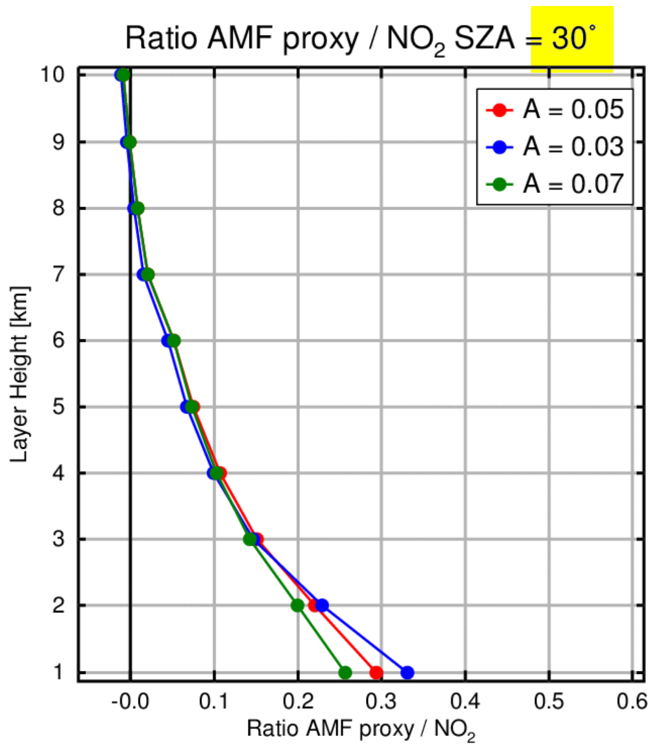
Synthetic data:

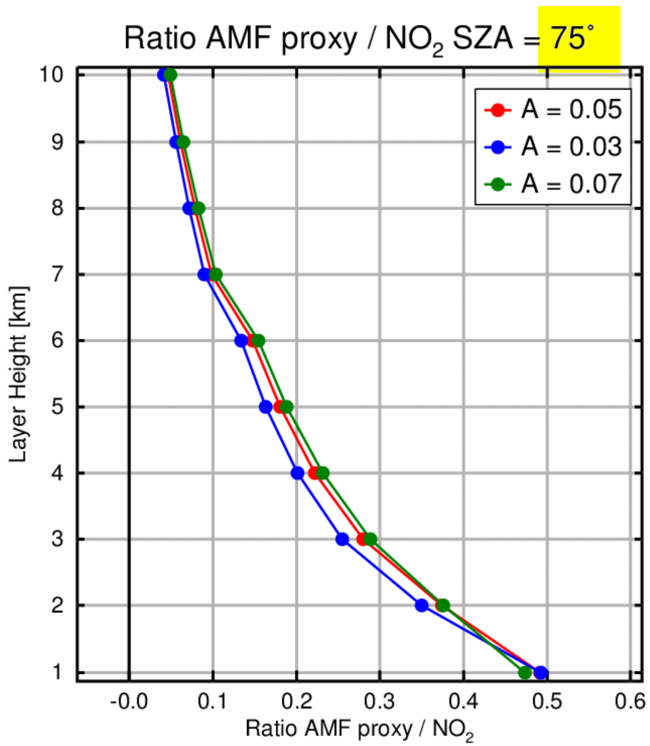
- Rayleigh atmosphere
- Constant albedo
- NO_2 layer in different altitudes
- DOAS fit on spectra
- NO_2 temperature dependence corrected by using 2 NO_2 x-sections
- AMF proxy included

- Ratio of AMF proxy / NO_2 to normalise signal

- Ratio of AMF proxy and NO_2 has strong dependence on NO_2 layer height
- Dependence on albedo is small between 3% and 7%

Sensitivity Study $NO_2(\lambda)$ / NO_2: SZA





- Effect varies with SZA; larger effect at larger SZA
- At large SZA, AMF proxy also found for high NO_2
- Dependence on albedo is small between 3% and 7%

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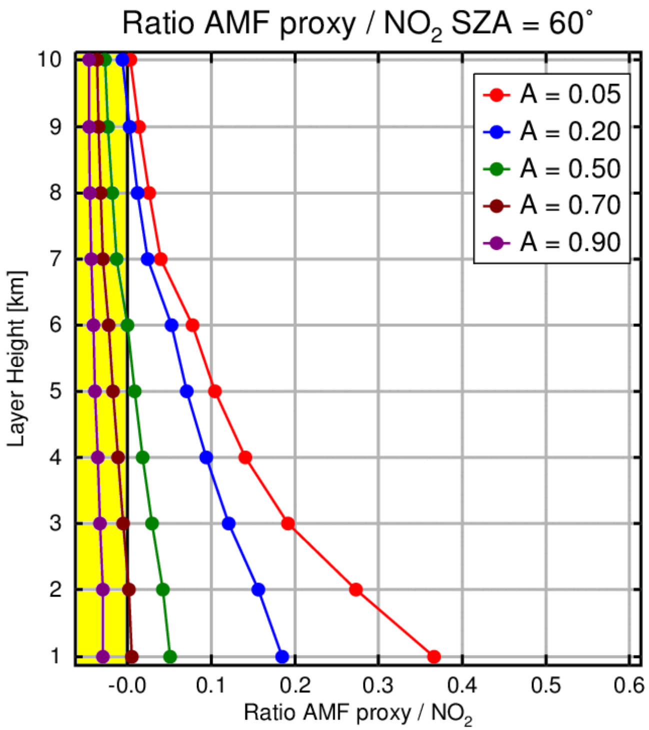
Sensitivity Study $NO_2(\lambda)$ / NO_2: Bright Surfaces

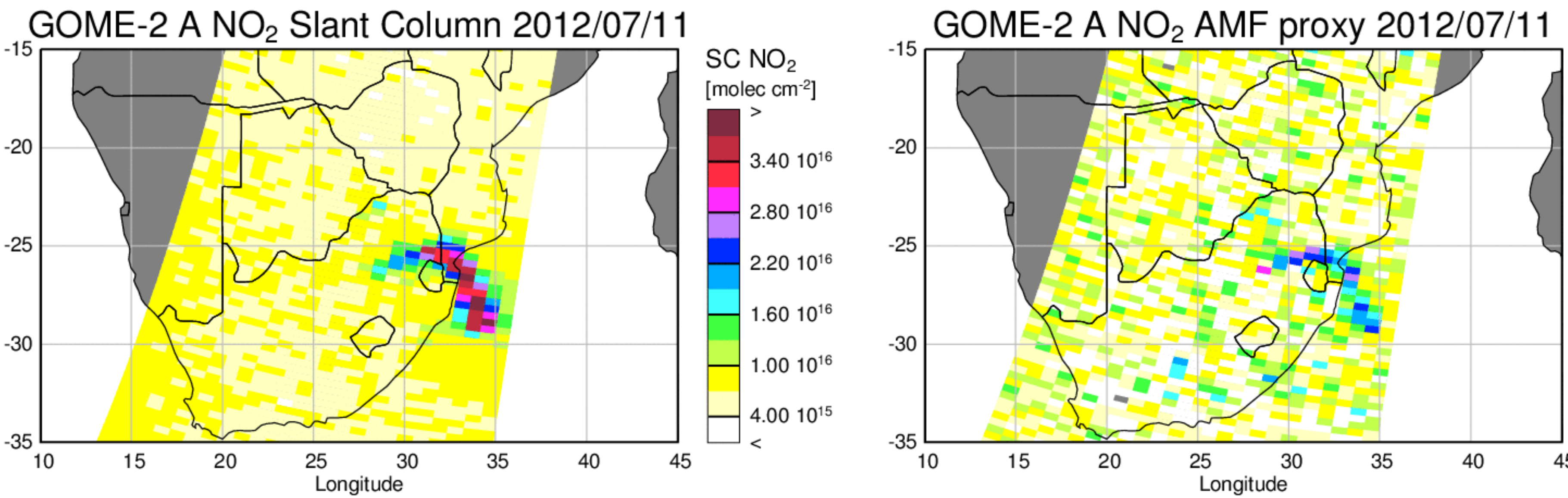


- Increasing albedo reduces effect as expected for reduced importance of Rayleigh scattering
- For large albedo (> 50%), negative fit factors are found for AMF proxy => wavelength dependence is inverted and only weakly dependent on altitude

⇒ multiple scattering over bright surfaces is stronger at shorter wavelengths

⇒ wavelength dependence of AMF is inverted

$NO_2(\lambda)$ / NO_2: Case Study Highveld: **GOME-2**



- NO_2 plume from Highveld power plants can be tracked onto the ocean
- NO_2 SC values increase downwind of the source
- AMF Proxy also has higher values within the plume, but
  - Is more narrow
  - Has largest values at beginning of plume, not at the end of it

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Summary

- At large NO_2 values (> 5 x 10^{16} molec cm^{-2}), AMF becomes a clear function of NO_2 column which needs to be corrected (> 10% effect)
- The effect increases with large SZA and low surface albedo
- A simple correction can be applied using tabulated factors

- At large BL NO_2 values, the wavelength dependence of the NO_2 AMF becomes relevant in the fit
- A simple empirical correction can be used to account for the AMF change
- At large NO_2 columns, the effect can be used to derive some information on NO_2 layer height

- All effects of large NO_2 values are expected to increase in frequency for instruments having better spatial resolution (S5P, S4)

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