BIRA's aerosol and NO_2 retrievals

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The retrieval algorithm

Forward model

Calculate radiances and O_4 and NO_2 DSCD @ different wavelengths and viewing geometries for a given atmosphere.

Linearized radiative transfer code (LIDORT v3.3) *(R. Spurr, 2007)*

INPUTS: - *P, T*
- *Surface albedo*
- *Trace gases (σ,ρ)*
- *Aerosol (extinction profile single scattering albedo phase function)*

Advantage of LIDORT : analytical calculation of weighting functions

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Aerosol inversion

- Optimal Estimation method *(Rodgers, 2000)*

$$k_{i+1} = k_i + (S_a^{-1} + K_i^T S_\varepsilon^{-1} K_i)^{-1} [K_i^T S_\varepsilon^{-1} (y - F(k_i)) - S_a^{-1} (k_i - k_a)]$$

k = aerosol extinction vertical profile

k_a= apriori aerosol extinction vertical profile
S_a = uncertainty covariance matrix of the apriori profile

F = Forward model (LIDORT)
y = measurement (O_4 DSCD and/or DI)
S_ε = uncertainty covariance matrix of the measurement

K = weighting functions = **∂y/∂k**

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NO_2 inversion

- **Optimal Estimation method** ***(Rodgers, 2000)***

$$k = k_a + (S_a^{-1} + K^T S_\varepsilon^{-1} K)^{-1} K^T S_\varepsilon^{-1} (y - K k_a)$$

k = NO_2 vertical profile

k_a= apriori NO_2 vertical profile

S_a = uncertainty covariance matrix of the apriori profile

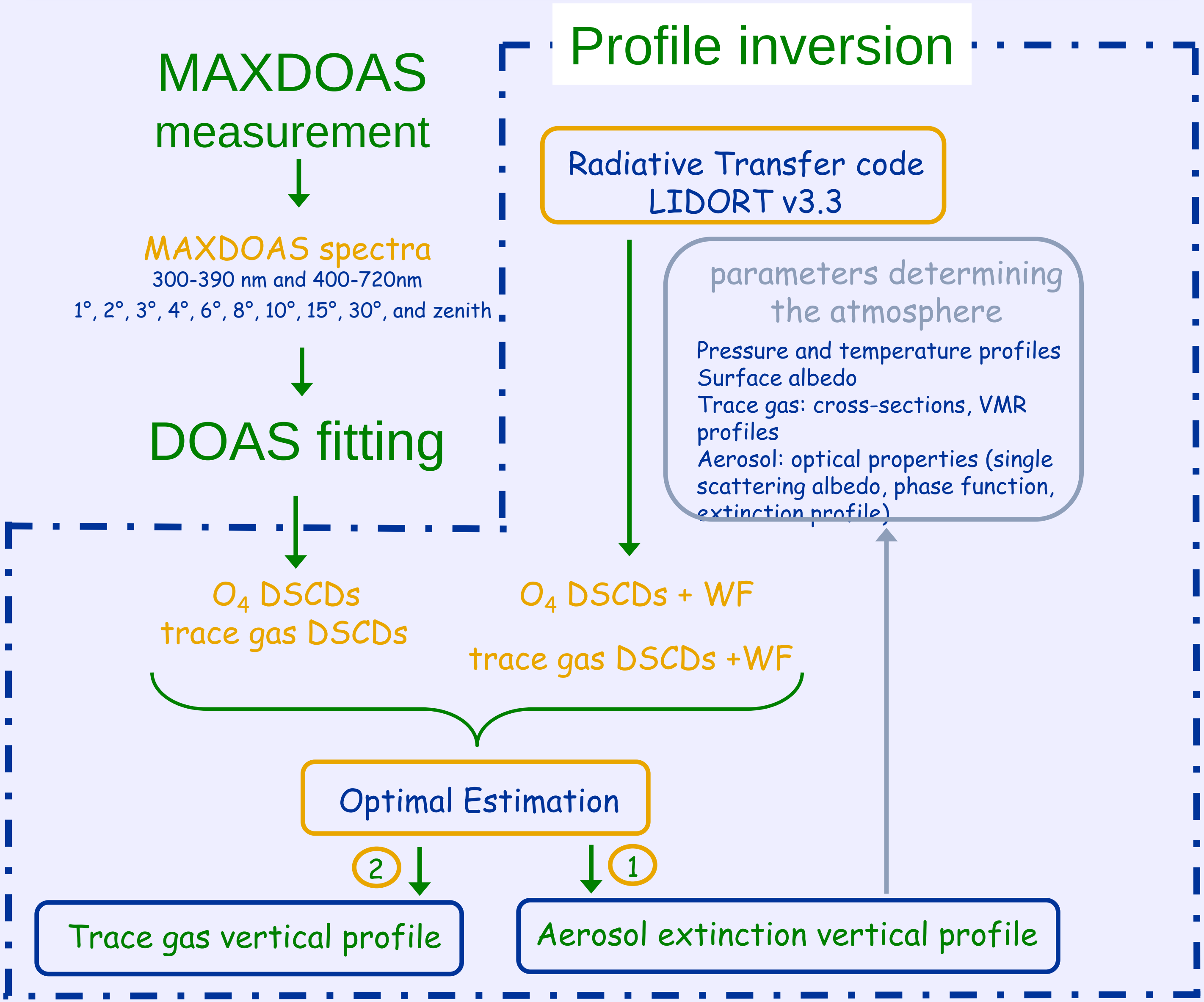
F = Forward model (LIDORT)

y = measurement (NO_2 DSCD)

S_ε = uncertainty covariance matrix of the measurement

K = weighting functions = $\partial y / \partial k$

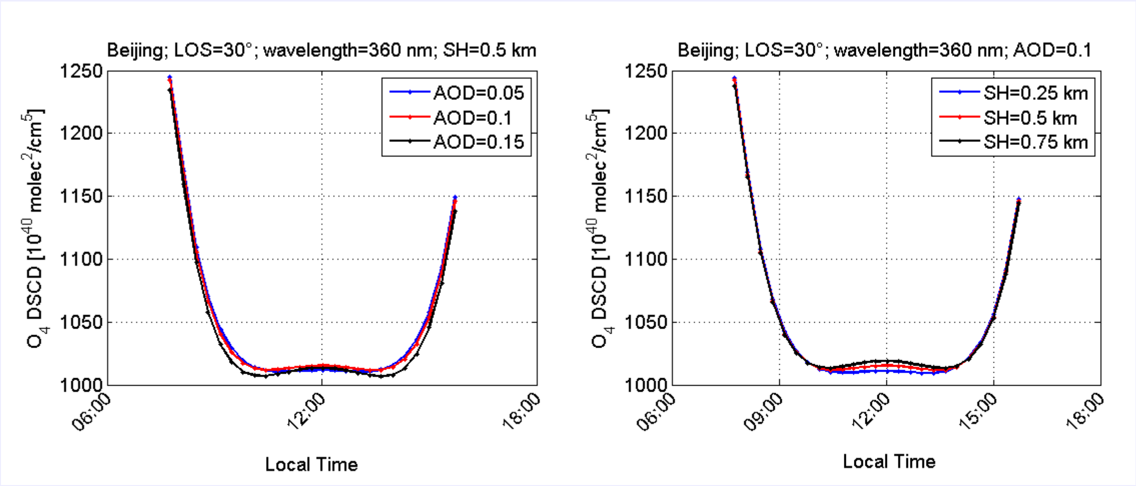
Flowchart


MAXDOAS
measurement
MAXDOAS spectra
300-390 nm and 400-720nm
1°, 2°, 3°, 4°, 6°, 8°, 10°, 15°, 30°, and zenith
DOAS fitting
Profile inversion
Radiative Transfer code
LIDORT v3.3
parameters determining the atmosphere
Pressure and temperature profiles
Surface albedo
Trace gas: cross-sections, VMR profiles
Aerosol: optical properties (single scattering albedo, phase function, extinction profile)
O4 DSCDs
trace gas DSCDs
O4 DSCDs + WF
trace gas DSCDs +WF
Optimal Estimation
2
1
Trace gas vertical profile
Aerosol extinction vertical profile

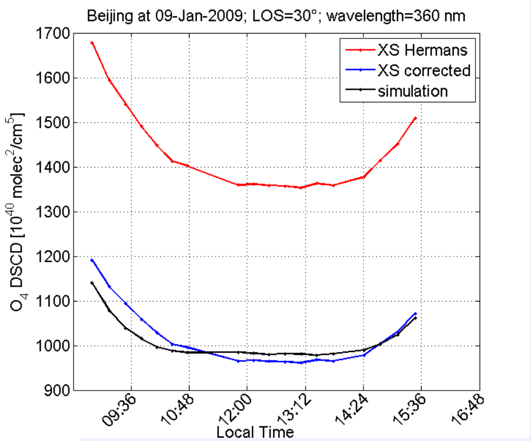
BIRA settings: O_4 xs

Based on the Beijing dataset

Case: 30° elevation , pointing north, clear-sky , AOD<0.15



Measured and simulated O_4 DSCD should be equal



But

sim. O_4 DSCDs = meas. O_4 DSCDs * 0.8±0.1

BIRA settings

FORWARD MODEL

- P,T: Radio sondes
- surface albedo: lambertian = 0.07
- O_3 US standard profiles

- Single scattering albedo and phase function calculated using a Mie routine and inputs from the AERONET.

OPTIMAL ESTIMATION

- O_4 DSCD * 0.75
- O_4 apriori: exponential profile; 1 km scaling height; AOD=0.05
- Sε: diagonal, (DSCD error)^2
- S_a: see next slide
- Only retrieve 4 km.
- non-linear equation for optimal estimation

- NO_2 DSCD
- apriori: NO_2 apriori: US standard + 0.25 ppb in the lowest layer, 0.05 ppb at 4 km and a linear decrease in between.
- Sε: diagonal, (DSCD error)^2
- S_a: see next slide
- Only retrieve 4 km.
- Linear equation for OE

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BIRA settings: S_a

Aerosol:

- S_a changes each iteration
- Lowest layer: $S_a(1,1)=(\text{factor}*\text{maximum}(\mathbf{x}_i))^2$
- At 4 km: $S_a(n,n)=0.2*S_a(1,1)$
- In between a linear decrease with altitude
- Off-diagonal elements were set using Gaussian correlation functions with a correlation length of 0.05km.

NO_2:

- $S_a=(\text{factor}*\text{apriori})^2$
- Correlation length = 0.2 km

Factor:

- For aerosol and NO_2 retrieval the factor making up the S_a is chosen to have a mean DFS of ~2.
- Factor aerosol = 0.1 for BIRA and Bremen data
- Factor NO_2 = 0.8 for BIRA data
- = 0.3 for Bremen data

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Results: aerosol

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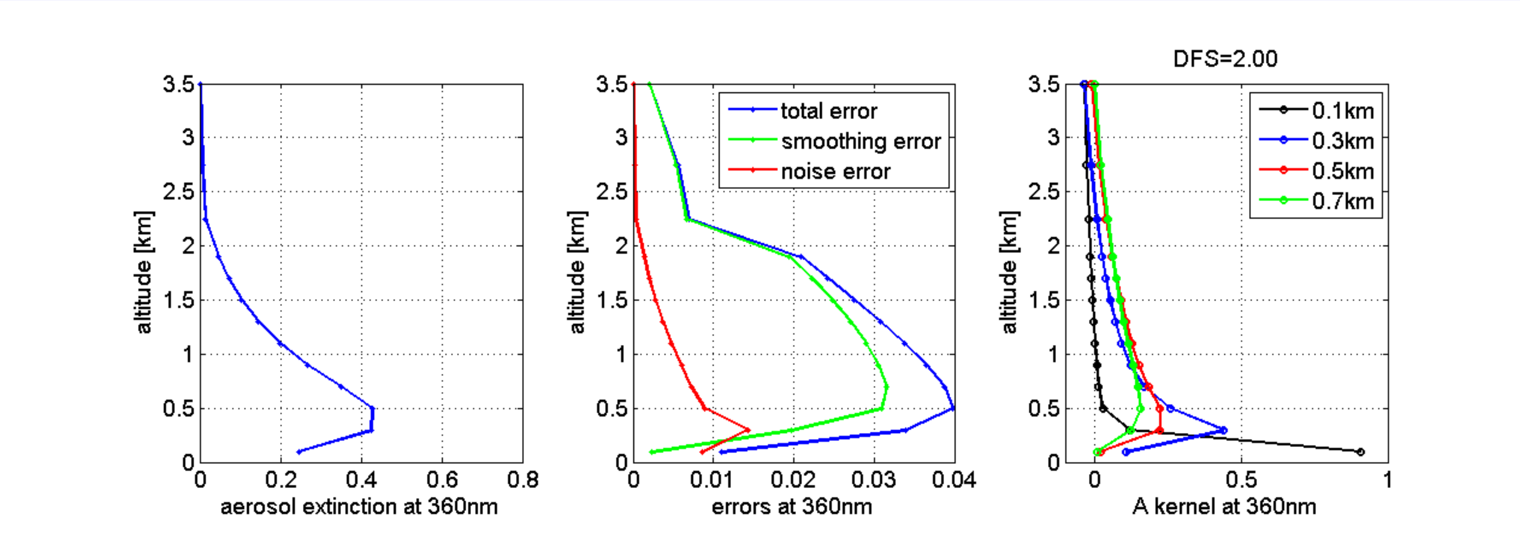
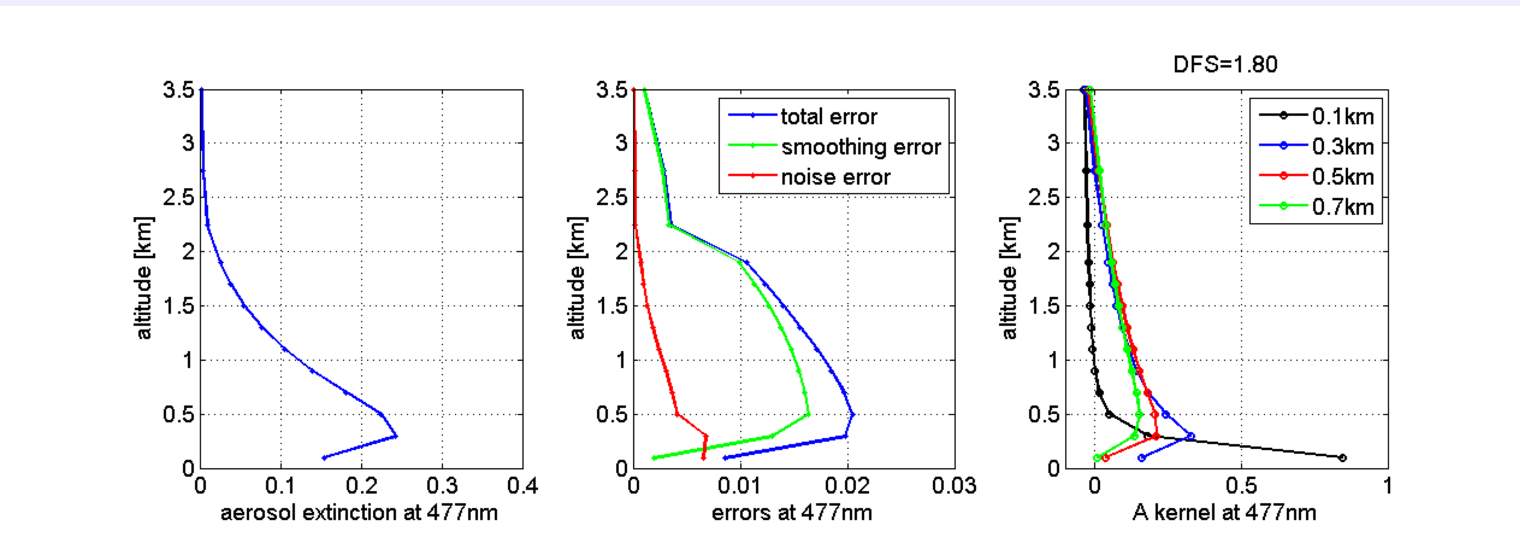
Results: Aerosol

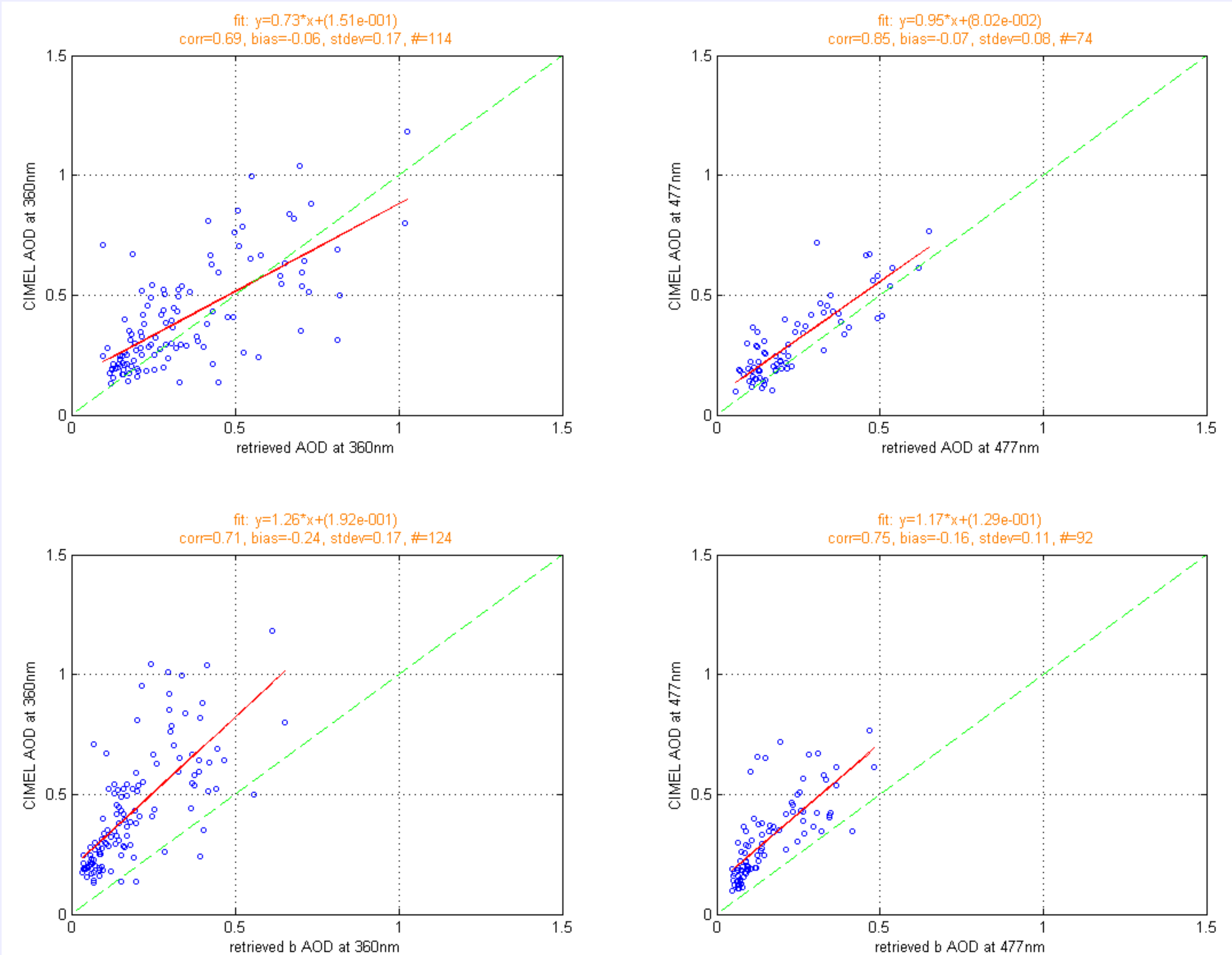




AOD

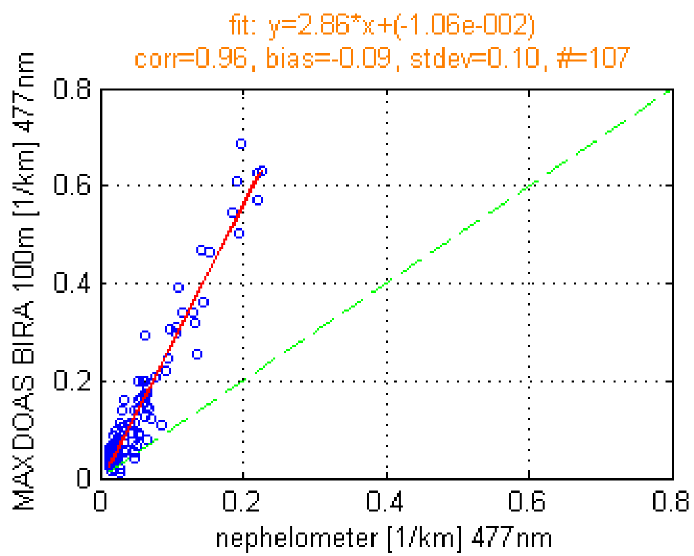
xs/0.75

xs/1.0

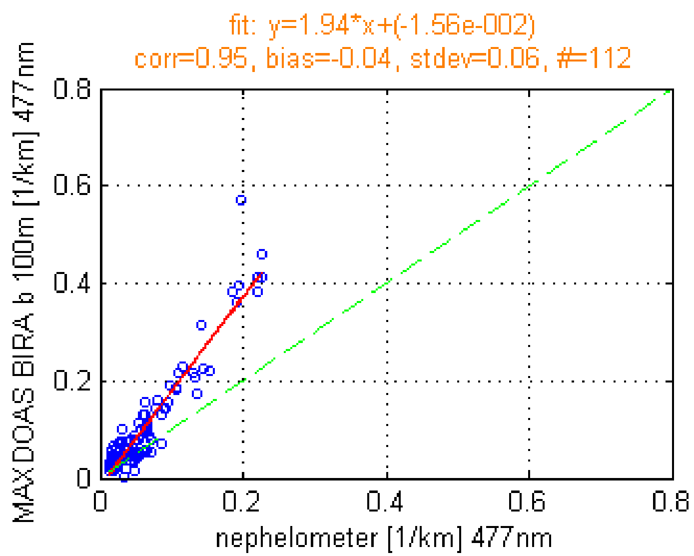


aerosol surface extinction

xs/0.75

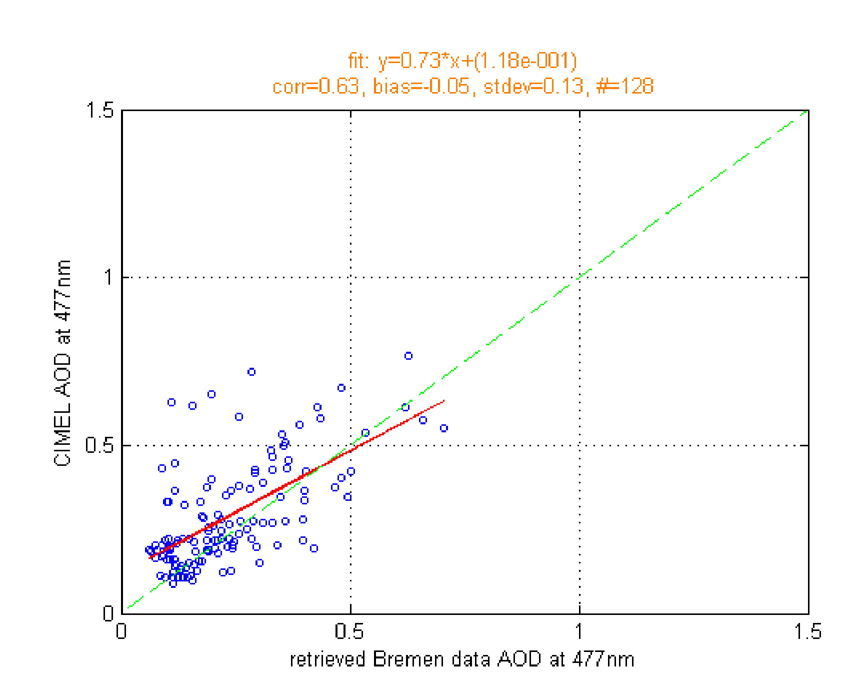


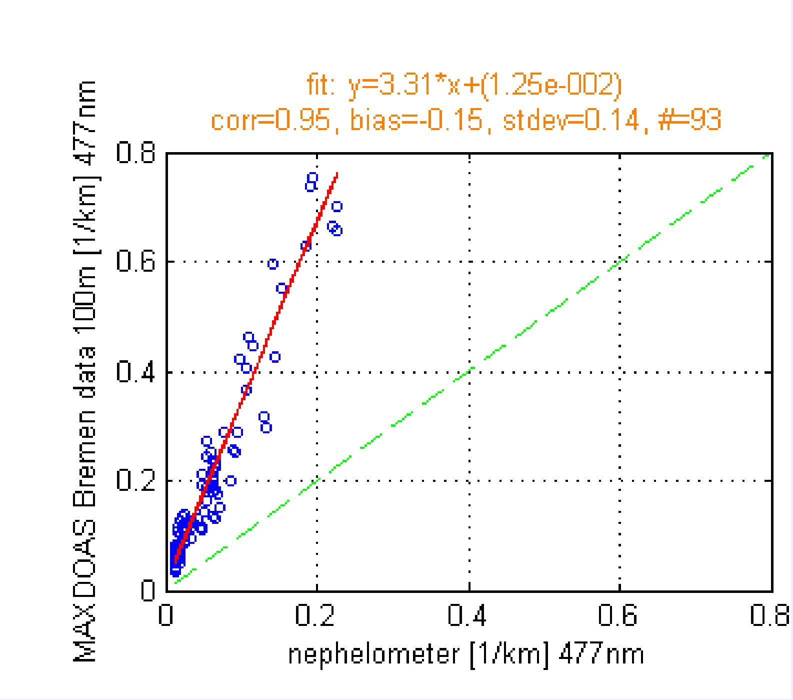
xs/1.0



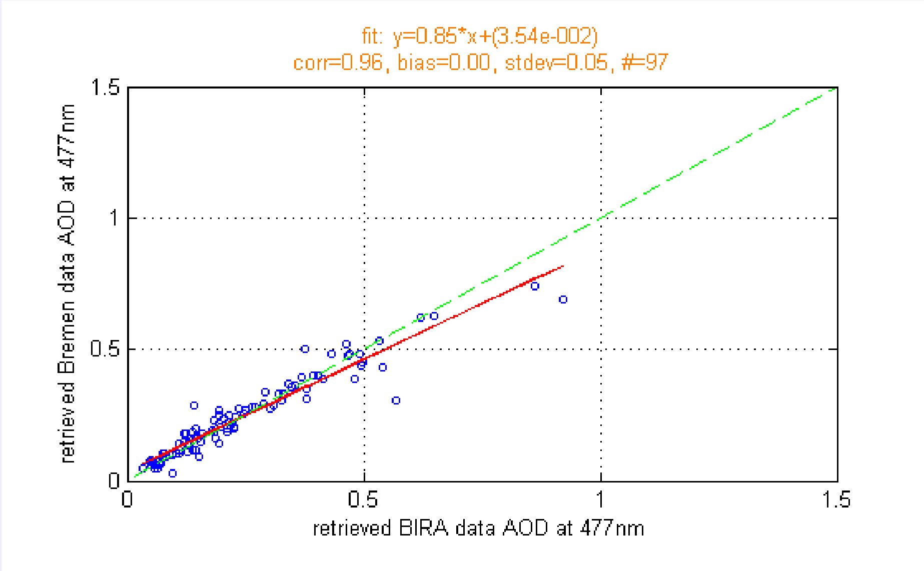
Paul Zieger; PSI Switzerland

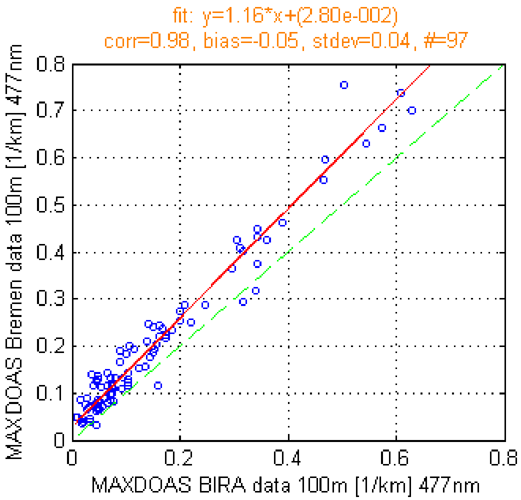
aerosol: Bremen data

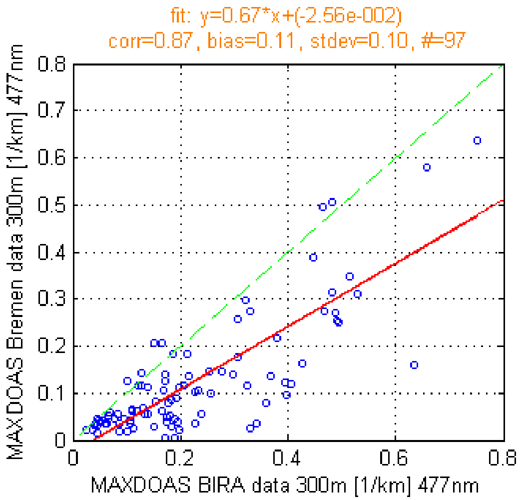


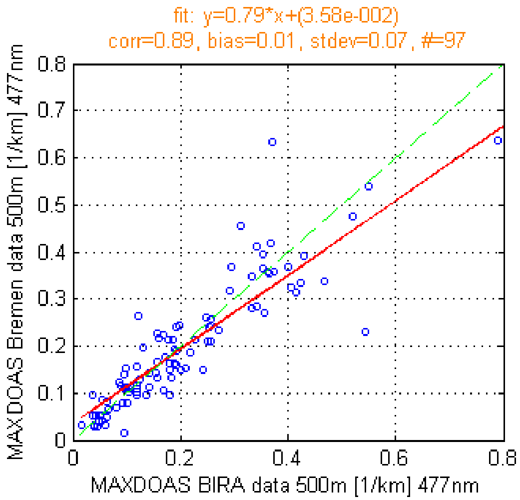


aerosol: compare









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Results: NO_2

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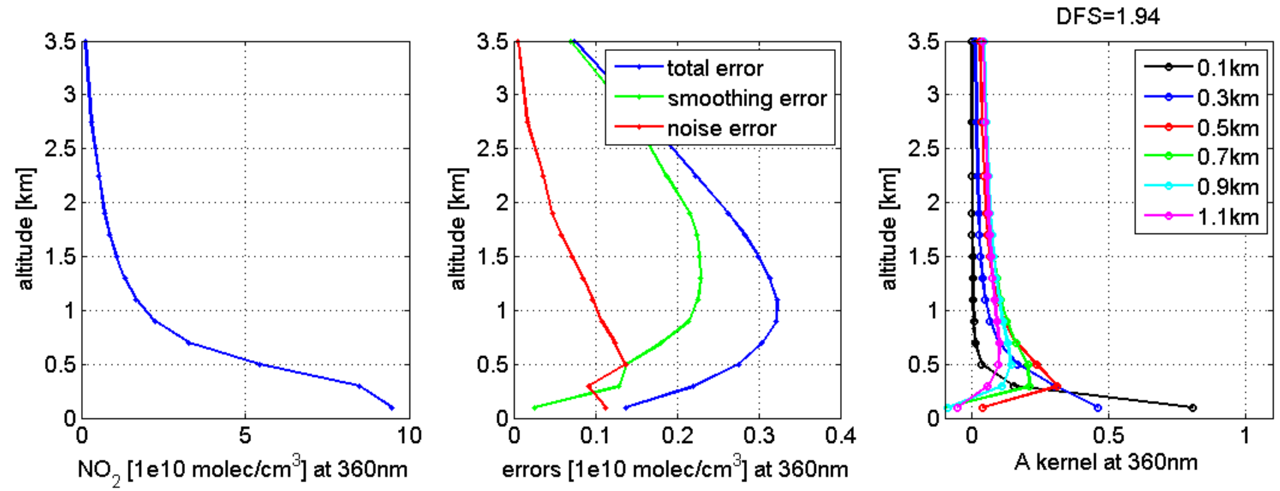
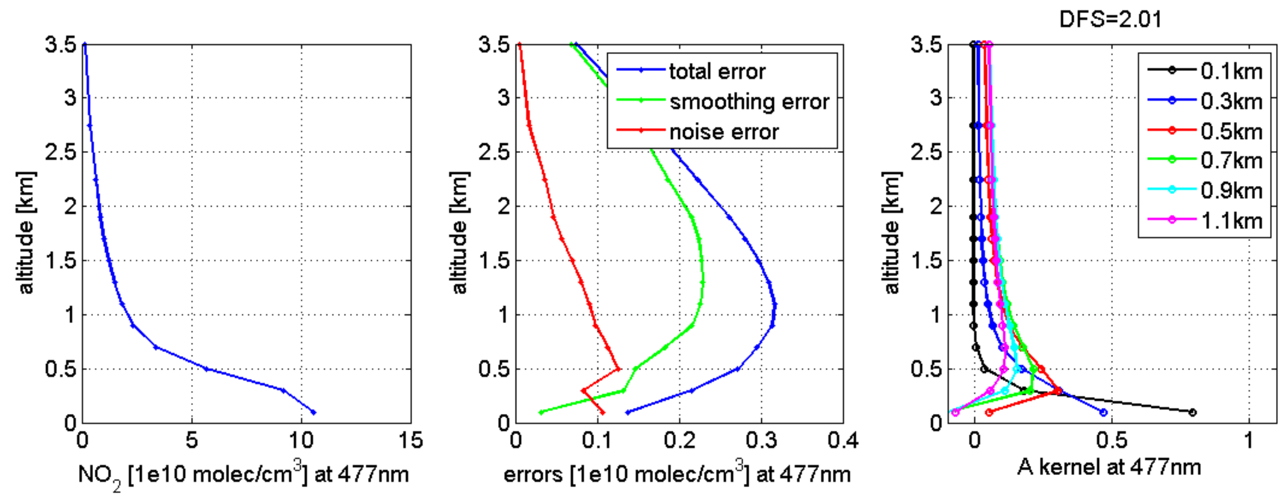
Results: NO_2



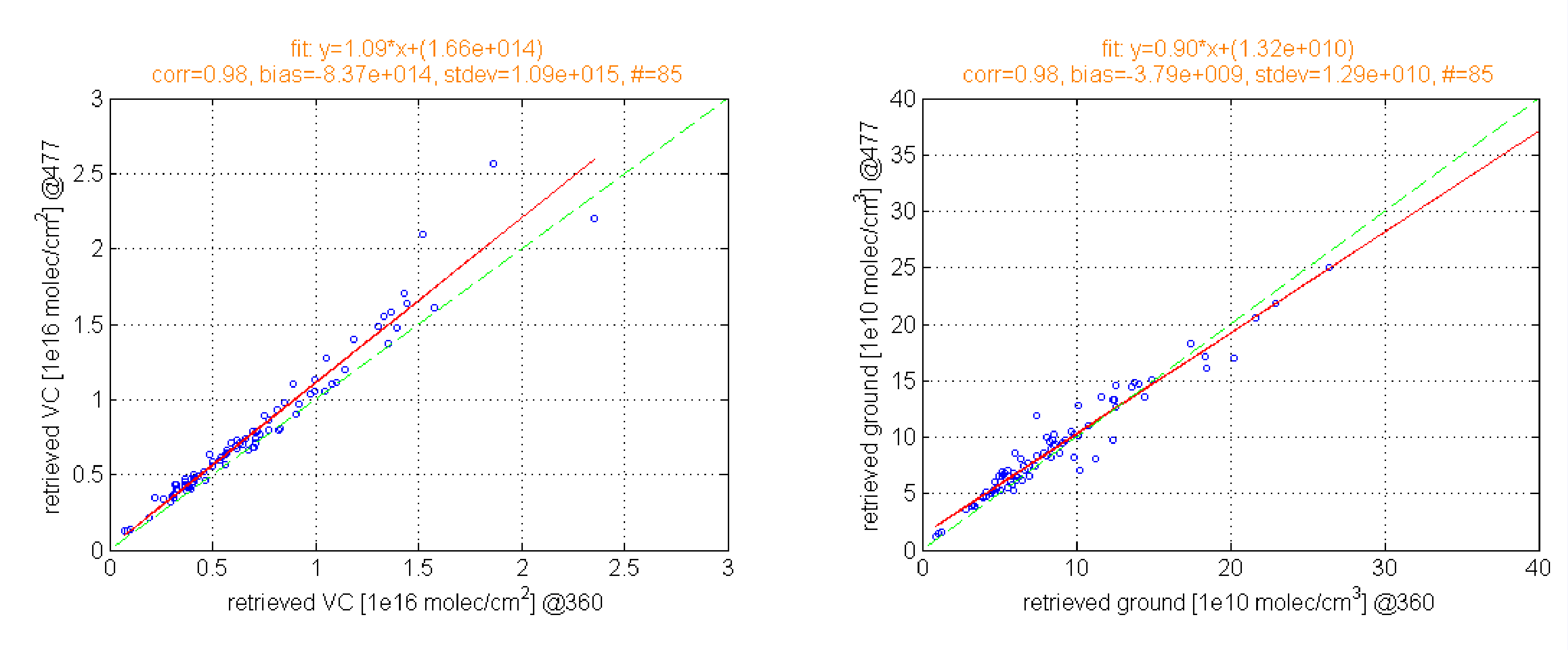
DFS=1.94
altitude [km]
NO2 [1e10 molec/cm3] at 360nm
total error
smoothing error
noise error
errors [1e10 molec/cm3] at 360nm
0.1km
0.3km
0.5km
0.7km
0.9km
1.1km
A kernel at 360nm



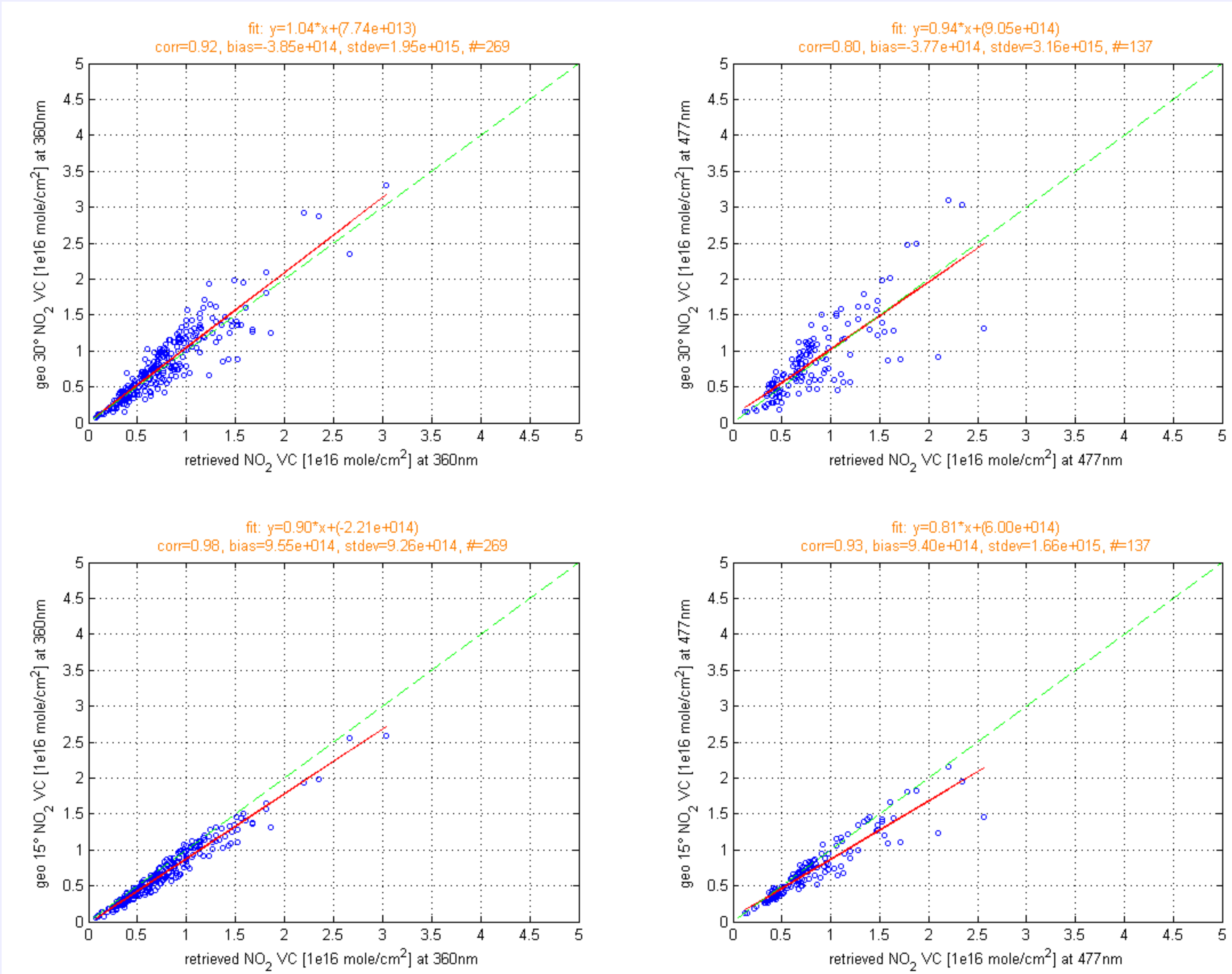
DFS=2.01
altitude [km]
NO2 [1e10 molec/cm3] at 477nm
total error
smoothing error
noise error
errors [1e10 molec/cm3] at 477nm
0.1km
0.3km
0.5km
0.7km
0.9km
1.1km
A kernel at 477nm

NO_2 VC and surface concentration

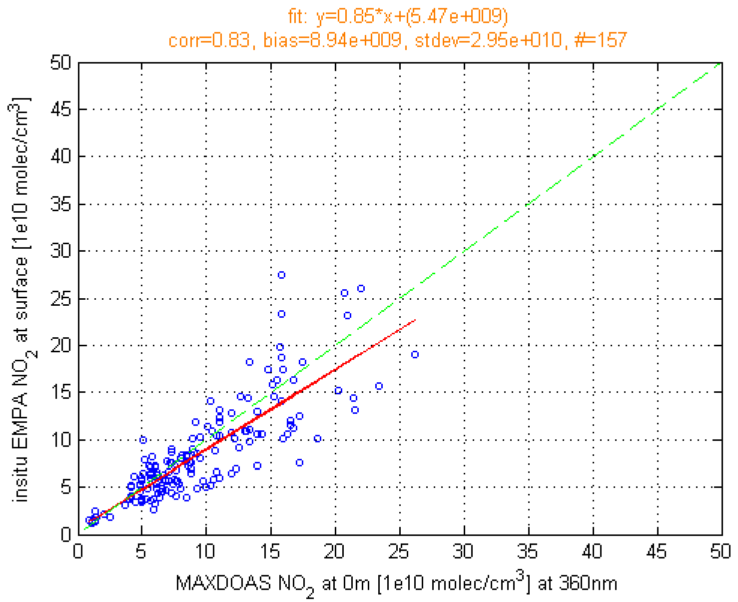
360 vs 477 nm

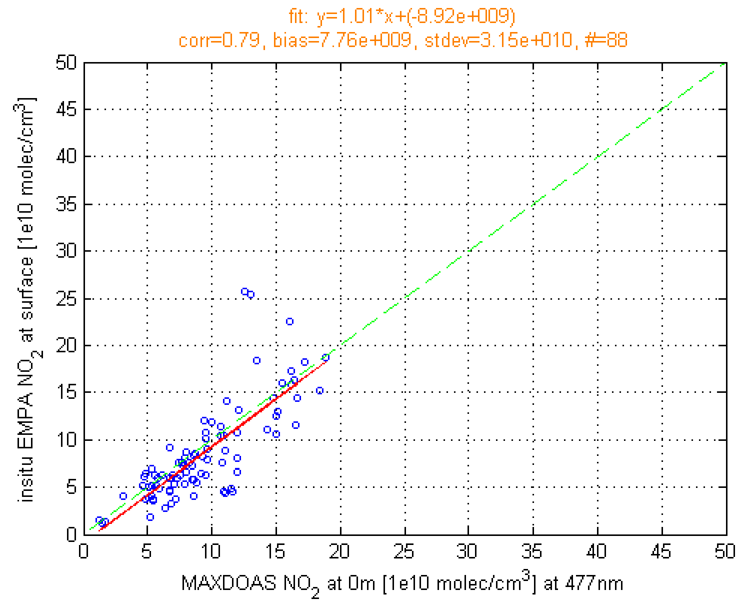


VC NO_2


fit: y=1.04*x+(7.74e+013)
corr=0.92, bias=-3.85e+014, stdev=1.95e+015, #=269
geo 30° NO2 VC [1e16 mole/cm2] at 360nm
retrieved NO2 VC [1e16 mole/cm2] at 360nm
fit: y=0.94*x+(9.05e+014)
corr=0.80, bias=-3.77e+014, stdev=3.16e+015, #=137
geo 30° NO2 VC [1e16 mole/cm2] at 477nm
retrieved NO2 VC [1e16 mole/cm2] at 477nm
fit: y=0.90*x+(-2.21e+014)
corr=0.98, bias=9.55e+014, stdev=9.26e+014, #=269
geo 15° NO2 VC [1e16 mole/cm2] at 360nm
retrieved NO2 VC [1e16 mole/cm2] at 360nm
fit: y=0.81*x+(6.00e+014)
corr=0.93, bias=9.40e+014, stdev=1.66e+015, #=137
geo 15° NO2 VC [1e16 mole/cm2] at 477nm
retrieved NO2 VC [1e16 mole/cm2] at 477nm

NO_2 surface concentration





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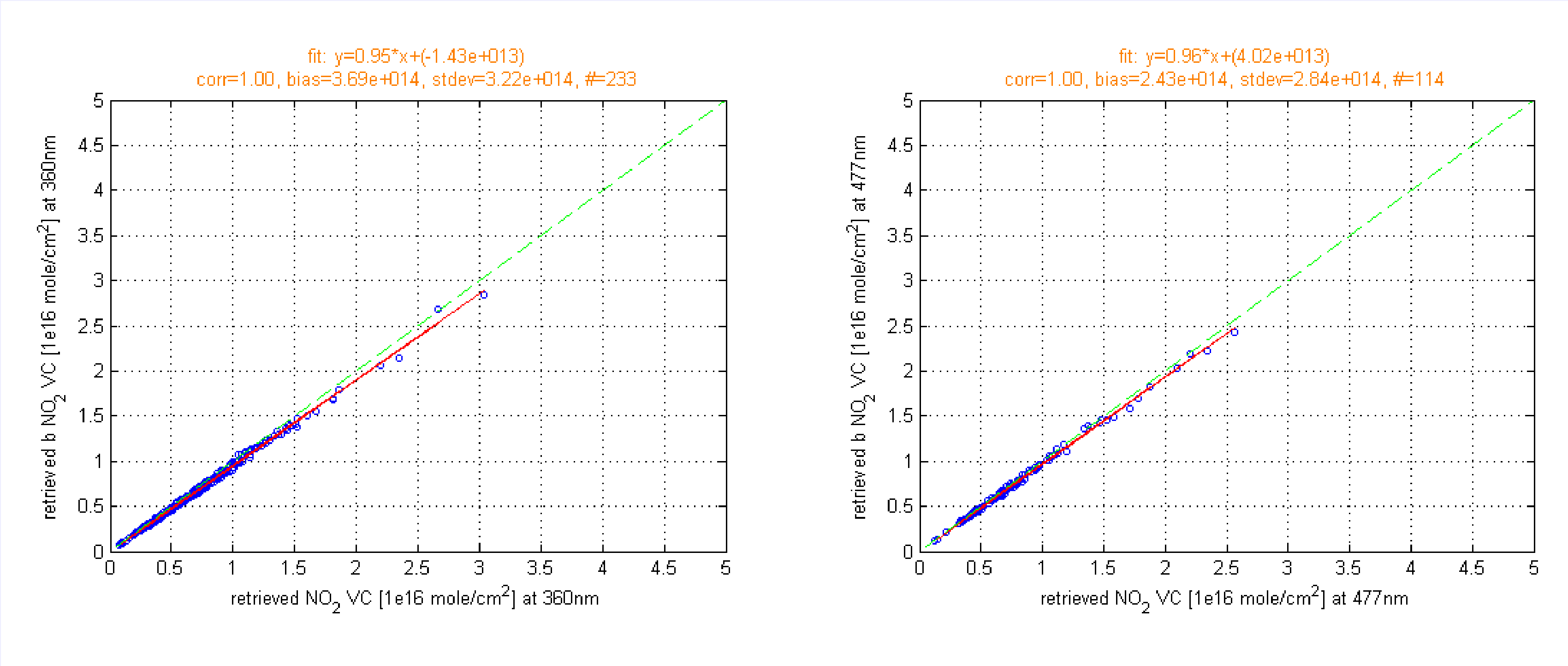
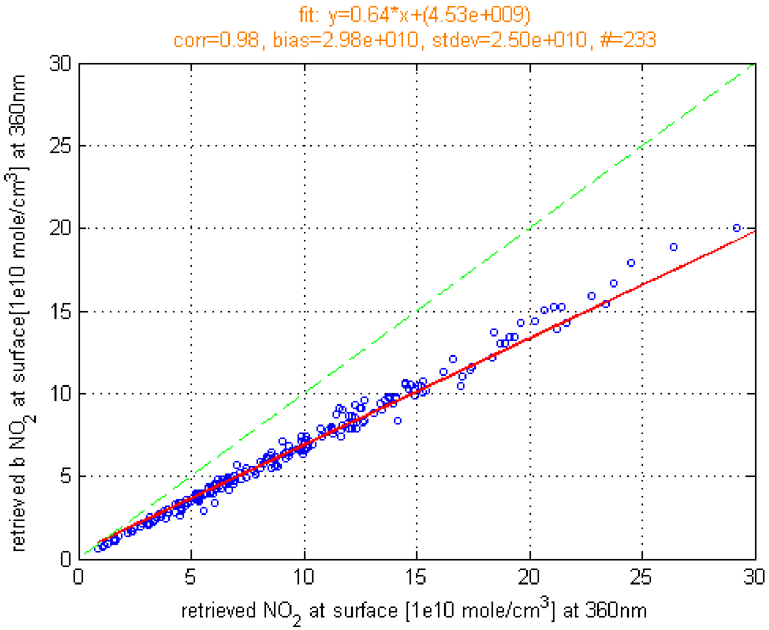
NO_2 VC

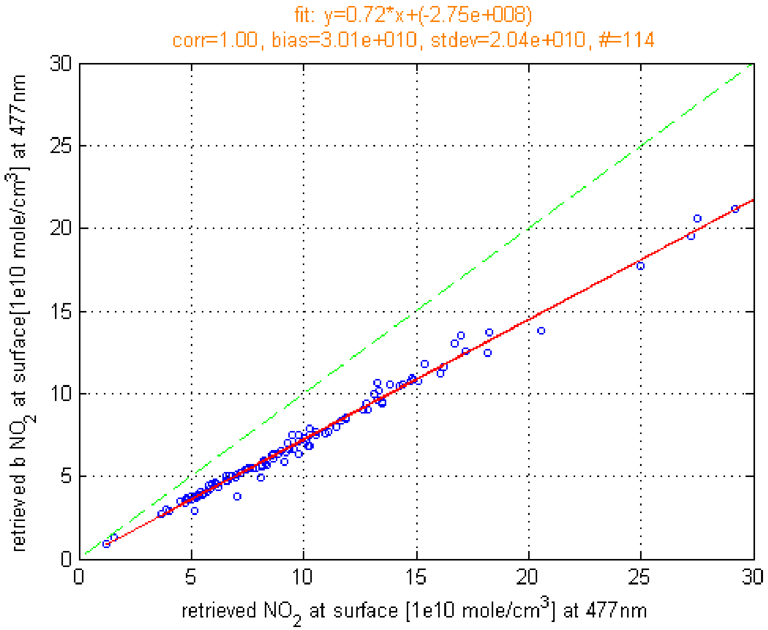
aerosol impact



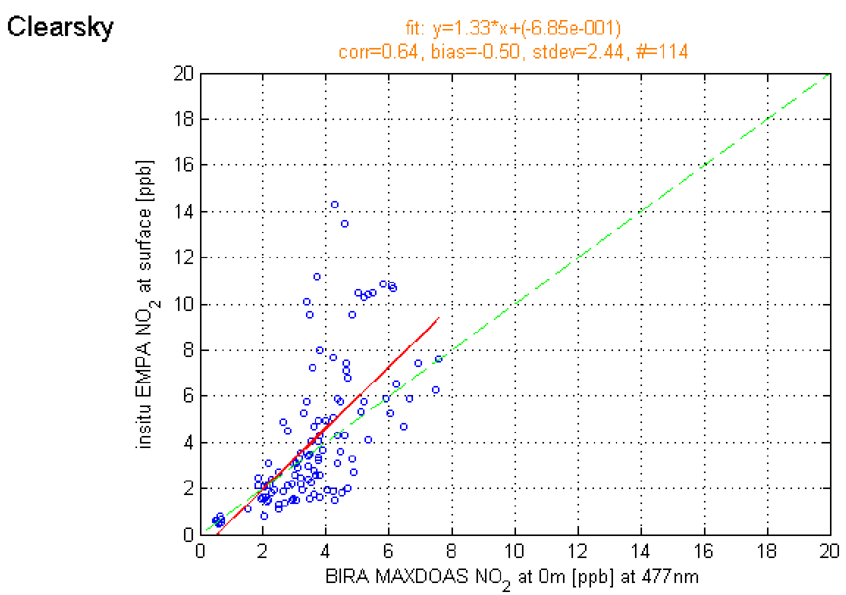
NO_2 surface concentration

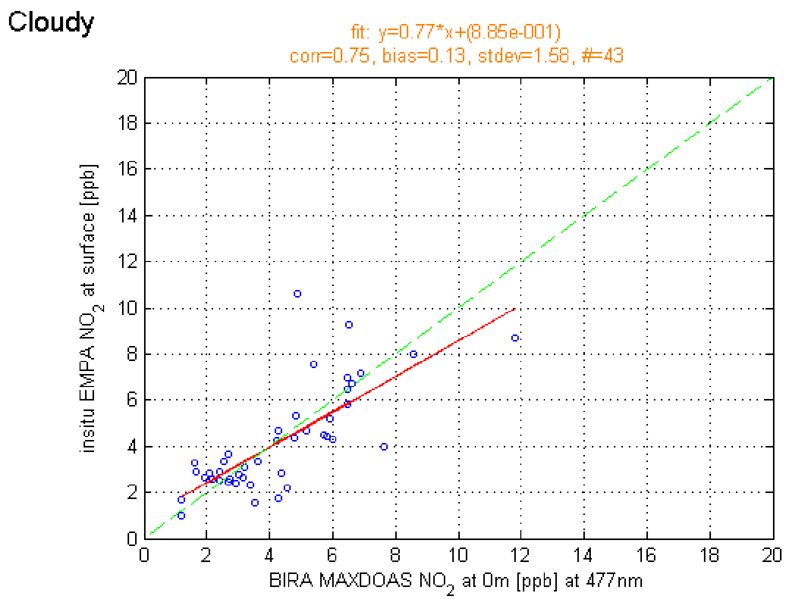
aerosol impact



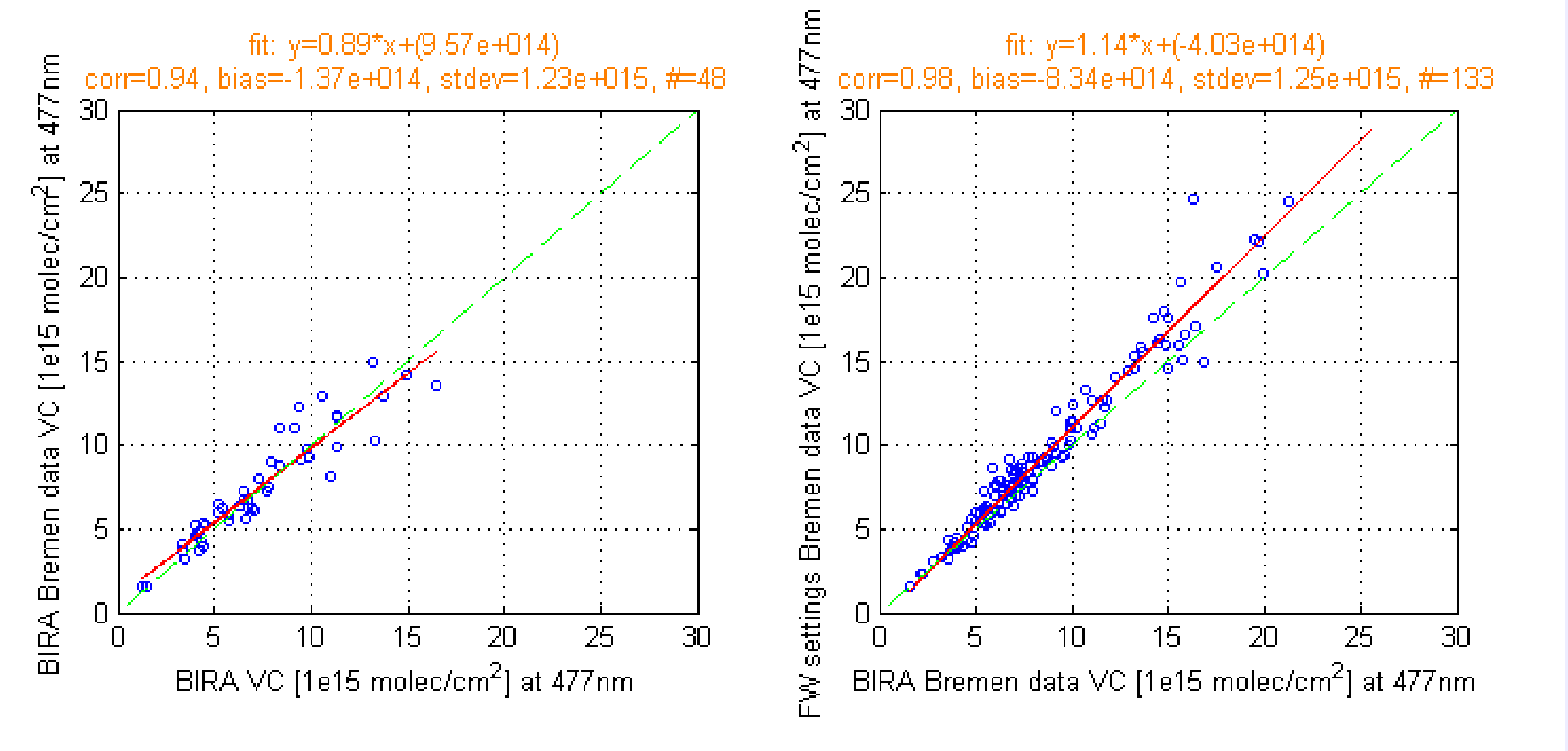


NO_2 surface concentration





Results: NO_2



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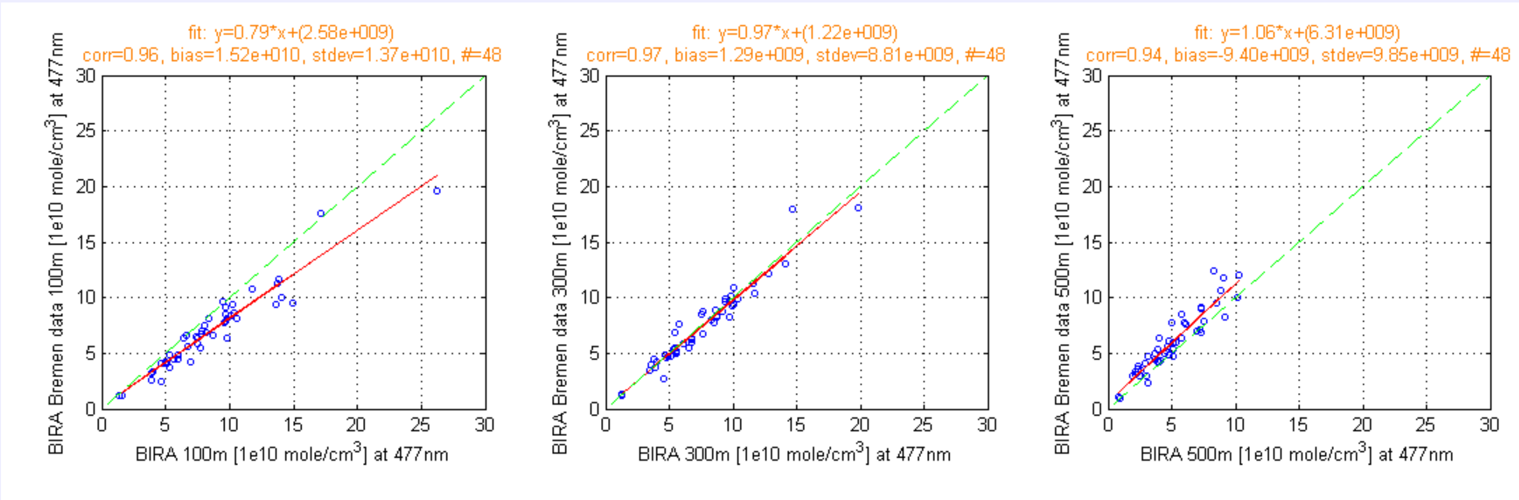
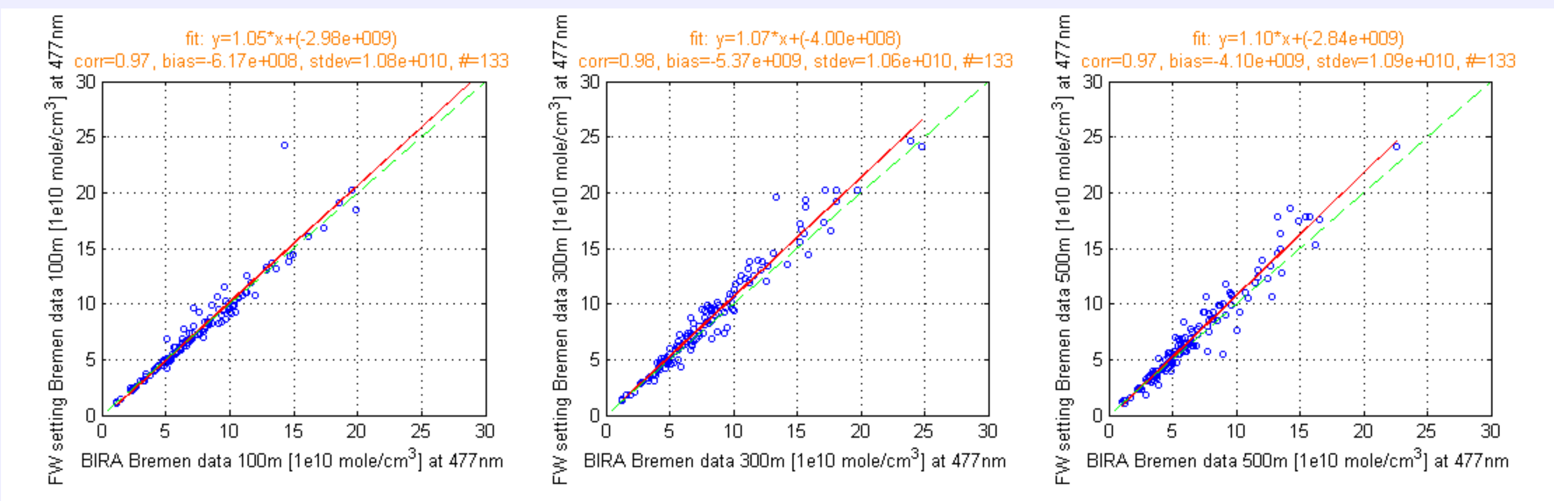
Results: NO_2

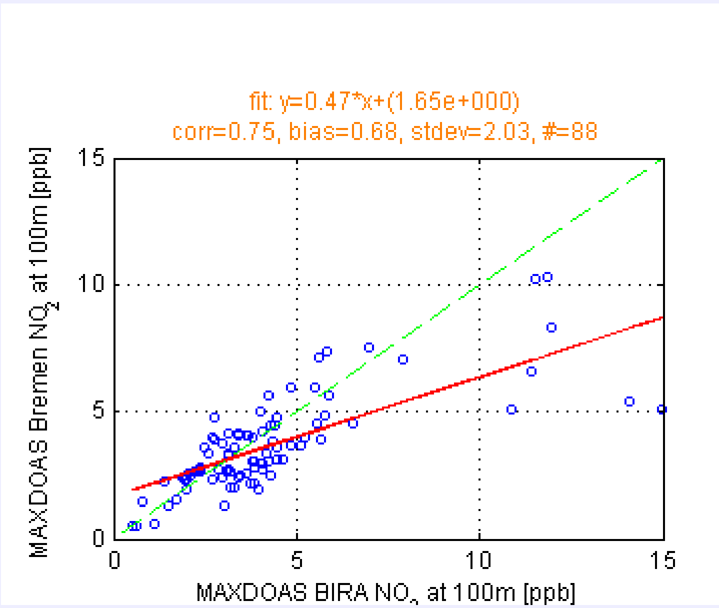


fit: y=0.79*x+(2.58e+009)
corr=0.96, bias=1.52e+010, stdev=1.37e+010, #=48
BIRA Bremen data 100m [1e10 mole/cm3] at 477nm
BIRA 100m [1e10 mole/cm3] at 477nm
fit: y=0.97*x+(1.22e+009)
corr=0.97, bias=1.29e+009, stdev=8.81e+009, #=48
BIRA Bremen data 300m [1e10 mole/cm3] at 477nm
BIRA 300m [1e10 mole/cm3] at 477nm
fit: y=1.06*x+(6.31e+009)
corr=0.94, bias=-9.40e+009, stdev=9.85e+009, #=48
BIRA Bremen data 500m [1e10 mole/cm3] at 477nm
BIRA 500m [1e10 mole/cm3] at 477nm

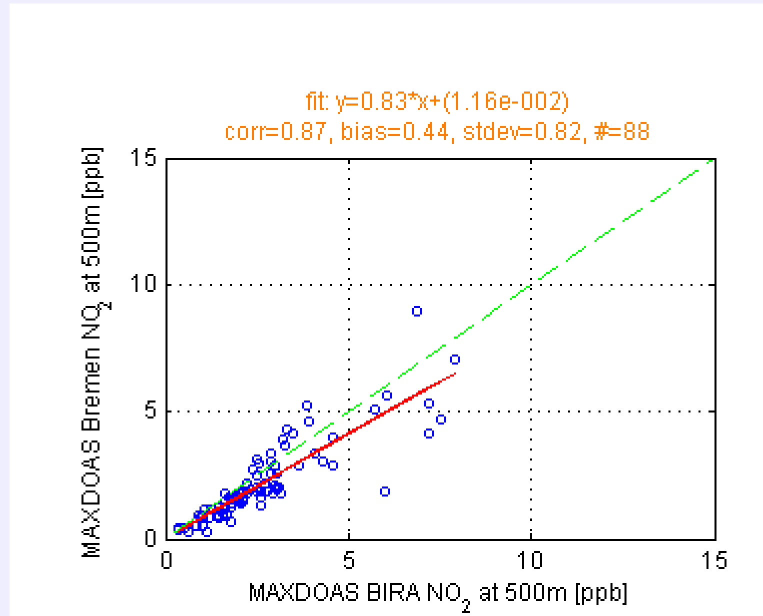


fit: y=1.05*x+(-2.98e+009)
corr=0.97, bias=-6.17e+008, stdev=1.08e+010, #=133
FW setting Bremen data 100m [1e10 mole/cm3] at 477nm
BIRA Bremen data 100m [1e10 mole/cm3] at 477nm
fit: y=1.07*x+(-4.00e+008)
corr=0.98, bias=-5.37e+009, stdev=1.06e+010, #=133
FW setting Bremen data 300m [1e10 mole/cm3] at 477nm
BIRA Bremen data 300m [1e10 mole/cm3] at 477nm
fit: y=1.10*x+(-2.84e+009)
corr=0.97, bias=-4.10e+009, stdev=1.09e+010, #=133
FW setting Bremen data 500m [1e10 mole/cm3] at 477nm
BIRA Bremen data 500m [1e10 mole/cm3] at 477nm

Results: NO_2



fit: y=0.47*x+(1.65e+000)
corr=0.75, bias=0.68, stdev=2.03, #=88
MAXDOAS Bremen NO2 at 100m [ppb]
MAXDOAS BIRA NO2 at 100m [ppb]



fit: y=0.83*x+(1.16e-002)
corr=0.87, bias=0.44, stdev=0.82, #=88
MAXDOAS Bremen NO2 at 500m [ppb]
MAXDOAS BIRA NO2 at 500m [ppb]

Summary

Summary

- Retrieval based on LIDORT and OE.
- Correction factor for O_4 cross section xs=xs/0.75.
- S_a for aerosol retrieval changes each iteration.
- S_a tuned so that the DFS~2.

- Aerosol have substantial influence on NO_2 profile shape.

- It all looks quite promising.

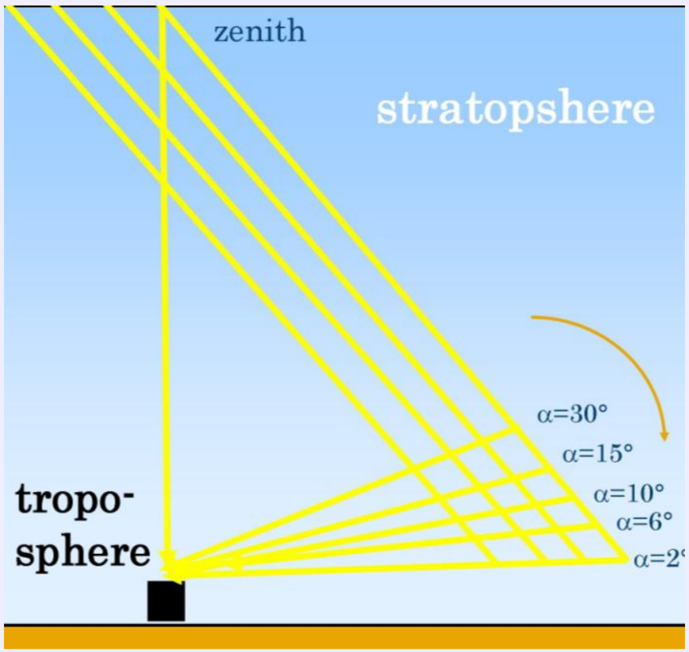
Results: NO_2

MAXDOAS measurement

Multi-AXis Differential Optical Absorption Spectroscopy

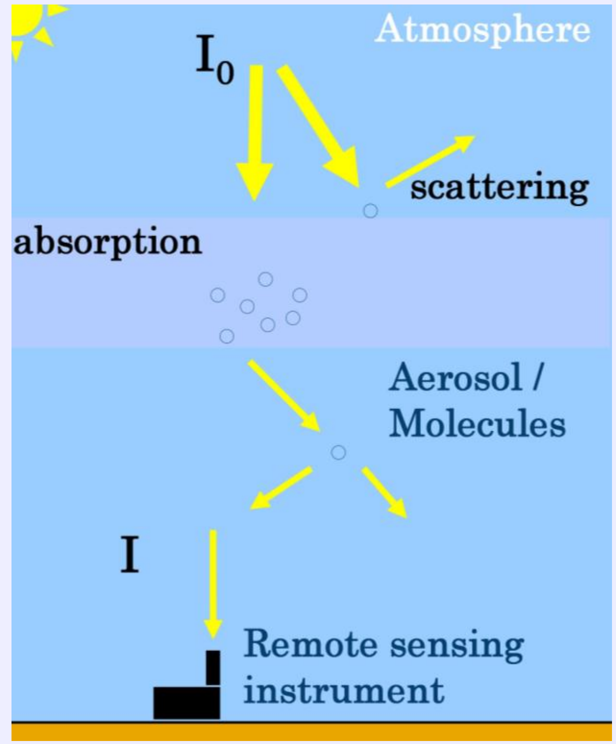
MAX

multiple elevation angles from zenith to horizon



- ❑ Increased sensitivity towards atmospheric absorbers present close to the surface
- ❑ eliminate strato. contr.

DOAS



- ❑ Use high frequency differential absorption structures to identify absorbers and quantify their abundance

MAXDOAS measurement

$$SCD = \int_0^L \rho(s)ds$$

Vertical distribution of the gas ρ

Light path

Aerosol (O_4)

- Provides information on the vertical distribution of gases and aerosol in the troposphere.

UV-VIS Channels