Relationship between satellite-observed active fires and tropospheric NO_2

Stefan F. Schreier, Andreas Richter, Anja Schönhardt and John P. Burrows

Institute of Environmental Physics/Remote Sensing, University of Bremen,
FB 1, P.O. Box 330440, D-28334 Bremen, Germany
Email: schreier@iup.physik.uni-bremen.de

1. NO_x emissions from biomass burning

Nitrogen oxides (NO_x = NO + NO_2) originate from a large number of anthropogenic and natural sources with the latter including the burning of biomass (living and dead vegetation).

During the combustion process, nitrogen (N) present in the biomass and in amino acids is converted to NO_x and mainly to NO, respectively. Further, NO_x may also result from the reaction of dissociated oxygen (O) with nitrogen (N_2) in the air at very high temperatures. These released chemical compounds play a role in many chemical reactions including the production of ozone (O_3).

The exposure to biomass burning related air pollution has impacts on the public health. However, there still exist large uncertainties about the exact amount of biomass burning emissions arising especially from the various approaches ("bottom-up" versus "top-down").

It is expected that with the ongoing trend of global warming and its feedback mechanisms, the frequency and intensity of fires will increase in many parts of the world, especially at higher latitudes inside of continents.

2. SCIAMACHY and MODIS

SCIAMACHY *on-board ENVISAT was launched in a sun-synchronous polar orbit in March 2002. It was designed for a wavelength region between 240-2380 nm at a moderate resolution of 0.2-1.5 nm with spatial resolution being 60 x 30 km². Local equatorial overpass time: ~10:00 a.m. The retrieval of atmospheric NO_2 is based on the Differential Optical Absorption Spectroscopy (DOAS) using the fitting window 425-450 nm. The stratospheric slant columns are removed by subtracting total NO_2 columns from a 'clean' region (180-220° longitude). Here, only pixels with cloud fraction < 0.2 are considered (FRESCO algorithm). Finally, tropospheric slant columns are converted into vertical columns by applying monthly airmass factors (MOZART model).*

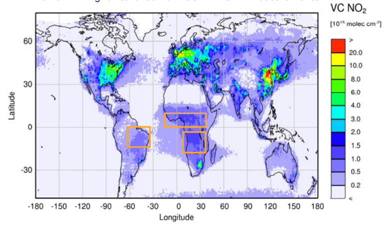
MODIS *on-board Terra was launched in a sun-synchronous near-polar orbit in December 1999. It was designed for collecting land surface products (e.g. fire) and provided with 36 spectral bands ranging in wavelength from 0.4-14.4 µm. Local equatorial overpass time: ~10:30 a.m. The differences in 4- and 11-µm blackbody radiation emitted at combustion temperatures are used to derive active fires at 1 km².*

5. Conclusions

- *Although NO_x emissions from biomass burning are relatively small in magnitude when compared to anthropogenic sources, they influence atmospheric chemistry in large parts of the world*
- *In some regions, the annual cycle of fire activity is reflected by the seasonal variability of tropospheric NO_2 to a high degree (r > 0.8)*
- *Increased wet season NO_2 levels over African regions may be attributed to higher emission rates of dominating savanna soils and agricultural lands*
- *Least-squares slopes and y-intercepts between fire counts and NO_2 columns show a heterogeneous distribution and could reflect spatial changes in vegetation and wet season NO_x sources, respectively*
- *The prediction of NO_2 columns was tested by using fire counts and coefficients of the 1 x 1° best fitting least-squares regression lines. It was shown that uncertainties decrease when spatially mean coefficients are applied*

3. Temporal correlation of fires and NO_2 columns

Fig.1: Global mean tropospheric NO_2 concentrations (2003-2010) on a 1 x 1° grid retrieved from SCIAMACHY measurements



NO_x emissions from biomass burning are about one order of magnitude smaller than emissions from industrialized parts of the world

Fire emissions occur in large regions, especially in the Tropics and Subtropics (Fig. 1)

SCIAMACHY NO_2 measurements and MODIS fire counts are used to analyze the empirical relationship between fire and NO_x emissions

NO_2 columns based on monthly means follow the seasonal pattern of fire activity

In the wet season, NO_2 is mainly emitted from other sources such as soil and lightning (Fig. 2)

Fig. 2: Temporal variability of tropospheric NO_2 (absolute) and cloud corrected fire counts (relative) for 2003-2010 over Africa north of the equator (left) [0° - 10°N, 15°W - 40°E], Africa south of the equator (middle) [20°S - 5°S, 10°E - 40°E] and South America (right) [15°S - 0°, 65°W - 35°E]

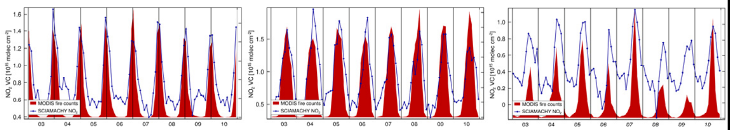
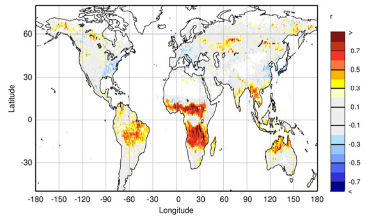


Fig. 3: Correlation coefficients describing the temporal relationship (2003-2010) between tropospheric NO_2 and fire counts (1 x 1°)



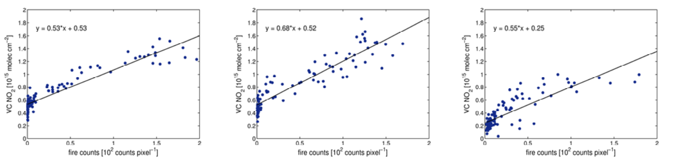
Correlation coefficients (r) between fire counts and NO_2 columns based on monthly means are highest in the African regions (> 0.85)

Temporal correlation is also observed in South-East Asia, Northern Australia and Boreal regions –> much less strong and widespread (Fig. 3)

Increased wet season NO_2 levels in the African regions –> higher emission rates of savanna soils dominating in the African regions when compared to tropical rain forests in the South American region?

Wet season NO_2 levels are reduced by two thirds when compared to the peak levels during the dry season (Fig. 4)

Fig. 4: Scatter plots and regression coefficients for tropospheric NO_2 and cloud corrected fire counts over Africa north of the equator (left), Africa south of the equator (middle) and South America (right) for 2003-2010. Each dot represents a spatial (region) and temporal (month) mean value



4. Simple linear model for NO_2 prediction

Fig. 5: Mean slopes (1 x 1°) of the best fitting least-squares regression lines (r > 0.3) for 96 months (2003-2010)

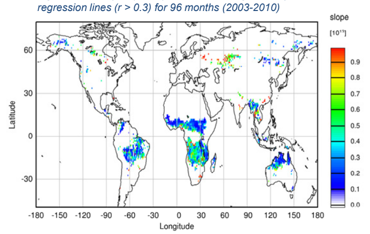
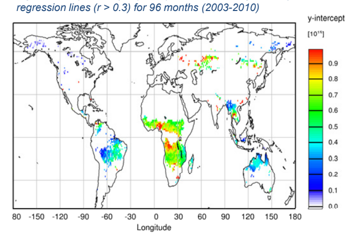


Fig. 6: Mean y-intercepts (1 x 1°) of the best fitting least squares regression lines (r > 0.3) for 96 months (2003-2010)



Monthly means of MODIS and SCIAMACHY data are used to create an linear relationship between fire counts and emission intensity (reflected in NO_2 columns)

$$NO_2 = a * fire\_counts + b$$

Lower (higher) slope values –> higher (lower) number of fires is necessary for a specific NO_2 level

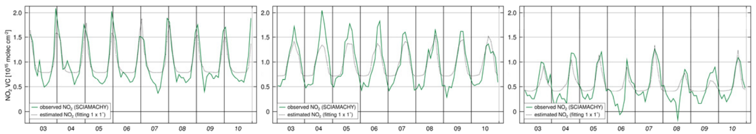
Variable slope values attributed to differing types and composition of vegetation? (e.g. agricultural lands, dry and wet savanna, forest) Smoldering vs. flaming?

Lower (higher) y-intercepts are attributed to lower (higher) wet season NO_2 levels originating from anthropogenic sources, lightning and soil (Fig. 6)

Least-squares coefficients on the basis of 1 x 1° pixels (Fig. 5 and 6) are used to predict the NO_2 columns

The uncertainties between observed and estimated NO_2 columns are up to ±50% for Africa north and south of the equator and up to ±100% in South America due to negative concentrations observed by the SCIAMACHY instrument occasionally (Fig. 7)

Fig. 7: Comparison between observed (SCIAMACHY) and estimated (least-squares fitting using 1 x 1° slopes and y-intercepts from Fig. 5 and 6) monthly mean tropospheric NO_2 in Africa north of the equator (left), Africa south of the equator (middle) and South America (right)



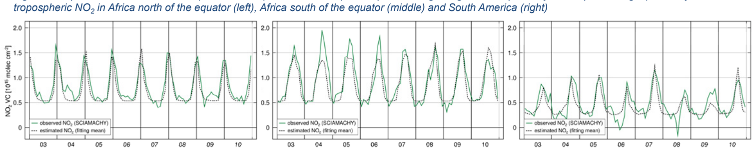
Mean regression coefficients (Fig. 4) are also used for the prediction of NO_2 columns with slope and y-intercept being averaged over the whole region

Uncertainties are reduced for the selected regions, especially during the wet season (Fig. 8)

For individual years, the estimated NO_2 columns in the dry season are still wrong by up to ±35%, ±50% and ±80% for Africa north and south of the equator and South America, respectively

These predictions are only first approximations

Fig. 8: Comparison between observed (SCIAMACHY) and estimated (least-squares fitting using mean slope and y-intercept from Fig. 4) monthly mean tropospheric NO_2 in Africa north of the equator (left), Africa south of the equator (middle) and South America (right)



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