Studies of NO_2 from Lightning and Convective Uplifting using GOME data

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Introduction

Every second 20 - 100 lightning discharges occur globally in thunderclouds. About 70%-90% of the lightning is intracloud (IC), and much of the lightning-produced NO_x finds its way to the top of the cloud. As early as 1827 von Liebig suggested that the NO_x are produced by lightning in large quantities. The physics of lightning as well as the role of the lightning chemistry in the nitrogen cycle is not fully understood today. At air temperatures above 2000 K, molecular oxygen breaks down into oxygen atoms that initiate the Zel'dovitch mechanism. The recombination of N and O atoms can form as much as 8% by volume NO. NO produced in lightning can be converted to NO_2 by reaction with O_3; in a matter of minutes, NO and NO_2 reach a steady state determined by the NO_2 photolysis rate coefficient and the temperature dependant rate constant for NO + O_3 . NO_2 can be converted to HNO_3 via reaction with OH, but the reaction is slow. It therefore is possible to measure enhanced NO_2 values hours or even days after the lightning stroke.

Currently, the global NO_x-production by thunderstorms is roughly estimated to be 0.3-22 Tg(N)/a. Precise knowledge of the atmospheric NO_x amounts is important as NO_x plays a key role in the formation of tropospheric ozone. Direct measurements of NO_x production by flashes are difficult, as they must be concurrent with the thunderstorm which is problematic for air borne sensors. Also, the number of measurements is necessarily limited, and all current estimates are based on extrapolation of a few local measurements to a global scale. Satellite measurements of NO_2 could fill this gap if they could be linked to individual lightning events.

Used Satellite Instruments

	LIS **Lightning Imaging Sensor** [Christian 1999]	**GOME** **Global Ozone Monitoring Experiment** [Burrows 1999]
Satellite	TRMM (NASA/NASDA)	ERS-2 (ESA)
Scan Geometry	Nadir	Nadir
Launched on	the 28th of Nov '97	the 21th of April '95
Latitudes	35°N - 35°S	Global
Orbital Altitude/Inclination	350km / 35°	795km / 98° (sunsynchronous)
Spectral Range	VIS	240 - 790 nm
Horizontal Resolution	4 - 7 km	320 x 40 km
Retrieval of Trace Gases		O_3, NO_2, H_2O, BrO, OClO, HCHO, SO_2 via Differential Optical Absorption Spectroscopy (DOAS)

GOME Sensitivity for Lightning produced NO_2

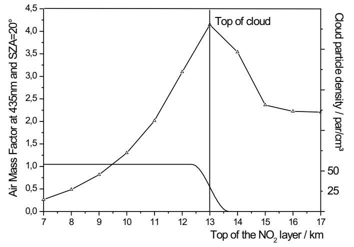

Fig. 1 AMF as a function of NO_2 layer height at 20° SZA: the layer being 1 km thick. The cumulus nimbus cloud range used is 4 to 13 km. The AMF is maximum for a NO_2 layer close to the cloud top. The simplified and smooth variation of cloud particles at the cloud edge, used for the cloud parameterization in SCIATRAN, is shown in the lower curve.

The curve shows the high sensitiviy of GOME for NO_2 at the top of the cloud.

This study investigated the sensitivity of GOME observations to different NO_2 distributions under, inside and above a cumulus nimbus cloud for a variety of cloud conditions. The dependence of the sensitivity to cloud density, height of clouds and NO_2-layers and solar zenith angle (SZA) are discussed. The feasibility study was undertaken using the radiative transport model SCIATRAN V1.0 developed at the IUP Bremen, which includes an explicit description of semi infinite clouds.

The results of SCIATRAN calculations yield the Air Mass Factor (AMF), which converts a slant column to a vertical column. It describes the effective absorption path of the light and is sensitive to the vertical distribution of the particular trace gas. As a result the AMF is a measure of the sensitivity of a measurement towards NO_2, larger values indicating higher sensitivity.

IIn figure 1, the dependence of the AMF on the height of a NO_2 layer in a thunderstorm cloud is displayed and demonstrates the high sensitivity towards NO_2 above the cloud and in the uppermost layers of the cloud. The sensitivity decreases rapidly towards the lower parts of the cloud and is negligible for NO_2 below the cloud.

Roughly 70% of the lightning discharges occur at the top of the cloud. The NO produced reacts with O_3 to produce NO_2. Satellite measurements from GOME therefore observe a significant part of the lightning produced NO_2.

Studies indicate that the dependence of the sensitivity to NO_2 within the cloud on a) solar zenith angle, b) the height of the NO_2, c) height of the cloud top, d) cloud particle density is weak. Figure 2 shows significantly higher in the top of the cloud and above than for clear sky above land and ocean. The reason is the multiple scattering inside the cloud, that results in high surface spectral reflectance.

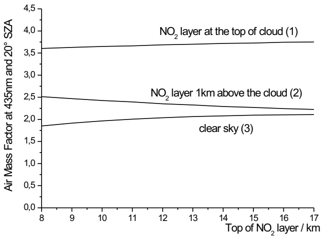

Fig. 2 The dependence of AMF on the height of a 1km thick NO_2 layer for different cloud scenarios: the SZA being 20°. In curve (1) the top of the NO_2 layer is also the top of cloud. In curve (2) the NO_2 layer is 1km above the cloud and the NO_2 layer (3) no cloud. The curves show, that the AMF is nearly independent of the height of the NO_2 layer for each scenario, but the AMF vary strongly with the scenario.

Conclusion with an Example of Measurement

Current Conclusions

The example of a thunderstorm close to the south eastern coast of Madagascar (figure 3) demonstrates the satellite detection of enhanced NO_2 concentration produced by lightning and convective uplifting. AMF calculations indicate, that as a result of the viewing geometry from space, the detector is insensitive to NO_2 below the cloud. The largest sensitivity of the space spectrometer GOME is in the upper region of the cloud, where 70% of the lightning discharges occur and above the cloud. In the region of interest the AMF is nearly independent of height of the NO_2, height of the cloud top and cloud particle density. Therefore the exact values of these parameters are not necessary for the retrieval but realistic assumptions must be made about the distribution of NO_2 in the cloud top.

Future Plans

The aims of the future work are to attempt to estimate and quantify the annual and seasonal budgets for LNO_2 in both the northern and southern hemispheres, using satellite data from GOME, which measures around 10.30 am local time.

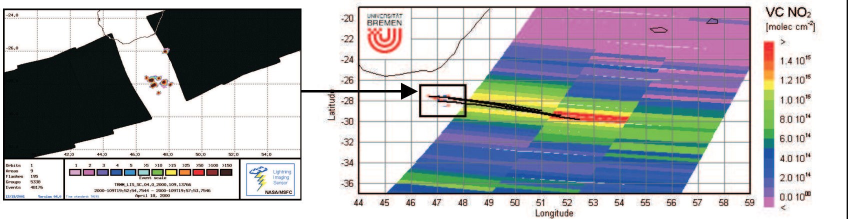

Fig 3 Flash activity and tropospheric excess NO_2 of the 18/19th of April 2000.

The figure displays a thunderstorm close to the southeastern coast of Madagascar. The tropospheric excess NO_2 is retrieved from GOME observations some fifteen hours after the flash activity detected by LIS. Tropical thunderstorms of this type have a typical duration of 1-2 days. The tropospheric excess NO_2 shows the strongly enhanced column of NO_2 in the area of the thunderstorm. The trajectories shows the path of the storm.

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Selected References

Burrows, J.P. et al., The Global Ozone Monitoring Experiment (GOME): Mission Concept and First Scientific Results, *J. Atmos. Sci.*, vol. 56(2), pp. 151-175, 1999.

Christian, H.J., et al, 1999, The Lightning Imaging Sensor (LIS): *proceedings of the 11th International Conference on Atmospheric Electricity, Guntersville*, 746-749

DeCaria et al., 2000, A cloud-scale model study of lightning-generated NO_x in an individual thunderstorm during STERAO-A, *JGR*, 105, D9, 11601-11616

Hild, L., Richter, A. and J. P. Burrows, 2001: Air Mass Factor Calculations for GOME Measurements of lightning-produced NO2, *Adv. in Space Res., in press*

Huntrieser, H., et al, 1998, Transport and production of NOx in electrified thunderstorms, *JGR*, 103, D21, 28247-28264

Richter, A. and J. P. Burrows, 2001: Tropospheric NO_2 from GOME measurements, *Adv. in Space Res., in press*

Wang et al.., Nitric oxide production by simulated lightning: Dependence on current, energy, and pressure, *JGR*, 103, D15, 19149-19159, 1998.

Winterrath, T., et al., Enhanced O_3 and NO_2 in thunderstorm clouds: Convection or production?, *GRL*, Vol. 26, No. 9, 1291-1294, 1999.