UPPSALA UNIVERSITET

On the NO_X production in lightning flashes

V. Cooray[1], M. Rahman[1] and V. Rakov[2]

[1]Division for Electricity and Lightning Research, Ångström Laboratory, Department of Engineering Sciences, Uppsala University, Sweden

[2]Department of Electrical and Computer Engineering, University of Florida, USA

UPPSALA UNIVERSITET

Introduction

✓ The lightning flash is a composite event consisting of several discharge processes such as leaders, return strokes, M-components, K-changes, continuing current.

✓ Direct measurement of NOx in triggered lightning shows that it is not only the return strokes in ground flashes that contributes to NOx but also other slow processes like continuing currents [Rahman et al. GRL, 2007].

✓ An estimation of the NOx yield of a lightning flash is made by treating the lightning flash as a composite event without using the energy dissipation as an input parameter.

NOx in laboratory discharges, return strokes and M-components

Goal: to calculate NOx production in electrical discharges, return strokes and M-components

Input parameter: discharge current
Maximum radius of the discharge channel (Braginskii´s theory)
Total energy in the discharge channel at maximum radius, temperature 20000 K.
Volume of heated gas beyond 2660 K
NOx is calculated

NOx in laboratory discharges, return strokes and M-components

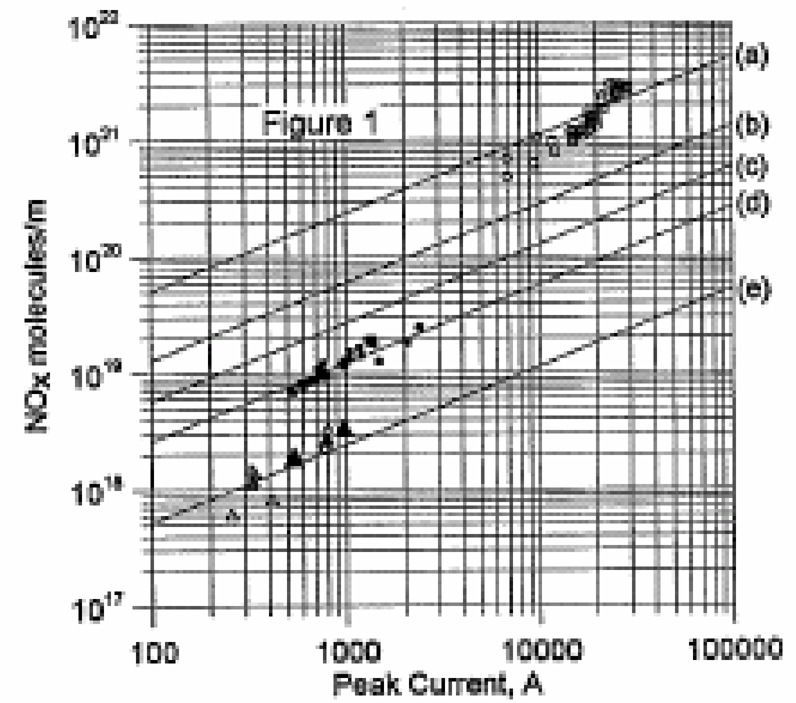

Figure 1. NOx at atmospheric pressure in (a) Wang et al. 1998 (b) first return stroke (c) subsequent return stroke (d) Rahman et al. 2005 (e) Rehbein et al. 2001

NOx in continuing currents

In 1-2 ms channel air is replaced by fresh air, Picone et al. 1981
Typical subsequent stroke, 12 kA creates continuing current
Return stroke channel radius 1.5 cm at pressure equilibrium
Temperature 15000 K
Air volume heated beyond 2660 K for each ms
NOx is calculated

Result: 2×10^{23} molecules/m/sec

NOx in the core of leader channel

Current in leader channel 100-200 A
Duration depends on the location
In a given section of leader channel current may flow for milliseconds
NOx/m/sec by leader is not very different to that of continuing current

NOx in corona sheath of the leader

Charge per unit length
Number of streamer discharges per unit length
Radius of the corona sheath (10^6 V/m negative and $5x10^5$ V/m positive)
Average length of the streamers in the corona sheath
Radius of streamer head, 100 μm
Total number of ion-pair produced in one meter
NOx for positive and negative streamers can be calculated

UPPSALA UNIVERSITET

NOx in a typical ground flash

Vertical channel with ´n´ horizontal branches, 5
Charge density on the leader channel is uniform, $5x10^{-4}$ C/m
Horizontal channel length, Vertical channel height, 5 km
Number of subsequent strokes, 3
Return stroke travel along the vertical channel with the current decreasing linearly with height
Current of a given M-component travels through one of horizontal branches in the cloud and reach ground along the vertical channel
Continuing current travels both vertical and one branch
Number of M-components, 1.6
Number of K-changes, 16
NOx scales linearly with pressure
Atmospheric pressure decreases exponentially
The total NOx produced by a typical ground flash can be calculated as

UPPSALA UNIVERSITET

NOx in a typical ground flash

$$NO_{x-ground} = \eta_{-ls}\lambda_p(1-e^{-H/\lambda_p}) + \eta_{+ls}L\,e^{-H/\lambda_p} + \frac{\eta_{lc}\lambda_p H}{v}\left(1-e^{-H/\lambda_p}\right) + \frac{\eta_{lc}}{v}\left(\lambda_p^2 - \lambda_p e^{-H/\lambda_p}\left[H+\lambda_p\right]\right)$$

$$+\frac{\eta_{lc}}{2vn}L^2 e^{-H/\lambda_p} + \eta_{fr}\lambda_p\left[1-\frac{\lambda_p}{H}+\frac{\lambda_p}{H}e^{-H/\lambda_p}\right] + \eta_{sr}\lambda_p\delta\left[1-\frac{\lambda_p}{H}+\frac{\lambda_p}{H}e^{-H/\lambda_p}\right]$$

$$+ k_m\eta_m\lambda_p(1-e^{-H/\lambda_p}) + \frac{k_k\eta_k}{n}L\,e^{-H/\lambda_p} + f_c\eta_c\tau_c\lambda_p(1-e^{-H/\lambda_p}) + f_c\eta_c\tau_c\frac{L}{n}e^{-H/\lambda_p}$$

UPPSALA UNIVERSITET

NOx in a typical cloud flash

Bipolar structure
Horizontal channels in negative and positive charge centres connected by a vertical channel
Total horizontal length in negative and positive charge centres are equal
Duration of current 100 ms
The total NOx produced by a typical cloud flash can be calculated as

$$NO_{x-cloud} = \eta_{+ls} L\, e^{-H/\lambda_p} + \eta_{-ls} L\, e^{-H_p/\lambda_p} + \frac{\eta_{lc}}{2vn} L^2 e^{-H/\lambda_p} + \frac{\eta_{lc}}{2vn} L^2 e^{-H_p/\lambda_p} + \frac{k_k \eta_k}{n} L\, e^{-H/\lambda_p} + \frac{k_k \eta_k}{n} L\, e^{-H_p/\lambda_p} + \eta_C \tau_D \lambda_P \left\{ e^{-H/\lambda_p} - e^{-H_p/\lambda_p} \right\}$$

UPPSALA
UNIVERSITET

Results

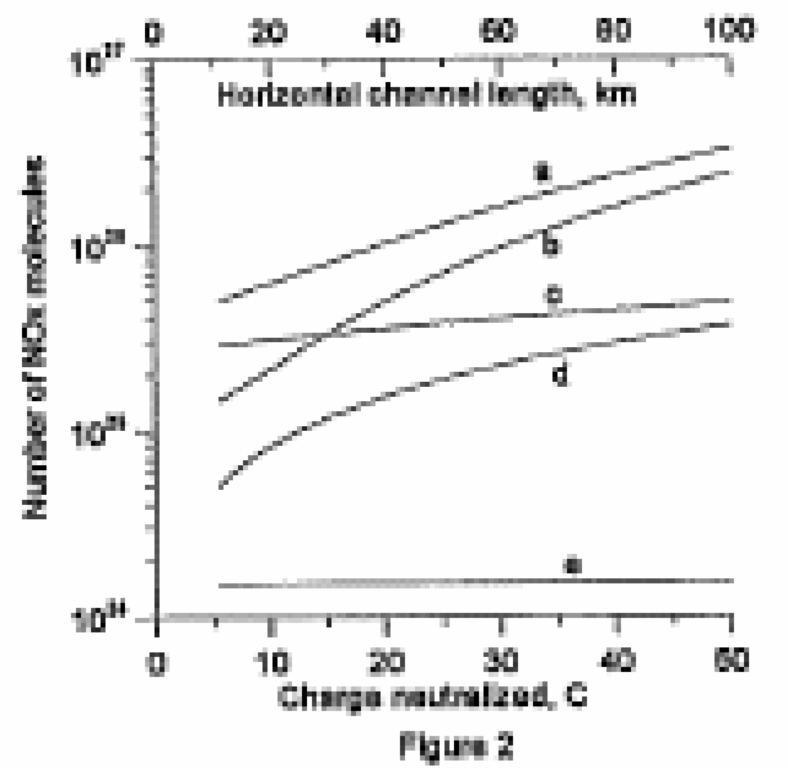

Figure 2. NOx produced by different processes in a ground flash

Results cont.

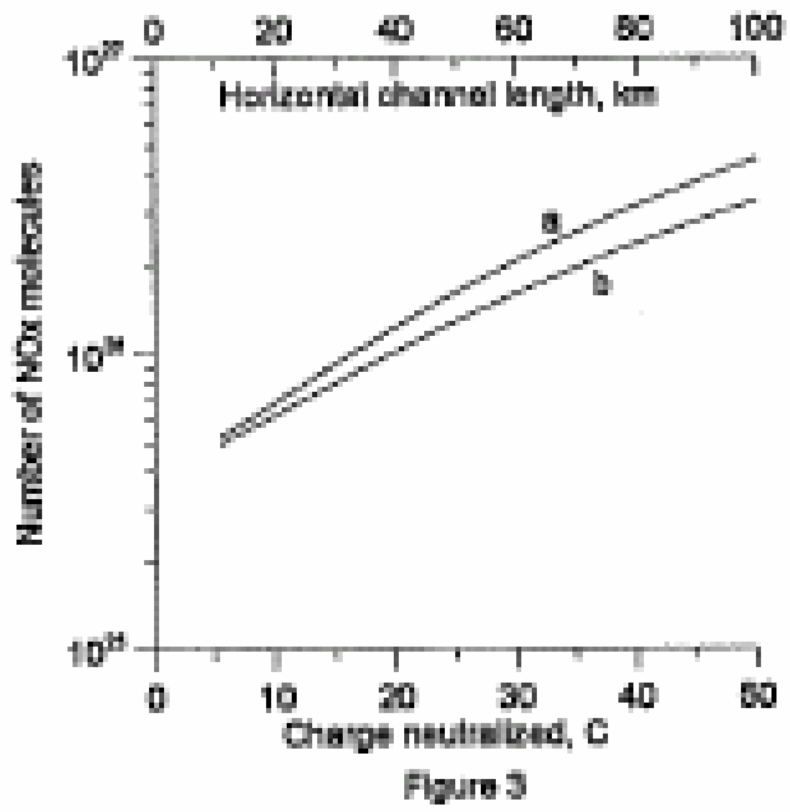

Figure 3. Total NOx produced by ground and cloud flashes

Results cont.

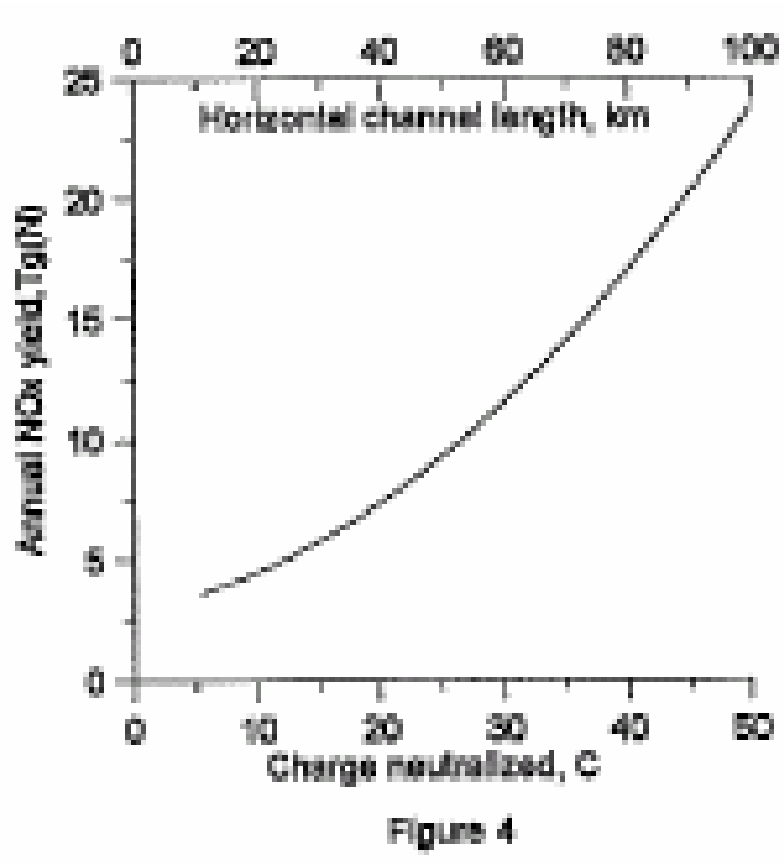

Figure 4. Global NOx produced by lightning as a function of dissipated charge

UPPSALA UNIVERSITET

Summary

The results show that

(a) cloud flashes are as efficient as ground flashes in NOx generation

(b) NOx production takes place mainly in slow discharge processes such as leaders and continuing currents with return strokes contributing only a small fraction

(c) the global annual NOx production by lightning is about 7 Tg(N) and

(d) in ground flashes only about 10% of the NOx is generated at heights below the charge center with 90% of the contribution coming from horizontal channels inside the cloud making the injection of NOx by thunderstorms into the atmosphere to take place at a height of 5 to 10 km.

Thank You!