# Systematic Quantitative Analysis of $NO_2$ Long-Range Transport Events and Comparison to Model Data

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**Achim Zien** (azien@iup.physik.uni-bremen.de), Andreas Richter, Andreas Hilboll, John P. Burrows; Institute of Environmental Physics, University of Bremen, FB 1, P.O. Box 330440, D-28334 Bremen

## Overview

- $NO_x$ is emitted in combustion processes, is toxic and affects the ozone budget.
- Upon uplift into the free troposphere, the lifetime can amount to multiple days.
- $NO_2$ long-range transport (LRT) can transport pollution from emission regions to remote, otherwise pristine areas, most likely induced by passing cold fronts.
- We perform systematic studies on data from the GOME-2 satellite instrument and the MACC-II reanalysis model to assess the global impact and to verify results.
- $NO_2$ LRTs are frequent and need to be studied using automatization.
- We present an algorithm to find and verify such events and assess basic properties.
- We show case studies to verify the algorithm and illustrate different $NO_2$ LRT scenarios.
- $NO_2$ LRT occurs along characteristic, mid-latitude routes, mostly during the winter months.

## Data Analysis

### GOME-2 tropospheric $NO_2$ VCD

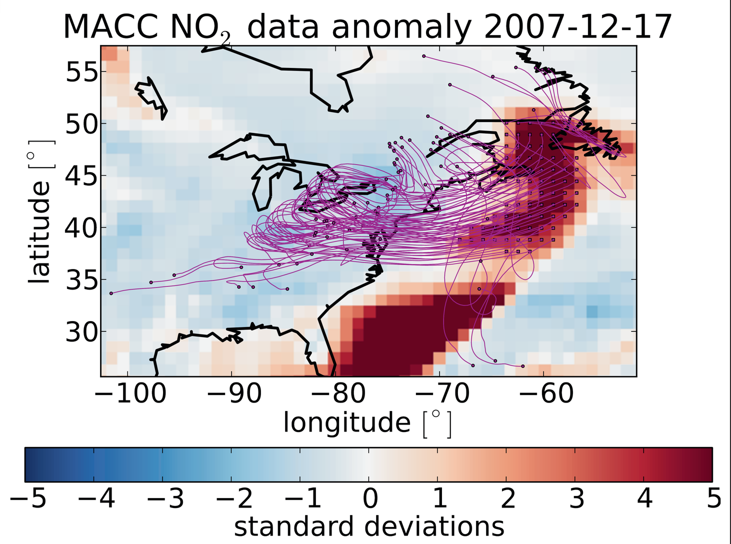
- GOME-2 observes $NO_2$ using the differential optical absorption spectroscopy (DOAS)
- the stratospheric contribution is removed by using a reference sector over the remote Pacific
- $NO_2$ transport is associated to frontal systems and clouds, which impact $NO_2$ retrieval
- the radiance-weighted cloud fraction allows to determine the contribution to the observed spectrum from the cloudy part of the image
- we use a modeled air-mass factor for a block profile of $NO_2$ at 3–5km a.g.l., vertically colocated with a cloud for the cloudy contribution (optical thickness: 50)
- this allows to estimate the $NO_2$ content within clouded long-range transport events

### Detection algorithm

- search for anomalies at least 5σ above the sliding mean in vertical column density (VCD) maps of $NO_2$ and include all connected pixels above 2σ to the plume (limited to the oceans)
- the plume includes only $NO_2$ above the sliding mean background level

### Tracing and verification algorithm

- trace all plume pixels from various altitude levels with the HYSPLIT lagrangian transport model using GDAS meteorological data
- select a trajectory (altitude and age), favoring: low dispersion, high source strength hit in the boundary layer and small age (to account for decay)
- verify plumes by demanding a minimum ratio between hit sources and $NO_2$ in the plume



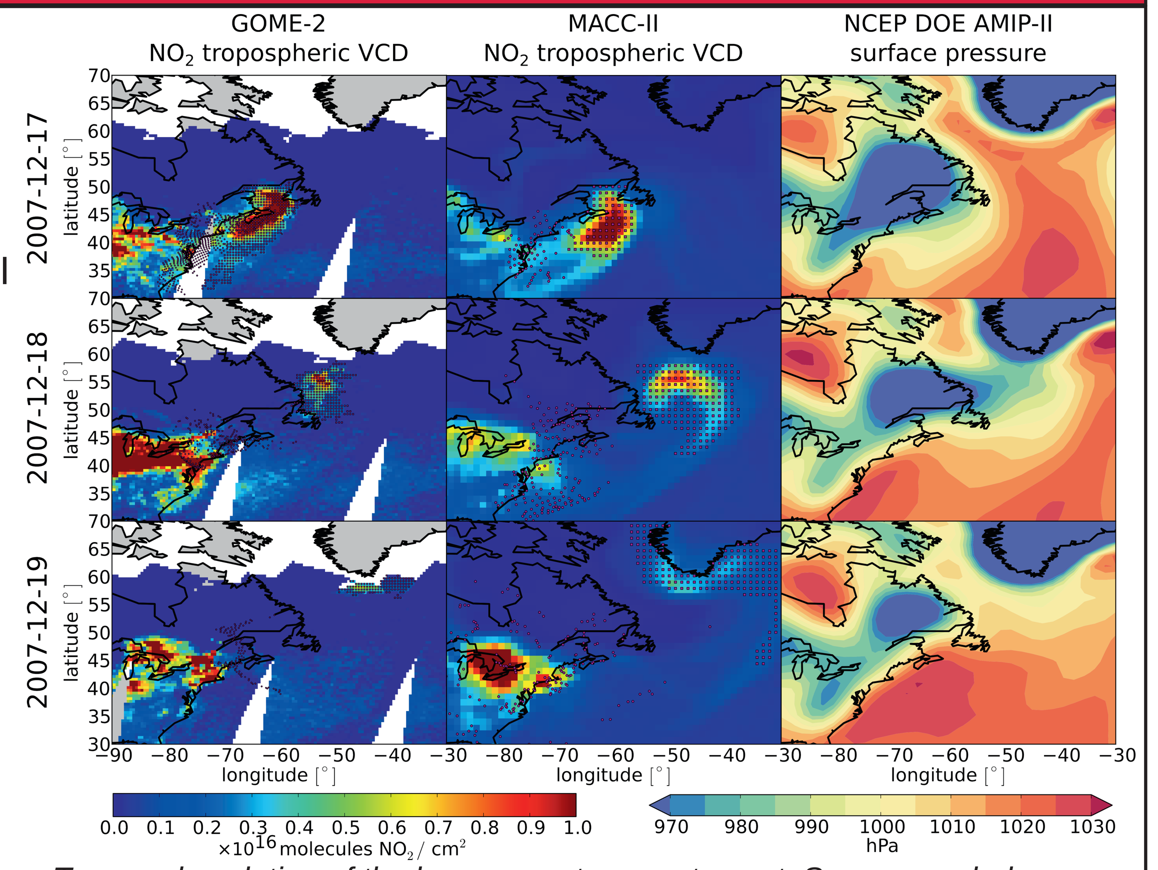

*Sample detected plume with selected HYSPLIT backtrajectory in magenta. Colormap gives the number of standard deviations from the ±6 days moving average $NO_2$ VCD.*

## Case Studies

- follow the evolution of a plume and discern different scenarios
- in-depth comparison between satellite and model data

### North Atlantic (Dec. 2007)

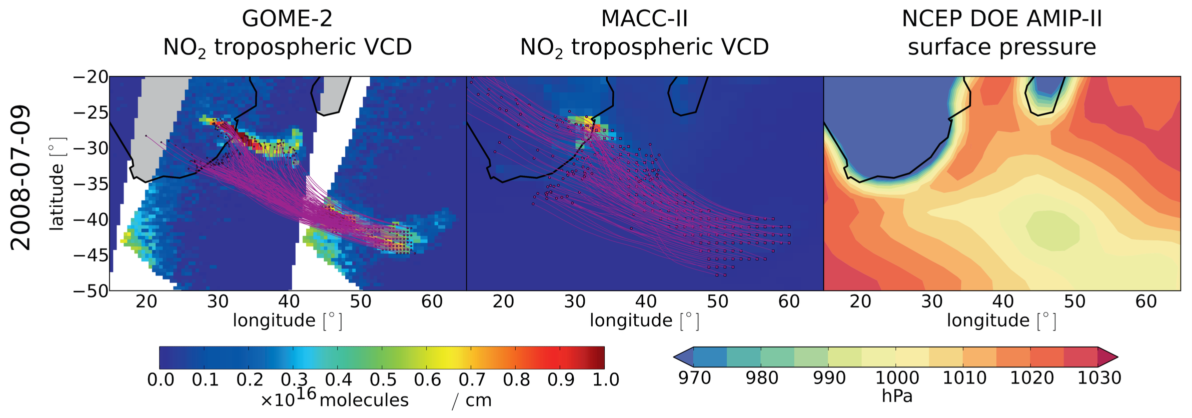
- a cold front passes the industrial emission region and lifts the $NO_2$ to the free troposphere
- a big plume (1.43Gg N) travels from the east coast of the USA towards Greenland
- observed $NO_2$ amount halves nearly every day; modelled amount decreases upon hitting Greenland




*Temporal evolution of the long-range transport event. Square symbols indicate pixels belonging to the plume, circles indicate the determined source regions. The NCEP data show a low-pressure system in association to the beginning transport event and subsequent decoupling. Plume age estimates to 9, 34 and 41 hours, respectively, for GOME-2 and 11, 22 and 43 hours for MACC-II.*

### South Africa (July 2008)

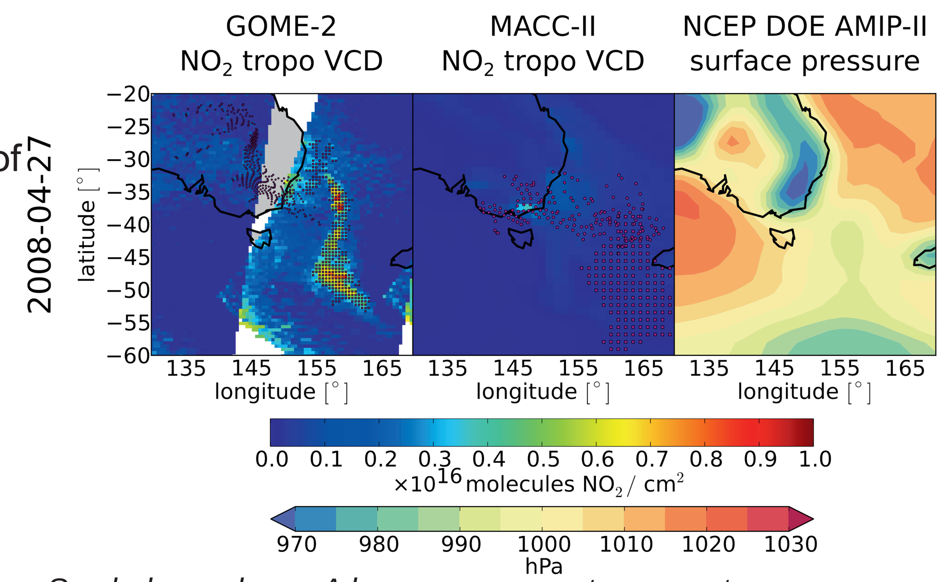
- $NO_2$ emissions picked up in the Highveld region are transported towards Australia
- emission altitudes of more than 1,500m allow for transport with a weaker cold front
- the model underestimates the amount of $NO_2$ exported




*Symbols as above, lines indicate the determined trajectory of the plume (omitted in other plots for clarity). A mild low-pressure system colocates with the observed and the much weaker modeled $NO_2$ plume. Plume age estimates to 36 and 32 hours, respectively. Earlier data show the plume parting from the continent.*

### Australia (April 2008)

- emissions tied to bushfire season, no non-bushfire plumes can be seen
- transport event is not adequately reproduced by model
- plume quickly dissolves

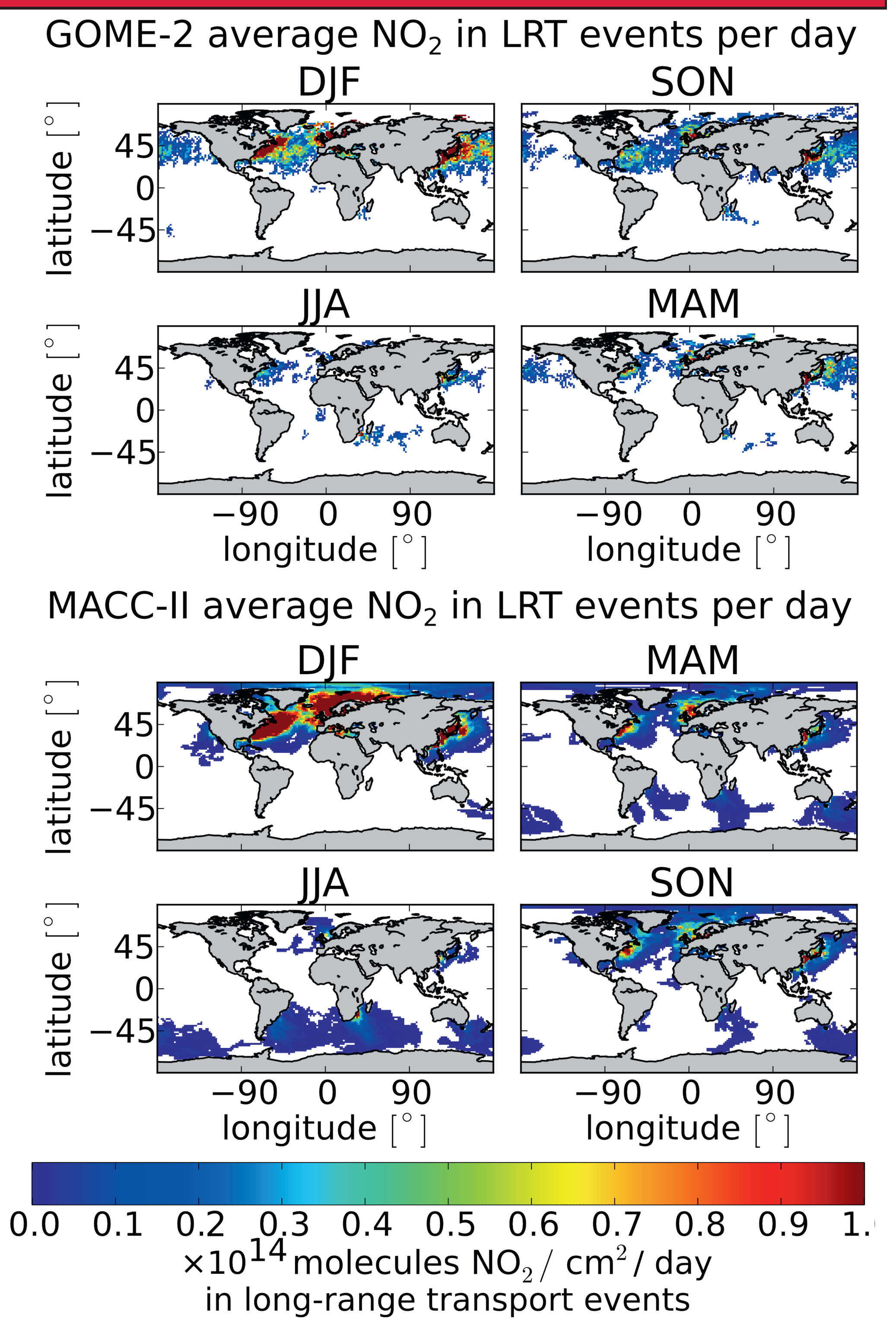



*Symbols as above. A low-pressure system swept across southern Ausralia to lift up bush-fire emissions and put them en route to the Antarctic. Plume age estimates to 20 hours for both datasets. Minor lightning events occur near the plume.*

## 3-year Analysis (2007–2009)

### Systematic analysis

- 1205 plumes found in GOME-2, 1185 in MACC-II data
- GOME-2 and MACC-II data agree on the global structure of $NO_2$ long-range transport
- no transport events in the tropics due to shorter photolytic $NO_2$ lifetime, less emission and less frontal systems
- east coast of North America, Europe, east China, South Africa and southeast Australia emit most LRT events
- Asian transport occurs frequently, but only localized
- European plumes tend to re-circulate onto the continent
- most plumes travel at altitudes between 1km and 5km a.s.l.
- detection frequency diminishes exponentially each day with plume age after the first day




*Seasonal daily average of $NO_2$ seen in long-range transport events, indicating the strength of the pathways of such events. Characteristic routes and strong seasonality are found in the North Atlantic, East Asia and South Africa.*

### Seasonality

- winter is the strongest LRT season due to less photolysis, higher anthropogenic emissions and more frequent frontal systems
- summer plumes are small and short-lived

## Selected References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