Global deposition of reactive nitrogen oxides constrained with satellite observations of NO$_2$

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Estimating Global Atmospheric Deposition

Maps of global total (wet+dry) deposition required for national and international science and policy

Direct observations are challenging

Long term monitoring is sparse

Chemical transport models offer our best estimates of deposition over long periods of time and across large spatial domains
**Top-Down Constraint on NOy Deposition**

Remote Sensing

**Effective mass balance between NOx emissions and NOy deposition**

Primary Nitrogen Oxides (NO+NO₂)

“NOₓ”

Chemistry

HNO₃, PAN, Organic-NO₃, Particulate-NO₃

Transport

Wet + Dry Deposition

Effective mass balance:

\[ F = V_d \times [C] \]
Two Decades of Consistent Satellite NO$_2$ Monitoring


SCIAMACHY (2002-2011)

GOME-2 (2006- )

Beijing

Tehran

Los Angeles

Mexico City

Mumbai
Surface NOx Emissions Inversion Approach

Remote Sensing Observations

Base (a priori) Simulation

\[ E_{\text{new}} = E_{\text{prior}} \cdot \left[ 1 - \beta \left( \Omega_{\text{SAT}} - \Omega_{\text{prior}} \right) / \Omega_{\text{prior}} \right] \]

A-priori estimate of NO\textsubscript{x} emissions

Top-down NOx emissions

Column sensitivity to an emission perturbation
Mean Global NOy Deposition (1996-2014)

NOy Deposition (kg N ha\(^{-1}\) yr\(^{-1}\))

Dry Deposition Fraction
Good Agreement with Wet Deposition Monitoring

Data from the World Data Centre for Precipitation Chemistry (2000-2002) ¹

¹ http://www.wdcpc.org/
Long Term Trends in Global NOy Deposition (1996-2014)

Integrated NOy Deposition (Tg N)

- **N. America**
- **Europe**
- **E. Asia**

- Decreasing
- Increasing

Significance: p < 0.01

kg N hr\(^{-1}\) yr\(^{-2}\)

**Graphs:**
- **Dry**
- **Wet**
Satellite-Derived Trends are Consistent with Available Data

Measured

Constrained Simulation

N = 109

N = 16

N = 11

$p < 0.01$
Uncertainty due to Coupling with Reduced Nitrogen?

Minimal impact of a $\uparrow 30\%$ perturbation in $NH_3$ emissions

Total NOy deposition over land robust to within 5%. Larger impacts over oceans where transport is important.
Changing Patterns in Regional/Long Range Transport

“Export” = Local Emissions – Local Deposition

Export from U.S. ↓ 50%

Export from Western Europe ↓ 40%

Export from China ↑ 3X
Changes to Global Ecosystems (e.g. Forest Cover)

Present Day Tree Cover

Long Term Trends in NOy Deposition

↓ 50% in North America
↓ 20% in Europe
↑ 2X in East Asia
Summary

Satellite NO$_2$ columns provide powerful top-down constraint on NOy deposition estimates

Large regional redistribution from 1996-2014, possible peak in global NOy deposition around 2011-2012

Useful for science and policy related to biodiversity and long-range pollution transport

Thank you!