Estimates of Lightning NO_x Production based on High-Resolution OMI NO_2 Retrievals

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Credit: Santiago Borja

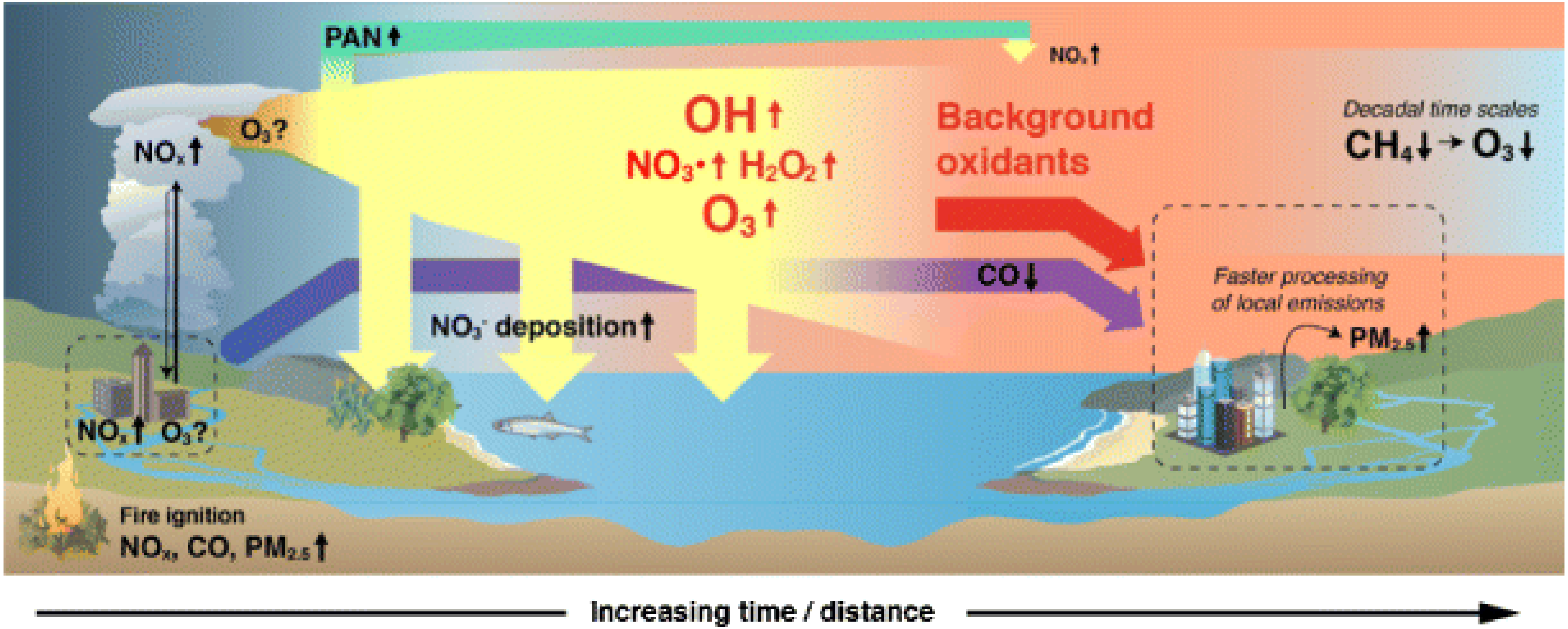
Background (Origin)

LNO_x (lightning NO_x)

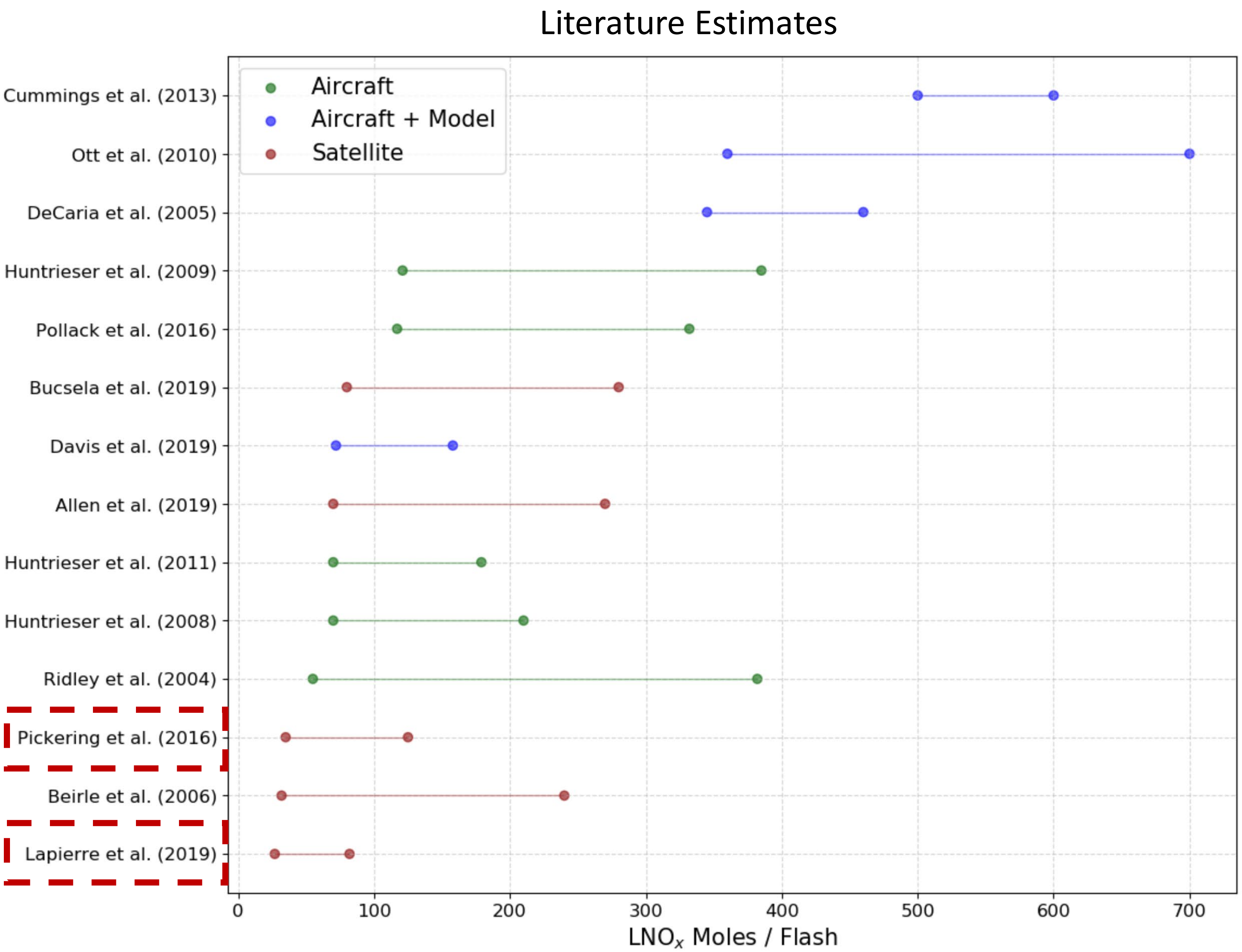
- **Hot-channel:** O_2 and N_2 dissociation producing **NO** (Zel'dovich and Raizer, 1967), the NO reacts in the atmosphere with **O_3** to form **NO_2** quickly.
- **Corona discharges**: directly produce **O_3** and **N_2O**.

- one of the **largest natural sources** of NO_x (2 - 8 Tg N yr^{-1}, 4 -16% of NO_x emissions)
- the **least known one** within the total atmospheric NO_x budget (Schumann and Huntrieser, 2007)

Background (Effects)



Background (Estimates)



Motivation

Calculating LNO_x directly (satellite + lightning data)

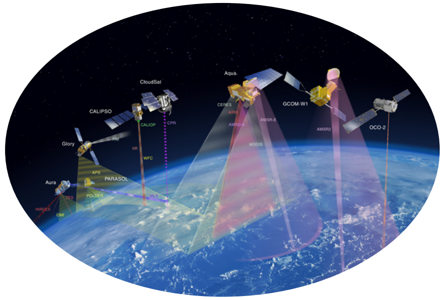
1. Which satellite?
2. What's the detection efficiency of lightning data?
3. How to get NO_x column during convection?
4. How to distinguish LNO_x with other NO_x, especially anthropogenic NO_x?

Data

Satellite data:

OMI (Ozone Monitoring Instrument)

13×24 km^2, 13:30 (local time)



Lightning data:

ENTLN (The Earth Networks Total Lightning Network)

Detection efficiencies of **intracloud** flashes and strokes are **88%** and **45%** over the Continental US (Lapierre et al. 2019)

Detection efficiencies of **cloud-to-ground** flashes and strokes is **> 90%** over the Continental US (Lapierre et al. 2019)

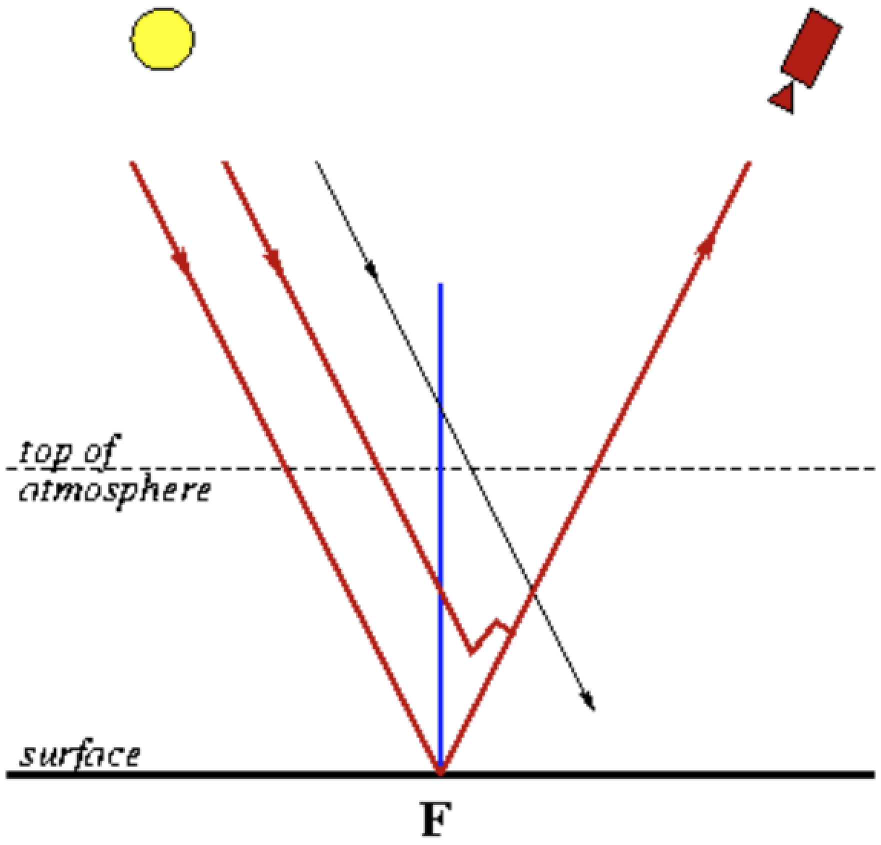
Methods

$$\mathrm{VCD}_{\mathrm{NO_2}} = \frac{\mathrm{SCD}_{\mathrm{NO_2}}}{\mathrm{AMF}}$$

SCD_{NO2}: NO_2 slant column densities;

VCD_{NO2}: NO_2 vertical column densities;

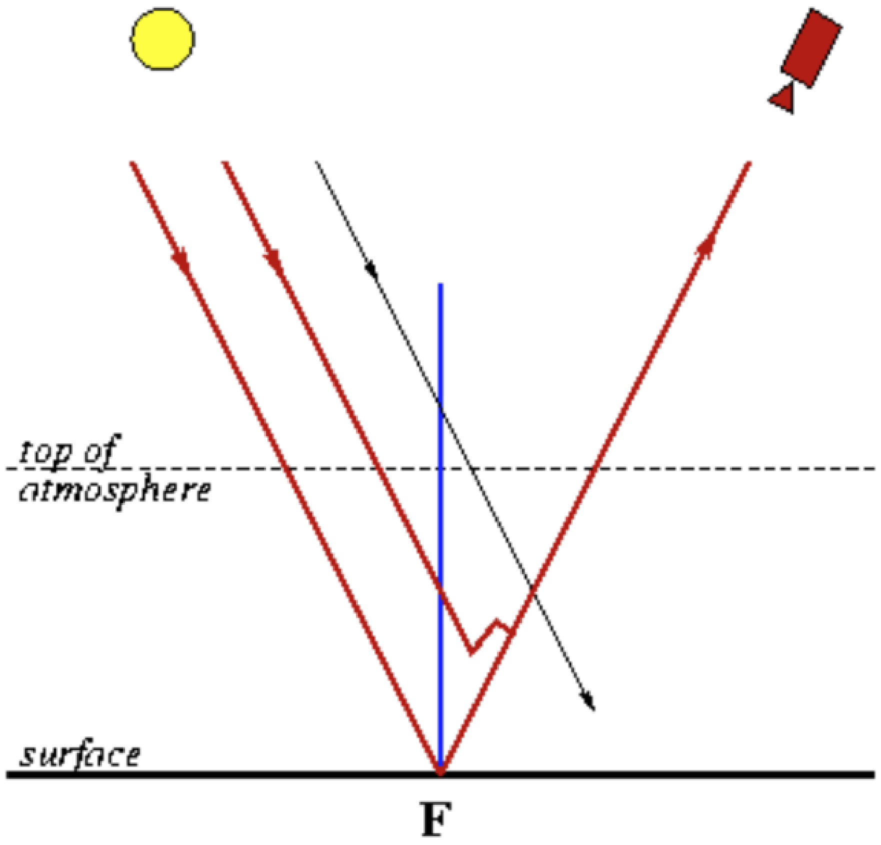
AMF: Air mass factors



http://sacs.aeronomie.be/info/scdvcd.php

Methods

$$\mathrm{VCD_{NO_2}} = \frac{\mathrm{SCD_{NO_2}}}{\mathrm{AMF}}$$



AMF Dependencies:

- NO_2 profile
- Scattering weights

solar zenith angle (SZA), viewing zenith angle (VZA),

relative azimuth angle (RAA), albedo, and surface pressure

http://sacs.aeronomie.be/info/scdvcd.php

Methods

The Berkeley High Resolution (BEHR) OMI NO_2 retrieval

$$\mathrm{AMF_{trop}} = \frac{\text{a priori SCD}}{\text{a priori VCD}_{\mathrm{trop}}}$$

$$\mathrm{AMF_{LNO_x}} = \frac{\text{a priori SCD}}{\text{a priori VCD}_{\mathrm{LNO_x}}} = \frac{\text{what satellite sees}}{\text{what we want}}$$

- **Both over-cloud and below-cloud LNO_x**
- **Both NO_2 pollution and LNO_2**

Criteria

Valid pixels ≥ 5 for each 1 x 1 grid (MJJA 2014):

① OMI

- **Cloud Radiance Fraction ≥ 90%** for each OMI pixel

  (Pickering et al. 2016)

- **Cloud Optical Pressure ≤ 650 hPa** for each OMI pixel

Criteria

Valid pixels ≥ 5 for each 1 x 1 grid (MJJA 2014):

② ENTLN

- **Flashes ≥ 2400** for 1 x 1 grid 2.4 h before OMI pass time (Lapierre et al. 2019)
- **Strokes ≥ 8160** for 1 x 1 grid 2.4 h before OMI pass time (Lapierre et al. 2019)

Criteria

Valid pixels ≥ 5 for each 1 x 1 grid (MJJA 2014):

③ WRF-Chem

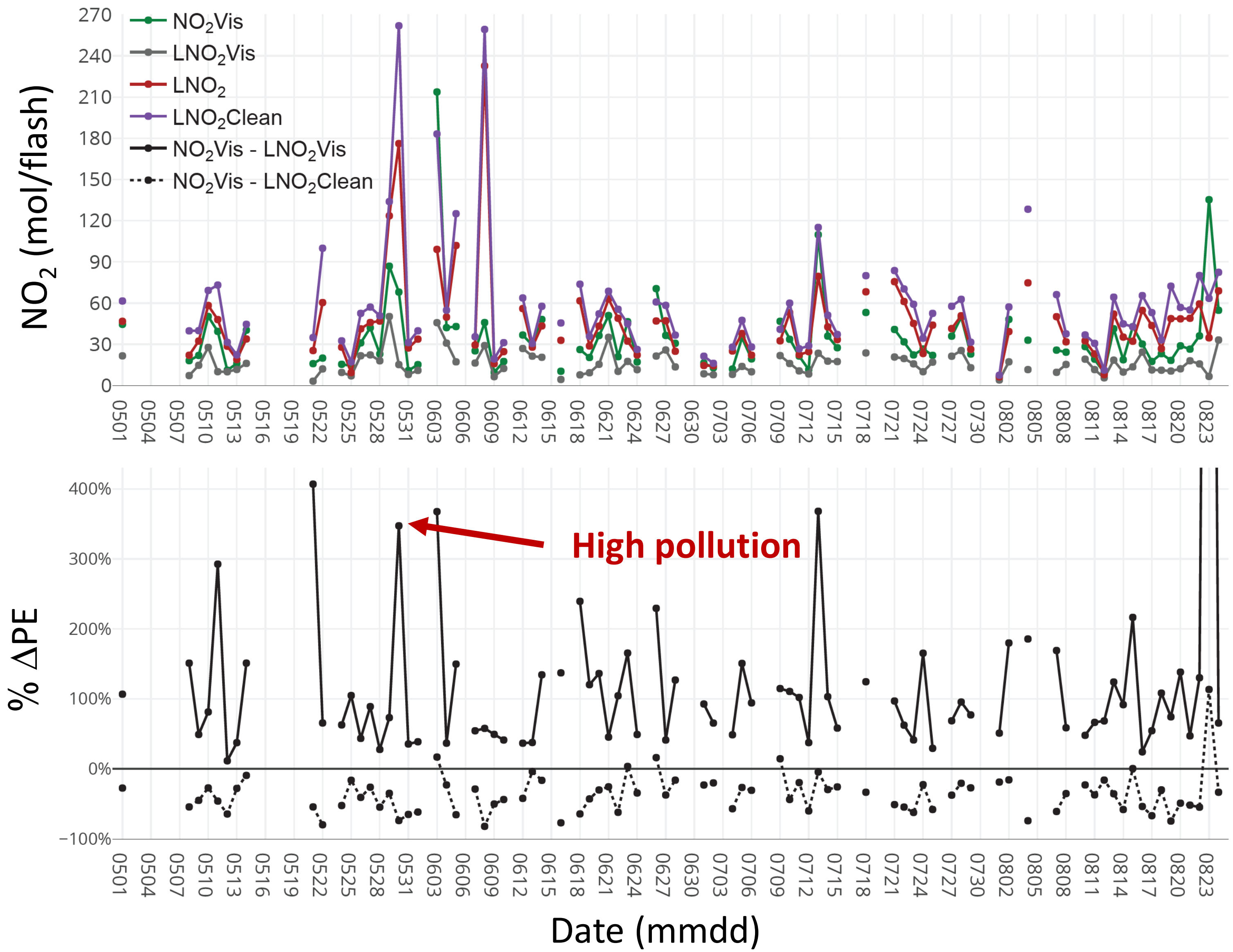
- **LNO_2Vis/NO_2Vis ≥ 50%**

Vis: the part **above the cloud pressure** detected by OMI

- **Flashes ≥ 1000 for 1 x 1 grid 2.4 h before OMI pass time**

Results

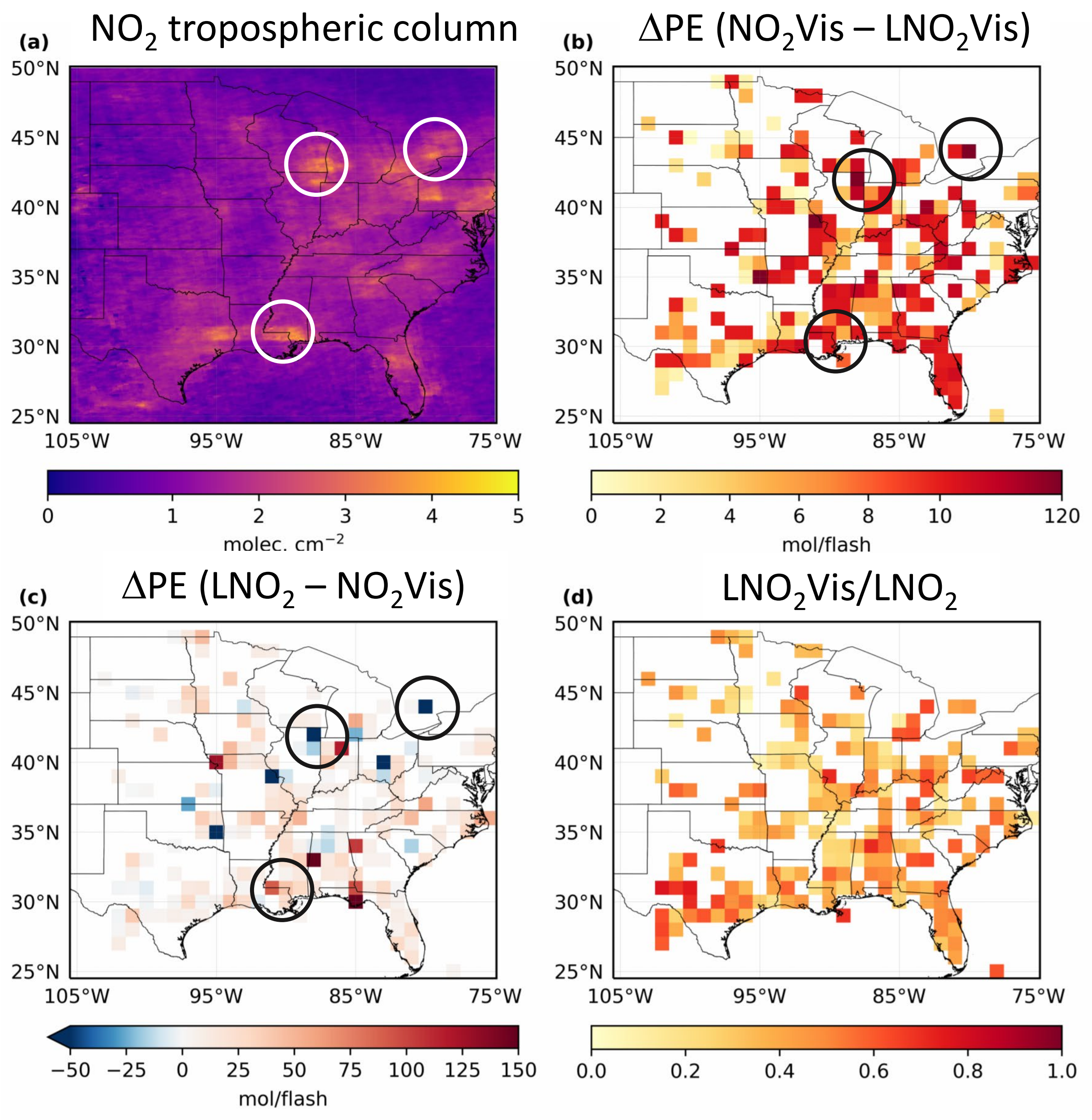
Comparisons between different methods



- LNO$_2$ production efficiency (PE): **20 -- 80** mol/flash
- LNO$_2$Clean > LNO$_2$ > NO$_2$Vis > LNO$_2$Vis
- LNO$_2$ method is suitable for **both clean and polluted** regions

Results

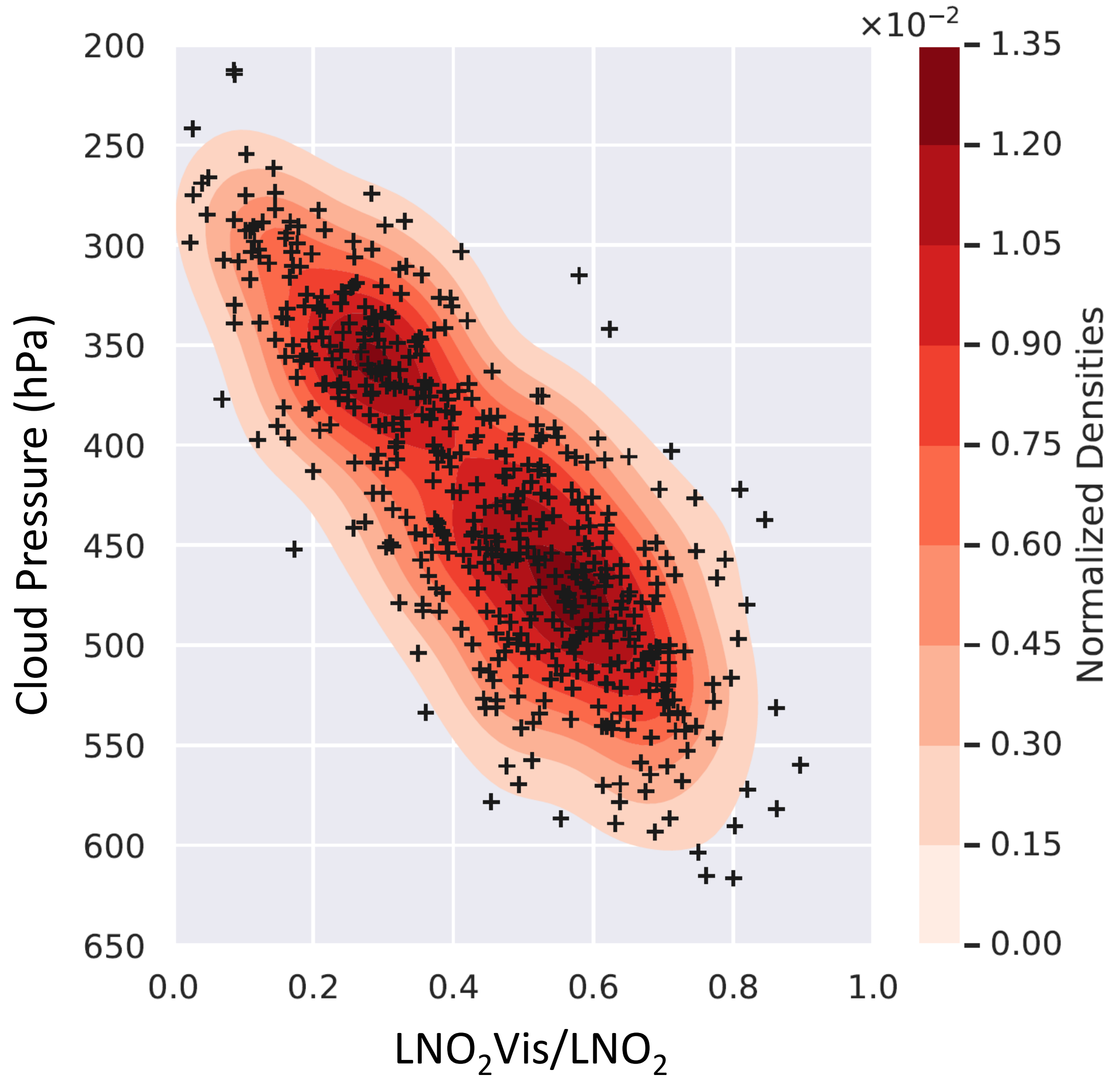
NO_2 pollution



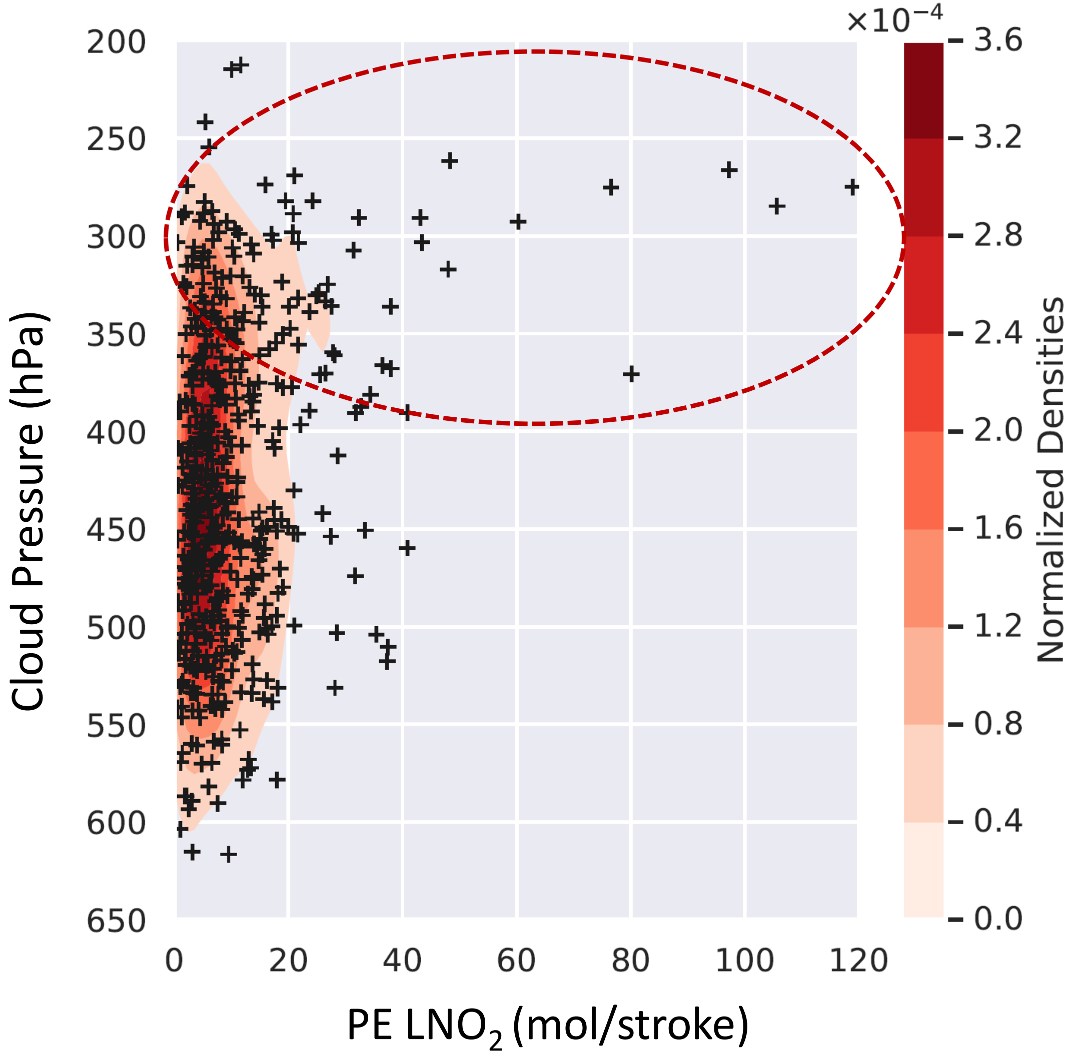
- The NO_2 pollution can be transported over cloud. (a, b)
- Many LNO_2 exists below the cloud. (d)
- The overestimation by NO_2Vis can't be counteracted by LNO_2 below the cloud. (c)

Results

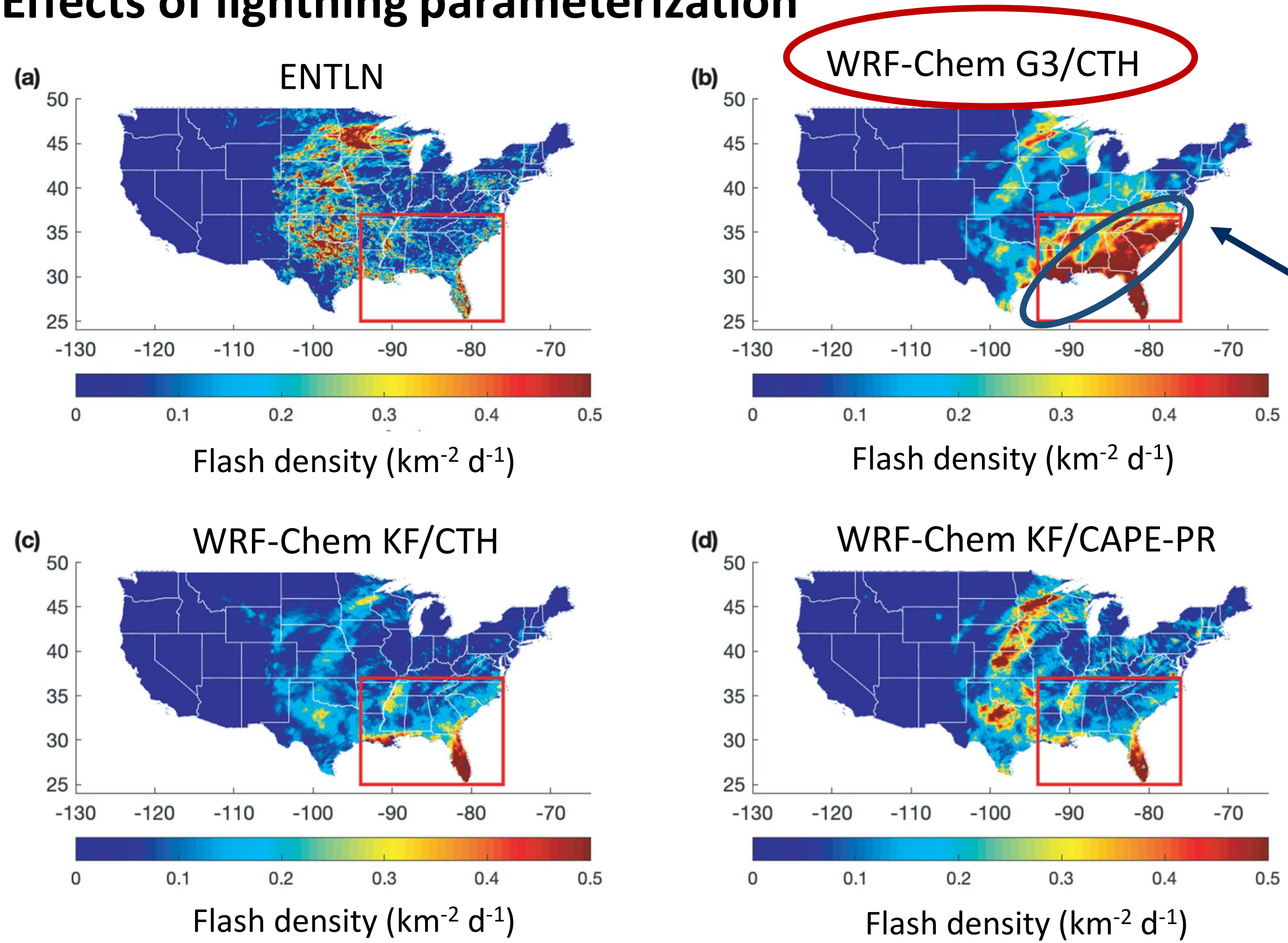
Effects of Cloud pressure



Caused by cloud or lightning?



Effects of lightning parameterization



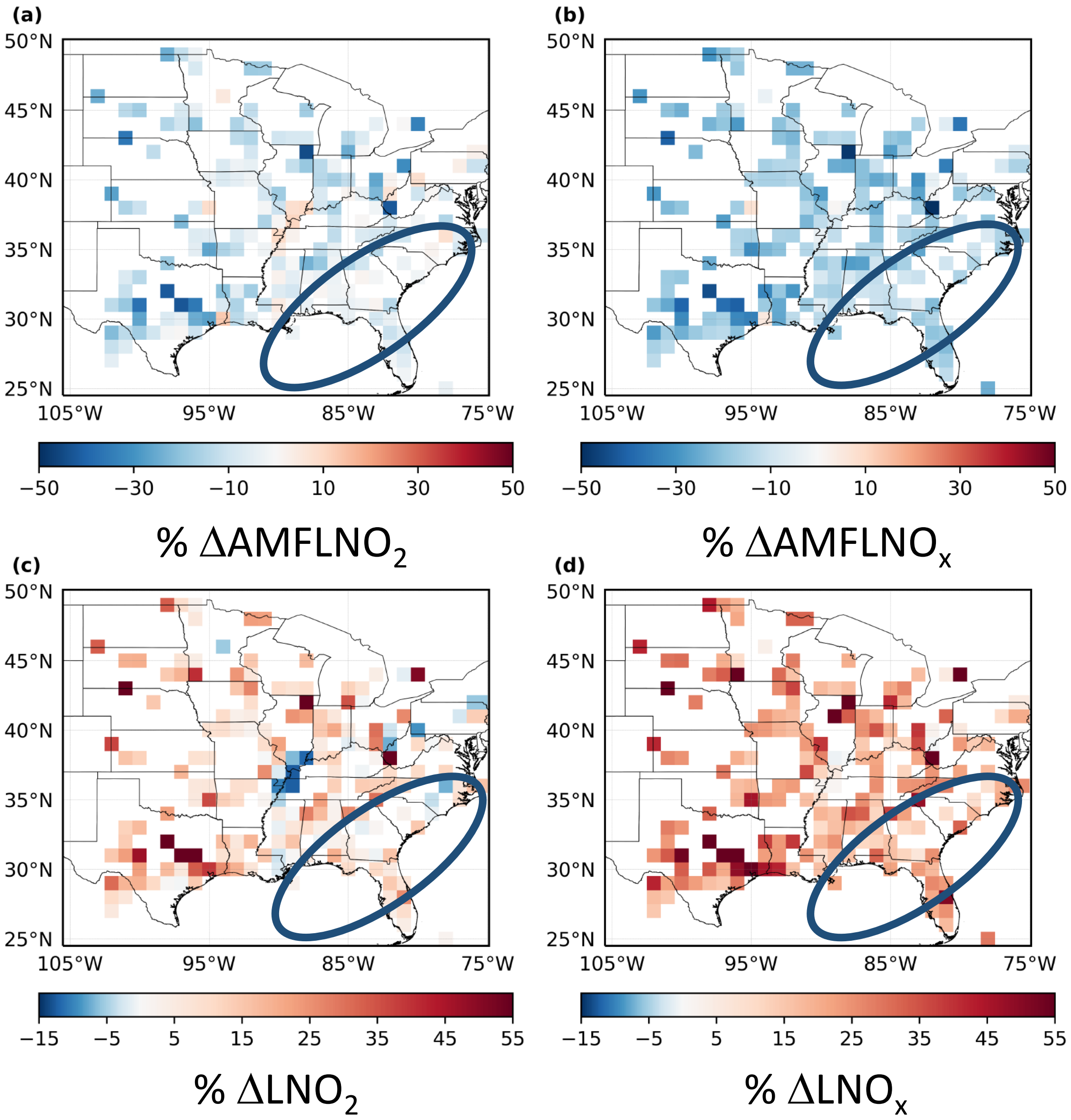
The largest differences

- convective parameterizations
- lightning parameterizations

Qin dan et al. (2019), *Atmos. Chem. Phys.*

Results

Effects of lightning parameterization



Setting of LNO production (WRF-Chem):

200 mol/flash → 1000 mol/flash

(official BEHR setting)

Summary

Focusing on the Continental US in MJJA 2014, we find that:

- The LNO_2 PE is 32 ± 15 mol NO_2/flash and 6 ± 3 mol NO_2/stroke.
- The LNO_x PE is 90 ± 47 mol NO_x/flash and 17 ± 9 mol NO_x/stroke.
- Our method reduces sensitivity to the background NO_2 and includes much of the below-cloud LNO_2.
- Careful consideration of the LNO_x parameterization and LNO_2 /NO_2 is needed, given its large influence on the estimation of LNO_2 and LNO_x PE.

Zhang et al. (2019), *Atmos. Meas. Tech. Discuss.*
Doi:10.5194/amt-2019-372

GitHub: zxdawn
Repo: BEHR-LNOx

Future

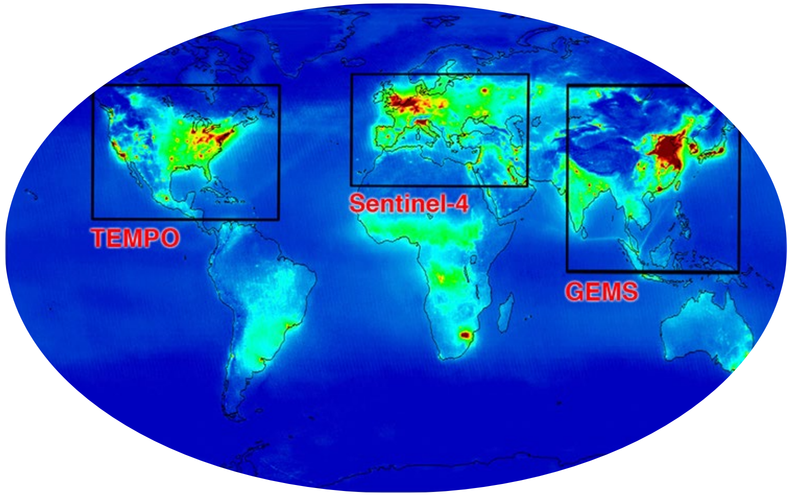
NO_2 instruments

Polar orbiting

TROPOMI

5.6 × 3.5 km² ✓

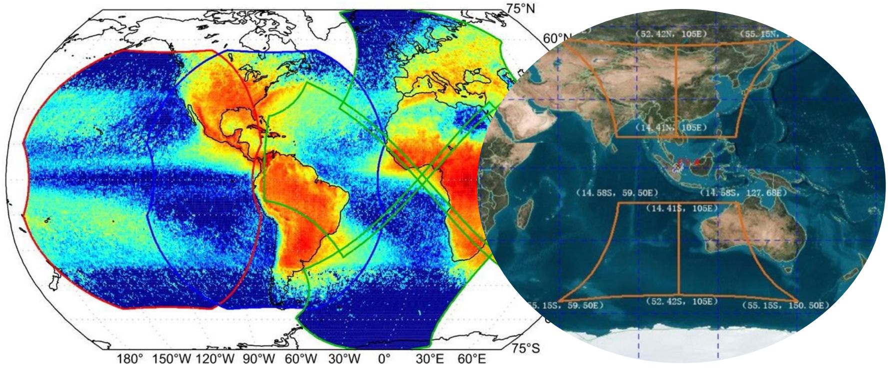
Geostationary



TEMPO, Sentinel-4, GEMS

Lightning instruments

Geostationary



GLM (GOES-16 and GOES-17) ✓

LI (MTG-I)

LMI (FY-4A ✓ and FY-4C)

Summary

Focusing on the Continental US in MJJA 2014, we find that:

- The LNO_2 PE is 32 ± 15 mol NO_2/flash and 6 ± 3 mol NO_2/stroke.
- The LNO_x PE is 90 ± [illegible] mol NO_x/flash and [illegible] mol NO_x/stroke.
- Our method reduces sensitivity to the background NO_2 and includes much of the below-cloud LNO_2.
- Careful consideration of the [illegible] parameterization and LNO_2 /NO_2 is needed, given its large influence on the estimation of LNO_2 and LNO_x PE.

Thank you!

AMS

Zhang et al. (2019), *Atmos. Meas. Tech. Discuss.*
Doi:10.5194/amt-2019-372

GitHub: zxdawn

Repo: BEHR-LNOx

Uncertainty

Uncertainty types	**Allen et al. 2019**	**Pickering et al. 2016**	**Zhang et al. 2019**
BEHR Tropopause Pressure	-	-	4%
Cloud Radiance Fraction	-	-	2%
Surface Pressure	-	-	0%
Surface Reflectivity	-	-	0%
LNO_2 Profile	5%	-	29%
Profile Location	-	-	1%
Strat VCD	10%	35-40%	10%
Systematic Errors in Slant Column	5%	15%	5%
lightning DE	25-50%	30%	15%
Tropospheric Background	30%	15%	20%
Time Window	10%	15%	8%
LNO_2 below OCP	10%	10%	-
LNO_2 lifetime	25%	0%	24%
NO/NO_2	20%	-	20%
Net	**58-72%**	**55%**	**51%**