



# CO<sub>2</sub> emissions from power plants derived from the OMI NO<sub>2</sub> dataset

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# Key Points

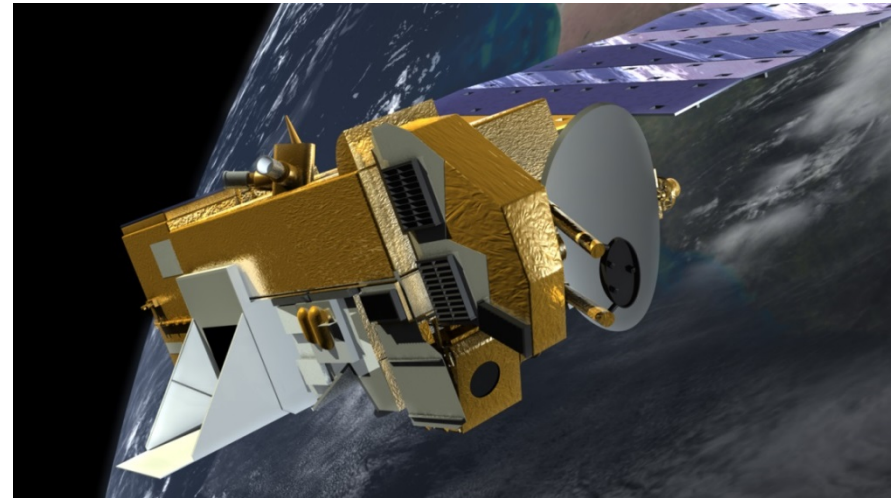
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- Ozone Monitoring Instrument (OMI) annual  $\text{NO}_x$  ( $\text{NO}_2 + \text{NO}$ ) emissions can be estimated for individual, isolated power plants
- $\text{NO}_x$  is a good tracer for anthropogenic  $\text{CO}_2$  emissions
- $\text{NO}_x:\text{CO}_2$  ratios have been derived from the Continuous Emission Monitoring System (CEMS)
- These ratios and OMI  $\text{NO}_x$  emission estimates are used to derive  $\text{CO}_2$  emissions from large point sources
- New approach of estimating  $\text{CO}_2$  emissions that can help to improve emission inventories in countries where emissions have very large uncertainties

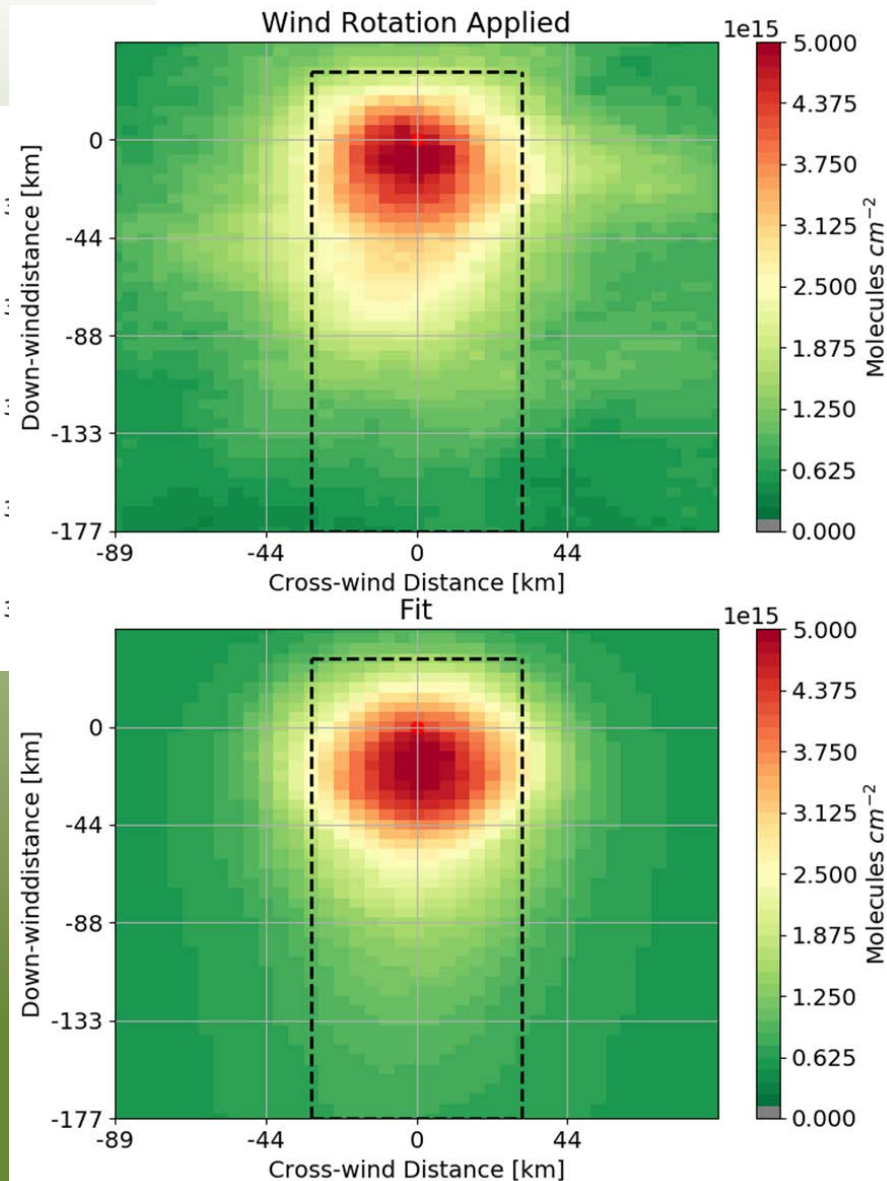


# The OMI instrument

- The Ozone Monitoring Instrument (OMI), on-board the Aura satellite, launched 2004 [Levelt et al., 2006]
- OMI is a nadir-viewing UV-visible instrument that detects scattered reflected sunlight (270-500 nm, at 0.42 nm resolution)
- Global daily coverage, ~30 km pixel size
- Measures NO<sub>2</sub>, O<sub>3</sub>, SO<sub>2</sub>, and aerosols



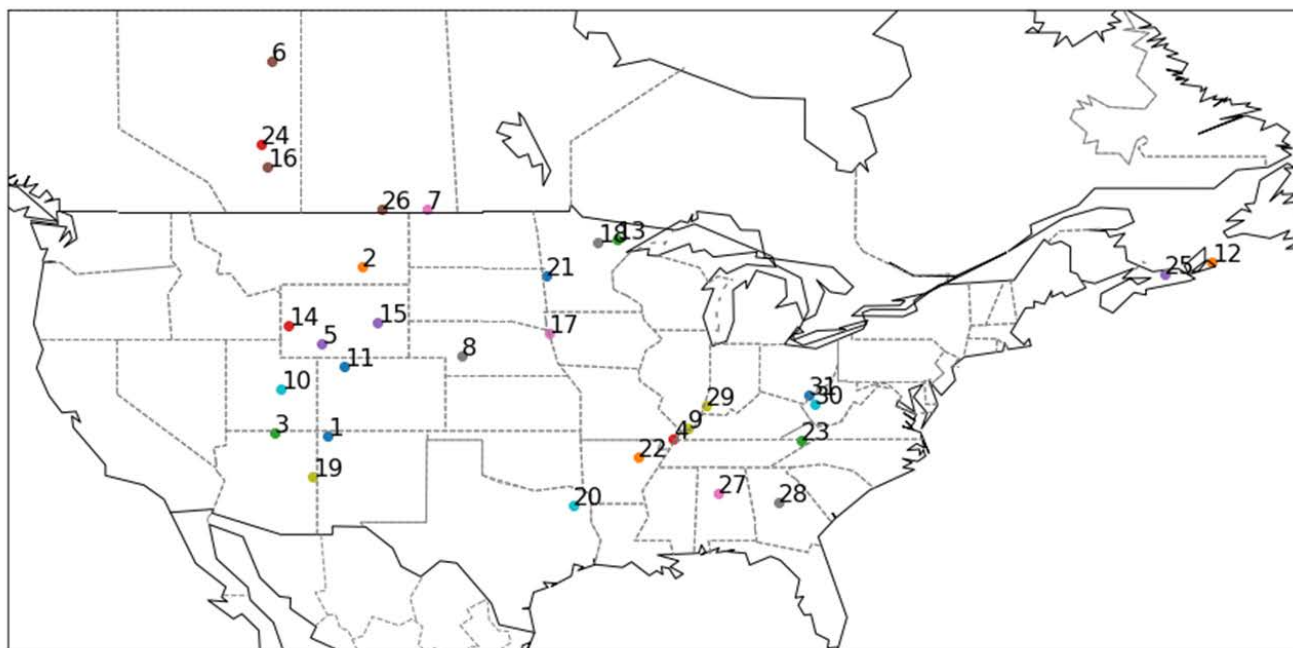
# OMI NO<sub>x</sub> emission estimates



- Tropospheric NO<sub>2</sub> VCD, SPv3 with air mass factor (AMF) corrections for North America [McLinden et al., 2014]
- Exponentially modified Gaussian (EMG) function to derive emissions from power plants (point source) [Fioletov et al., 2015]
- Before the fitting, a wind rotation is applied, wind speed > 0.5m/s
- Assuming lifetime 3h, plume spread  $\sigma=22\text{km}$  (for EMG)
- ERA-Interim wind fields merged with the OMI dataset, 900-950hPa
- April-October was used for sites located above 40°N

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# Power plants in North America



- |                          |                       |
|--------------------------|-----------------------|
| • 1 FourCorners          | • 17 GeorgeNeal       |
| • 2 Colstrip             | • 18 Boswell          |
| • 3 Navajo               | • 19 Coronado         |
| • 4 NewMadrid            | • 20 Monticello       |
| • 5 JimBridger           | • 21 BigStone         |
| • 6 Syncrude             | • 22 Independence     |
| • 7 SaskPowerA           | • 23 Eastman          |
| • 8 GeraldGentleman      | • 24 AlbertaPowerB    |
| • 9 Shawnee              | • 25 NovaScotiaPowerB |
| • 10 Hunter              | • 26 SaskPowerB       |
| • 11 Craig               | • 27 James_H_Miller   |
| • 12 NovaScotiaPowerA    | • 28 Scherer          |
| • 13 USSteelCorp-Minntac | • 29 Gibson           |
| • 14 Naughton            | • 30 John_E_Amos      |
| • 15 DaveJohnston        | • 31 Gen_J_M_Gavin    |
| • 16 AlbertaPowerA       |                       |

Isolated, large- to mid-size (coal-fired) power plants

NO<sub>x</sub> emissions from the NO<sub>2</sub> measurements we assume:

NO<sub>2</sub>:NO<sub>x</sub>=0.7 (GEM-MACH)

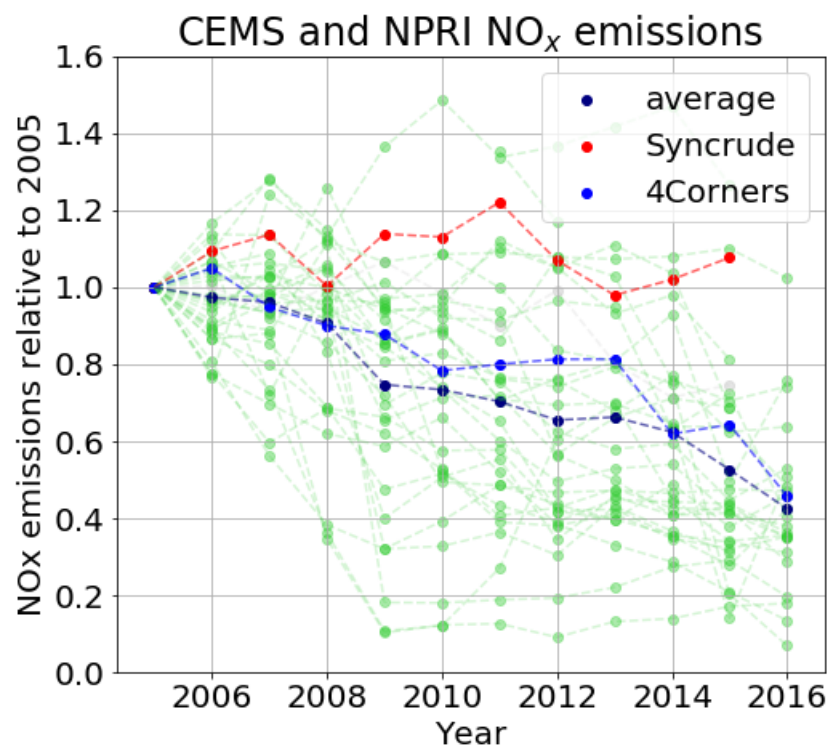
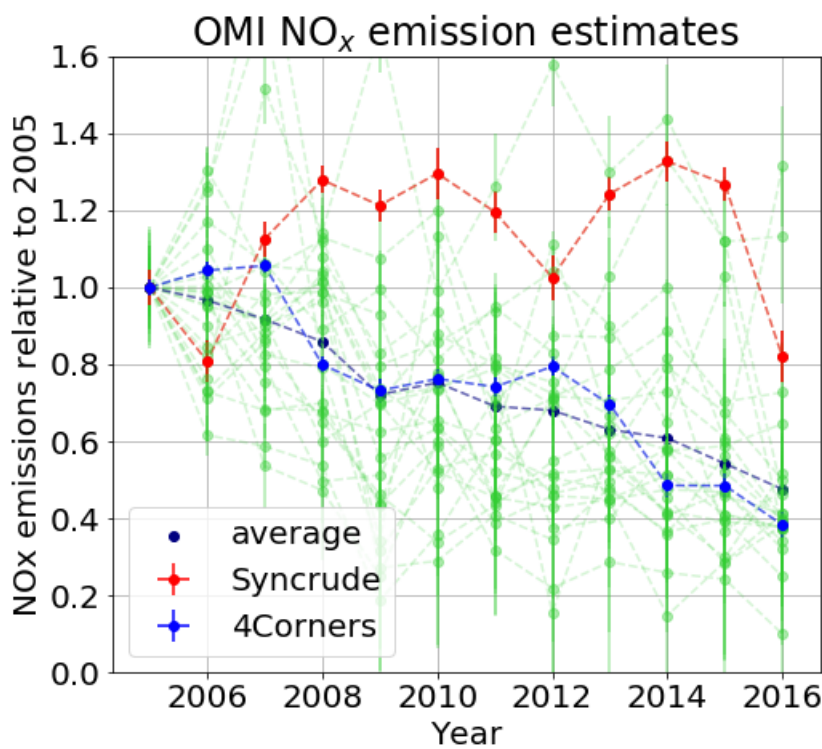
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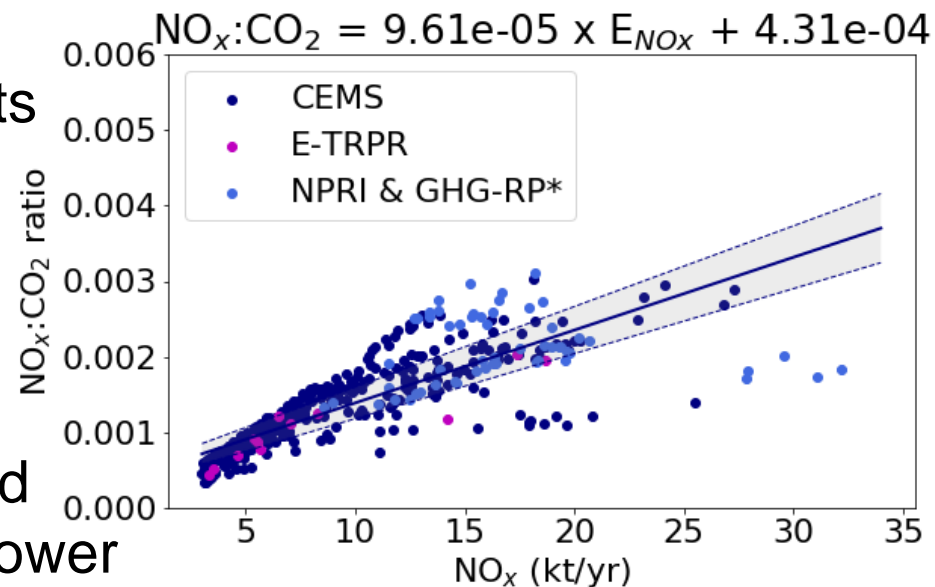
# NO<sub>x</sub> emissions from NA power plants

- NO<sub>x</sub> emissions are decreasing across North America (US+CA)
- On average by 50% between 2005 and 2016
- Good agreement between the trends from OMI estimates and CEMS
- Individual NO<sub>x</sub> emissions estimated with the OMI NO<sub>2</sub> dataset correlate well with the CEMS dataset (s=0.78 and R=0.84)



# NO<sub>x</sub>:CO<sub>2</sub> ratios

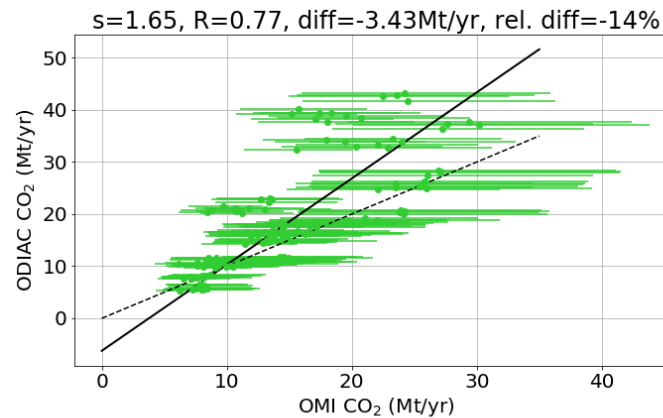
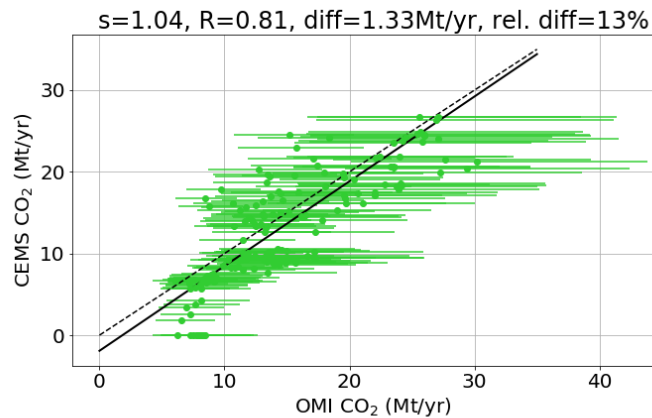
- CEMS data, emissions by stack, 2004-2016
- For large/mid-size power plants (>5 MW-h) with NO<sub>x</sub> controls
- Increasing NO<sub>x</sub>:CO<sub>2</sub> ratio for increasing NO<sub>x</sub> emissions
- Also shown: the Canadian (NPRI/GHG-RP, light blue) and European (E-TRPR, purple) power plant emissions, the ratio also seems to be valid for those
- For facilities without NO<sub>x</sub> controls, we found a ratio of approximately:  
NO<sub>x</sub>:CO<sub>2</sub> ~ (2.38 ± 0.94) × 10<sup>-3</sup>



# CO<sub>2</sub> emissions from US power plants

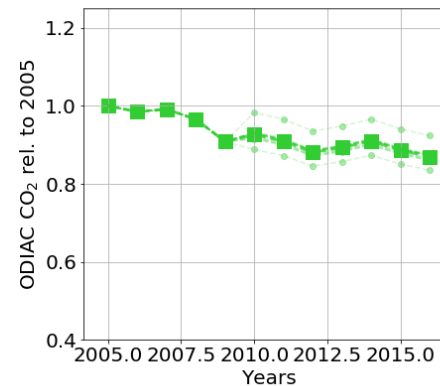
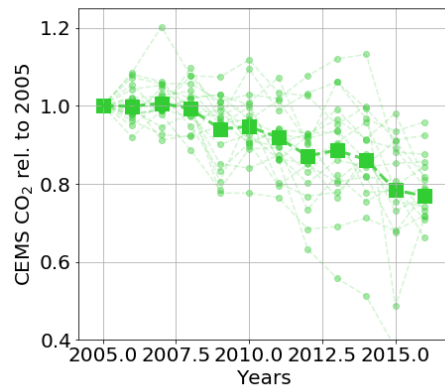
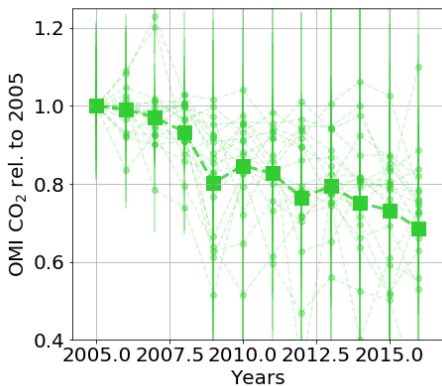
## “OMI CO<sub>2</sub>“:

From annual OMI NO<sub>x</sub> emission estimate and the linear NO<sub>x</sub>:CO<sub>2</sub> ratio (per stack) → total emissions are divided by the number of emitting stacks of the facility to obtain NO<sub>x</sub>:CO<sub>2</sub> ratio



CO<sub>2</sub> emissions in 2016 relative to 2005:

- OMI: ~30%
- CEMS: ~23%
- ODIAC: ~13%



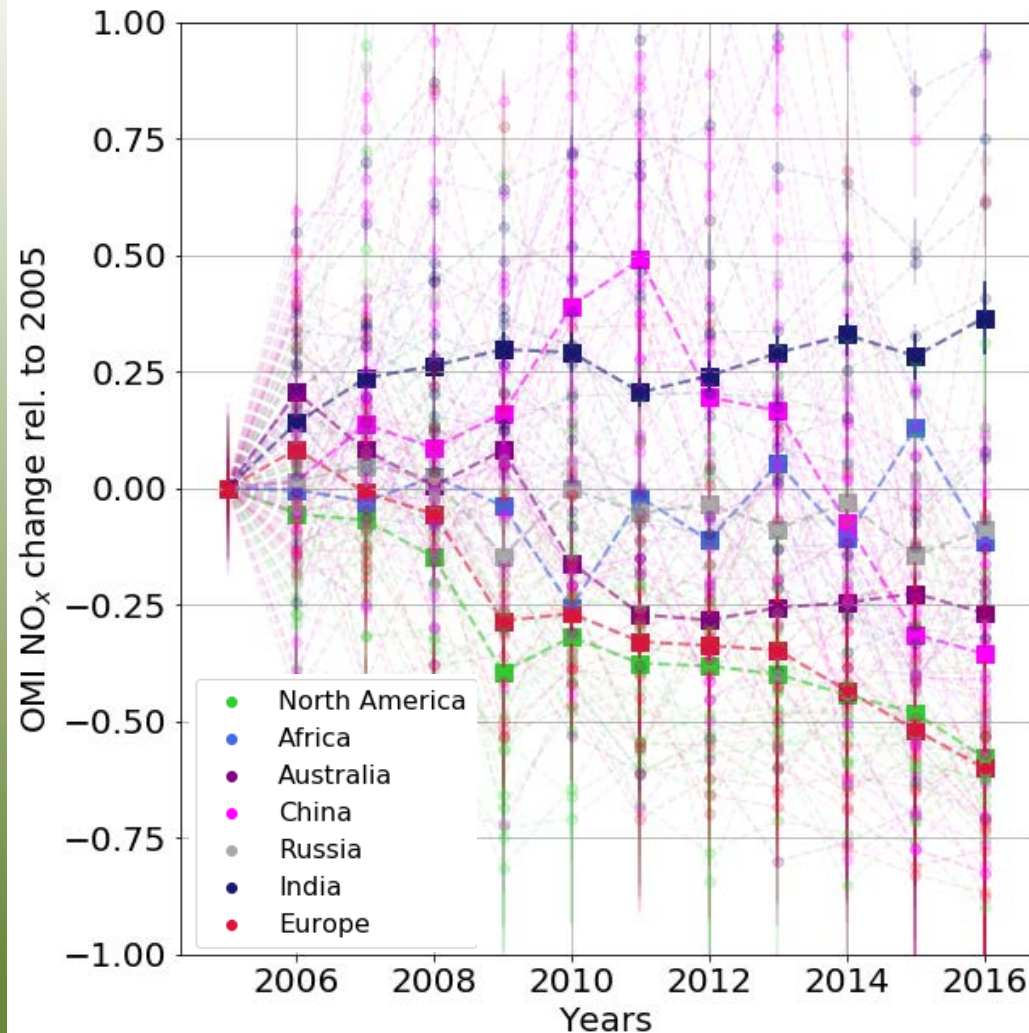


# NOx emissions around the world



- |                          |                            |                            |                   |                  |                     |
|--------------------------|----------------------------|----------------------------|-------------------|------------------|---------------------|
| ● 1 FourCorners          | ● 19 SaskPowerB            | ● 5 Liuzhou                | ● 23 Xiangfan     | ● 7 Pavlodar     | ● 13 Bokaro         |
| ● 2 Colstrip             | ● 20 James_H_Miller        | ● 6 Houshi                 | ● 24 Guangan      | ● 8 Almaty       | ● 14 MaeMo          |
| ● 3 Navajo               | ● 21 Scherer               | ● 7 Emeishan               | ● 25 Erdaojiang   | ● 9 Karaganda    | ● 1 Drax            |
| ● 4 NewMadrid            | ● 22 Gibson                | ● 8 Datong                 | ● 26 Donghae      | ● 10 Ekibastuz   | ● 2 Ratcliff        |
| ● 5 JimBridger           | ● 23 John_E_Amos           | ● 9 HuadianHuangjiaozhuang | ● 27 Pohang       | ● 11 Ufa         | ● 3 FiddlersFerry   |
| ● 6 Syncrude             | ● 24 Gen_J_M_Gavin         | ● 10 Xining                | ● 28 Pingliang    | ● 12 Nizhnekamsk | ● 4 LeHavre         |
| ● 7 SaskPowerA           | ● 1 Matimba                | ● 11 Xigu                  | ● 29 Changchun    | ● 1 Sasan        | ● 5 Leini           |
| ● 8 GeraldGentleman      | ● 1 BayswaterPowerStation  | ● 12 HunanLianyuan         | ● 30 Qitah        | ● 2 Talcher      | ● 6 Taranto         |
| ● 9 Shawnee              | ● 2 GladstonePowerStation  | ● 13 Fuzhou                | ● 31 Mudanjiang   | ● 3 Chandrapur   | ● 7 Belchatow       |
| ● 10 Hunter              | ● 3 AGLLOYYang             | ● 14 Longweiping           | ● 32 Jiamusi      | ● 4 Neyveli      | ● 8 Kozenice        |
| ● 11 Craig               | ● 4 ValesPointPowerStation | ● 15 Luohuang              | ● 33 Qiqihar      | ● 5 Suratgarh    | ● 9 Rybnik          |
| ● 12 USSteelCorp-Minntac | ● 5 StanwellPowerStation   | ● 16 HuanengFuzhou         | ● 34 Shuangyashan | ● 6 Panipat      | ● 10 Rovinari       |
| ● 13 DaveJohnston        | ● 6 TarongPowerStation     | ● 17 HangHauLongyan        | ● 1 Surgut        | ● 7 Kahalgaon    | ● 11 Luhansk        |
| ● 14 AlbertaPowerA       | ● 7 CallidePowerStation    | ● 18 Yongan                | ● 2 Reftinskaya   | ● 8 Durgapur     | ● 12 Ponetsk        |
| ● 15 GeorgeNeal          | ● 1 Guangan                | ● 19 Huolinhe              | ● 3 Kostromskaya  | ● 9 Farrakka     | ● 13 Kurakhove      |
| ● 16 Coronado            | ● 2 Panzhihua              | ● 20 Tongliao              | ● 4 Magnitogorsk  | ● 10 Ramagundam  | ● 14 Janschwalde    |
| ● 17 Independence        | ● 3 YingBaobao             | ● 21 Fengcheng             | ● 5 Cheryabinsk   | ● 11 Mettur      | ● 15 Mannheim       |
| ● 18 Eastman             | ● 4 Honghe                 | ● 22 Daqing                | ● 6 Omsk          | ● 12 Jojobera    | ● 16 AgiosDimitrios |

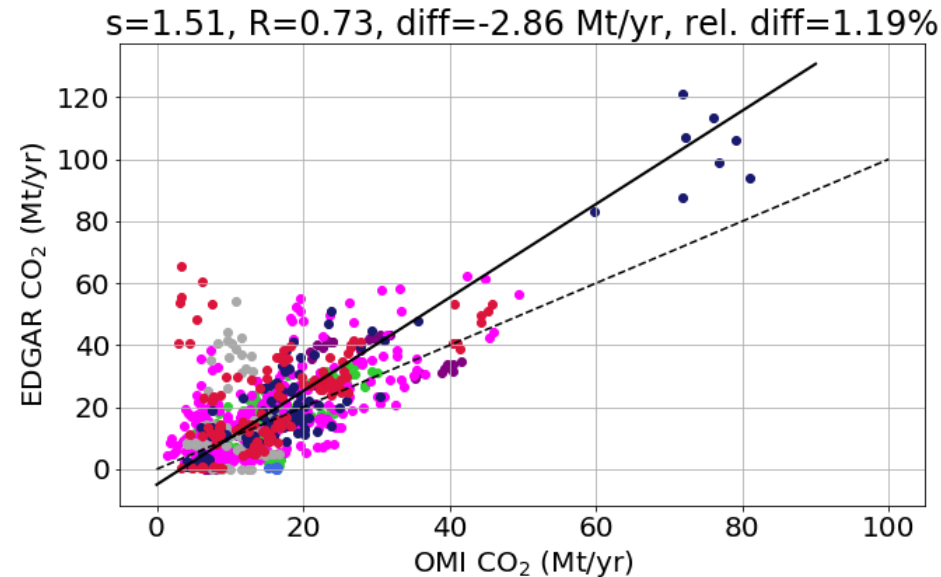
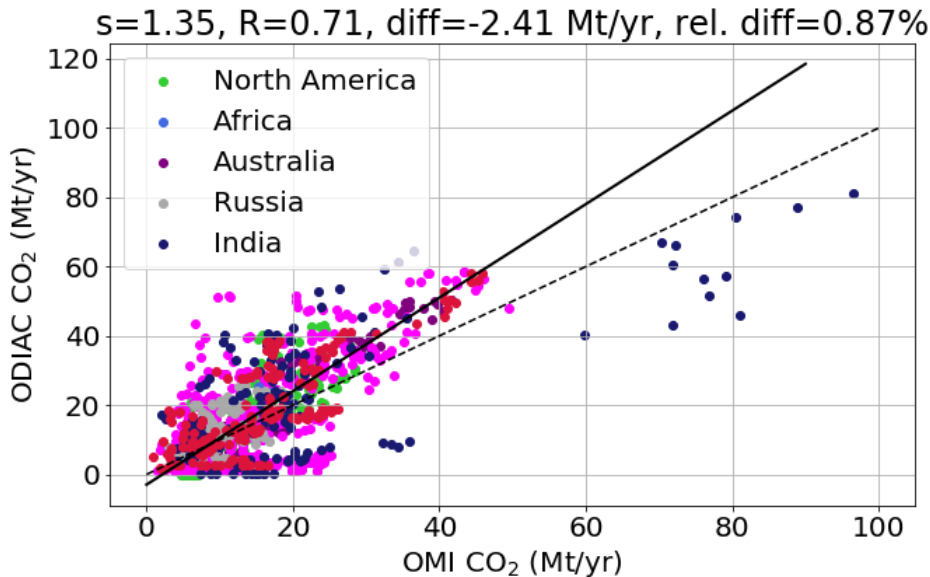
# NO<sub>x</sub> emissions around the world



- Reduction of NO<sub>x</sub> emissions by over 50% for the power plants in North America (US+CA) and Europe, and a reduction in Australia by around 25%
- Reduction of NO<sub>x</sub> emissions for the power plants in China since 2011
- Increasing NO<sub>x</sub> emissions for the power plants in India (~40%)
- Nearly constant emissions for Russia and South Africa



# CO<sub>2</sub> emissions around the world



- Overall good agreement between the “OMI CO<sub>2</sub>” emissions and the ODIAC and EDGAR v4.2.3 CO<sub>2</sub> inventories
- Some missing sources (possibly due to wrong coordinates in the ODIAC inventory in China and India)
- EDGAR CO<sub>2</sub> for Matimba (South Africa) are underestimated

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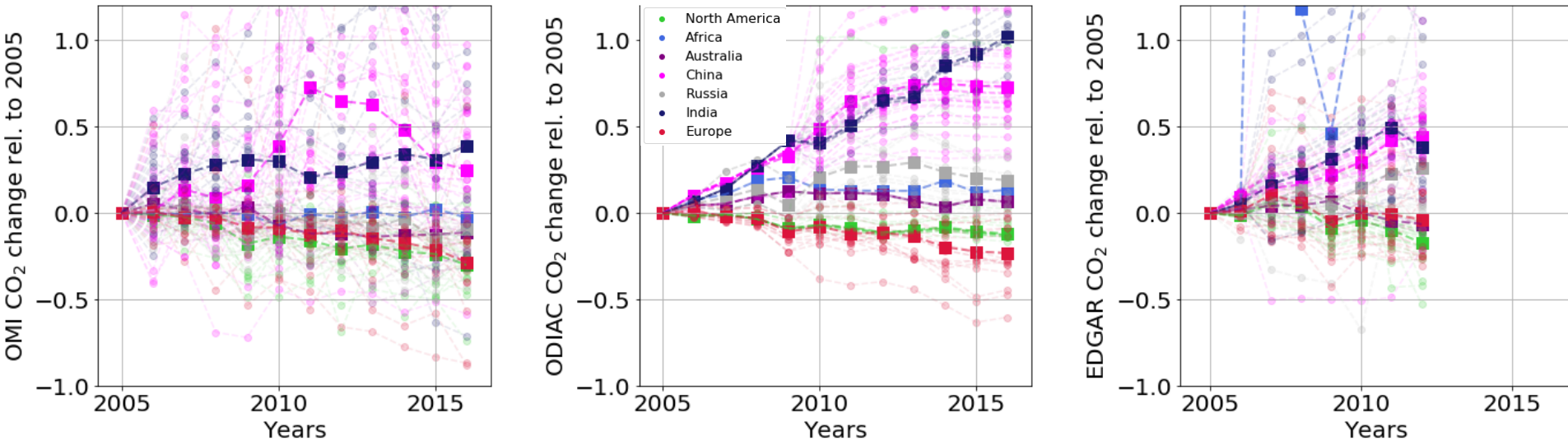


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# CO<sub>2</sub> emissions around the world



- Reduction in North America and Europe by ~25% since 2005
- According to OMI estimates reduction for of CO<sub>2</sub> for power plants in China after 2011, not seen in ODIAC
- Increasing trend in India (different rate for OMI and ODIAC)
- Note, only for the power plants shown on slide 9, this is not a national average

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# Comparison with OCO-2 estimates

plant	year	NO <sub>x</sub> :CO <sub>2</sub>	OMI CO <sub>2</sub> (kt/d)	ODIAC CO <sub>2</sub> (kt/d)	OCO-2 overpass	OCO-2 CO <sub>2</sub> (kt/d)
Gavin +Kyger	2015	1.28x10 <sup>-3</sup>	56	104	2015/07/30	49±10
Matimba	2014	1.86x10 <sup>-3</sup>	44	71	2014/11/07	33±3
Matimba	2016	1.85x10 <sup>-3</sup>	44	68	2016/10/11	34±10

- OCO-2 CO<sub>2</sub> emission estimates from Nassar et al., 2017, GRL
- OCO-2 emission estimates are based on one overpass at a specific time and date
- OMI are estimated from all measurements from the specified year (or April-October for Gavin/Kyger power plants)
- Nevertheless, the emission estimates between OCO-2 and OMI agree reasonably well





# Conclusions

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- $\text{NO}_x$  emission can be estimated from OMI measurements for large- to mid-size power plants and refineries, with uncertainties around 30%
- $\text{NO}_x:\text{CO}_2$  emission ratios in good agreement with previous studies [Berezin et al., 2013; Reuter et al., 2014, Tong et al., 2018]
- $\text{CO}_2$  emission can be estimated from the OMI  $\text{NO}_x$  emission estimates and the  $\text{NO}_x:\text{CO}_2$  emission ratio (from CEMS), uncertainties are around 35-45%
- Can be applied outside North America, however, there are larger uncertainties for China and India





# Implications for future research

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- This method can help to improve current emission inventories by identifying missing sources
- It help improve emission inventories in countries where emissions have large uncertainties
- It can be used when CO<sub>2</sub> measurements are not available
- NO<sub>x</sub> emissions from cities can be estimated from the OMI dataset [Beirle et al., 2011] and can help estimate CO<sub>2</sub> emissions from cities
- It can be applied to new satellite instruments such as TROPOMI that has a smaller pixel size that can make it possible to estimate monthly, weekly emissions or even for single overpasses.

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