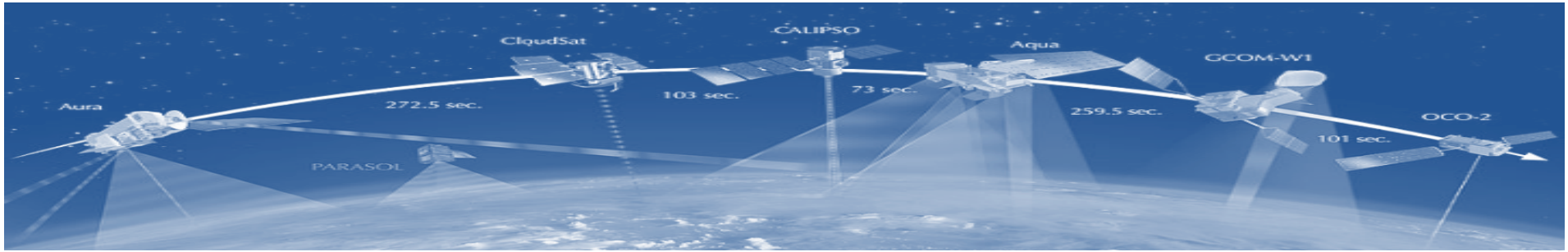


# $SO_2$ emission estimates using OMI $SO_2$ and $NO_2$ retrievals for 2005 - 2017

**Zhen Qu**[1], Daven K. Henze[1], Can Li[2,3], Nicolas Theys[4], Yi Wang[5], Jun Wang[5], Wei Wang[6], Jihyun Han[7], Changsub Shim[7], Russell R. Dickerson[3], Xinrong Ren[3], Helen Worden[8]

zhen.qu@colorado.edu

Aug 27th, 2019, Aura STM

Funding: NASA ACMAP & HAQAST

[1]University of Colorado Boulder, [2]NASA Goddard Space Flight Center, [3]University of Maryland, [4]Belgian Institute for Space Aeronomy, [5]University of Iowa, [6]China National Environmental Monitoring Center, [7]Korea Environment Institute, [8]National Center for Atmospheric Research.

# Motivations



- Top-down estimates: different magnitude of $SO_2$ emissions

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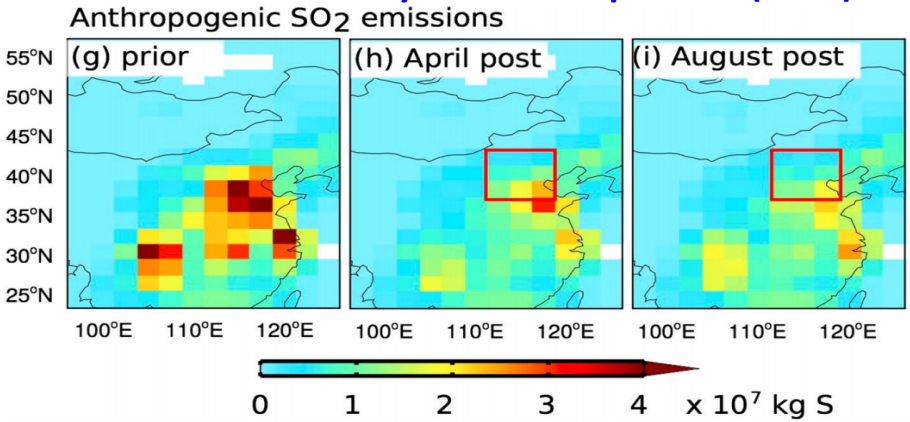
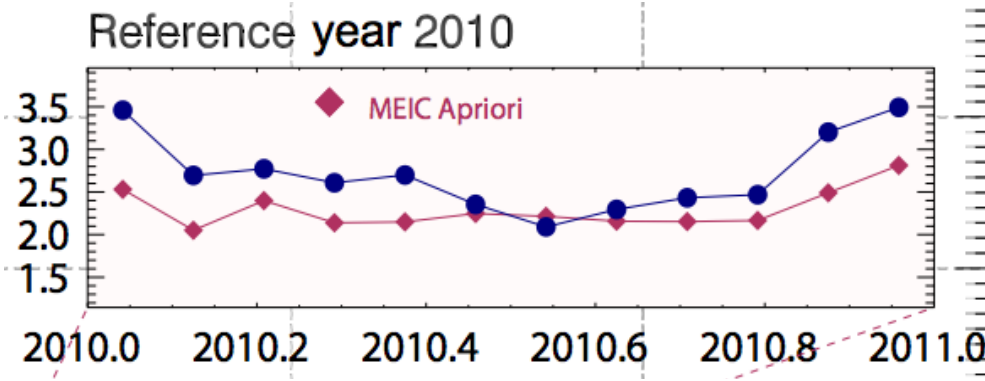
- Top-down emissions in China: 843 Gg S in April 2008 from Wang et al. [2016], but 1542 Gg S from Koukouli et al. [2018].

**constrained by OMI NASA product (2008)**




(Wang et al. 2016)

**constrained by OMI BIRA product (2010)**




(Koukouli et al. 2018)

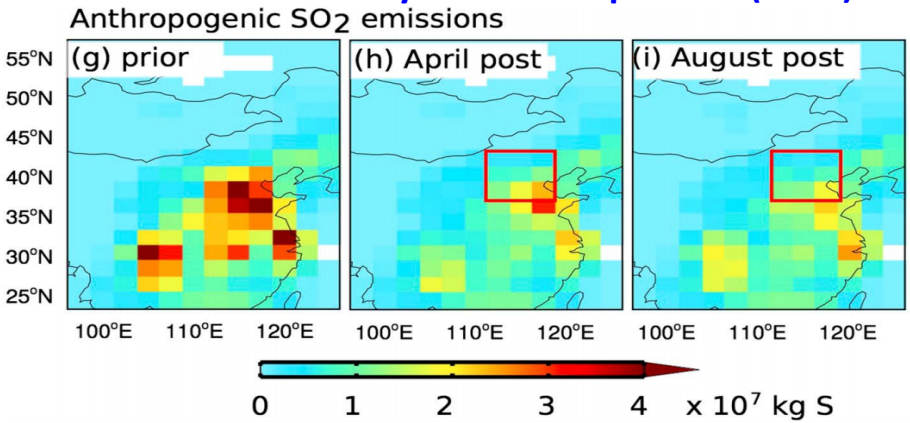
# Motivations



- Top-down estimates: different magnitude of $SO_2$ emissions

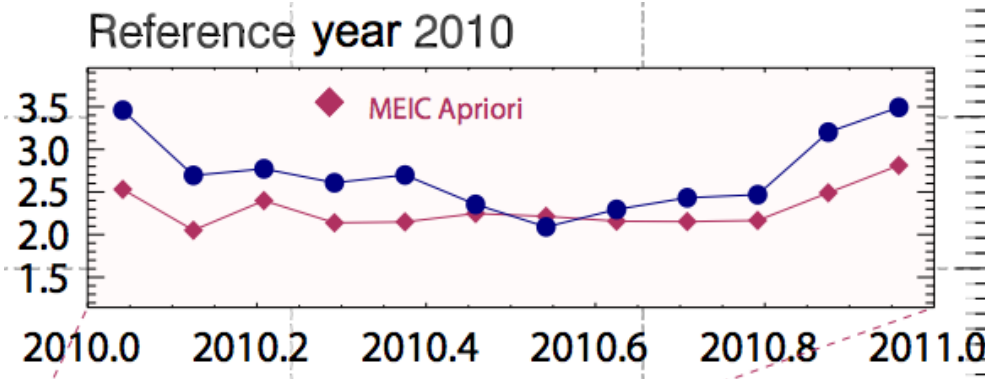
- Top-down emissions in China: 843 Gg S in April 2008 from Wang et al. [2016], but 1542 Gg S from Koukouli et al. [2018].
- Lack of detailed comparison & evaluation of the magnitude, seasonality, and inter-annual variation of the newest OMI $SO_2$ retrievals.

**constrained by OMI NASA product (2008)**




(Wang et al. 2016)

**constrained by OMI BIRA product (2010)**




(Koukouli et al. 2018)

# Evaluation of OMI $SO_2$ retrievals



- Three products: NASA standard (SP), NASA prototype, BIRA

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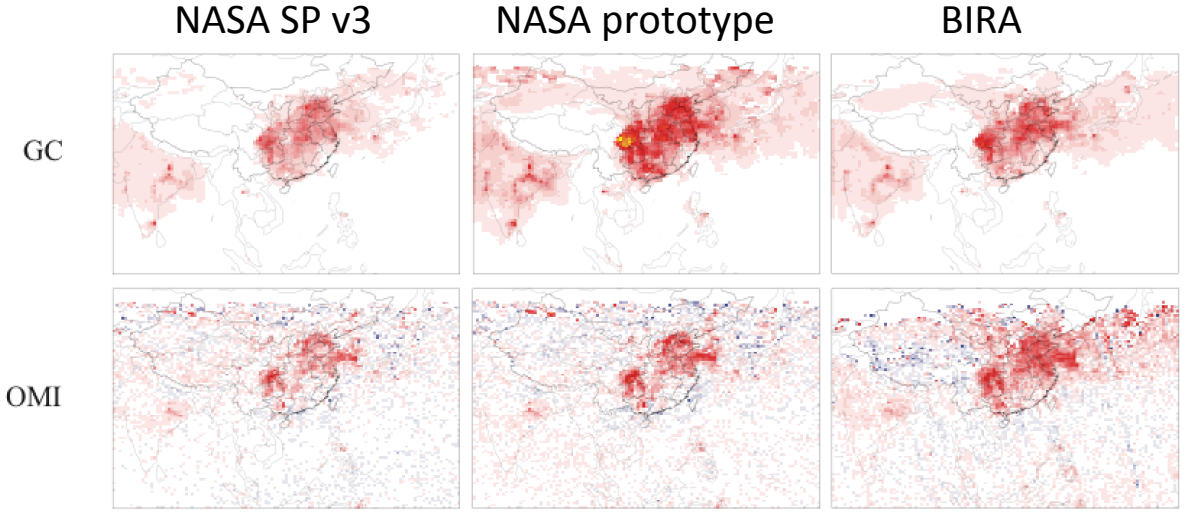
## $SO_2$ slant column density (SCD)




- GC column: NASA prototype >BIRA
- OMI column: NASA < BIRA
- more positive GC – OMI ➔ more decrease of emissions using NASA product

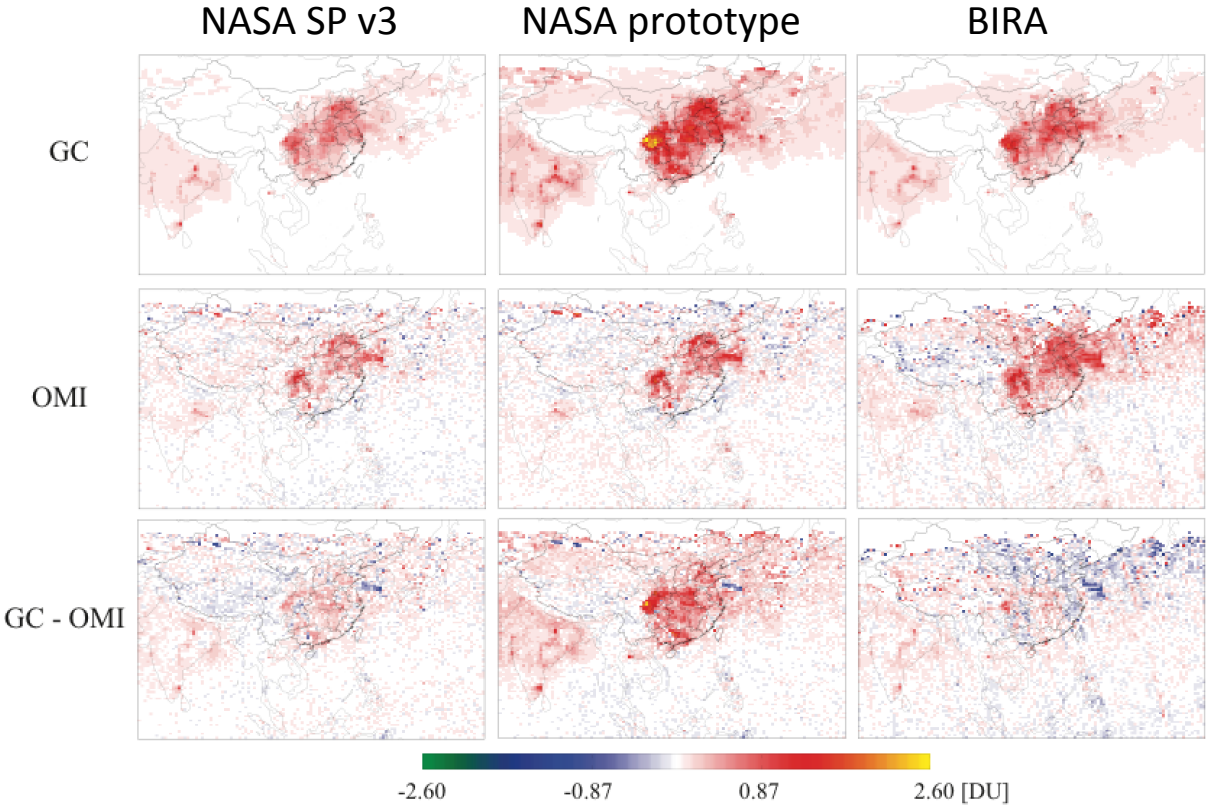
(Qu et al., 2019a)

# Evaluation of OMI $SO_2$ retrievals



- Three products: NASA standard (SP), NASA prototype, BIRA
- Differences in model and OMI column drives emission estimates

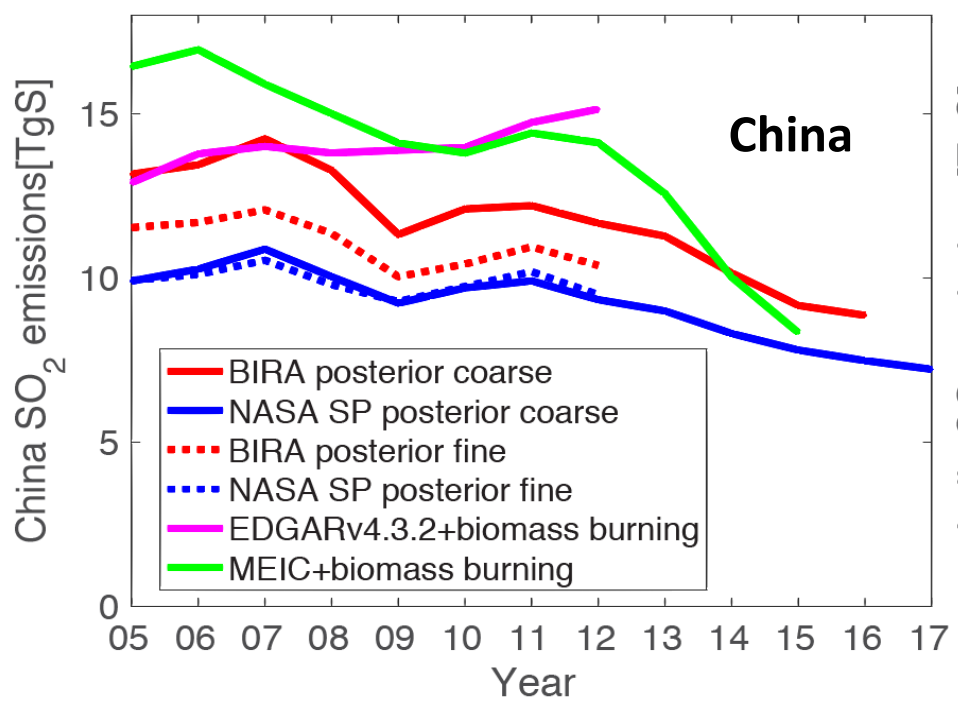
**$SO_2$ slant column density (SCD)**

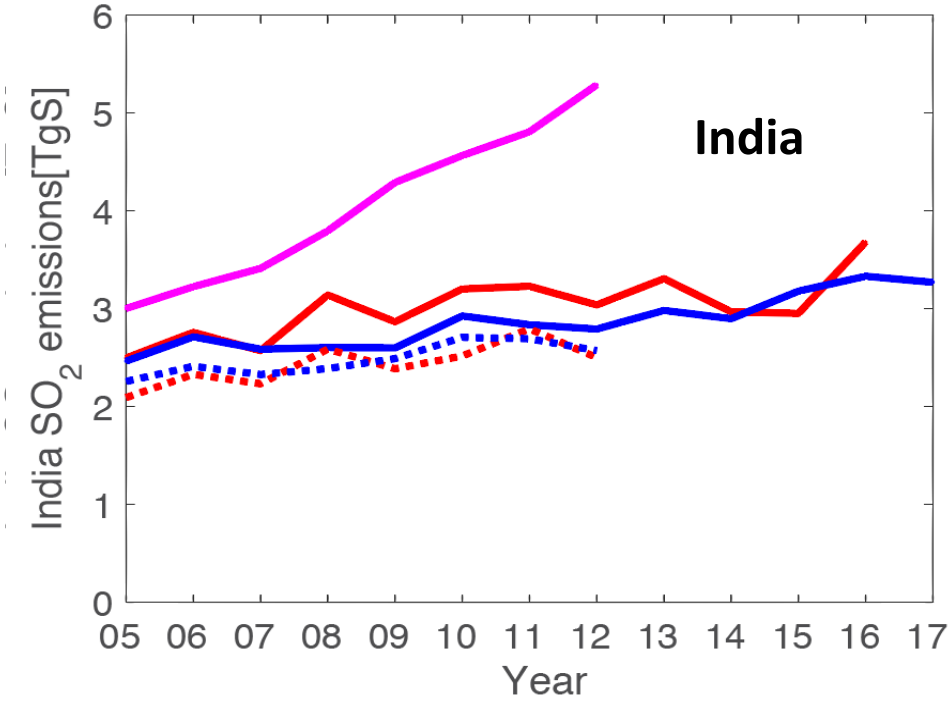



- GC column: NASA prototype >BIRA
- OMI column: NASA < BIRA
- more positive GC – OMI ➔ more decrease of emissions using NASA product
- GC – OMI: more consistent at low latitude (small VZA) and in July in NH (small SZA)

(Qu et al., 2019a)

# Trend of $SO_2$ emissions




- From GEOS-Chem 4D-Var

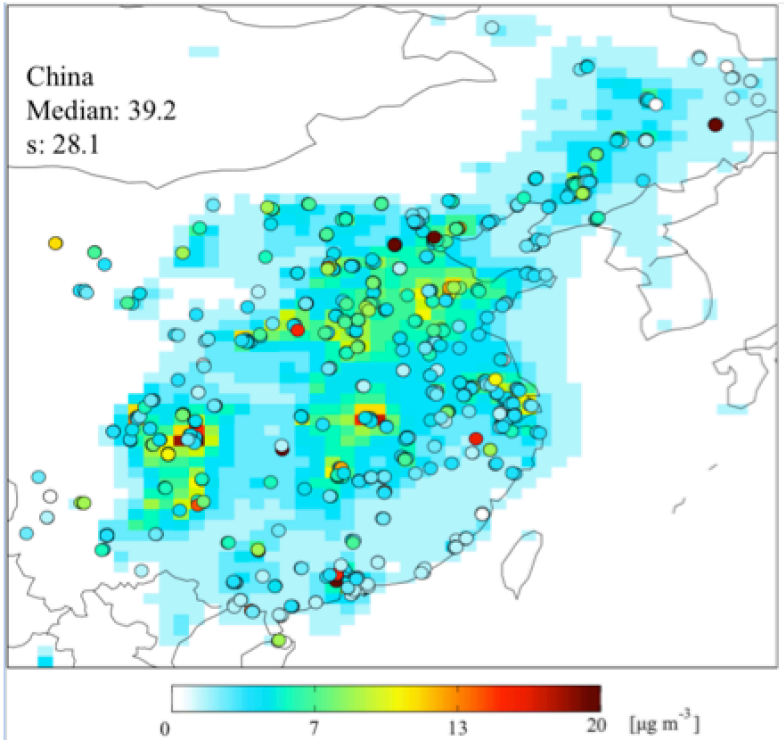
(Qu et al., 2019a)

# Mixed performance compared with surface measurement

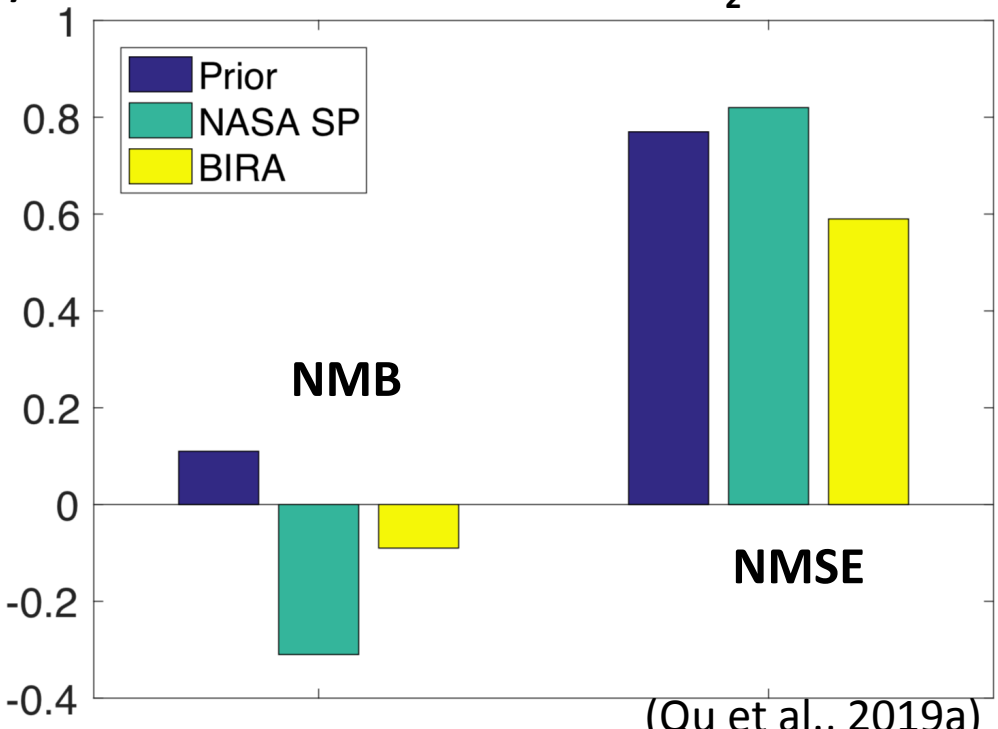


- Reduced NMB and NMSE in China using BIRA posterior, but increased using NASA SP posterior.

**Annual mean surface $SO_2$ concentration (2010)**




**NMB & NMSE of surface $SO_2$ in China**




(Qu et al., 2019a)

# Mixed performance compared with surface measurement



- Reduced NMB and NMSE in China using BIRA posterior, but increased using NASA SP posterior.
- China, South Korea and India: the NASA posteriors have better statistics in seasonality but worse in spatial variability and trend than BIRA posteriors.
- US: the NASA posteriors have better seasonality and spatial variability.

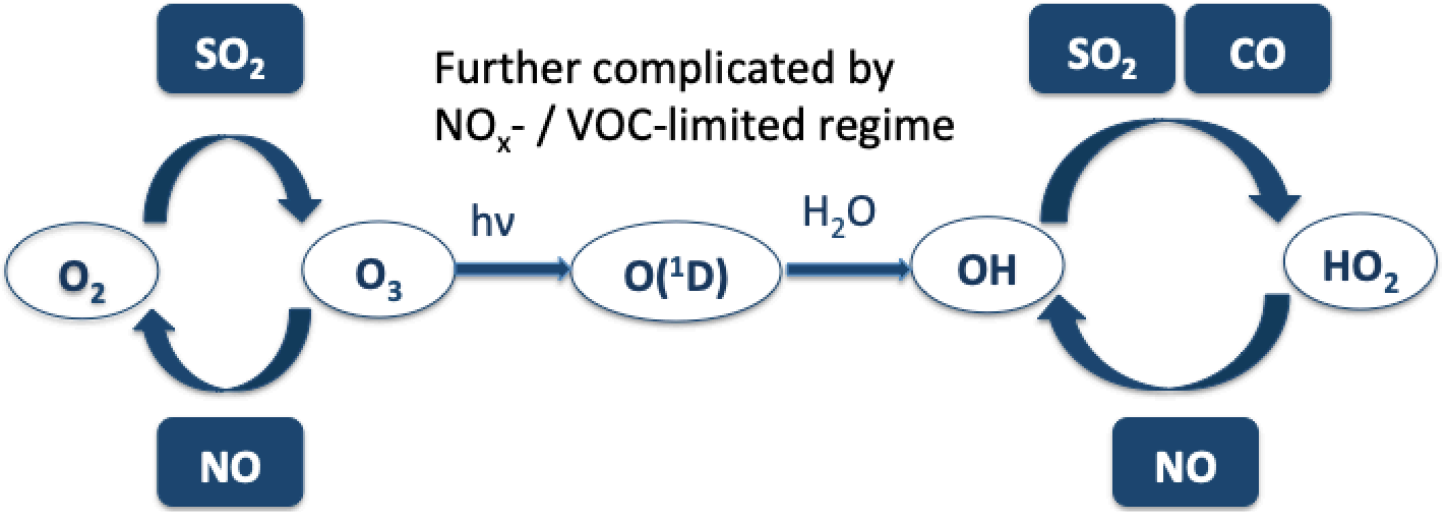
(Qu et al., 2019a)

# Top-down $SO_2$ emissions



**Still …**

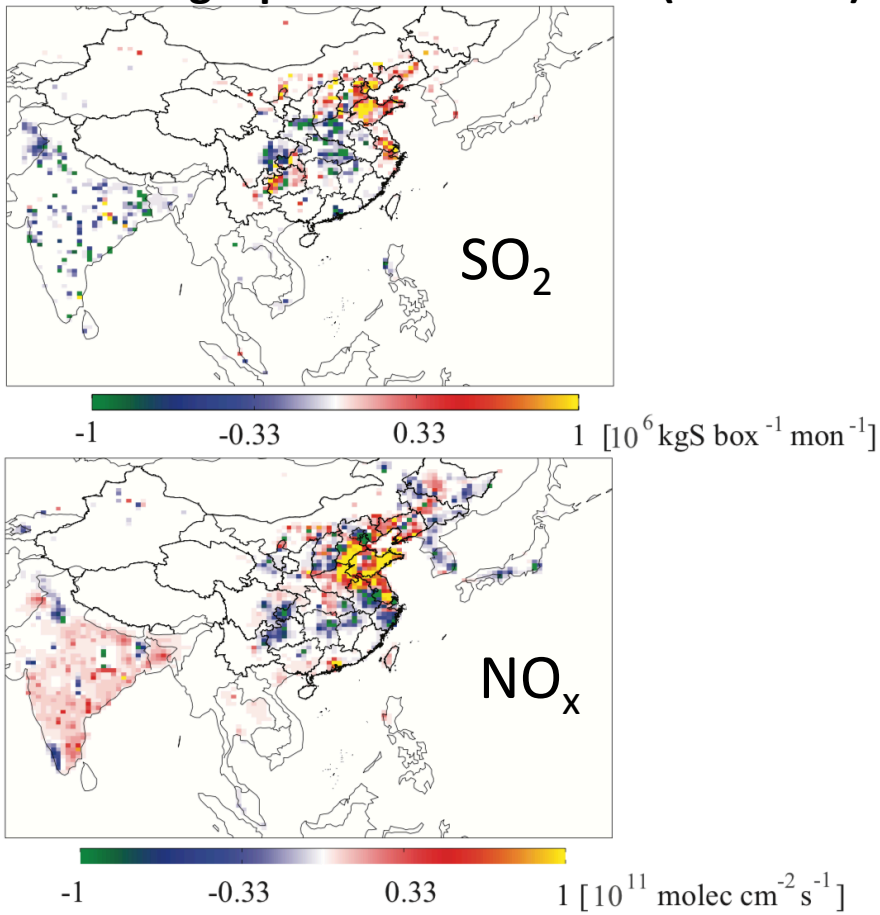
- Chemical interactions are not being considered so far
- Uncertainties in other species emissions are likely degrading the top-down emission of the constrained species



# Joint $NO_2$ & $SO_2$ inversion



**Joint − Single posterior emissions (Jan 2010)**




**Joint:** assimilate $NO_2$ and $SO_2$ observations to optimize $NO_x$ and $SO_2$ emissions simultaneously

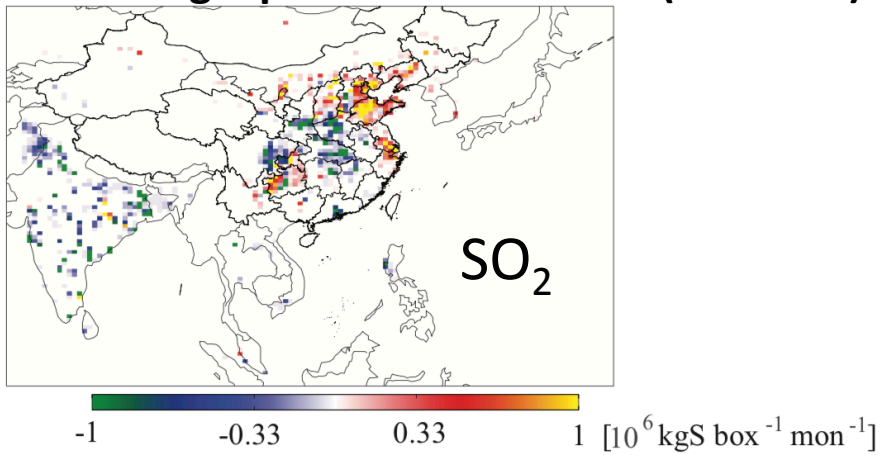
**Single:** only assimilate $NO_2$ ($SO_2$) observations to optimize $NO_x$ ($SO_2$) emissions

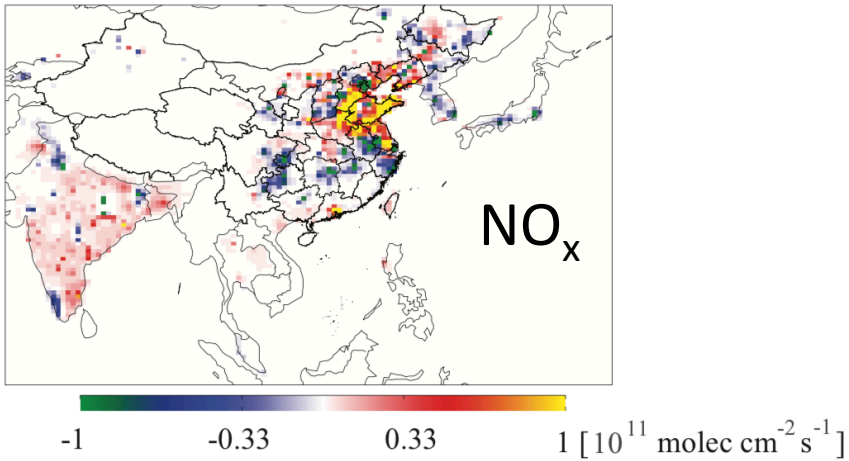
(Qu et al., 2019b)

# Joint $NO_2$ & $SO_2$ inversion

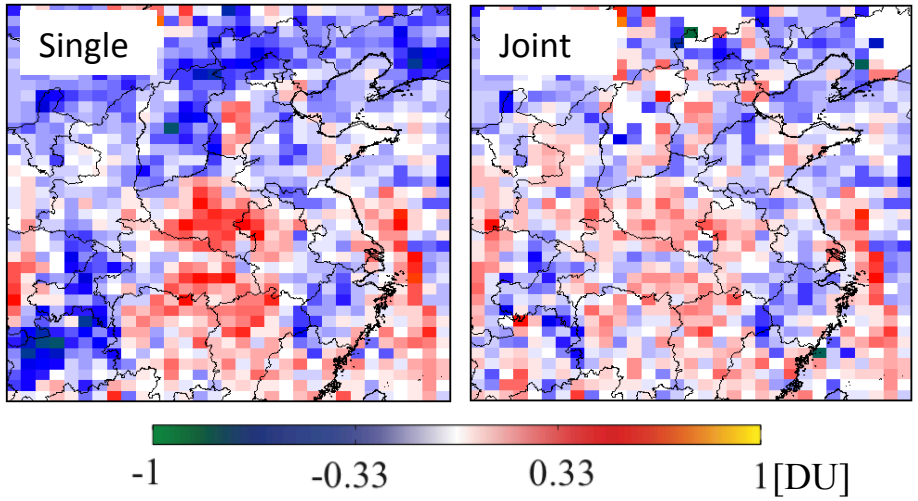


**Joint − Single posterior emissions (Jan 2010)**




**$SO_2$ columns (GEOS-Chem − OMI)**



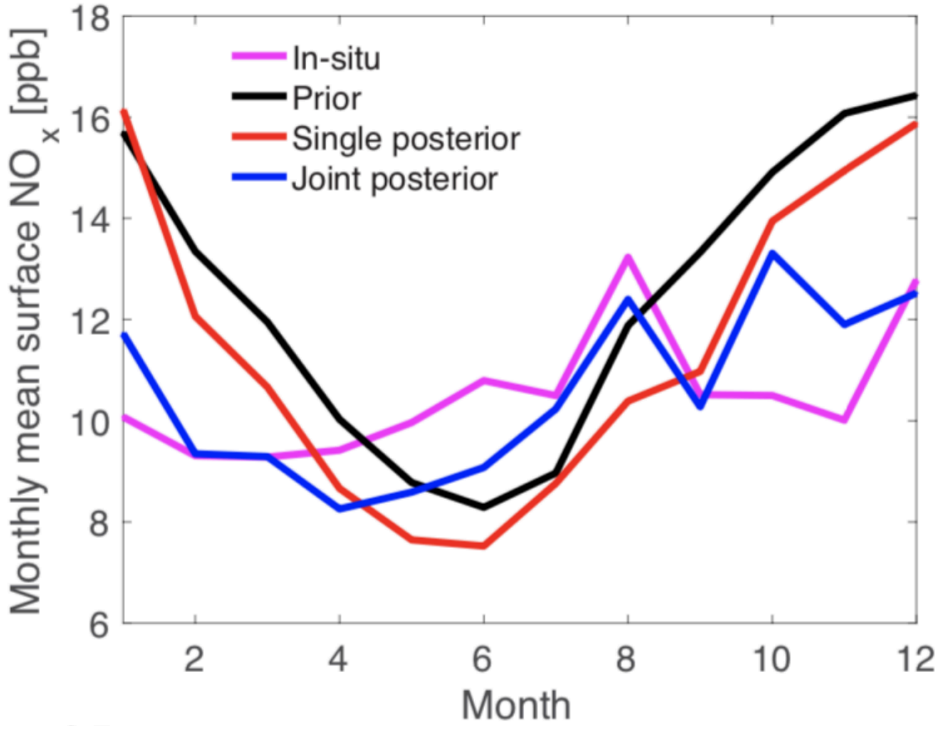

- Better match satellite and surface $NO_2$ and $SO_2$ measurements when satellite retrievals of the species being optimized have large uncertainties.

(Qu et al., 2019b)

# Joint $NO_2$ & $SO_2$ inversion



**Surface $NO_x$ concentration in India (2010)**

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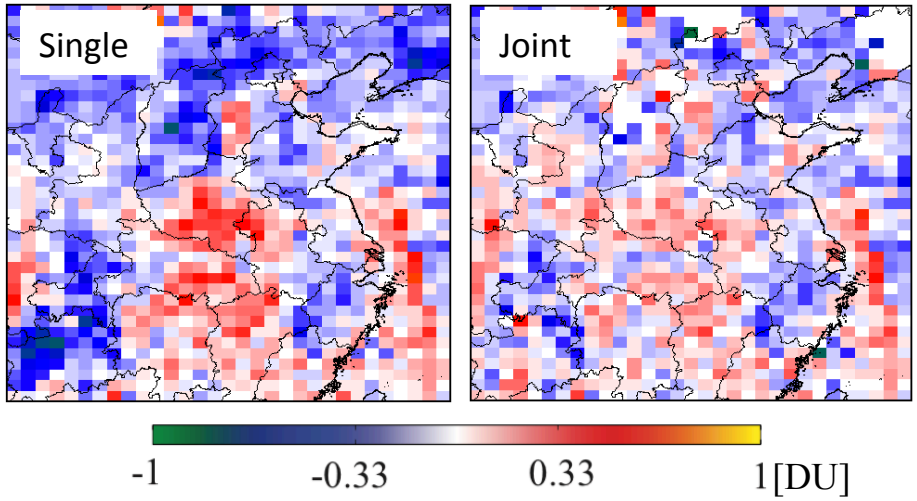


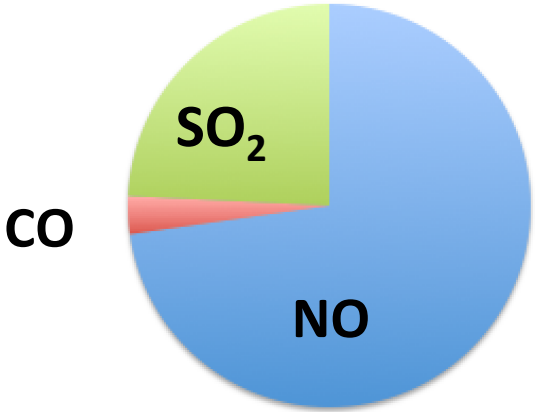

- Better match satellite and surface $NO_2$ and $SO_2$ measurements when satellite retrievals of the species being optimized have large uncertainties.

(Qu et al., 2019b)

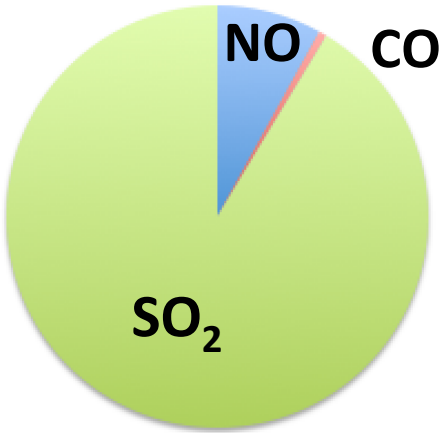
# Accounting for correlated co-emitted pollutants in 4D-Var



Transportation




Energy




**Sector-based emission scaling factor**

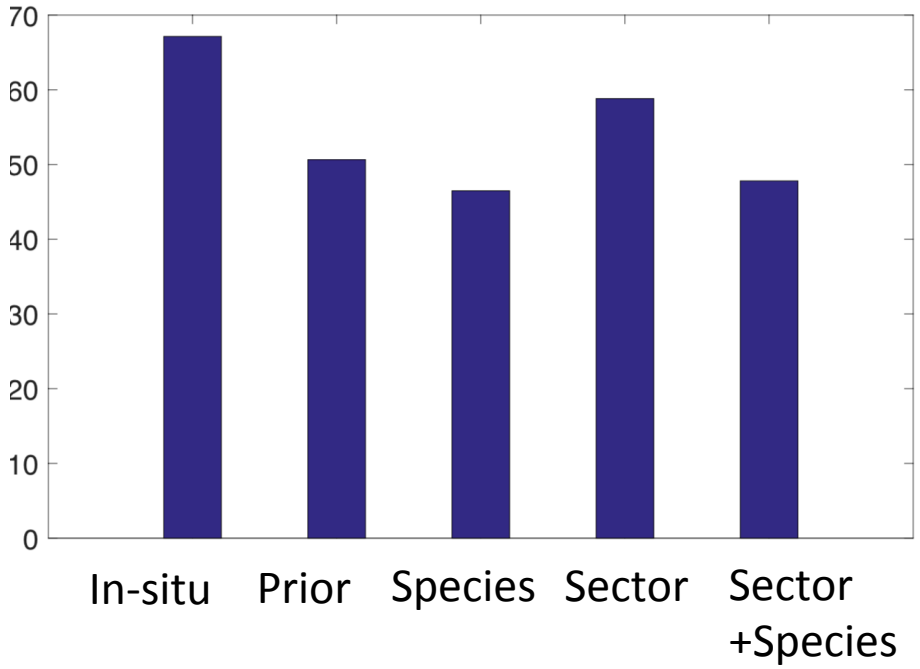
**Assimilate:**
MOPITT CO
OMI $NO_2$
OMI $SO_2$

**Similar ratio of $NO_x$, $SO_2$ and CO emissions in the same sector, yet very different across sectors.**

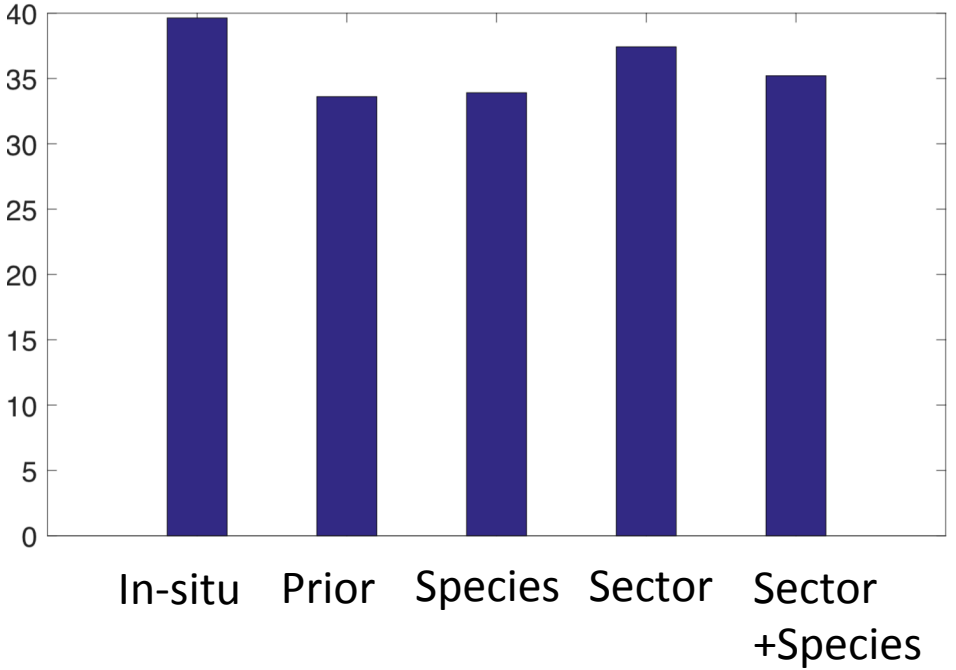
# Evaluations of posterior simulations with measurements



**Surface $SO_2$ concentrations in China [ug $m^{-3}$]**




**Surface $NO_2$ concentrations in China [ug $m^{-3}$]**




- NMB of posterior simulations from sector-based inversions are 59.8% ($SO_2$) and 61.4% ($NO_2$) smaller than the ones from species-based inversion.


# Take home messages:

- Treatment of clouds, radiative transfer model, and retrieval algorithm lead to differences in NASA and BIRA $SO_2$ retrievals, which are most consistent when VZA and SZA are small;
- $SO_2$ emissions continuously increase in India from 2005 - 2017 and start to decrease in China from 2008;
- Reduced error in $NO_x$ and $SO_2$ top-down emissions using multiple species joint inversion, through correction of OH concentration in the model, at months when observation uncertainties of optimized species are large;
- A new sector-based inversion is developed to estimate emissions at process level using satellite observations.

Qu et al. (2019a), $SO_2$ emission estimates using OMI $SO_2$ retrievals for 2005 – 2017

Qu et al. (2019b), Hybrid mass balance / 4D-Var joint inversion of $NO_x$ and $SO_2$ emissions in East Asia