New perspectives on air quality in East Asia: what we can learn from GEMS

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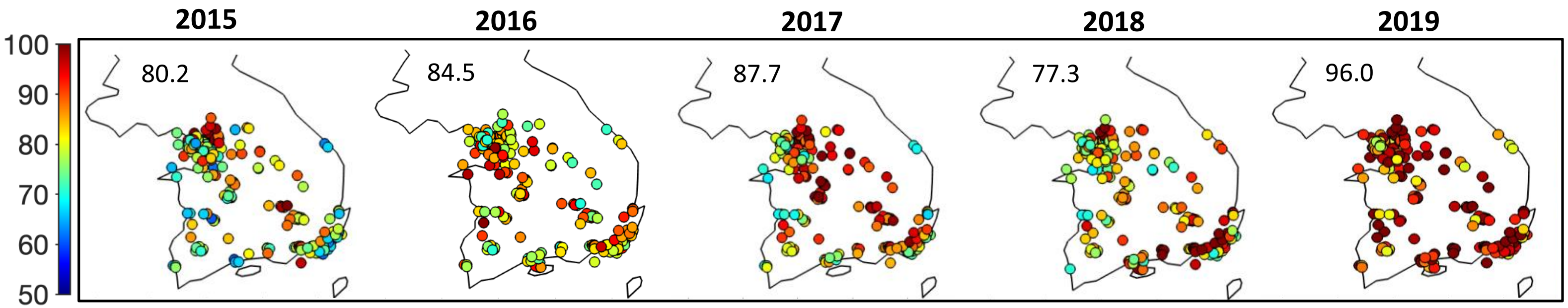
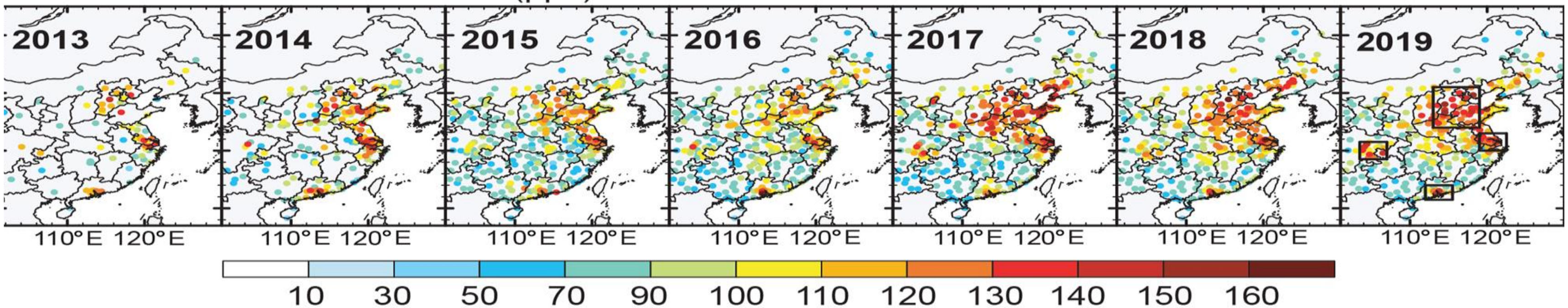
Why is ozone pollution over Korea and China getting worse?

Maximum Monthly 90th percentile MDA8 ozone, ppb

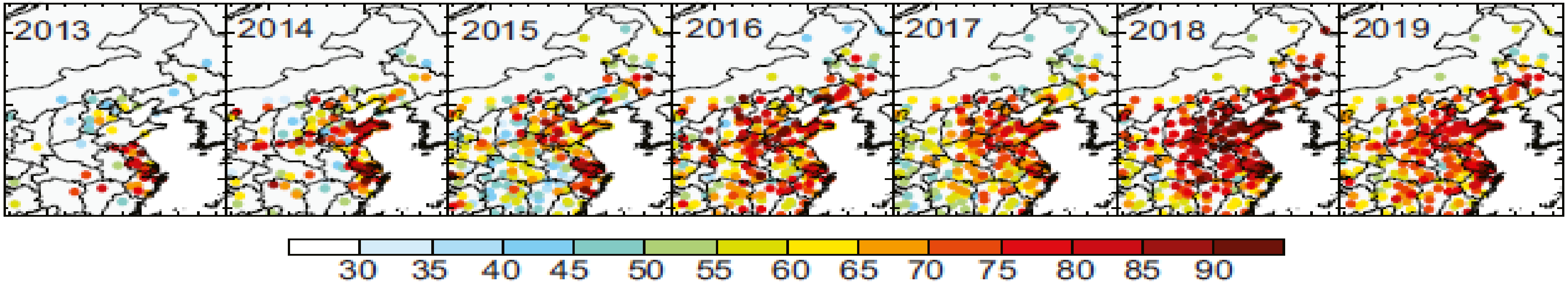
Seoul concentrations and rate of increase are highest in May



Summer maximum MDA8 ozone (ppb)



Maximum MDA8 ozone (ppb) in March

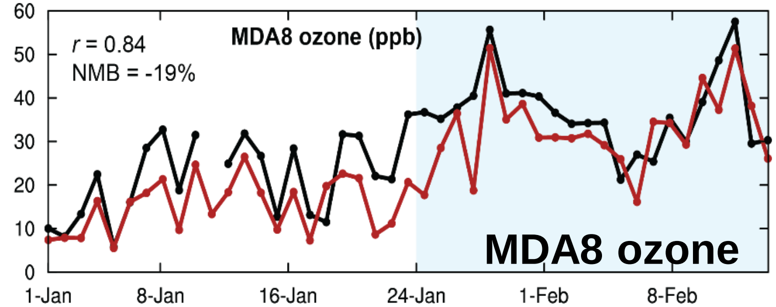


Hypothesis: decreasing PM (summer) and NO_x (rest of year), flat or increasing VOCs

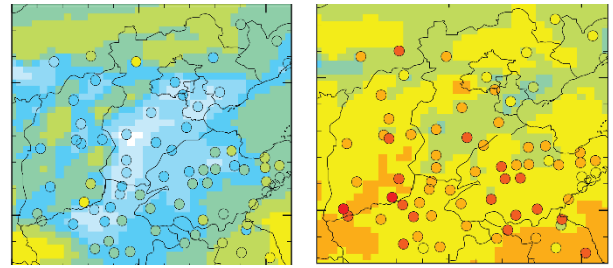
Li et al. [2020, 2021], Colombi et al., in prep.

COVID-19 lockdown revealed fast wintertime ozone production in Beijing

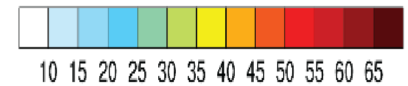
Beijing: **observations** and **GEOS-Chem**

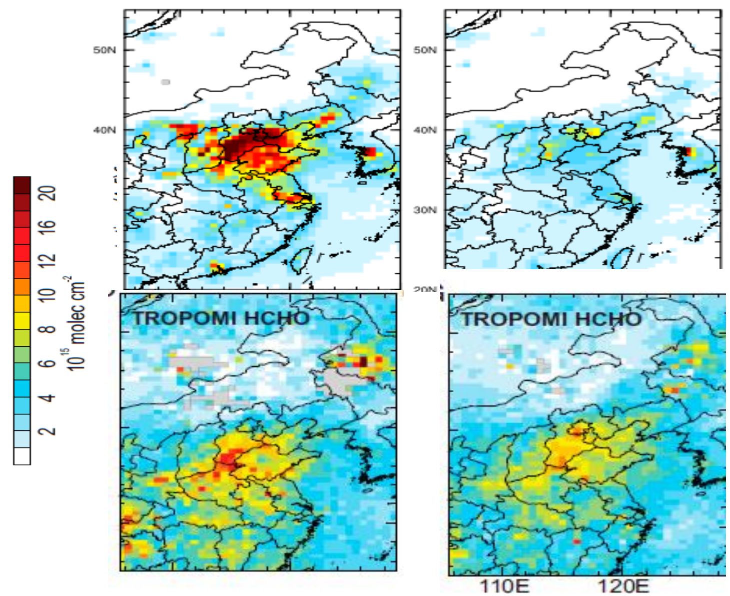


before Jan 24 after Jan 24



MDA8 ozone (ppb)
in N China Plain
circles = observed,
background = GEOS-Chem





TROPOMI
NO_2

TROPOMI
HCHO

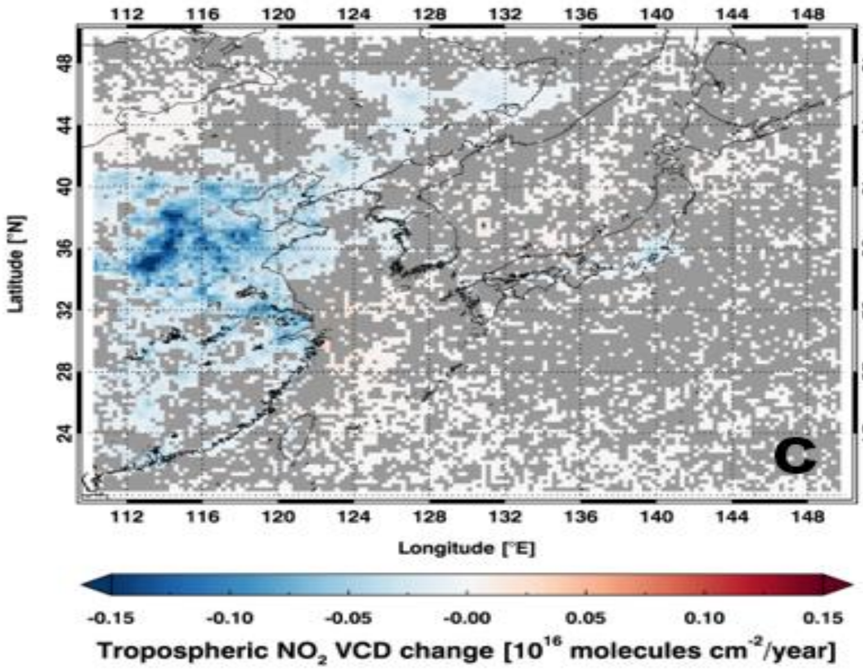
- NO_x emissions decreased by 70% during lockdown, causing ozone production to surge under strongly VOC-limited conditions
- Formaldehyde from VOCs provides the main HO_x radical source:

$$HCHO + h\nu \xrightarrow{2O_2} CO + 2HO_2$$

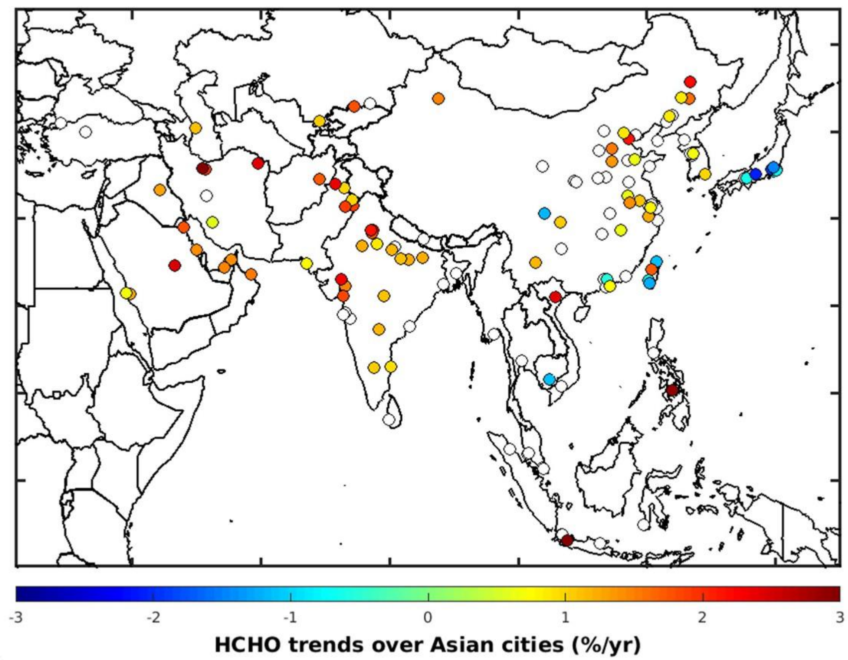
Li et al., 2021

Importance of NO_2 and HCHO monitoring from space to understand ozone trends

OMI NO_2 trend, 2011-2019



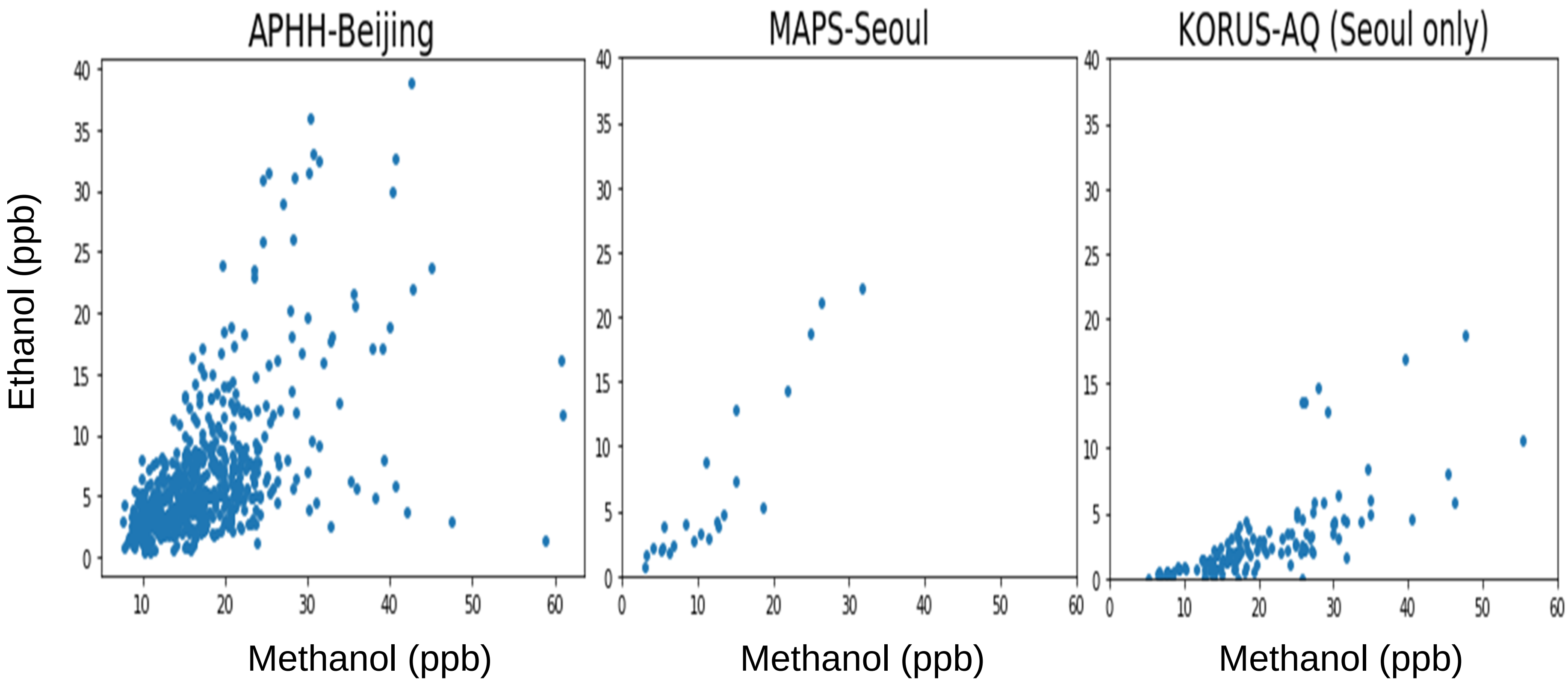
OMI HCHO trend, 2015-2019



Korea and China are now targeting VOC emissions – we need to verify this from space

Ahn et al., submitted; Bauwens et al., 2022

Evidence of very high residential use of volatile chemical products (VCPs) in Korea and China – missing from current inventories

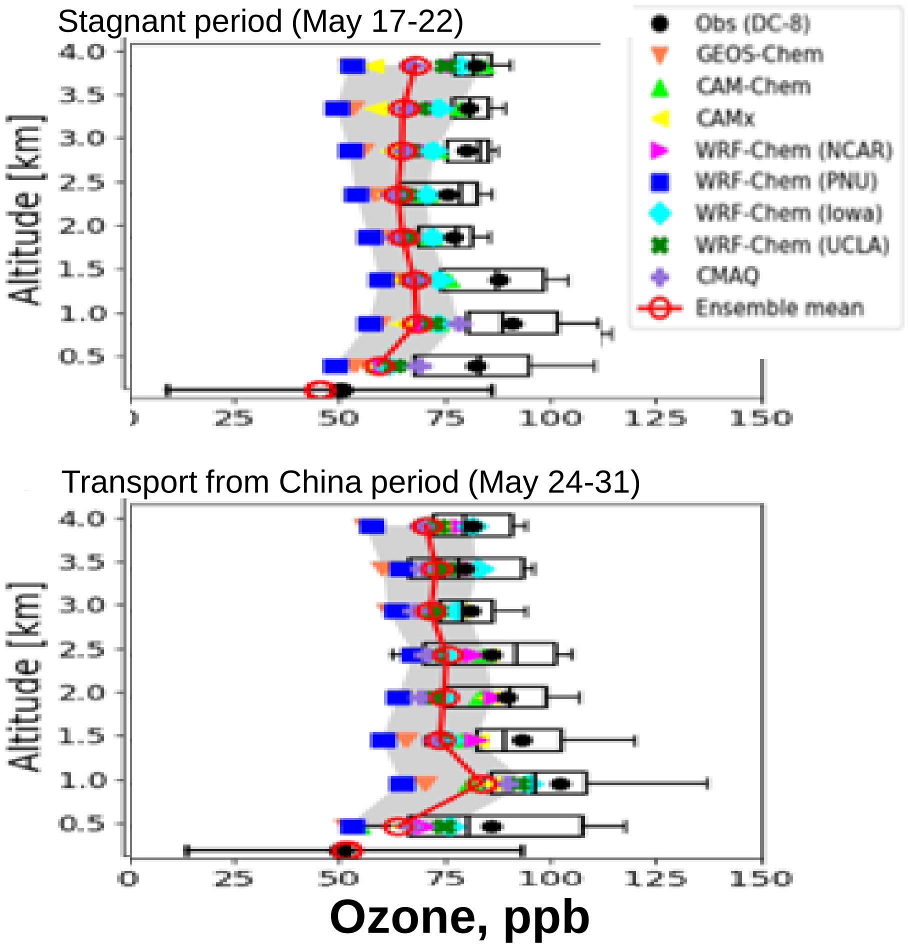


- Ethanol is common component of residential VCPs; very high in Korea and China
- Methanol is highly correlated with ethanol – also used in VCPs?
- Residential VCP emissions could be a driver of VOC reactivity – need to be addressed in VOC emission controls

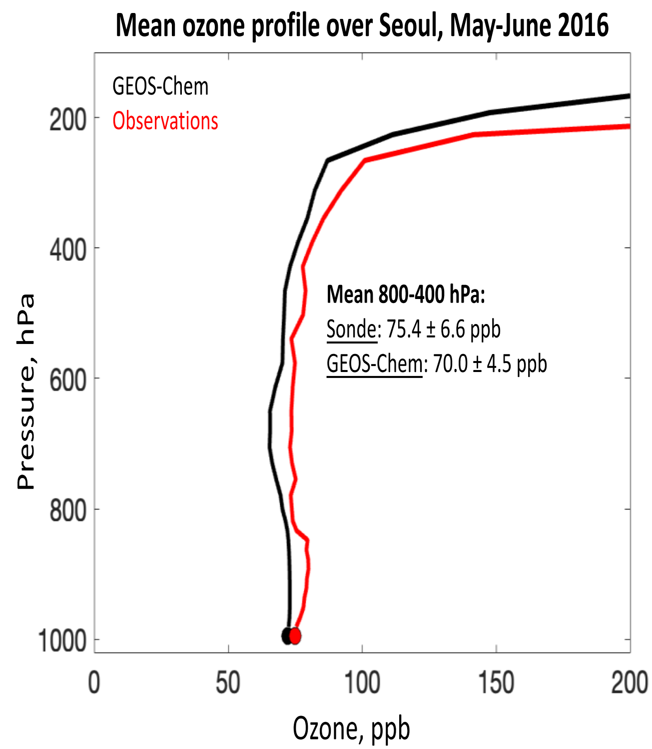
Beaudry et al., in prep.

Very high free tropospheric ozone background over East Asia, underestimated in models

KORUS-AQ, May-June 2016



corrected in GEOS-Chem by nitrate photolysis:



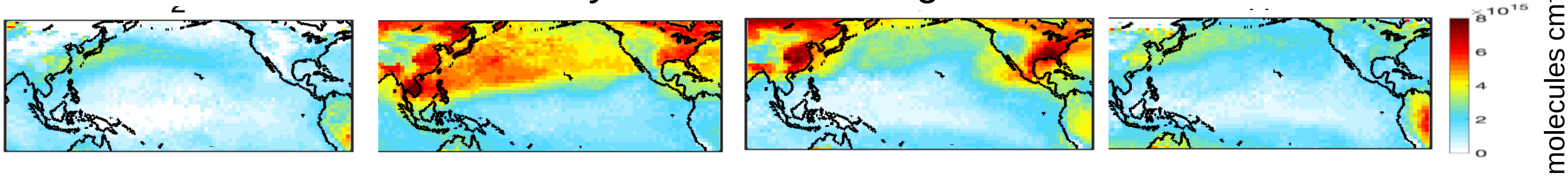
- 60 ppb air quality standard for Korea is not achievable with such high background
- Origin of high background is not clear; it doesn't seem to come from China
- GEMS observations of free tropospheric ozone can help address that issue

Park et al. [2021]; Colombi et al., in prep.

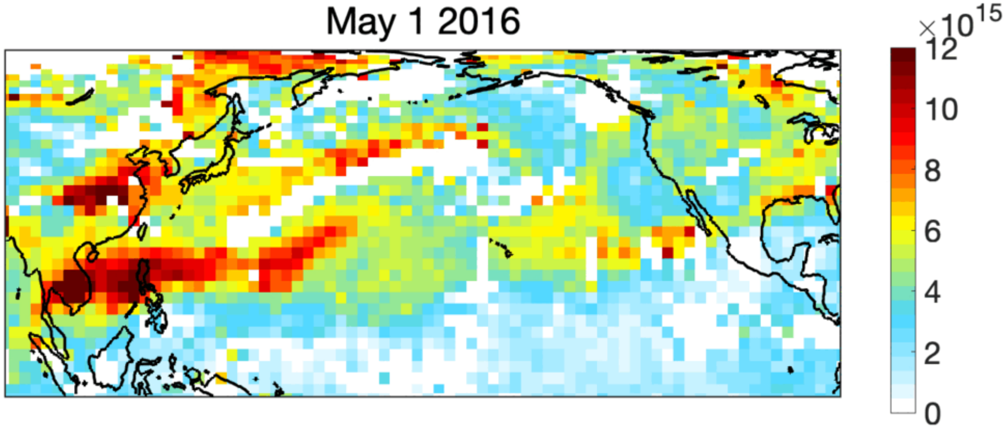
Peroxyacetylnitrate (PAN) from IASI as tracer for global anthropogenic influence on ozone

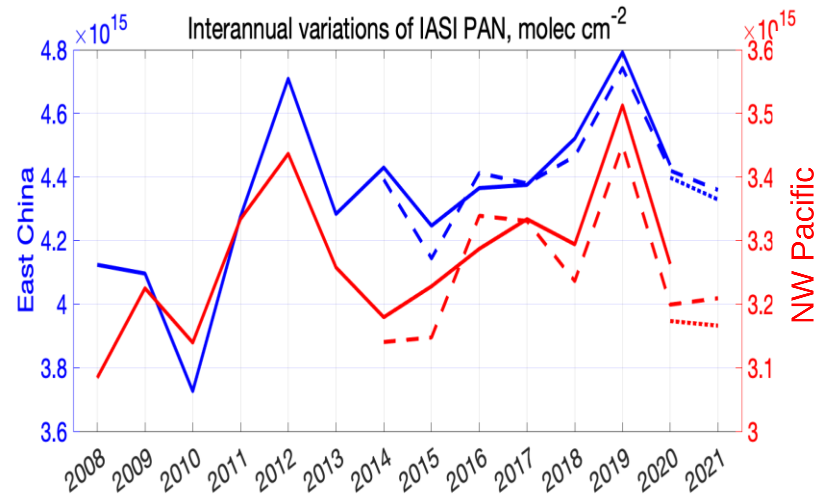
PAN is reservoir for NO_x, is also produced along with ozone: VOC + OH $\xrightarrow{NO}$ ozone; VOC + OH $\xrightarrow{NO_2}$ PAN

Feb 2016 | May | Aug | Nov



May 1 2016



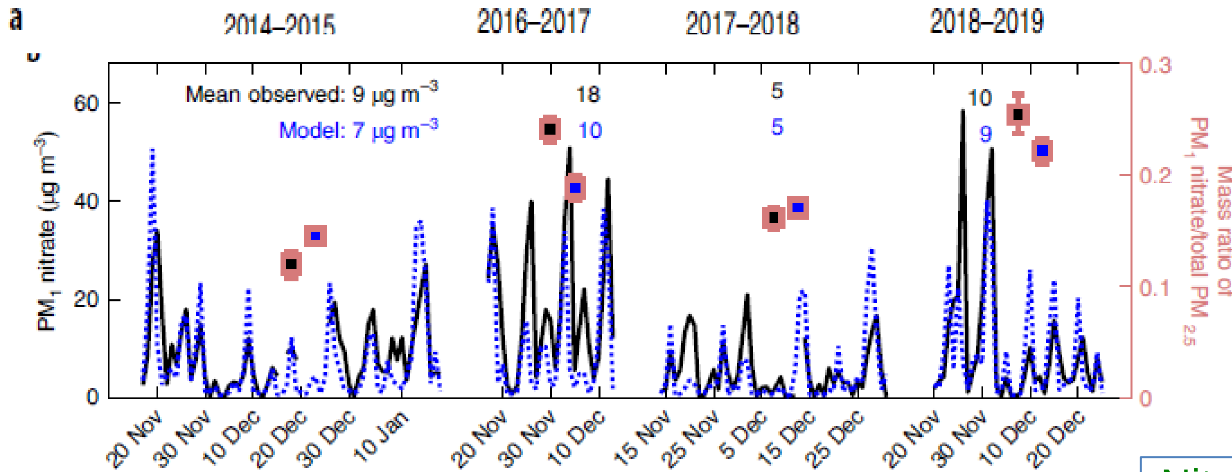


- Transpacific transport of PAN is evidence for global-scale transport of ozone pollution
- Increasing PAN over 2008-2019 IASI record is indicative of increasing ozone
- Data suggest increasing contribution from Southeast Asia

Zhai et al., in prep.

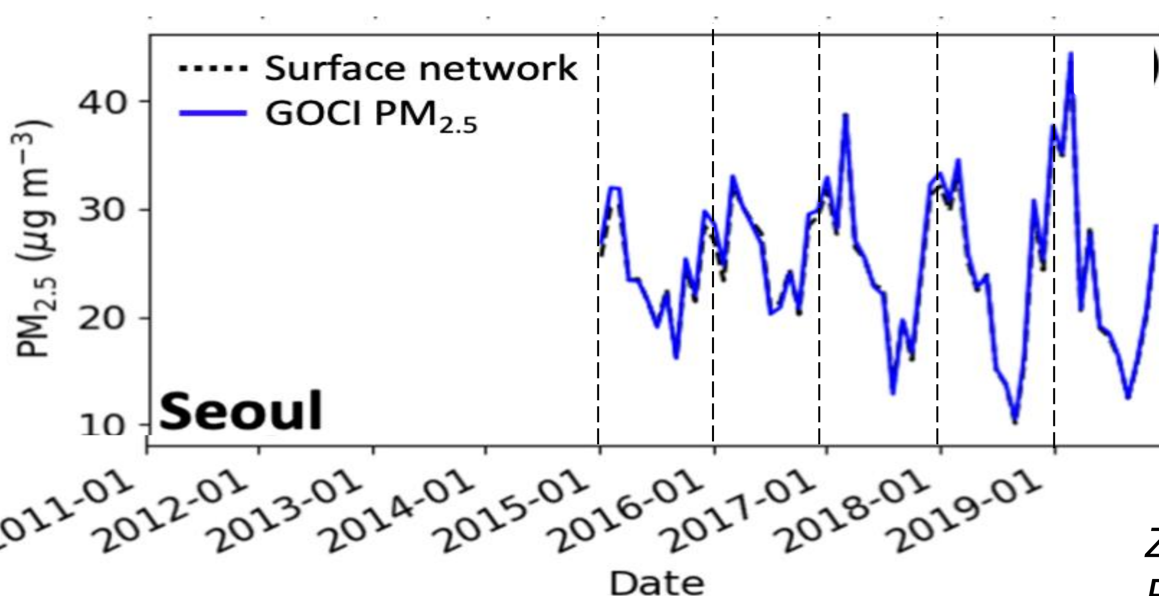
Wintertime $PM_{2.5}$ nitrate in urban China has not responded to NO_x controls… …and has gotten worse during pollution episodes

PM_1 nitrate in Beijing, winters 2014-2019



Maybe also in Seoul, where winter $PM_{2.5}$ has been increasing?

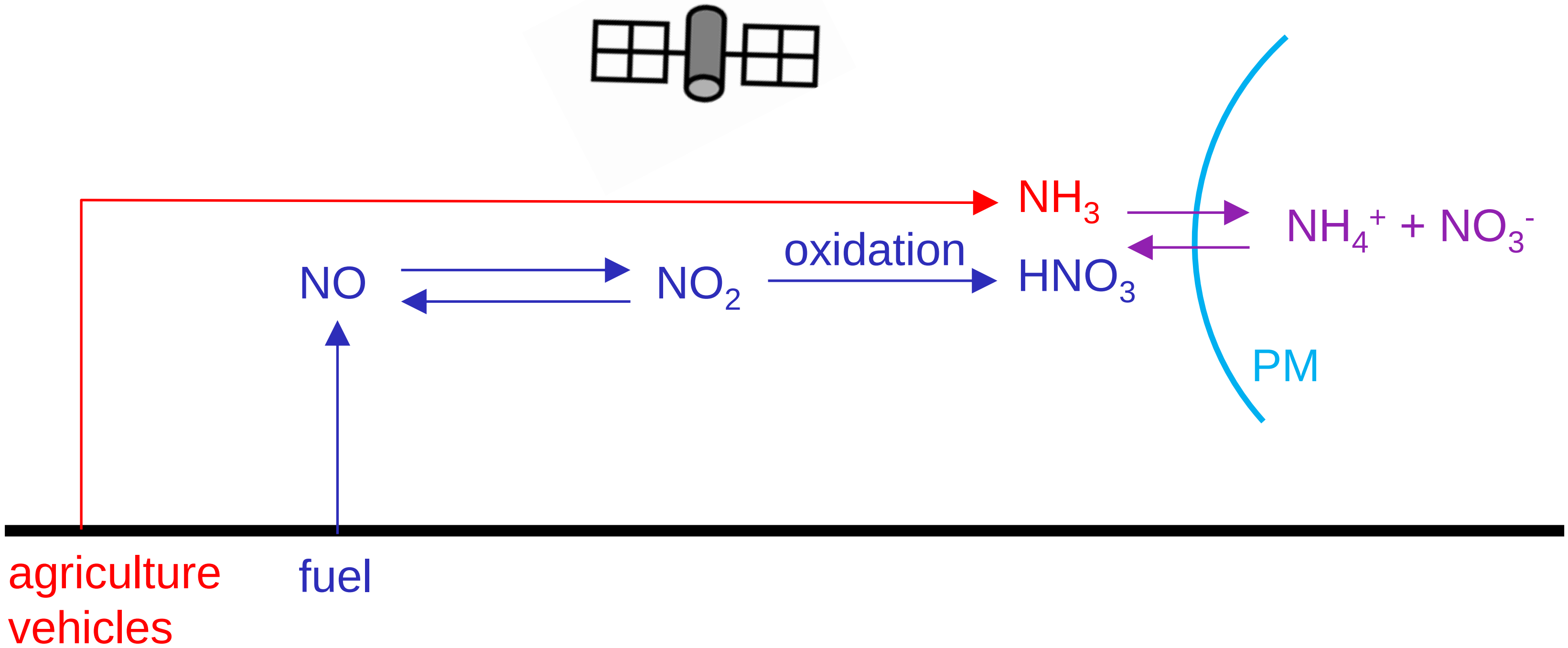
Nitrate formation may be NH_3-limited



Zhai et al. [2021]; Pendergrass et al. [2022]

Use tropospheric NH_3/NO_2 column (Ω) ratio measured from space to diagnose whether PM nitrate formation is NO_x- or NH_3-limited

NO_2: OMI, TROPOMI, GEMS
NH_3: IASI, CrIS

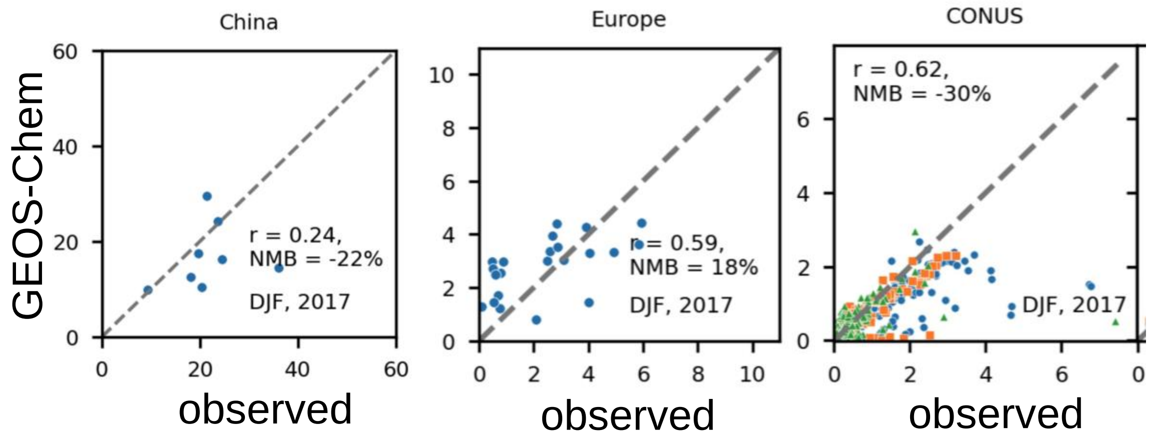


- **If** satellites measured Ω_{HNO3} **and if** all NH_3 and HNO_3 were in boundary layer, **then** $\Omega_{NH3}/\ \Omega_{HNO3} = 1$ would be threshold for NH_3-limited vs. NO_x- (or VOC-) limited regime

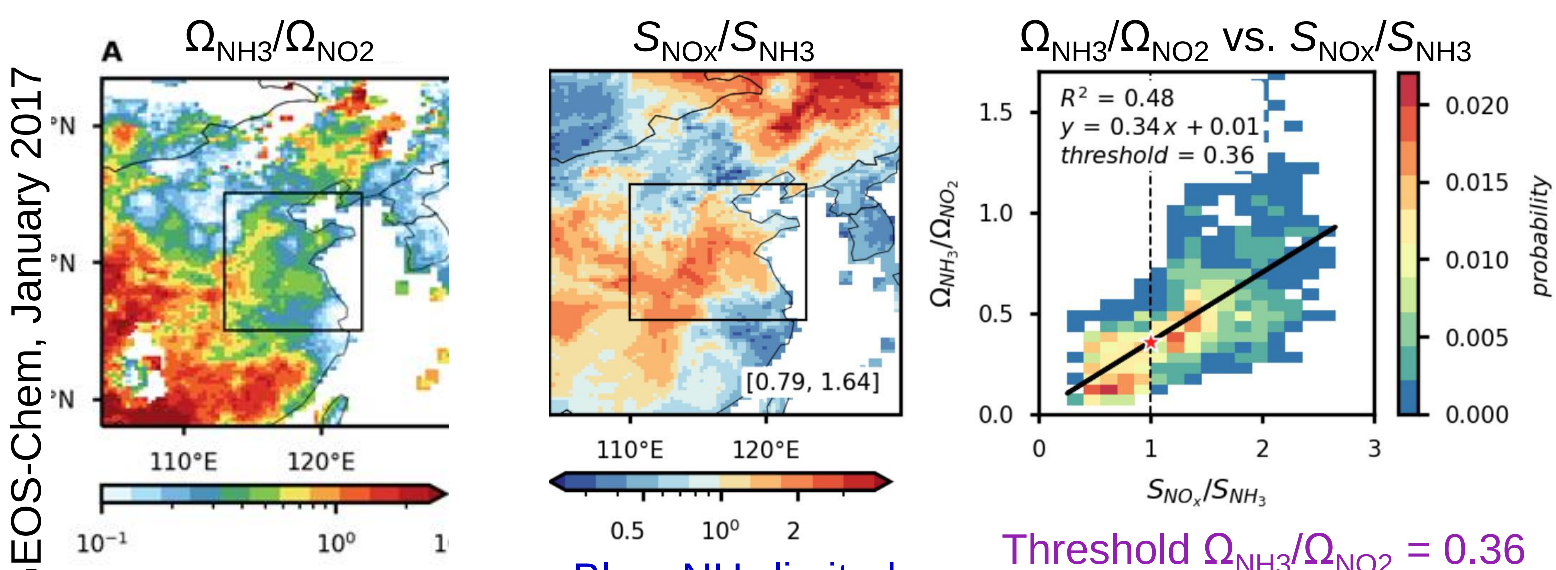
- **But** we measure Ω_{NO2}, some of that NO_2 is in free troposphere, and there's a lag and <1 yield in conversion from NO_x to HNO_3
  need model to diagnose $\Omega_{NH3}/\ \Omega_{NO2}$ threshold and relevant spatial scale

Using GEOS-Chem model to relate $\Omega_{NH3}/\Omega_{NO2}$ to chemical regime

Model has credible simulation of $PM_{2.5}$ nitrate [$\mu g\ m^{-3}$]:



1. Diagnose relative sensitivities $S_X = d\log[NO_3^-]/d\log E_X$ in model world;
2. Use sensitivity ratio S_{NOx}/S_{NH3} to diagnose chemical regime;
3. Plot $\Omega_{NH3}/\Omega_{NO2}$ vs. S_{NOx}/S_{NH3} to diagnose threshold column ratio.



Blue: NH_3-limited

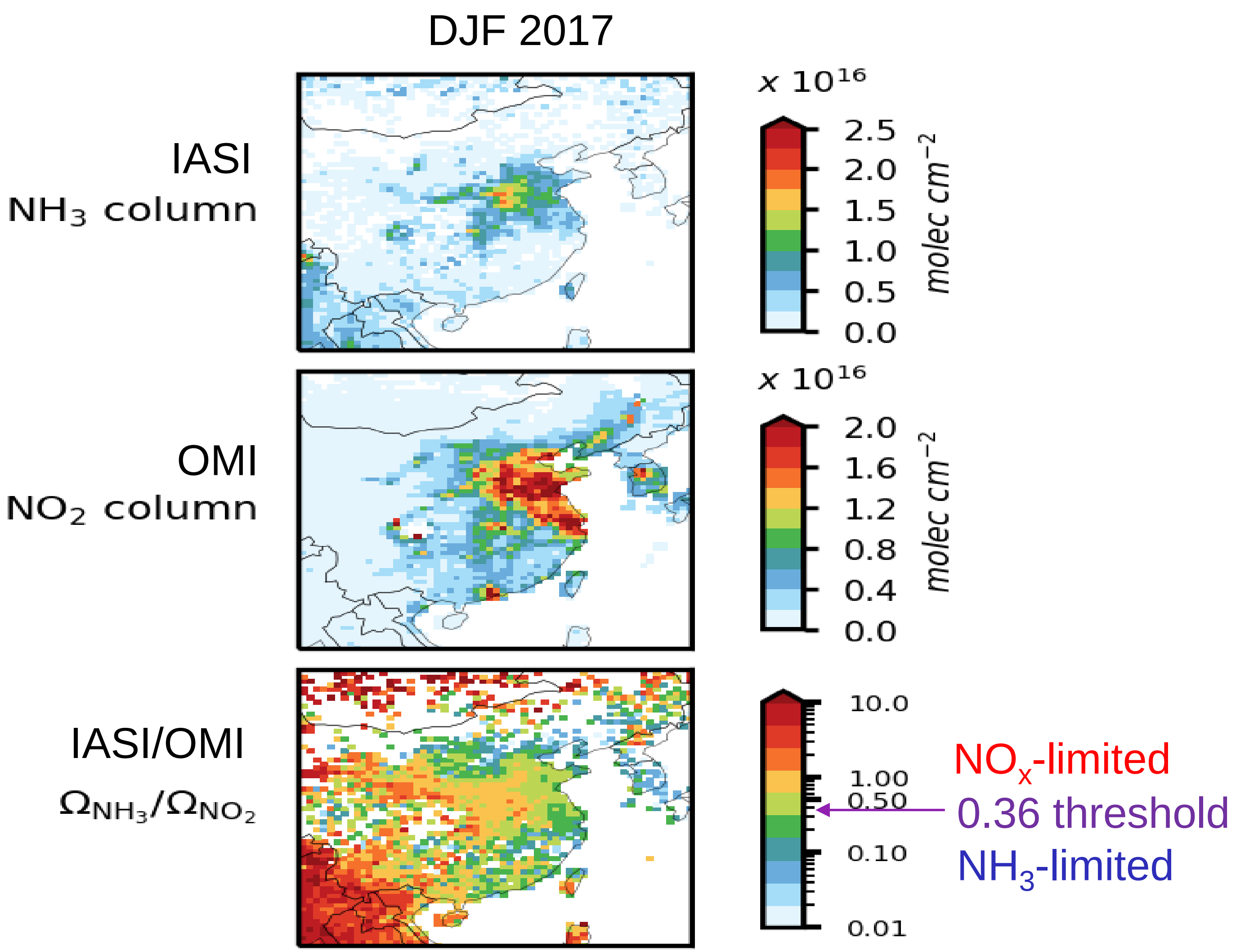
Red: NO_x-limited

Threshold $\Omega_{NH3}/\Omega_{NO2}$ = 0.36

Dang et al., in prep.

Real-world application to OMI NO_2 and IASI NH_3 data

using model-determined threshold ratio $\Omega_{NH3}/\Omega_{NO2}$ = 0.36 for transition between regimes



Urban eastern China and S. Korea are NH_3-limited for PM nitrate production in winter

Dang et al., in prep.

Take-aways

GEMS data density can enable better understanding of emerging air quality issues in East Asia

- NO_x and VOC emission trends
- HCHO as a driver of ozone production
- HCHO and CHOCHO as proxies of VCP emissions
- Factors controlling free tropospheric background ozone and its trend
- NH_3/NO_2 ratios (with IASI or CrIS) as diagnostic for particulate nitrate formation regime