Air quality forecasts using the NASA GEOS model

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In collaboration with:

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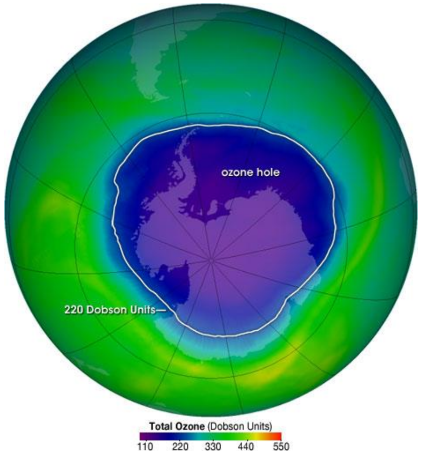
Atmospheric Chemistry and Dynamics Lab: Bryan Duncan, Melanie Follette-Cook, Junhua Liu, Julie Nicely

7 June 2018

Why we care about atmospheric chemistry

1. Climate & Dynamics



2. Air Quality

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Air pollution is the single largest environmental risk factor

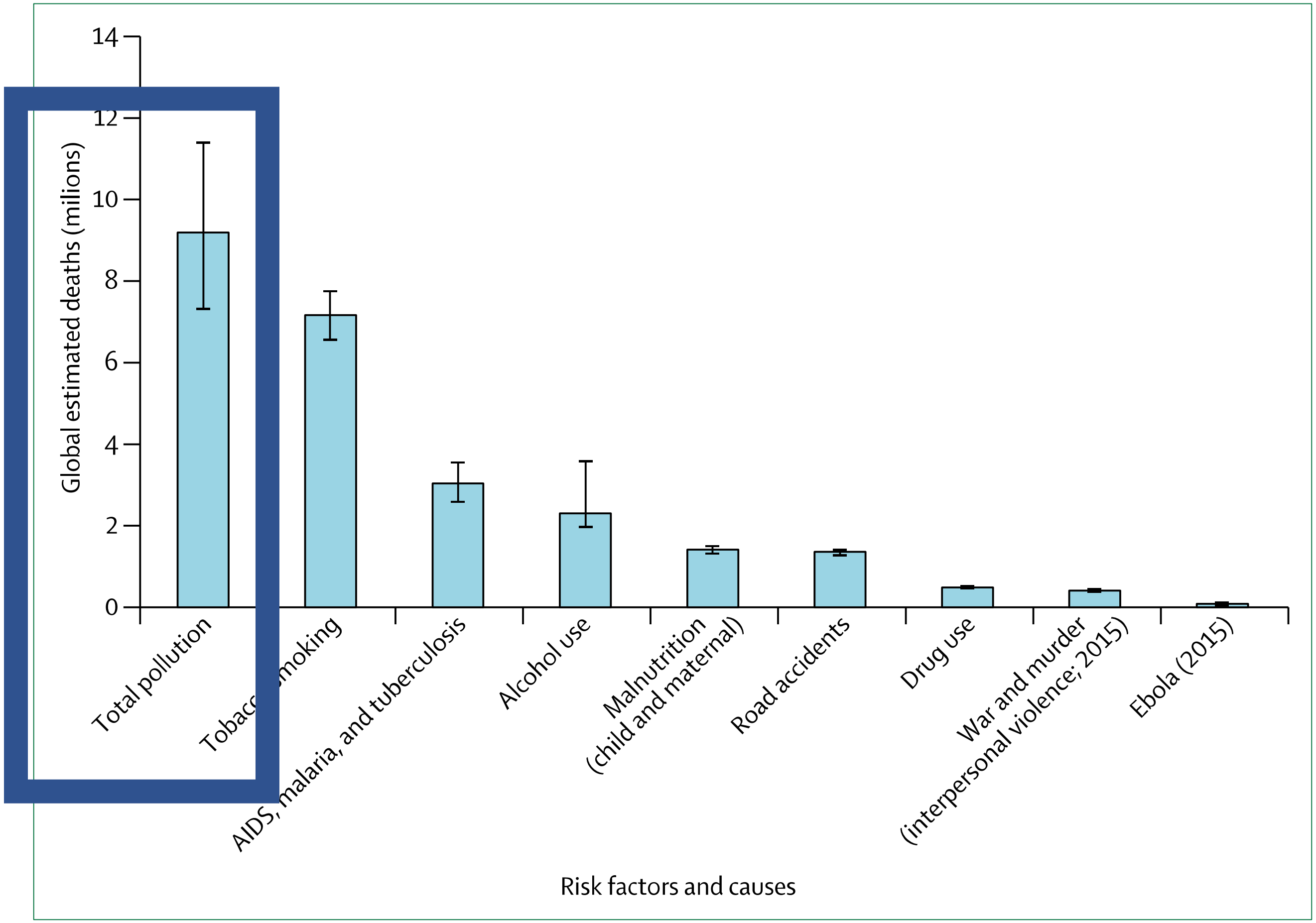

Figure 5: **Global estimated deaths by major risk factor and cause, 2015**
Using data from the GBD Study, 2016.[41]

The Lancet, 2017

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Air pollution is the single largest environmental risk factor

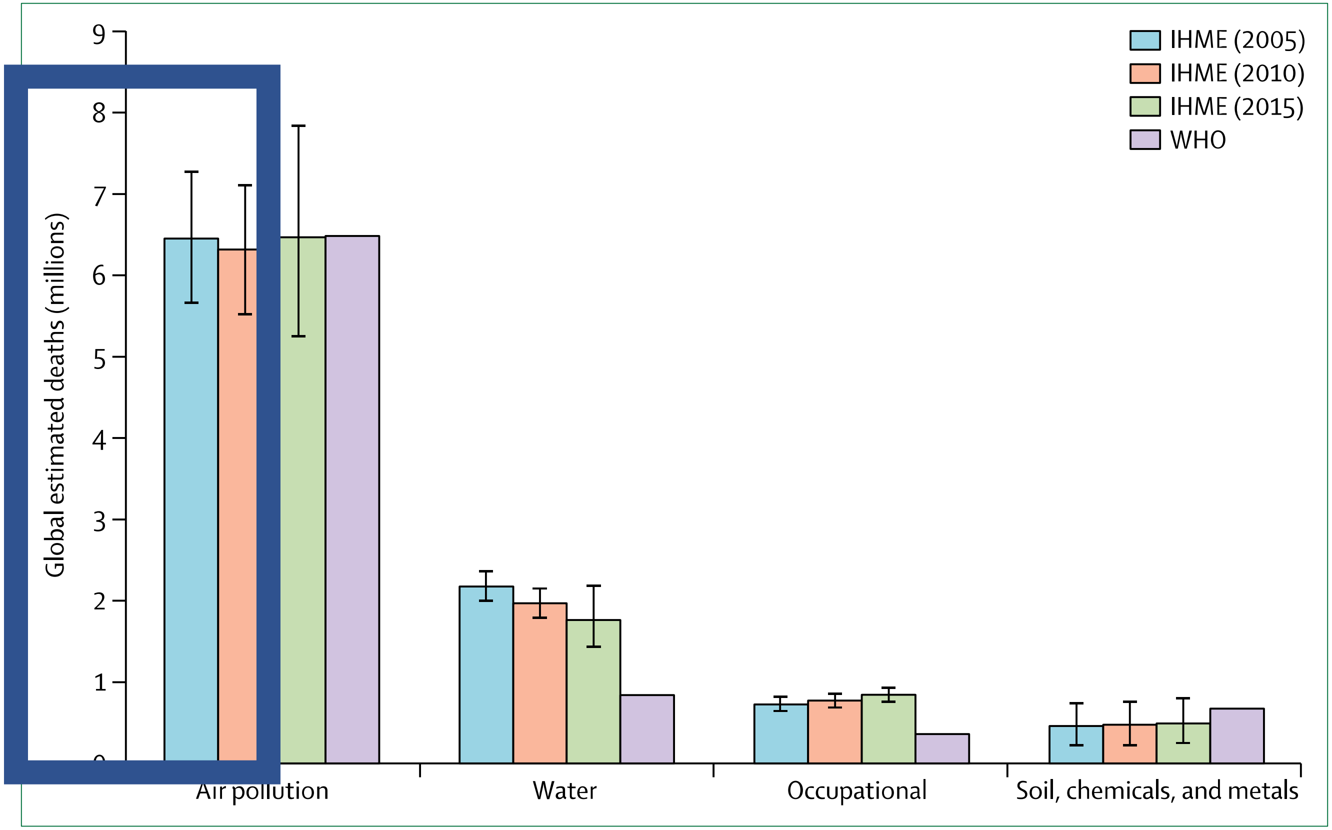

Figure 4: **Global estimated deaths (millions) by pollution risk factor, 2005–15**
Using data from the GBD study[42] and WHO.[99] IHME=Institute for Health Metrics and Evaluation.

The Lancet, 2017

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Air quality is a global problem

- 1 of every 9 death is related to air pollution (WHO)
- $5 Trillion in welfare losses every year (World Bank)
- Locally up to 50% crop loss due to ozone

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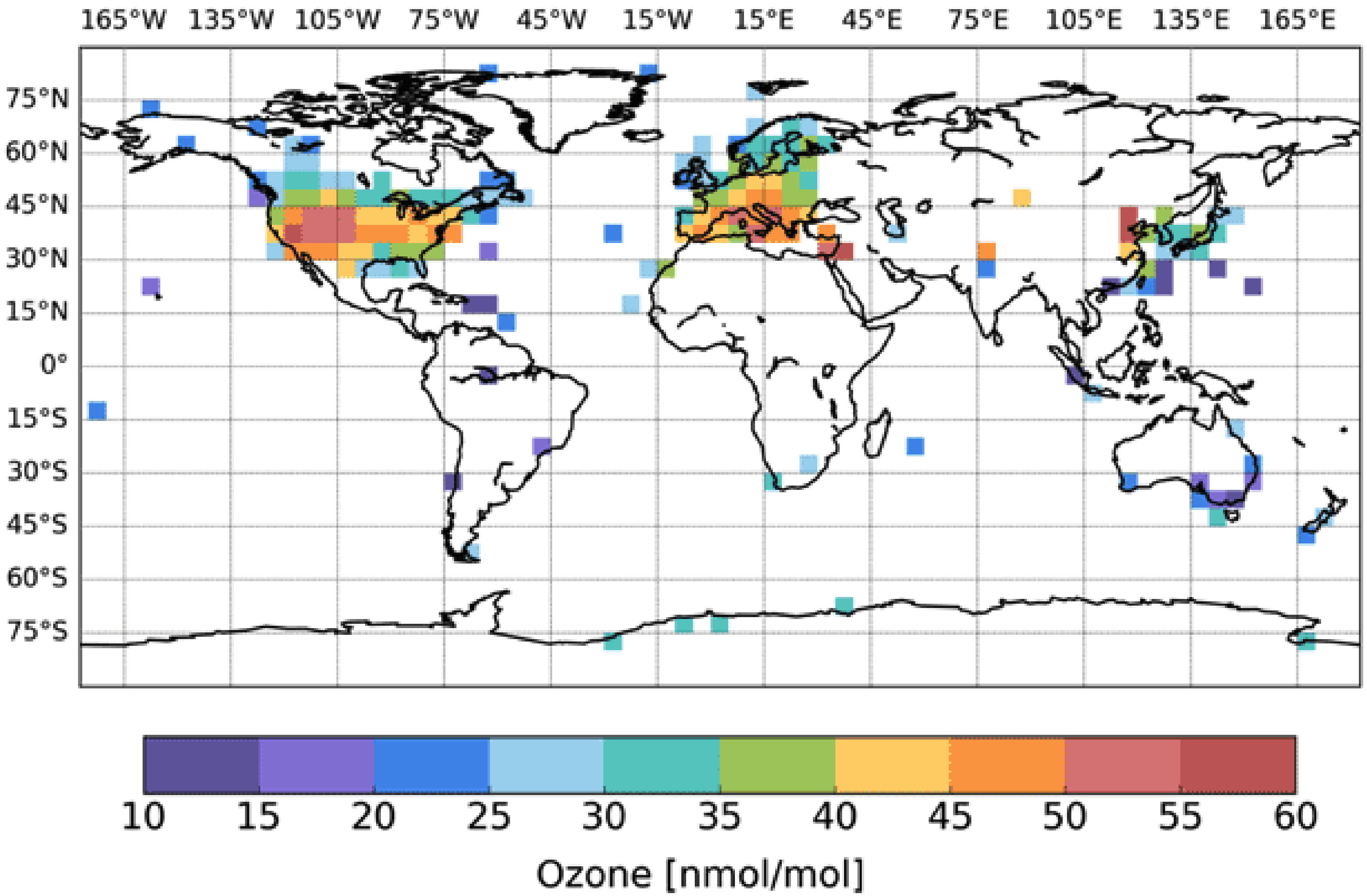
Surface observations are sparse!



Tropospheric Ozone Assessment Report TOAR (Schulz et al., 2017)

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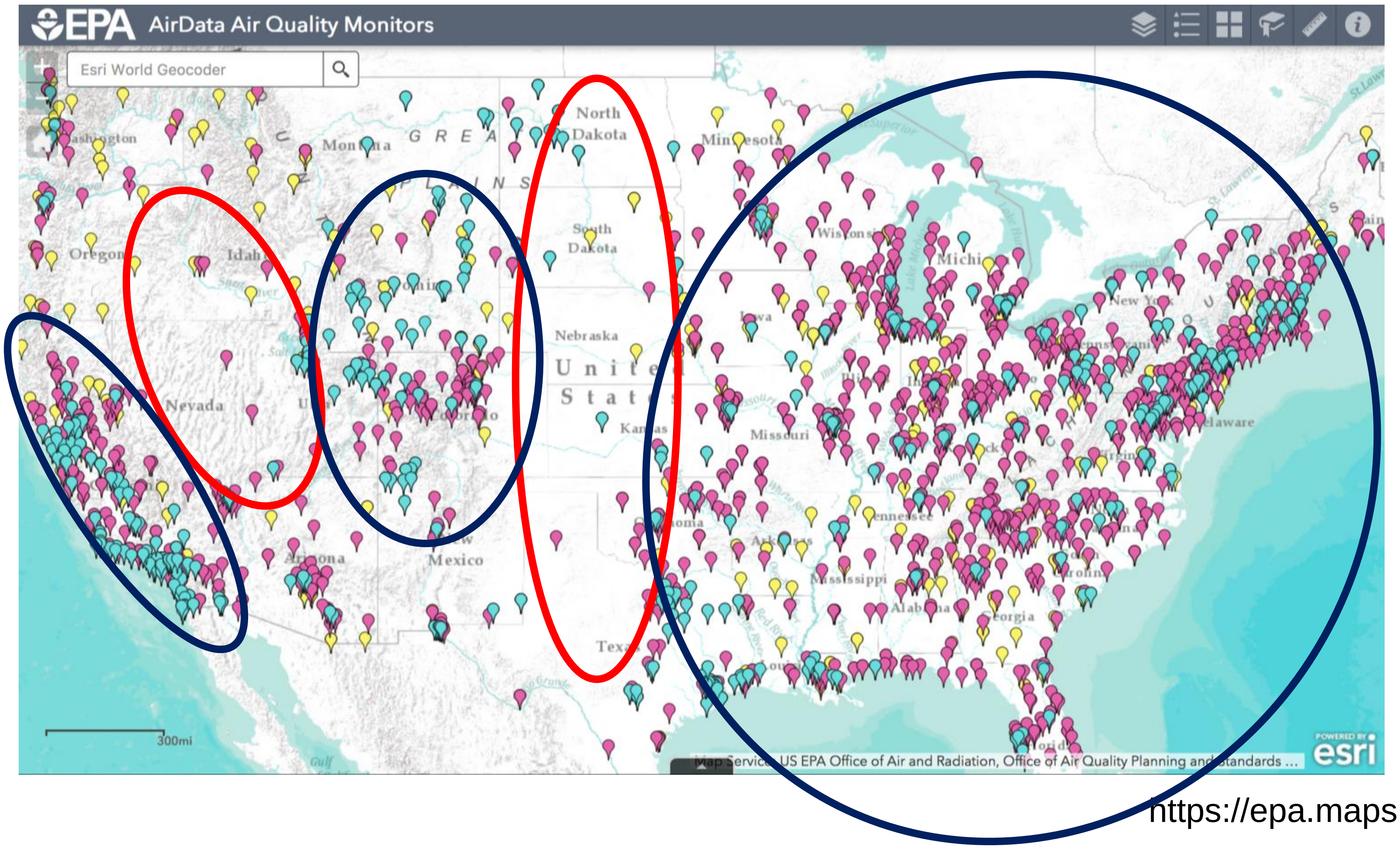
Point source measurements

Surface observations of pollutants are point source measurements which can be sparse



https://epa.maps.arcgis.com

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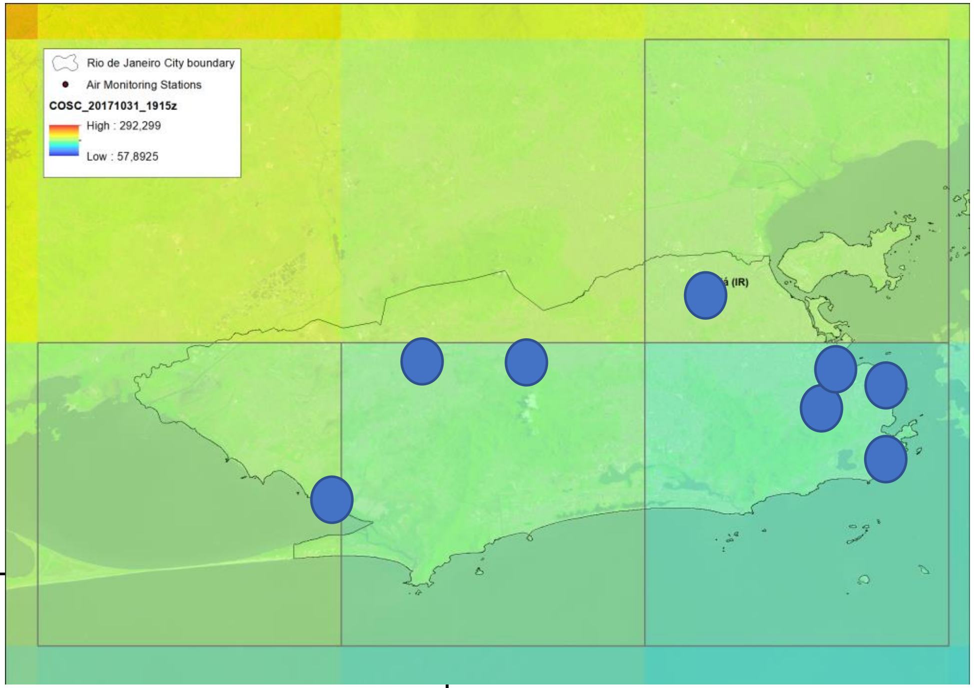
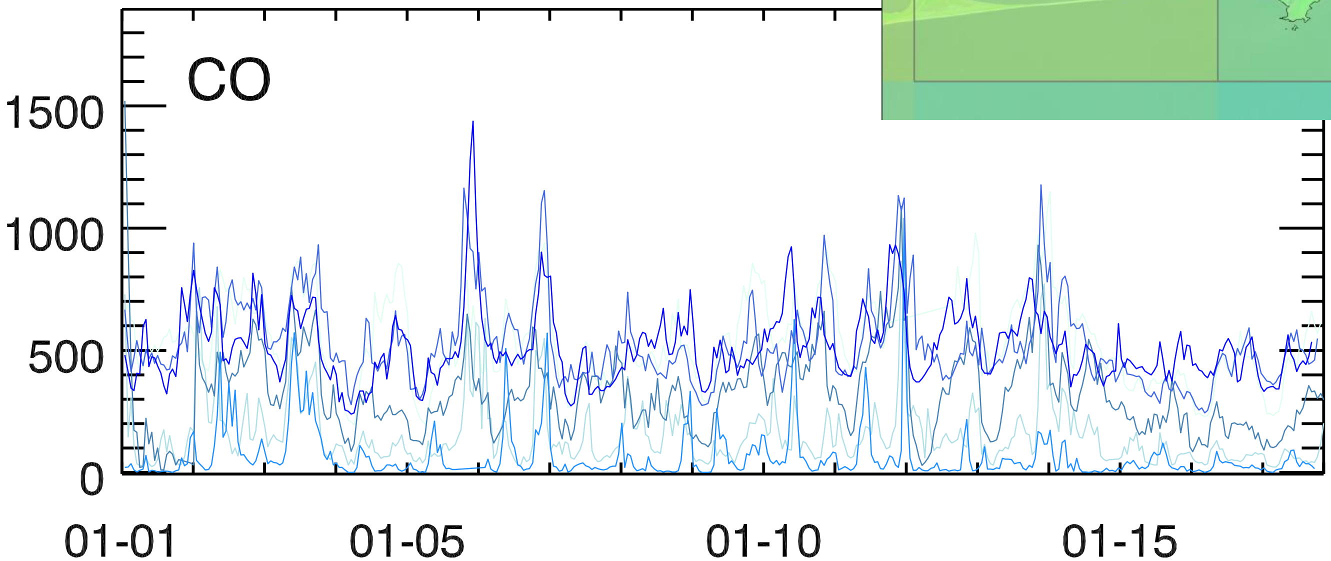
And highly variable!





GOVERNO DO Rio de Janeiro

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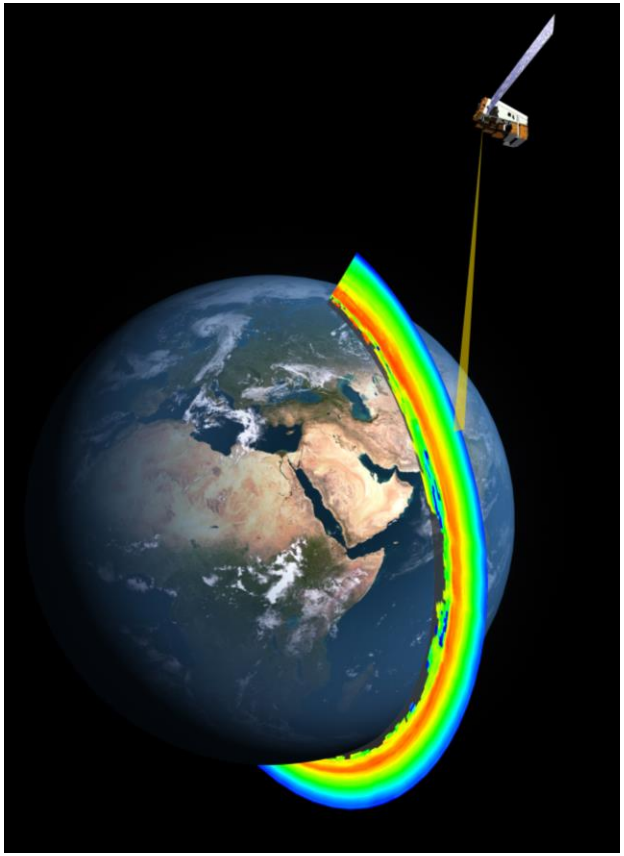
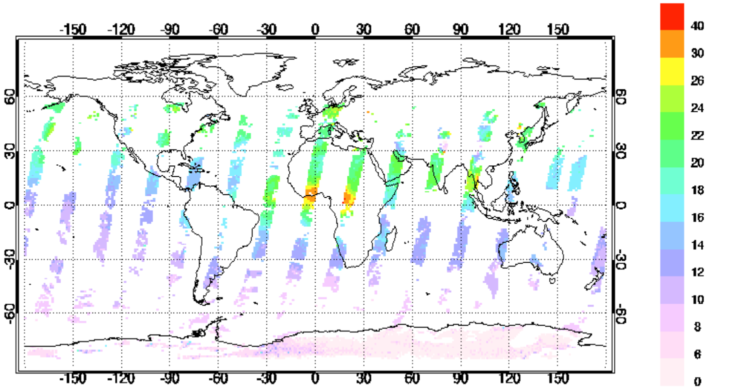
Current data coverage from space is limited

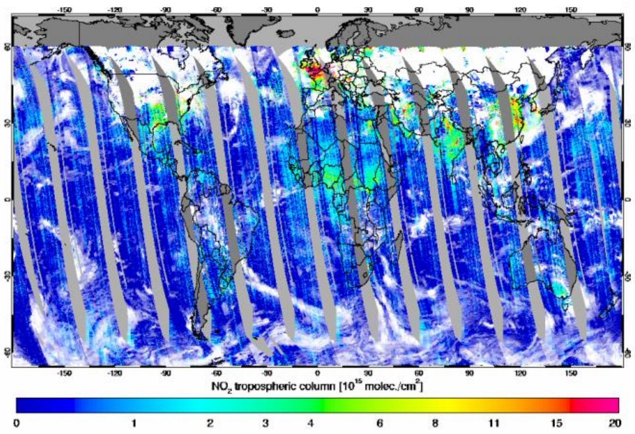


Terra MOPITT (CO)



www.acom.ucar.edu

Aura OMI (NO_2, O_3)



www.temis.nl

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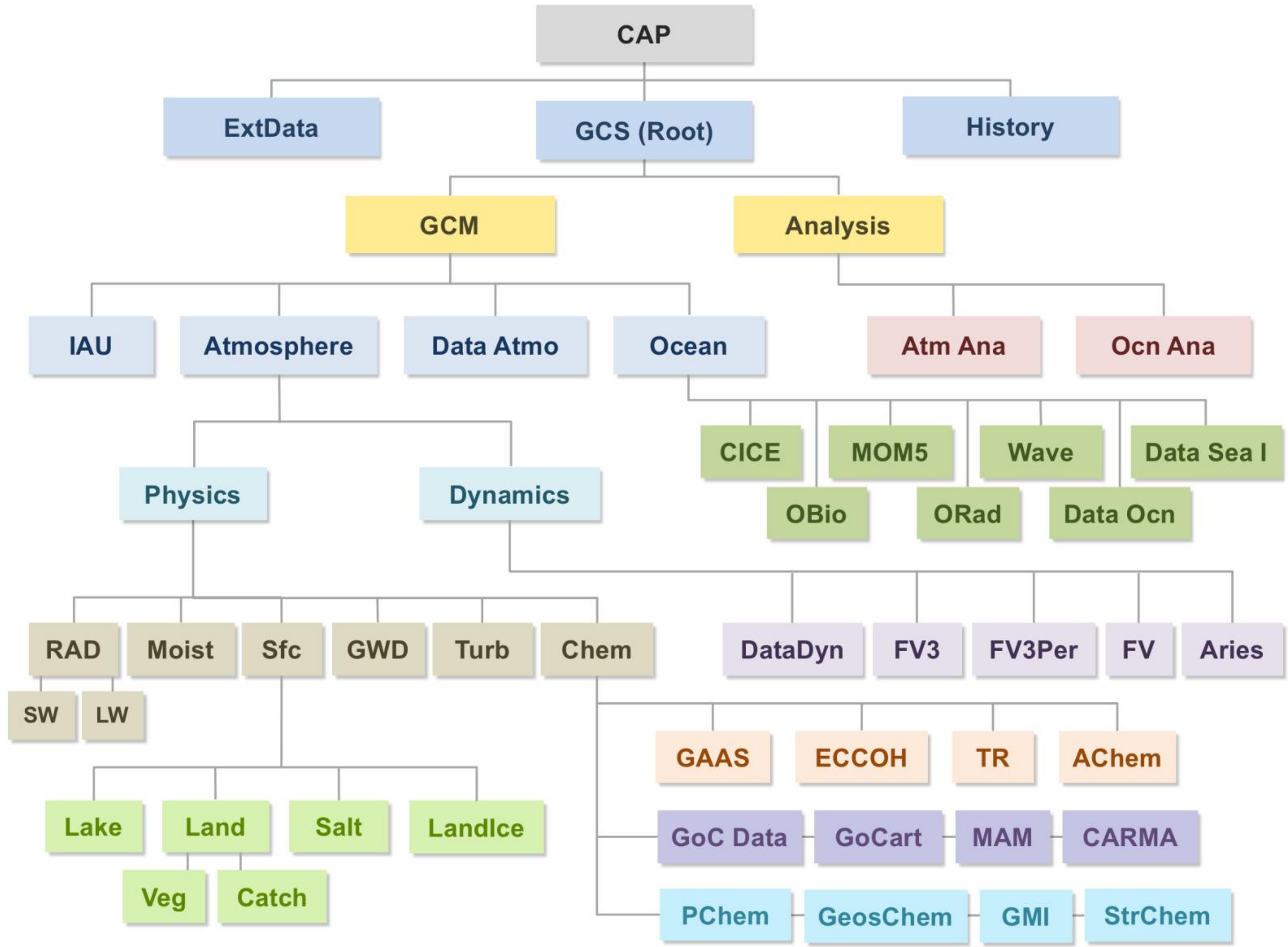
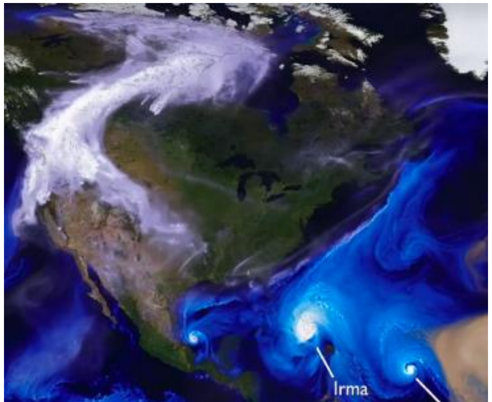
NASA's GEOS Model

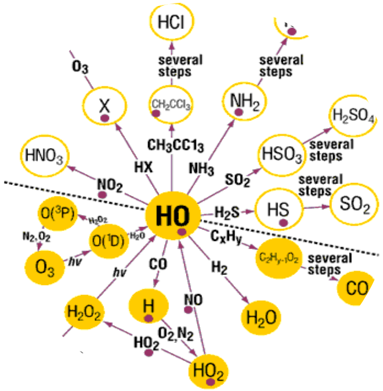


NASA GMAO’s Composition Forecast



GEOS - FP

+



GEOS - Chem

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GEOS-Chem is a state-of-the science chemistry model

Tropospheric and Stratospheric full chemistry

- 220 reactive species, 720 reactions
- 100+ user/developer groups worldwide
- Updated version is released about every year

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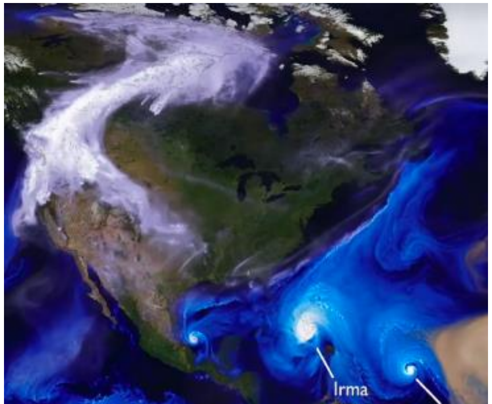
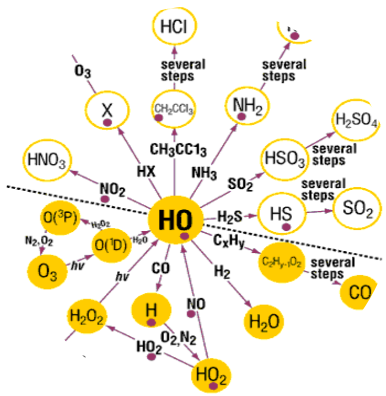
Chemistry is ***not*** cheap!



GEOS - FP



GEOS - Chem

GEOS - CF

- One **5-day forecast** per day <u>since March 2017</u>
  - 1-day analysis
  - 5-day forecast
  - c360 (0.25°, ~**25x25 km^2**) resolution
  - Currently no data assimilation of constituents in GEOS-CF

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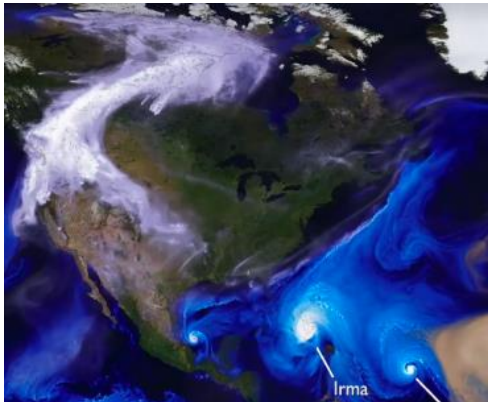
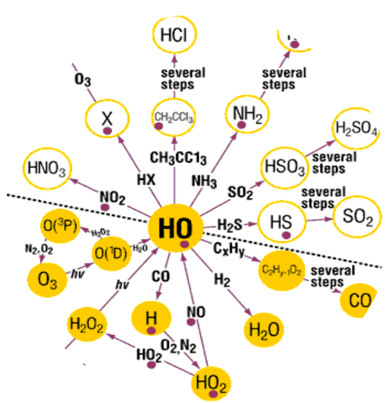
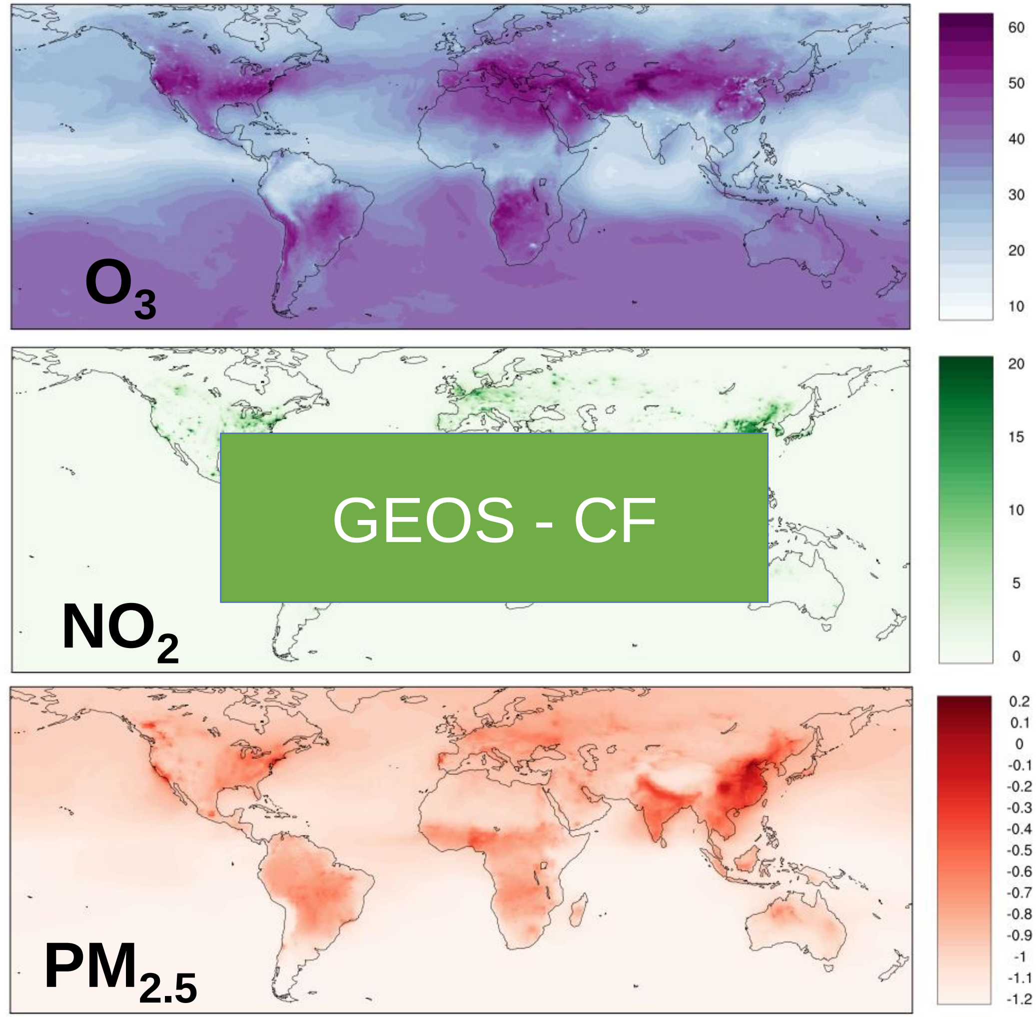


GEOS - FP



GEOS - Chem



GEOS - CF

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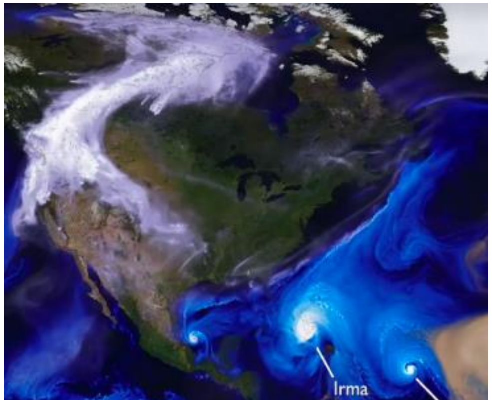
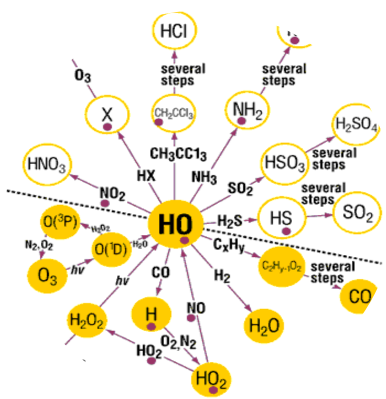


GEOS - FP

Research product

GEOS - CF



GEOS - Chem

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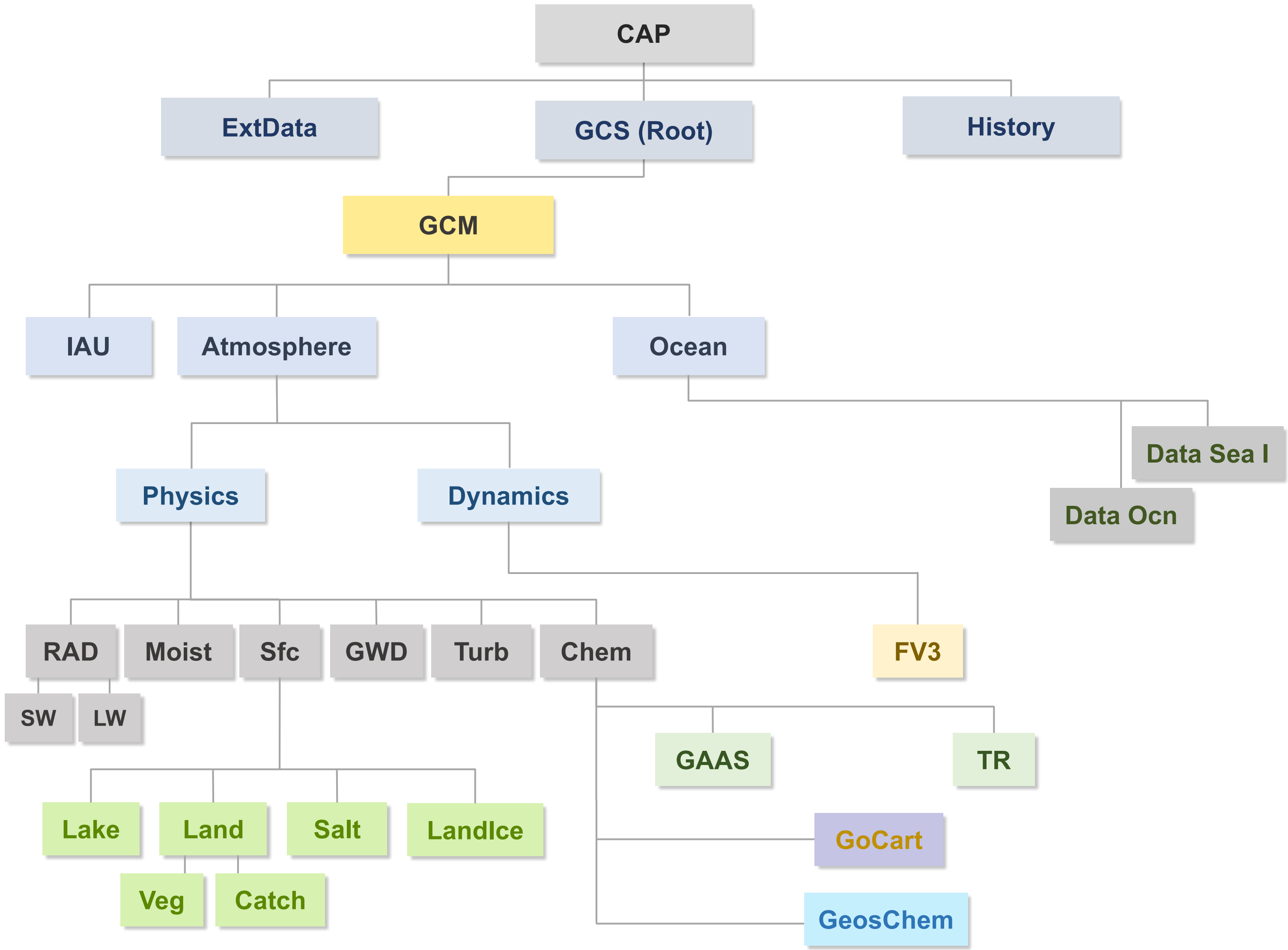
GEOS configuration for GEOS-CF



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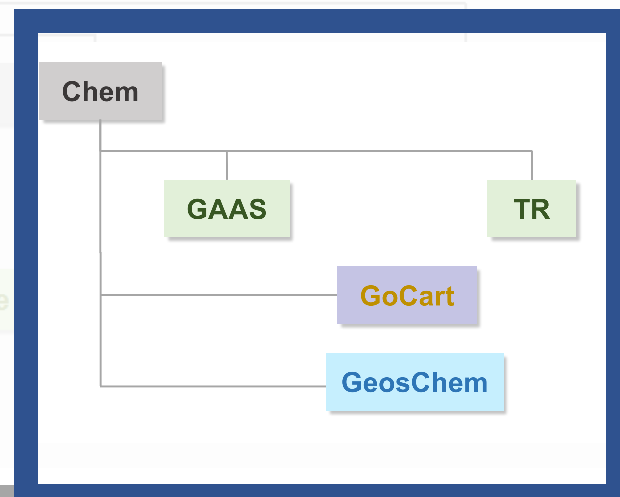
GEOS is a modular system

- Run a version of the GEOS model with **both** GOCART and GEOS-Chem

Big differences are

1) GEOS-Chem are fully coupled to the gas-phase chemistry, especially for SOA
2) GOCART assimilates AOD



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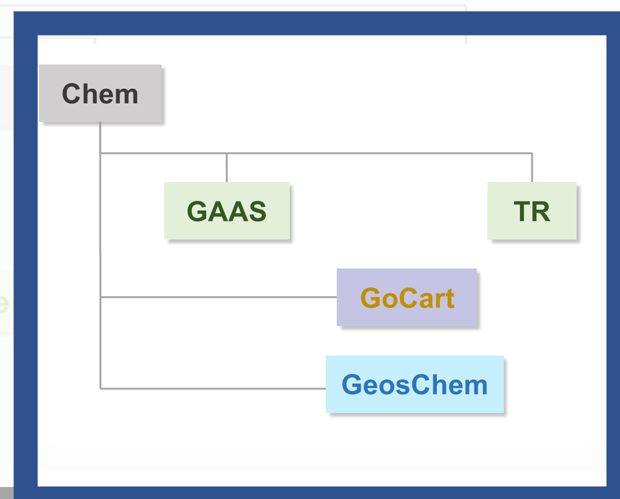
Future work to couple GOCART and GEOS-Chem



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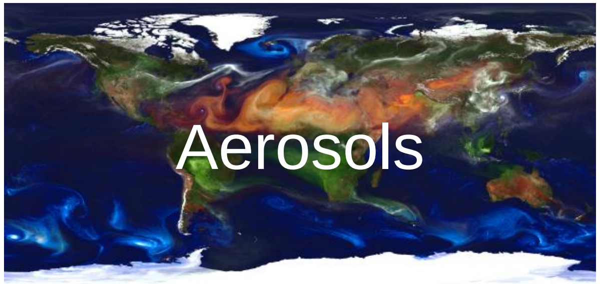
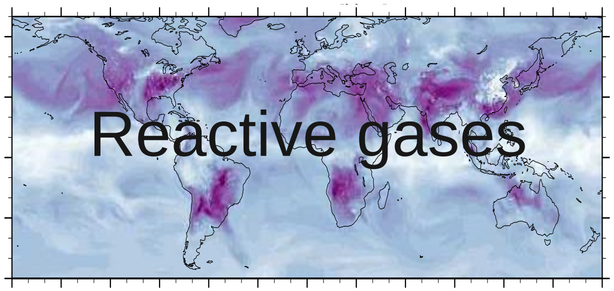
Contributors to Air Pollution





- Particulate matter (PM):
  - Organic Carbon
  - Black Carbon
  - Sea salt
  - Nitrate
  - Sulfate
  - Dust

- Ozone (O_3)
- Nitrogen dioxide (NO_2)
- Sulfur dioxide (SO_2)
- Volatile organic compounds (VOCs): e.g., Formaldehyde, Benzene, Toluene, and many more…

GOCART

GEOS-Chem

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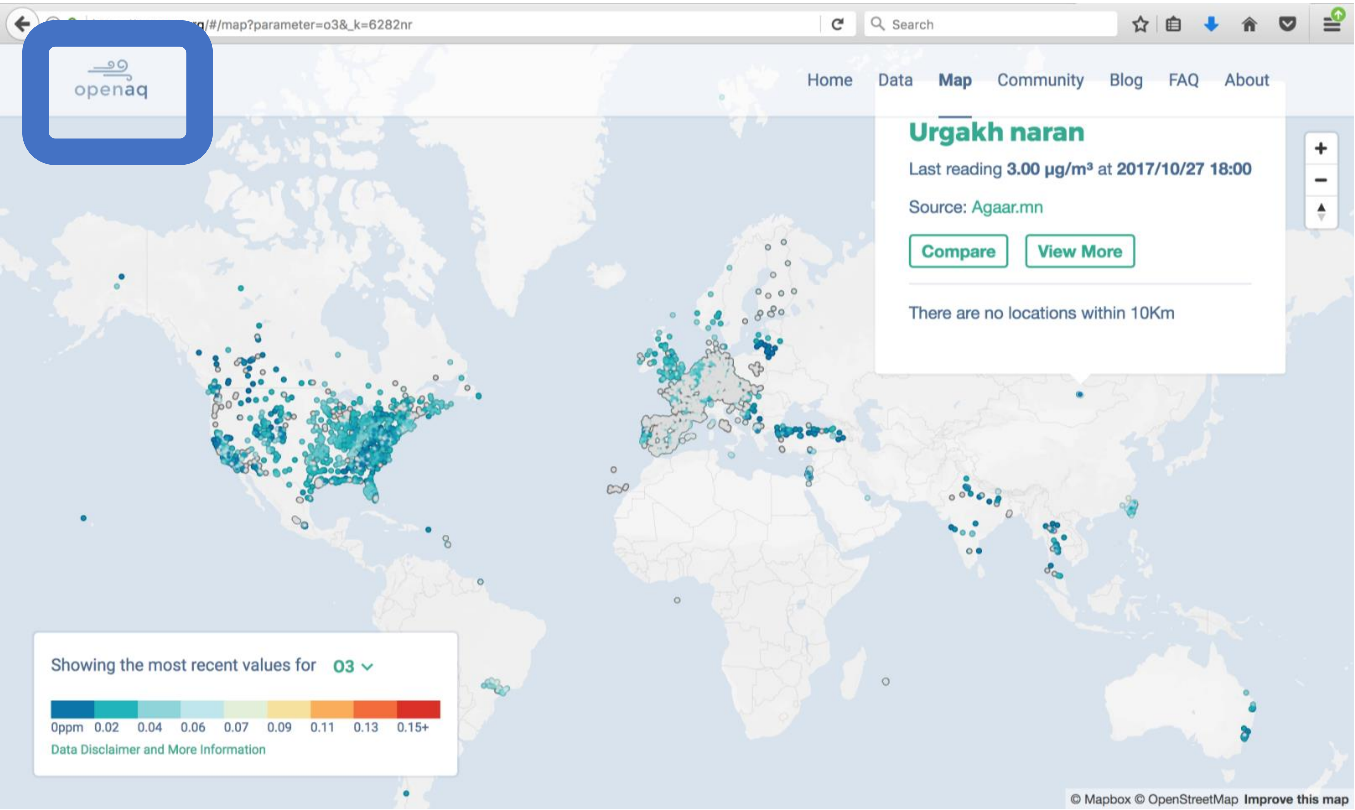
OpenAQ surface observation data base



OpenAQ is a non-profit compiling publically available air quality data in near-real time into an open-source data base

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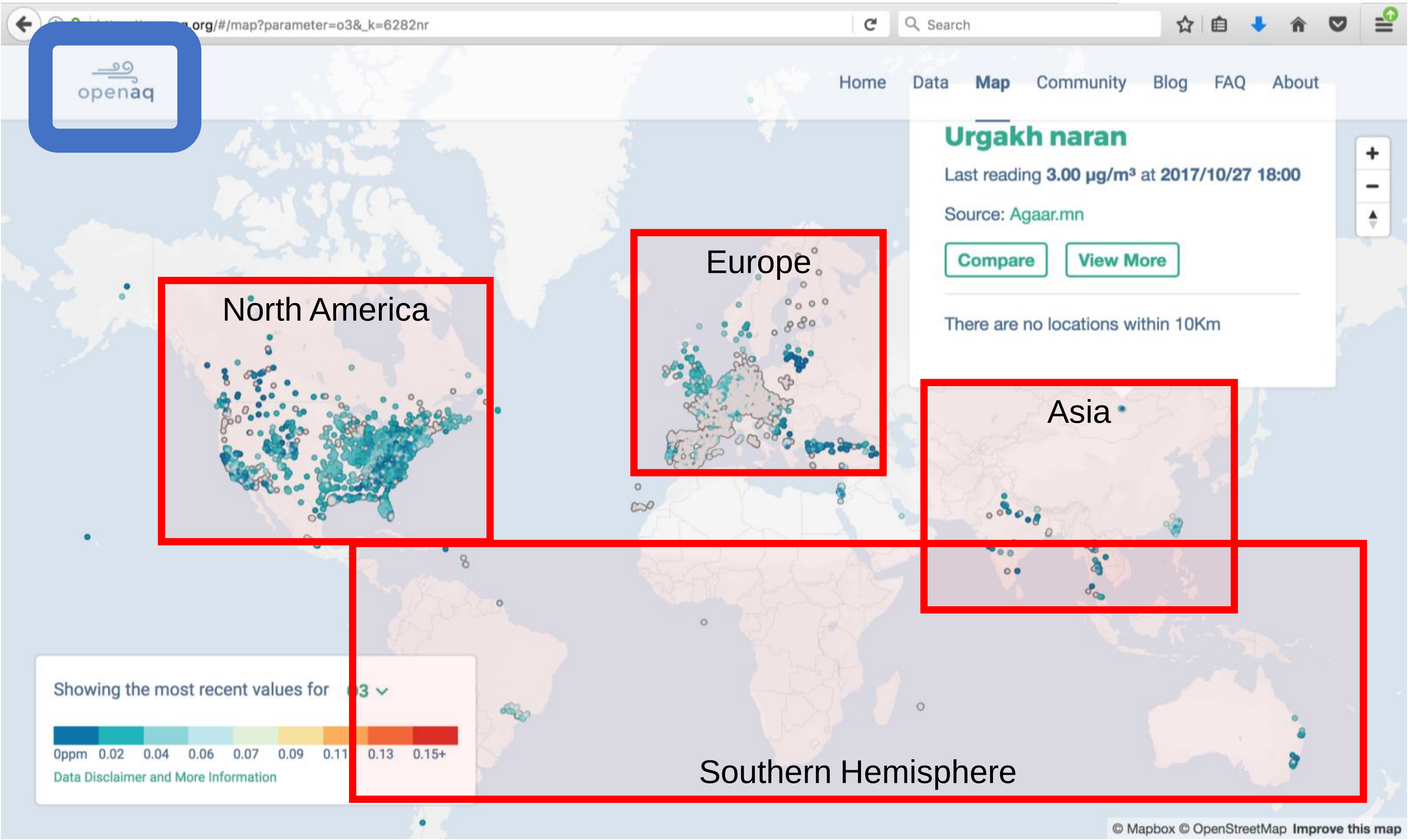
OpenAQ surface observation data base



https://openaq.org

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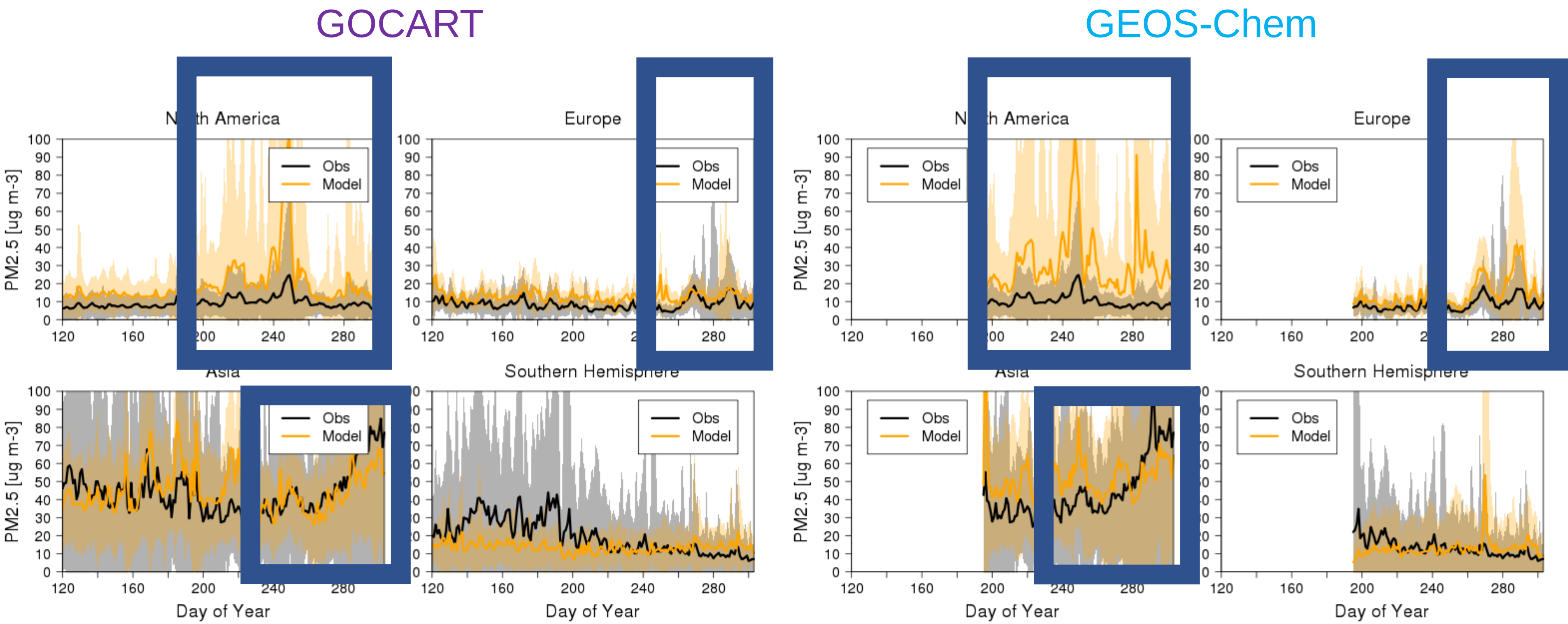
GOCART vs GEOS-Chem $PM_{2.5}$



In all the following analysis showing $PM_{2.5}$ from GEOS-Chem

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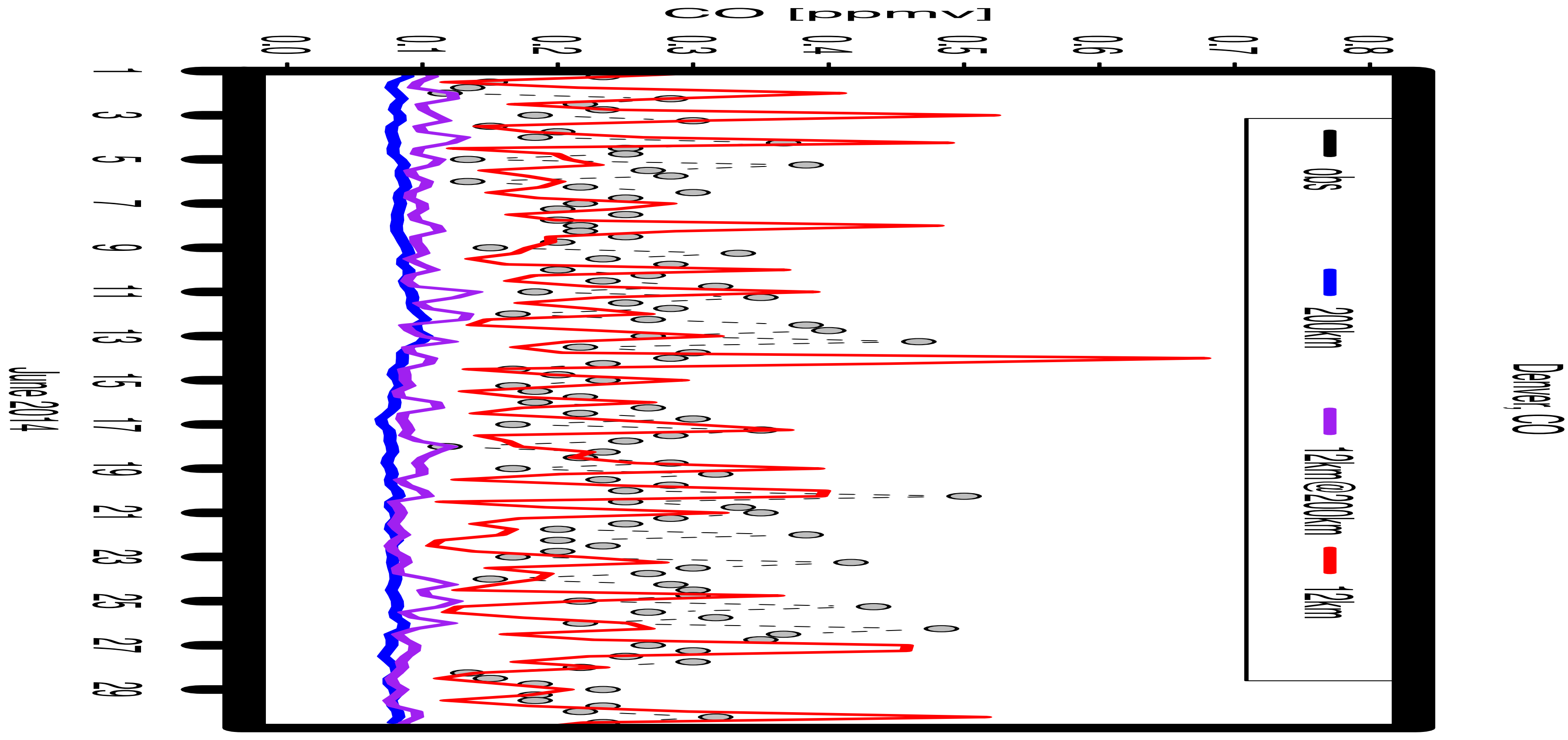
High resolution critical to resolve features relevant to air quality



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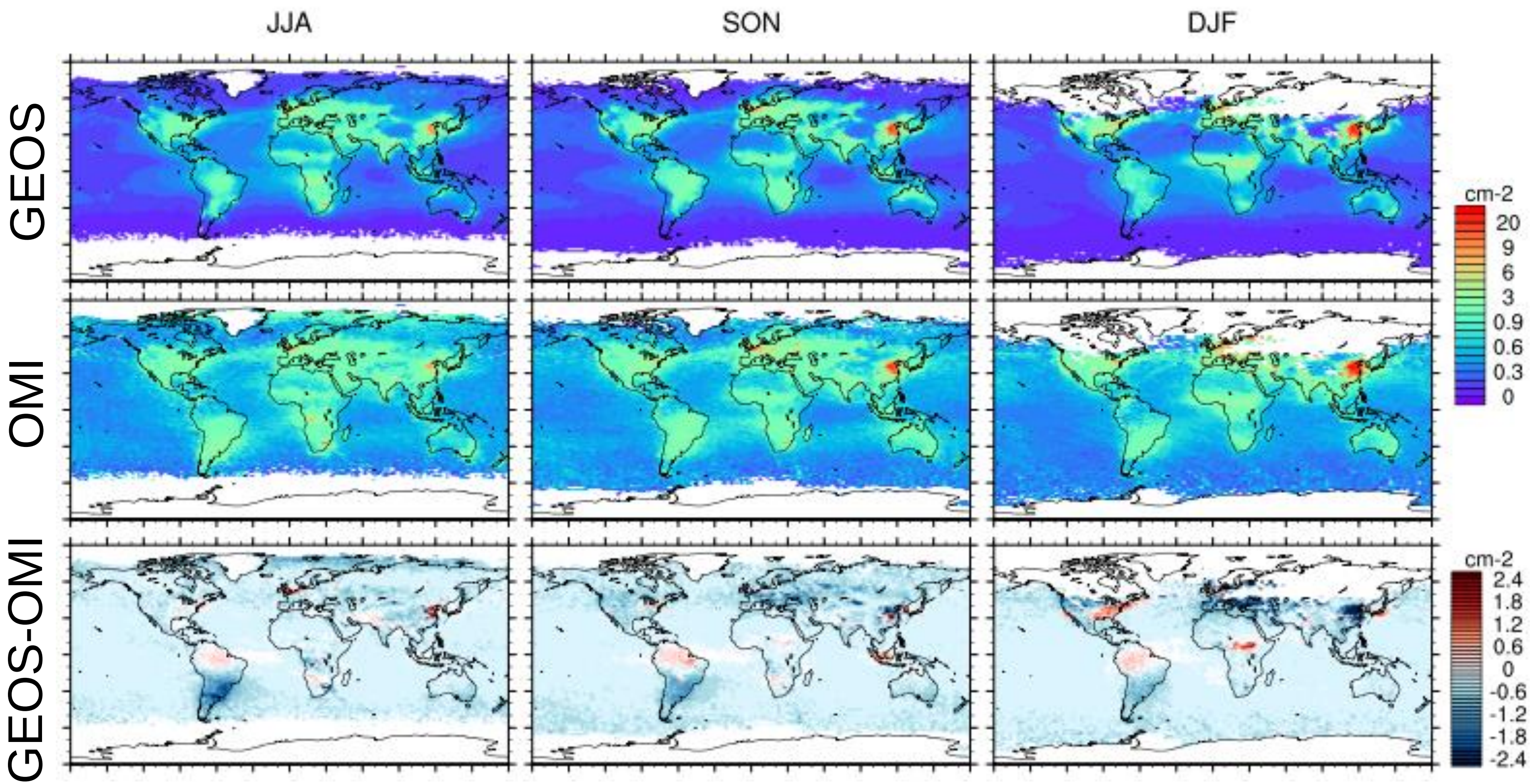
Global evaluation of NO_2: comparison against OMI tropospheric columns



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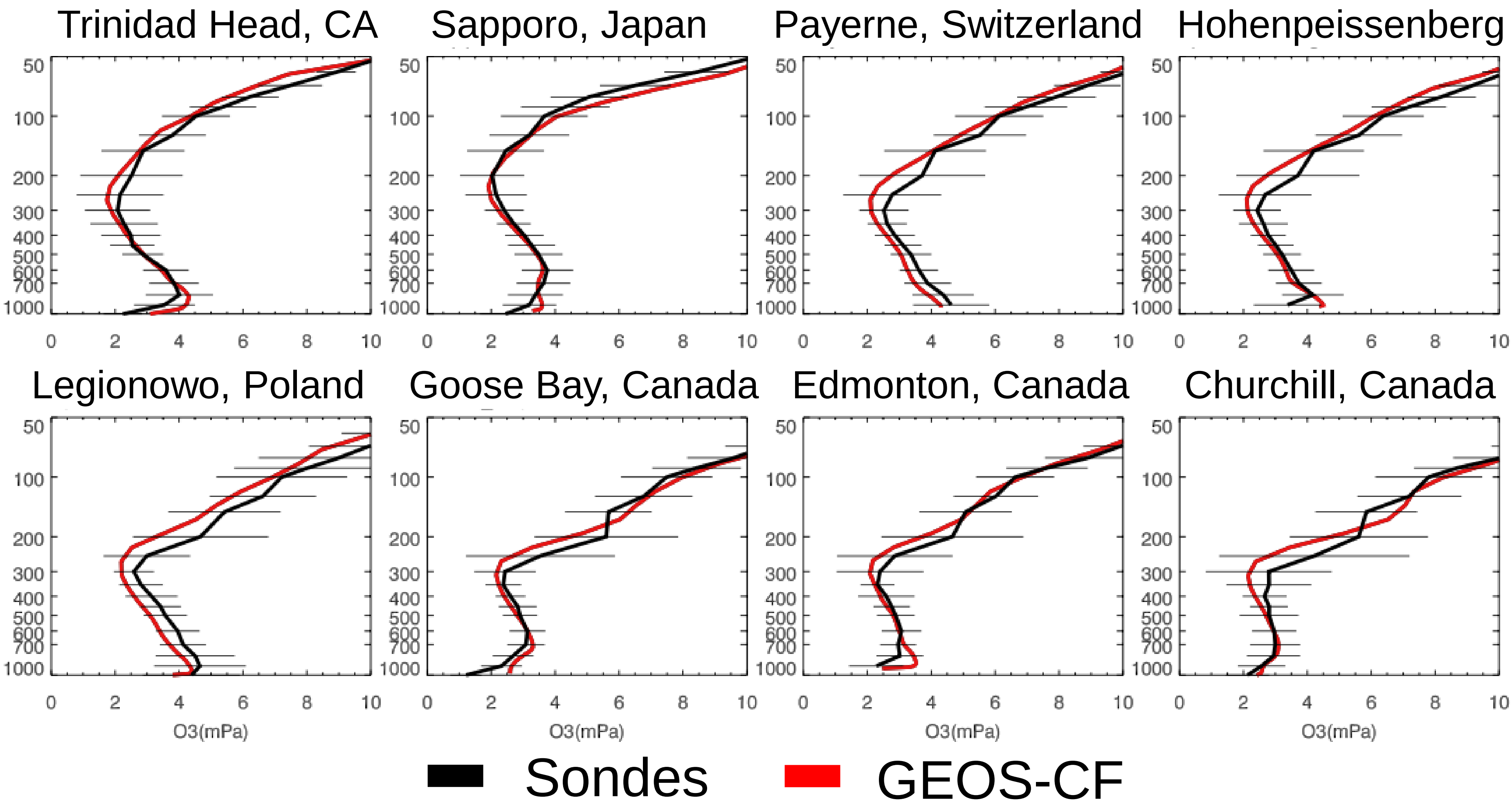
Comparison of GEOS-CF O_3 against ozone sondes



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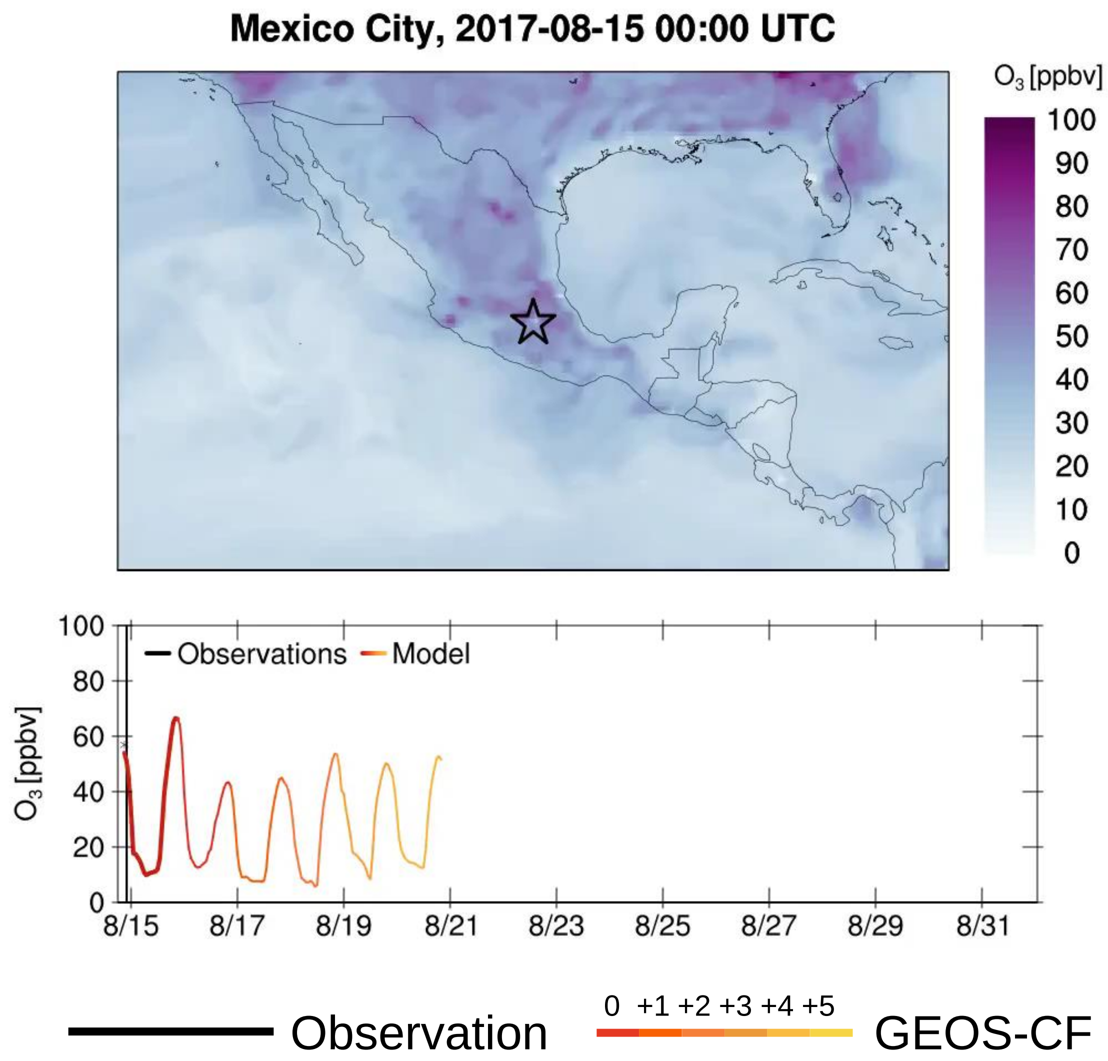
Ozone forecast against surface observations for Mexico City



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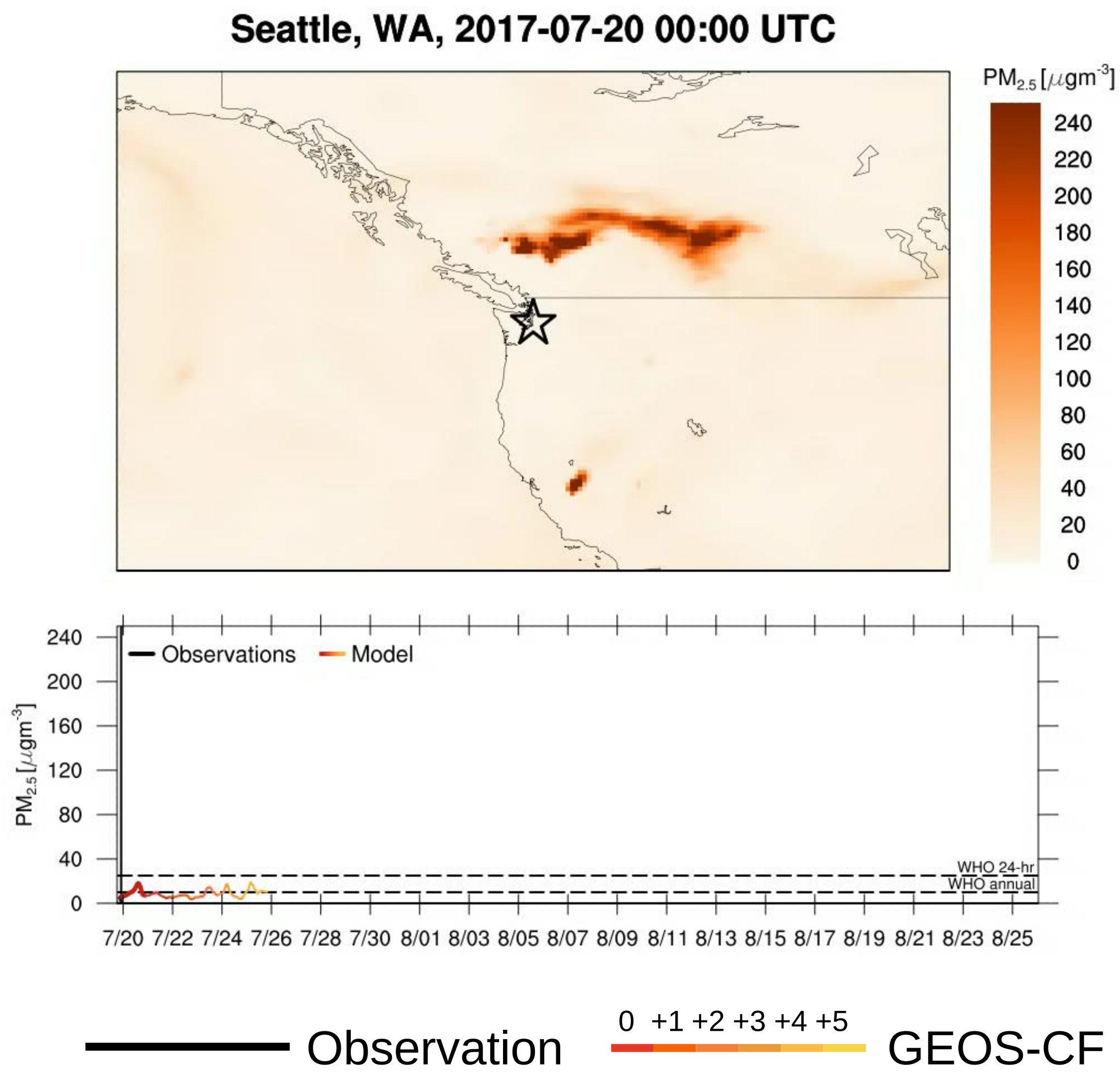
Local evaluation of $PM_{2.5}$ from wildfires



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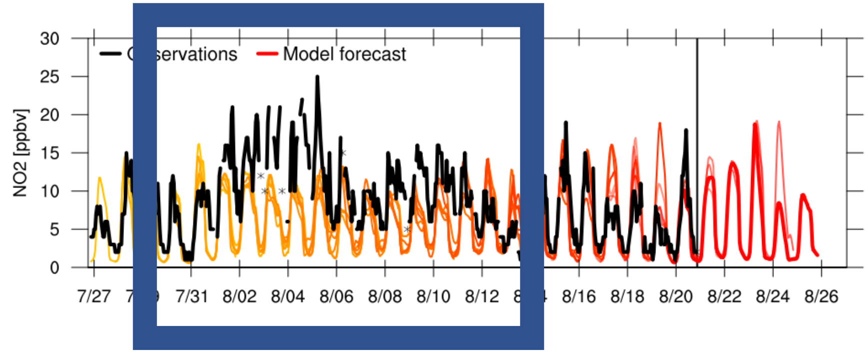
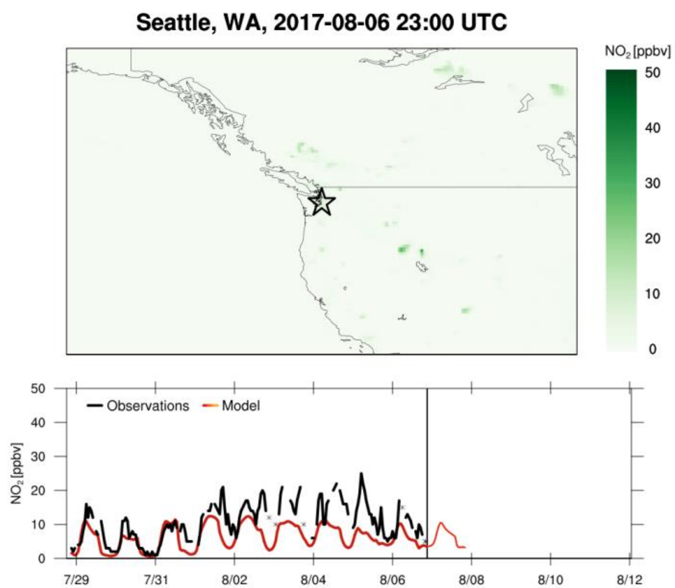
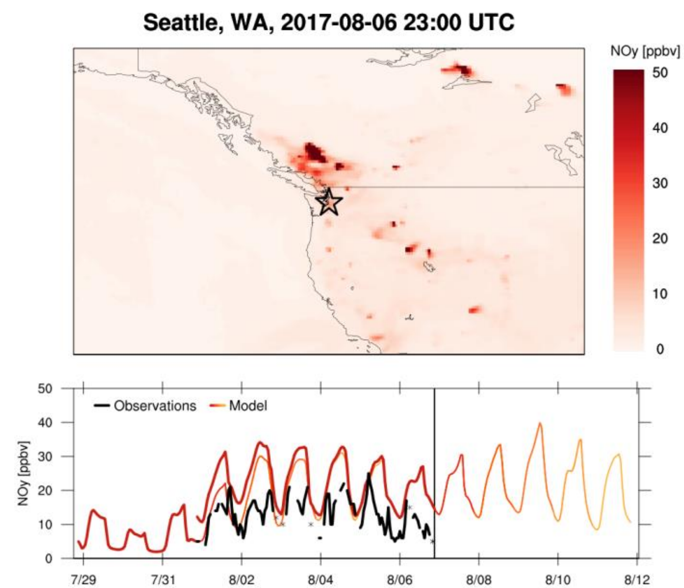
Local evaluation of NO_y from wildfires



$NO_y = NO + NO_2 + HNO_3 + HNO_4 + HONO + 2*N_2O_5 + PAN + OrganicNitrates + AerosolNitrates$





Observation   0 +1 +2 +3 +4 +5   GEOS-CF

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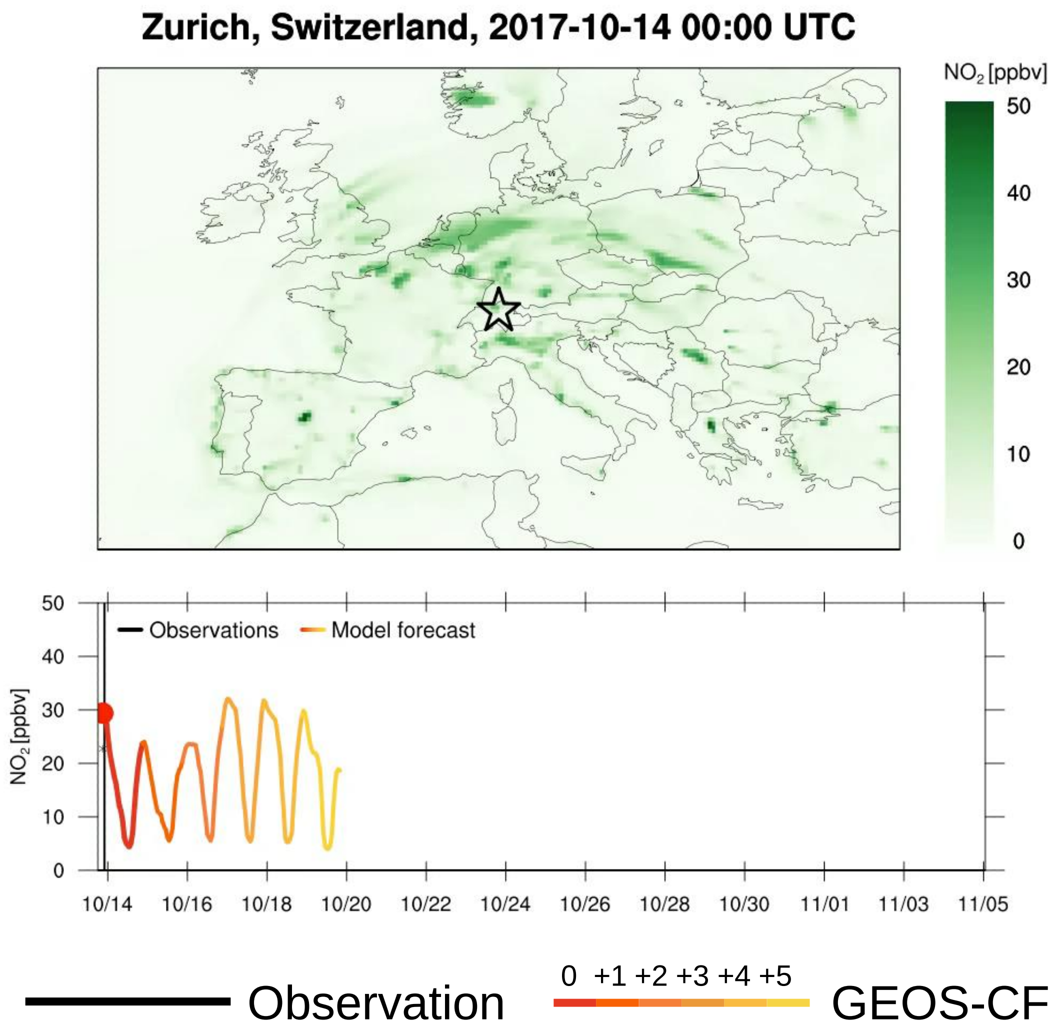
Local evaluation of NO_2: model captures diurnal and weekly variations



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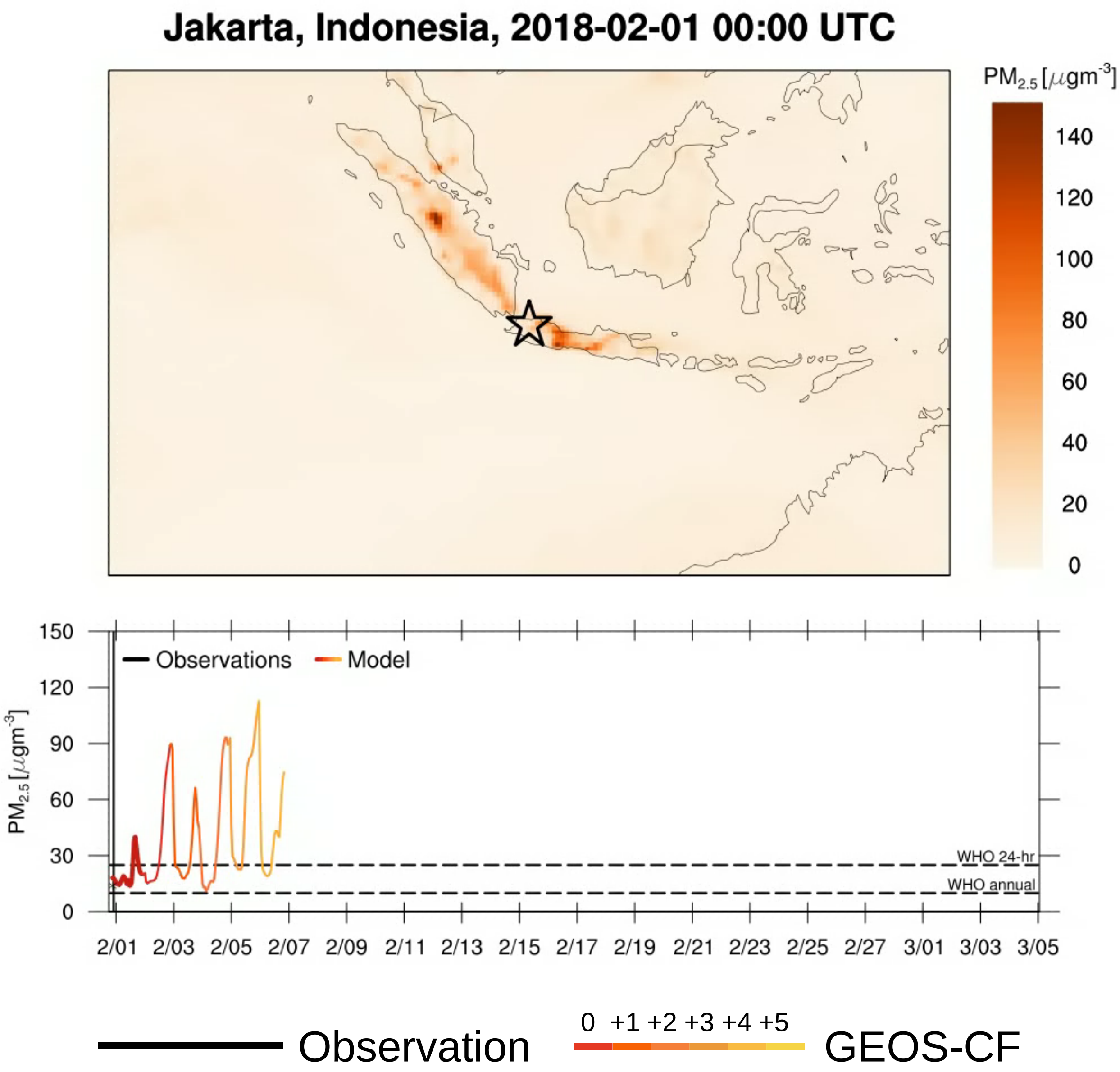

What comes out depends on what goes in

Working with local governments

- Rio De Janeiro
- Jakarta

to improve emissions in the model to improve local forecasts

Fires from Indonesia impact urban centers in Singapore and Malaysia

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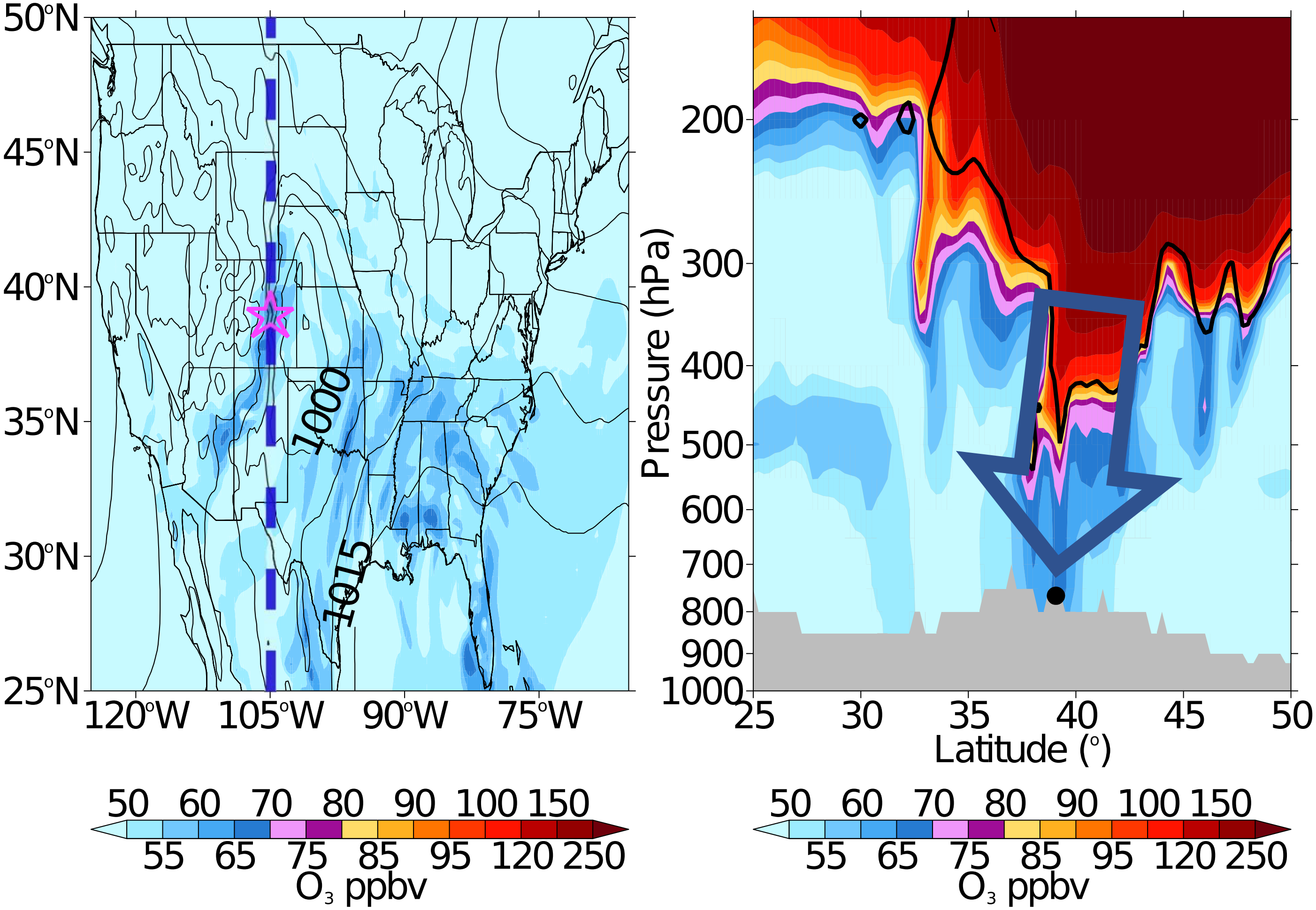
Stratospheric intrusions (SI)



Several **peaks in O_3** at monitoring stations reported in **AZ, CO and MD** April 16-18, 2018, **likely caused by SIs**

With several exceeding the NAAQS O_3 > 70 ppb regulatory limit

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Application: Health Air Quality Index (HAQI)

HAQI is a **multi-pollutant** index

The Canadian HAQI is a function of O_3, NO_2, and $PM_{2.5}$

$$AQHI = (\frac{1000}{10.4}) \times [(e^{0.000537 \times O_3} - 1) + (e^{0.000871 \times NO_2} - 1) + (e^{0.000487 \times PM_{2.5}} - 1)]$$

(Stieb et al., 2008, J. Air & Waste Manage. Assoc.)

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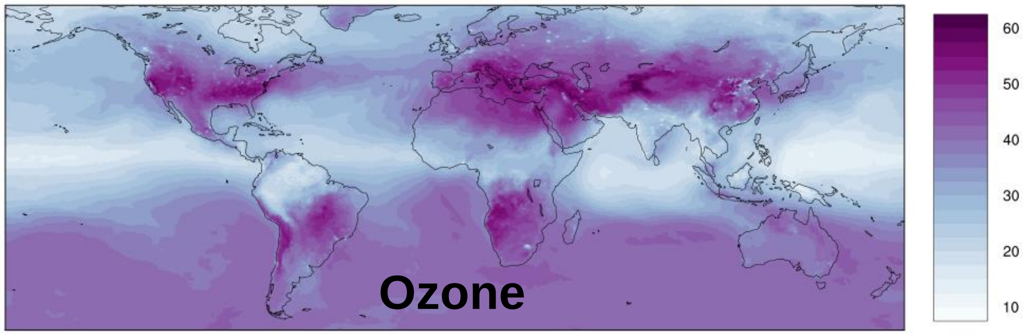
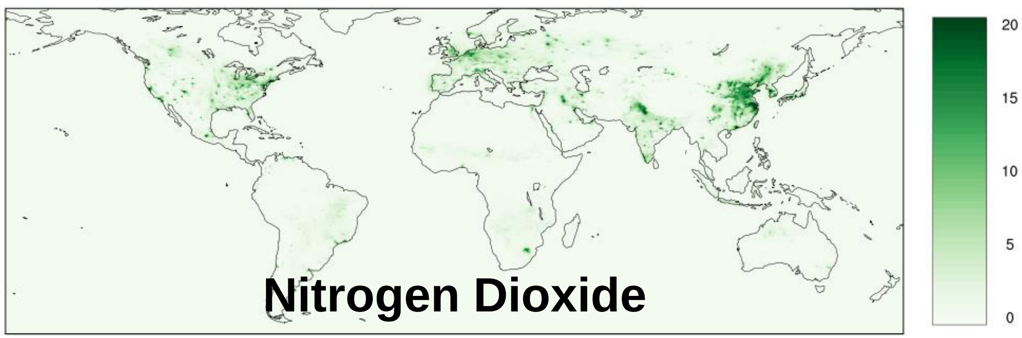
Application: Health Air Quality Index (HAQI)

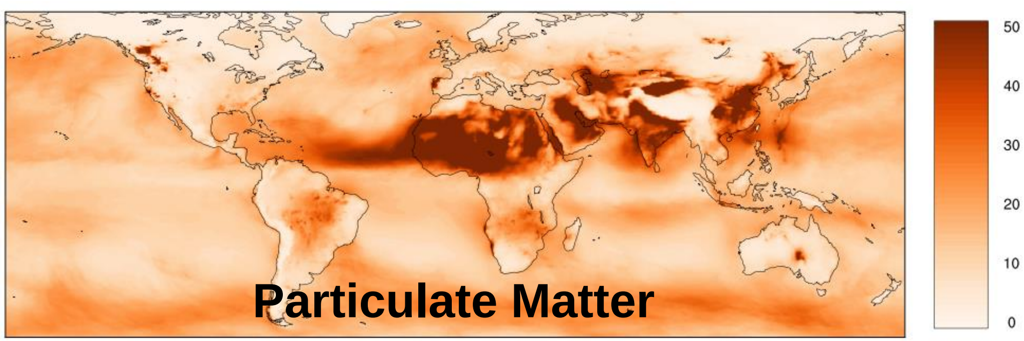
HAQI is a **multi-pollutant** index



- **O_3 influences Background levels**



- **NO_2 is Short-lived**
- **Extreme gradients**



- **$PM_{2.5}$ driver of spatial gradients**

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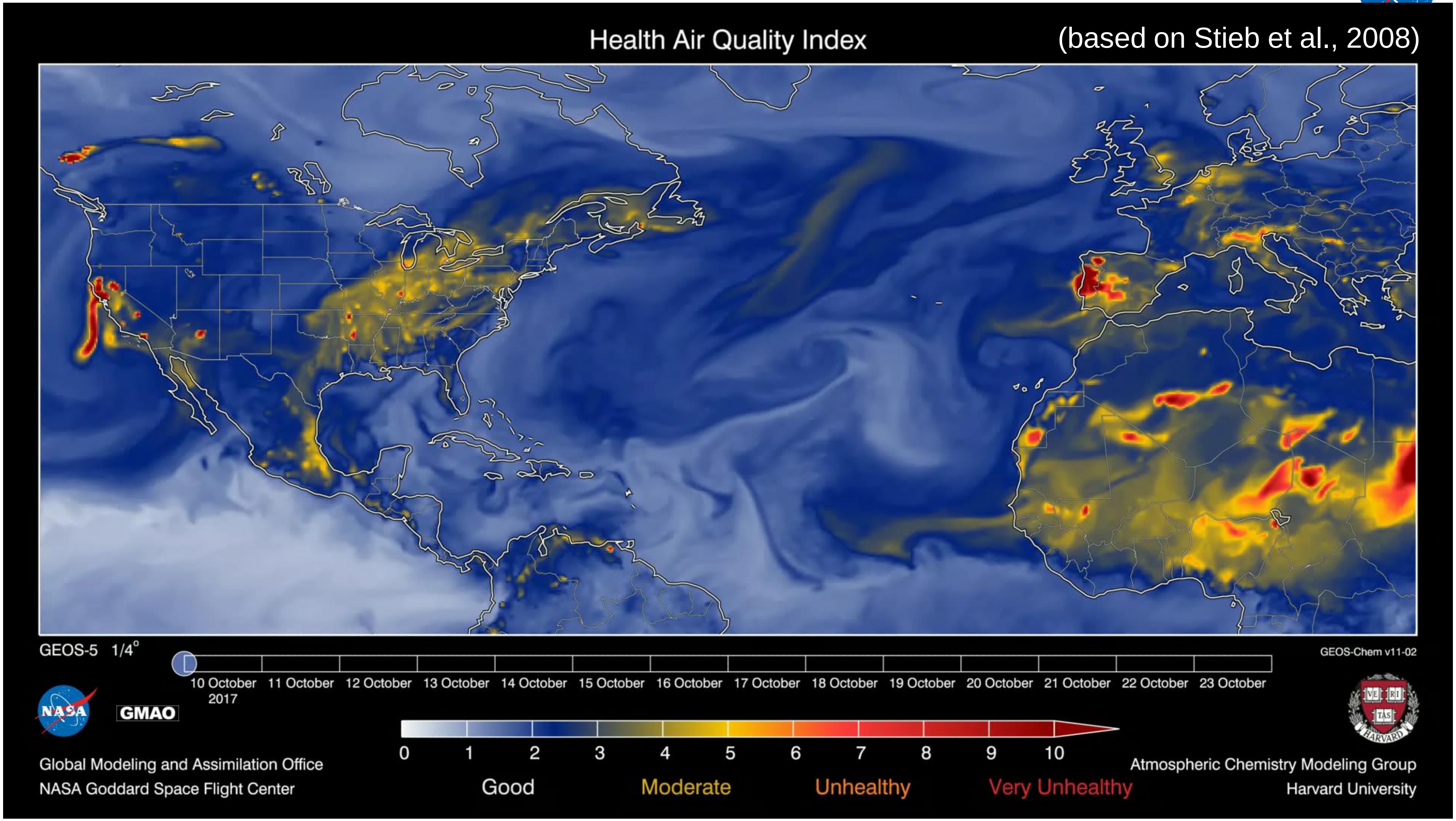

- NYU and UNICEF will use GEOS-CF to refine HAQI for children

NYU

unicef

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Summary

✓ GEOS-CF produces daily global air quality forecasts at 25km horizontal resolution

❑ Output available to public in late-2018

1. Visualization tool https://fluid.nccs.nasa.gov

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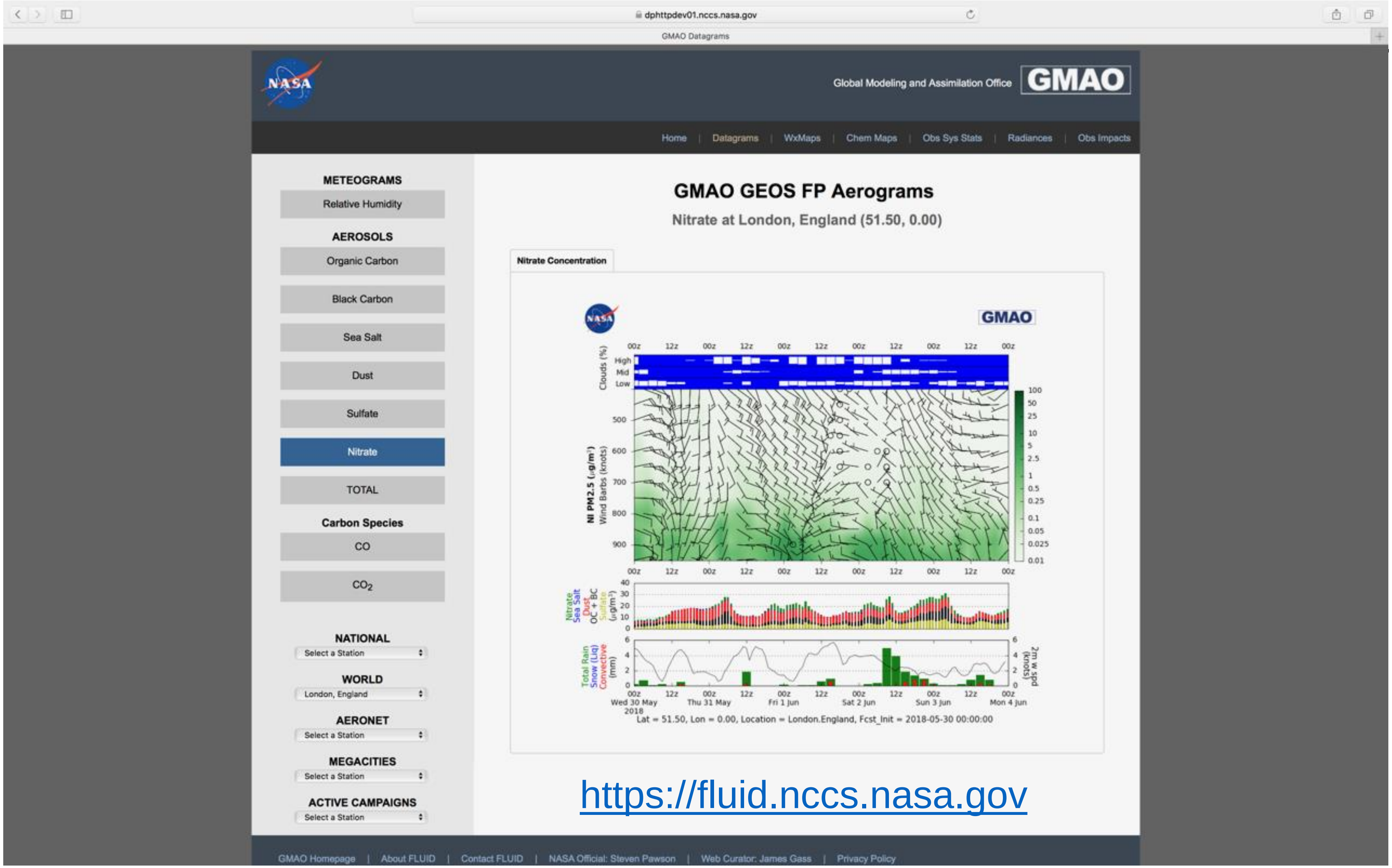
Summary



https://fluid.nccs.nasa.gov

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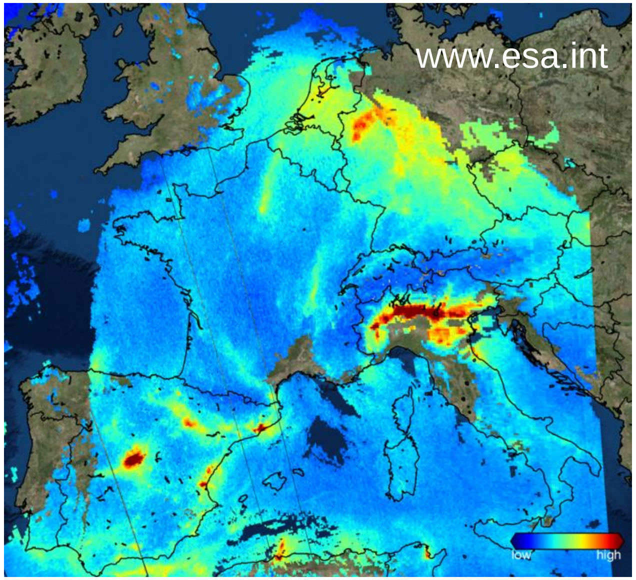
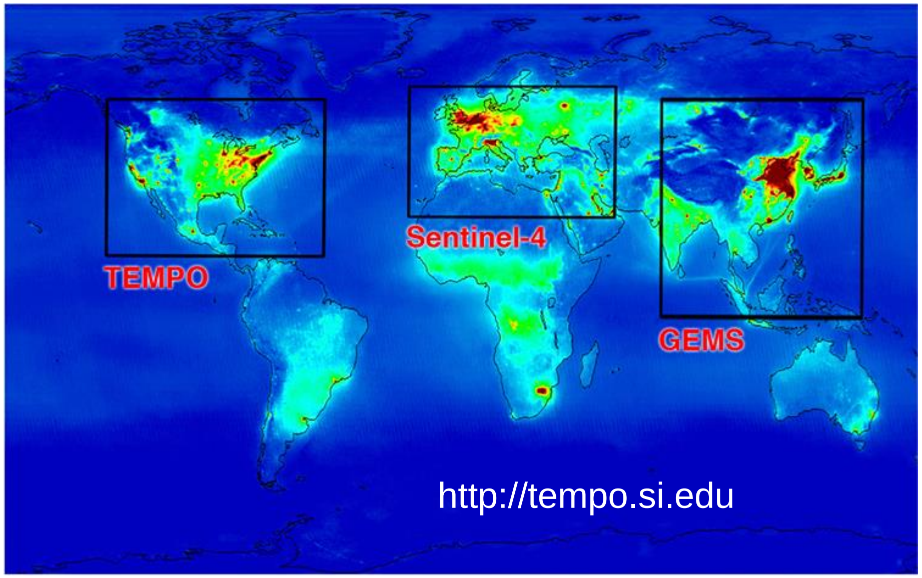
What's next: Data assimilation system for tropospheric constituents

- Impacts of joint assimilation of O_3, NO_2 and CO:
  - ✓ Reduction of CO bias
  - ✓ Better spatiotemporal representation of NO_2
  - ✗ Further increase of tropospheric ozone
- Weak observational constraint in current configuration





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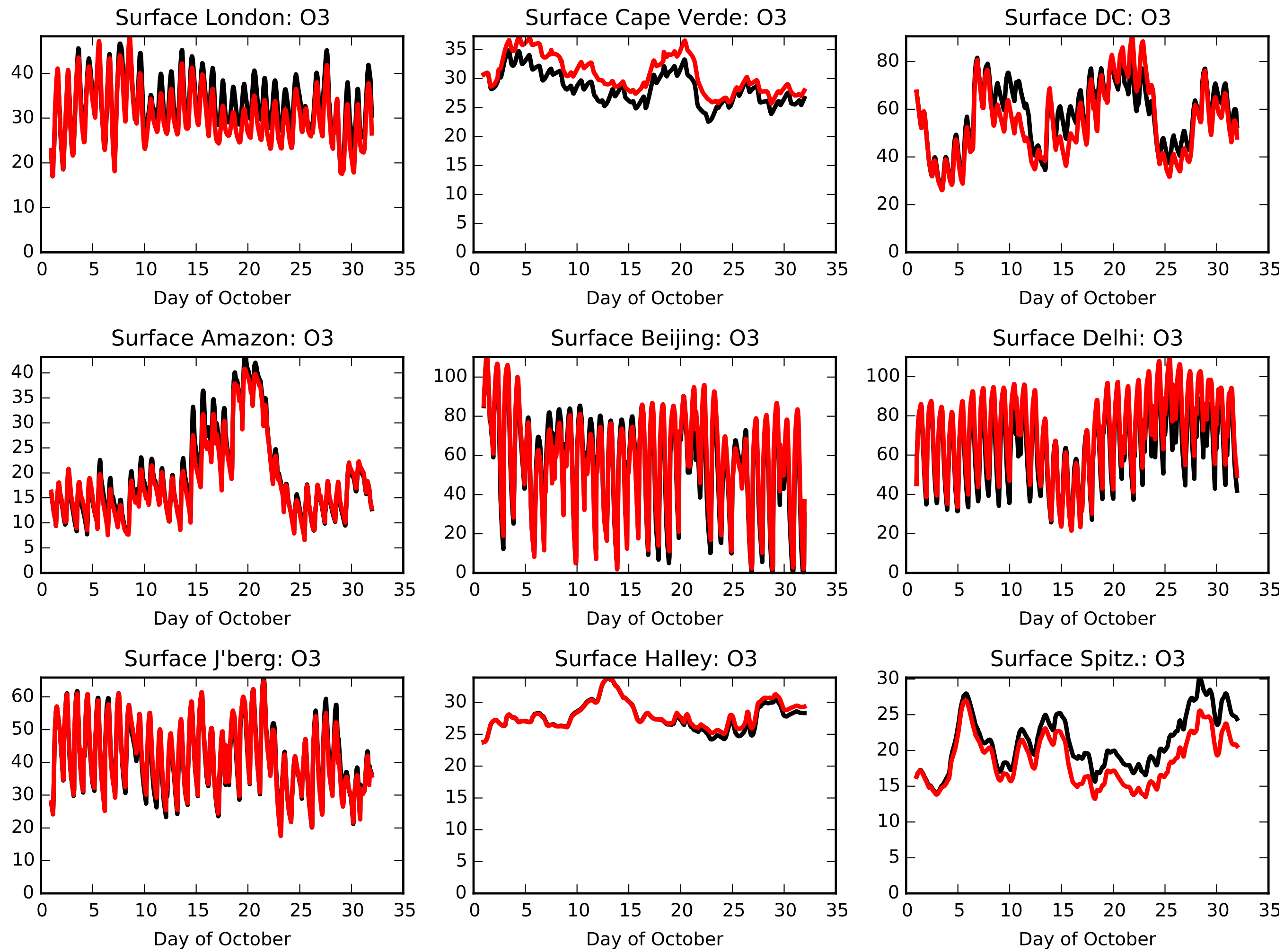
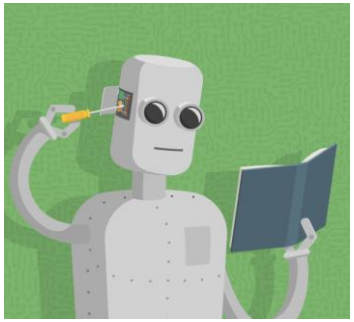
What's next: Machine learning mechanism for chemistry solver (random forest)



Black: GEOS-Chem

Red: Machine Learning



Mat Evans
York University

Summary

✓ GEOS-CF produces daily global air quality forecasts at 25km (16 miles) horizontal resolution

❑ Output available to public in late-2018

1. Visualization tool https://fluid.nccs.nasa.gov
2. Data access through NASA GES DISC and OpenDAP

Under development:

1. A 2-5 year simulation to collect statistics
2. Assimilation system for trace gases (O_3, NO_2, CO)
3. Machine Learning for chemistry solver
4. GOCART and GEOS-Chem coupling in GEOS

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Collaborations & Opportunities

Government, Public, NGO, Industry,

Research / Mitigation

Flight campaign planning

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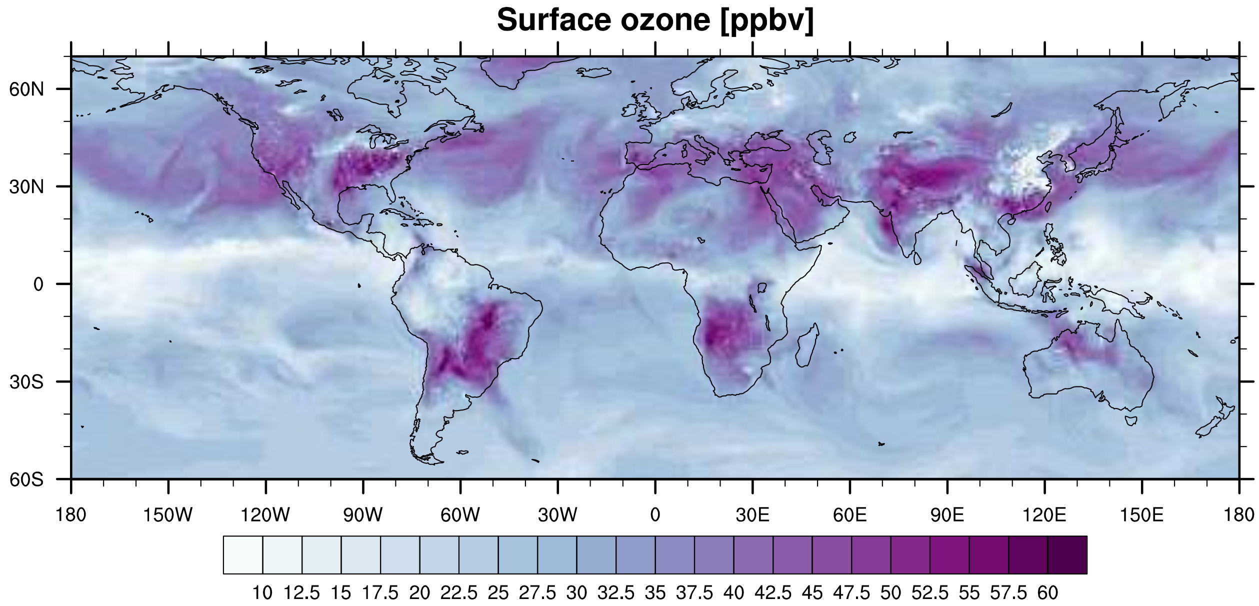
Thank you!



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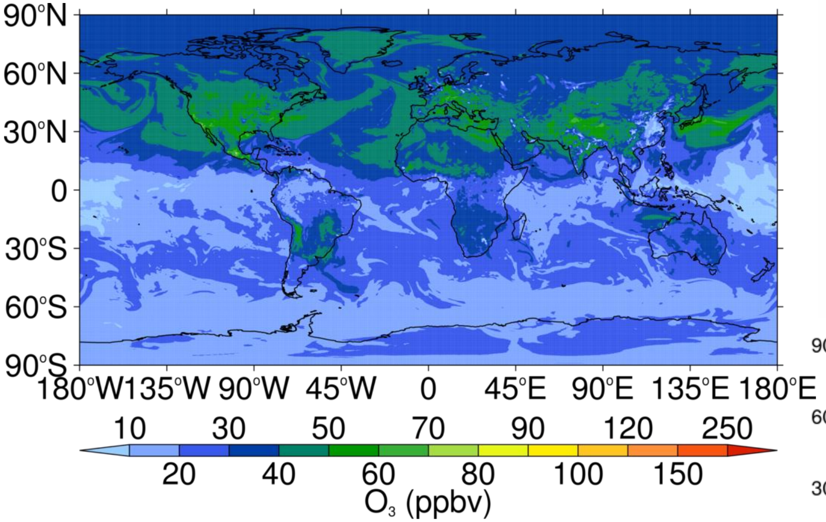
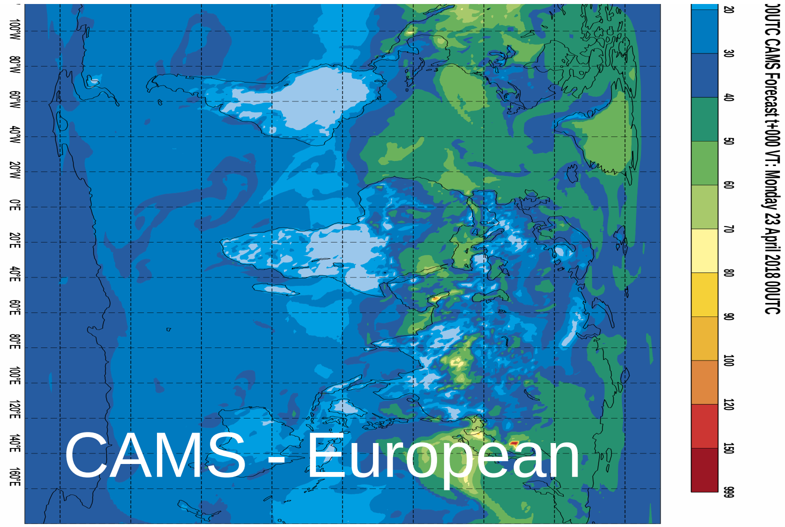
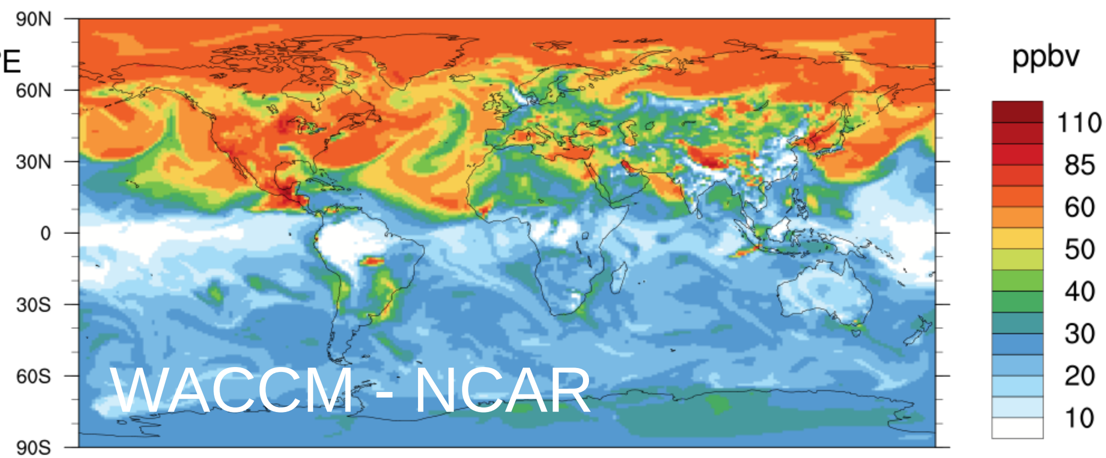
Compared to other global modelling centers

GEOS - CF







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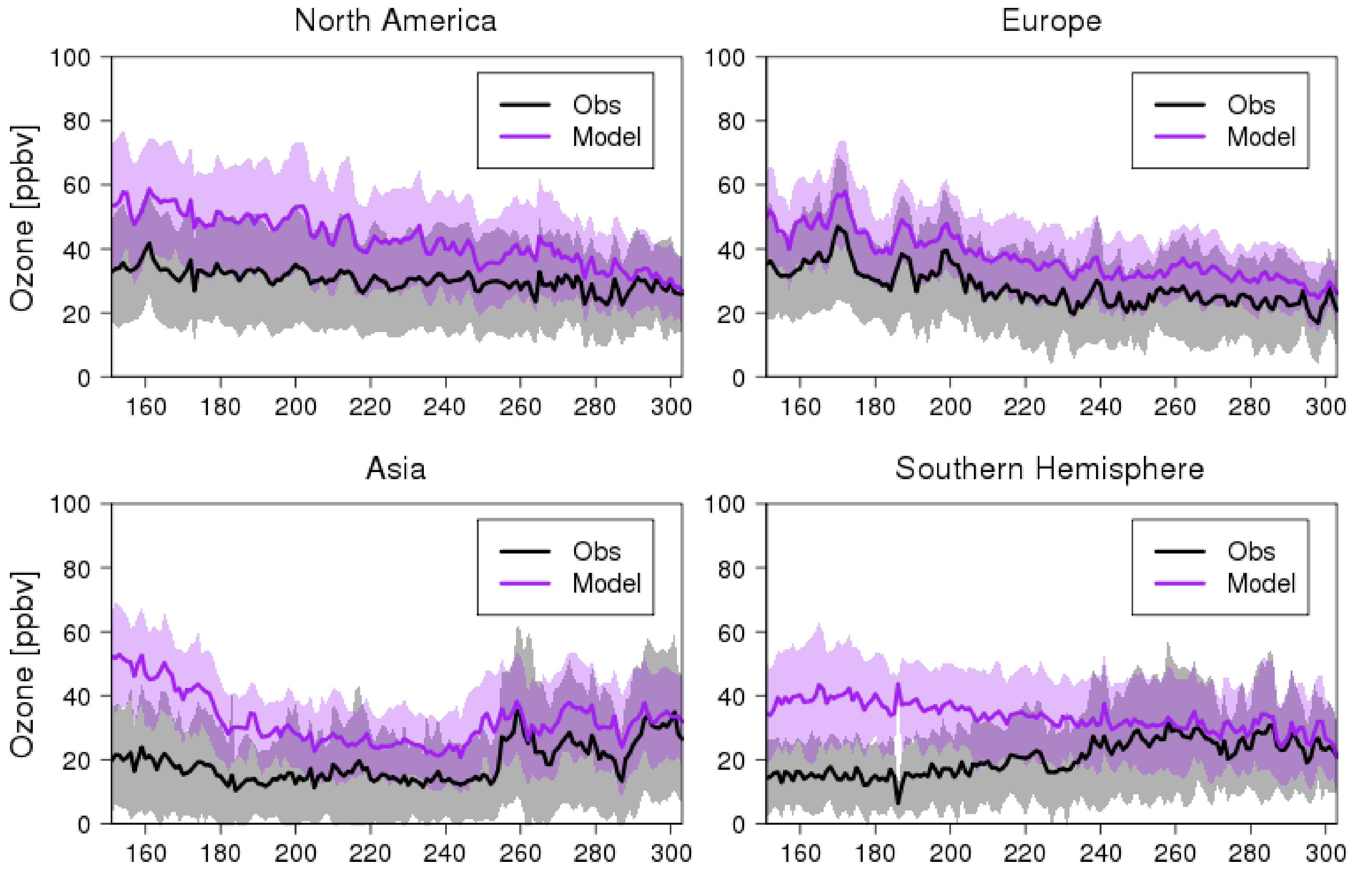
Surface O_3 observations compared to GEOS CF



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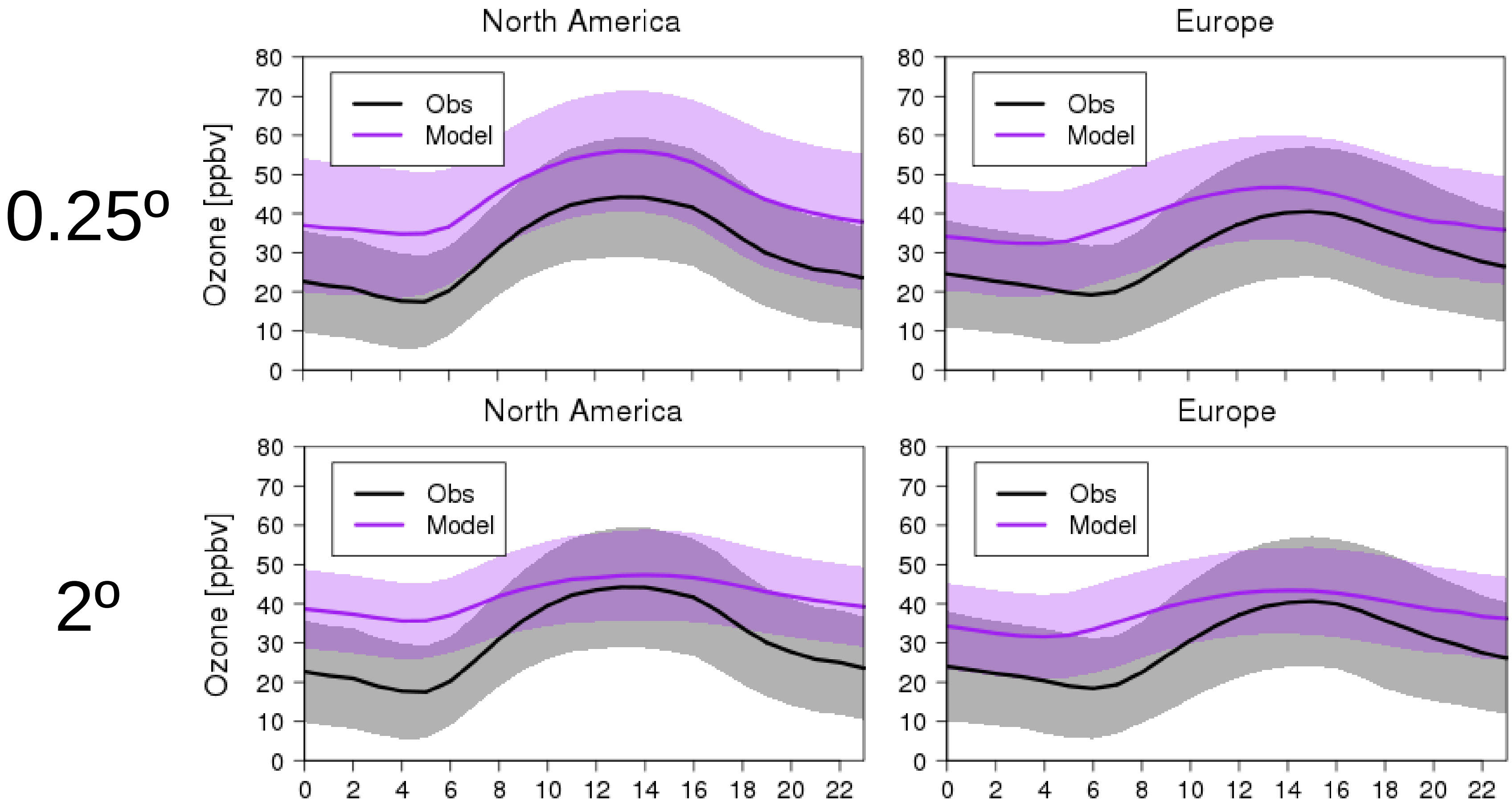
Diurnal cycle of surface O_3 is reproduced at the higher resolution



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Closeness plot

At each station, monthly long hourly data N=744.

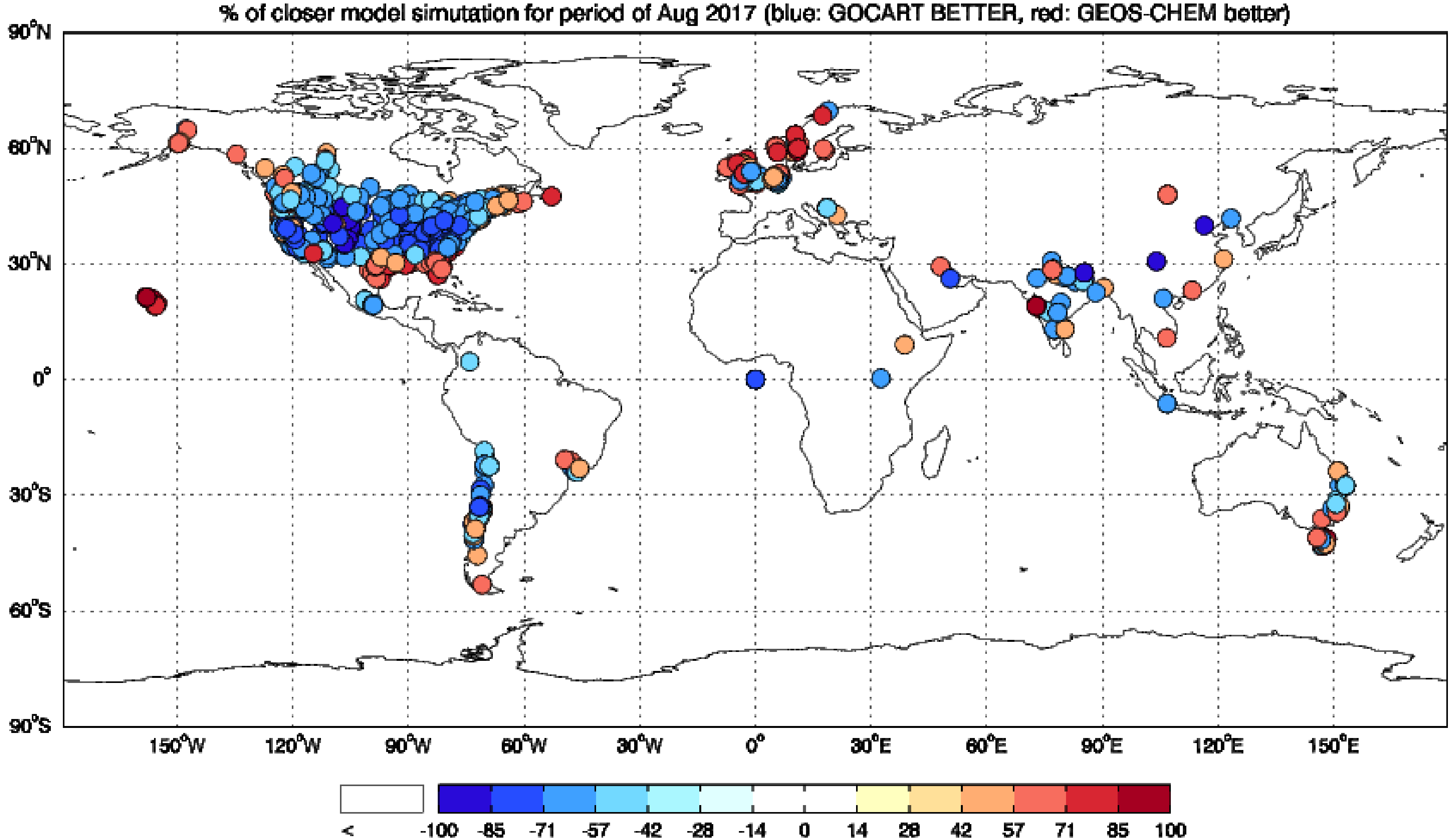
Calculate the (N_{G5})frequency of GOCART with lower biases: $|G5_t - obs_t| < |GCC_t - obs_t|$

$-1 * N_{G5} / N * 100$ (negative shown with blue)

Similar calculation of N_{GCC} for GOES-Chem with lower biases.

$N_{GCC} / N * 100$ (positive shown with red)

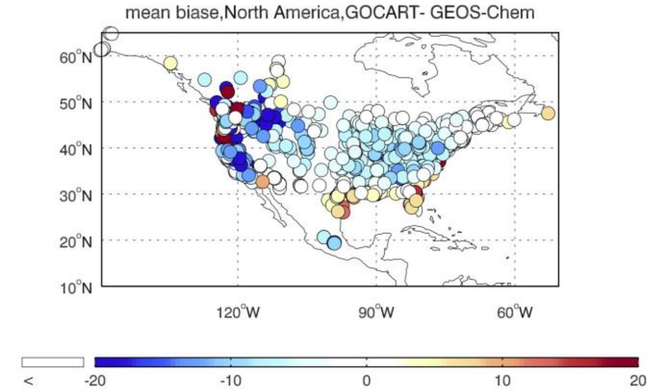
Closeness plots



GOCART Better

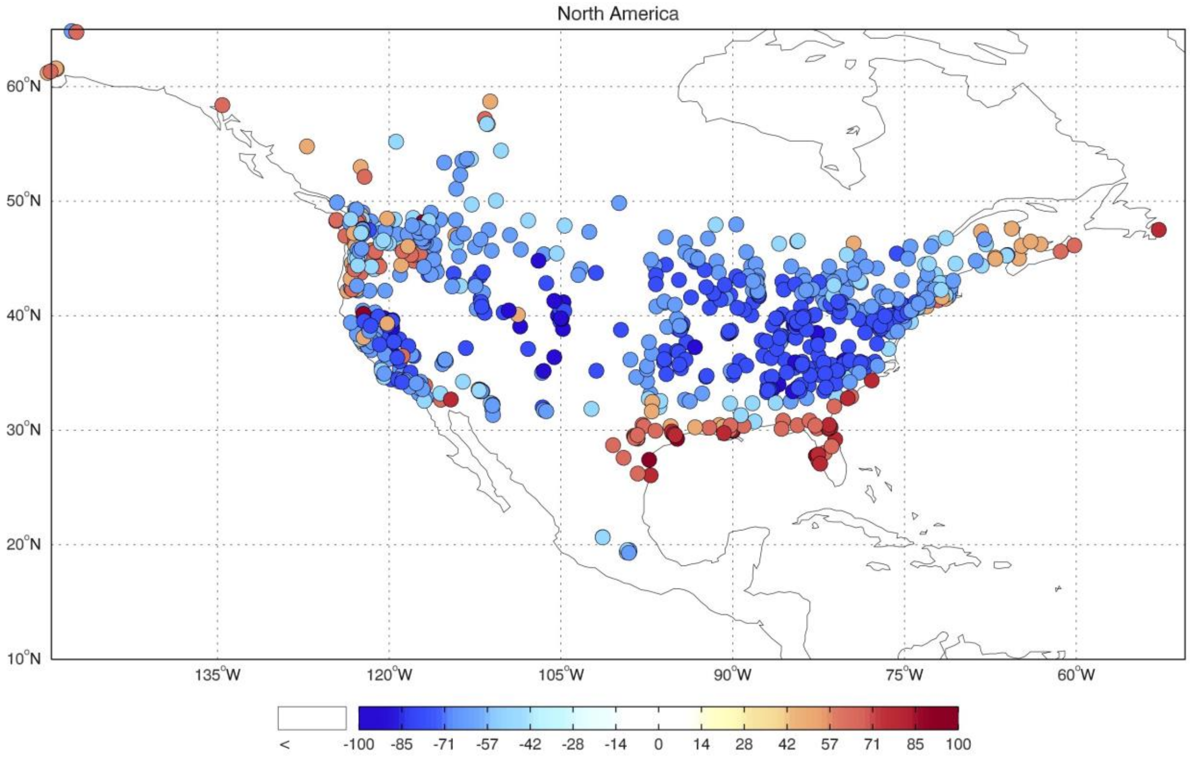
GEOS-Chem better

Mean biases (G5-GCC)

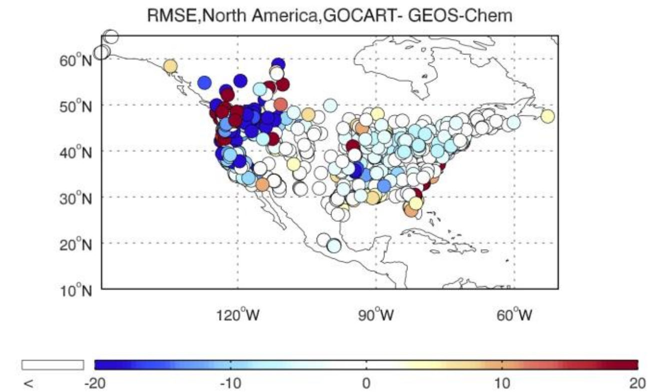


GOCART Better

GEOS-Chem better



RMSE(G5-GCC)



Correlation(GCC-G5)