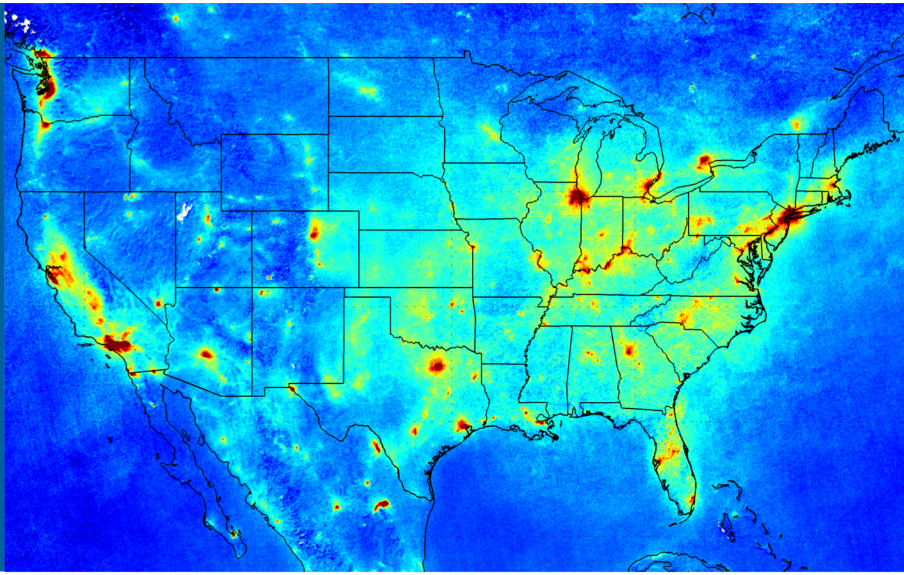
FUNDING PROVIDED BY NASA, DOE OFFICE OF FOSSIL ENERGY, & THE EPA SOLUTIONS FOR ENERGY AIR CLIMATE & HEALTH (SEARCH) CENTER

USING SATELLITE DATA TO ESTIMATE AIR POLLUTION AT HIGH SPATIOTEMPORAL RESOLUTION



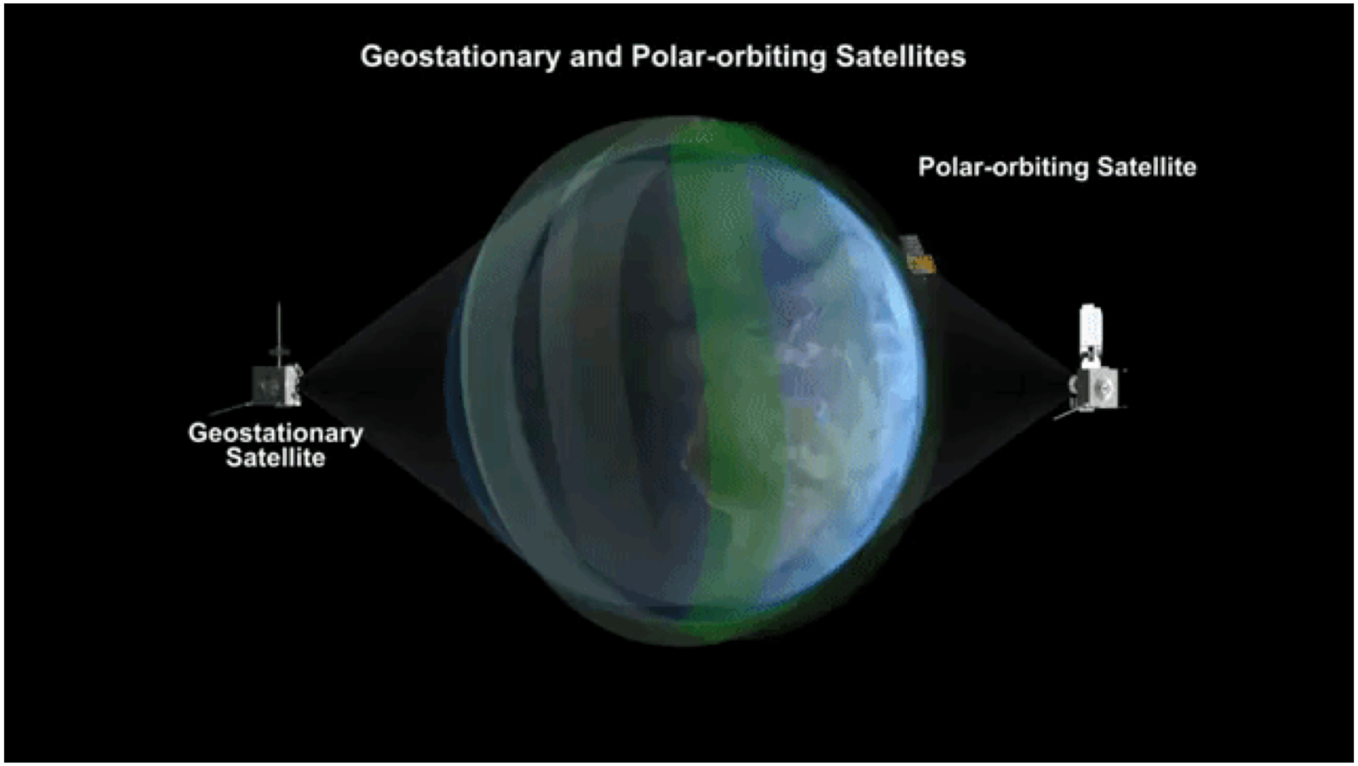
Satellite NO_2 observed by the newest instrument, TROPOMI, during July 2018

DAN GOLDBERG, PH.D.

Postdoctoral Scientist
Argonne National Laboratory
Washington, DC

March 29th, 2019
Portland, Oregon
TWEEDS 2019

POLAR-ORBITING SATELLITES VS. GEOSTATIONARY SATELLITES



Animation from UCAR COMET

Polar-orbiting, or low-earth-orbiting, satellites have global coverage *but* only one snapshot (sometimes fewer) per day. ← All current air quality monitoring satellites are these.

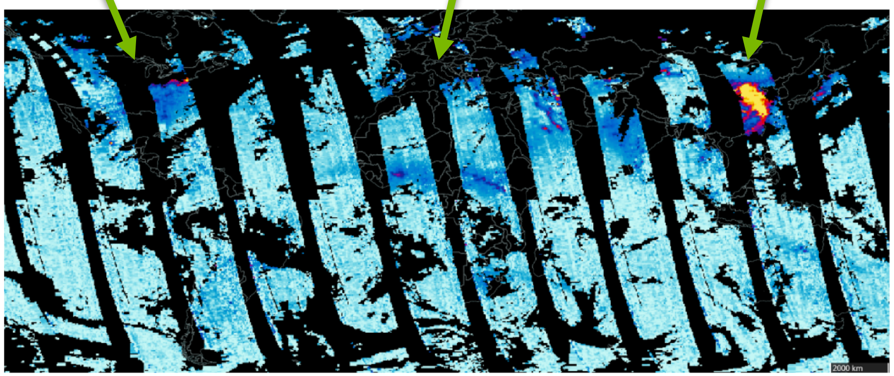
Geostationary satellites have partial global coverage, but many snapshots (100x, 1000x) per day.

MOST USEFUL SATELLITES FOR AIR QUALITY PURPOSES

To monitor trace gases (i.e., NO_2 , SO_2 , etc.):

<u>Tropospheric Monitoring Instrument (TROPOMI)</u>

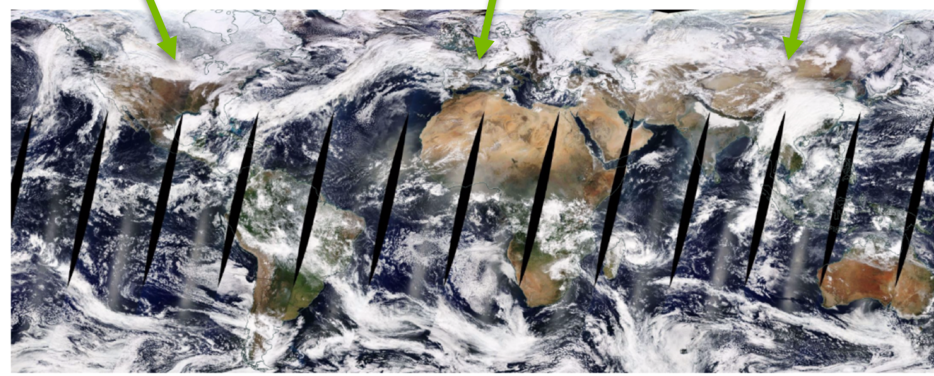
North America Europe Asia



To monitor aerosols (i.e., particulate matter):

<u>Moderate Resolution Imaging Spectroradiometer (MODIS):</u>

North America Europe Asia



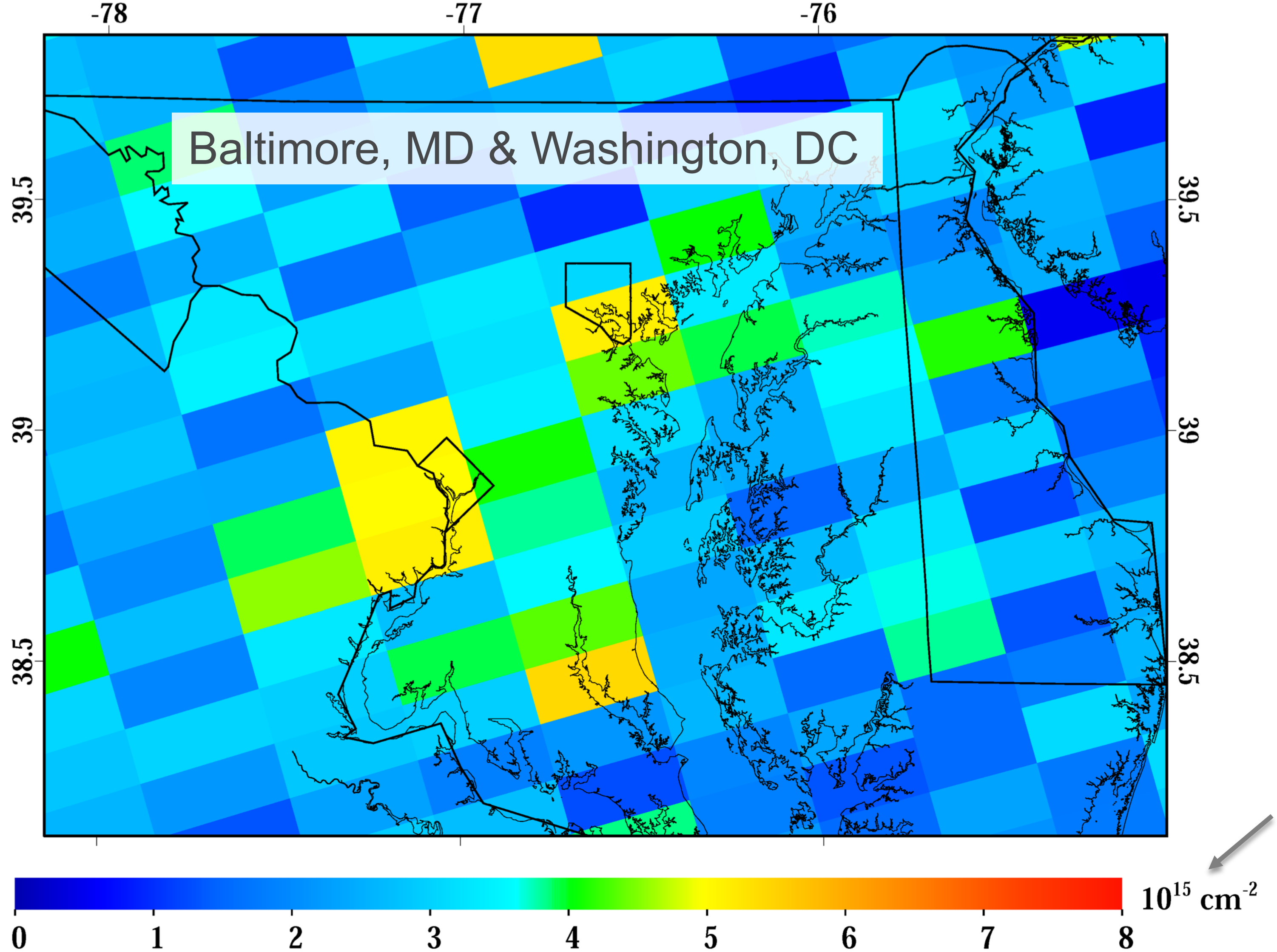
Quick looks (like above) are available at: https://worldview.earthdata.nasa.gov/ or http://www.temis.nl/airpollution/

Both satellite instruments are known for their longevity; over 14 years of consistent data!

However, both are also low-earth orbiting satellites, which means only 1 snapshot per day.

OMI NO_2 SATELLITE DATA

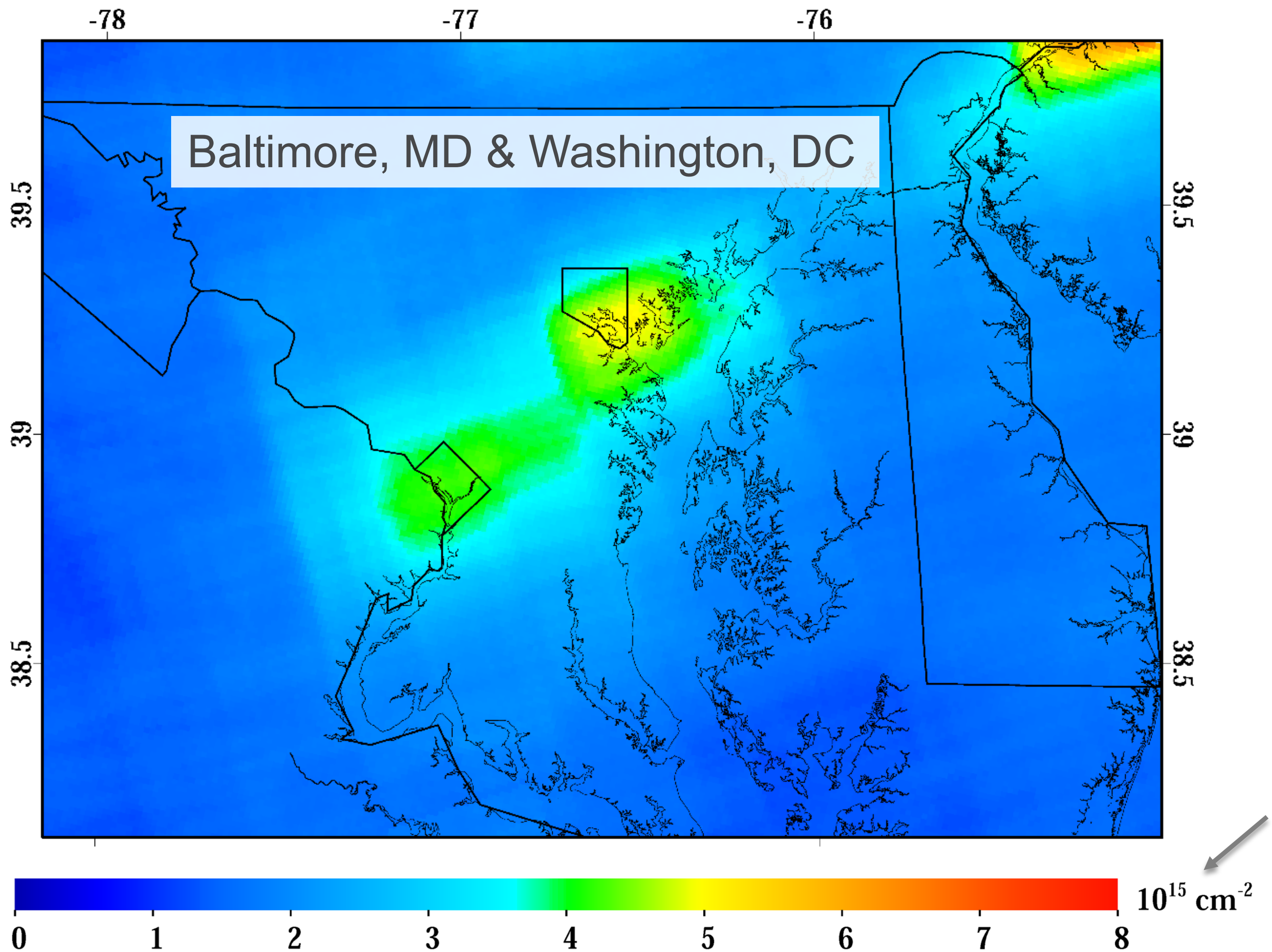
One day: July 18, 2011



Units are molecules per cm^2

OMI NO_2 SATELLITE DATA

Ten months: June & July 2008 – 2012



Units are molecules per cm^2

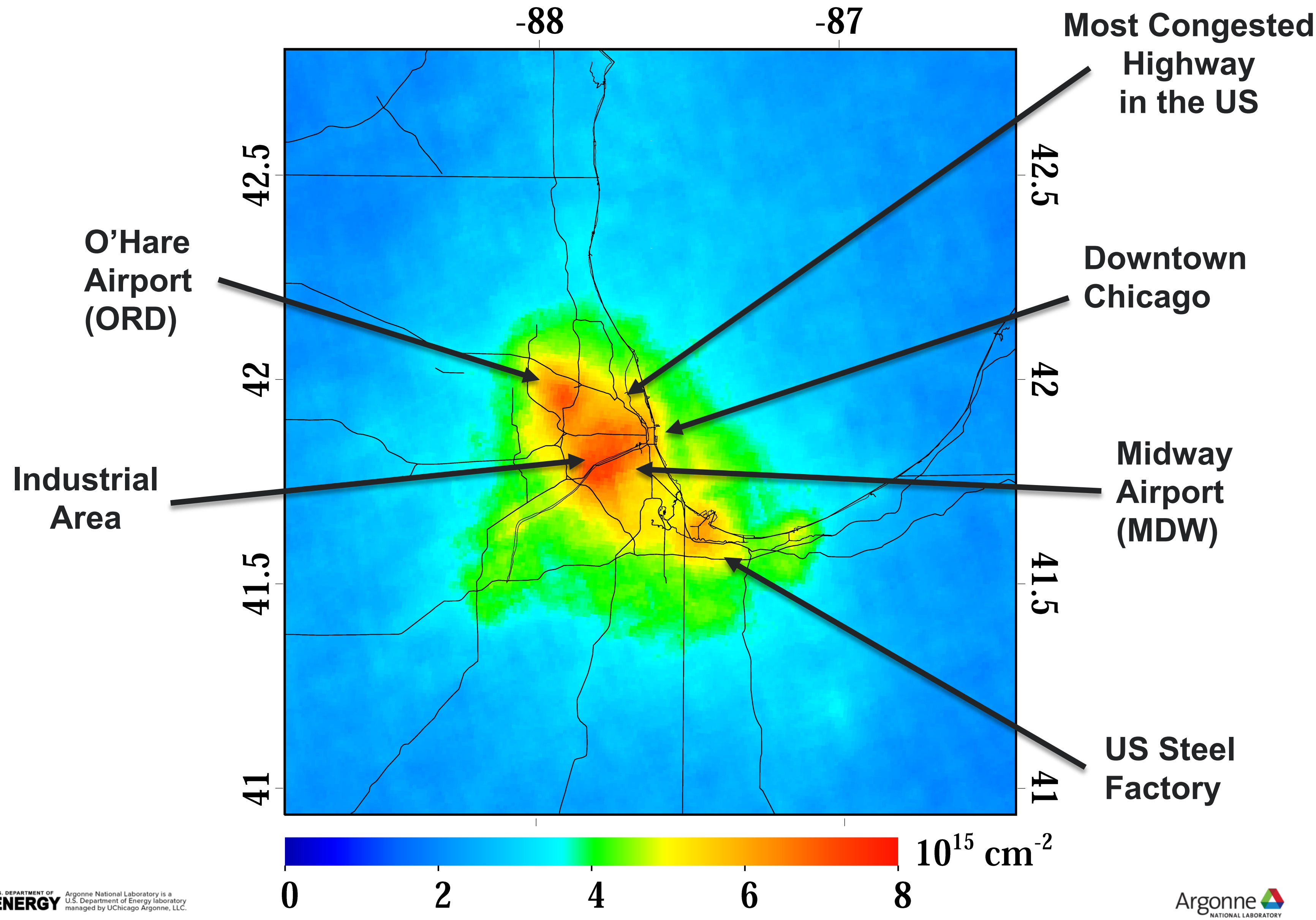
DERIVING NO_X EMISSIONS ESTIMATES USING SATELLITE DATA

GOLDBERG ET AL., 2019;

GOLDBERG ET AL., IN PREP.

HOW TO DERIVE EMISSIONS FROM SATELLITE DATA

<u>Step 1:</u> Isolate data from a single source (showing TROPOMI NO_2 for 2018)



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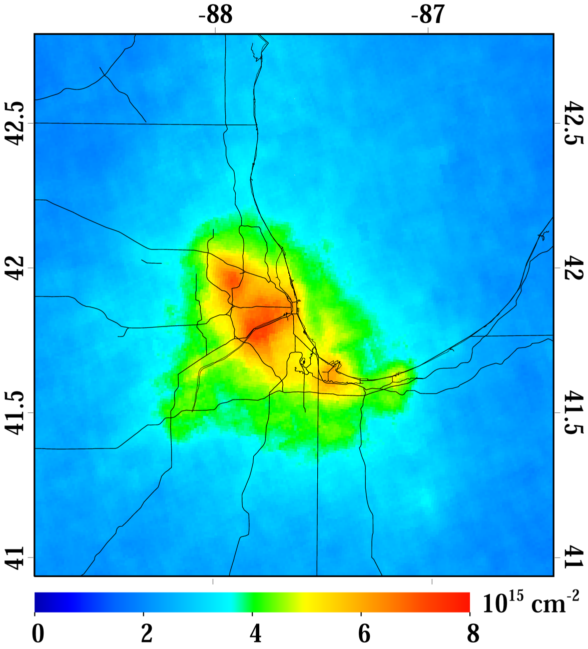

HOW TO DERIVE EMISSIONS FROM SATELLITE DATA

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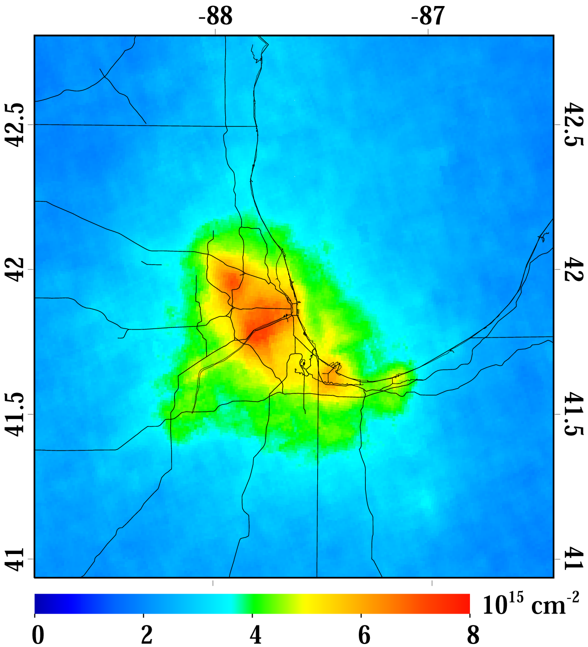
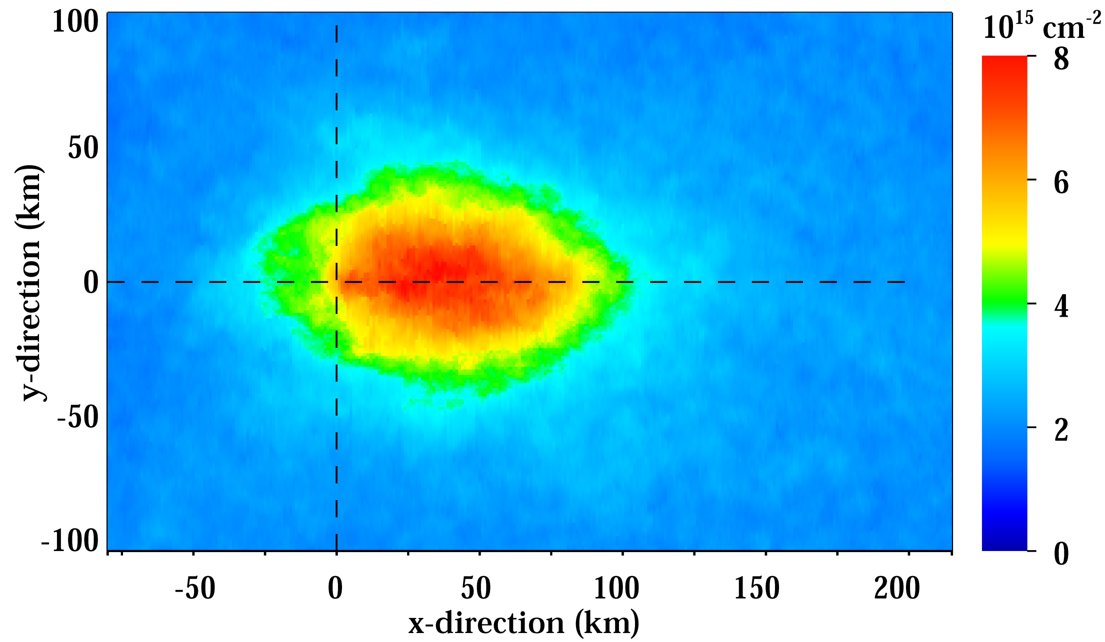


<u>**Step 2:**</u> **Rotate based on each day's winds**



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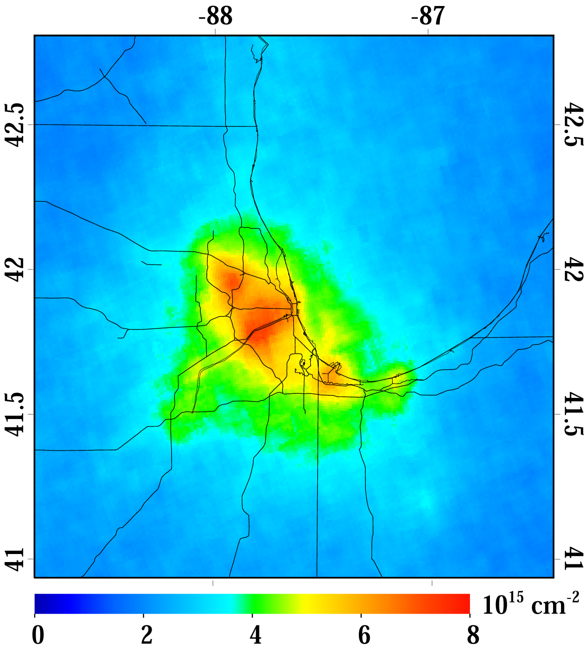

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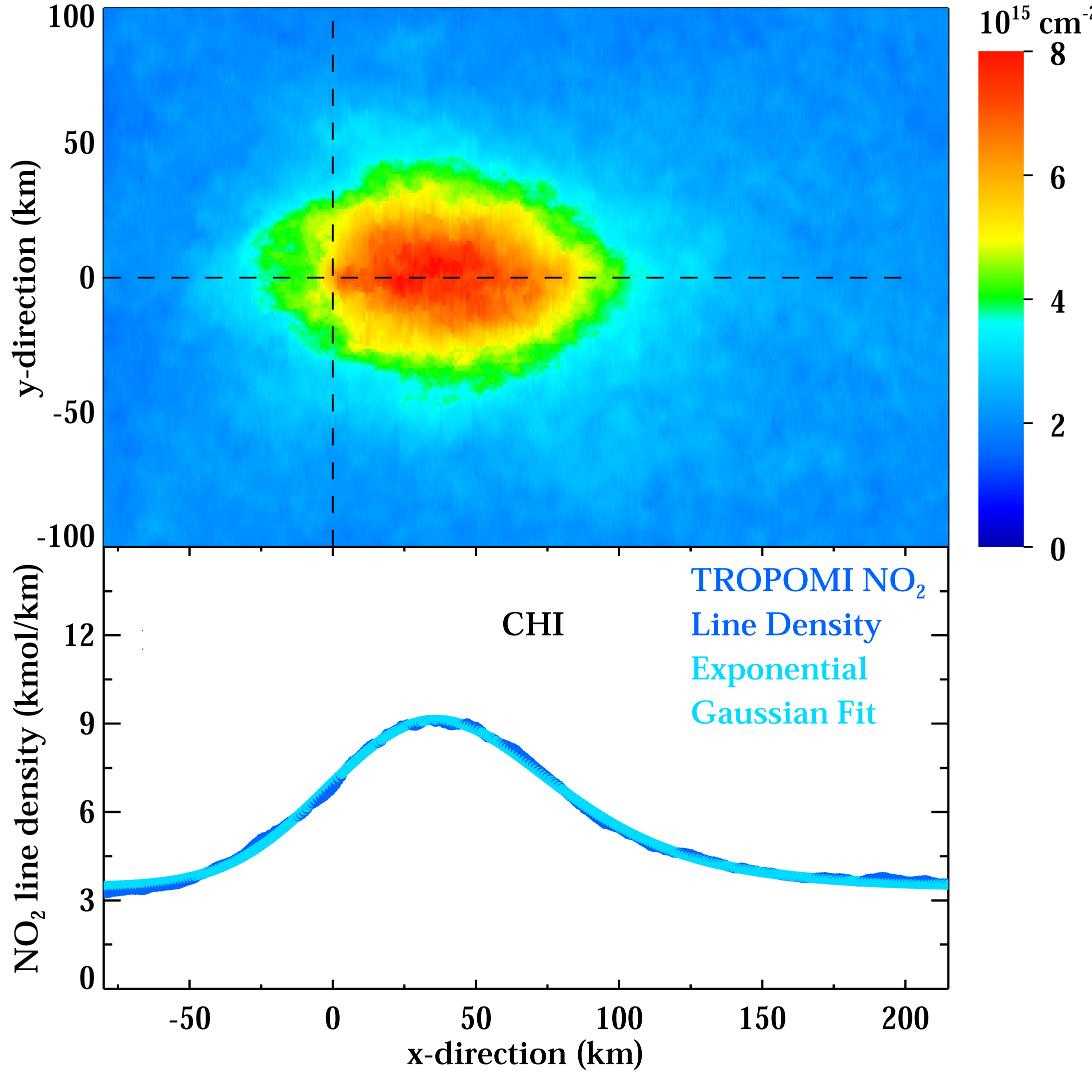

Step 3: Fit the decaying plume to an exponentially modified Gaussian function

HOW TO DERIVE EMISSIONS FROM SATELLITE DATA

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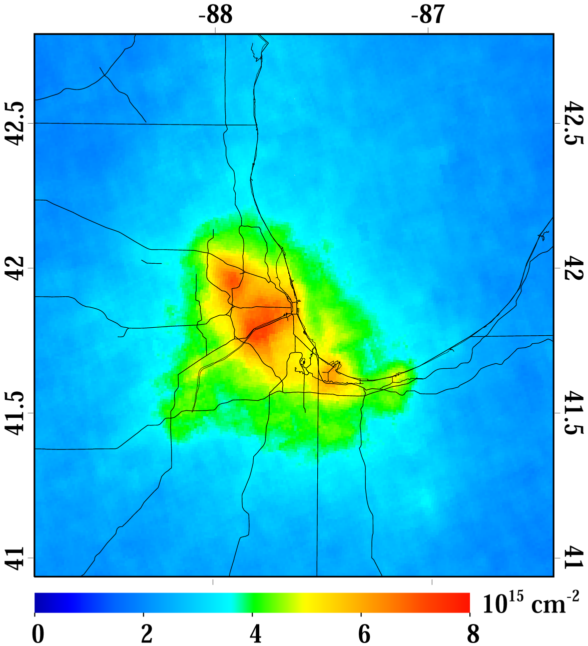

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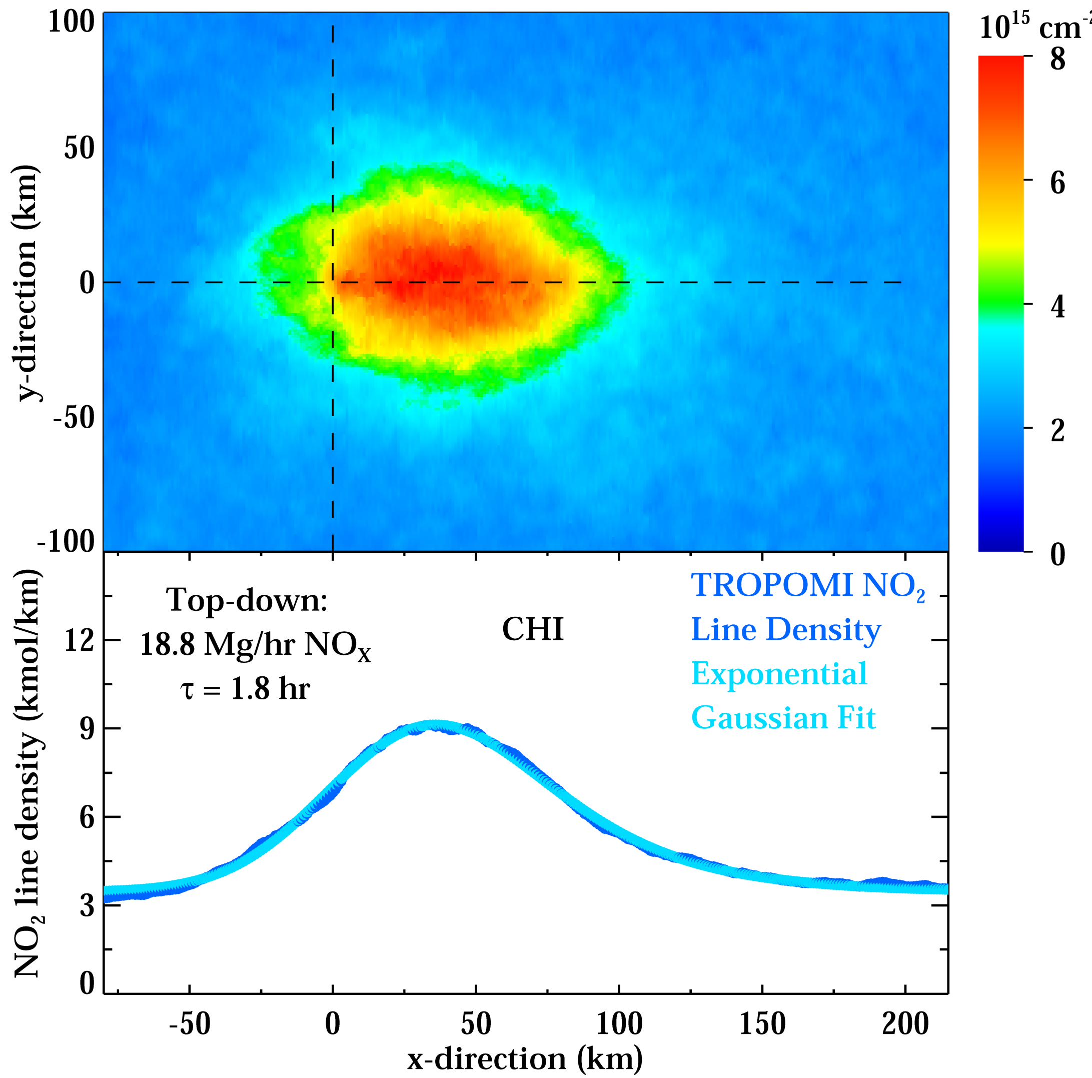


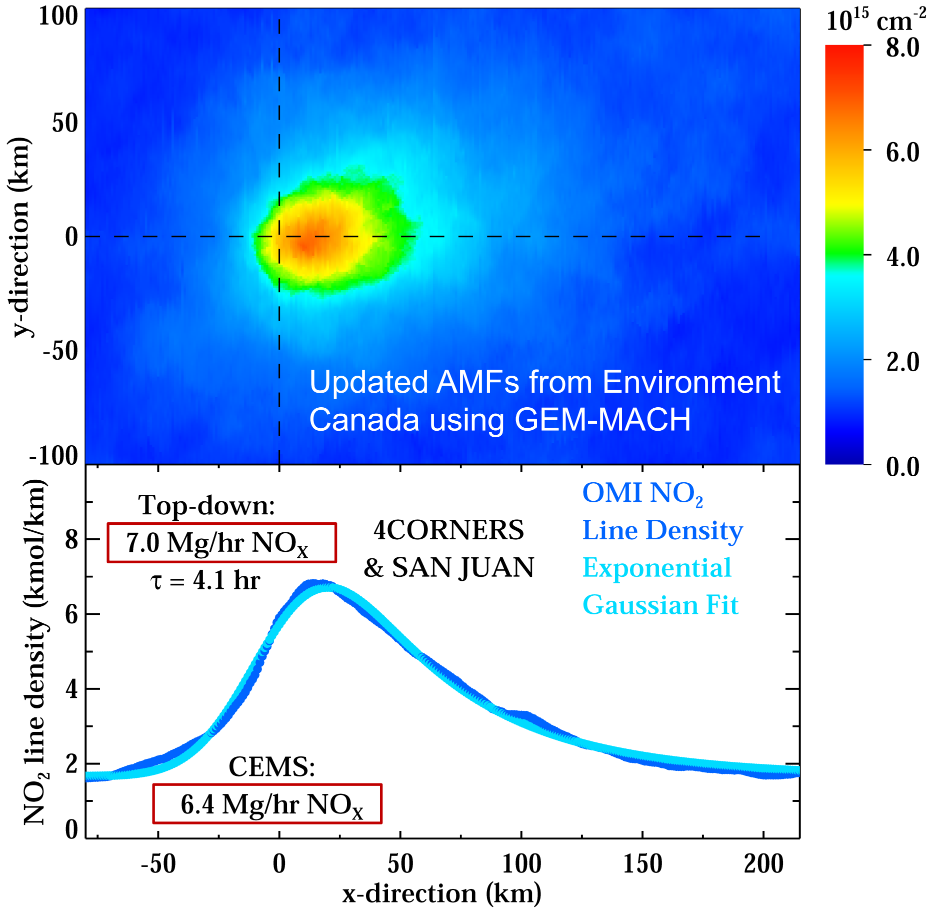
Step 3: Fit the decaying plume to an exponentially modified Gaussian function

Step 4: The fit will give a burden and decay distance, which can be used to calculate the emissions rate and lifetime

HOW DO WE KNOW THIS METHOD WORKS???

We compare to known NO_X emissions sources: US power plants

OMI NO_2 with updated AMFs

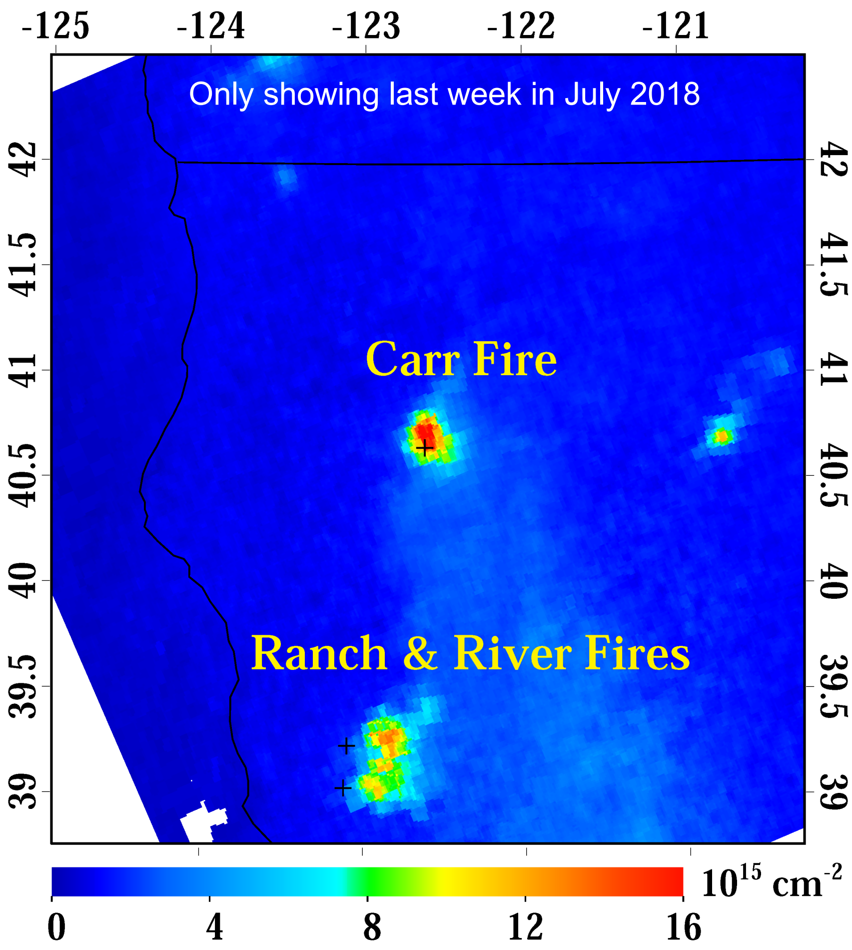


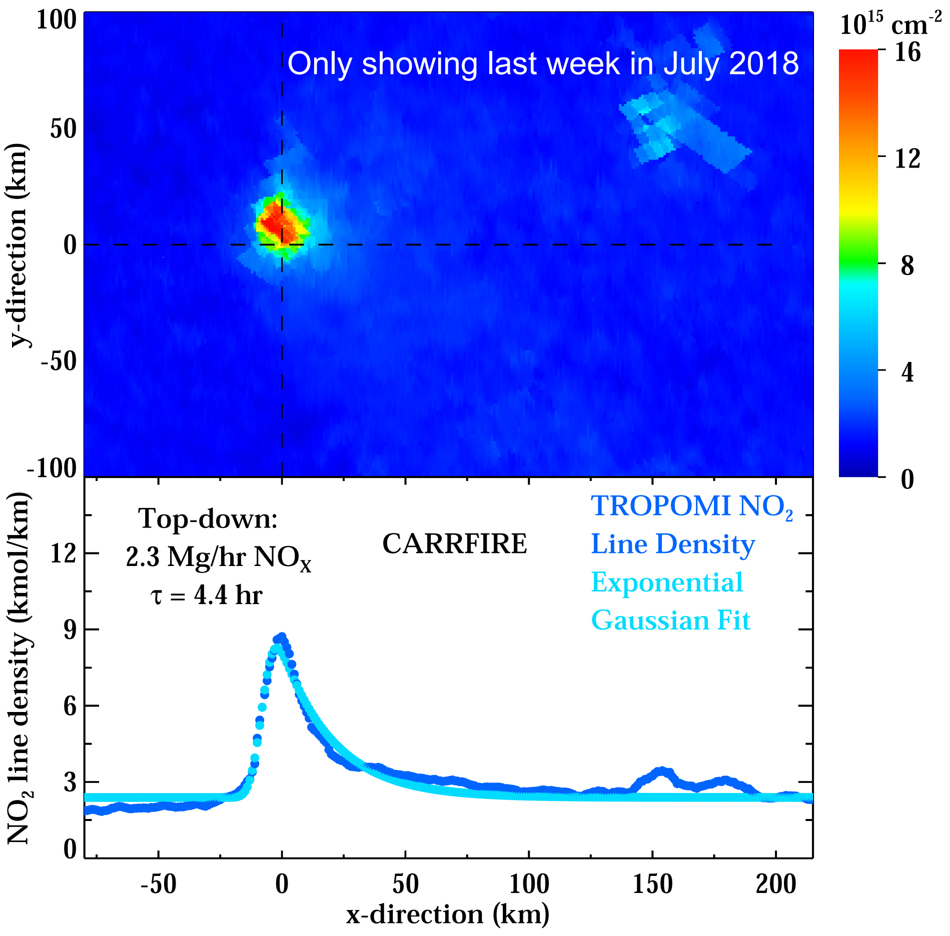
- After re-processing satellite data with regional air mass factors, there is very good agreement between the top-down method and the reported emissions (CEMS) to within ± 15%.

For more info on the satellite re-processing methodology see: McLinden et al., 2014; ACP, Goldberg et al., 2017; ACP

For more info on the inverse modeling method see: de Foy et al., 2014, 2015 AE; Goldberg et al., 2019; ACP.

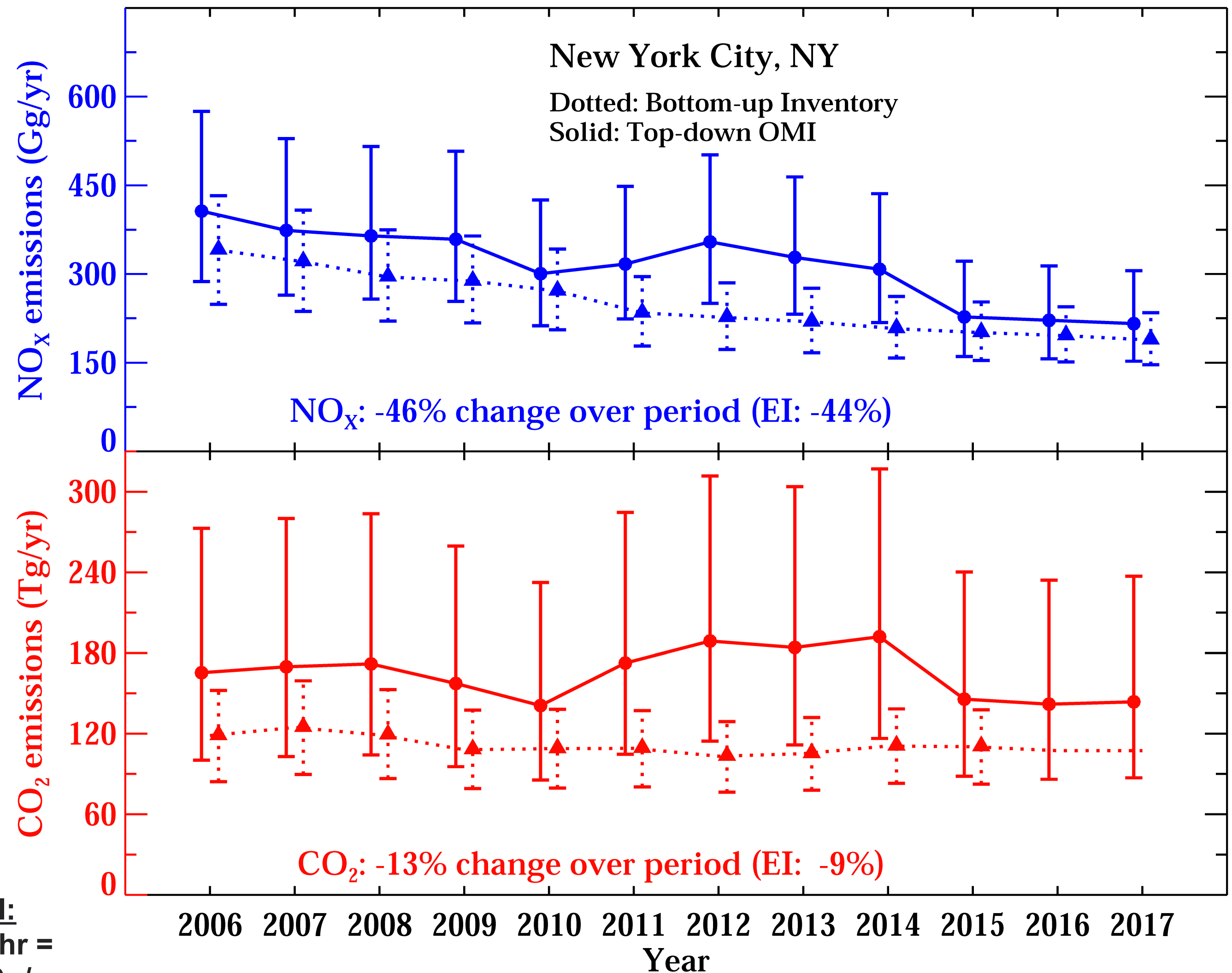
SOME INTERESTING APPLICATIONS: WILDFIRE NO_X EMISSIONS





- Can derive NO_X emissions from wildfires (Carr Fire: Approx. ¼ emissions of Chicago)

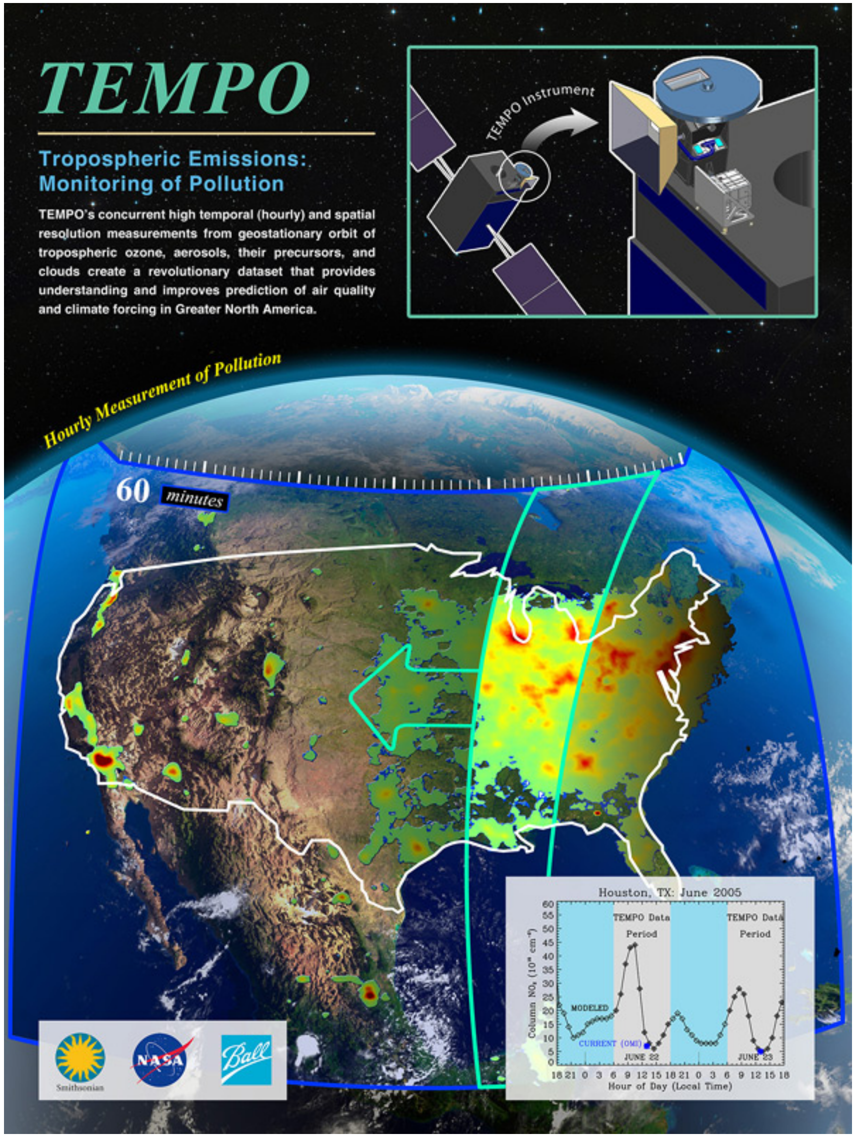
SOME INTERESTING APPLICATIONS: LONG-TERM NO_X & FOSSIL-FUEL CO_2 TRENDS



Use NO_X-to-CO_2 ratio as reported by the state to convert to fossil-fuel CO_2 emissions

FYI:
1 Mg/hr = 8.76 Gg/yr

COMING SOON: TEMPO & GEMS



Characteristics:

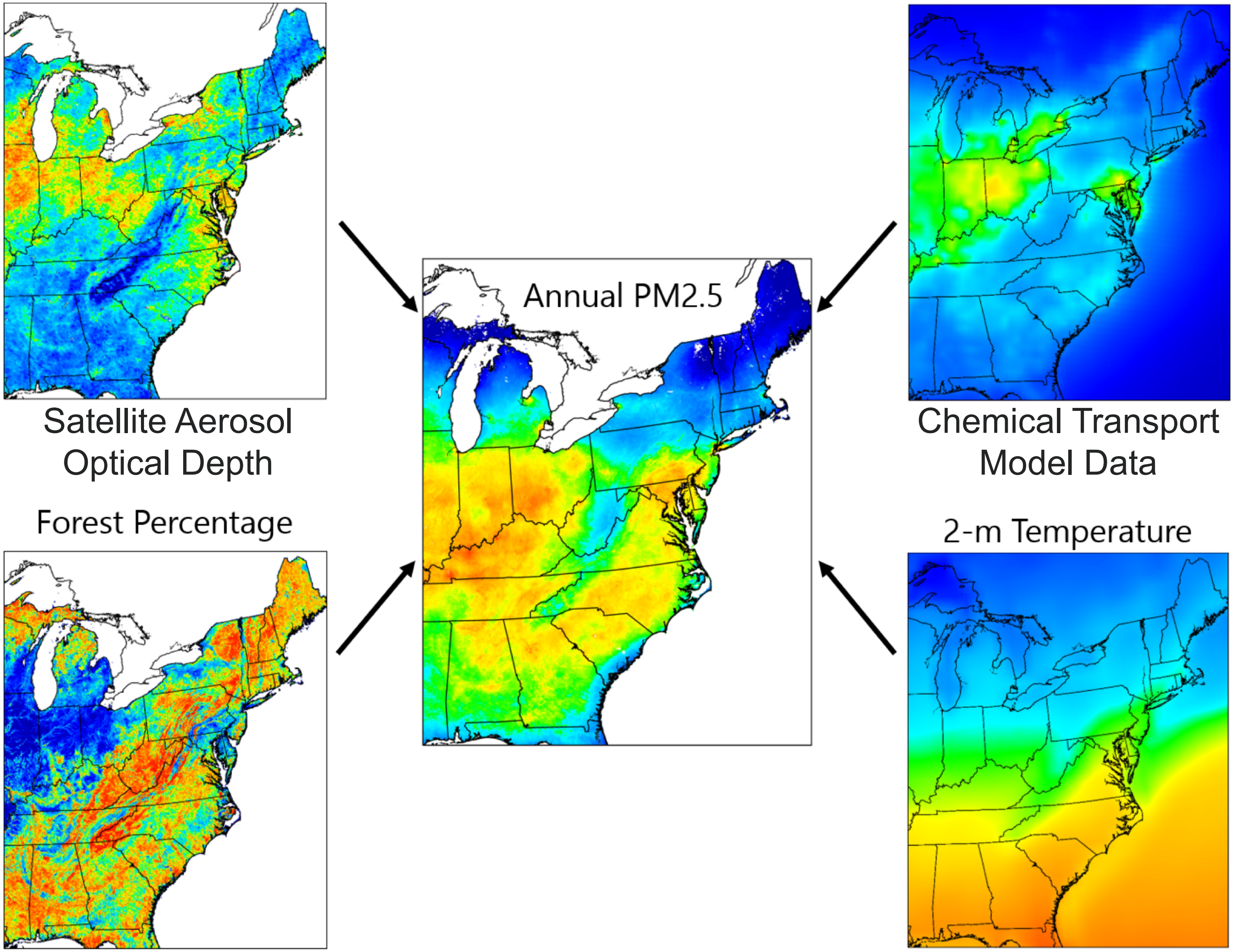
- Geostationary orbit
  - GEMS: East Asia
  - TEMPO: North America
- Hourly resolution that can show diurnal variability of emissions!
- Spatial resolution:
  - TEMPO: 2 km x 4.5 km
  - GEMS: 7 km x 8 km
- Species: O_3, NO_2, SO_2, HCHO, glyoxal, aerosols, among others

Image: NASA

ESTIMATING DAILY 1 KM $PM_{2.5}$ CONCENTRATIONS USING A COMBINATION OF SATELLITE DATA & CHEMICAL TRANSPORT MODELS

GOLDBERG ET AL., 2019

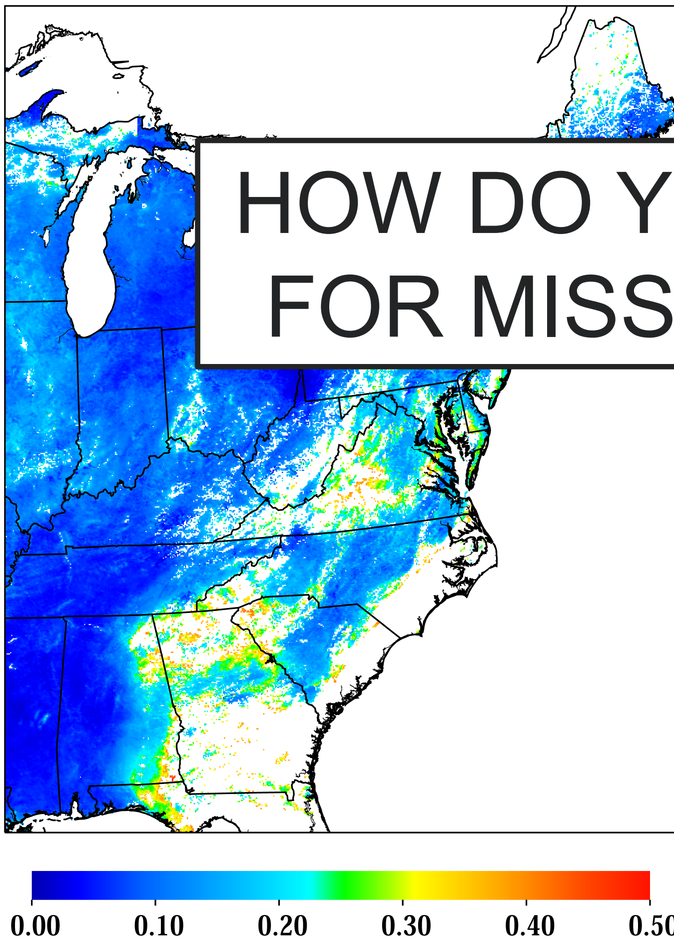
OUTLINE OF OUR $PM_{2.5}$ STATISTICAL MODEL



INTRODUCTION TO MAIAC AEROSOL OPTICAL DEPTH (AOD)

MAIAC = Multi-Angle Implementation of Atmospheric Correction
Operational AOD algorithm released by NASA June 2018

Example: July 15, 2008

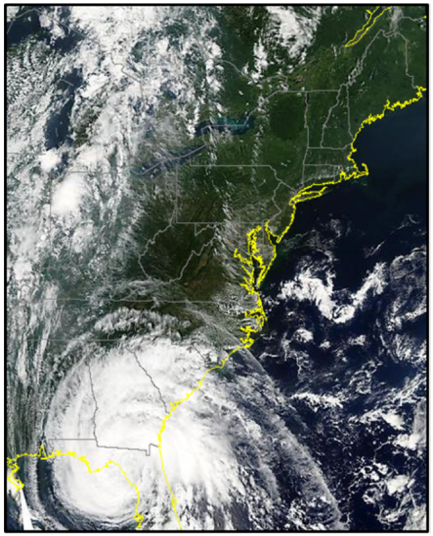


HOW DO YOU ACCOUNT FOR MISSING DATA???

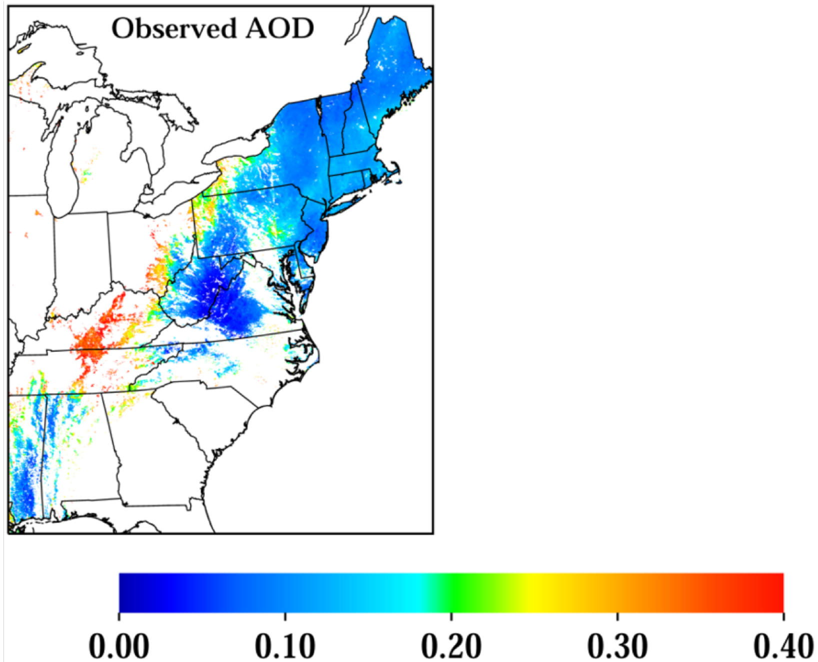
- Calculates Aerosol Optical Depth (AOD) from the NASA ... Terra & Aqua
- The algorithm "observes the same grid cell over time, helping to separate atmospheric and surface contributions… using multi-angle observations from different orbits." Lyapustin et al., 2018.

GAP-FILLING METHODOLOGY: EXAMPLE AUGUST 22, 2008

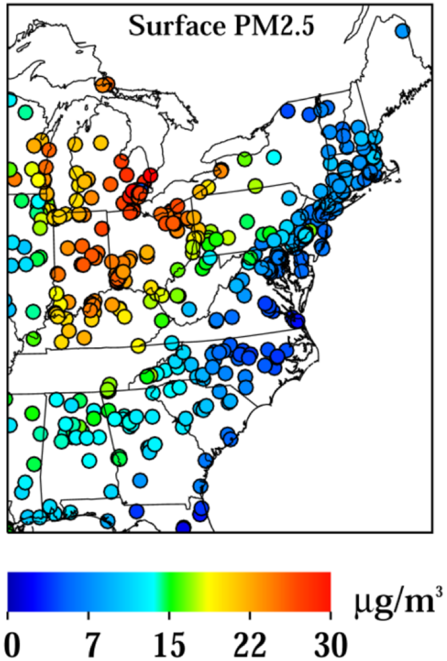
Aqua MODIS visible image



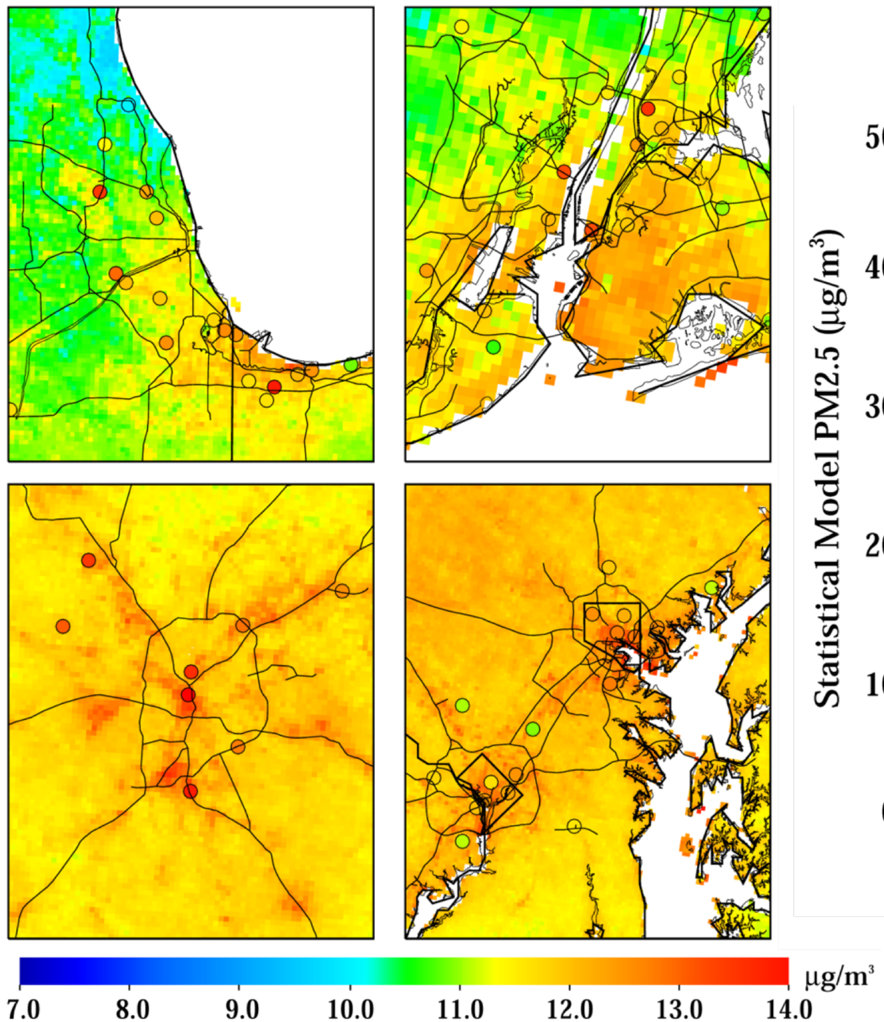
Observed MAIAC AOD

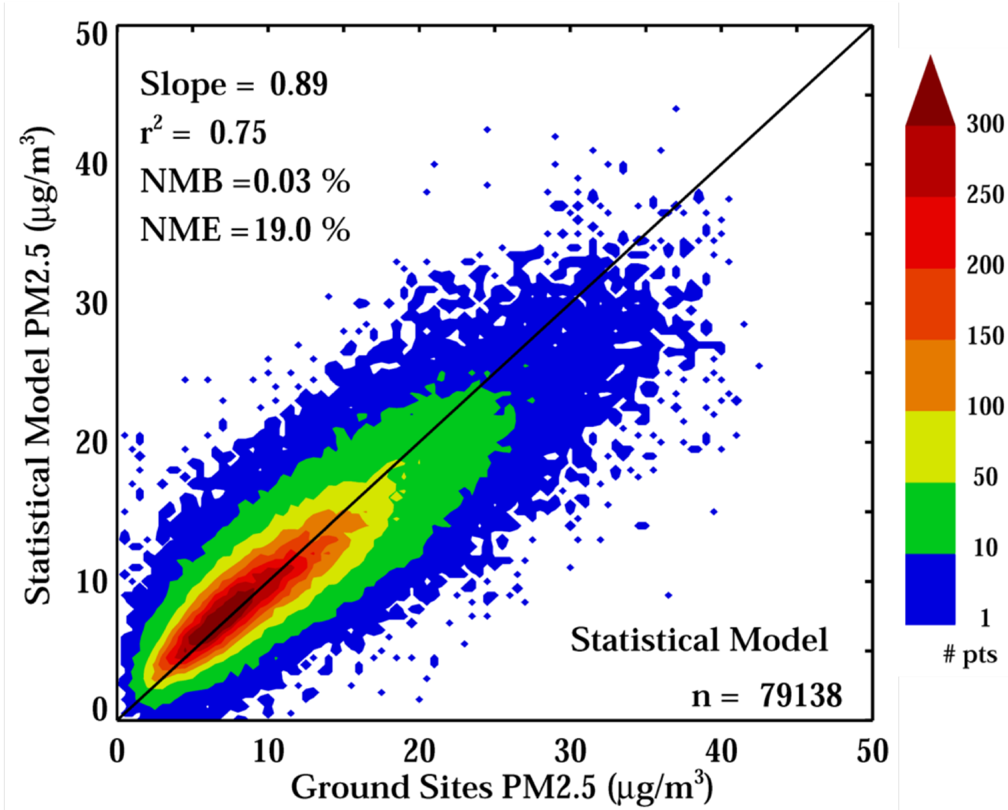


Observed Surface $PM_{2.5}$



2008 ANNUAL AVERAGED SURFACE $PM_{2.5}$ FROM OUR *DAILY* REGRESSION MODEL



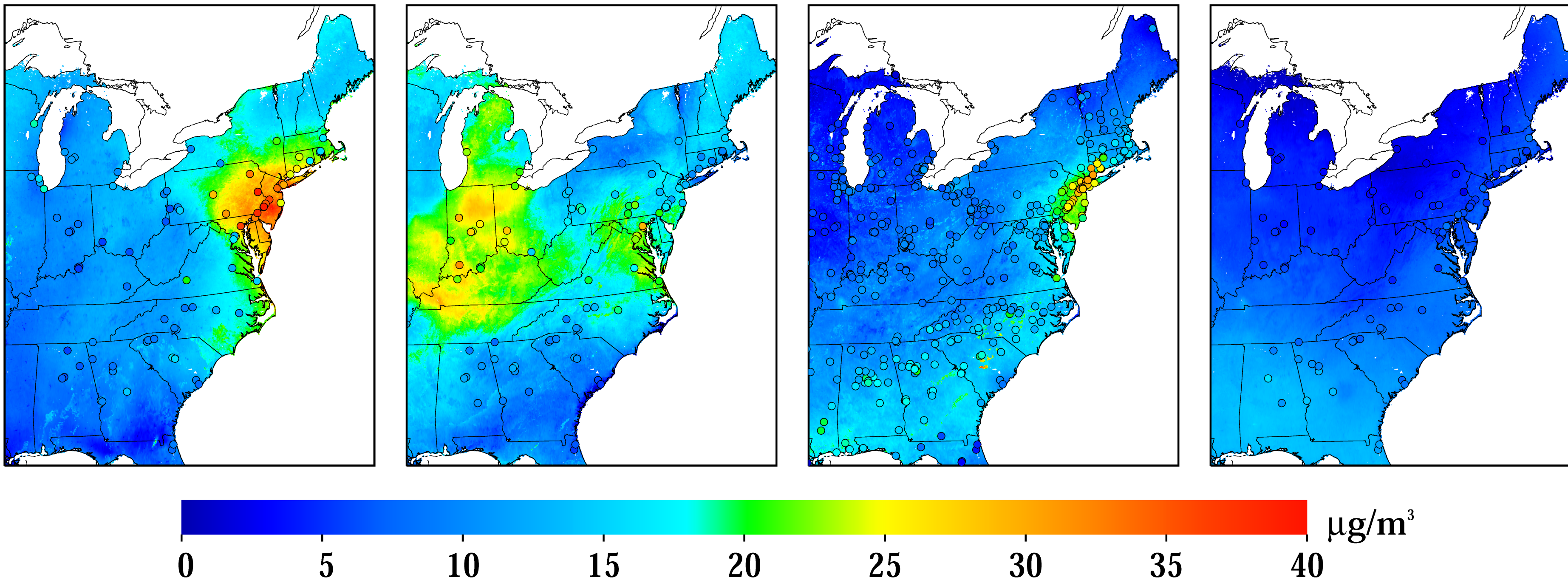


Model estimates daily $PM_{2.5}$ with excellent accuracy and precision. Comparable to other studies such as from Dalhousie, Harvard & Emory.

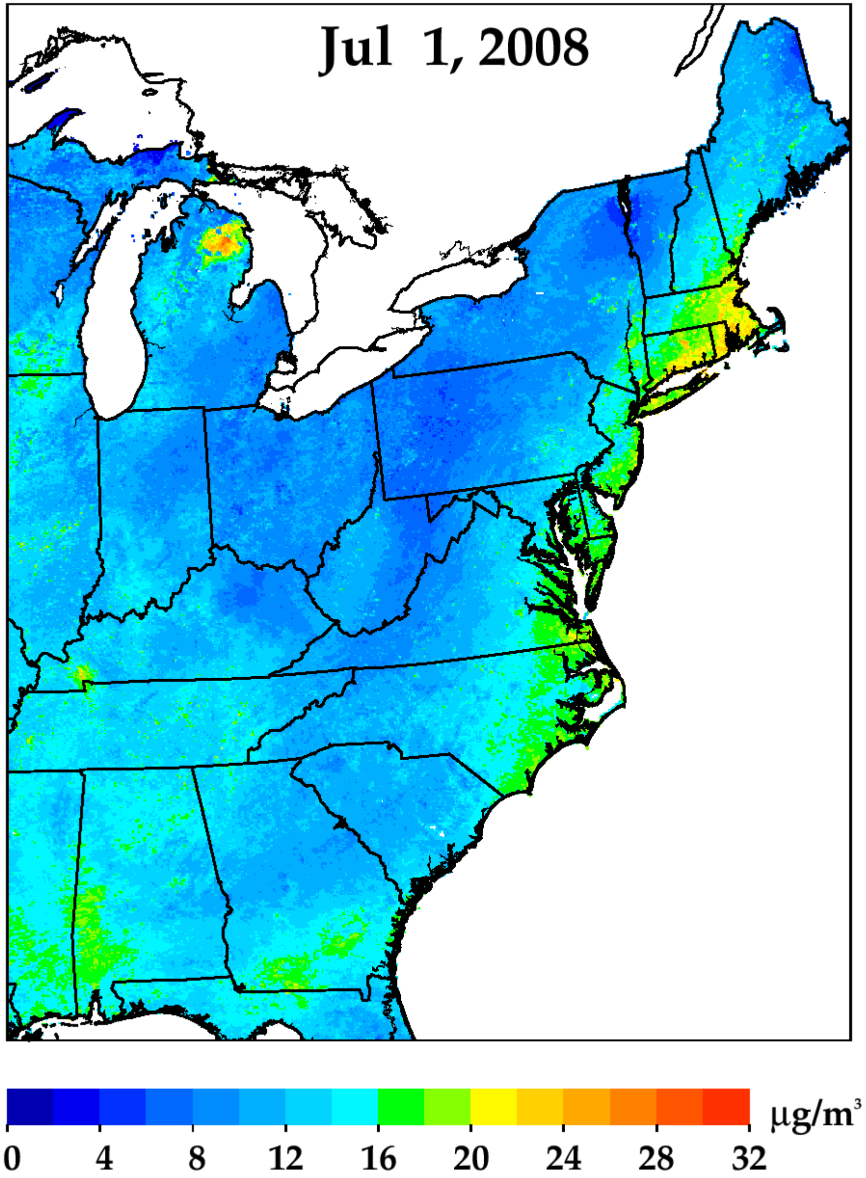
****10-fold cross-validation: 90% of the observations are used to predict values at the remaining 10% of the monitoring sites. Process is repeated 10 times.**

DAILY $PM_{2.5}$ ESTIMATES FROM OUR STATISTICAL MODEL

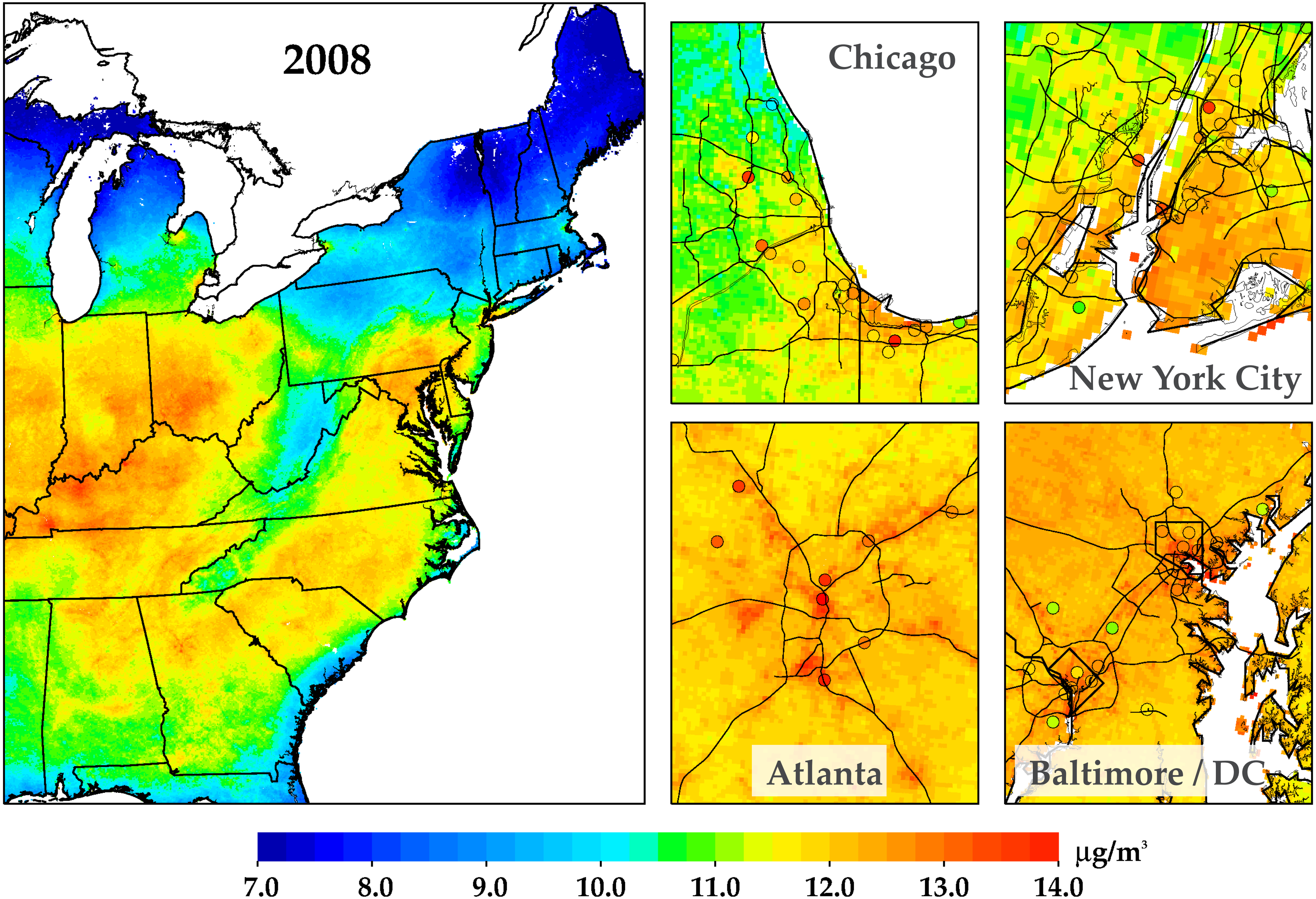
January 29th, 2008: NE US $PM_{2.5}$ episode	February 23rd, 2008: MW US $PM_{2.5}$ episode	June 23rd, 2008: SE Wildfires	October 2nd, 2008: Clean day



DAILY $PM_{2.5}$ ESTIMATES FROM OUR STATISTICAL MODEL



ANNUAL $PM_{2.5}$ ESTIMATES FROM OUR STATISTICAL MODEL



CONCLUSIONS

- Emissions: OMI and TROPOMI NO_2 have been used to estimate top-down NO_X emissions
  - Advantages: Timely & independent of bottom-up methods
  - Disadvantages: Spatially aggregated (little info on sectors)

- Exposure: The $PM_{2.5}$ statistical model driven by satellite data is computationally efficient (uses only 11 covariates) and generates a high-fidelity estimate (r^2 = 0.75 using a 10-fold cross-validation) of daily $PM_{2.5}$ at 1 km spatial resolution.
  - Information from ground monitors and chemical transport models are key contributors to the model's performance!

LET'S CONNECT ON TWITTER!
@DGOLDBERGAQ

OR EMAIL:
DGOLDBERG@ANL.GOV

THANK YOU!