Bridging scales with satellite and in-situ data:
from agricultural ammonia to volcanic emissions

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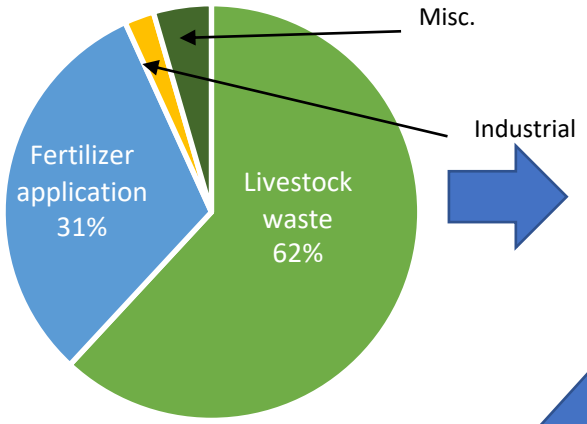
NASA Health and Air Quality Applied Sciences Team #5 meeting
Phoenix, Arizona
January 4, 2018

Ammonia (NH_3): air quality and ecosystem health

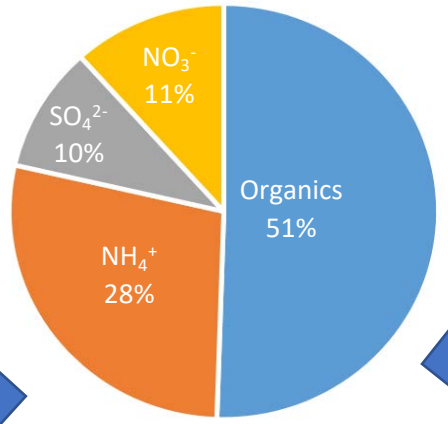
2011 U.S. NH_3 Emissions

Total = 3.44×10^9 kg



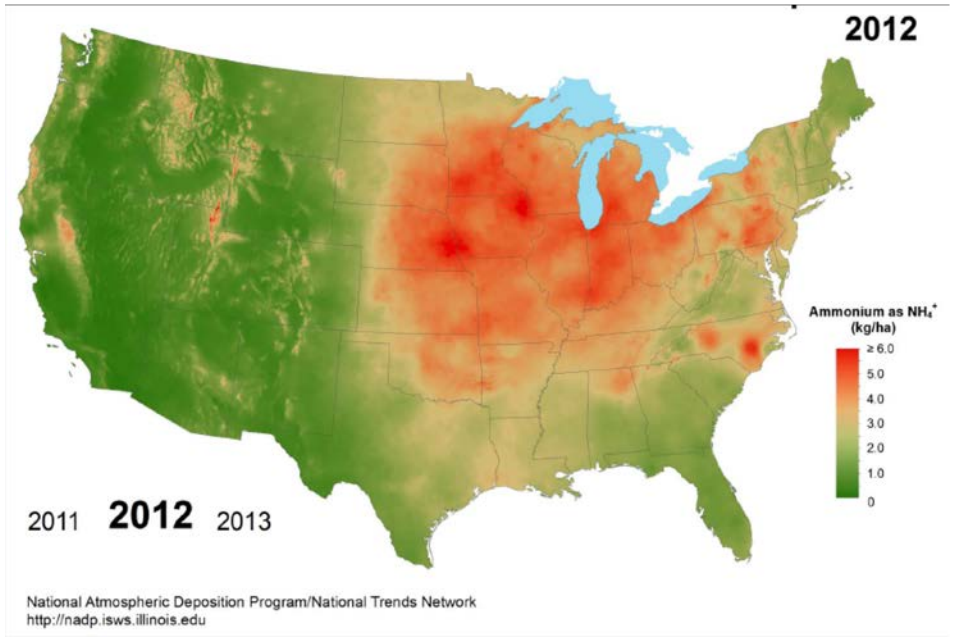
(EPA, 2011)

Aerosol composition by mole Boulder, CO

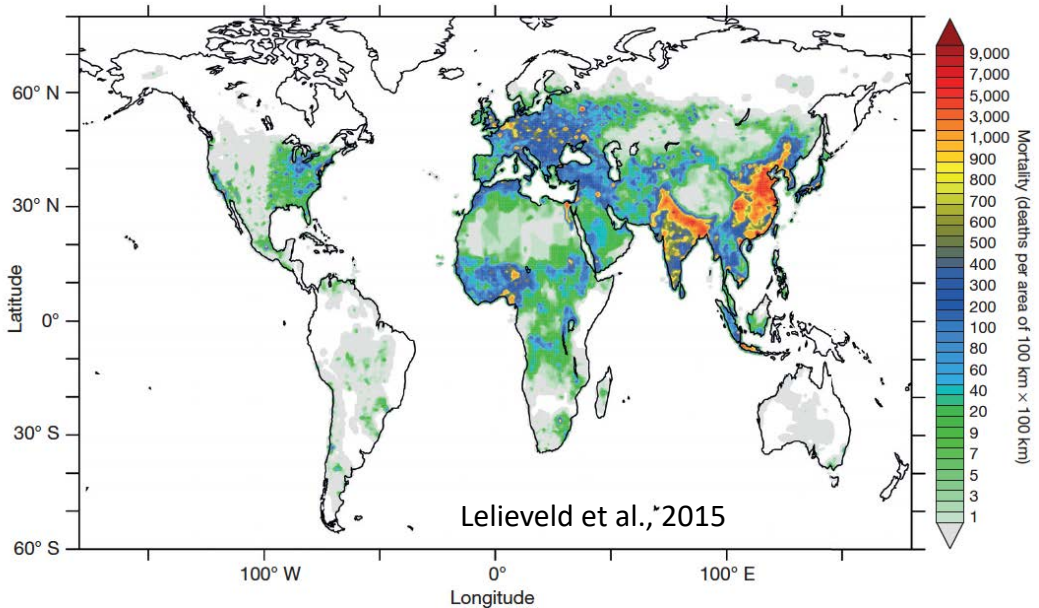


Adapted from Jimenez et al. (2009)

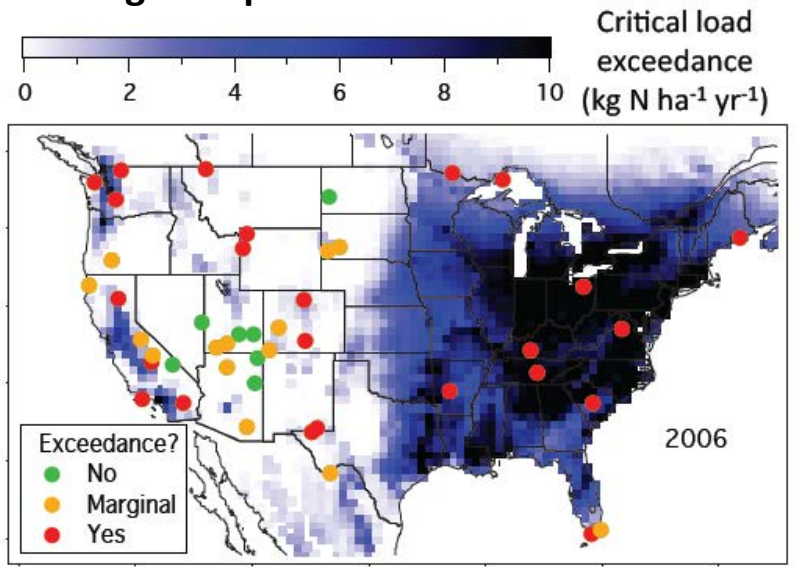
NH_4^+ deposition in US



Deaths per year/10^4 km^2 from pollution (agriculture 20%)

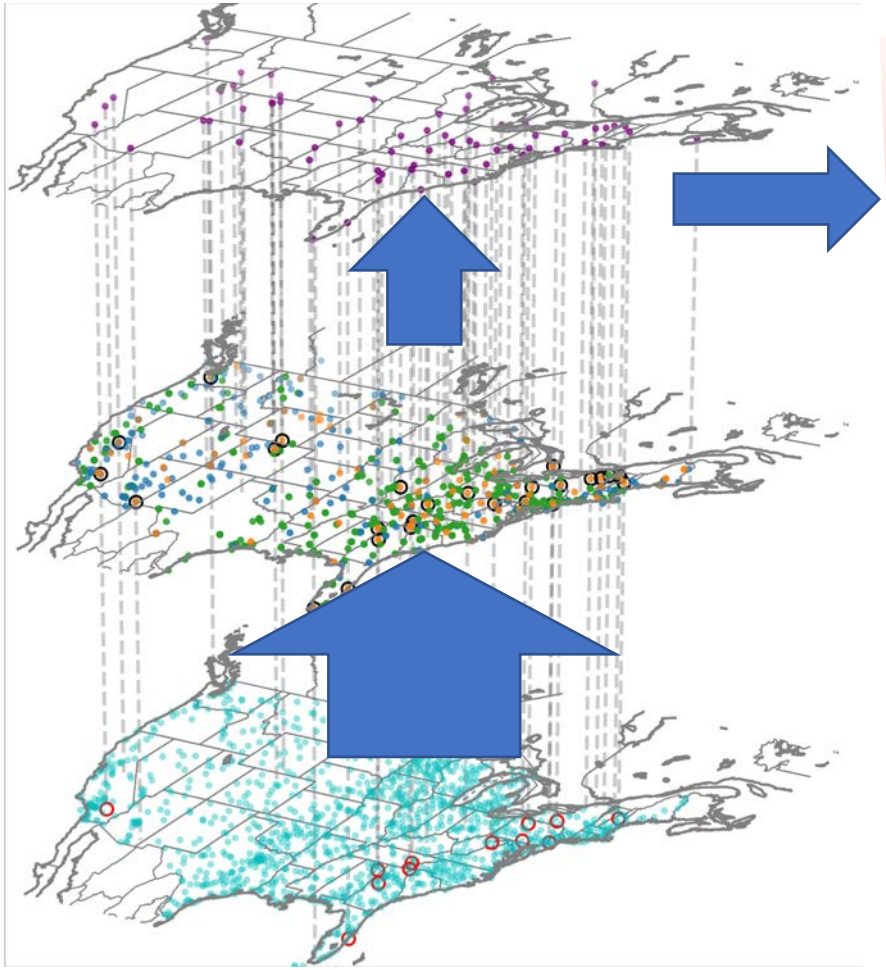


Excess nitrogen deposition in National Parks



Surface observational networks to constrain inorganic PM2.5

Network	Frequency	Number of sites
Gas phase NH_3		
AMoN	Every 2 weeks	61
Aerosol composition		
CASTNET	Weekly	106
IMPROVE	Every 3rd day	223
EPA CSN	Every 3rd day	921
Meteorological conditions		
NOAA Integrated Surface Database	Hourly	1287

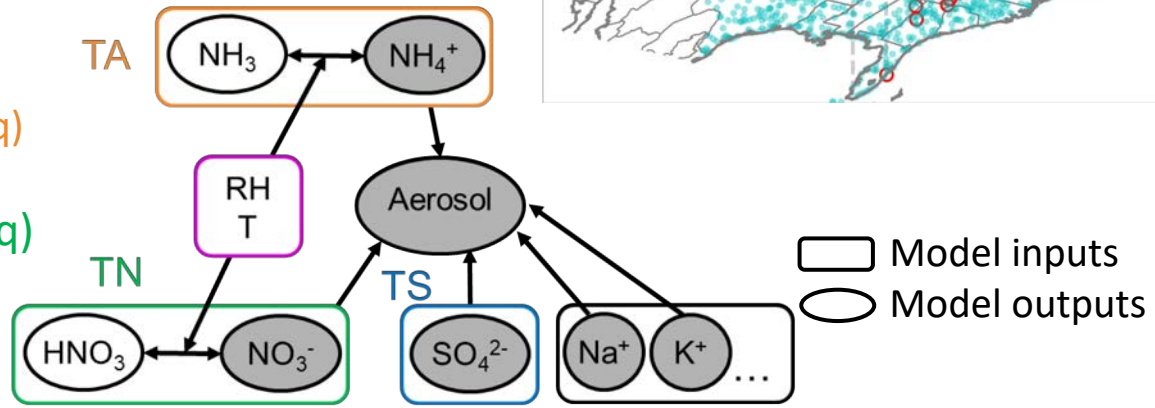


61 AMoN sites exist NH_3 observations

25 AMoN sites have NH_3 and aerosol composition

12 AMoN sites have
- gas phase NH_3
- aerosol composition
- met. observations

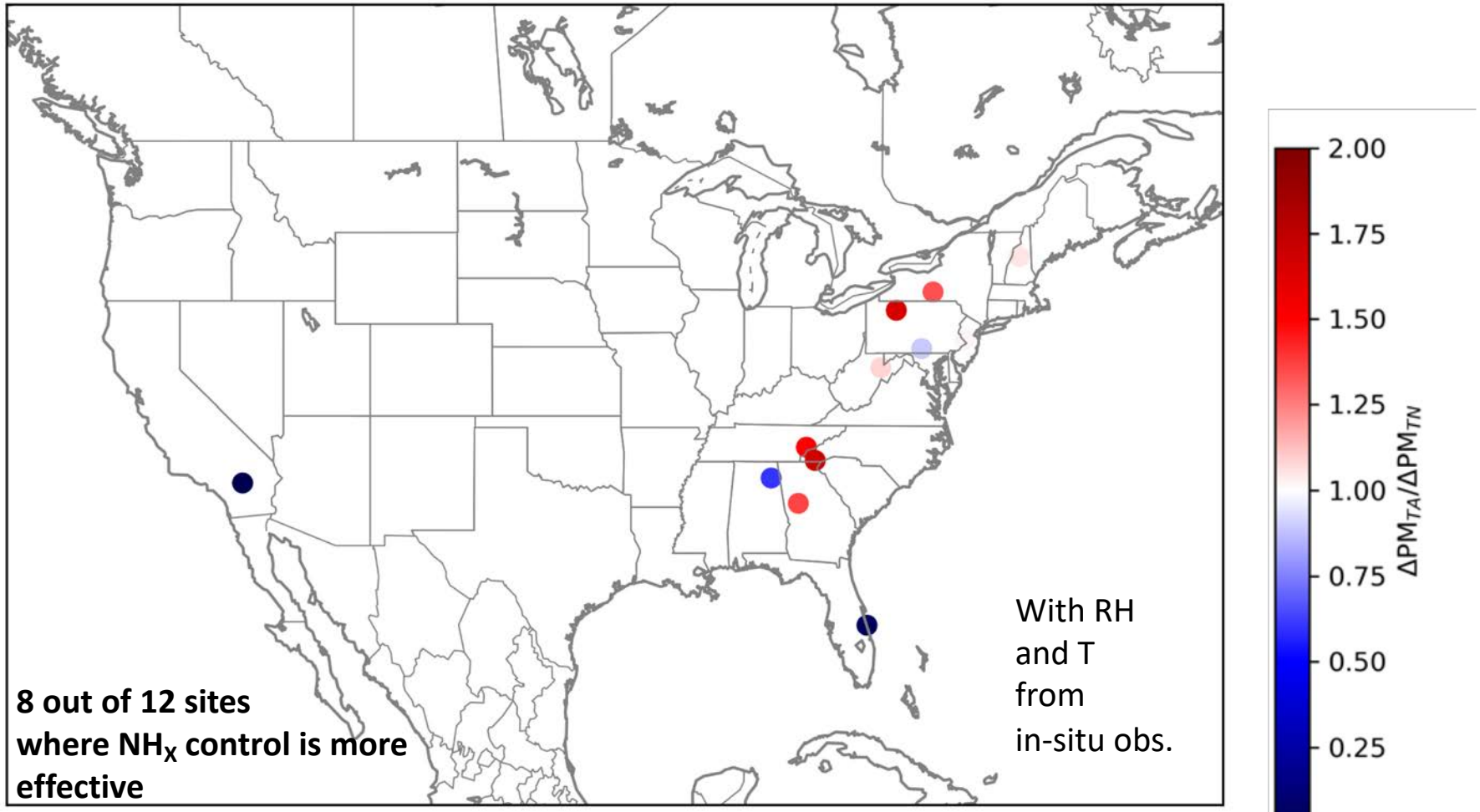
Total NH_x
TA = NH_3 (g) + NH_4+ (aq)
Total nitrate
TN = HNO_3 (g) + NO_3^- (aq)
Total SO_4 (TS)
K, Na…RH, T



Use thermodynamic aerosol chemistry model (ISORROPIA II) to predict PM2.5 sensitivities to changes in total nitrate vs. total NH_x

Sensitivity to $PM_{2.5}$ for reductions of total NH_x and nitrate

NO_3^- reduction more effective ← ratio<1 | $\frac{PM_{25}\text{ reduction with 50\% reduction of total } NH_x}{PM_{25}\text{ reduction with 50\% reduction of total } NO_3^-}$ | ratio>1 → NH_3 reduction more effective



Satellite NH_3 data can augment these types of analyses, also to constrain emission inventories

IASI satellite NH_3 measurements: oversampling for high spatial resolution

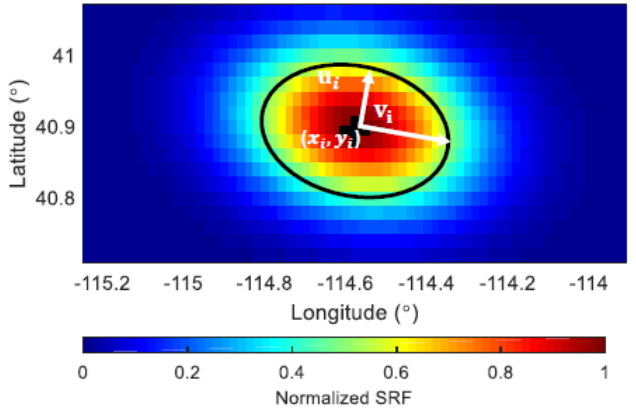
(Sun et al., AMT, 2018)

- Uses a 2-D Gaussian function to approximate the spatial response function (SRF)

  (SRF determines the spatial response of the satellite pixel with respect to its center)

- Overlapping satellite pixels from different times are grid-averaged

- Weighted mean in each grid is used to plot the NH_3 map



Spatial response function $\mathbf{SRF(i,j)}$

+

Uncertainty $\boldsymbol{\sigma(i)}$

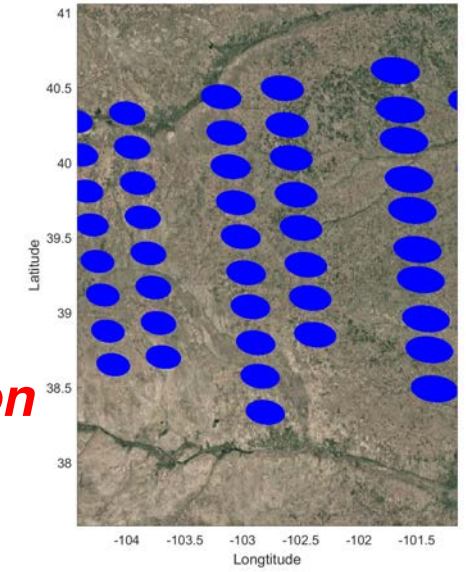
Weighted mean at grid j

$$C(j) = \frac{\sum_i \frac{SRF(i,j)}{\sigma(i)} \Omega(i)}{\sum_i \frac{SRF(i,j)}{\sigma(i)}}$$

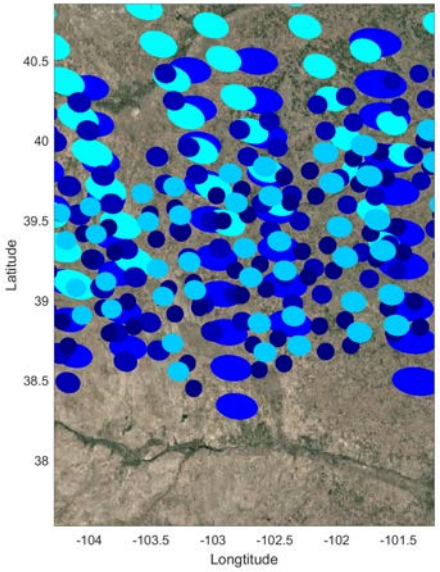
$\Omega(i)$: the vertical column density measured at pixel i

$\sigma(i)$: the uncertainty of vertical column density measured at pixel i

Trade temporal for spatial resolution for few km resolution



Satellite track on a single day



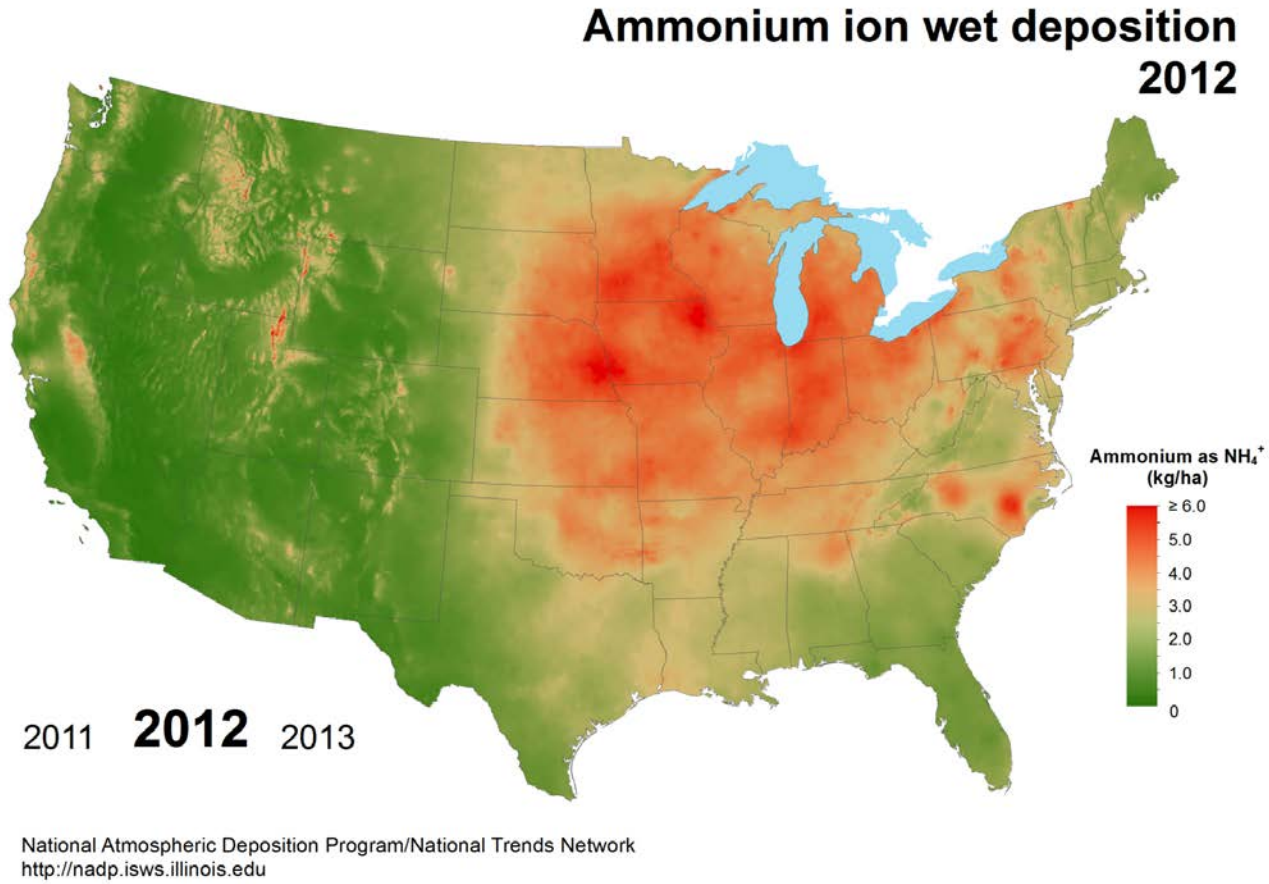
Satellite tracks on 5 continuous days

NH_3 IASI annual average and monthly changes

2008-2016, Metop/A & Metop/B, oversampling high resolution (0.02°×0.02°) maps

While NH_3 has a short lifetime and exhibits strong spatial gradients, its impact extends well beyond source regions.

Satellites can be used to identify siting requirements for next generation of ground-based networks



NH_3 IASI monthly changes: watching agriculture breathe

2008-2016, Metop/A & Metop/B, oversampling high resolution (0.02°×0.02°) maps

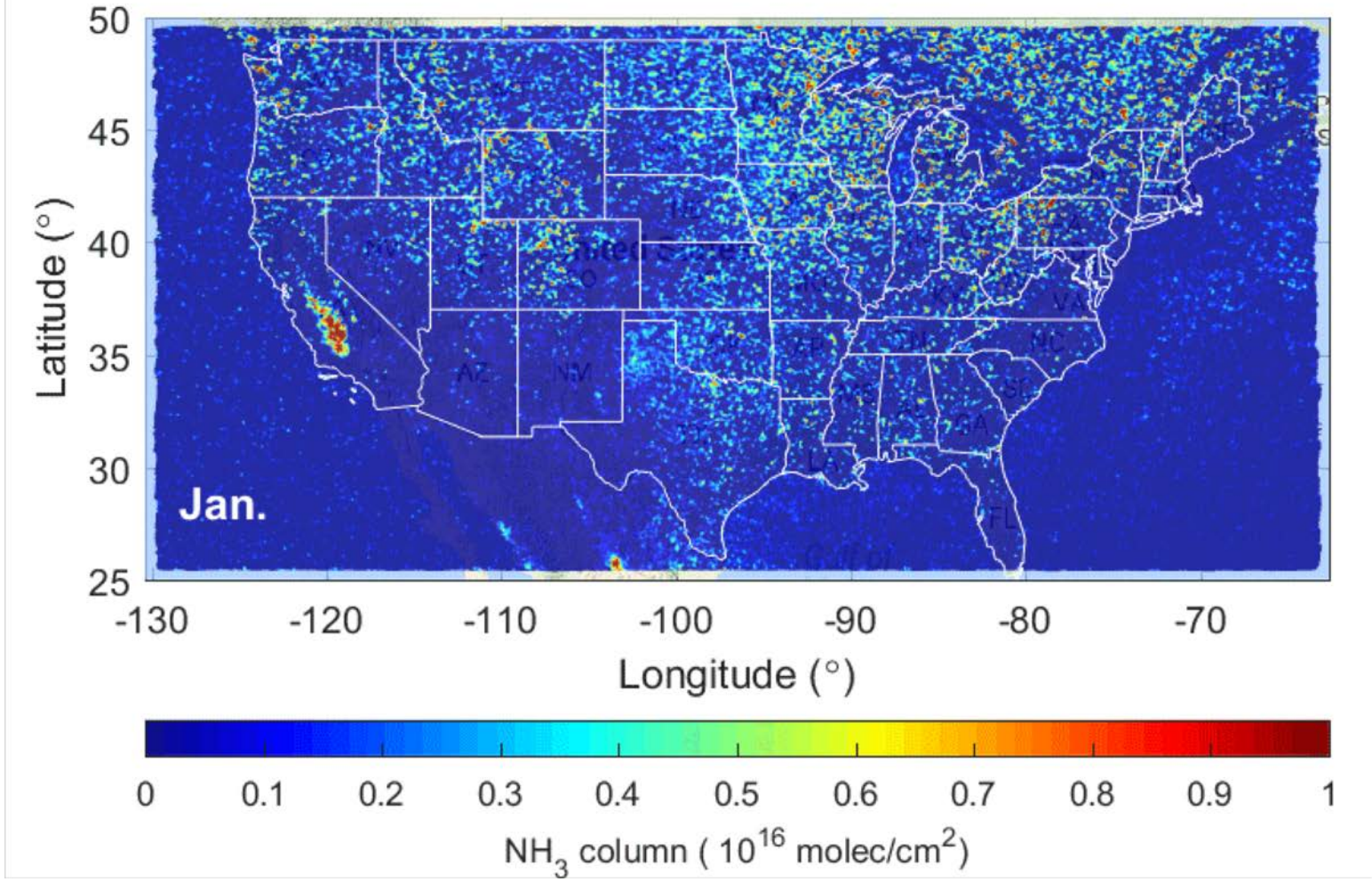
- **Overall seasonality:** low in winter, peak in spring/ summer

- **A high variability of seasonality:**

San Joaquin Valley peaks in July

Midwest in spring in May

High plains in July / August



[1] Land use data are from census of agriculture, USDA, 2012

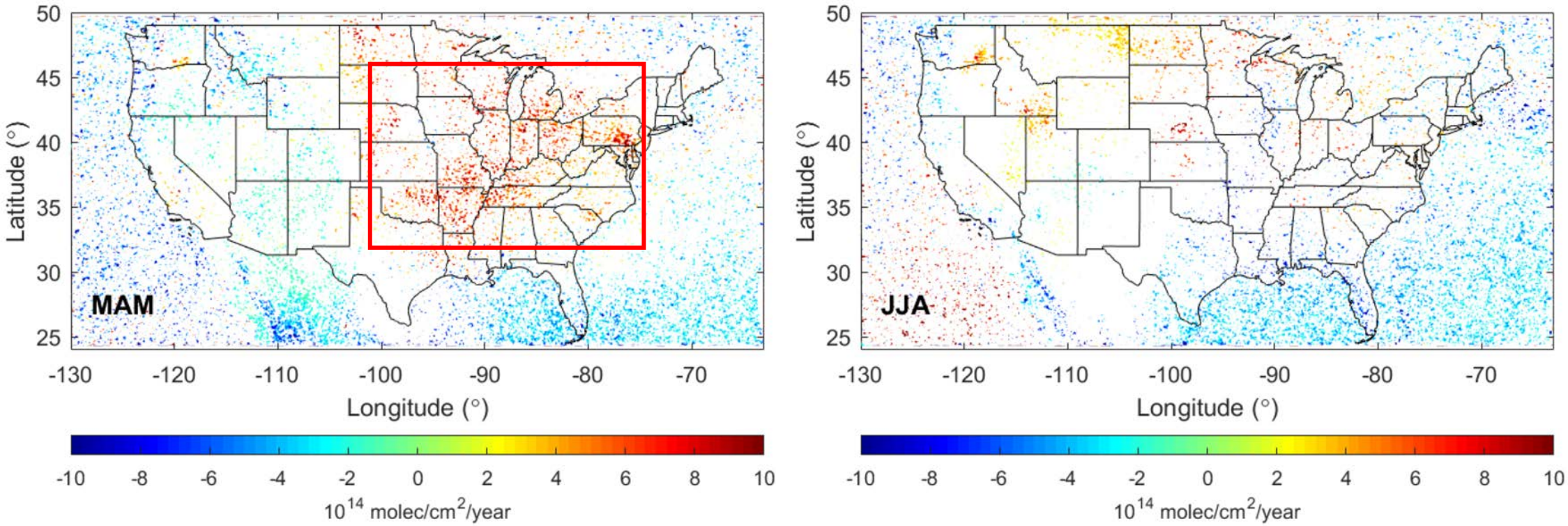
Trends in gas phase NH_3 (IASI) – Trends TT (Duncan and West)

2008-2016 seasonal oversampling, IASI NN v2.2r (removed discontinuities for trend analyses)

linear regression: slope>0 & p<0.05; decrease: slope<0 & p<0.05

NH_3 concentrations increasing over wide areas, particularly in spring (fertilizer usage)

…decreasing NO_x and SO_2 emissions in NE also a factor



Up to 10% per year in select locations

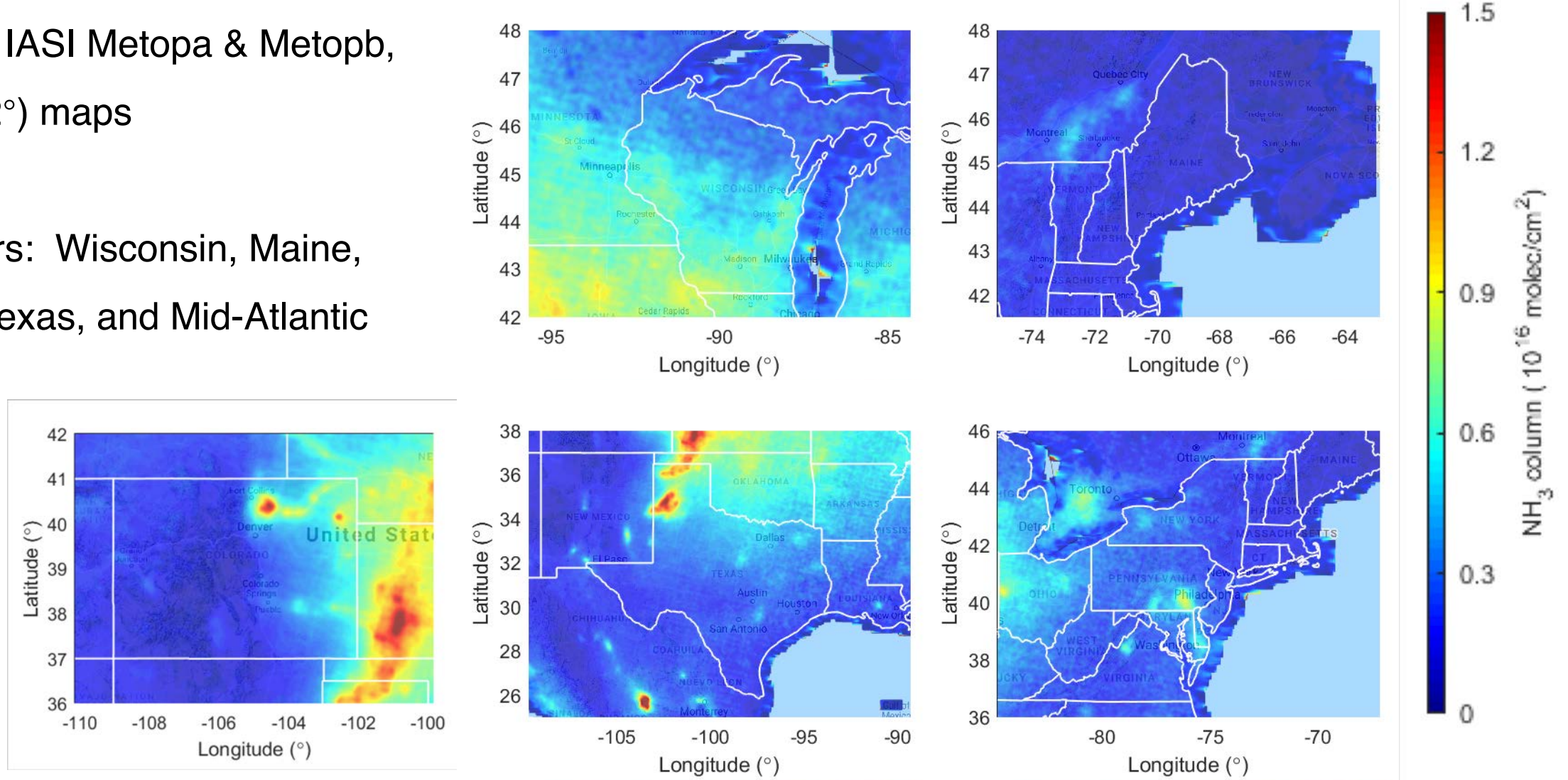
Spatial patterns of NH_3 (IASI) – Haze TT (Fiore)

2008-2016, IASI Metopa & Metopb,

(0.02°×0.02°) maps

Stakeholders: Wisconsin, Maine,

Colorado, Texas, and Mid-Atlantic



Annual maps provide useful information on emission source locations

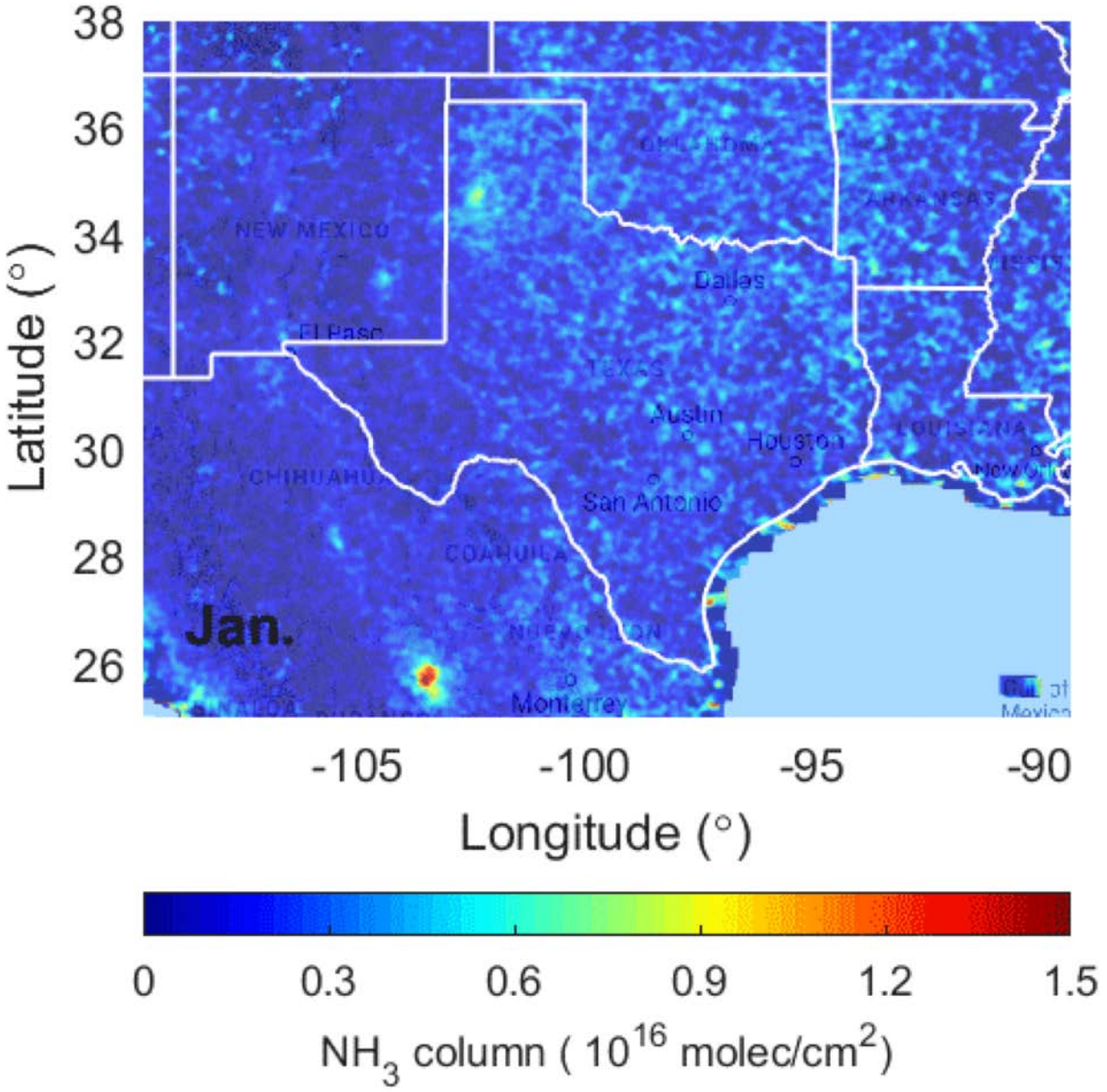
Monthly changes in NH_3 (IASI) – Haze TT (Fiore)

Texas case study:

Annual mean does not capture the hotspots change

Large month-to-month variations in both magnitudes and locations

Significant differences with various emission inventories



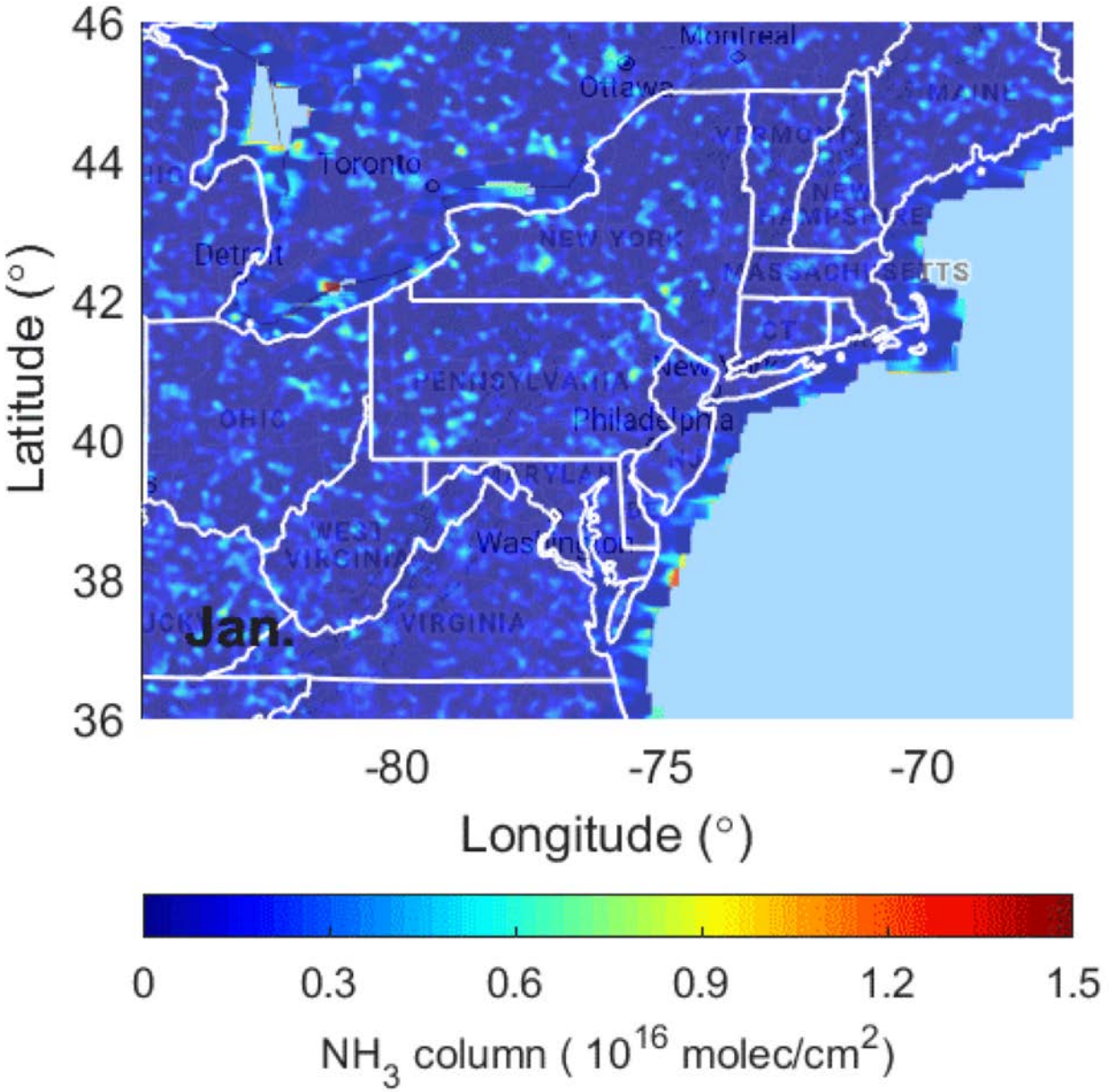
Monthly changes in NH_3 (IASI) – Haze TT (Fiore)

Mid-Atlantic case study:

Annual mean does not capture the hotspots change

Large month-to-month variations in both magnitudes and locations

Significant differences with various emission inventories



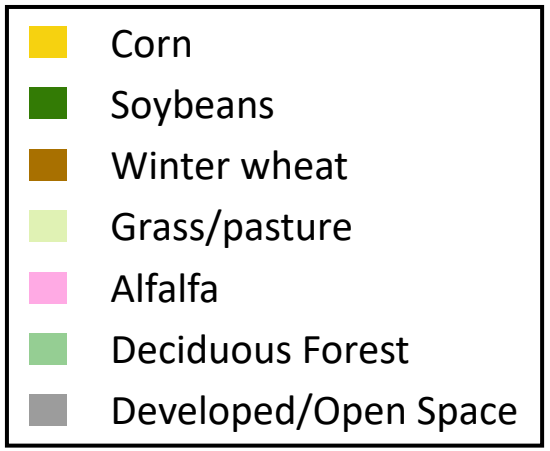
Examining NH_3 concentrations with USDA CropScape

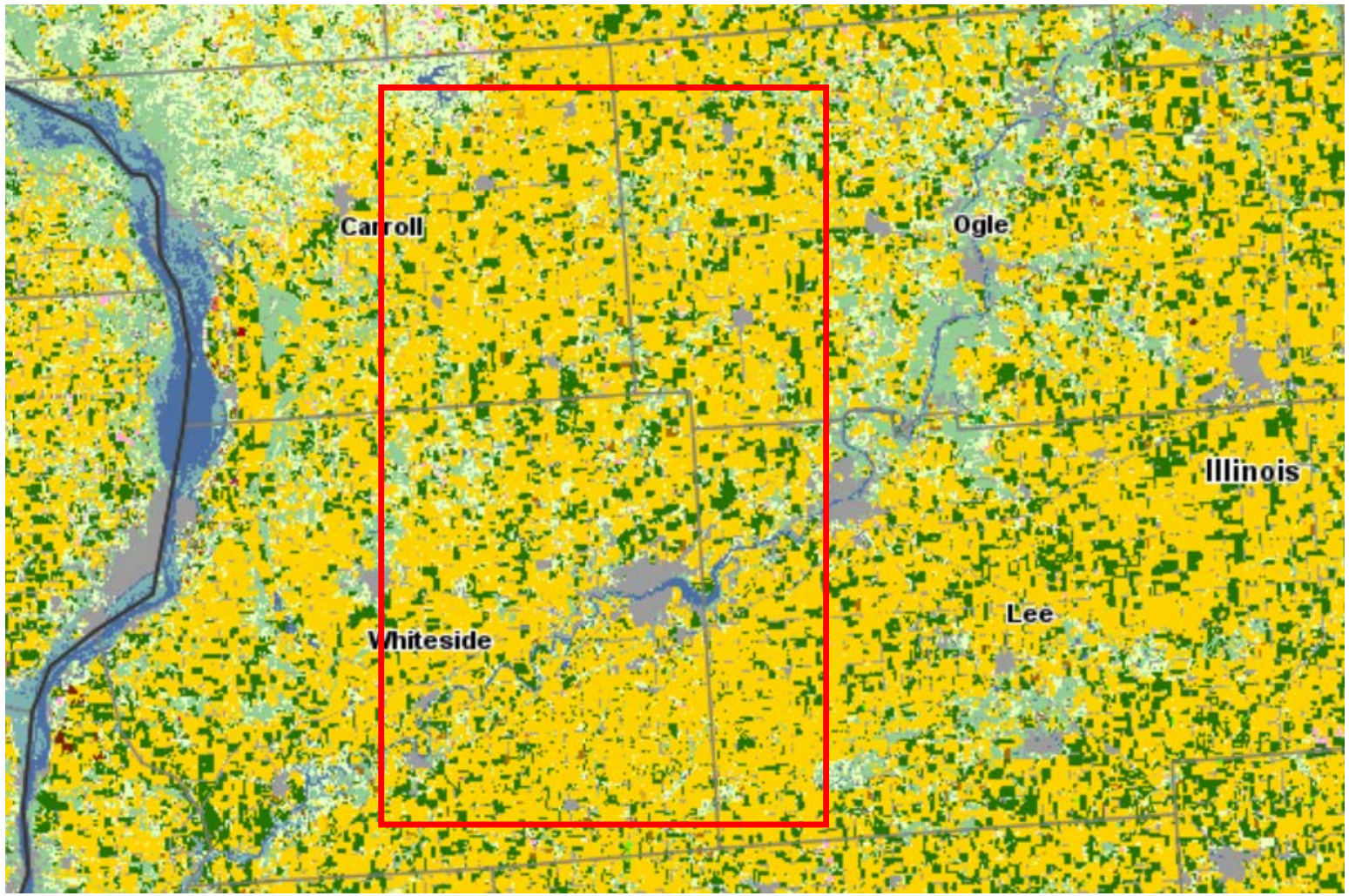
Whiteside county, IL:

Corn dominated region [1]

$$\left(\frac{S_{Corn}}{S_{Soybean}} \approx 4\right)$$

Feedlots: limited [2, 3]





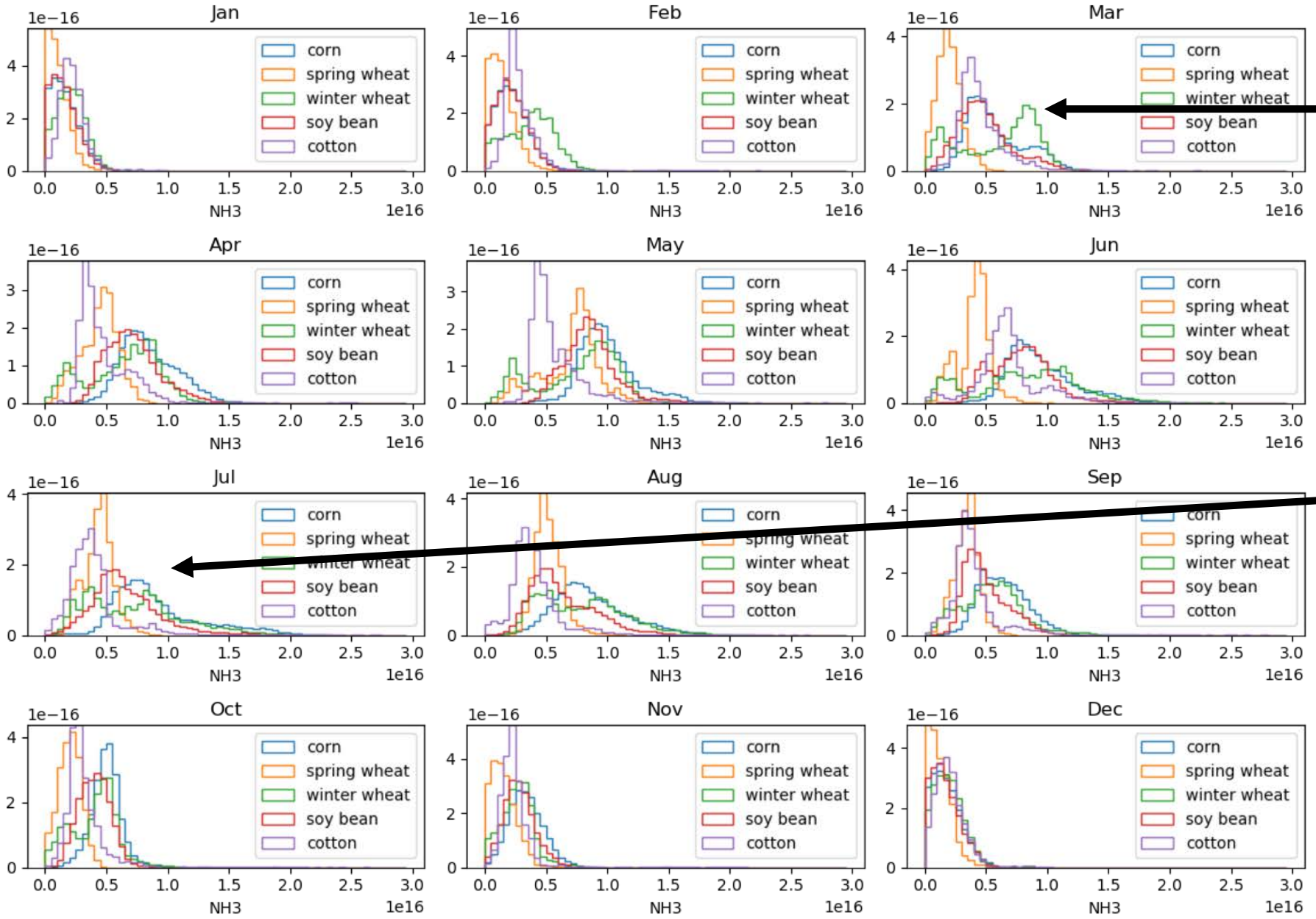
Cropland map [1]

[1] USDA CropScape database [2] USDA National Agricultural Statistics Service, 2018 [3] Google earth

Observational constraints of crop type and emissions

F. Paulot, NOAA GFDL

Monthly histograms of NH_3 columns over crop type for US



Winter wheat fertilized early spring

Corn higher NH_3 than soybeans

High-spatial resolution satellite maps allows for new observational constraints on agricultural emissions

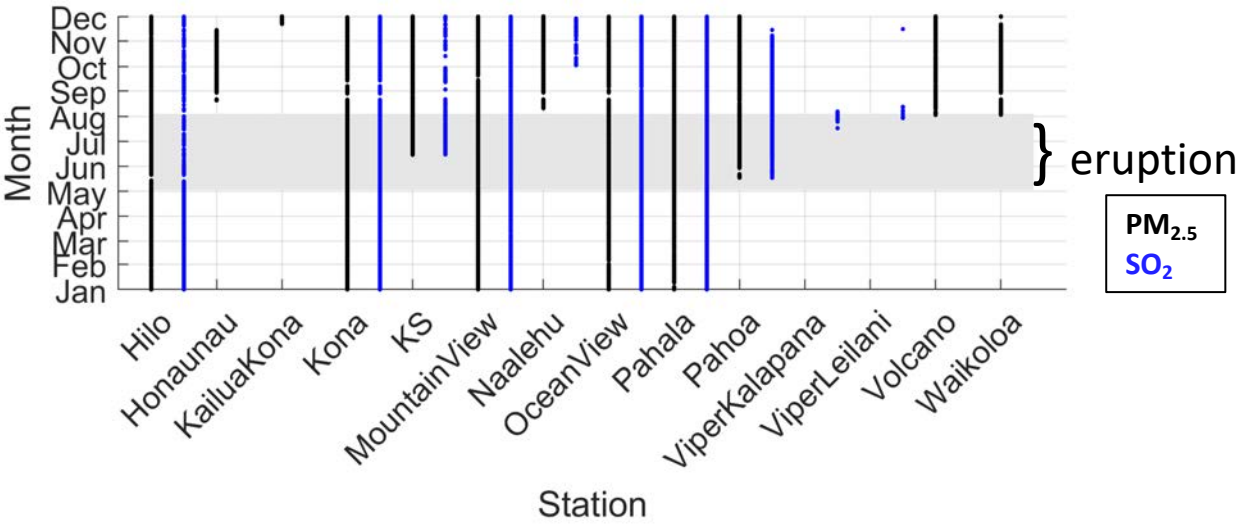
Volcanic smog = vog in Hawaii

- major air quality issues on big island of Hawaii during the ~ 3 month 2018 Kilauea eruption

- excellent case study of highly-networked area (10 surface air quality networks!)

- satellite data, integrated with surface/model data, may provide more complete picture of air quality in space/time

HI Department of Health network data coverage



screenshot from
Hawaii Interagency Vog Information Dashboard

CNN U.S. » Crime + Justice | Energy + Environment | Extreme Weather | Space + Science Live TV U.S. Edition +

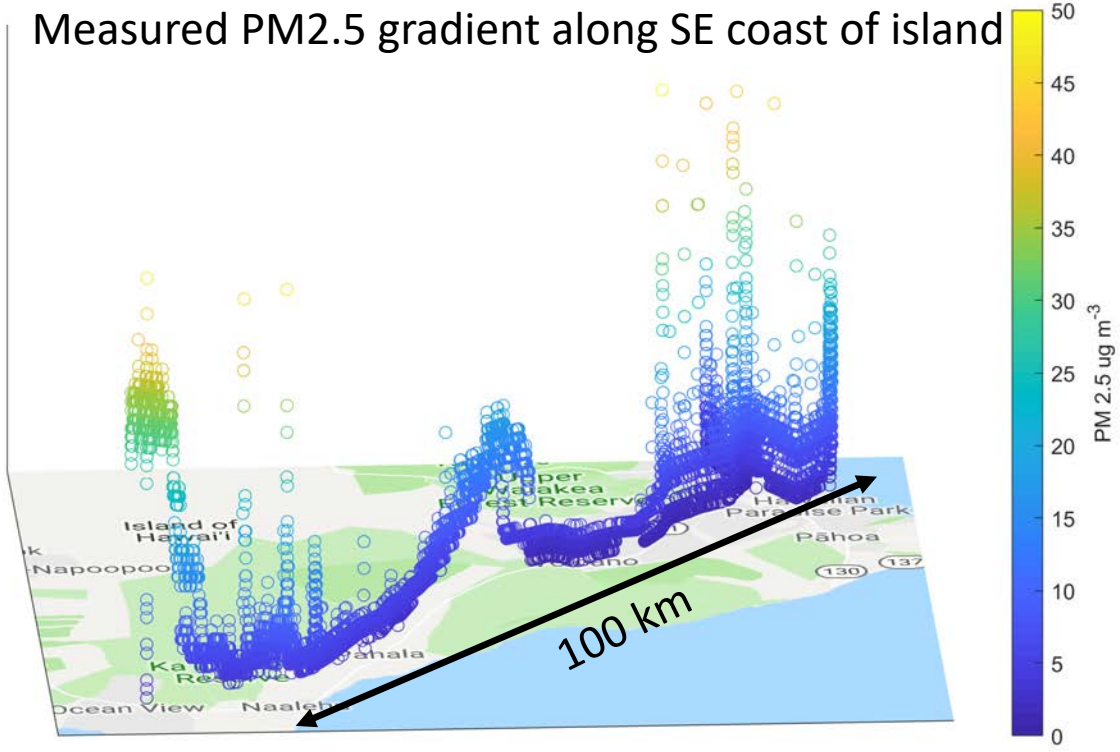
Geologists say the Hawaii volcano eruption could last for months, or even years

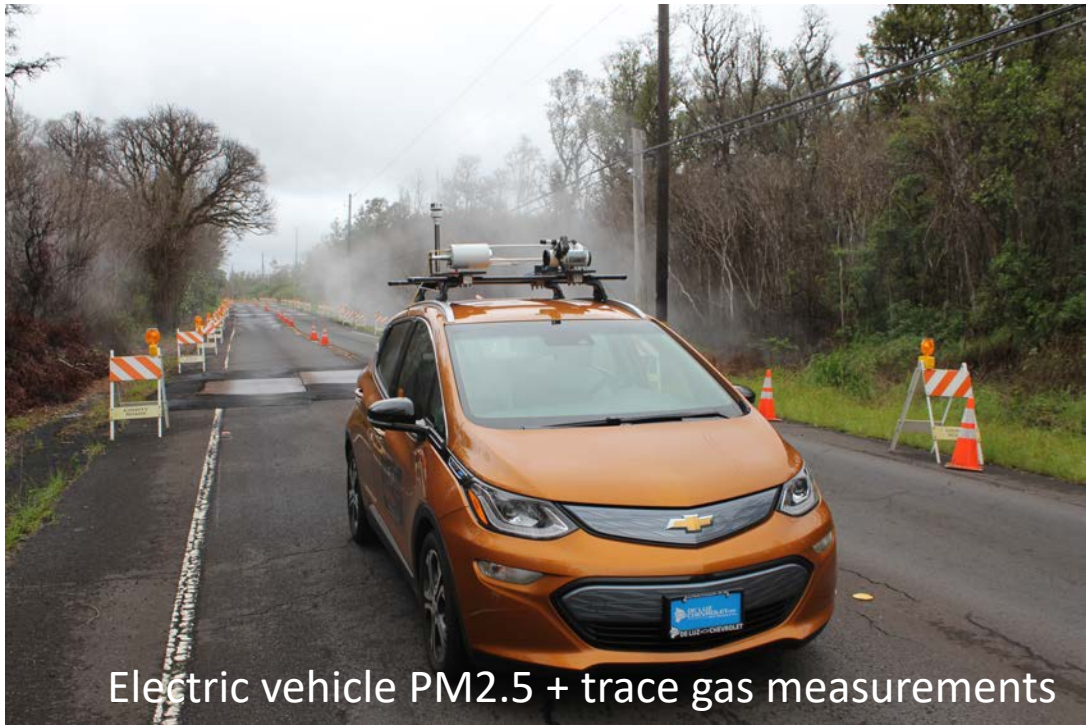
By David Williams, CNN

Updated 3:14 PM ET, Mon July 23, 2018

vog on Kona coast

Measured PM2.5 gradient along SE coast of island





Electric vehicle PM2.5 + trace gas measurements

Satellite data for air quality during Kilauea eruption

Original plan: synthesize surface networks, OMI/OMPS SO_2, examine spatial mobile laboratory gradients between stations, SO_2 sondes to better constrain spatiotemporal patterns of air quality in Hawaii

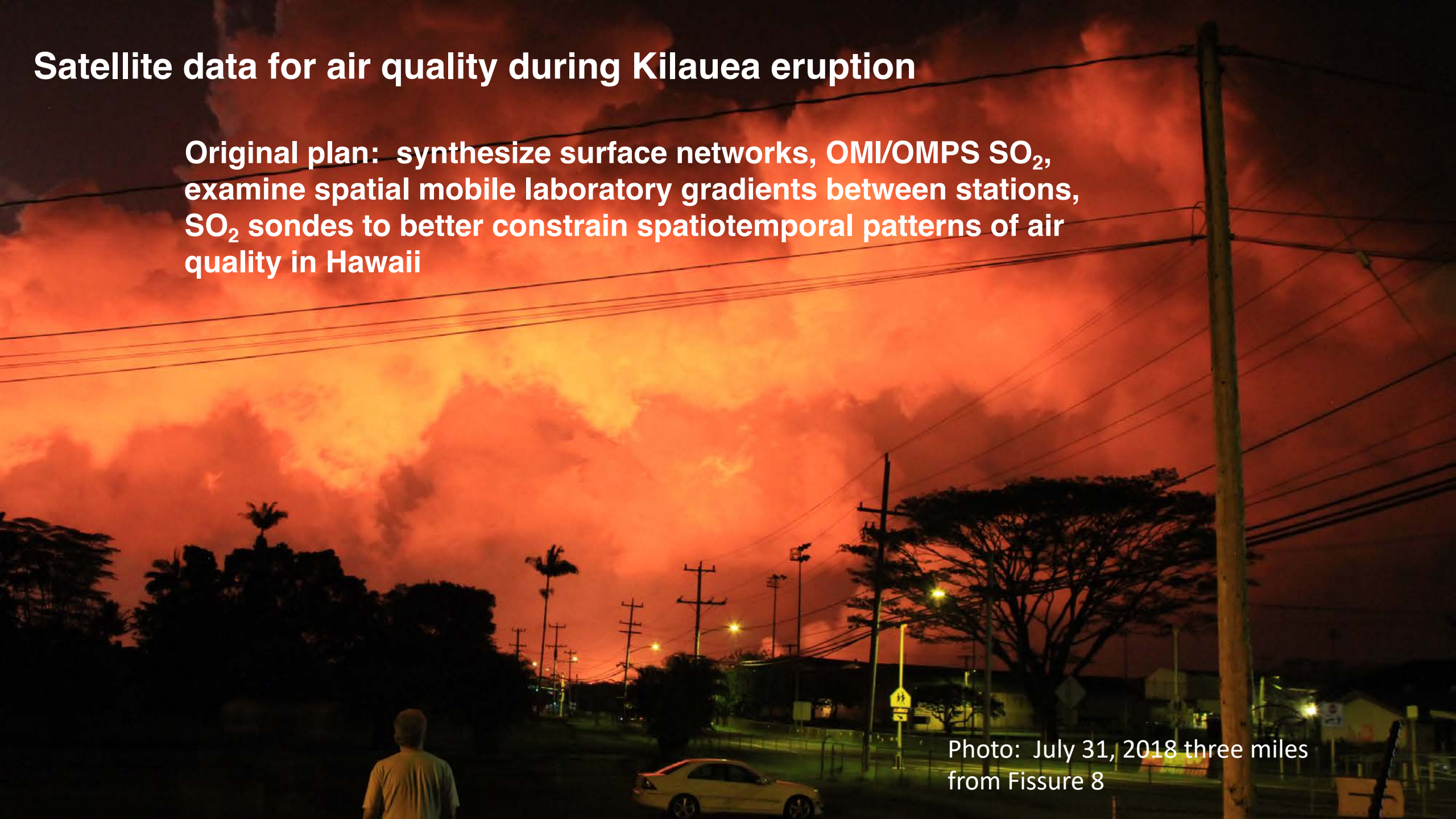


Photo: July 31, 2018 three miles from Fissure 8

NEWS

Kilauea Volcano's Eruptions Could Continue for Months or Years, Report Says

By Sean Breslin · July 26 2018 05:00 PM EDT · weather.com

At a Glance

- A new report from the Hawaii Volcano Observatory says the eruptions at the Kilauea Volcano could continue for months or years.
- Lava flows have been reported at the lower East Rift Zone since May 3.
- Since the eruptions began, more than 700 homes have been destroyed on the Big Island.

While Hawaii's Kilauea Volcano has been erupting almost continuously since 1983, a recent spate of eruptions that have destroyed hundreds of homes could continue indefinitely, according to a new report.

Issued by the U.S. Geological Survey's Hawaii Volcano Observatory, the report says the eruptions in Kilauea's lower East Rift Zone could become the longest ever recorded at the volcano, as the lava flows show no sign of slowing down. That could mean more homes in danger, and with more than 700 dwellings

EOS

GEOCHEMISTRY, MINERALOGY, VOLCANOLOGY

News

Kīlauea Eruption Abruptly Slows Down

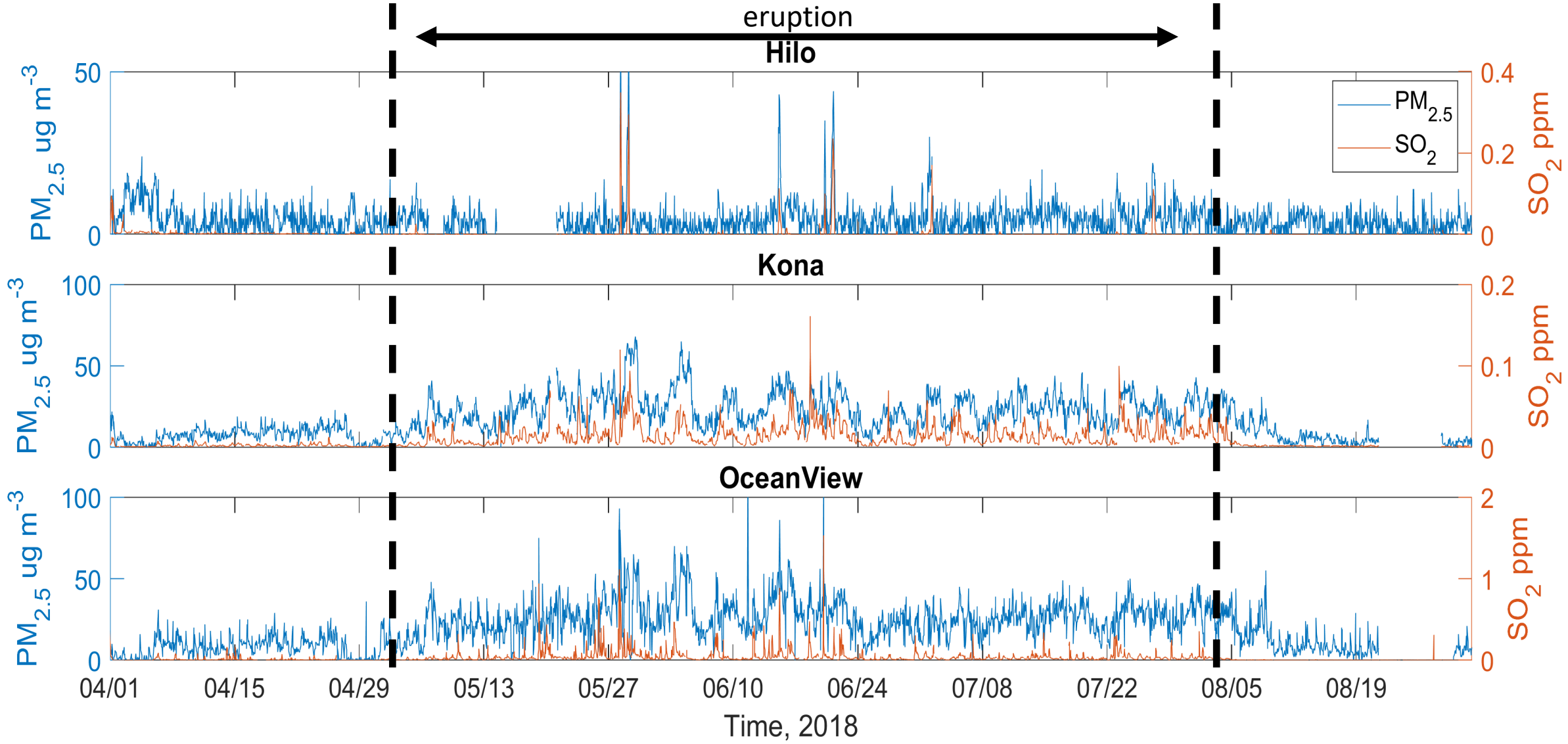
Volcanologists say it's too soon to know whether the sudden drop in activity signals the end of the eruption or just a pause.

Signs of a Slowdown

Although they were not obvious at the time, Neal says scientists now recognize that the volcano may have been giving signs since mid-July that the eruption was going to change.

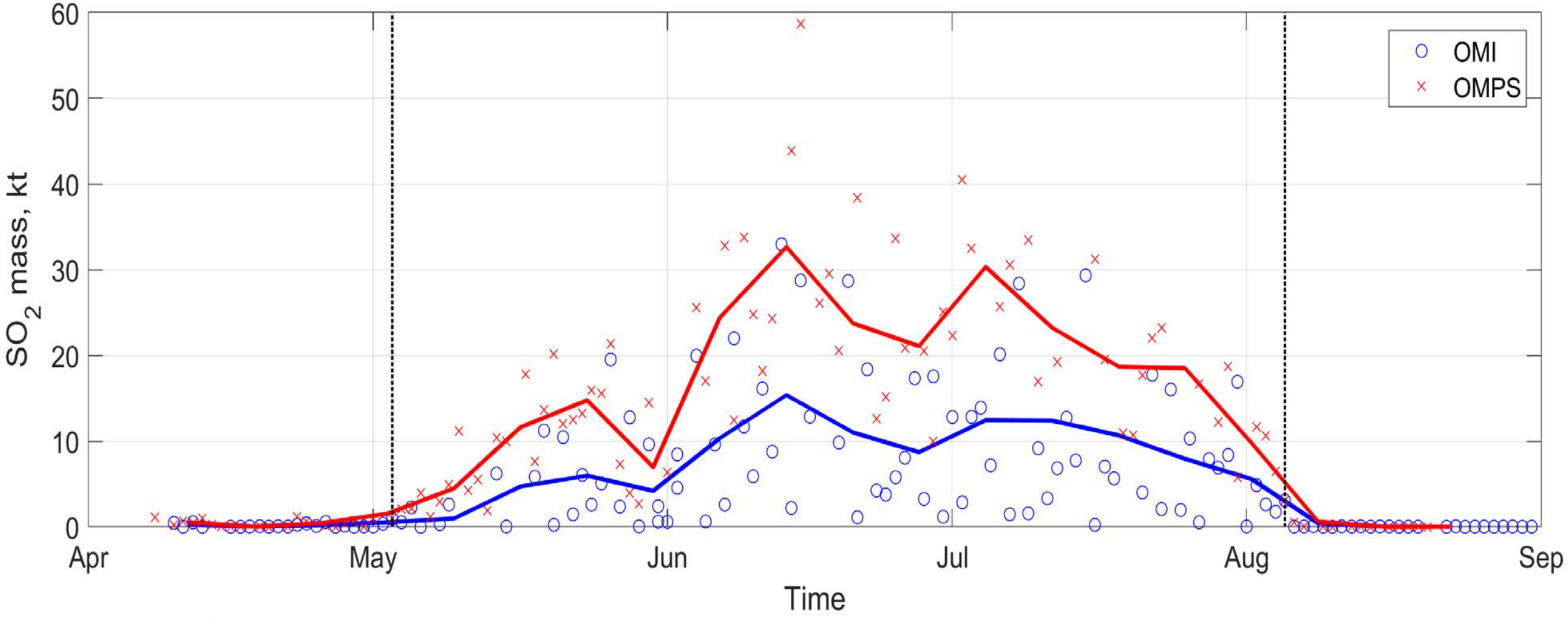
https://eos.org/articles/kilauea-eruption-abruptly-slows-down AGU Eos newsletter: August 9, 2018

Surface PM2.5 and SO_2 datasets



$PM_{2.5}$ and SO_2 surface data showed no obvious trends during July into early August

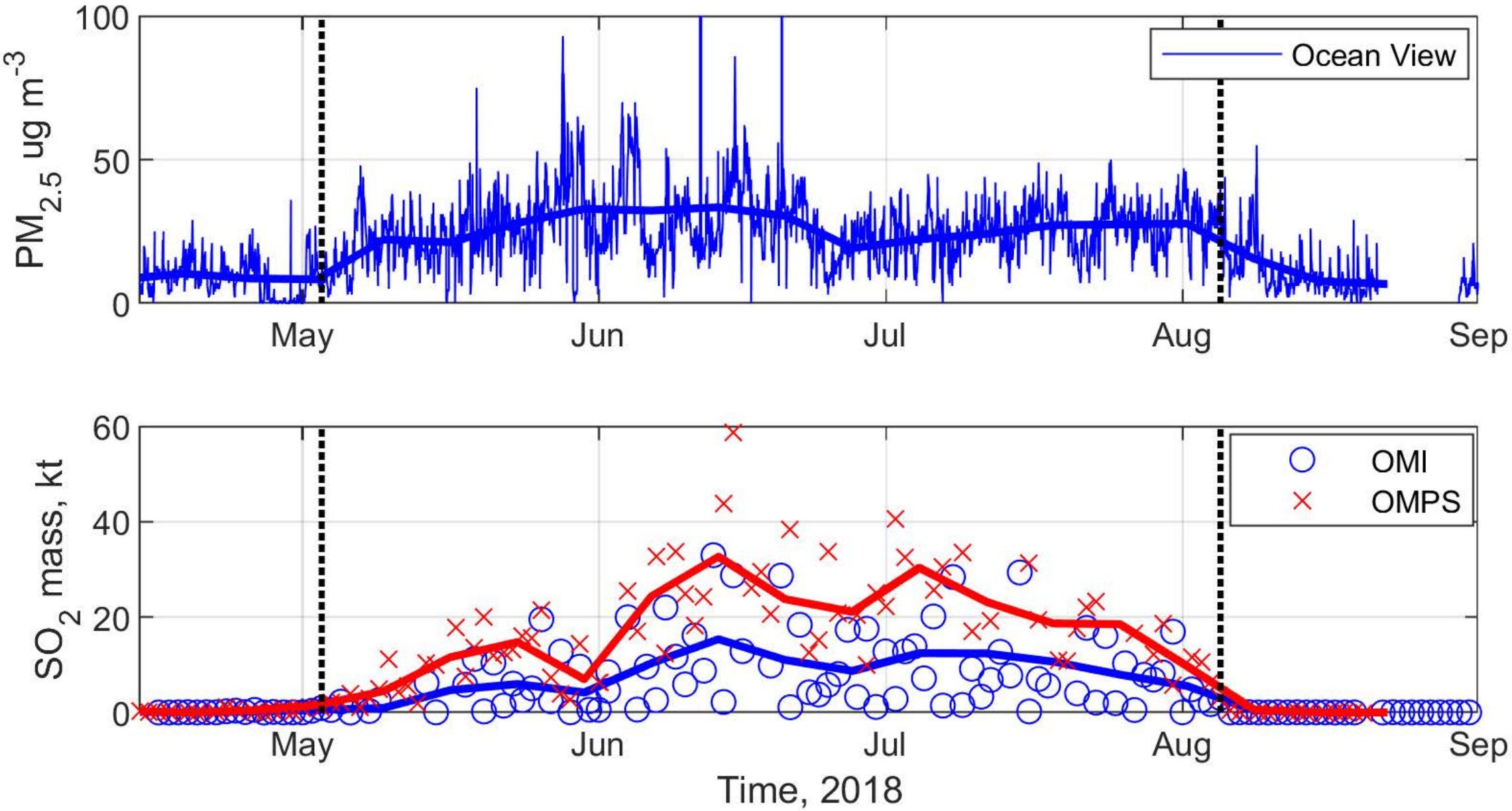
What did SO_2 mass from OMI and OMPS suggest?



SO_2 decreasing significantly during July prior to the shutdown on Aug. 4, 2018

Future work: TROPOMI SO_2 (?), integration of surface/satellite/model products

Comparison of surface PM2.5 and satellite SO_2



Using satellites to bridge scales: ongoing work and future directions

Agriculture

- Satellite NH_3 provides excellent constraints on the spatial pattern of NH_3 emissions
  - relevant for siting of next generation of ground-based network locations (N deposition, background trends, etc.)

- Because NH_3 emissions vary strongly with time, annual means not be representative of their importance

- NH_3 levels trending upwards up to 3-5%/year in Midwest, particularly in agricultural regions

- High-resolution NH_3 and land use provide observational constraints on crop-type emissions and potentially fertilizer usage

Volcanoes

- Satellite SO_2 was a useful indicator of the 2018 Kilauea eruption intensity, not well recognized by some stakeholders (opportunity!)

- Synthesized satellite datasets in Hawaii have promise of improved maps of air quality

Year 2.5 Progress Update, PI Mark Zondlo

SPATIOTEMPORAL VARIABILITY OF AMMONIA THROUGH SYNTHESES OF IN-SITU-, GROUND-BASED, AND REMOTE SENSING MEASUREMENTS

- Validation of satellite NH_3 at pixel scale
  - Zondlo et al., JGR paper in prep. for IASI
- Spatial variability of NH_3
  - Paper published on oversampling algorithm (Sun et al., *Atmos. Meas. Tech.*, 2018)
  - Paper published with EPA on San Joaquin Valley ammonium nitrate formation (Kelly et al., *JGR-A*, 2018)
- Temporal variability of NH_3
  - 1 paper in prep. on monthly US emissions at high spatial resolution
  - NASA Earth Observatory Image of the Day on Dec. 10, 2018 with IASI NH_3
  - 1 paper in prep. on ammonia dry deposition in North Carolina with EPA
  - 1 paper in prep. on the effectiveness of NH_x control for PM2.5 from observational datasets
- Integrating satellite/surface data for Kilauea eruption (new)
  - Examining how satellite data can help fill in gaps of the existing surface network and be an indicator for volcanic activity
- Stakeholder talks to Western Regional Air Partnership Regional Technical Operations Working Group, Colorado Dept. of Public Health and the Environment, California Air Resources Board, EPA ORD, New Jersey DEP + 8 academic talks in 2018

Tiger Team Participation

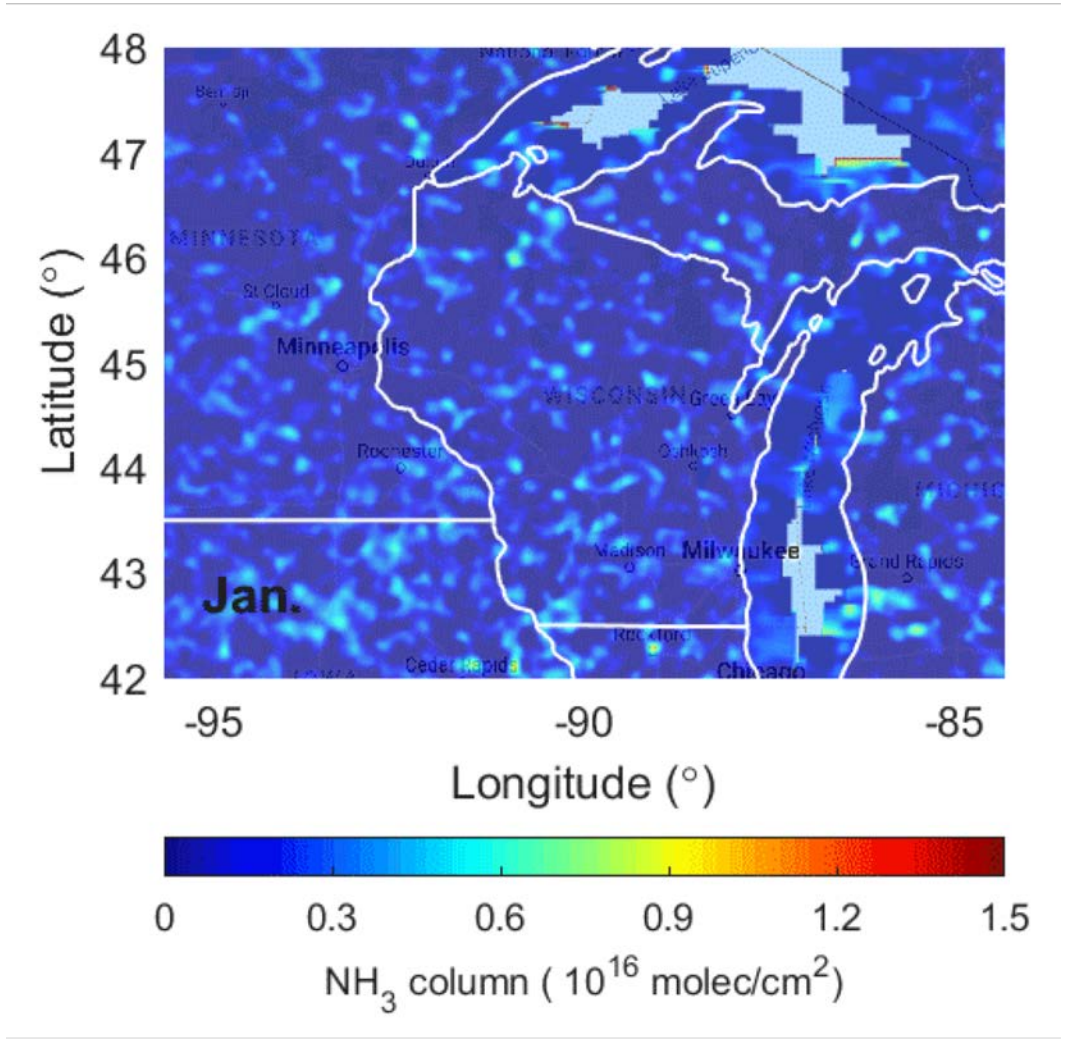
- TT Trends (Duncan/West)
  - Ammonia trends for eastern US from satellite
  - Monthly trends in Mid-Atlantic region
- TT SIP (Fiore)
  - 2-page primer on the availability and use of satellite ammonia to stakeholders written for archival
- TT High-resolution (Kinney)
  - Measured 50 transects of PM2.5 across Central Park to compare to maps from satellite and low-cost sensor network gradients across this part of Manhattan
- TT Regional Haze (Fiore)
  - Delivering ammonia spatial maps monthly to four regional stakeholders for constraining ammonia emission inventories
- TT 2017 Fires (O'Neill)
  - Examining NH_3/CO enhancement ratios from CrIS satellite observations to examine precursor PM2.5 emissions from fires

2 papers published

4 papers in preparation

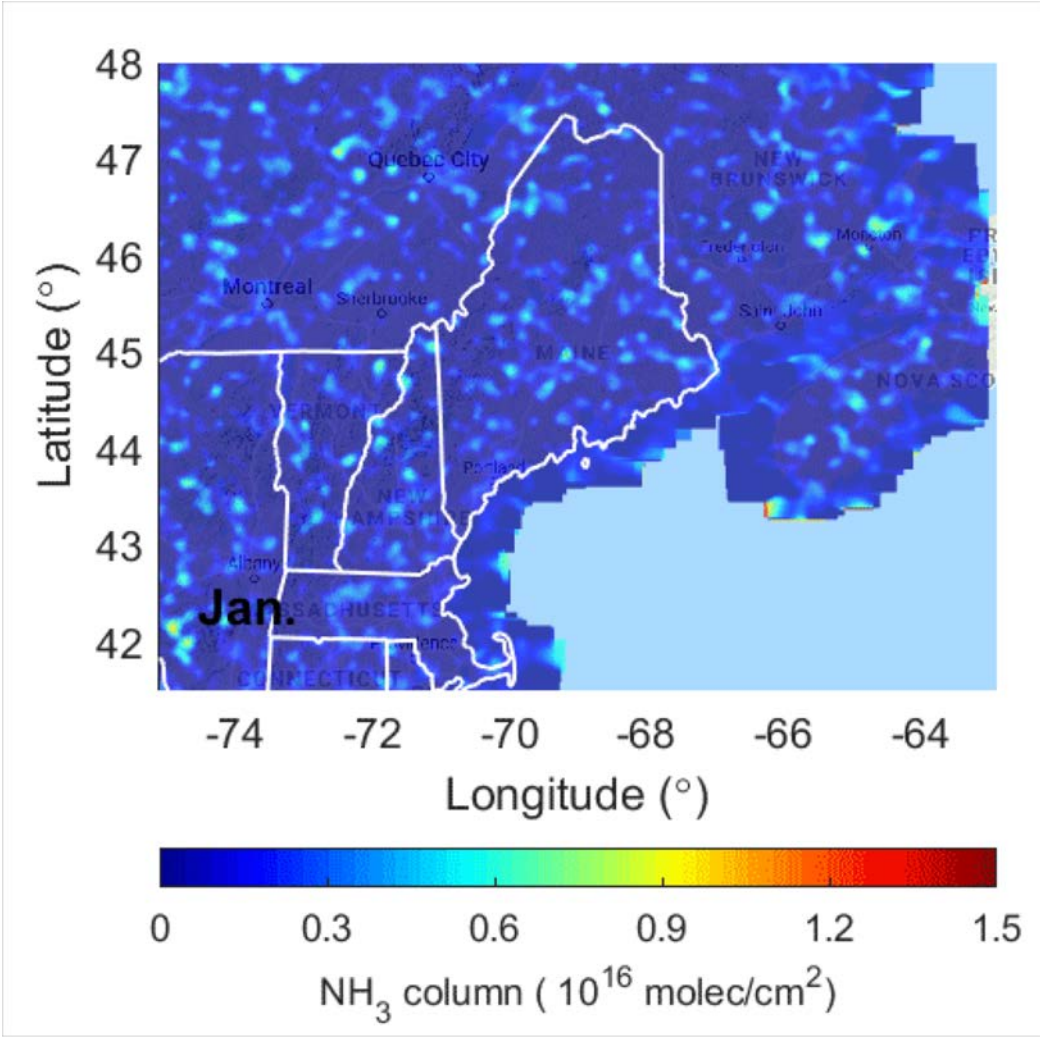
2008-2016, IASI Metopa & Metopb, oversampling high resolution (0.02°×0.02°) maps

Seasonal variation



2008-2016, IASI Metopa & Metopb, oversampling high resolution (0.02°×0.02°) maps

Seasonal variation



2008-2016, IASI Metopa & Metopb, oversampling high resolution (0.02°×0.02°) maps

Seasonal variation