From Agricultural Ammonia to Volcanic Sulfur

Satellite Measurements to Improve Emissions Inventories

PRINCETON UNIVERSITY

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Stakeholders:

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John Walker, ORD / EPA; James Kelly, EPA Ofc. of Air Quality Planning and Standards

Fabien Paulot, NOAA GFDL

HAQAST

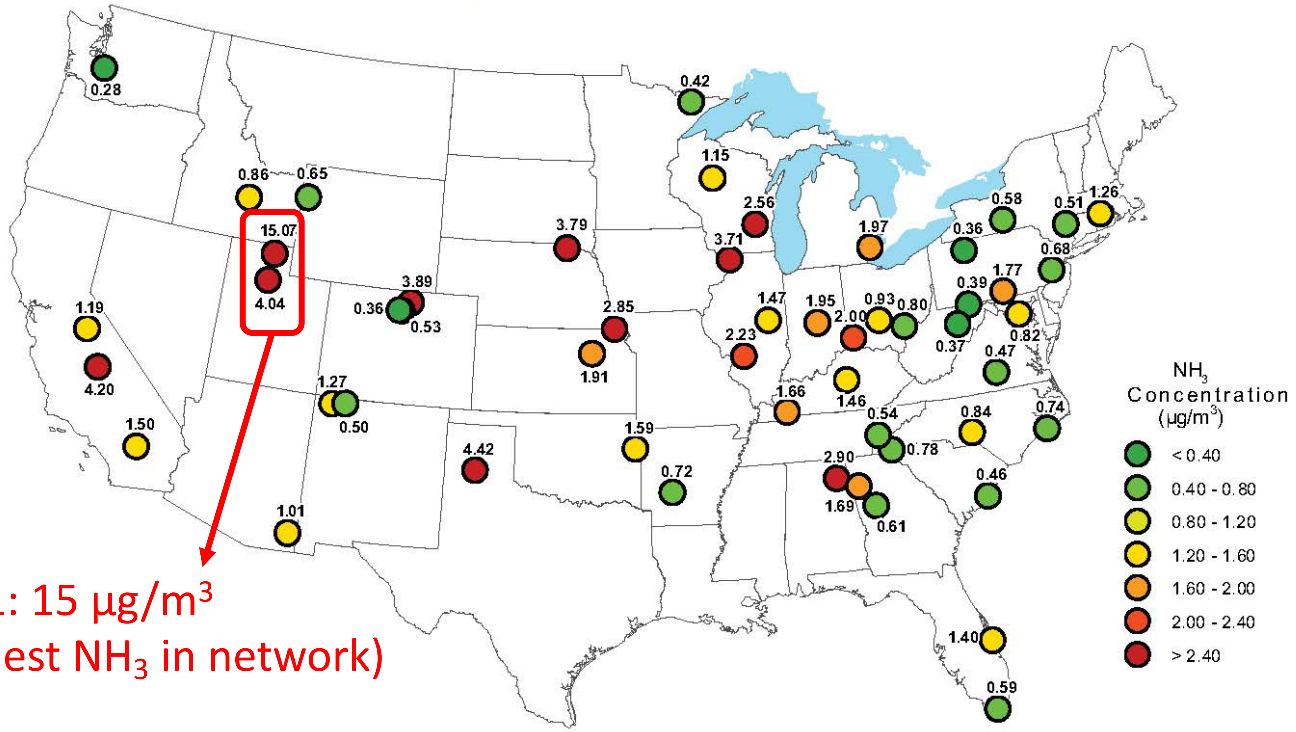
NASA

HAQAST-4 Madison, Wisconsin

July 17, 2018

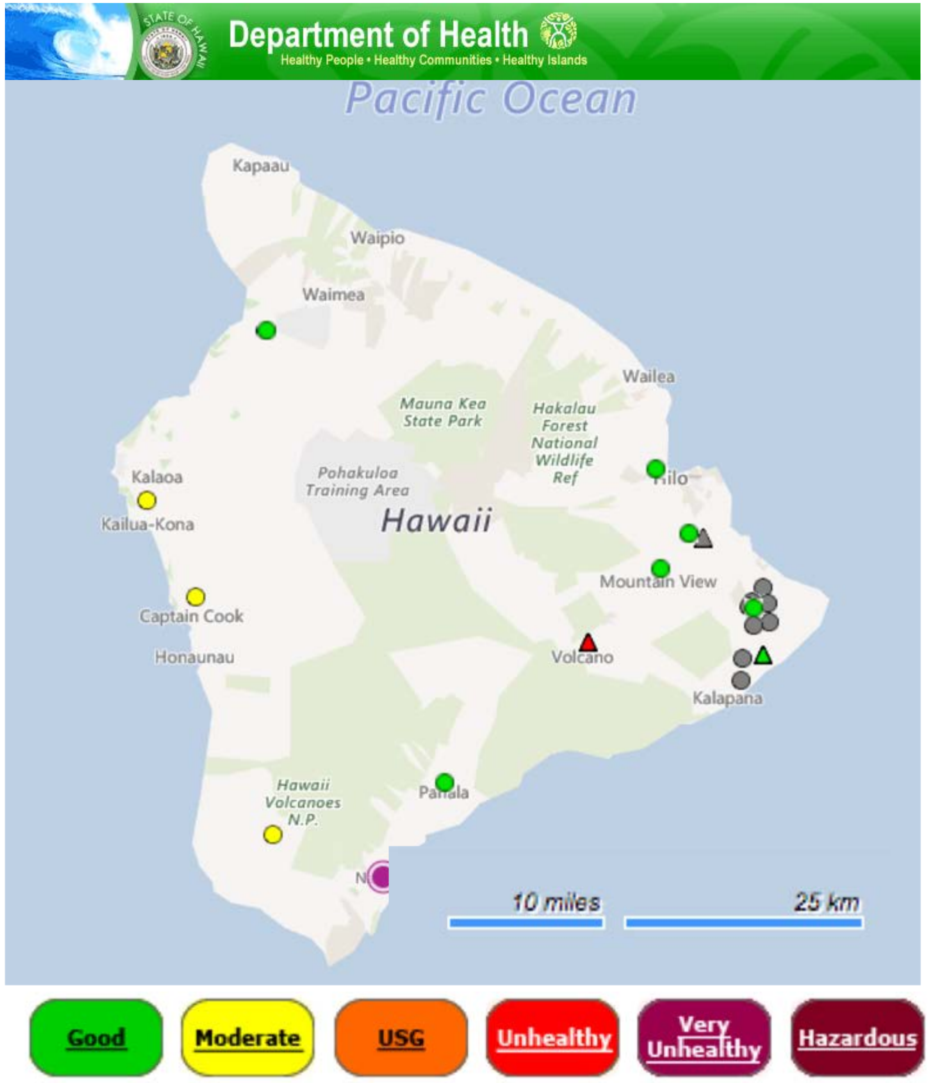
Short-lived pollutants difficult for ground-based networks

Ammonia Monitoring Network (AMoN)



UT01: 15 $\mu g/m^3$
(highest NH_3 in network)

SO$_2$ ground-based network, Hawaii

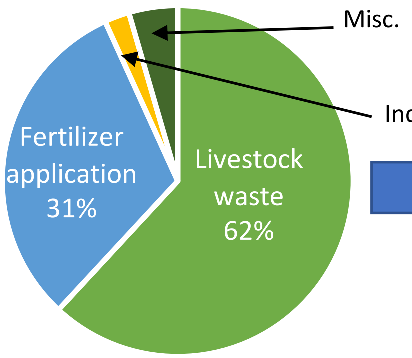


- large gaps exist between stations
- interpolating between stations inaccurate because large spatial gradients exist
- station siting problematic and may bias measurements
- strong temporal gradients as well

Ammonia (NH_3): air quality and ecosystem health

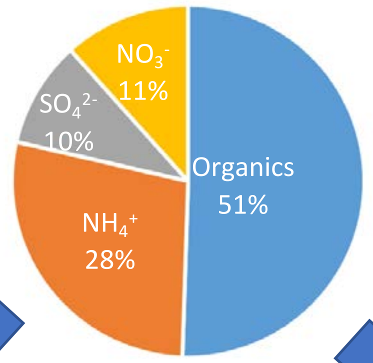
2011 U.S. NH_3 Emissions

Total = 3.44×10^9 kg



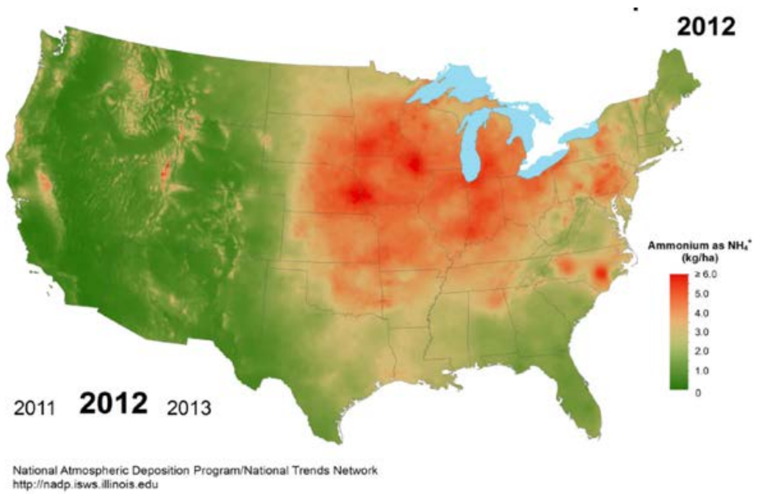
(EPA, 2011)

Aerosol composition by mole
Boulder, CO

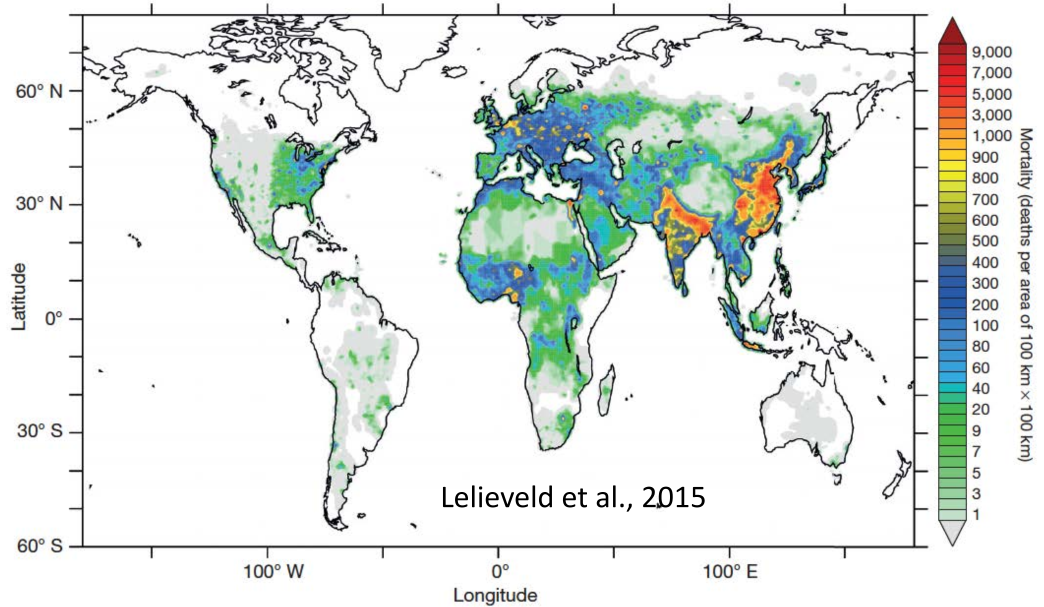


Adapted from Jimenez et al. (2009)

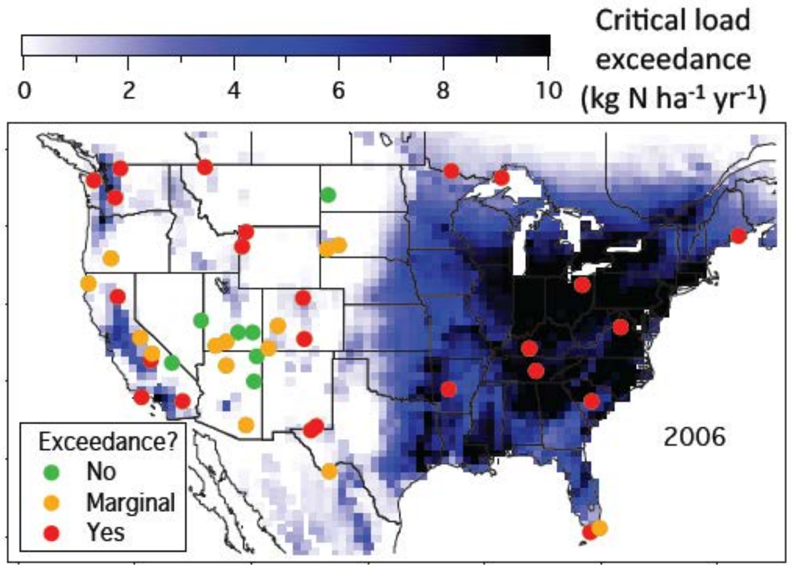
NH_4^+ deposition in US



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

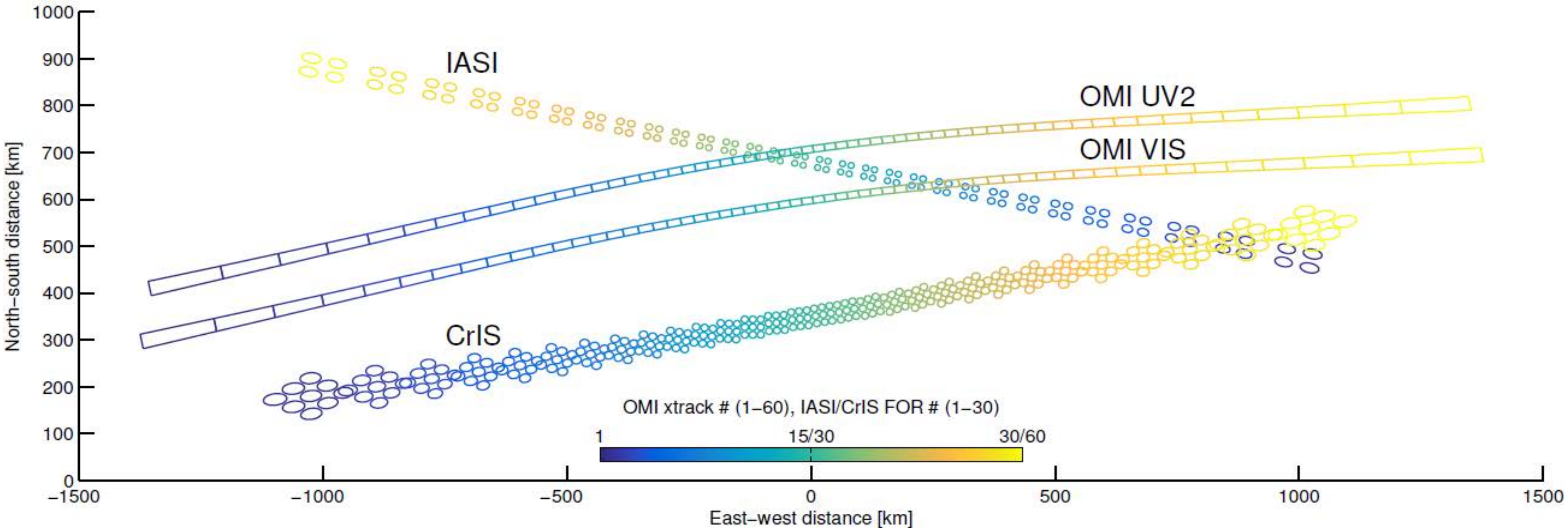


Excess nitrogen deposition in National Parks



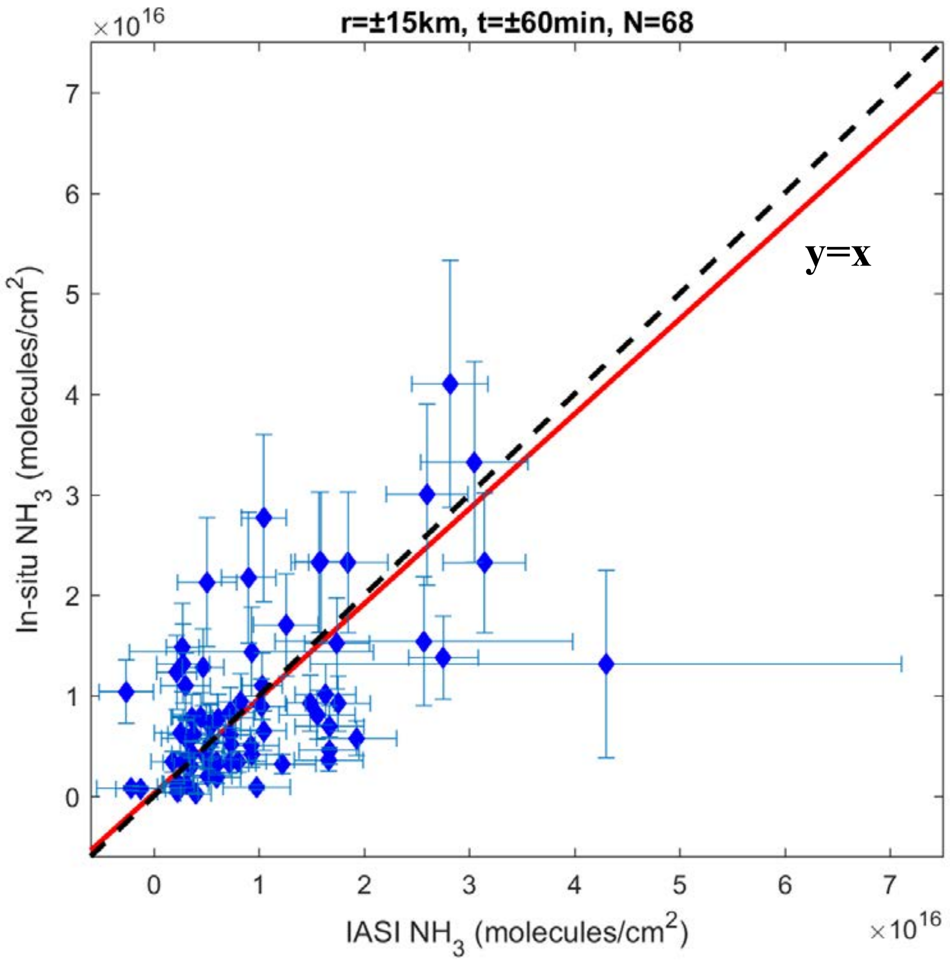
Satellite measurements of NH_3

Instrument	Satellite	Day, equator crossing time (local)	Pixel size at nadir (km^2)	NH_3 data availability	Product	Spectral Resolution (cm^{-1})	Noise (K)	Swath width (km)	# pixels across swath	Data accessible to public
IASI	MetOp-A	9:30	12 × 12	2007-present	column	0.5	0.17	2200	60	Y
	MetOp-B	8:45	12 × 12	2013-present	column	0.5	0.17	2200	60	Y
CrIS	S-NPP	13:30	14 × 14	2014-present	profile	0.625	0.04	2200	90	late 2018
TES	Aura	13:30	5.3 × 8.5	2004-2015	profile	0.1	0.15	5.3	1	Y
AIRS	Aqua	13:30	13.5 × 13.5	2002-present	profile	0.5	0.2	1650	90	TBD

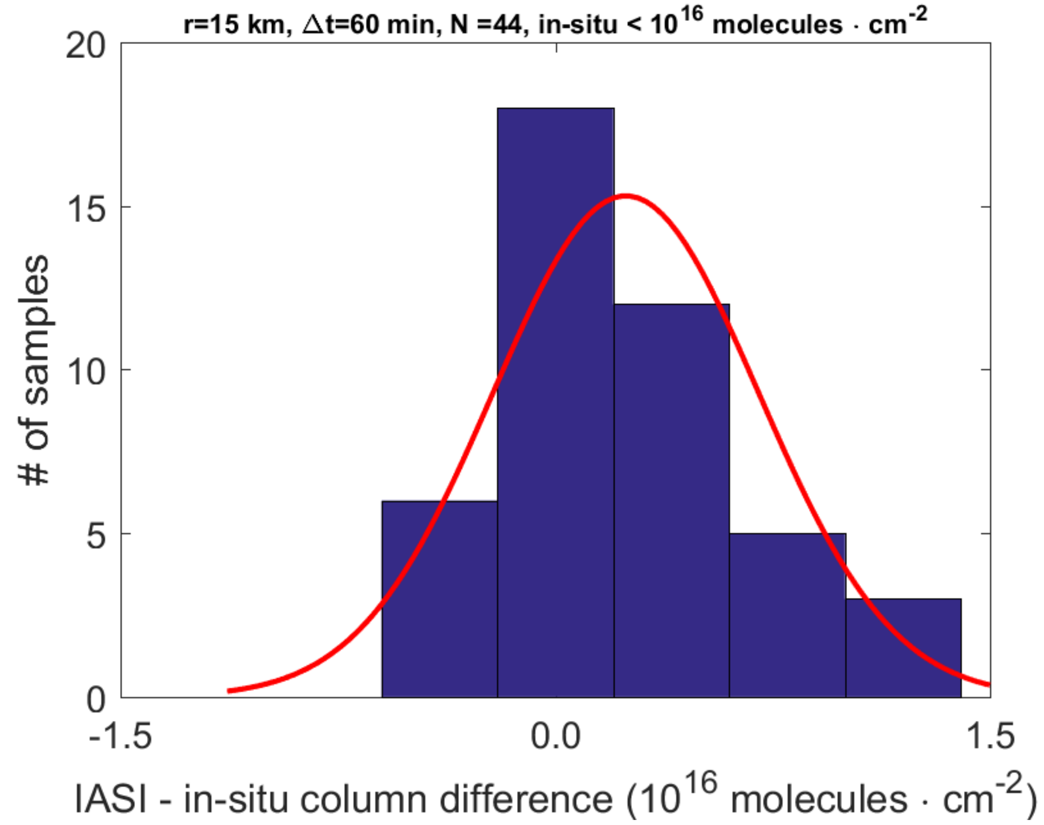


Validation of IASI NH_3

Validation with aircraft/surface measurements within ±15 km of IASI pixel center, ±60 minutes of overpass time



$y=(0.94 \pm 0.16)x + (0.26 \pm 1.83)\ 10^{15}$ r: 0.59



mean =2.4e+15 [1.0e+15, 3.8e+15]
sigma=4.6e+15 [3.8e+15, 5.8e+15]

No strong bias apparent in data, "noisy" below 1×10^{16} molec cm^{-2} but appears normally distributed

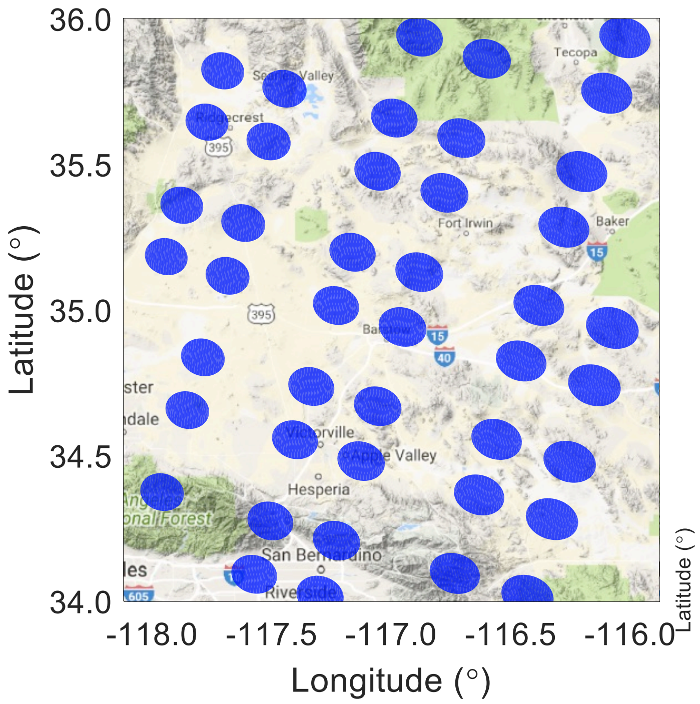
Oversampling algorithm: acquiring high spatial resolution

Oversampling: temporal averaging of the data on **a spatial grid finer than the pixel** resolution

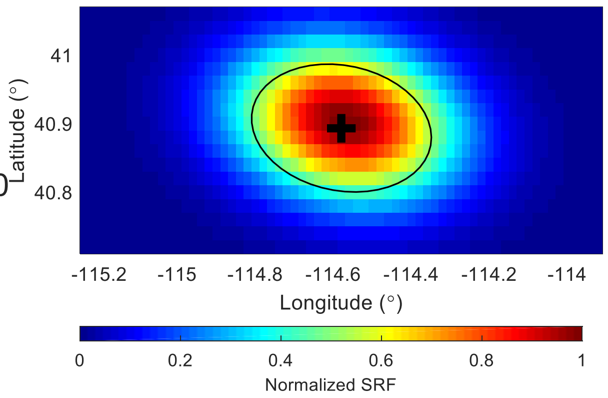
Oversampling lots of overlapping satellite pixels

Achieves **high signal-to-noise ratio** at **high spatial resolution** by sacrificing temporal resolution

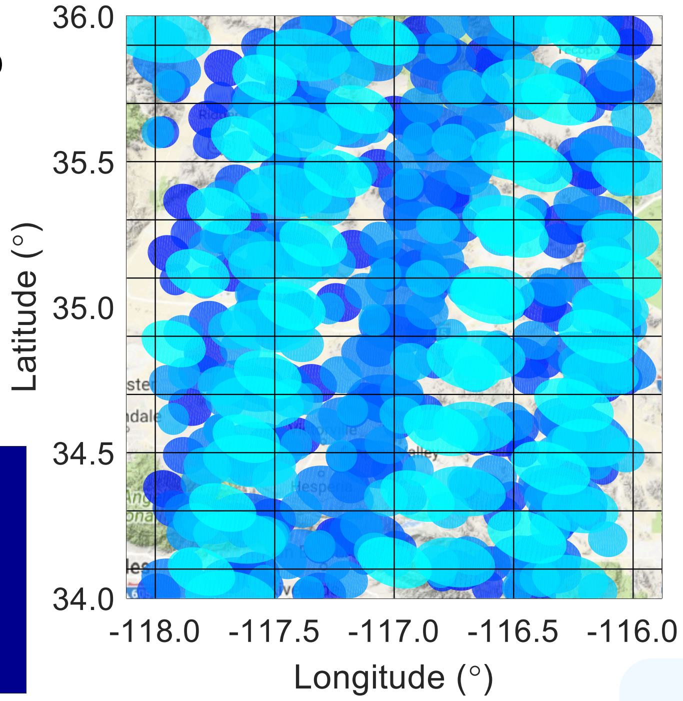
IASI pixels on Jan. 1, 2014



Need a finer resolution to locate the sources: use 2D Guassian spatial response function



IASI pixels on Jan. 1 - 10, 2014



(Pixels sampled on different days are marked by different colors)

Capable of a much finer spatial resolution

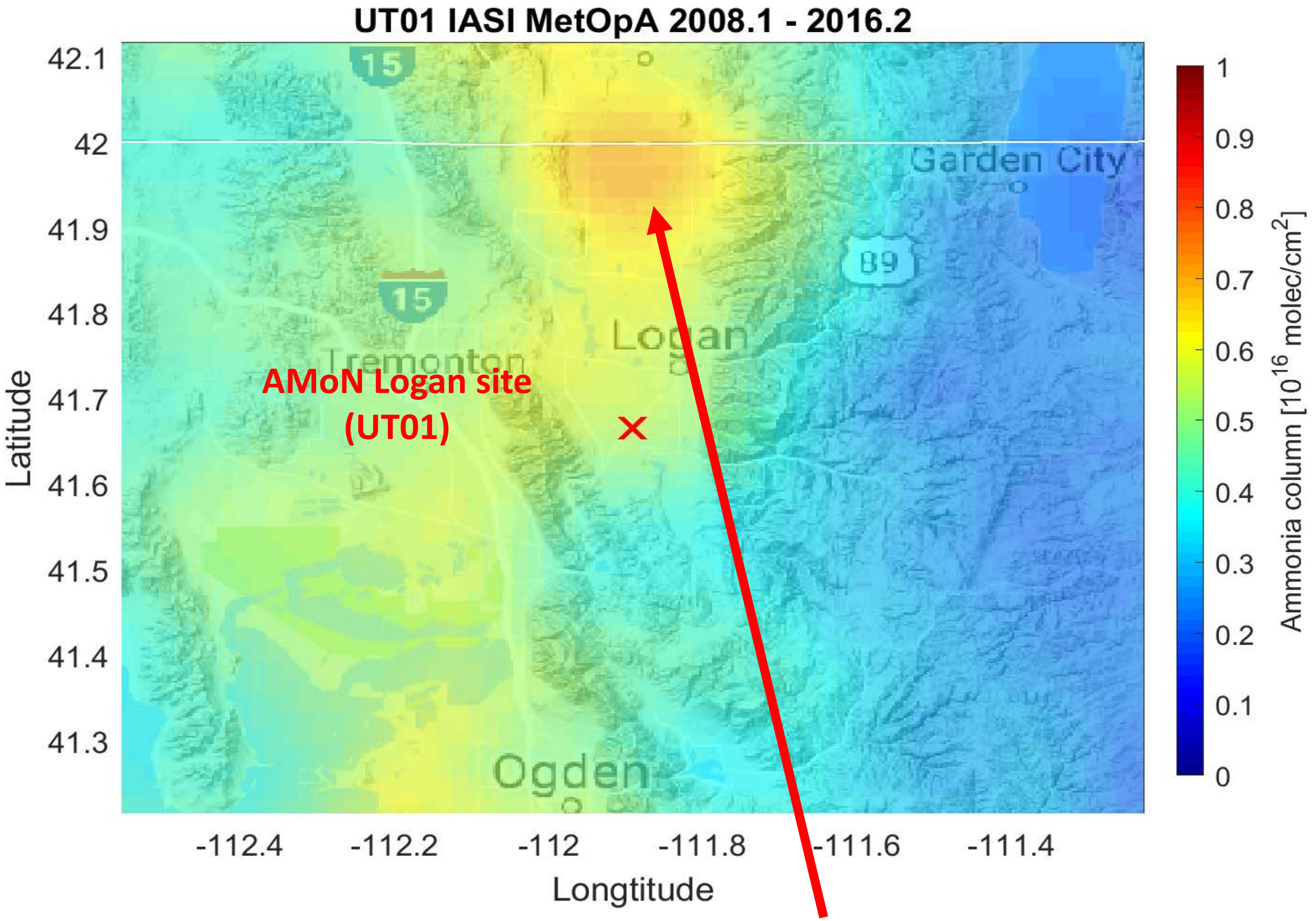
Revisit high NH_3 AMoN site in Cache Valley, Utah

- site located immediately next to concentrated animal feeding operation!

Is this site representative of the region? What would it observe if, e.g., a few km away?

Revisit Cache Valley

- UT01 has the highest NH_3 in AMoN
- site is not representative of the area
- NH_3 actually higher in the northern portions of the valley vs. southern



NH_3 maximized in northern portion of Valley

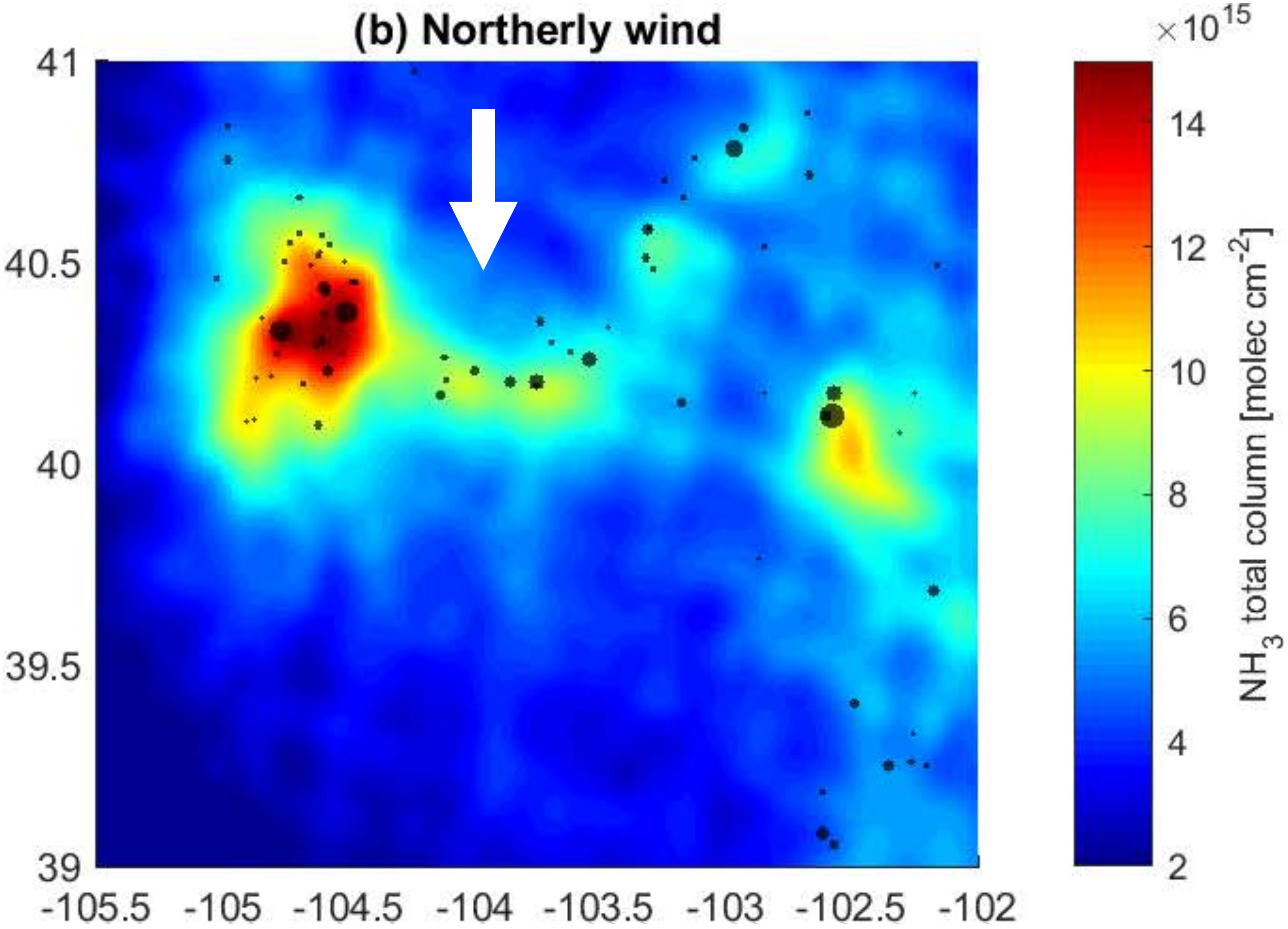
Satellites may help guide the next generation of design for future surface observation networks.

Northern Colorado: meteorological variations

[w/ Kang Sun, Univ. Buffalo]

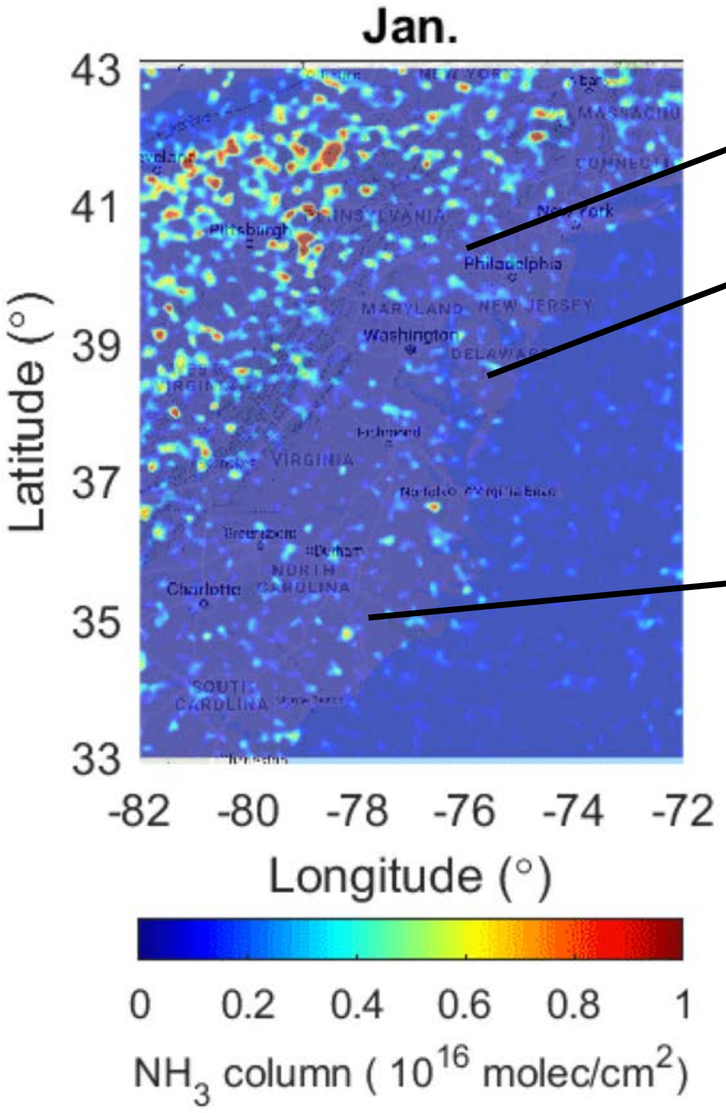
- plumes emitted from individual CAFOs in northeast Colorado

- capable of quantifying losses (deposition, aerosol loss)



Relative temperature differences between northerly (colder) and southerly (warmer) winds also observed.

Trends TT (Duncan & West): spatiotemporal NH_3 variations in agricultural areas in eastern U.S.

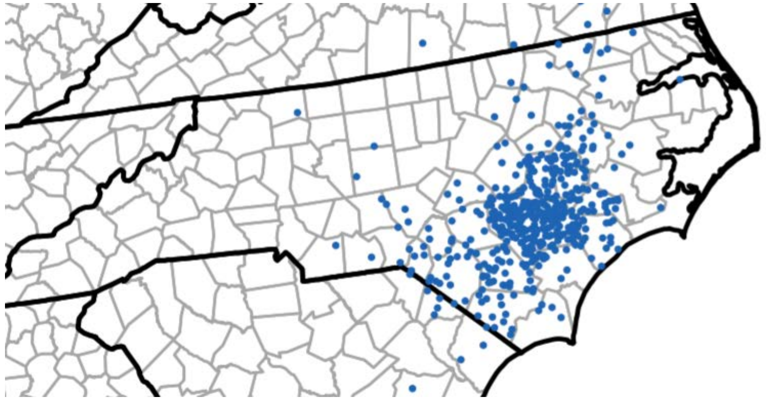


Hot spots & agricultural land use

southeast PA, dairy, croplands, USDA, 2012

Lower DelMarVa, croplands/poultry, USDA, 2012

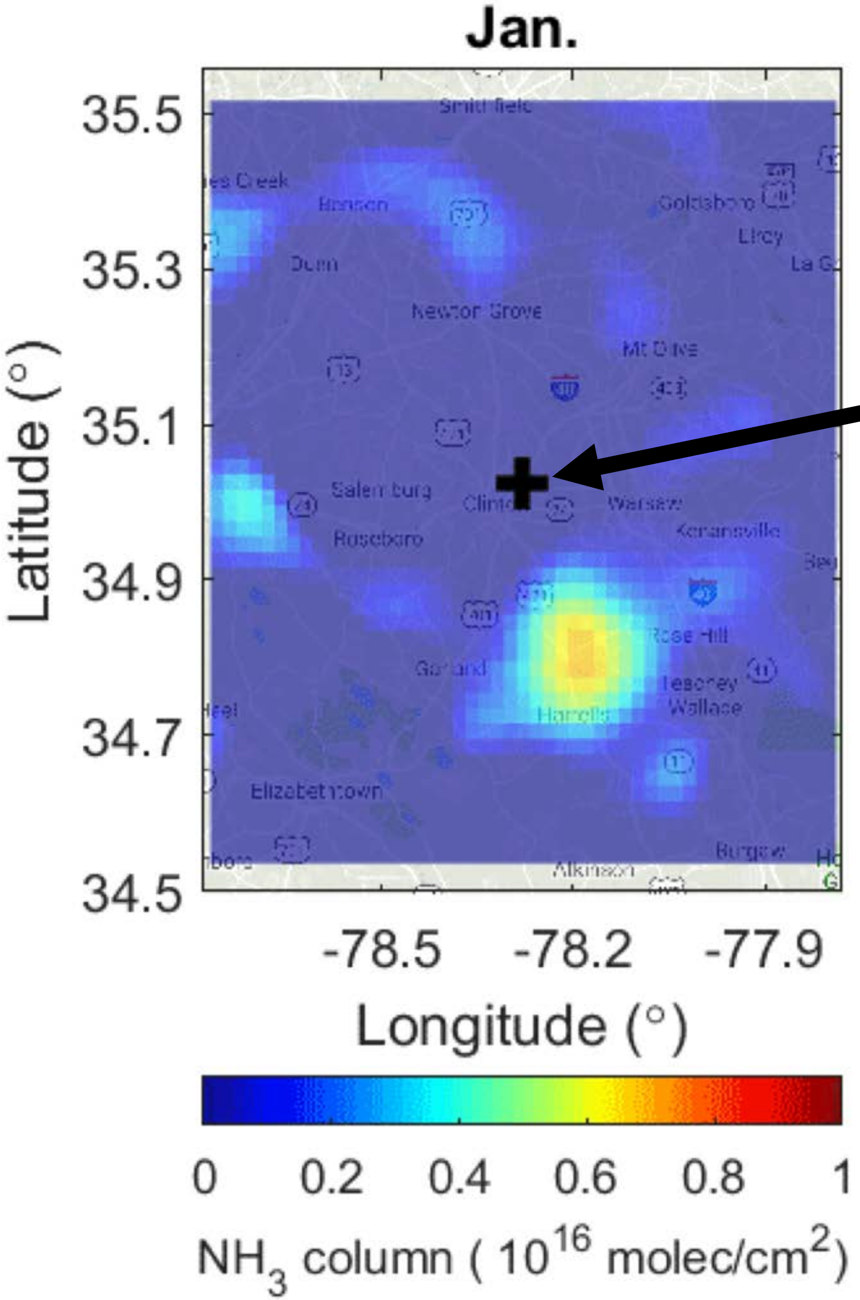
southeast NC, cropland/hogs, USDA, 2012



1 Dot = 20,000 Hogs and Pigs

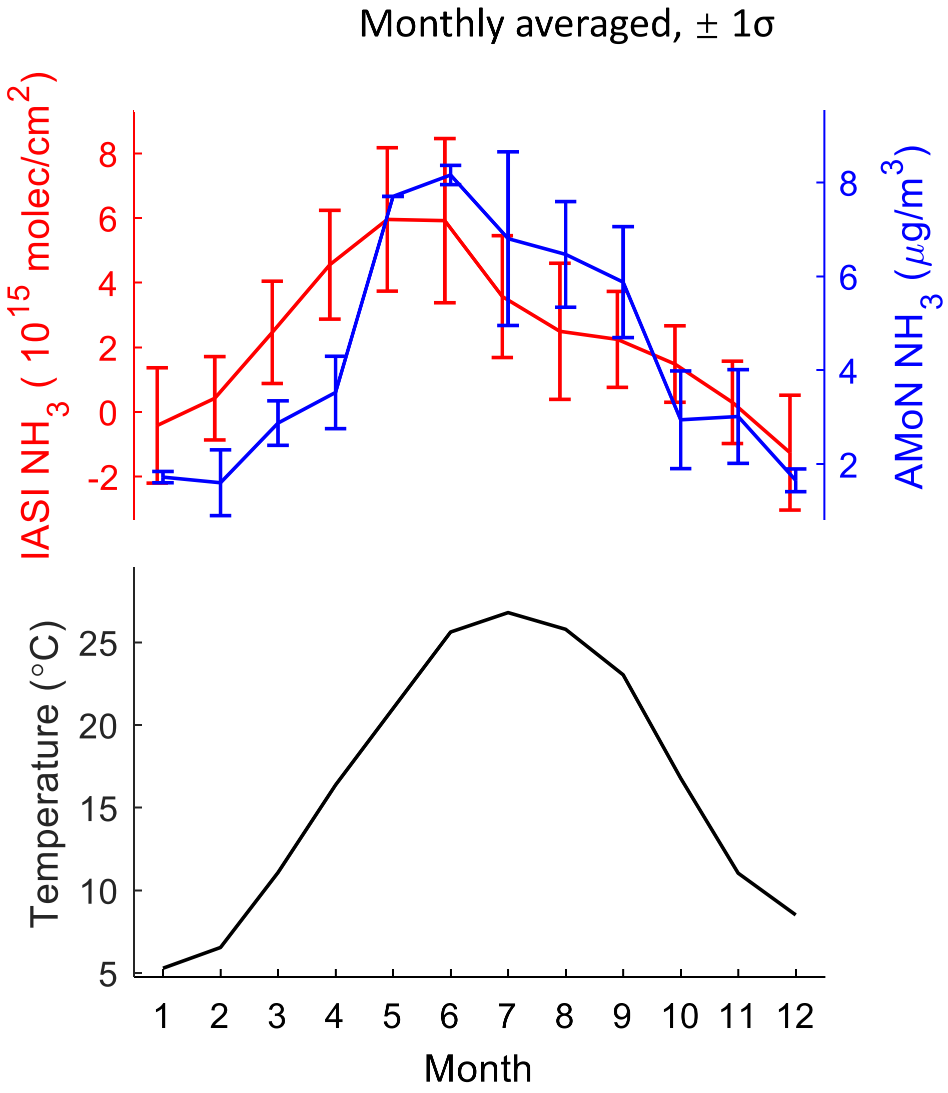
How well do these trends compare to AMoN?

Comparison of IASI monthly trends vs. AMoN (±50 km)



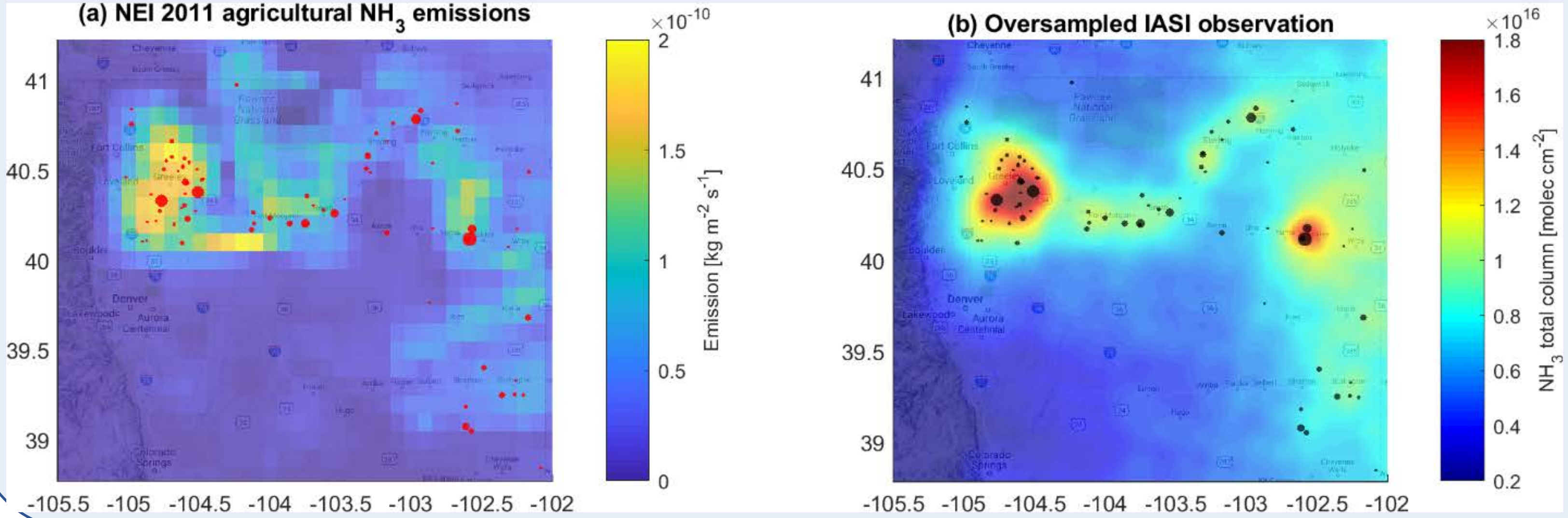
Late spring/early summer peak likely due to combination of volatilization and fertilizers.

Good temporal agreement at other agricultural sites between IASI and AMoN.



Comparison with emission inventories and models

For northeast Colorado:

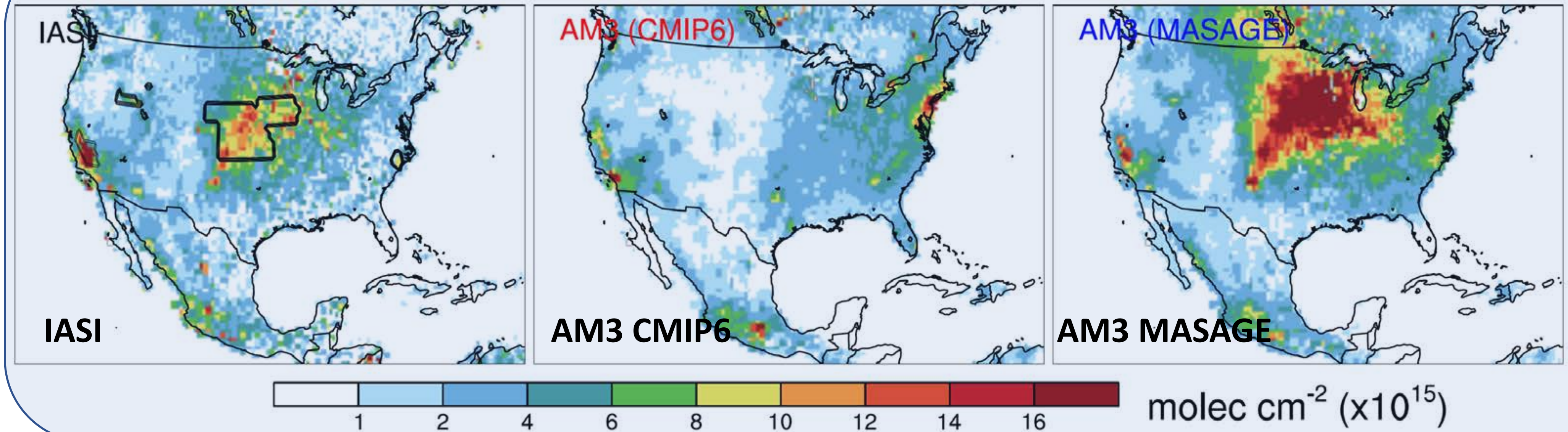


NEI 2011 (2014, 2017)

- inventories inconsistent spatially with observations by IASI

[Kang Sun, Univ. Buffalo]

For U.S.:



GFDL AM3

Two different emissions

F. Paulot, GFDL

Seasonal evolution of ammonia in the US

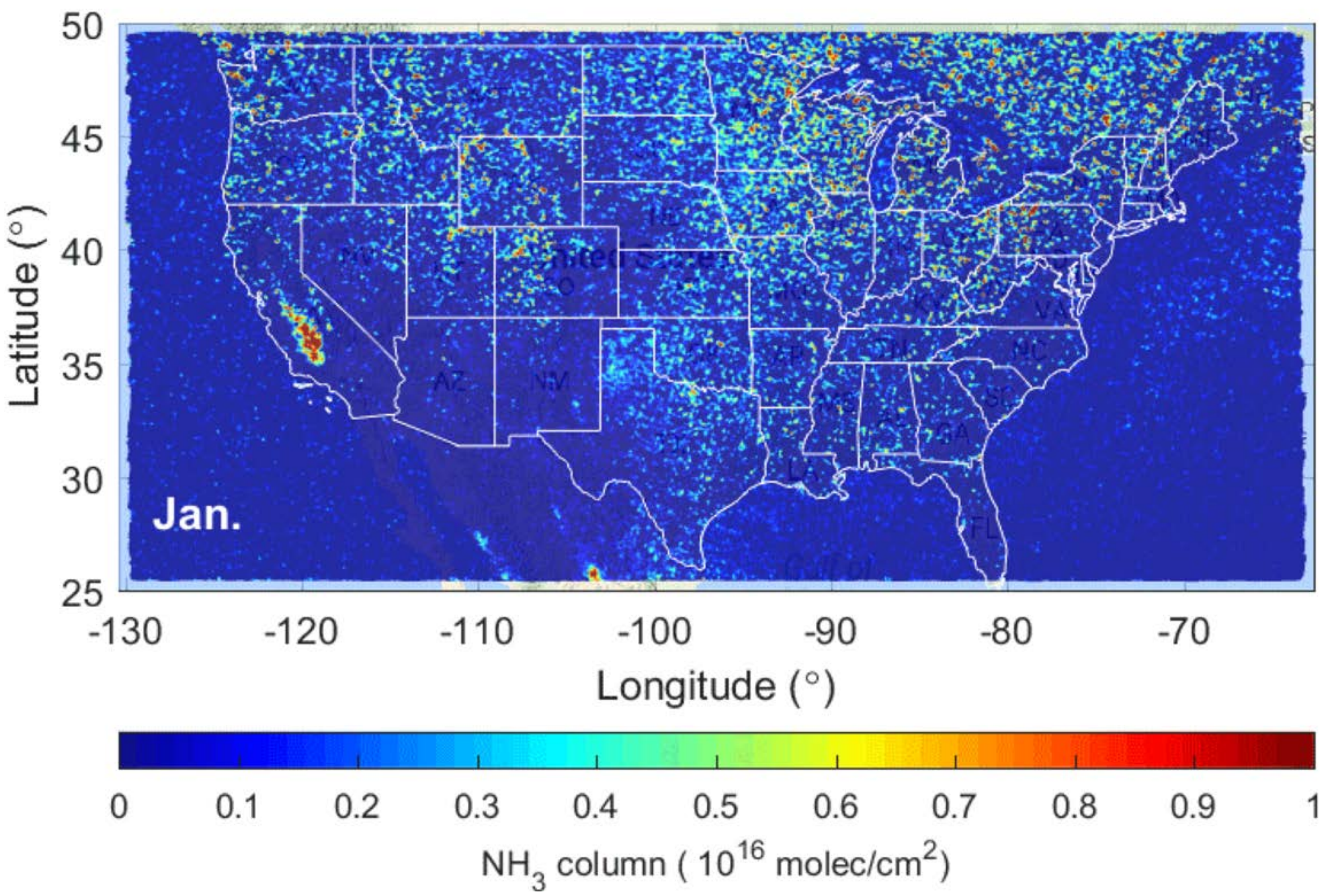
2008-2016, Metop/A & Metop/B, oversampling high resolution (0.02°×0.02°) maps

Overall annual cycle:

- low in winter, peak in spring / summer

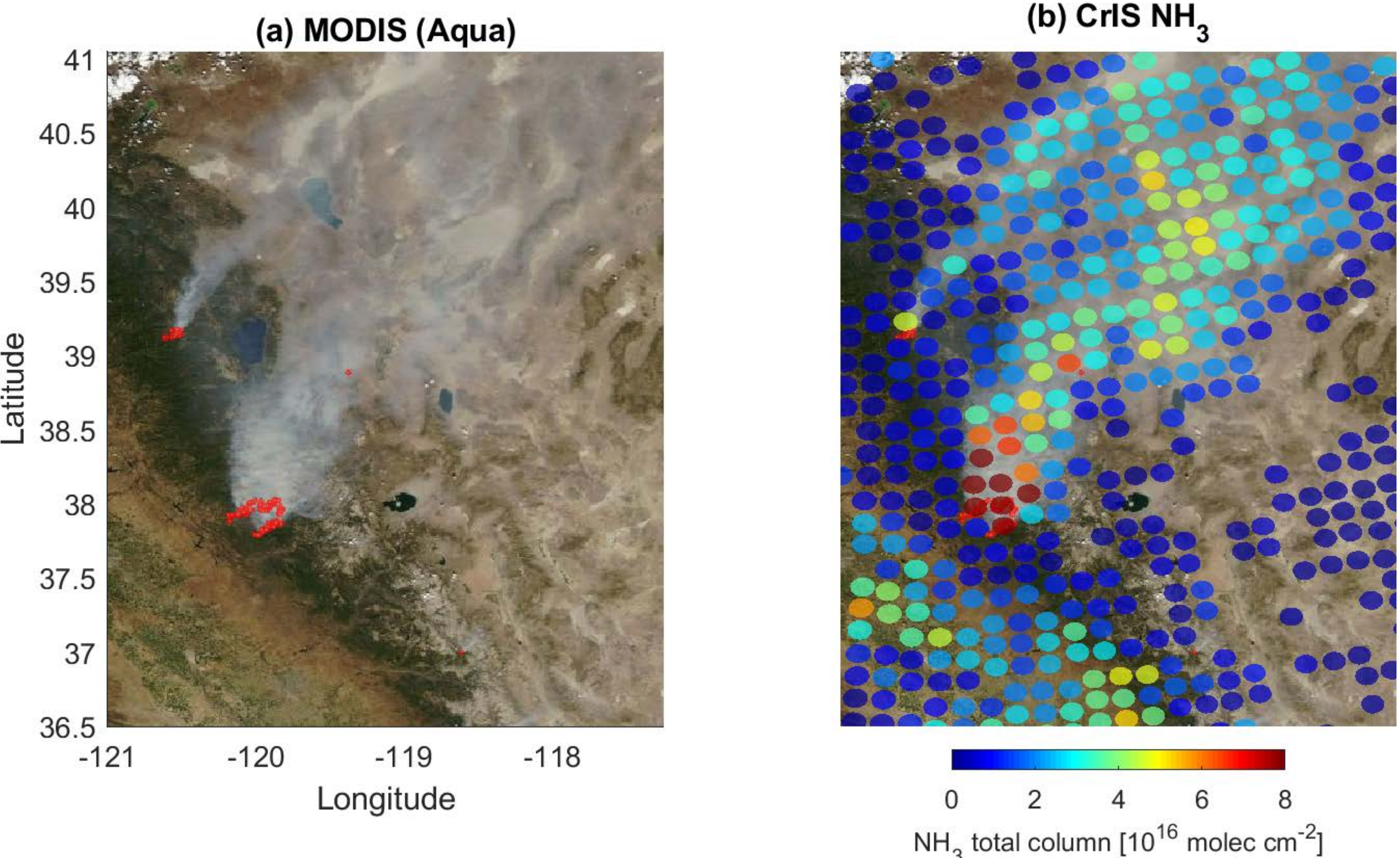
Different seasonalities across US:

- Corn Belt (IL/IA): peaks in April to May
- San Joaquin Valley (feedlots/crops): July
- western High Plains (feedlots): July-August



Temporal emissions: wildfire NH_3 emissions

Rim Fire (CA) on August 23, 2013



For large emissions, temporal averaging likely not needed for CrIS NH_3.

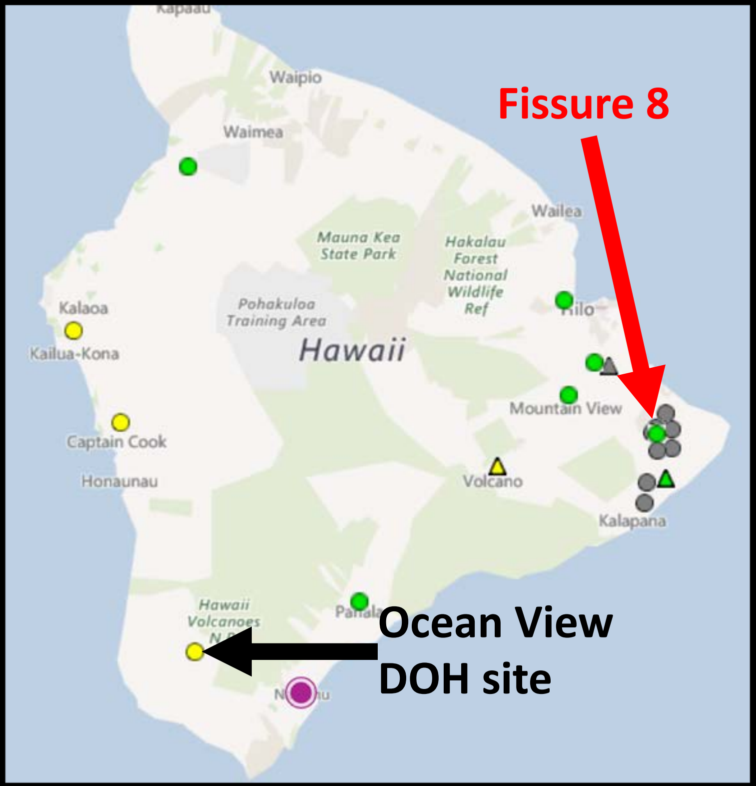
Examining similar examples for post-fertilization "blooms" as well as industrial NH_3 leaks.

Volcanic emissions of SO_2 and air quality

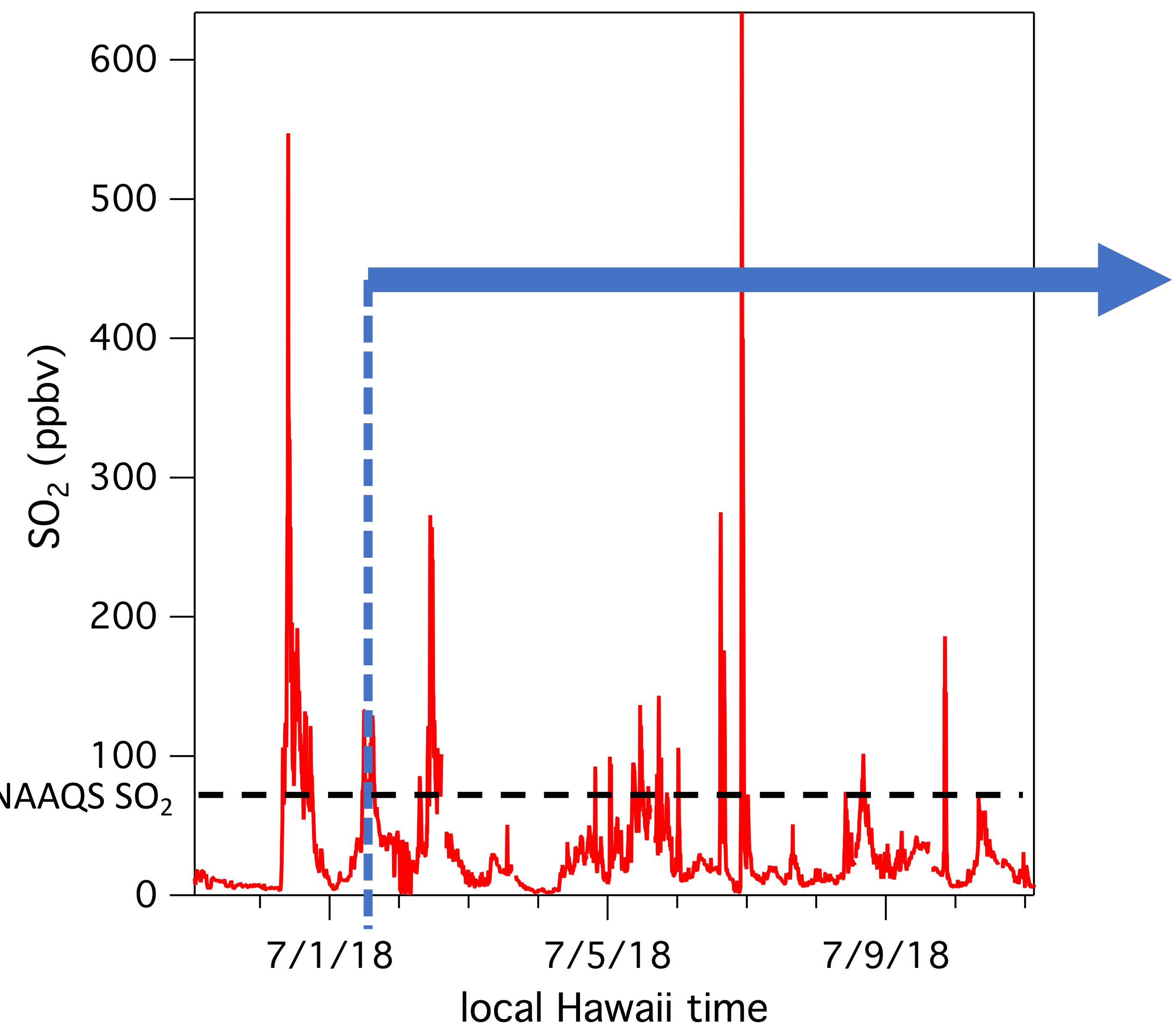
Use satellites to augment existing surface networks and emissions inventories

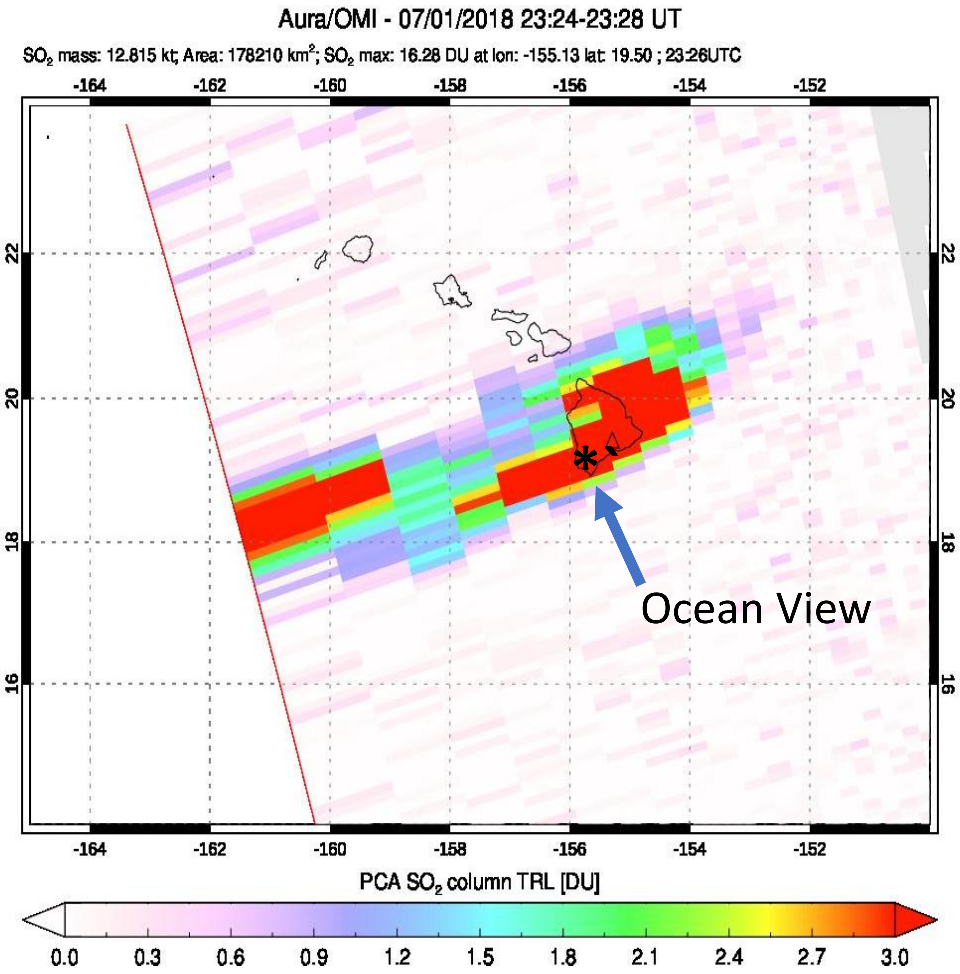
Derive exposure maps / datasets for subsequent health studies

[Daniel Tong, Susan Anenberg, Lok Lamsal, Mark Zondlo + …]



Ocean View surface monitoring station vs. Aura/OMI

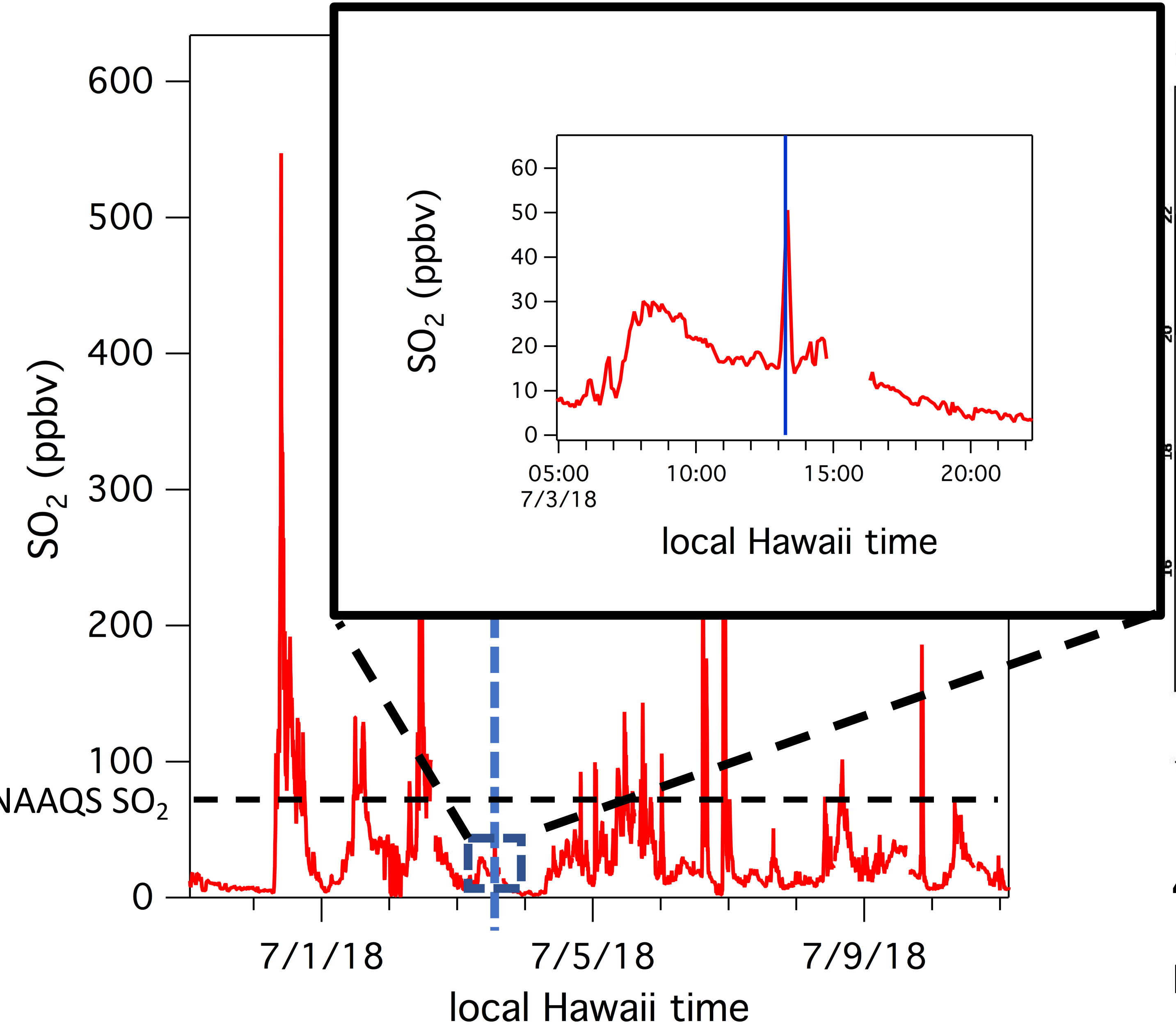


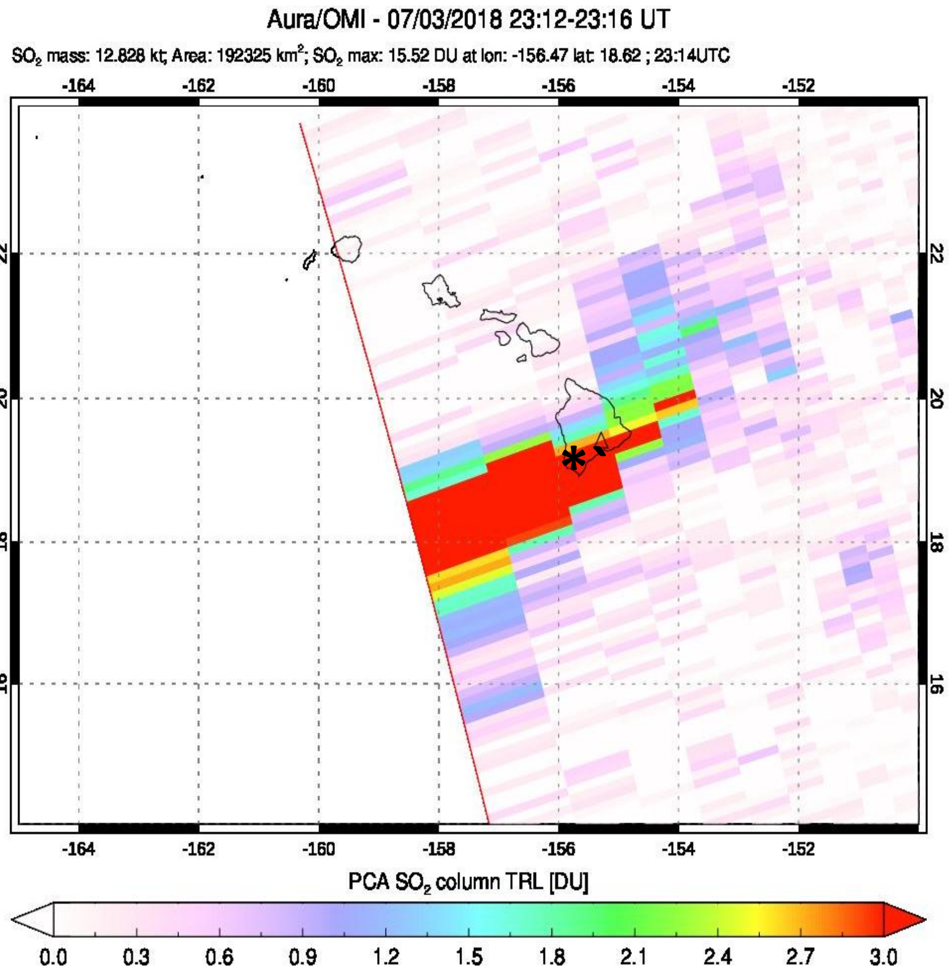


78 ppbv SO_2

Over NAAQS standard, SO_2 enveloping island

Ocean View surface monitoring station vs. Aura/OMI

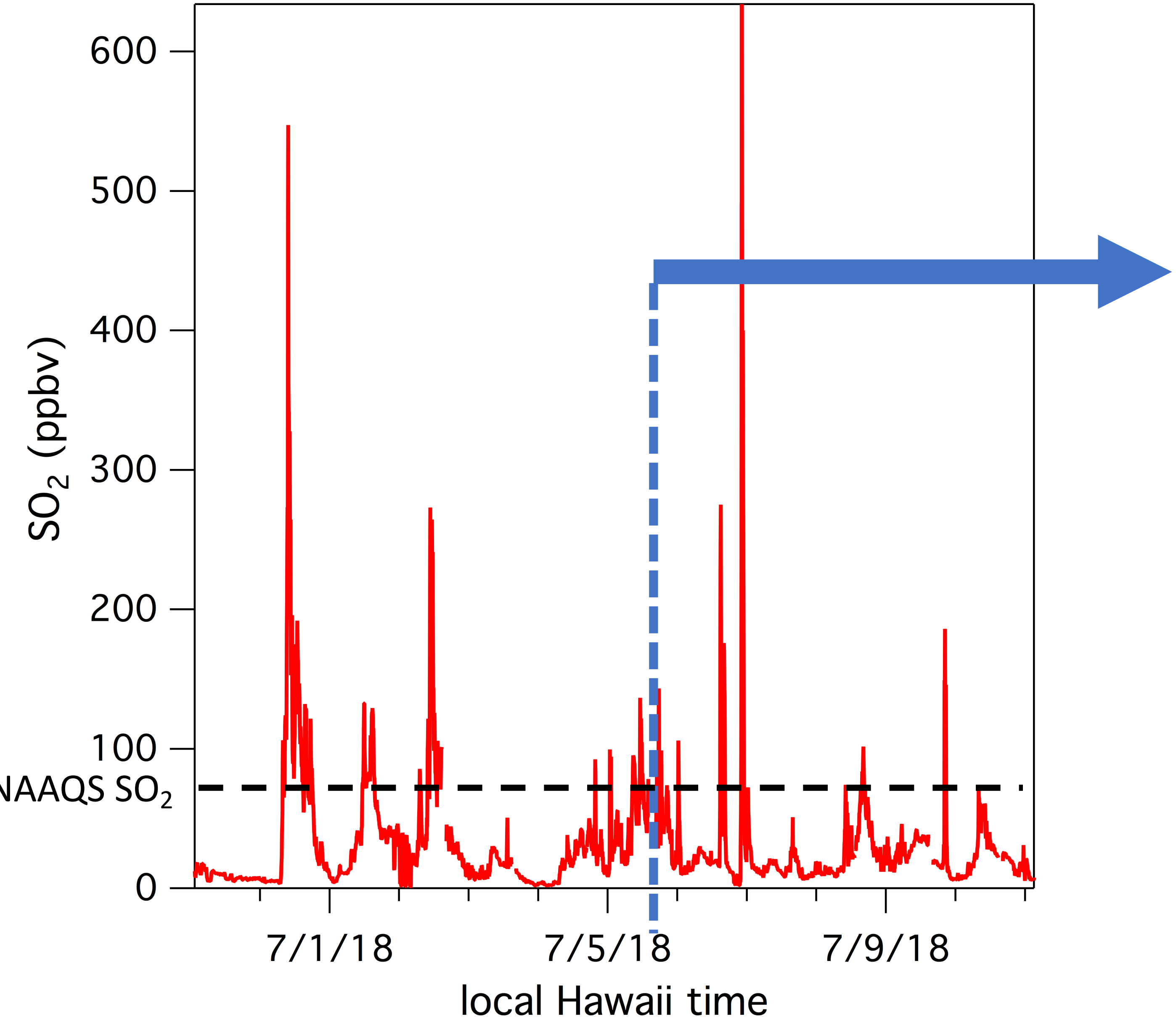




43 ppbv SO_2

Plume skirting edge of site

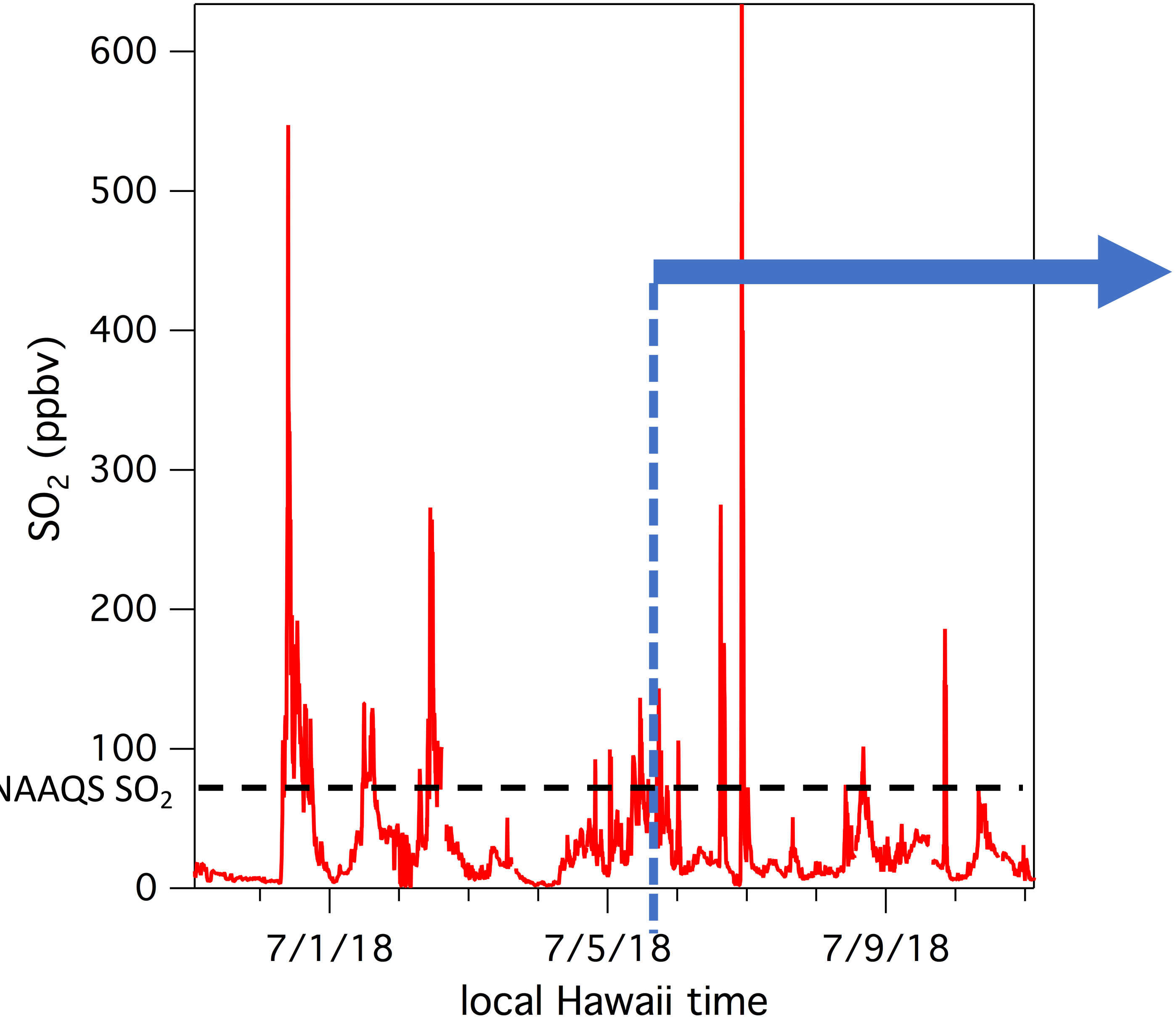
Ocean View surface monitoring station vs. Aura/OMI



No satellite measurements but view toward Ocean View (left side) vs. clearer air right side

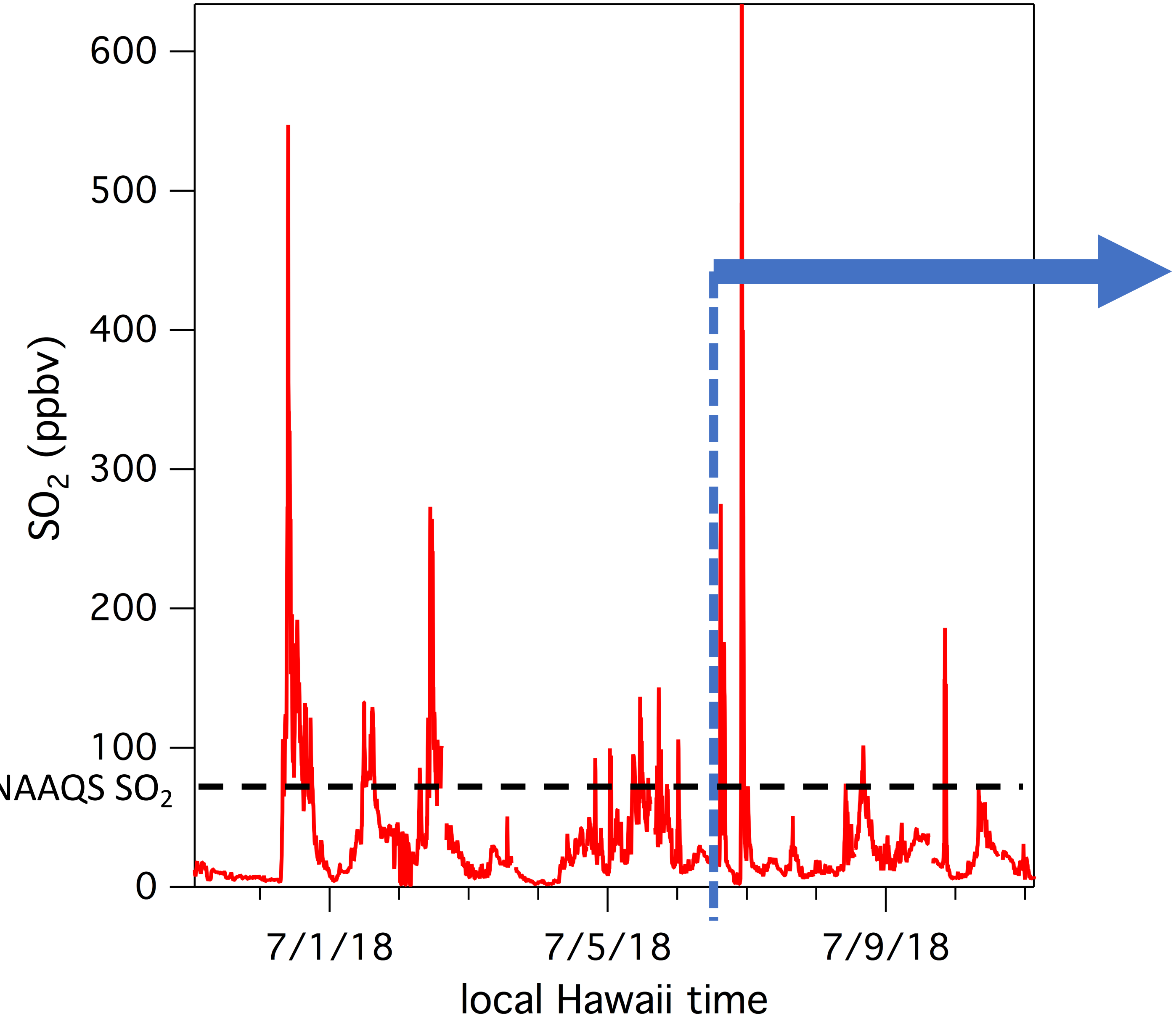
Visual gradient of vog along Mauna Loa

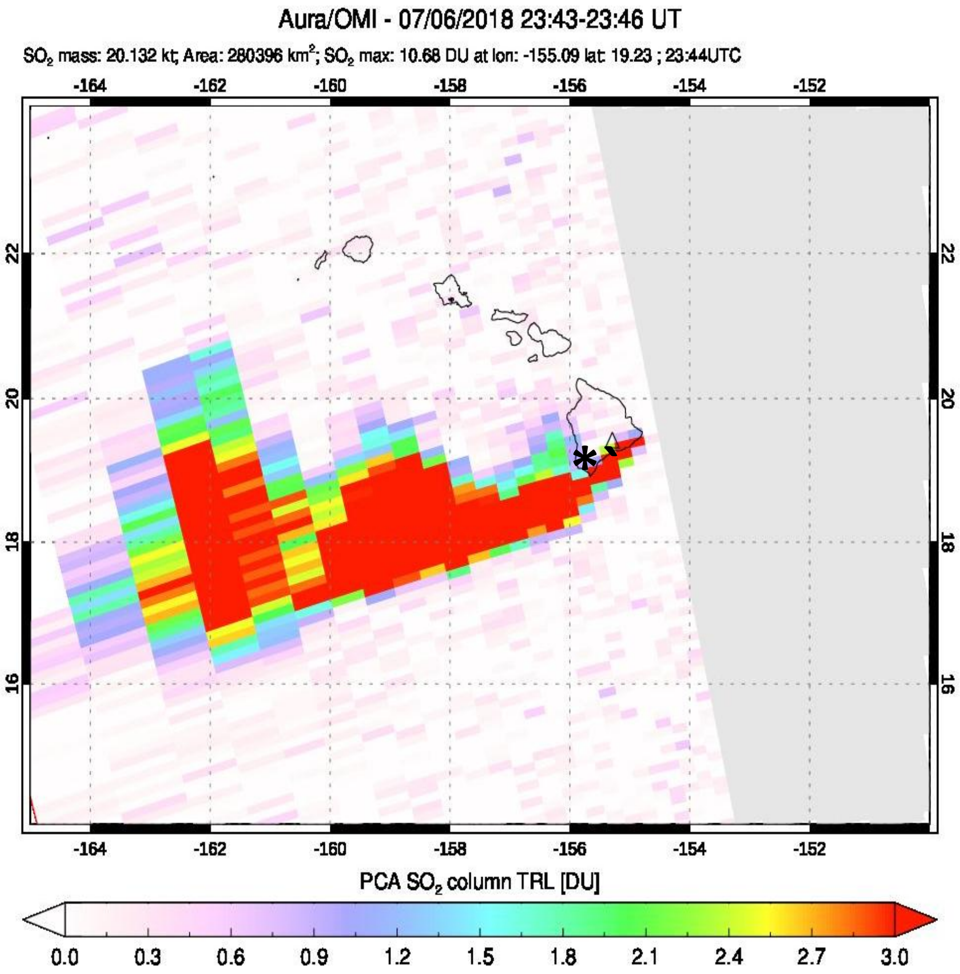
Ocean View surface monitoring station vs. Aura/OMI



Ocean View – visibility < 10 miles

Ocean View surface monitoring station vs. Aura/OMI

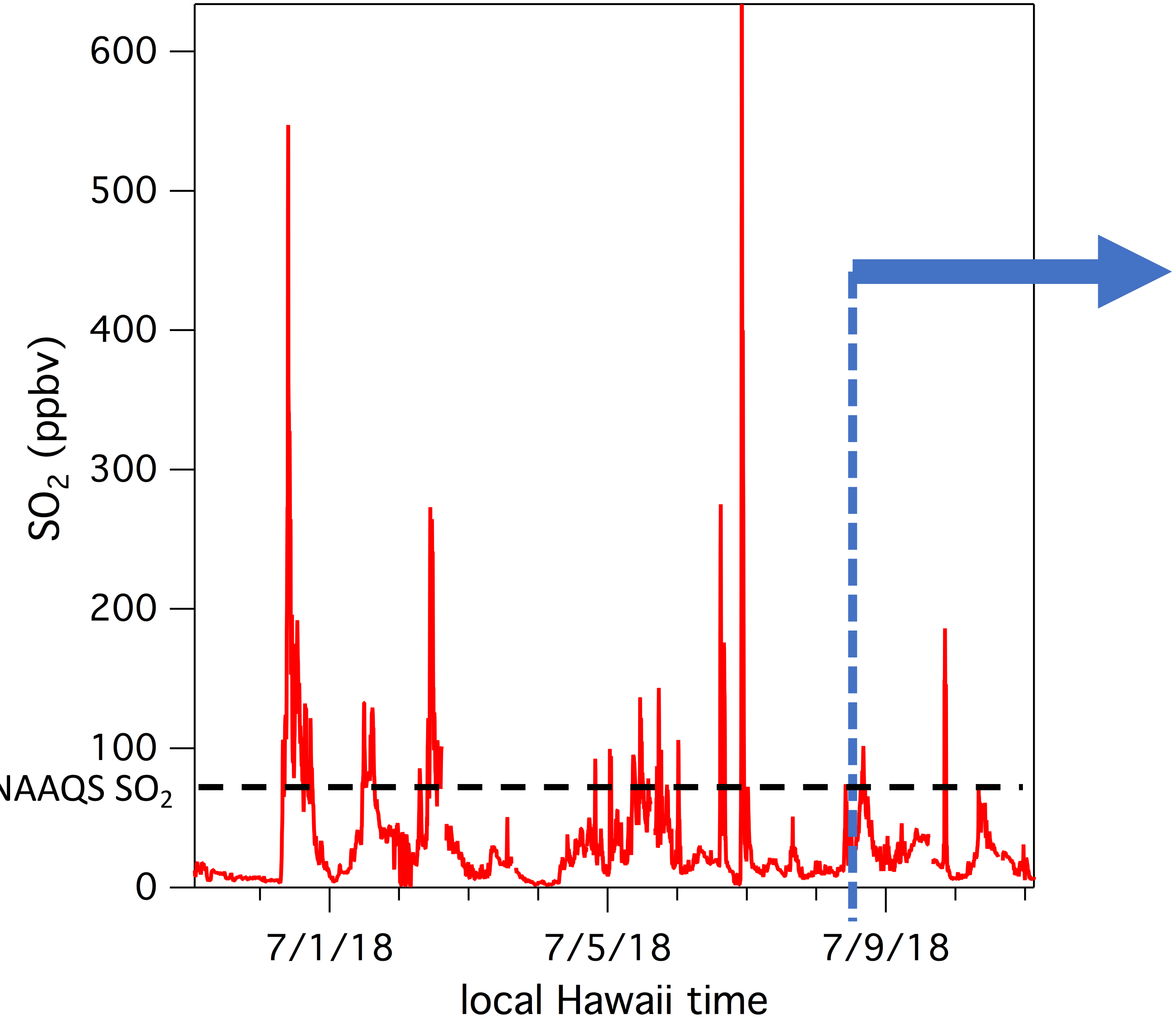


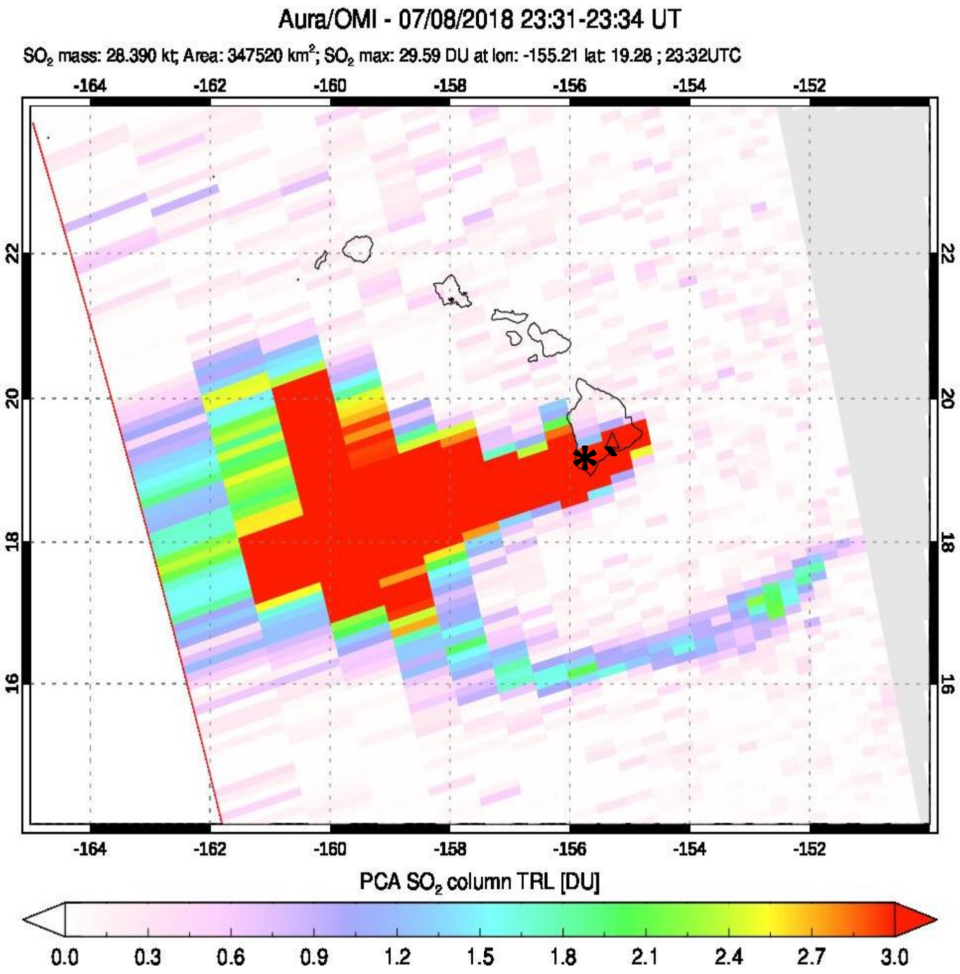


19 ppbv SO_2

Plume edge near site, high temporal variability

Ocean View surface monitoring station vs. Aura/OMI

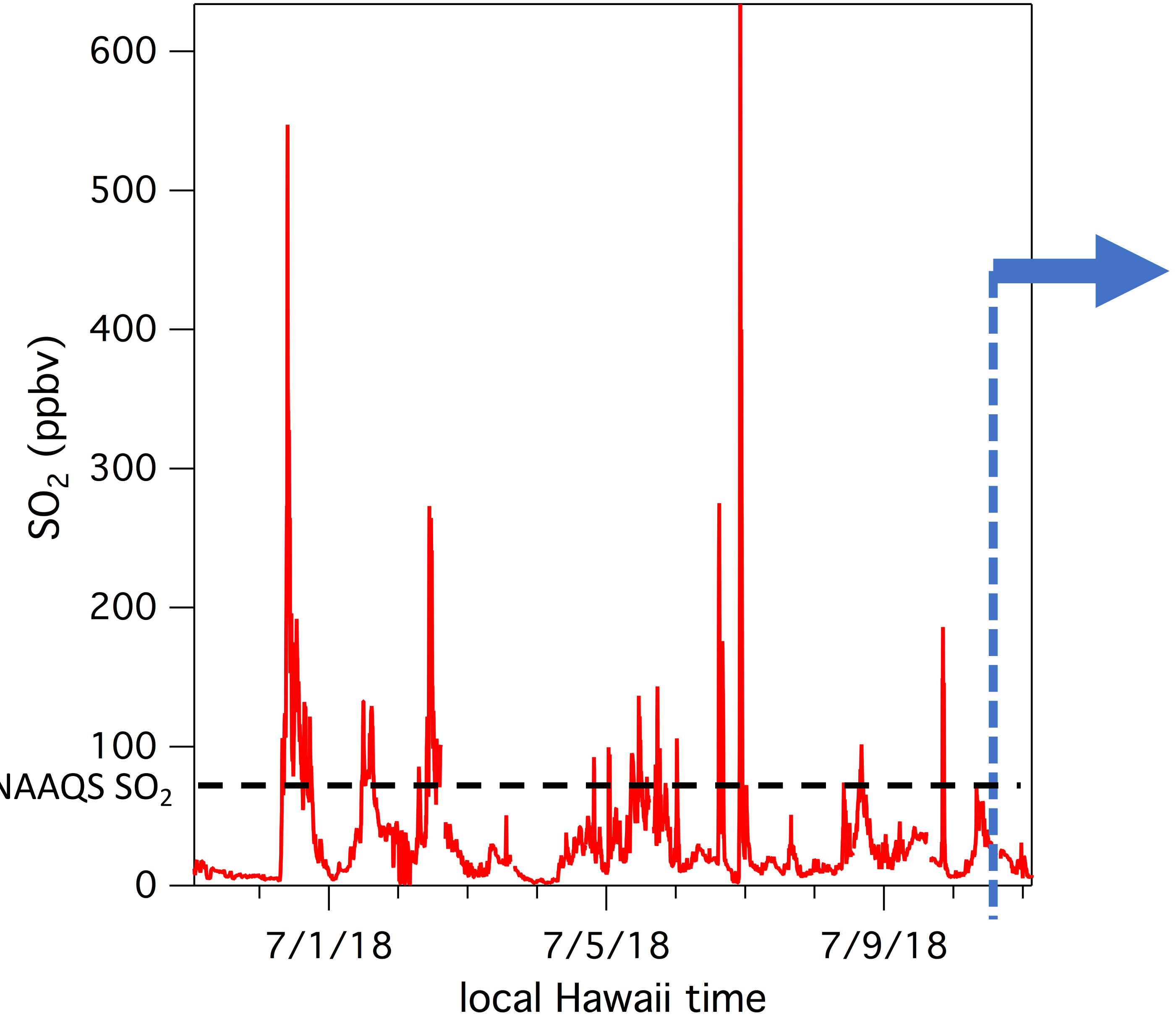


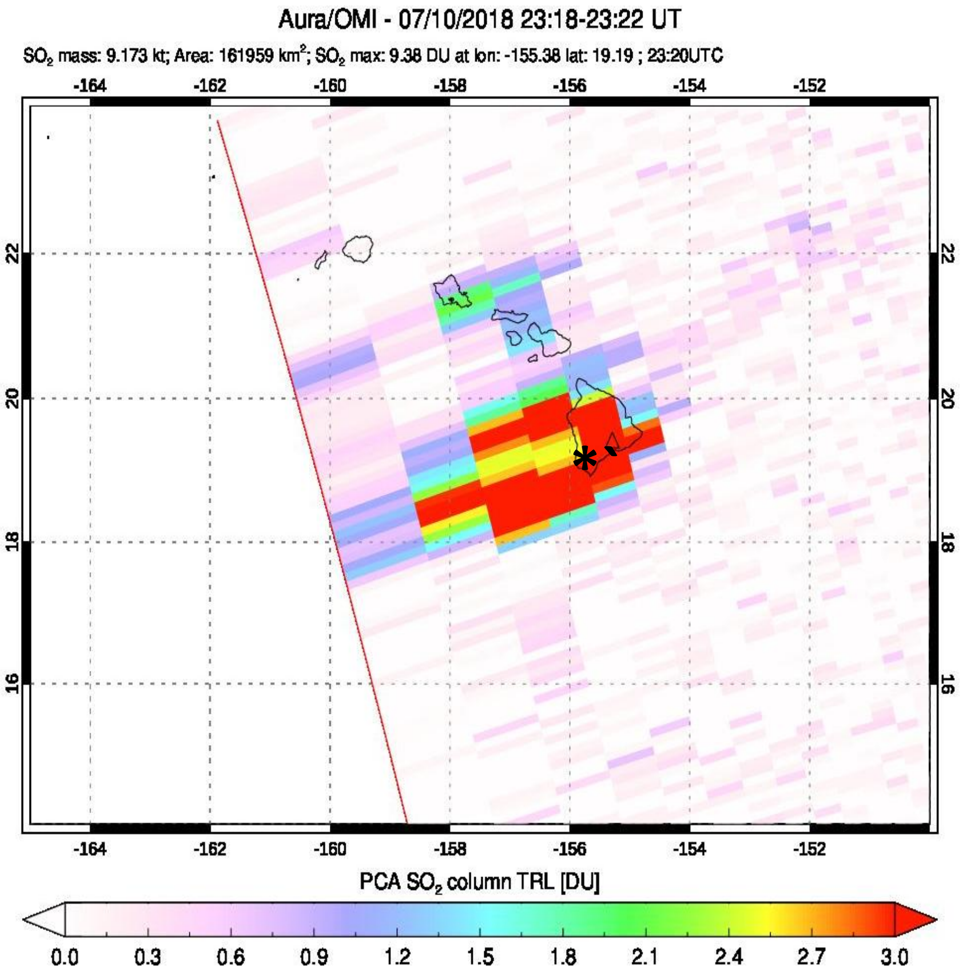


28 ppbv SO_2

Plume edge near site, high temporal variability

Ocean View surface monitoring station vs. Aura/OMI





28 ppbv SO_2

Site surrounded by higher levels

HAQAST volcanic response team

Deliverables to stakeholders:

- SO_2 emission estimates

- high-resolution spatial (12 km), temporal (hourly) maps of SO_2 and PM2.5 for big island
  - satellite: SO_2, aerosol optical depth
  - surface: AirNow stations, EPA SO_2/H_2S network, Kohala/MIT, mobile monitoring
  - model: High-resolution WRF + CMAQ with chemistry

- general guidance for use of satellite products during eruptions

- explore applications for epidemiology studies

Deliverable to public:

- consolidate air quality information on common website

Potential stakeholders:

Tom Moore, Western Regional Air Partnership
Seeking to involve Heatlh / Air Quality to Hawaii

<u>Emerging HAQAST team</u>
Daniel Tong
Susan Anenberg
Lok Lamsal
…. (others welcome)
Mark Zondlo

<u>Quantify volcanic emissions</u>
Christoph Kern and Tamar Elias, USGS

<u>Air quality forecastding</u>
Pius Lee and Youhua Tang, NOAA Natl. Air Quality Forecast Capability

HAQAST

Year 2 Progress Update, PI Zondlo

Spatiotemporal variability of ammonia through syntheses of in-situ-, ground-based, and remote sensing measurements

- **Task 1: Validation of IASI, CrIS, AIRS NH_3 at pixel scale**
  - Completed for IASI – Zondlo et al., *JGR* manuscript in prep.
- **Task 2: Spatial variability**
  - Oversampling algorithm developed for high-resolution maps of NH_3 to compare to emission inventories
    Sun et al., *ACP* submission expected, Aug. 2018
- **Task 3: Temporal variability**
  - Monthly maps of NH_3
  - Fertilization, episodic emissions (days-weeks)
  - US spatial/temporal/inventory comparison, in prep.

6 invited talks, 3 stakeholder presentations (CDPHE, CARB, EPA)

Trends TT (Duncan/West)

- Monthly trends of NH_3 over mid-Atlantic/NE US
- Comparison to AMoN trends

Hi-Res TT (Kinney)

- 50 transects of across Manhattan for PM2.5
- consistent with low-cost sensor network for spatial gradients

SIP TT (Fiore)

- 2-page overview on use and availability of satellite NH_3

Satellite NH_3 and SO_2 are critical for improved emissions

Example #2: AMoN site in North Carolina

• site located in the middle of a field

How representative is this site during fertilizer events?

Episodic emissions

- wildfires, fertilization large but short-lived events (~ days to a week)

- monitoring sites often not located near these sites

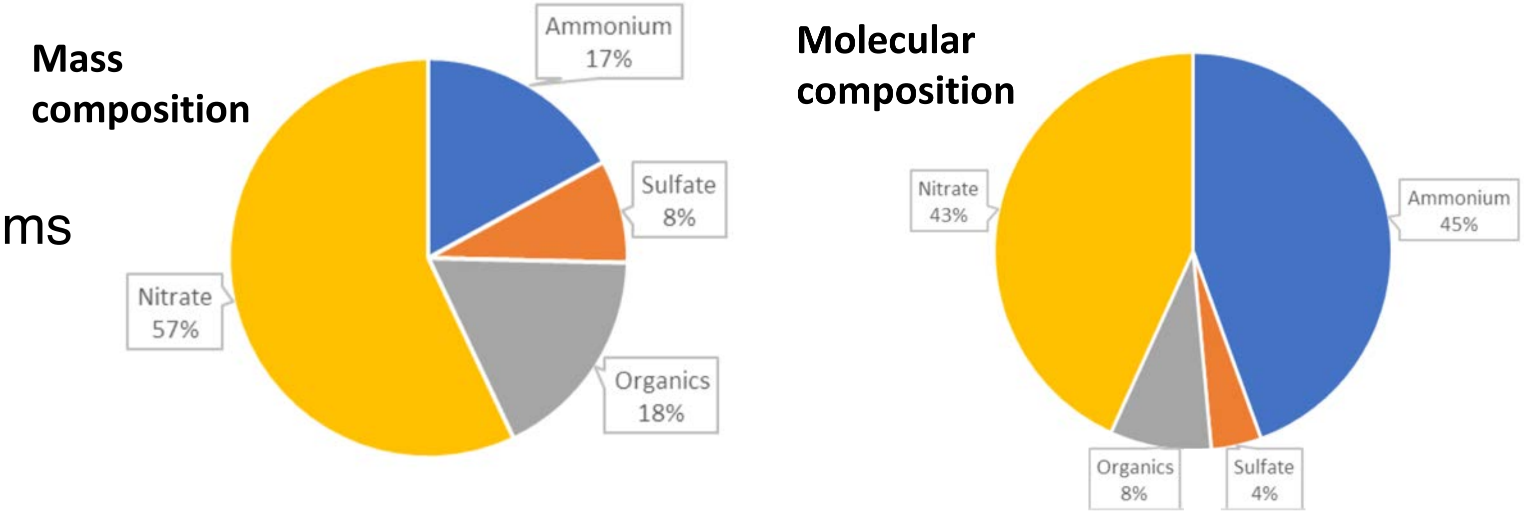
- AMoN network require two-week measurements (integrated), so capturing events is challenging

Why should we care about ammonia (NH_3)?

- important aerosol precursor for particulate matter
  - human health
  - regional haze
- nitrogen deposition in sensitive ecosystems
- climate effects

  (NH_4^+ aerosol scattering - **cooling**)

  (conversion to N_2O in soils – **warming**)



San Joaquin Valley, CA (AQS observation, 2011)

There is a general lack of measurements, which challenges our ability to address these issues