

Ammonia (NH₃) Distributions and Recent Trends by 14-year AIRS Measurements

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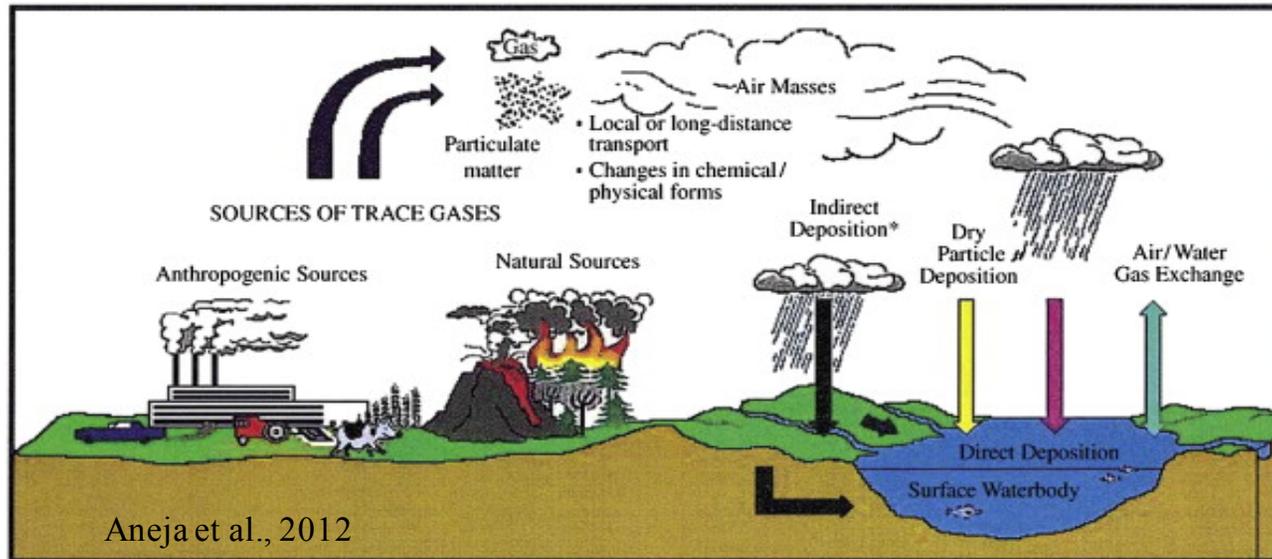
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* Published in **GRL: Increased Atmospheric Ammonia over the World's Major Agricultural Areas Detected from Space**

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Why Ammonia (NH₃)

- affect air quality, ecosystem, and climate, primarily from anthropogenic sources



Sources:

- Fertilizer use for crop production;
- Animal feeding operations;
- Emission increase with:
 - Nitrogen storage and pH of soils;
 - Surface temperature exponentially;
 - Soil moisture, etc.
- Biomass burning and volcanoes.

Sinks:

- Dry and wet deposition (soil acidification and eutrophication);
- Convert to particulate ammonium by reacting with sulfuric and nitric acids, arising from SO₂ and NO_x.

Ammonia - precursor gas of PM_{2.5}

- Precursor gases for PM_{2.5} (by secondary inorganic aerosols - a large portion of PM_{2.5}):
 - ✓ Sulfur dioxide (SO₂);
 - ✓ Nitrogen oxides (NO_x);
 - ✓ Ammonic (NH₃);
- Only NH₃ is not regulated;
- Ammonia is the limiting species in PM_{2.5} formation, regulating SO₂ and NO_x alone cannot determine the fate of PM_{2.5};
- Meteorological conditions (wind, rain, temperatures, etc.) affects the concentration of ammonia gases.



Why Satellite Remote Sensing

- *Ammonia in situ measurements are rare, global coverage is impossible.*
- Satellite measurements with daily and large global coverage are challenging and have been lacking partly because *the lifetime of NH₃ is relatively short* and partly because it requires high sensitivity for the retrievals that can be only obtained from areas with high thermal contrasts near the surface (Clarisse *et al.*, 2010).
- AIRS (Atmospheric InfraRed Sounder) has the advantages:
 - *afternoon overpasses (1:30pm)* are best correlated with the daily emission peak time and during the daily period with the highest thermal contrast.
 - AIRS *large coverage* with wide swaths and cloud-clearing provide *daily NH₃ maps*.
 - The *15-year data records* makes AIRS the best sensor for NH₃ trends and variability studies (to date).

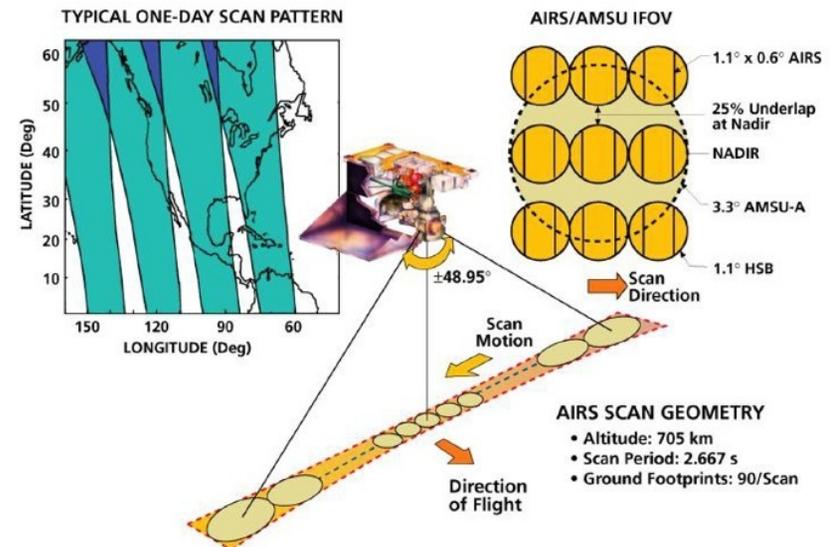
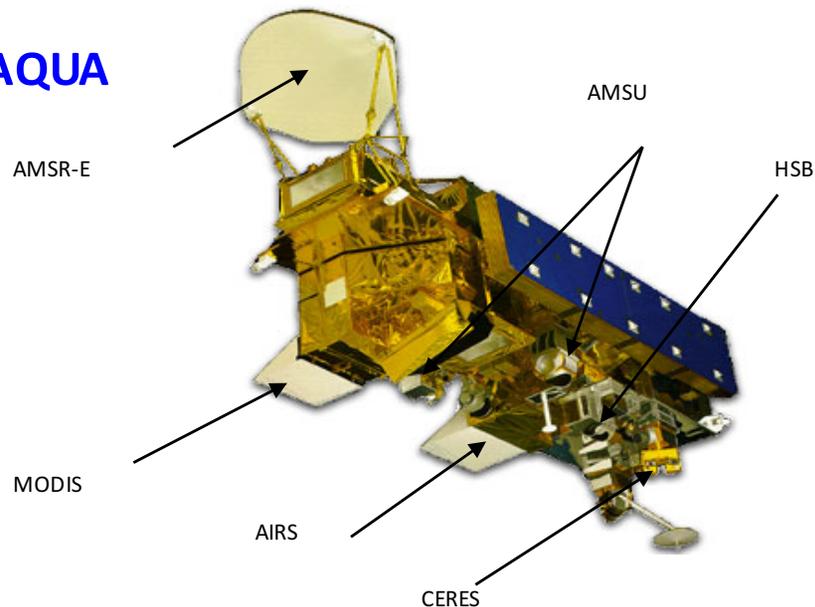
Atmospheric InfraRed Sounder (AIRS)

Launched May 2002; afternoon (1:30pm) overpass; daily global coverage



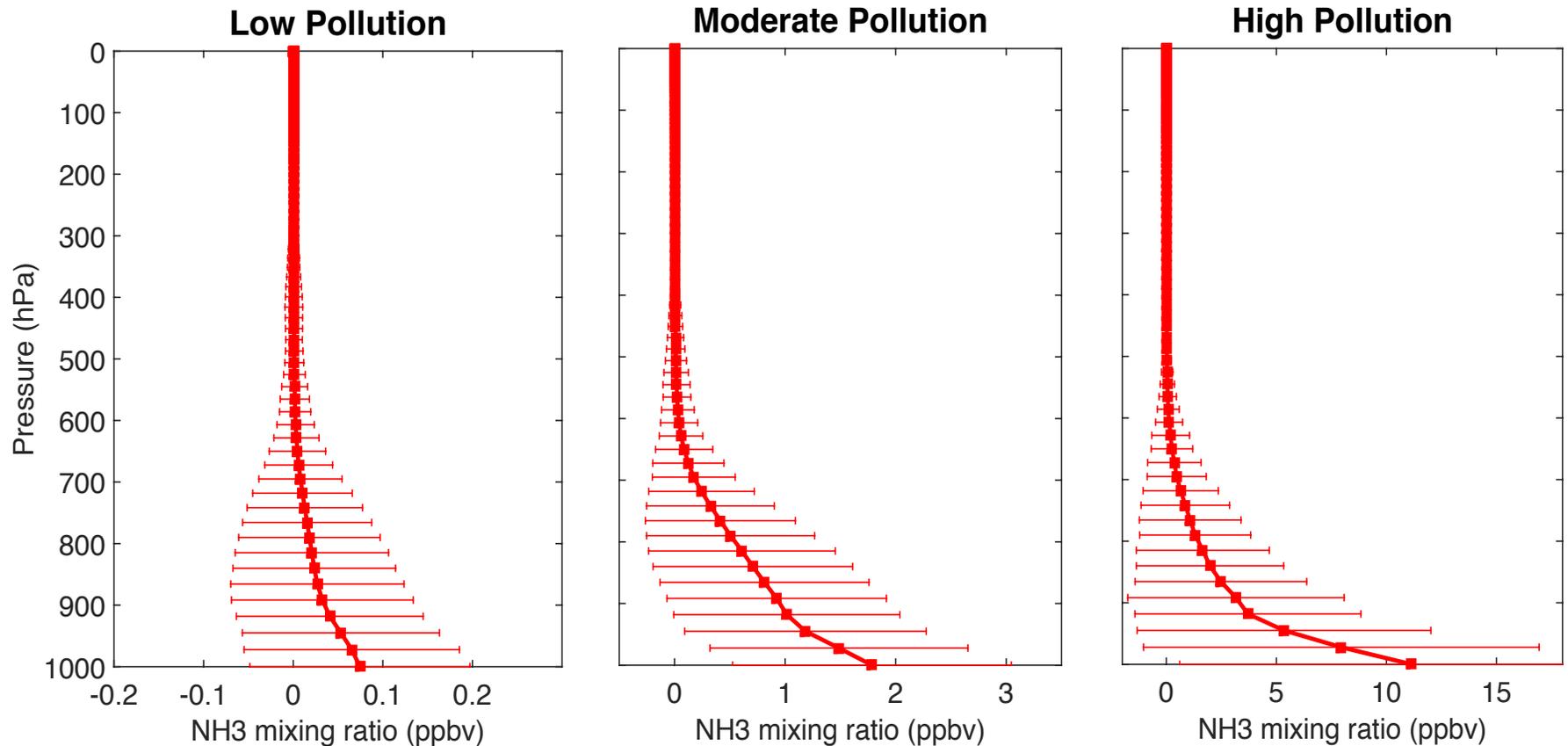
- A grating spectrometer originally designed to improve weather forecast and now also used for climate and air quality studies.
- Spectral resolution at $1/1200$ ($\sim 0.5 \text{ cm}^{-1}$)
- Covers 650-2665 in three bands with a total of 2378 channels
- Spatial resolution 13.5 km^2 (with retrievals at $\sim 45 \text{ km}^2$)
- Wide swaths and cloud clearing provide daily global coverage
- Very high Signal-to-Noise accuracies of 1K over 1 km-layer.

AQUA



AIRS NH₃ Algorithm

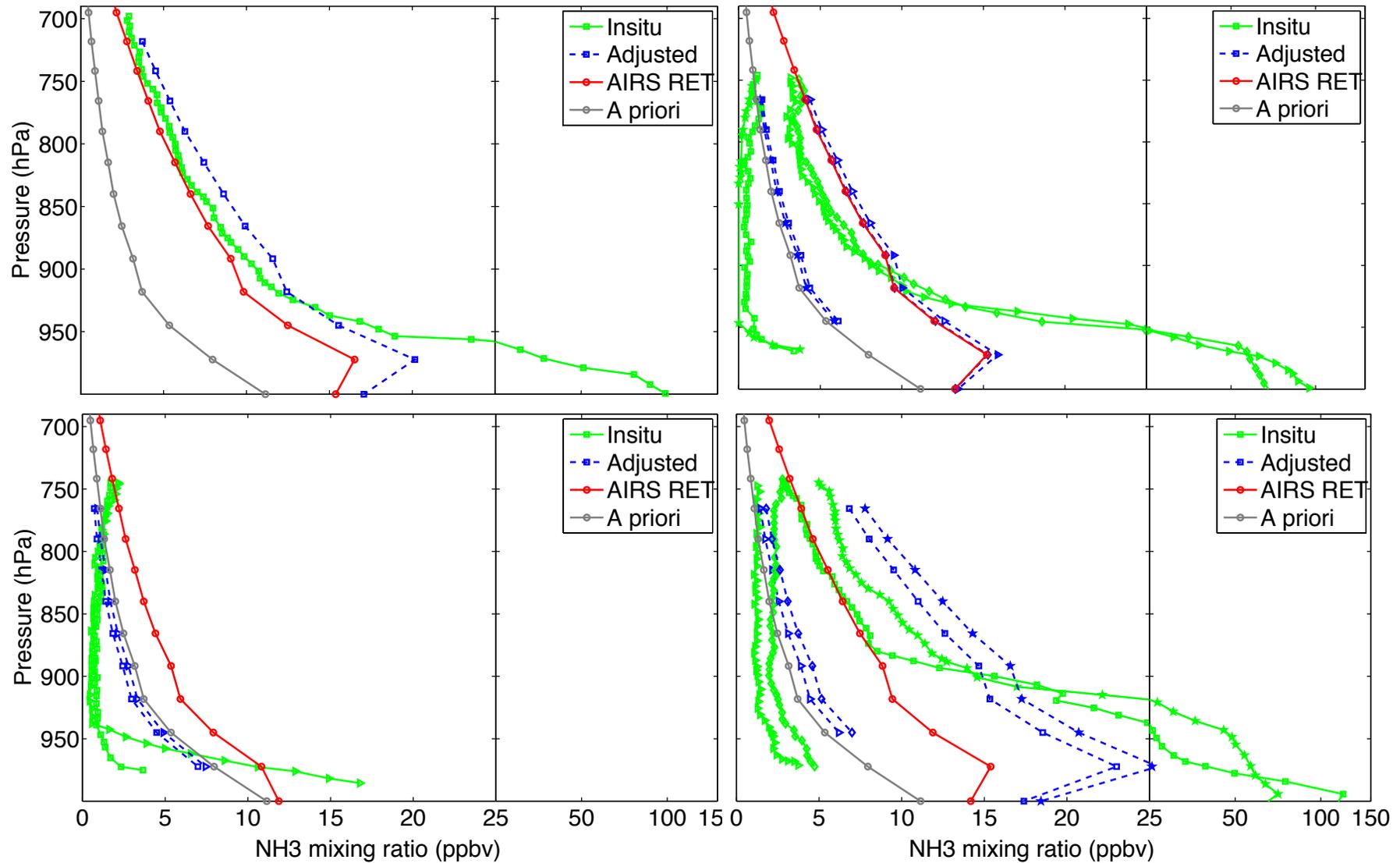
- Globally one set *a priori* (GEOS-chem). Variation in the retrievals are from measurements.
- Select *a priori* levels based on brightness temperature differences



Validation vs CRDS/Picarro in DISCOVER-AQ CA

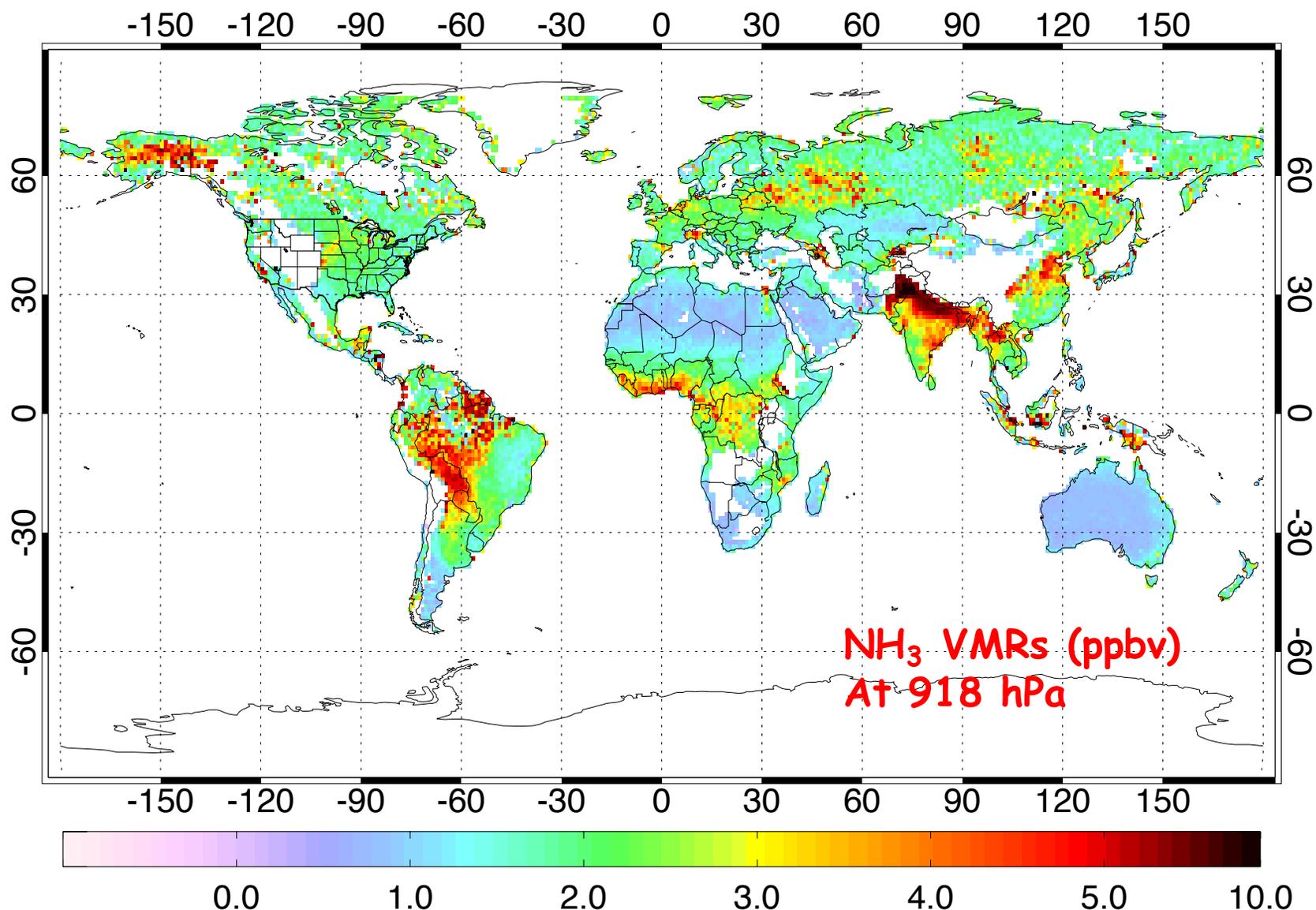
CRDS/Picarro Spiral Profiles Only - 01/16 to 02/06, 2013

(data courtesy of Co-author J. Nowak)



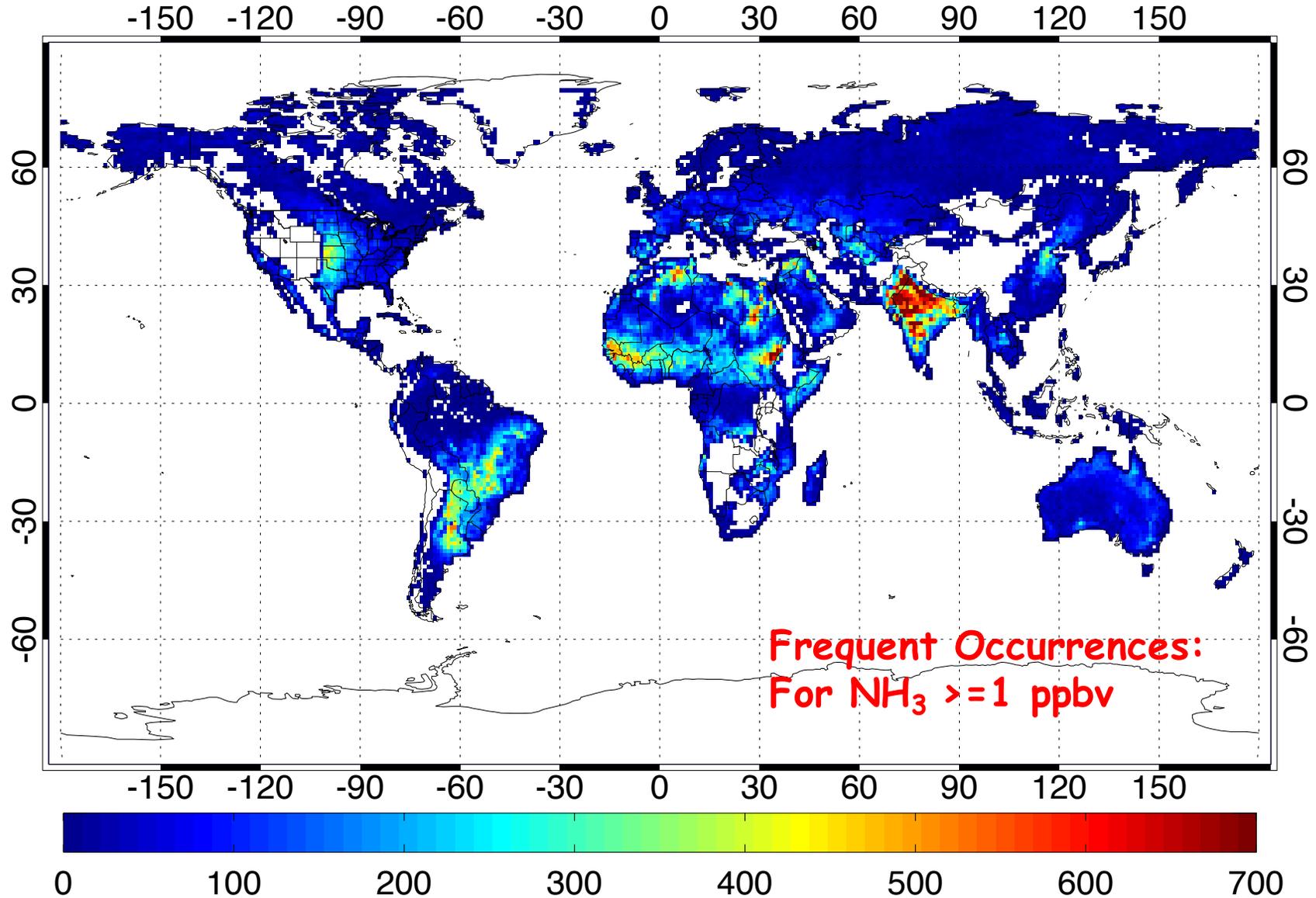
- Gray - a priori; Red - retrievals; Green solid - in situ; and Green dashed - convolved in situ.
- AIRS L2 pixel sizes are ~45 km², can coincide with multiple in situ profiles.
- AIRS NH₃ measurements are most sensitive at 850-950 hPa layer.

Global NH₃ in 2002-2015

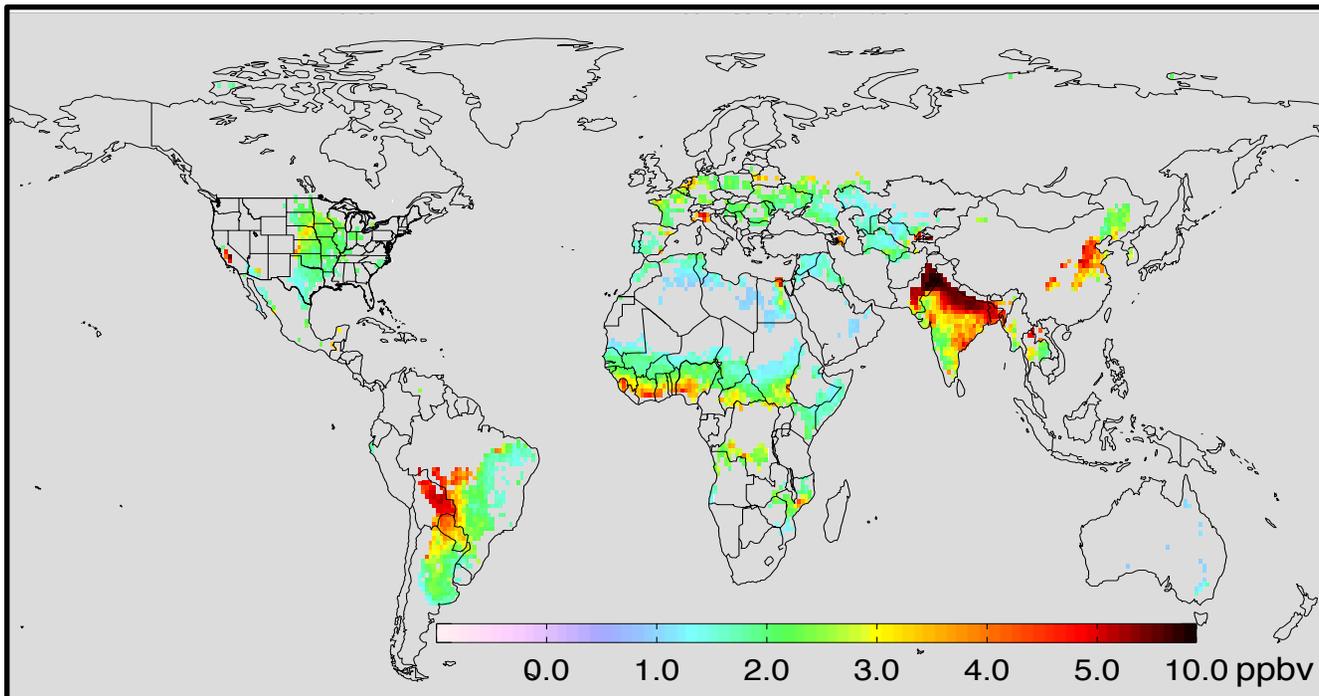


- High concentrations are mainly due to human activities and fires;
- Sources are seen in valleys (e.g., **San Joaquin Valley, California** in the U.S., the **Po Valley**, Italy, Fergana Valley, Uzbekistan, and the **Sichuan Basin** in China); Agricultural especially in irrigated lands (e.g., Azerbaijan, **Nile Delta** and near Nile River in Egypt, the Mid-West U.S., in **the Netherlands**, in Mozambique and Ethiopia, Africa, and especially the Indo-Gangetic Plain of South Asia).

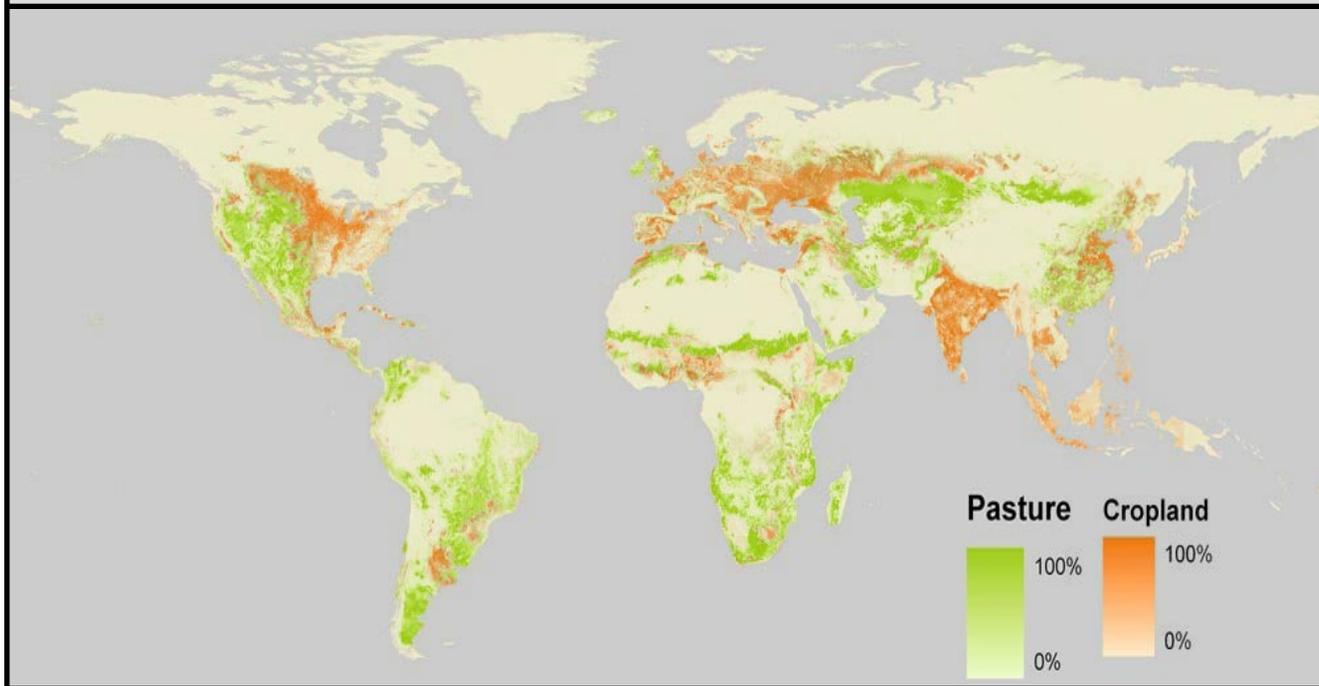
Global Frequent Occurrences in 2002-2015



Use occurrences of higher emissions (lower) to distinguish between the two major sources: agricultural (high VMRs & high frequencies); BB emissions (high VMRs & low frequencies).

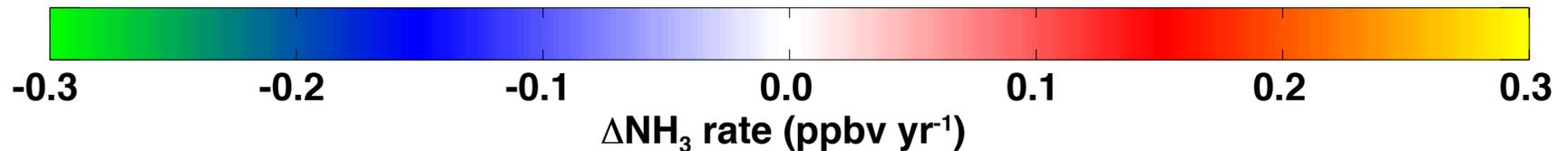
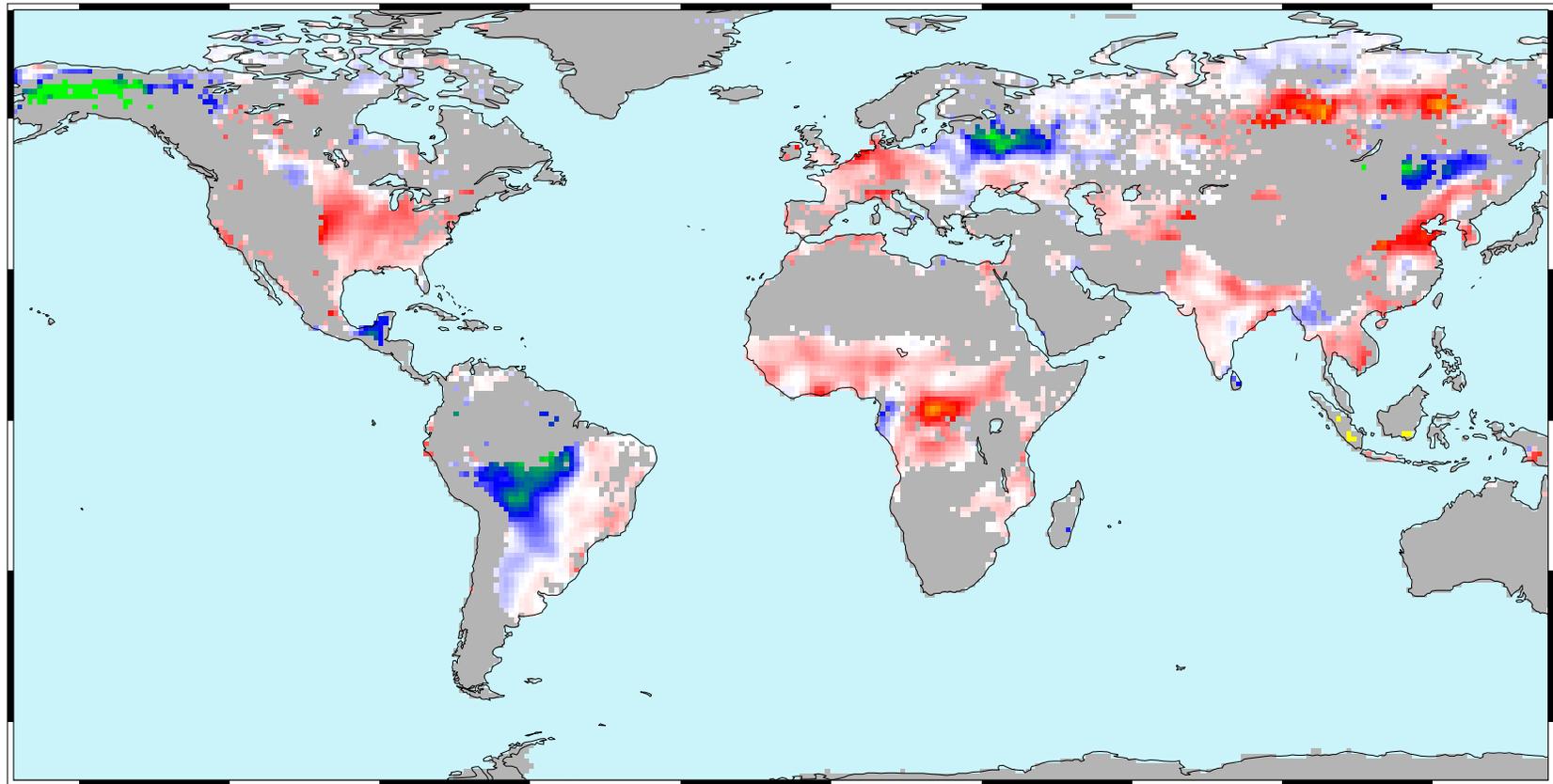


Top panel: The NH₃ VMRs from the persistent sources, i.e., ≥ 1.4 ppbv for more than 40 days;



Bottom panel: Pasture and Cropland Map (<http://OurWorldInData.org>)

NH₃ Trends - Last 14 years



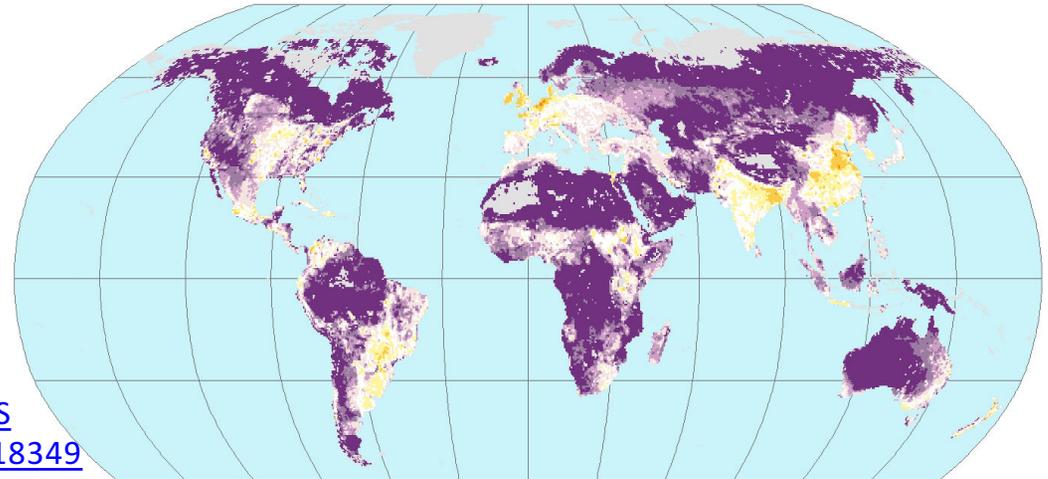
- Global trends in atmospheric NH₃ (i.e., VMRs at 918hPa for each 1x1 grid)
- Red-yellow colors represent increases due to agriculture emission increases and reduced scavenging by acid aerosols
- Blue-green colors represent decreases due to possibly reduced agricultural burning and fewer wild fires

NH₃ Increase - Fertilizer Applications

Global Nitrogen Fertilizer Application

Global Fertilizer and Manure, Version 1

Country /Region	Mean fertilizer use (TgN yr ⁻¹) [trend] 2002-2013
US	11.5 [+0.7% yr ⁻¹]
EU	11.0 [-0.3% yr ⁻¹]
China	31.2 [+2.7% yr ⁻¹]
S. Asia	18.8 [+3.6% yr ⁻¹]

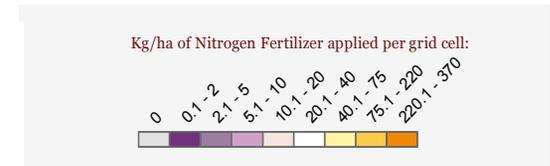
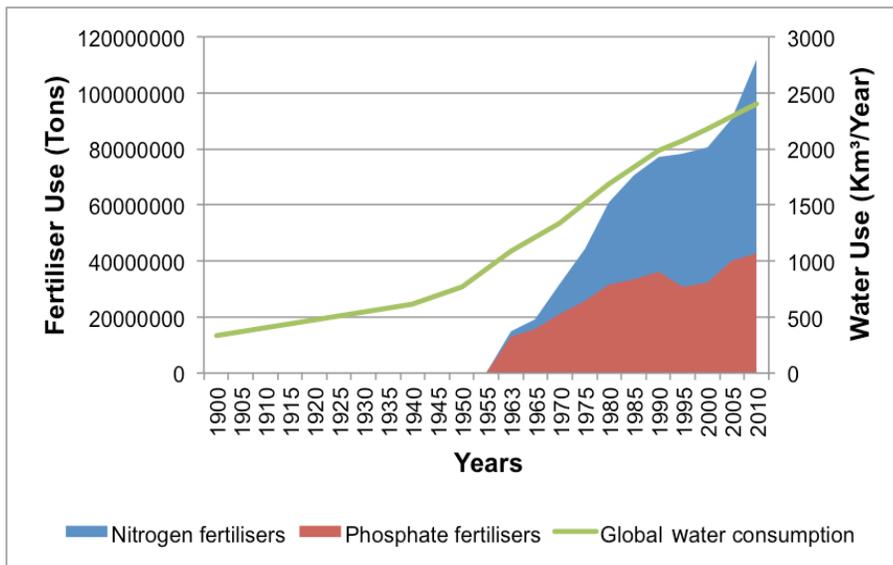


Robinson Projection

<http://data.worldbank.org/indicator/AG.CON.FERT.ZS>

<http://www.ars.usda.gov/Services/docs.htm?docid=18349>

Courtesy of Russ Dickerson

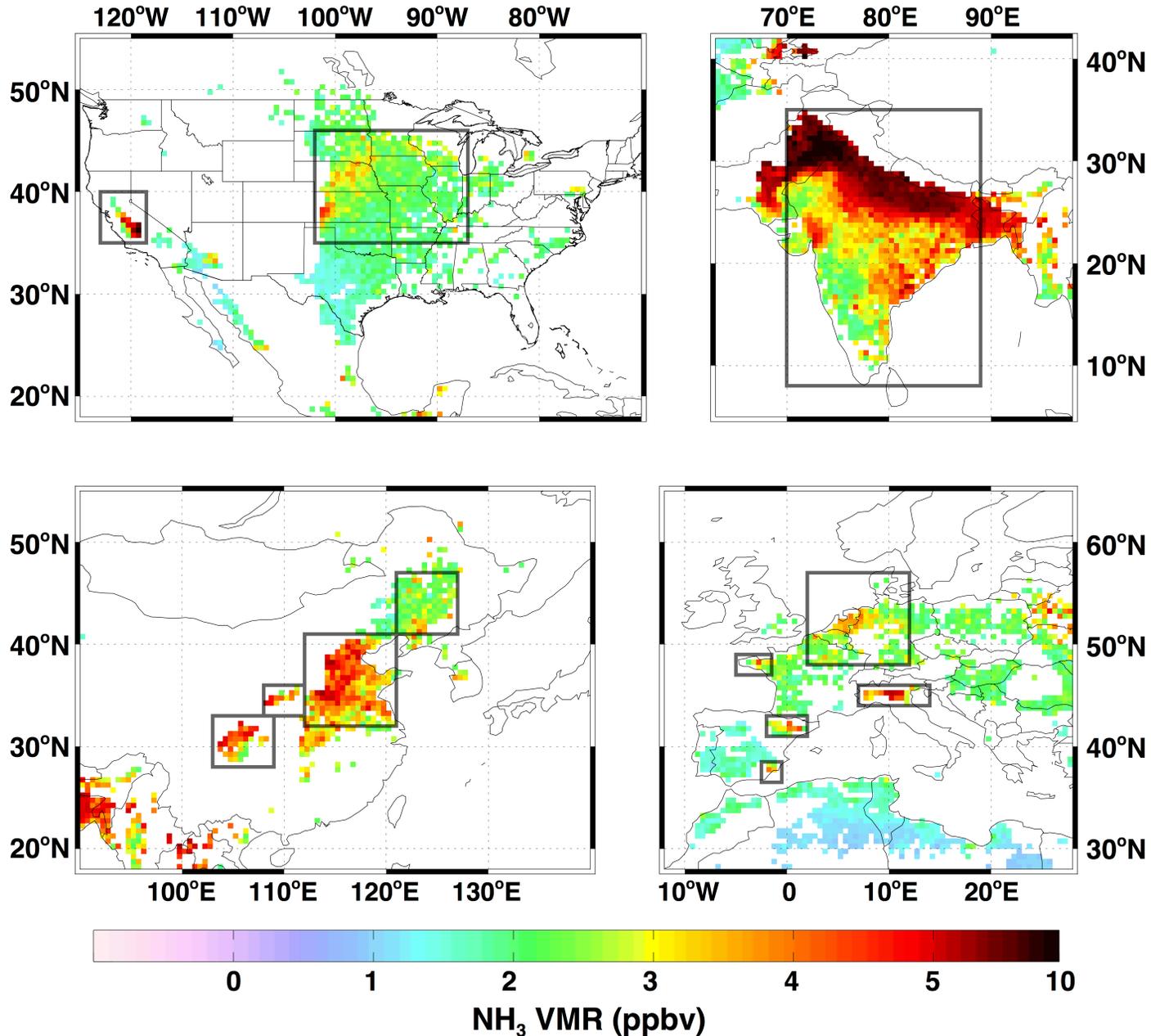


<http://sedac.ciesin.columbia.edu/>

<https://freshwaterwatch.thewaterhub.org/>

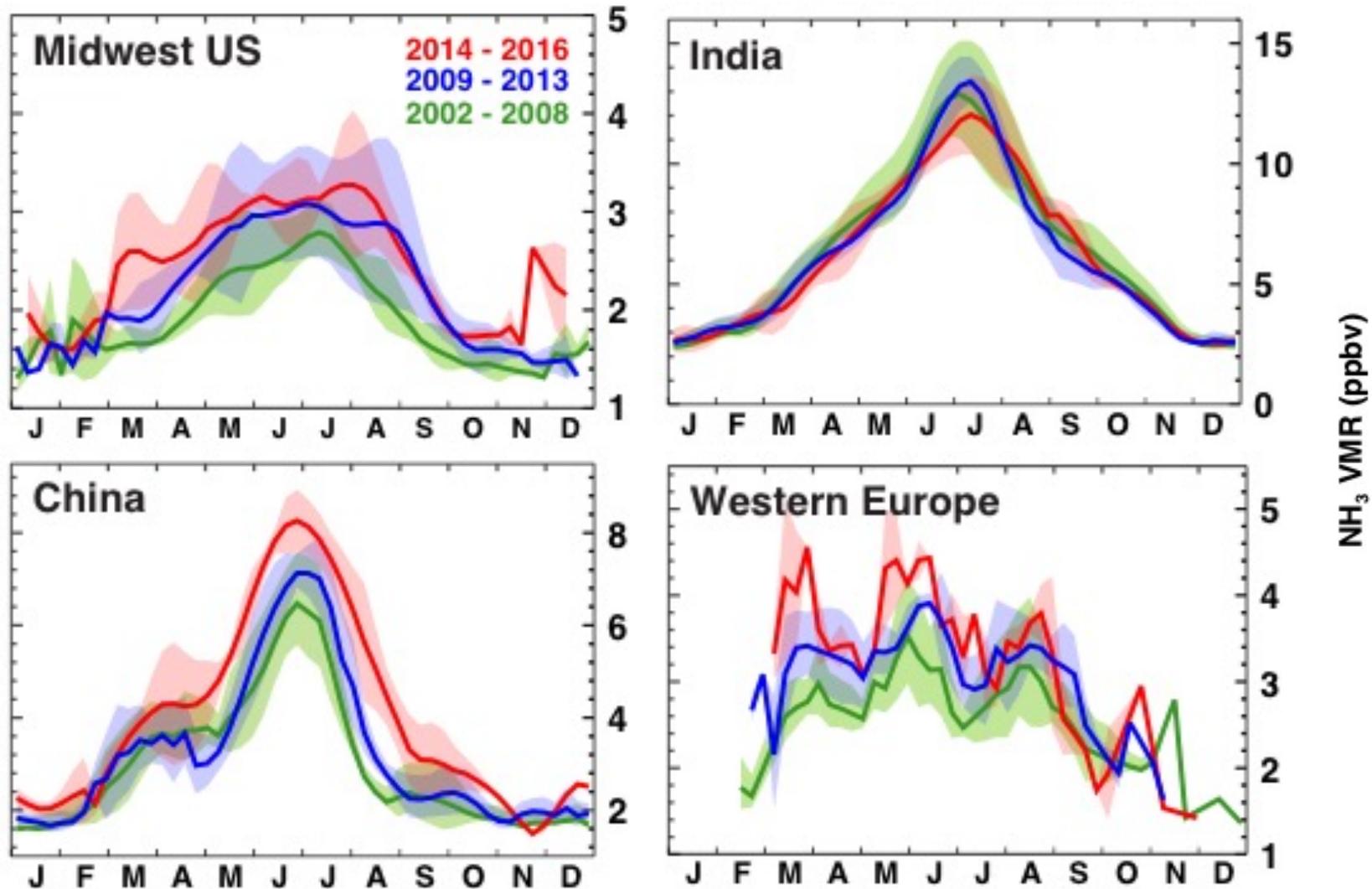
NH₃ over USA, China, India, and Europe

Using high concentration and high frequencies



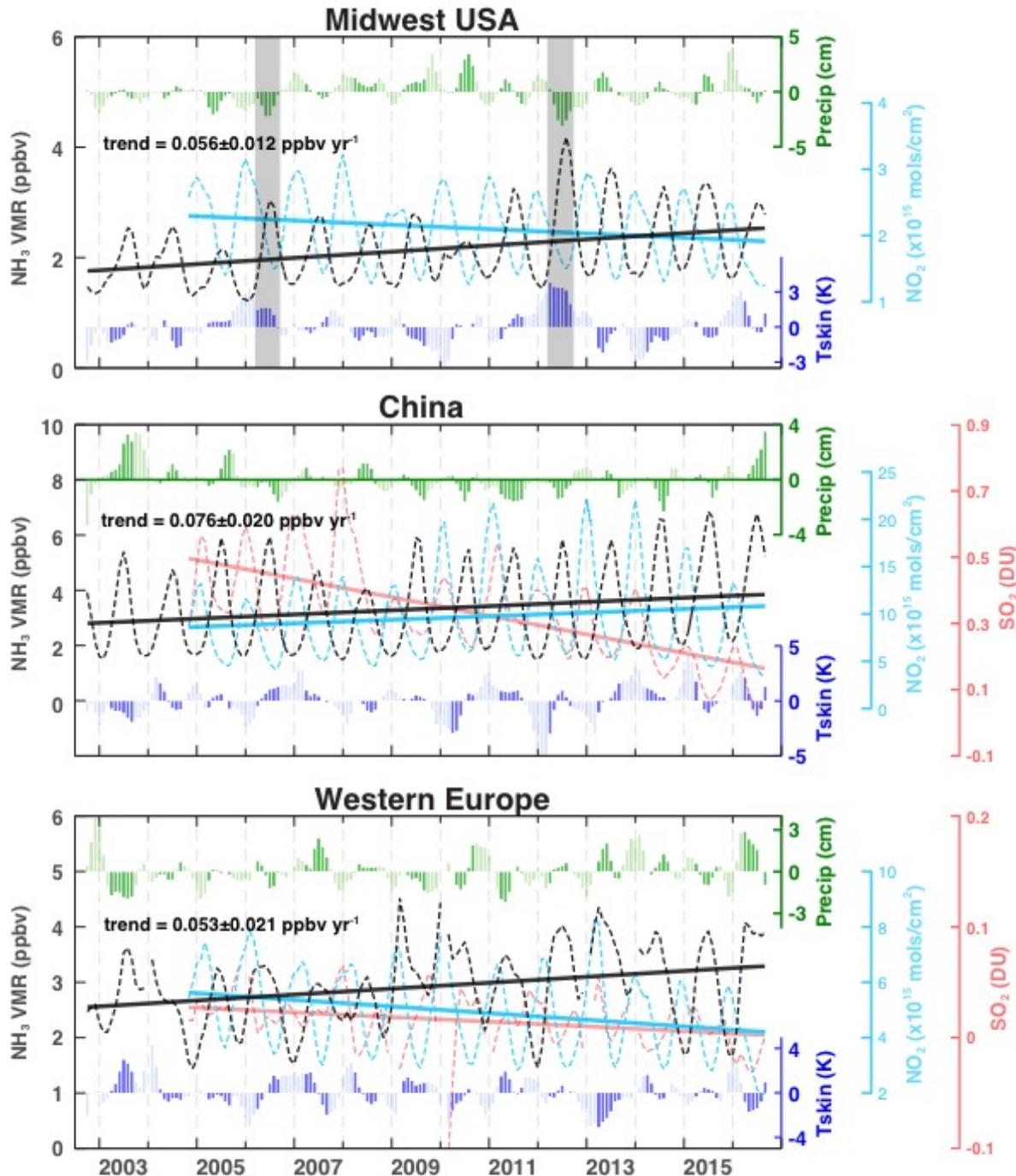
AIRS NH₃ Seasonal Variation

- over USA, China, Europe, and S. Asia



- The highest NH₃ concentrations in average occur in South Asia, and China. Note scales.
- NH₃ in India seasonal variation are broad and no obvious increasing/decreasing trends;
- NH₃ for USA, China and Europe have increased, with peaks in both spring and summer;

AIRS NH₃ vs OMI NO₂ for US (top), SO₂ for China (middle) and NO₂ for Western Europe (lower)



All show increasing NH₃ trends (black) 2002-2016.

Decreased SO₂ largely explains the NH₃ increases in Midwest U.S. (not shown), China, and Europe.

OMI NO₂ decreasing explains winter NH₃ increasing over the US and Europe.

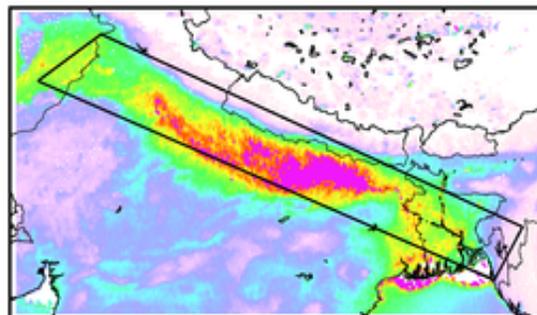
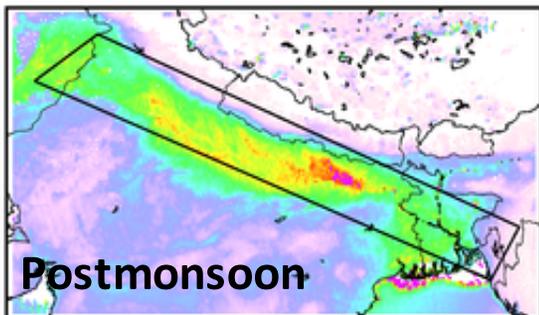
Meteorological conditions also affect NH₃ concentrations (high surface temperatures and low precipitation), see shaded anomalies in the top panel.

ECMWF surface skin temperatures show increases over the US and China can possibly link climate change to the increased NH₃ emissions.

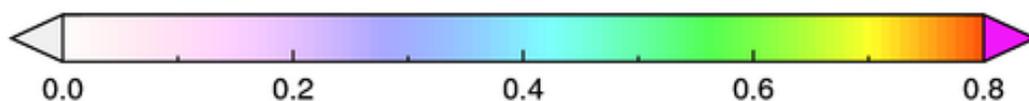
South Asia Aerosols Trends

2003-2007

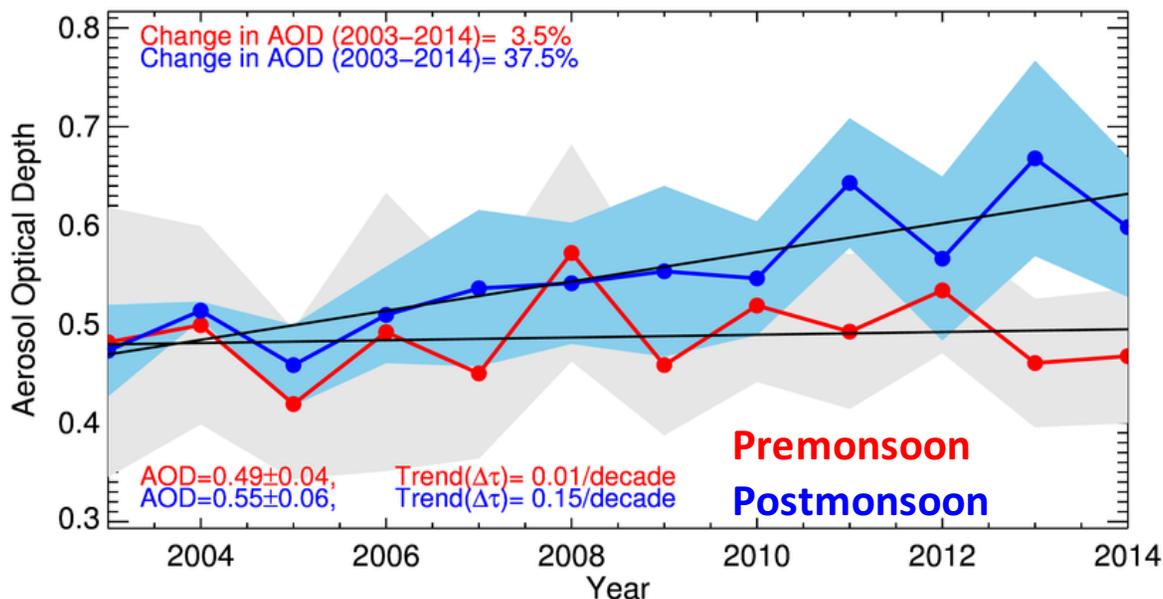
2008-2014



Aerosol Optical Depth at 550 nm



IGP



Courtesy of NASA MODIS team

- No obvious NH_3 increased in the AIRS observations over South Asia, while the fertilizer usage has increased;
- Recent increases in SO_2 and NO_x from uncontrolled coal combustion and other sources;
- Greater conversion of gaseous NH_3 into particulate sulfates and nitrates.
- Dust influence in premonsoon and sea salt during monsoon, more fine mode aerosols in postmonsoon.

Way Forward

- Continued NH₃ data record



AIRS - Atmospheric InfraRed Sounder
Grating spectrometer
166 kg. 256 W
13.5 km FOV at nadir, contiguous
Launched on Aqua in 2002

IASI - Infrared Atmospheric Sounding Interferometer
Michelson interferometer
236 kg. 210 W
12 km FOV at nadir, non-contiguous
Launched on MetOp-a in 2006 and MetOp-B in 2012



CrIS - Cross-track Infrared Sounder
Michelson interferometer
85 kg. 110 W
3x3 14 km FOVs at nadir, contiguous
Launched on S-NPP in 2011

Summary

- AIRS NH_3 products not only include 14 years data record, it also provide daily maps!
- AIRS retrieved vertical profiles show good agreement (~5 - 15%) with in situ profiles from the 2013 DISCOVER-AQ field campaign in central California.
- AIRS daily measurements captures the strong continuous NH_3 emission sources from the anthropogenic (agricultural) source regions, as well as emissions from biomass burning (BB).
- Ammonia trends increase over agriculture regions, where fertilizers are used as routine practice, decrease over BB regions (with insufficient records).
- Ammonia concentrations increase resulted primarily from decreases in concentrations of acidic aerosols (sulfate and nitrate), an unintended consequence of effective controls of NO_x and SO_2 emissions.