

# Ammonia (NH<sub>3</sub>) Distributions and Recent Trends by 14-year AIRS Measurements

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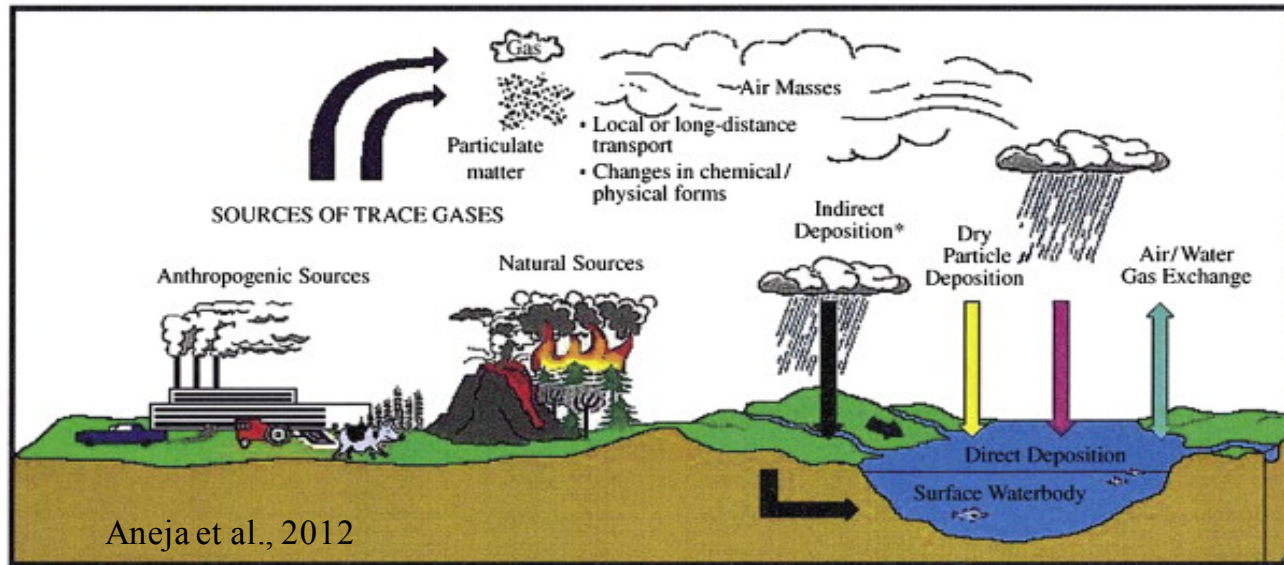
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\* Published in GRL: **Increased Atmospheric Ammonia over the World's Major Agricultural Areas Detected from Space**

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# Why Ammonia ( $\text{NH}_3$ )

- 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  $\text{SO}_2$  and  $\text{NO}_x$ .

# 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 ( $SO_2$ );
  - ✓ Nitrogen oxides ( $NO_x$ );
  - ✓ Ammonic ( $NH_3$ );
- Only  $NH_3$  is not regulated;
- Ammonia is the limiting species in  $PM_{2.5}$  formation, regulating  $SO_2$  and  $NO_x$  alone cannot determine the fate of  $PM_{2.5}$ ;
- Meteorological conditions (wind, rain, temperatures, etc.) affects the concentration of ammonia gases.



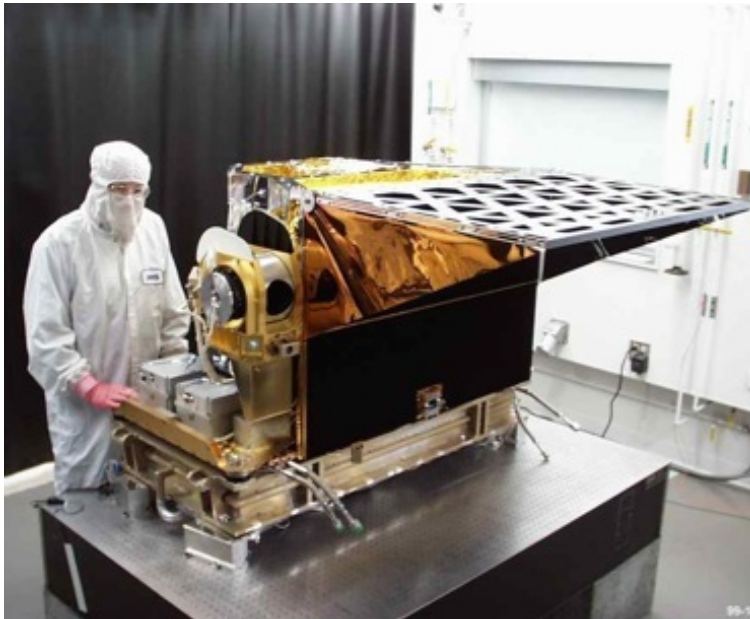
# Why Satellite Remote Sensing

- *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  $\text{NH}_3$  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  $\text{NH}_3$  maps*.
  - The *15-year data records* makes AIRS the best sensor for  $\text{NH}_3$  trends and variability studies (to date).



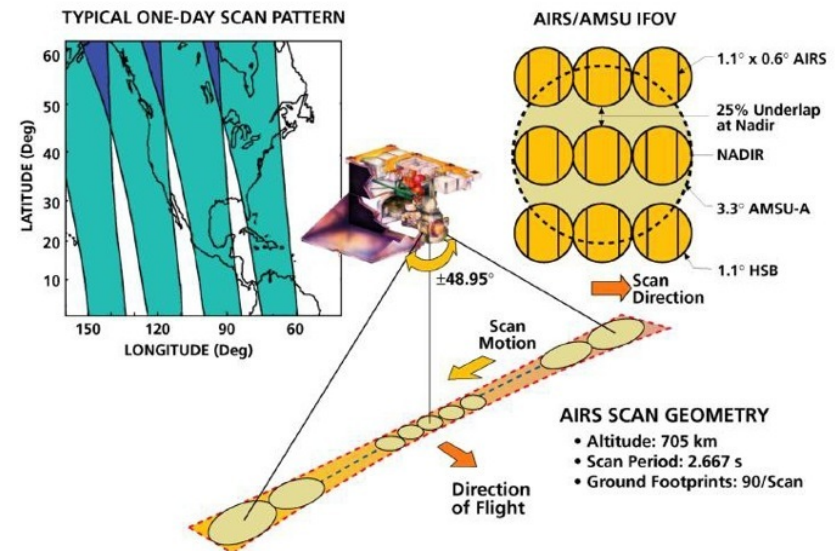
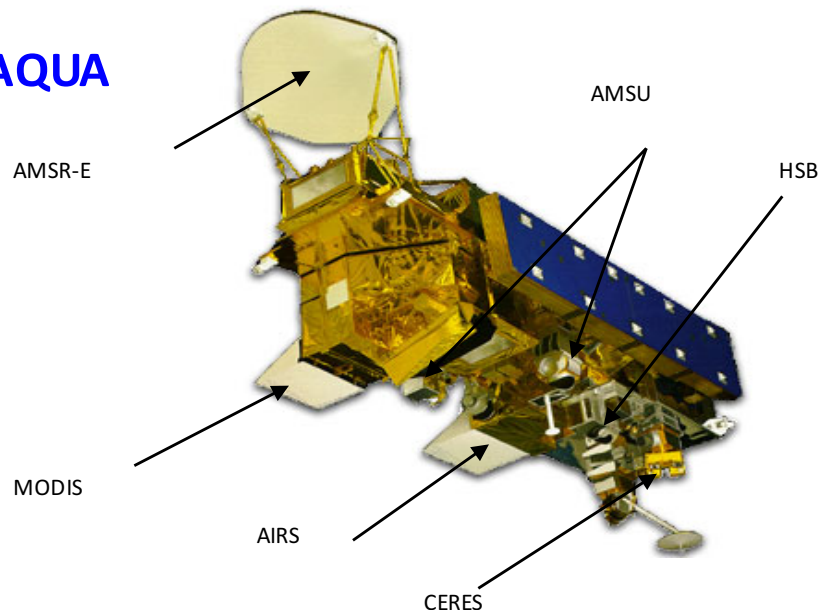
# Atmospheric InfraRed Sounder (AIRS)

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



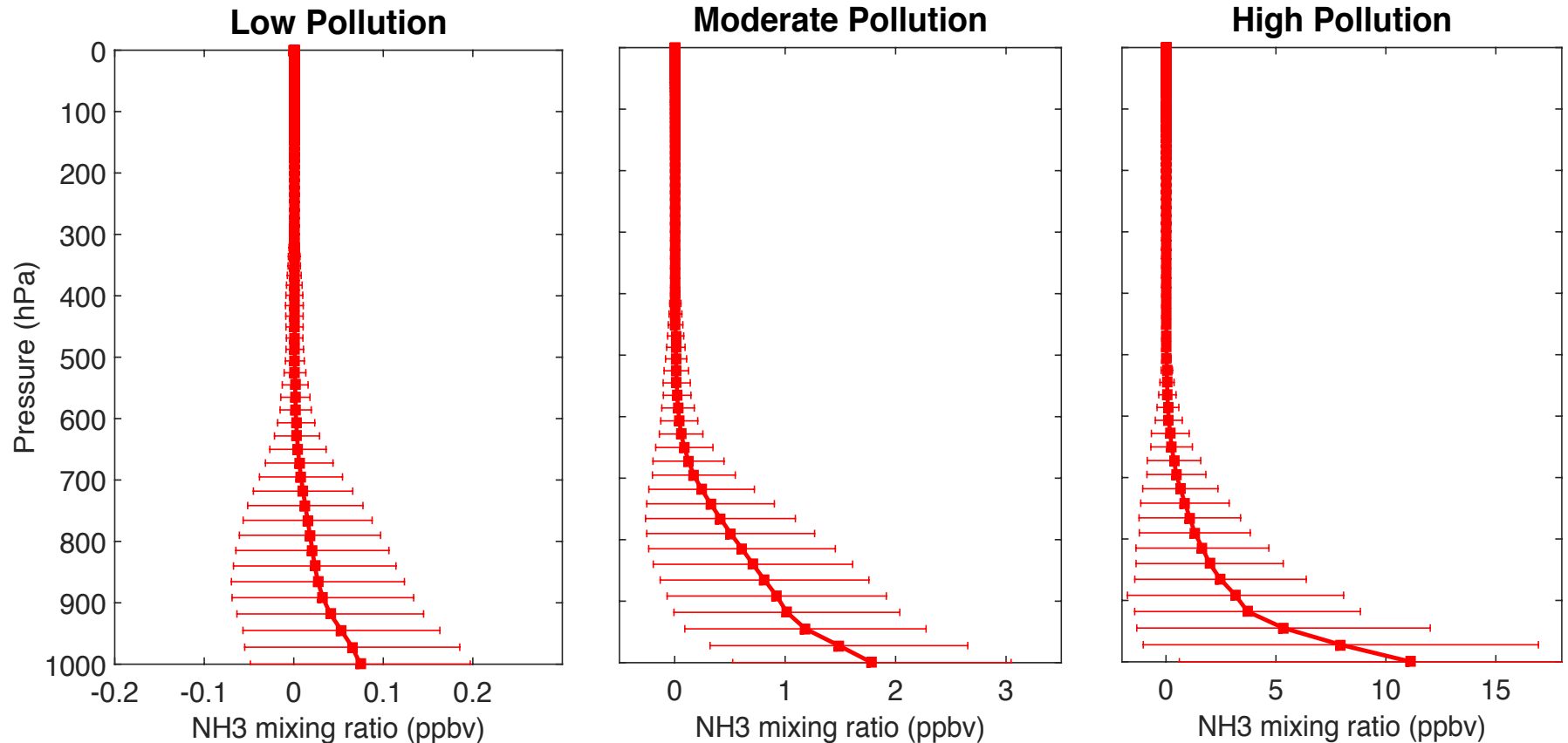
- A grating spectrometer originally designed to improve weather forecast and now also used for climate and air quality studies.
- Spectral resolution at  $1/1200$  ( $\sim 0.5 \text{ cm}^{-1}$ )
- Covers 650-2665 in three bands with a total of 2378 channels
- Spatial resolution  $13.5 \text{ km}^2$  (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 NH<sub>3</sub> Algorithm

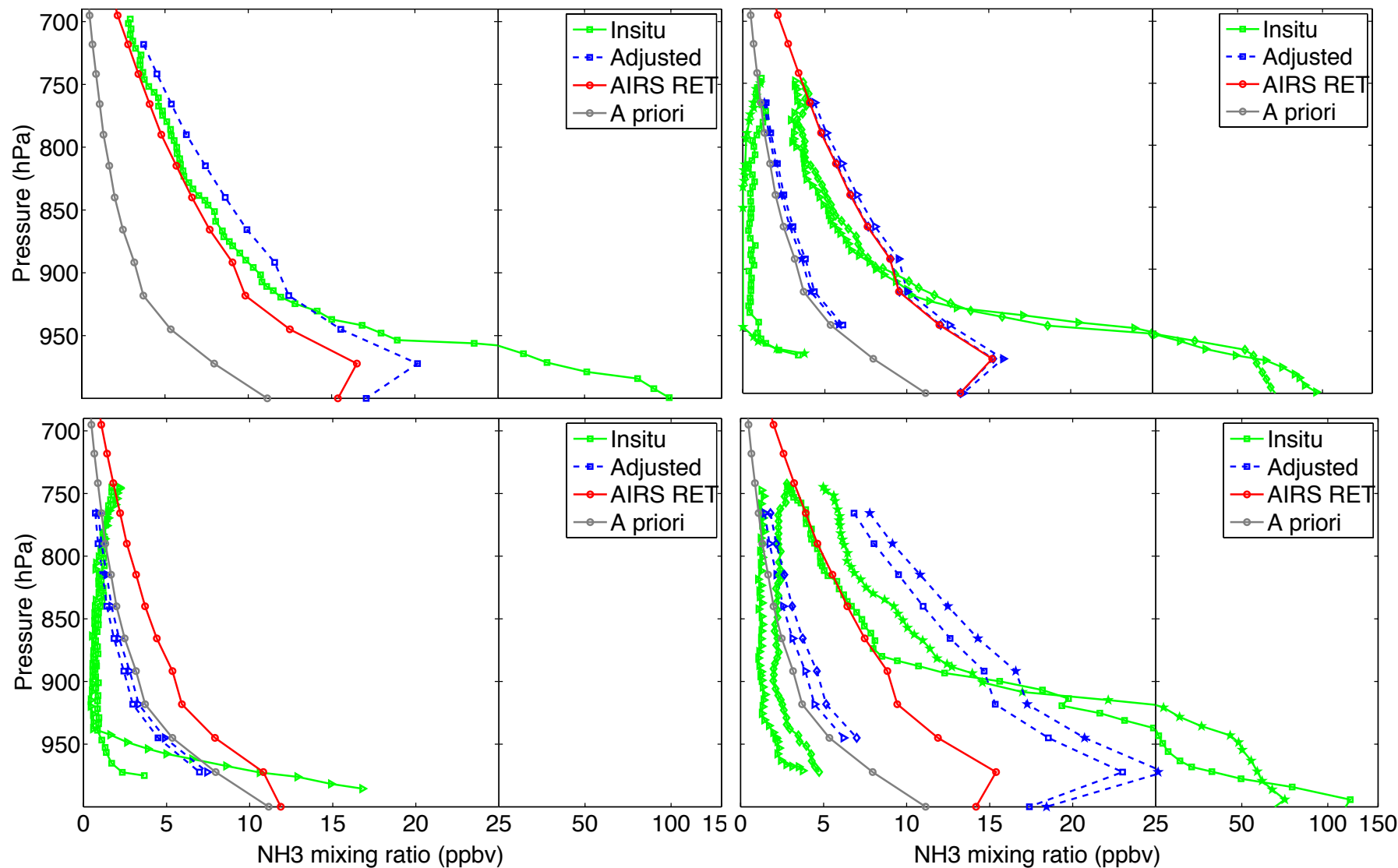
- Globally one set *a priori* (GEOS-chem). Variation in the retrievals are from measurements.
- Select *a priori* levels based on brightness temperature differences



# Validation vs CRDS/Picarro in DISCOVER-AQ CA

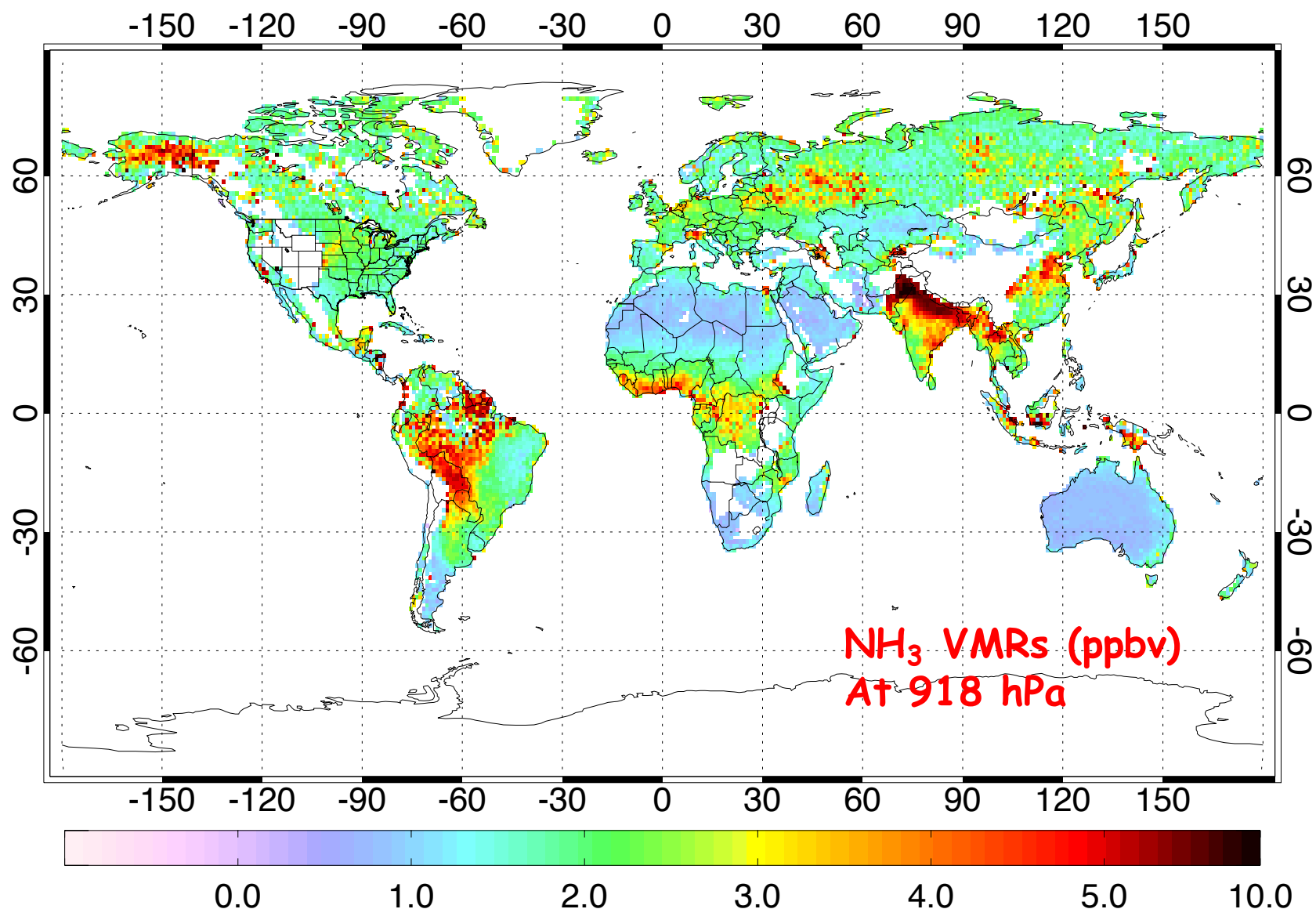
CRDS/Picarro Spiral Profiles Only - 01/16 to 02/06, 2013

(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 km<sup>2</sup>, can coincide with multiple in situ profiles.
- AIRS NH<sub>3</sub> measurements are most sensitive at 850-950 hPa layer.

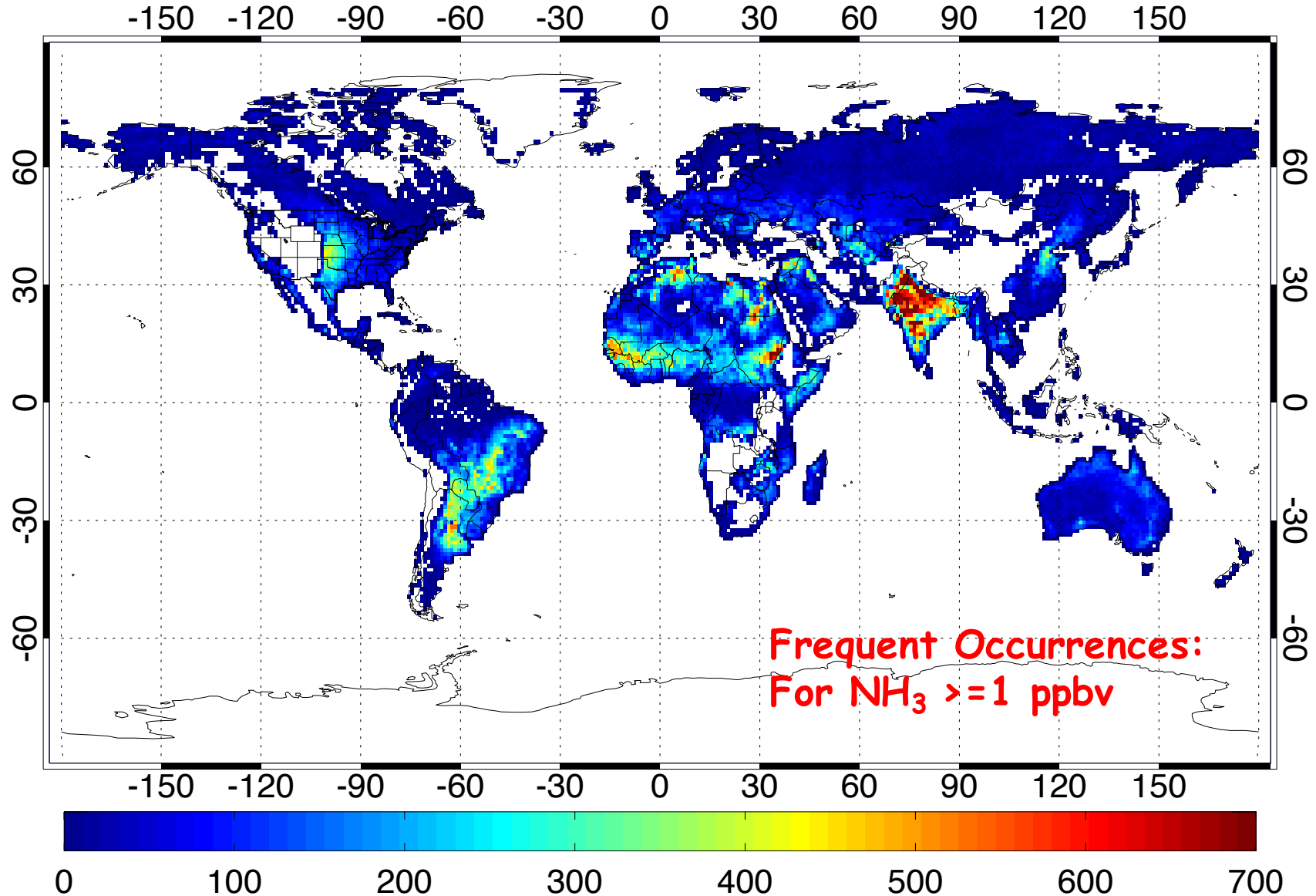
# Global $\text{NH}_3$ in 2002-2015



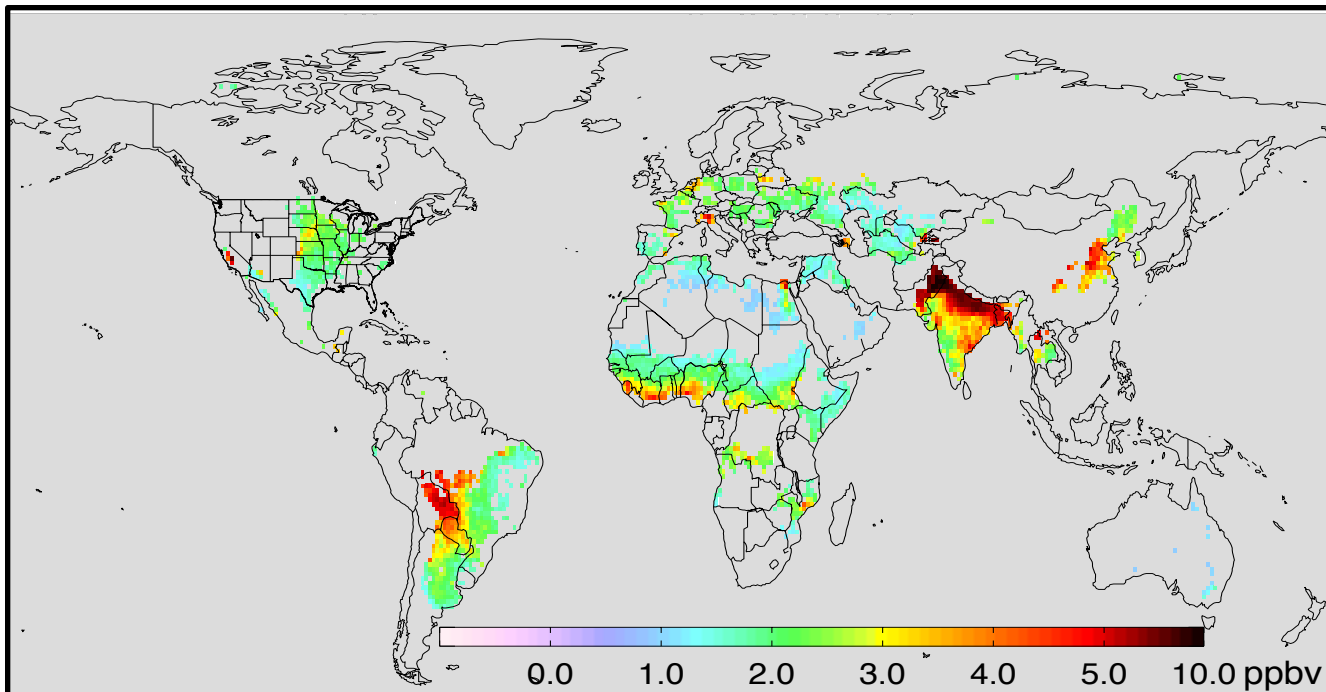
- High concentrations are mainly due to human activities and fires;
- Sources are seen in valleys (e.g., **San Joaquin Valley, California** in the U.S., the **Po Valley**, Italy, Fergana Valley, Uzbekistan, and the **Sichuan Basin** in China); Agricultural especially in irrigated lands (e.g., Azerbaijan, **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).



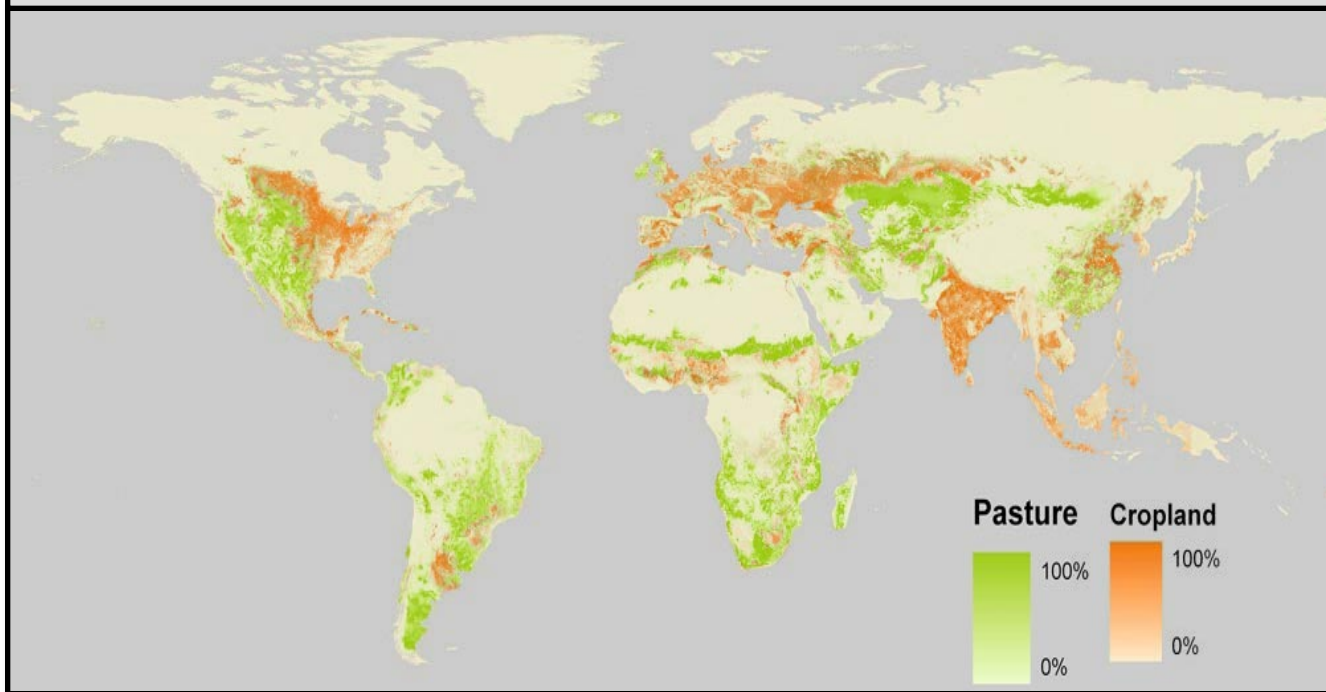
# Global Frequent Occurrences in 2002-2015



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

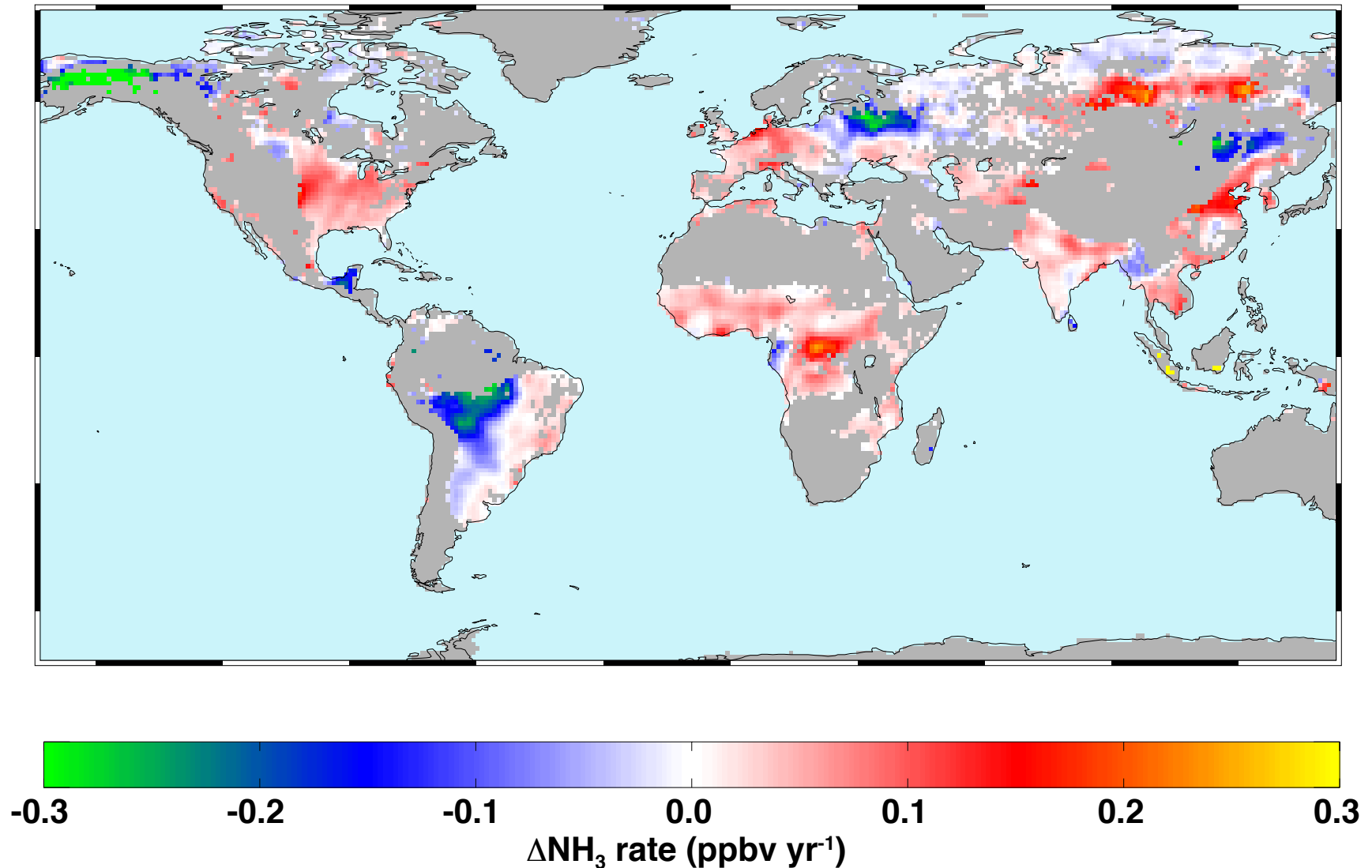


Top panel: The NH<sub>3</sub> VMRs from the persistent sources, i.e.,  $\geq 1.4$  ppbv for more than 40 days;



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

# NH<sub>3</sub> Trends - Last 14 years



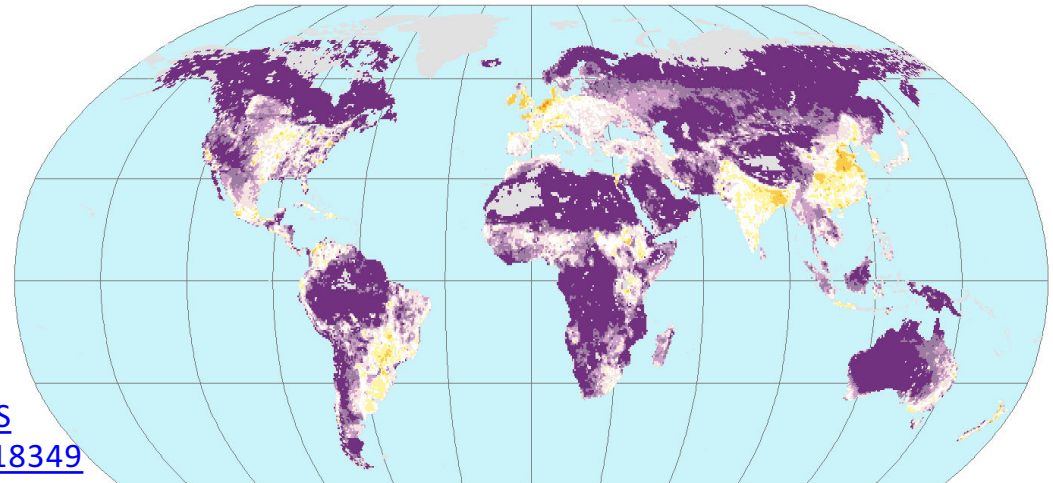
- Global trends in atmospheric NH<sub>3</sub> (i.e., VMRs at 918hPa for each 1x1 grid)
- Red-yellow colors represent increases due to agriculture emission increases and reduced scavenging by acid aerosols
- Blue-green colors represent decreases due to possibly reduced agricultural burning and fewer wild fires

# NH<sub>3</sub> Increase - Fertilizer Applications

## Global Nitrogen Fertilizer Application

Global Fertilizer and Manure, Version 1

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

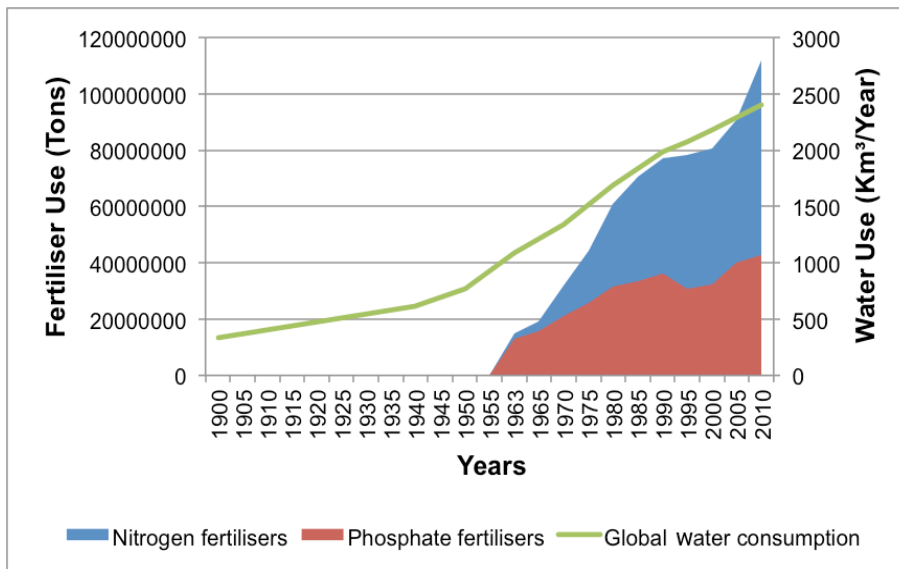


Robinson Projection

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

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

Courtesy of Russ Dickerson



Kg/ha of Nitrogen Fertilizer applied per grid cell:

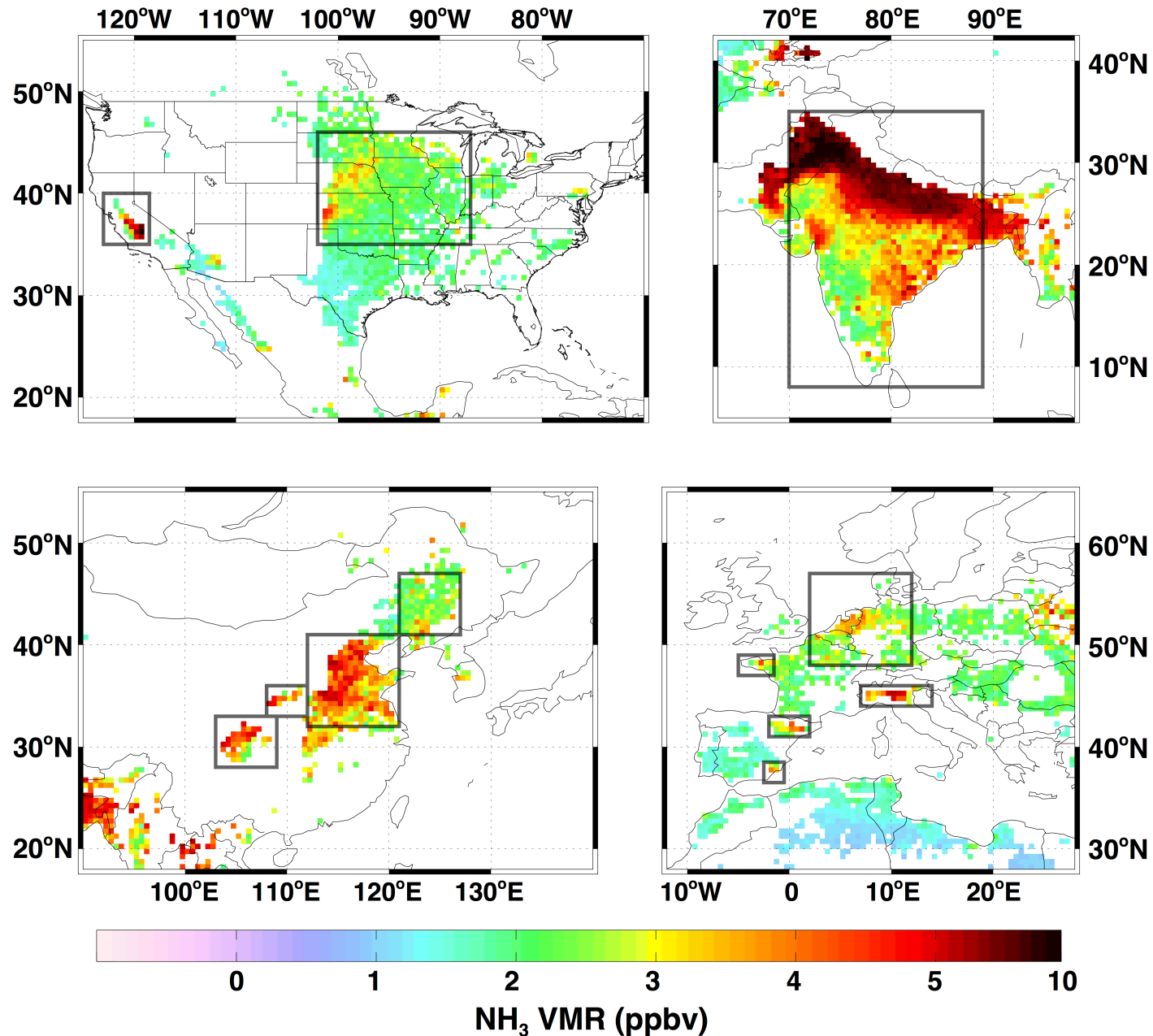


<http://sedac.ciesin.columbia.edu/>

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

# NH<sub>3</sub> over USA, China, India, and Europe

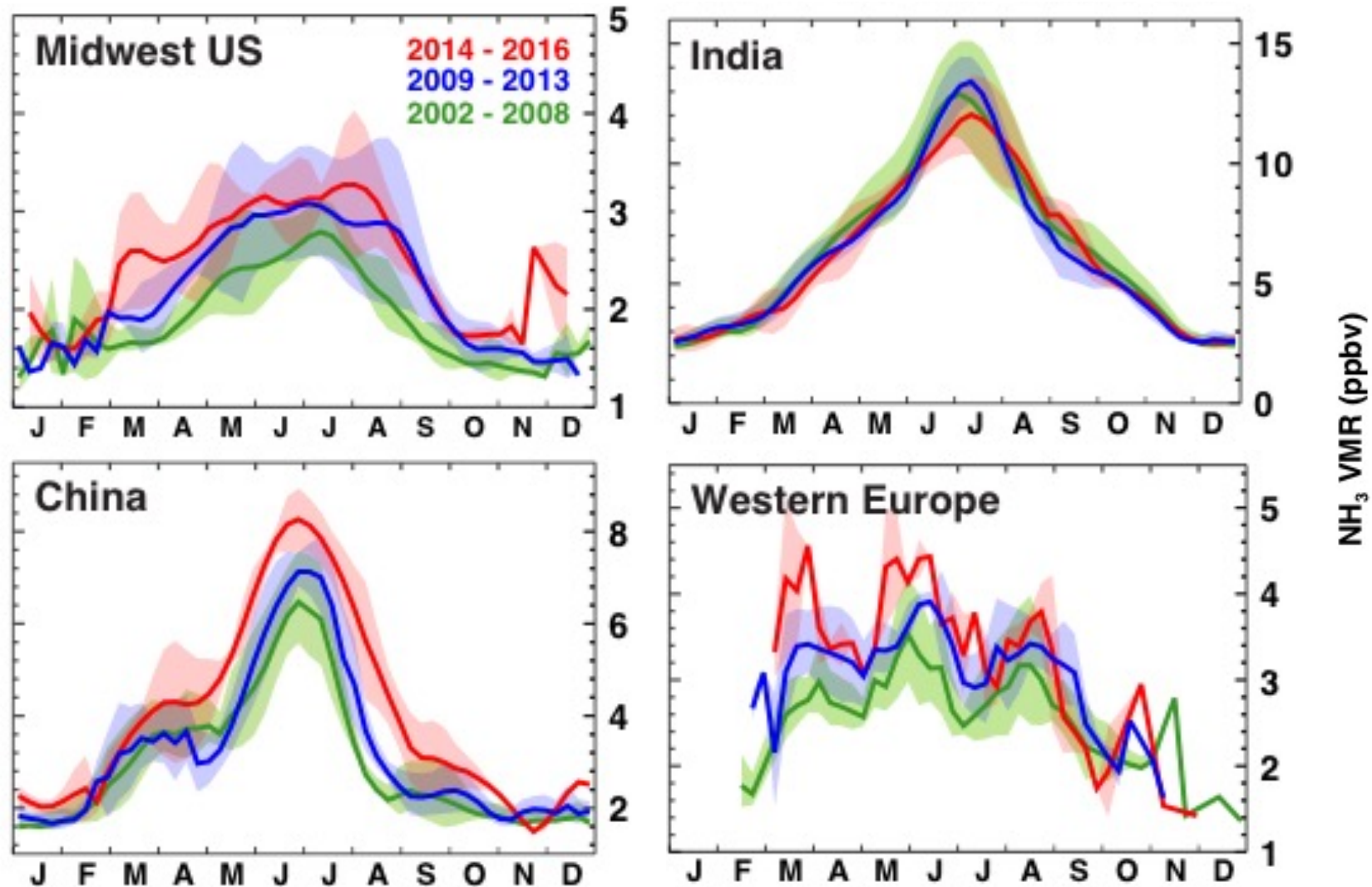
Using high concentration and high frequencies





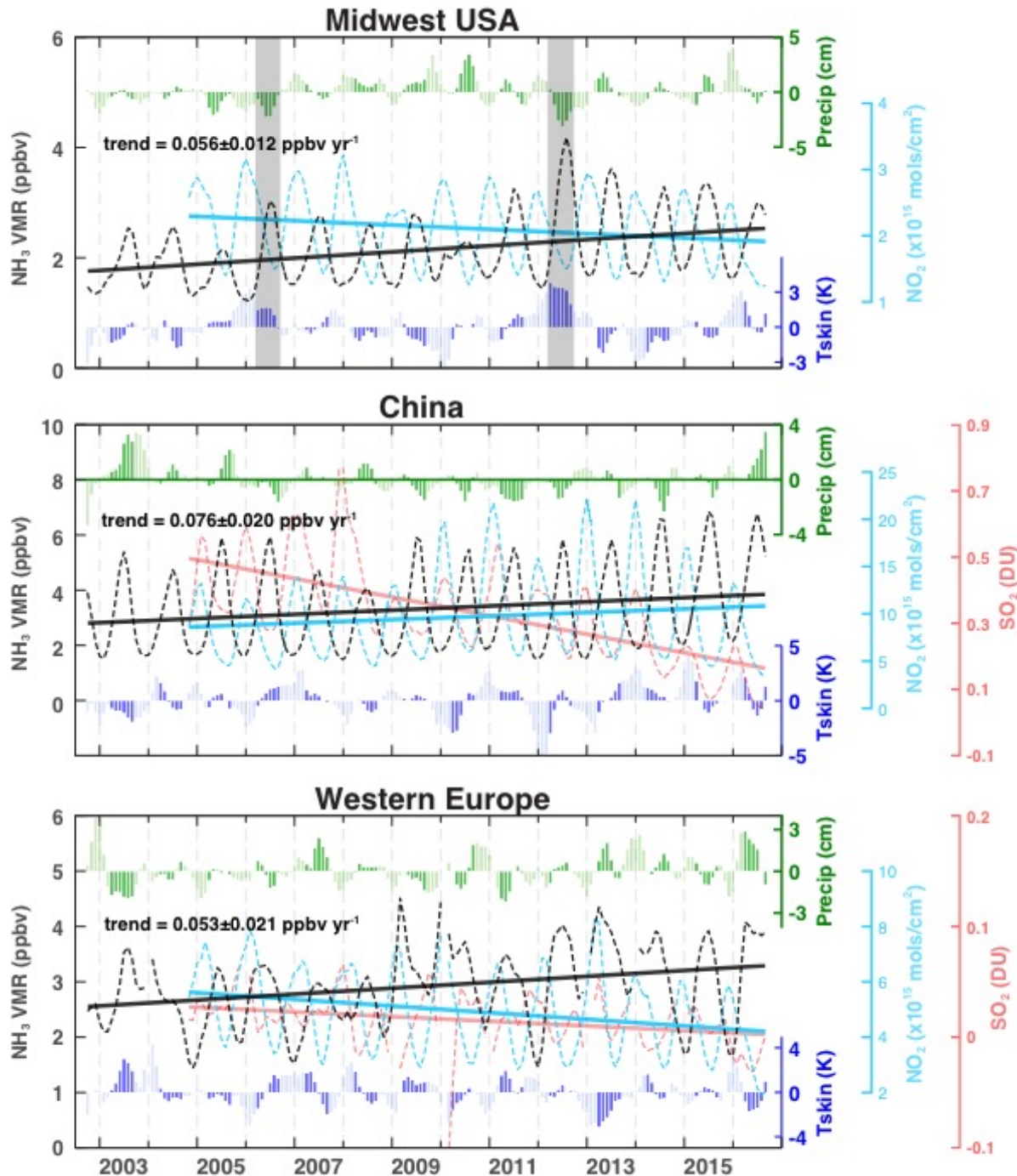
# AIRS NH<sub>3</sub> Seasonal Variation

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



- The highest NH<sub>3</sub> concentrations in average occur in South Asia, and China. Note scales.
- NH<sub>3</sub> in India seasonal variation are broad and no obvious increasing/decreasing trends;
- NH<sub>3</sub> for USA, China and Europe have increased, with peaks in both spring and summer;

# AIRS NH<sub>3</sub> vs OMI NO<sub>2</sub> for US (top), SO<sub>2</sub> for China (middle) and NO<sub>2</sub> for Western Europe (lower)



All show increasing NH<sub>3</sub> trends (black) 2002-2016.

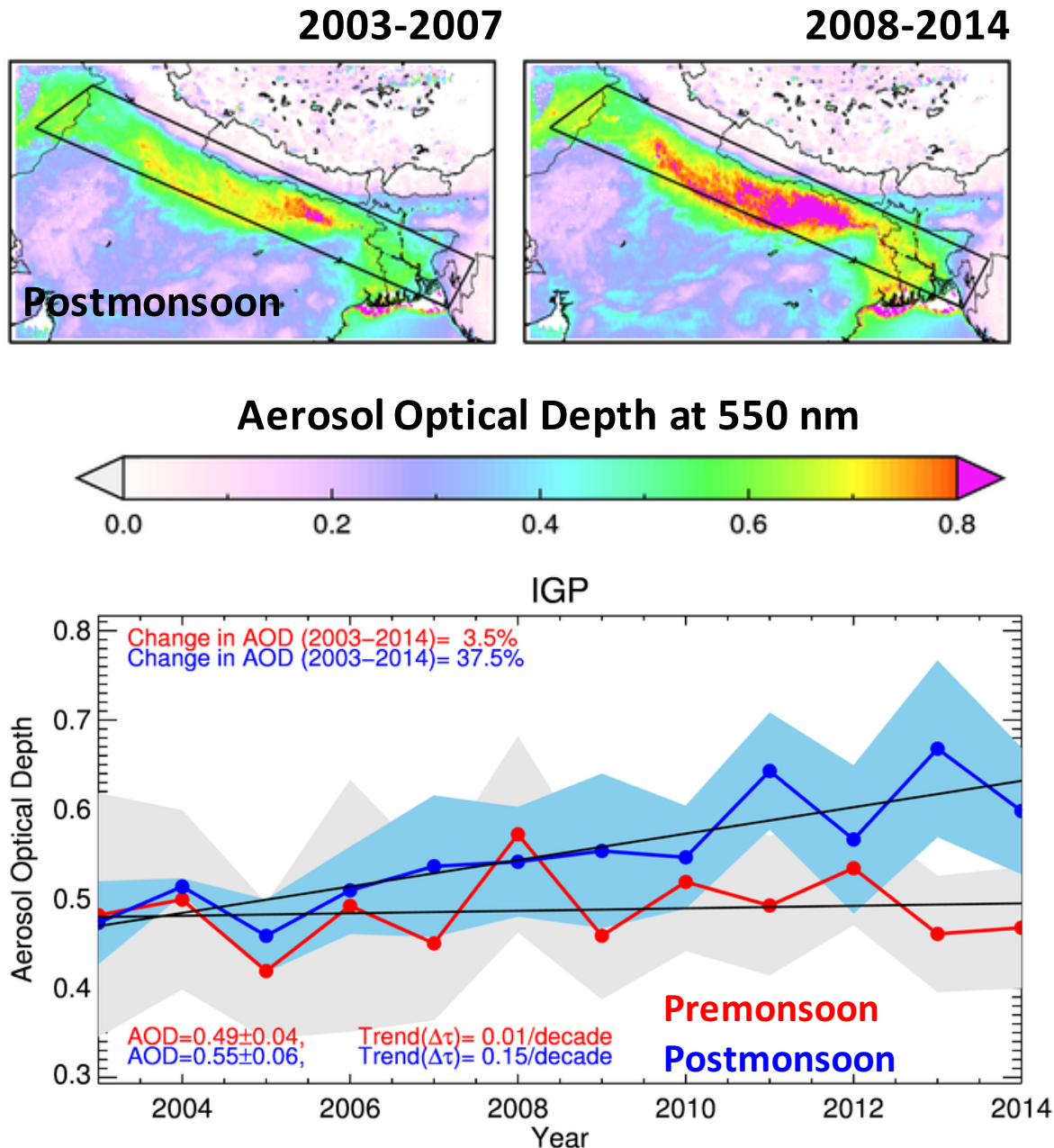
Decreased SO<sub>2</sub> largely explains the NH<sub>3</sub> increases in Midwest U.S. (not shown), China, and Europe.

OMI NO<sub>2</sub> decreasing explains winter NH<sub>3</sub> increasing over the US and Europe.

Meteorological conditions also affect NH<sub>3</sub> 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 NH<sub>3</sub> emissions.

# South Asia Aerosols Trends



Courtesy of NASA MODIS team

- No obvious  $\text{NH}_3$  increased in the AIRS observations over South Asia, while the fertilizer usage has increased;
- Recent increases in  $\text{SO}_2$  and  $\text{NO}_x$  from uncontrolled coal combustion and other sources;
- Greater conversion of gaseous  $\text{NH}_3$  into particulate sulfates and nitrates.
- Dust influence in premonsoon and sea salt during monsoon, more fine mode aerosols in postmonsoon.



# Way Forward

## - Continued $\text{NH}_3$ 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  $\text{NH}_3$  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  $\text{NH}_3$  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  $\text{NO}_x$  and  $\text{SO}_2$  emissions.