# Ammonia ($NH_3$) Distributions and Recent Trends by 14-year AIRS Measurements

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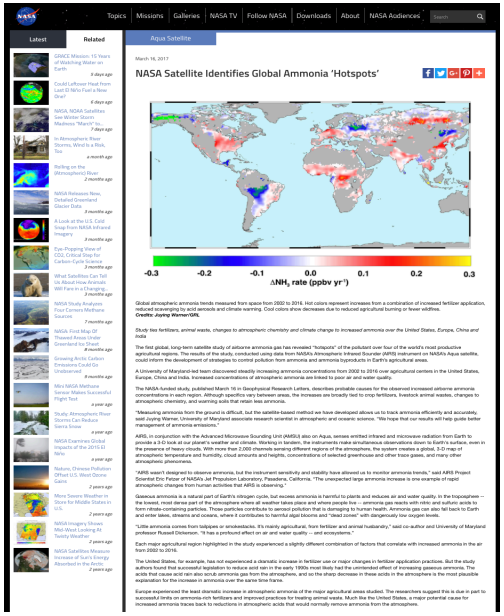
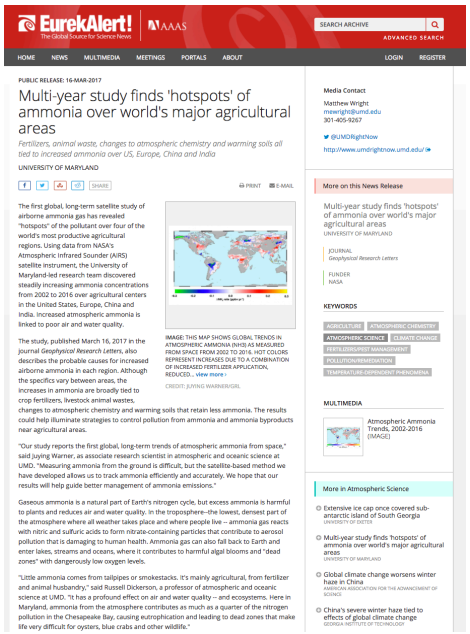
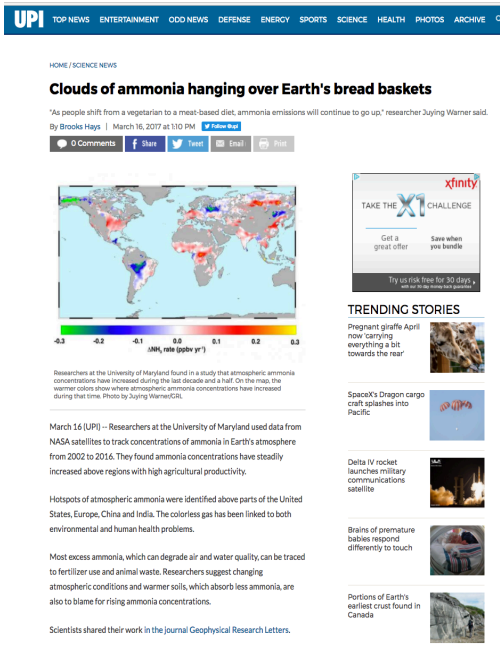
# In the Media

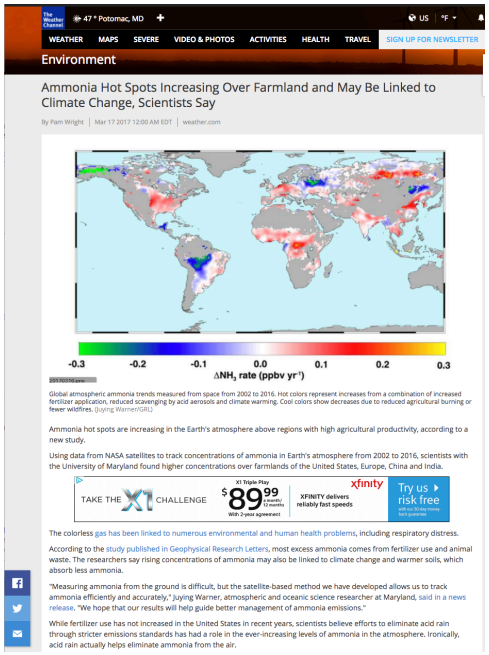


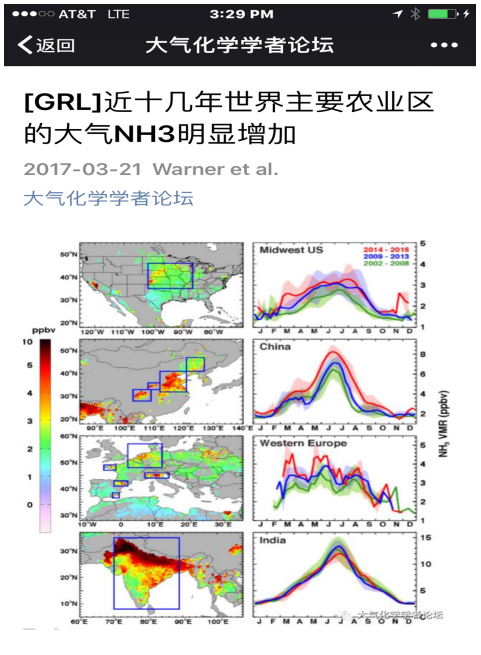


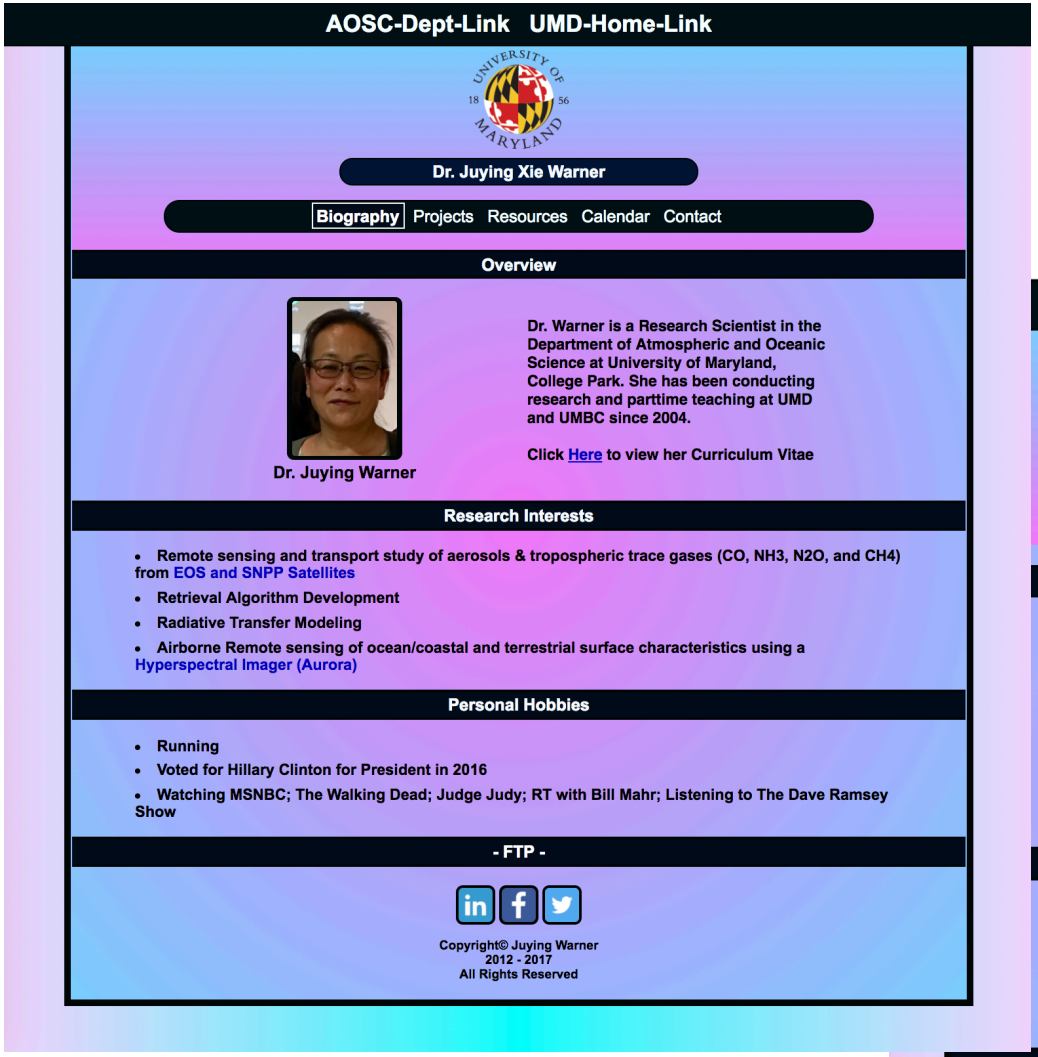




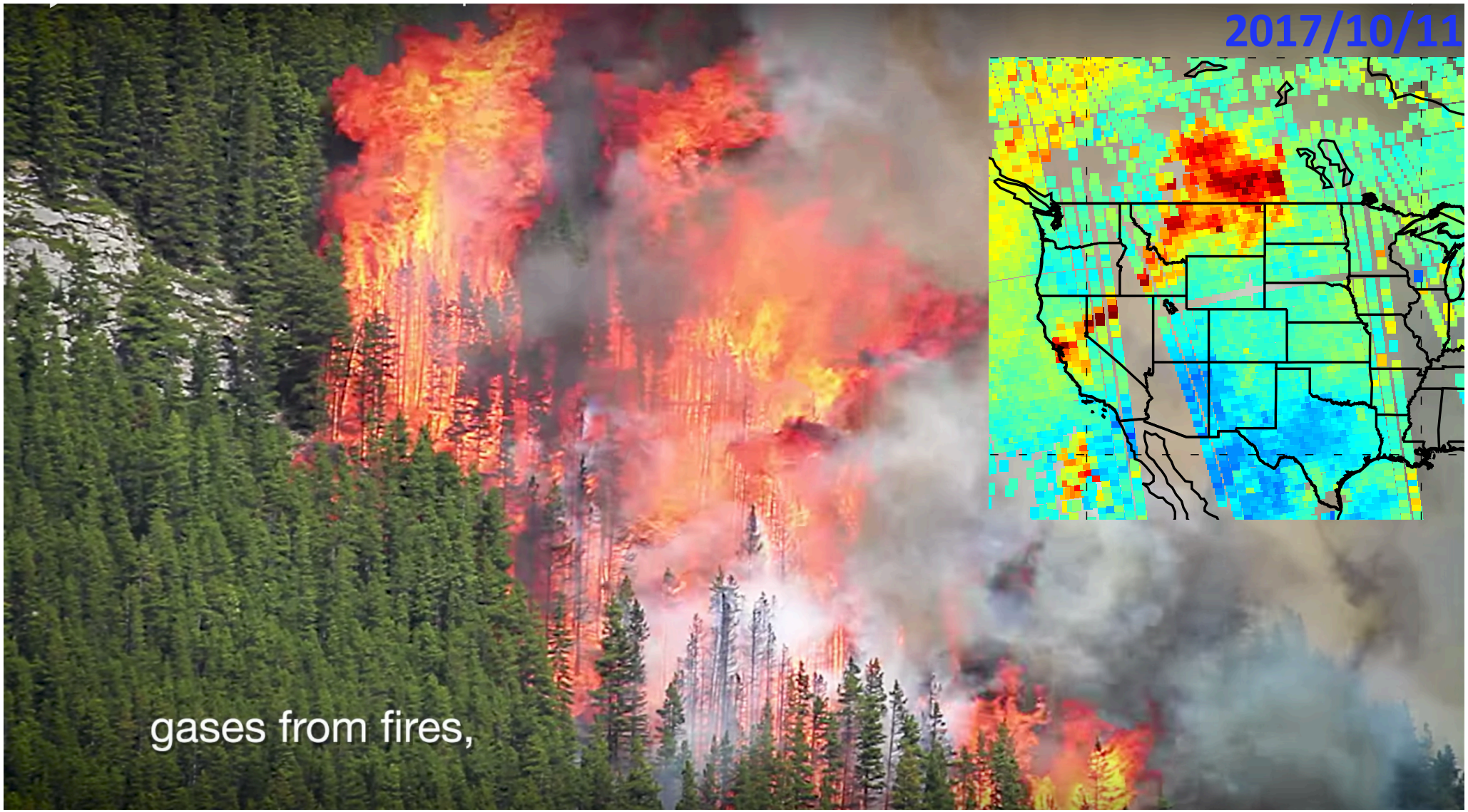

- the UK: The Guardian, Indian: DownToEarth, New Zealand: Radio New Zealand Rurals

# On the Web

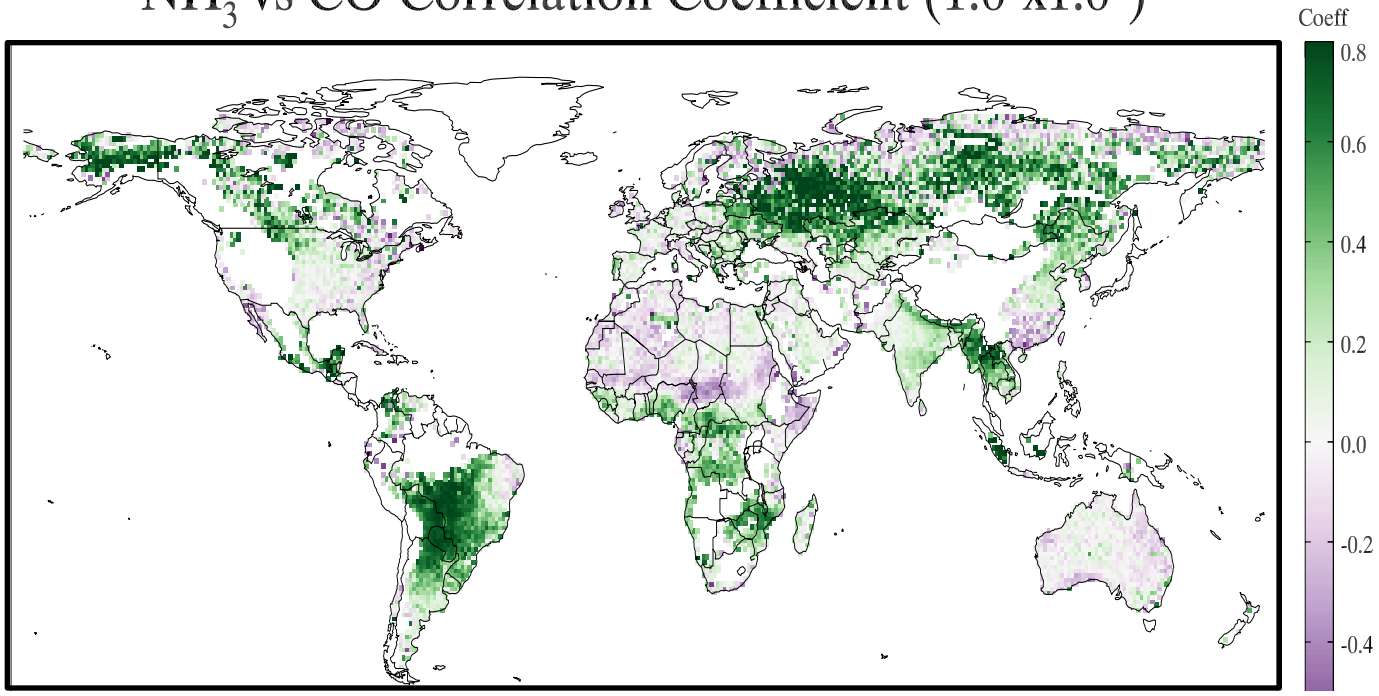



- AIRS $NH_3$ data used in the publications
- $NH_3$ monthly means - Land and daytime
- Pursuing funds for daily products

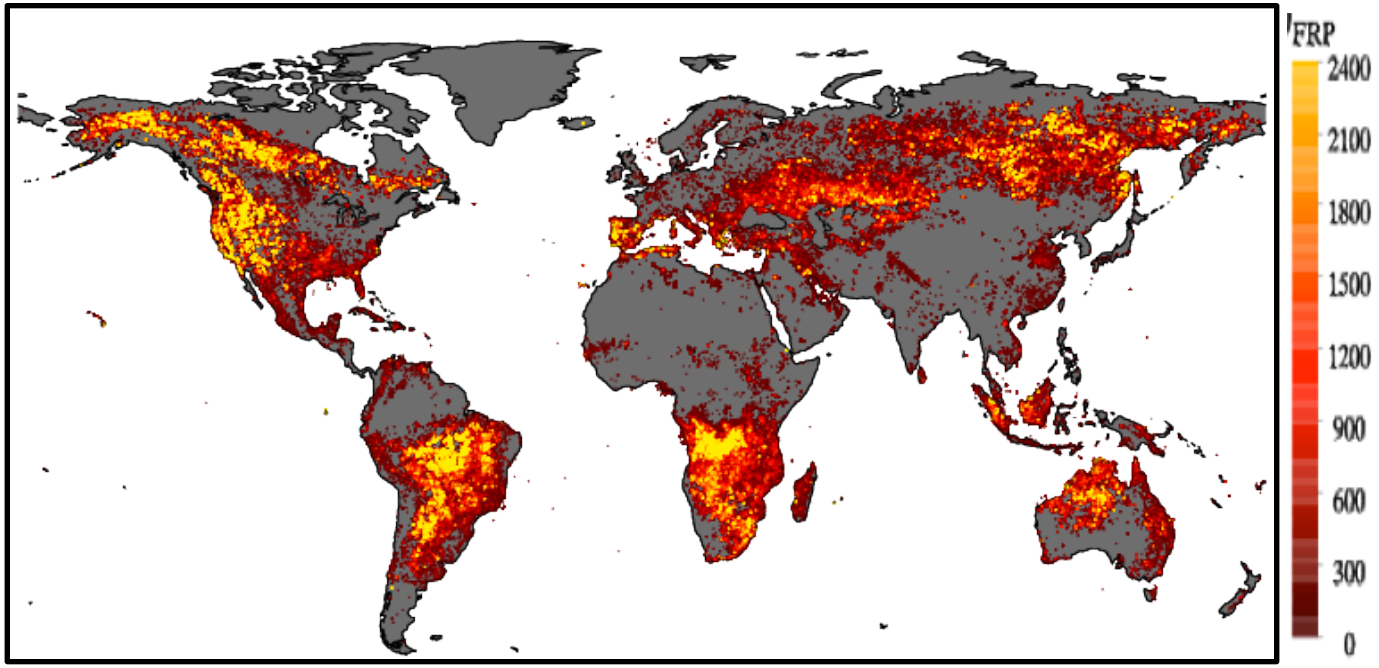
# AIRS carbon monoxide (CO) Observations of Santa Rosa Fire



$NH_3$ vs CO Correlation Coefficient ($1.0^o$x$1.0^o$)




MODIS Fire Radiative Power (FRP) Summer 2003-2015

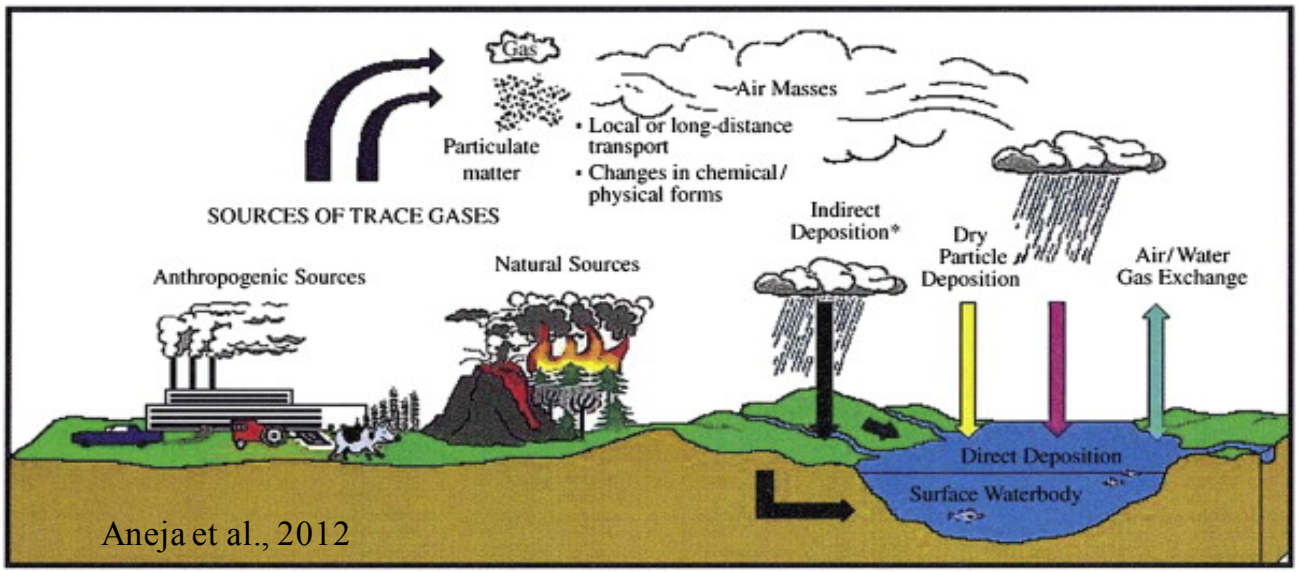



# AIRS $NH_3$ and CO Emitted from Fires

- Correlation coefficients of collocated $NH_3$ and CO.
- BB emissions show positive correlations;
- Agricultural emissions show negative correlations.
- Positively correlations NH3/CO are highly agreeable with MODIS Fire Radiative Power.

# Why Ammonia ($NH_3$)

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




**Sources:**

- Fertilizer use for crop production;
- Anima 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 $SO_2$ and $NO_x$.

# Ammonia – precursor gas of $PM_{2.5}$

- Precursor gases for $PM_{2.5}$ (by secondary inorganic aerosols - a large portion of $PM_{2.5}$):
  - ✓ Sulfer 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.***

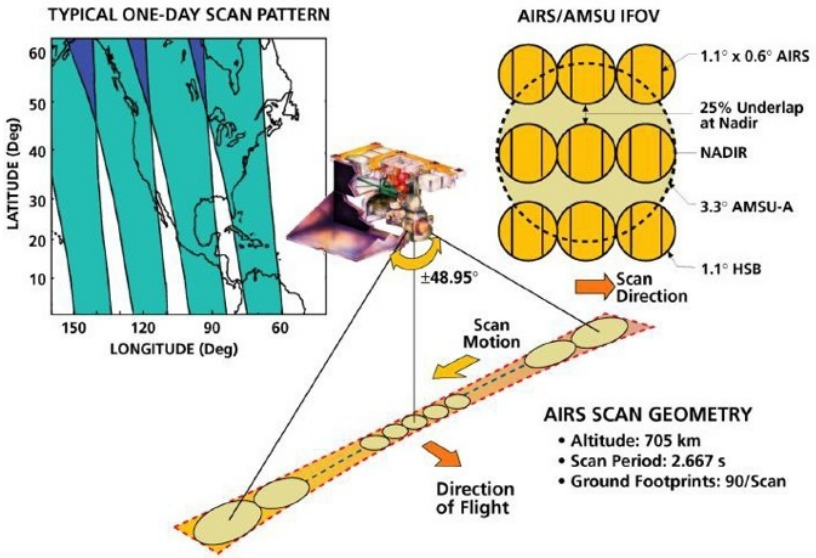
- Satellite measurements with daily and large global coverage are challenging and have been lacking partly because ***the lifetime of $NH_3$ is relatively short*** and partly because it requires high sensitivity for the retrievals that can be only obtained from areas with high thermal contrasts near 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 $NH_3$ maps.***
  - The ***15-year data records*** makes AIRS the best sensor for $NH_3$ trends and variability studies (to date).

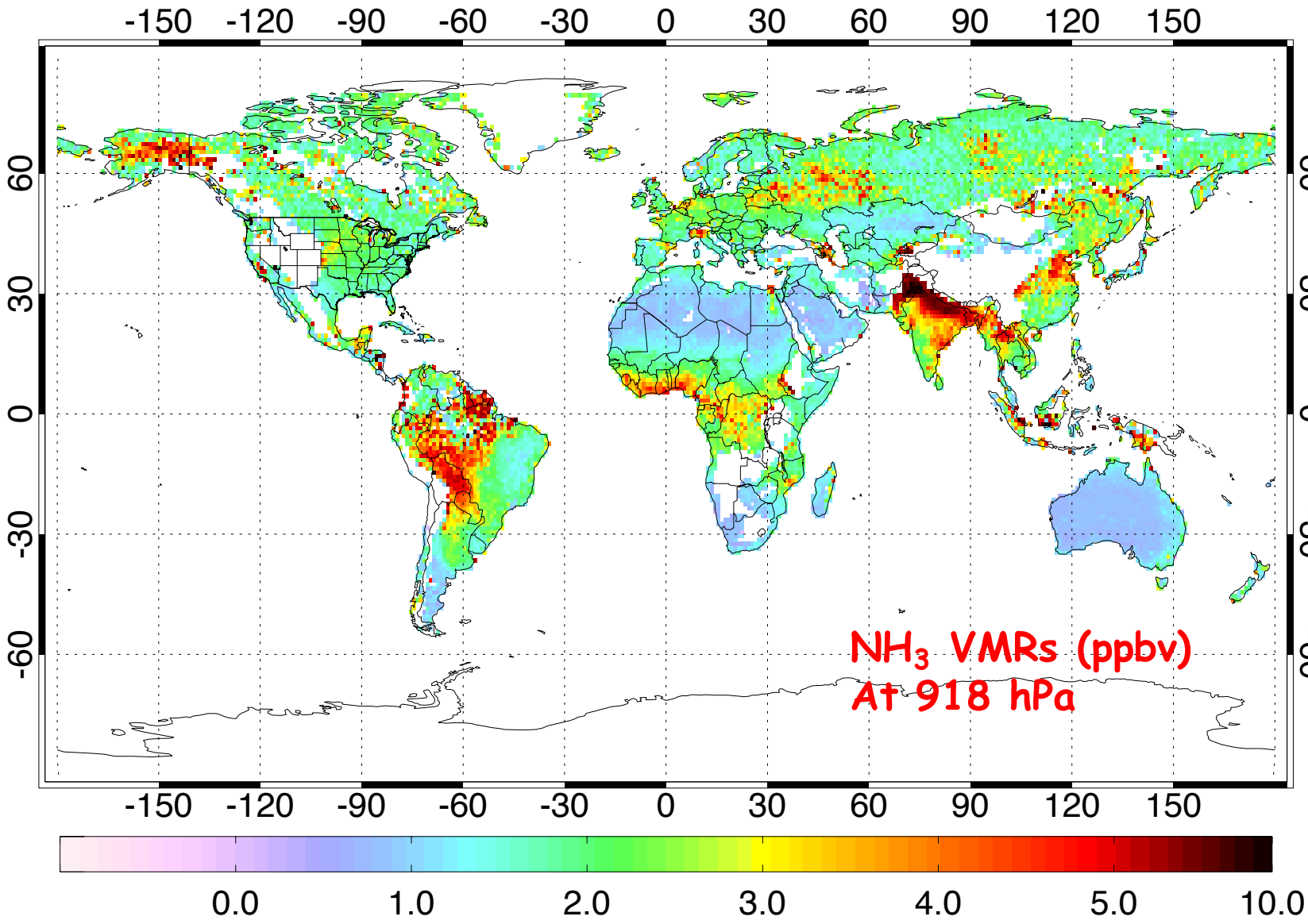
# Atmospheric InfraRed Sounder (AIRS)

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

- Due to Similarities between AIRS~CrIS
- NUCAPS – a heritage of AIRS algorithm
- The AIRS $NH_3$ codes can be a plug-in for NUCAPS!

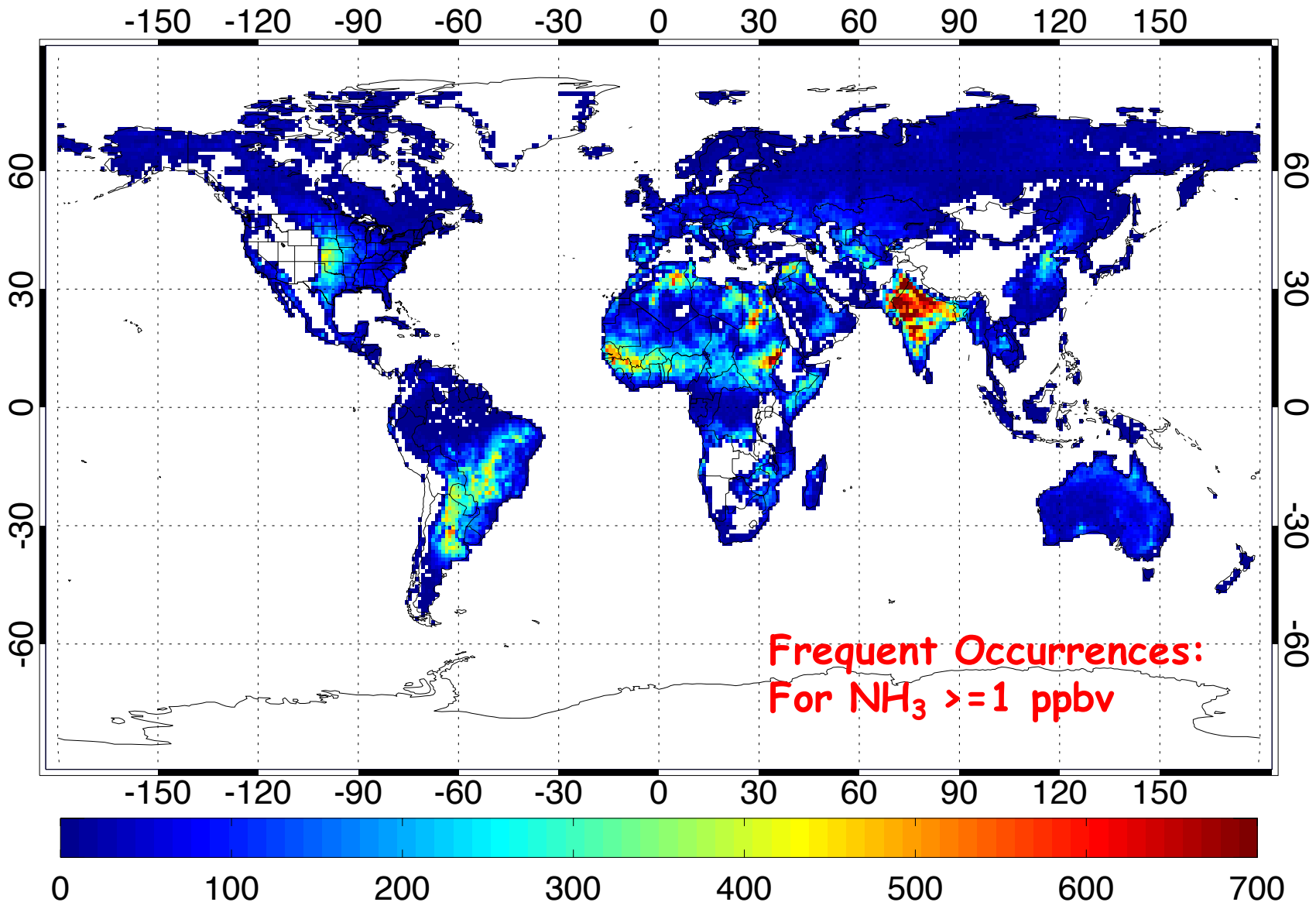


# Global $NH_3$ in 2002-2015

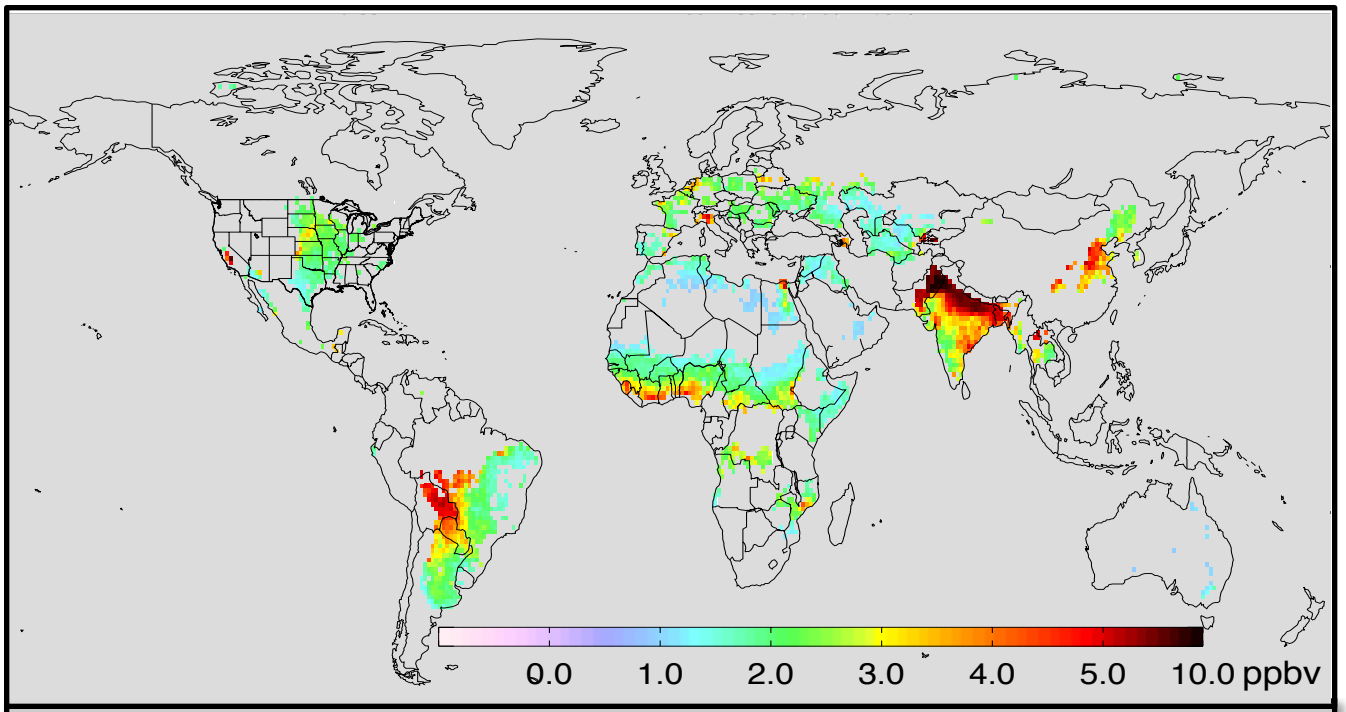


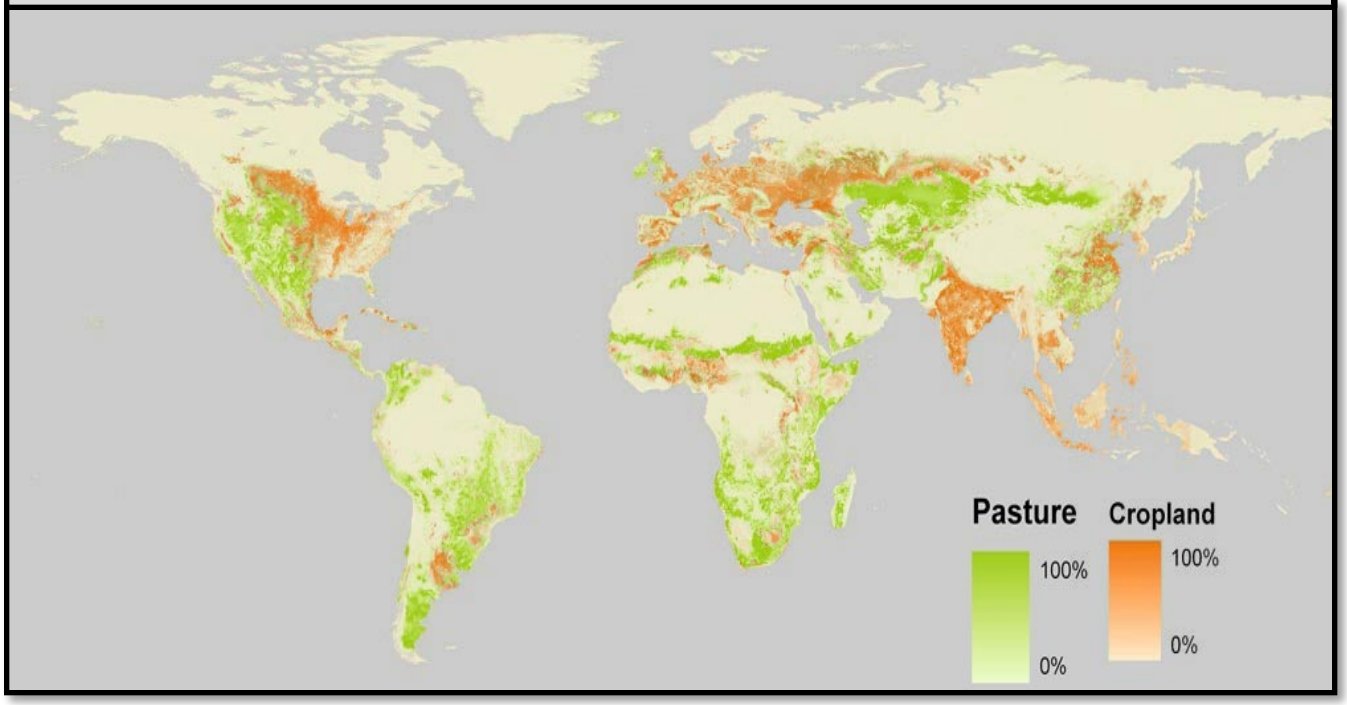

- High concentrations are mainly due to human activities and fires;
- Sources are seen in valleys (e.g., **San Joaquin Valley, California** in the U.S., the **Po Valley**, Italy, Fergana Valley, Uzbekistan, and the **Sichuan Basin** in China); Agricultural especially in irrigated lands (e.g., Azerbaijan,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

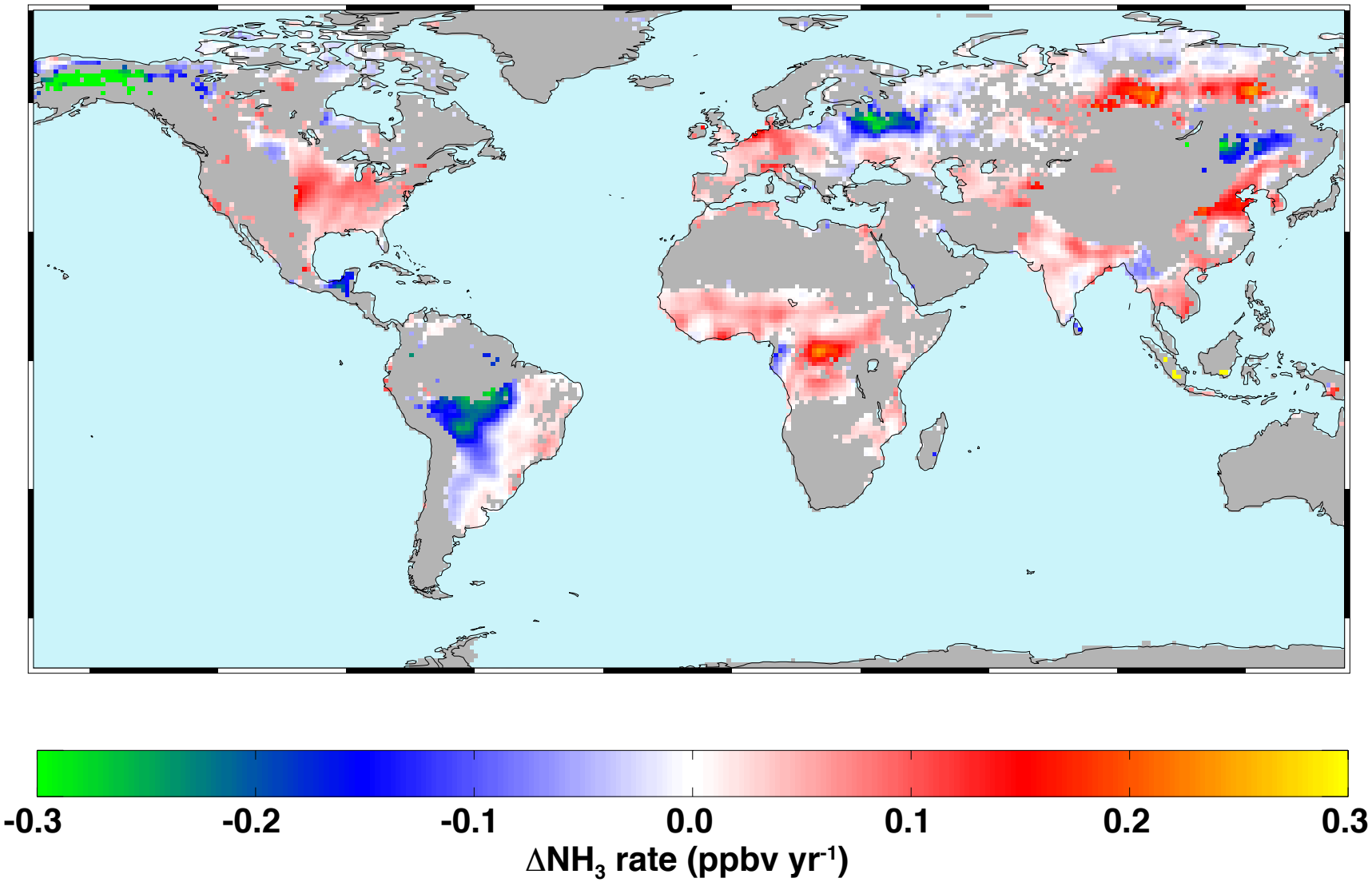



<u>Top panel:</u> The $NH_3$ VMRs from the persistent sources, i.e., ≥ 1.4 ppbv for more than 40 days;

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

# $NH_3$ Trends - Last 14 years

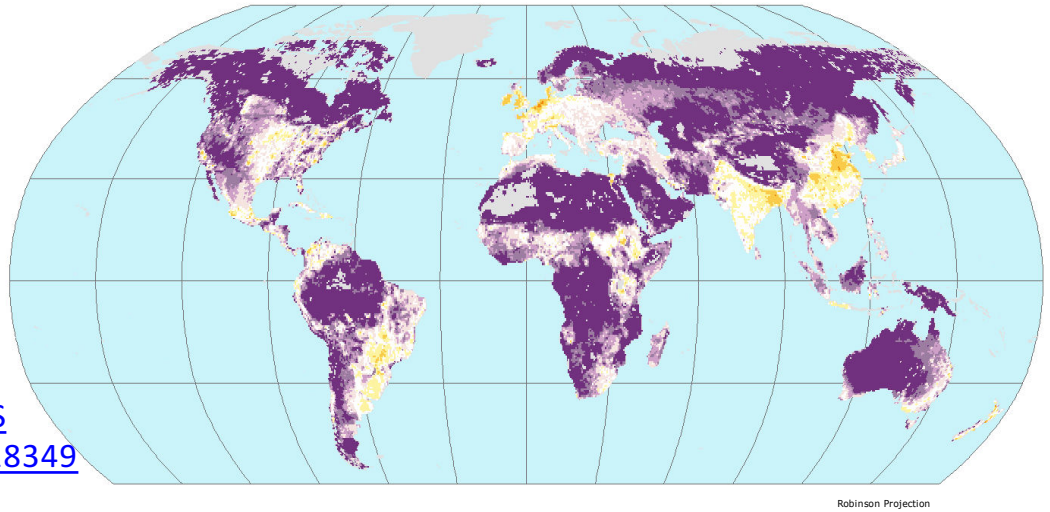



- Global trends in atmospheric $NH_3$ (i.e., VMRs at 918hPa for each 1x1 grid)
- Red-yellow colors represent increases due to agriculture emission increases and reduced scavenging by acid aerosols
- Blue-green colors represent decreases due to possibly reduced agricultural burning and fewer wild fires

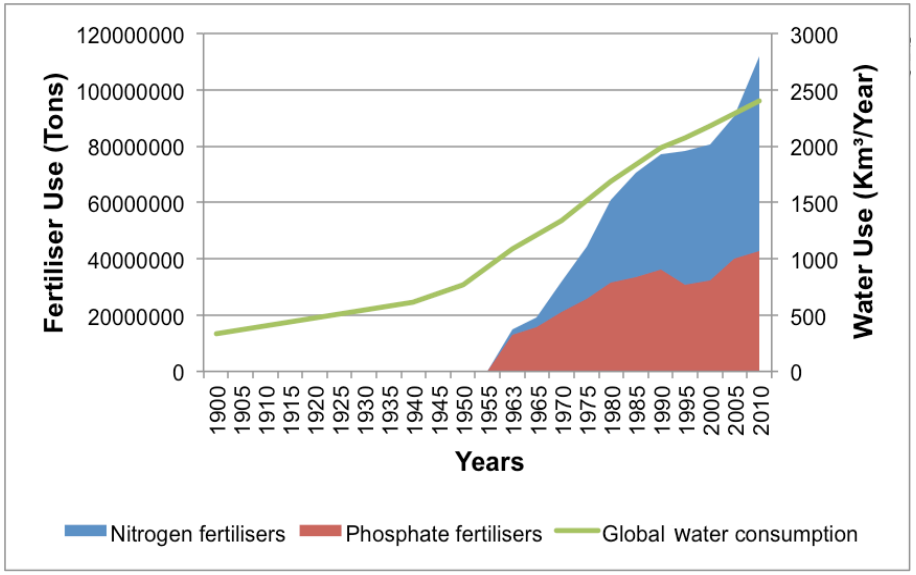
# $NH_3$ Increase – Fertilizer Applications

| 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% $yr^{-1}$] |

http://data.worldbank.org/indicator/AG.CON.FERT.ZS
http://www.ars.usda.gov/Services/docs.htm?docid=18349
Courtesy of Russ Dickerson



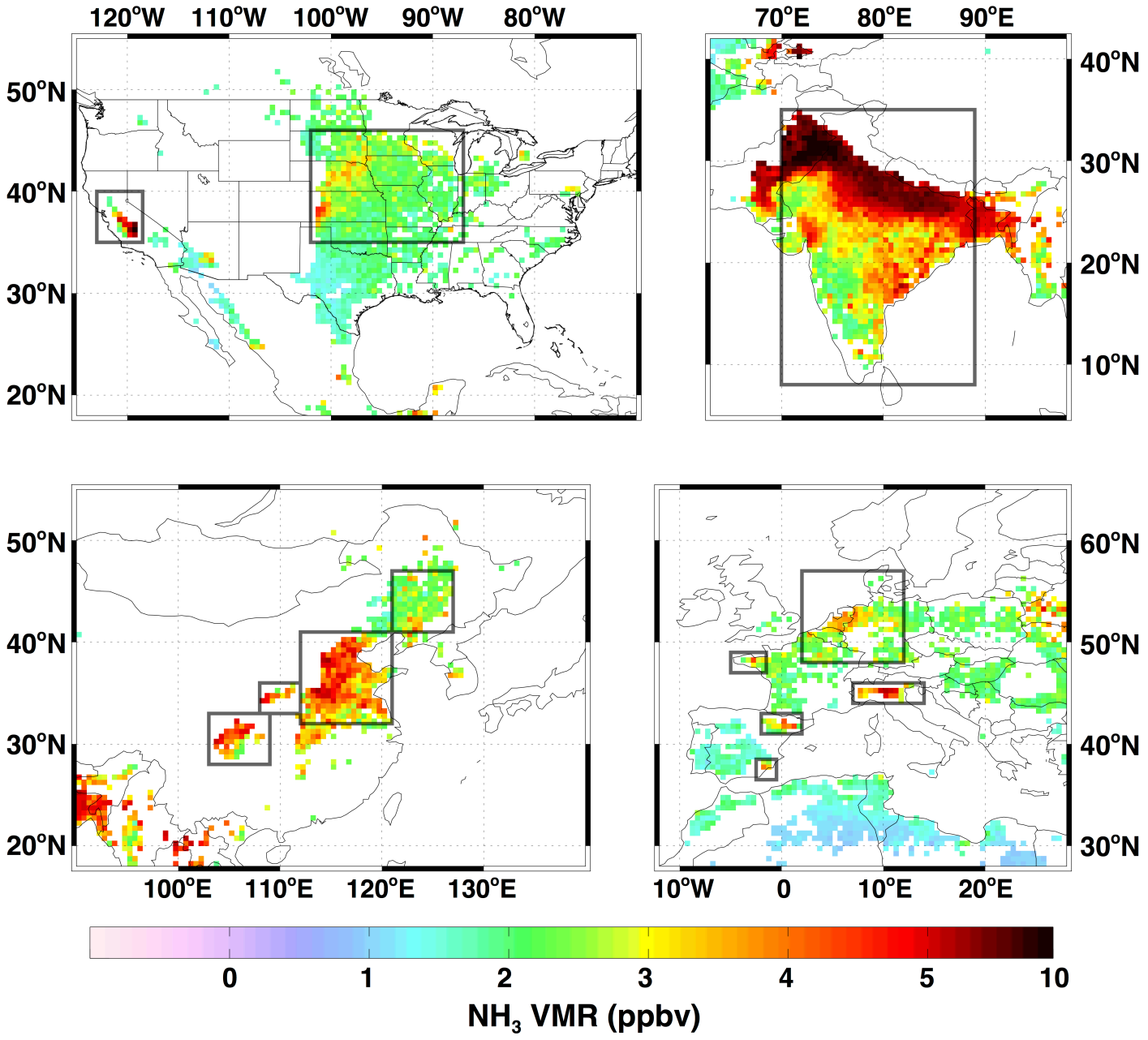

http://sedac.ciesin.columbia.edu/

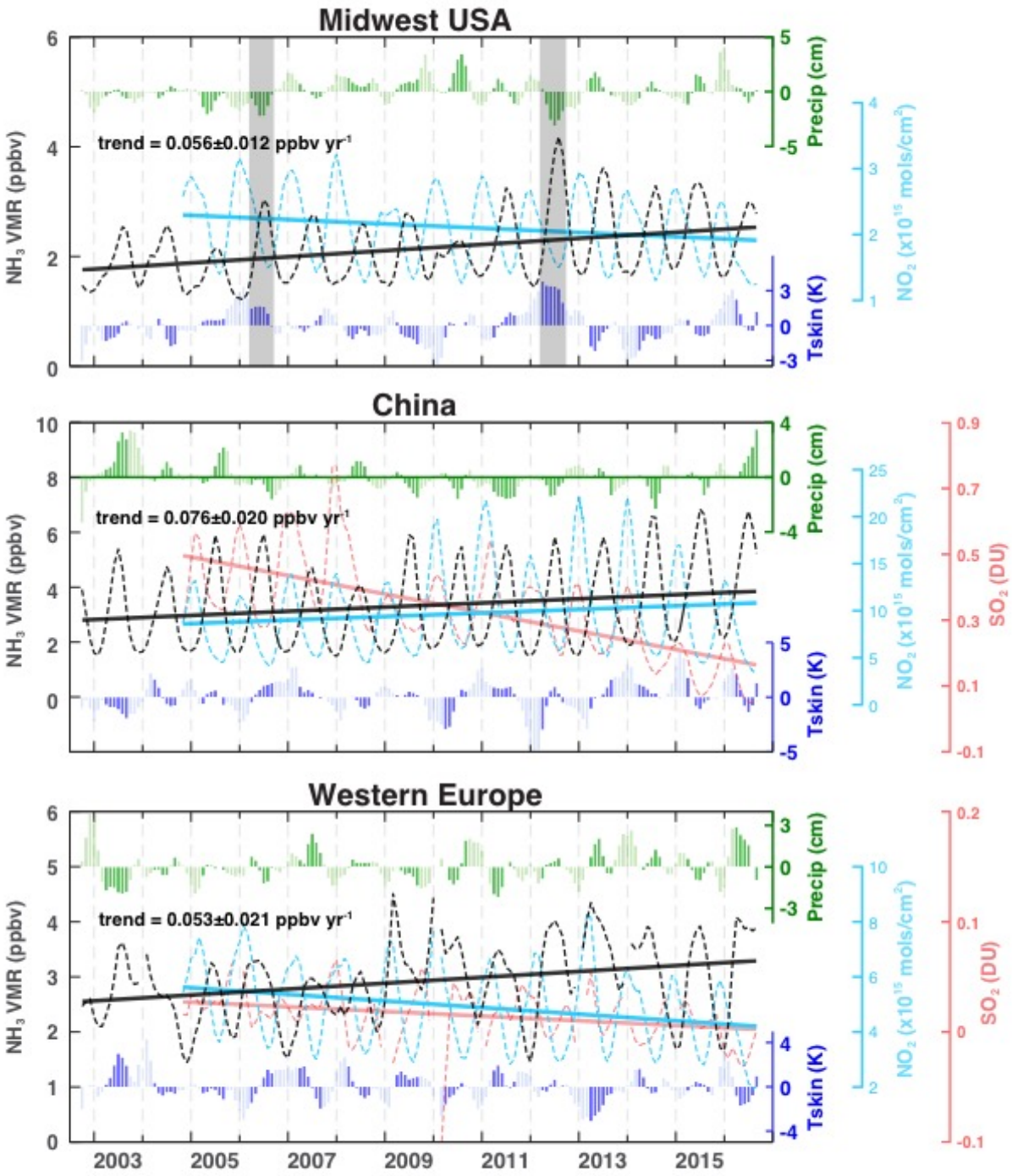



https://freshwaterwatch.thewaterhub.org/

# $NH_3$ over USA, China, India, and Europe

## Using high concentration and high frequencies






# AIRS $NH_3$ vs OMI $NO_2$ for US (top), $SO_2$ for China (middle) and $NO_2$ for Western Europe (lower)

All show increasing $NH_3$ trends (black) 2002-2016.

Decreased $SO_2$ largely explains the $NH_3$ increases in Midwest U.S. (not shown), China, and Europe.

OMI $NO_2$ decreasing explains winter $NH_3$ increasing over the US and Europe.

Meteorological conditions also affect $NH_3$ 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 $NH_3$ emissions.

# 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.