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

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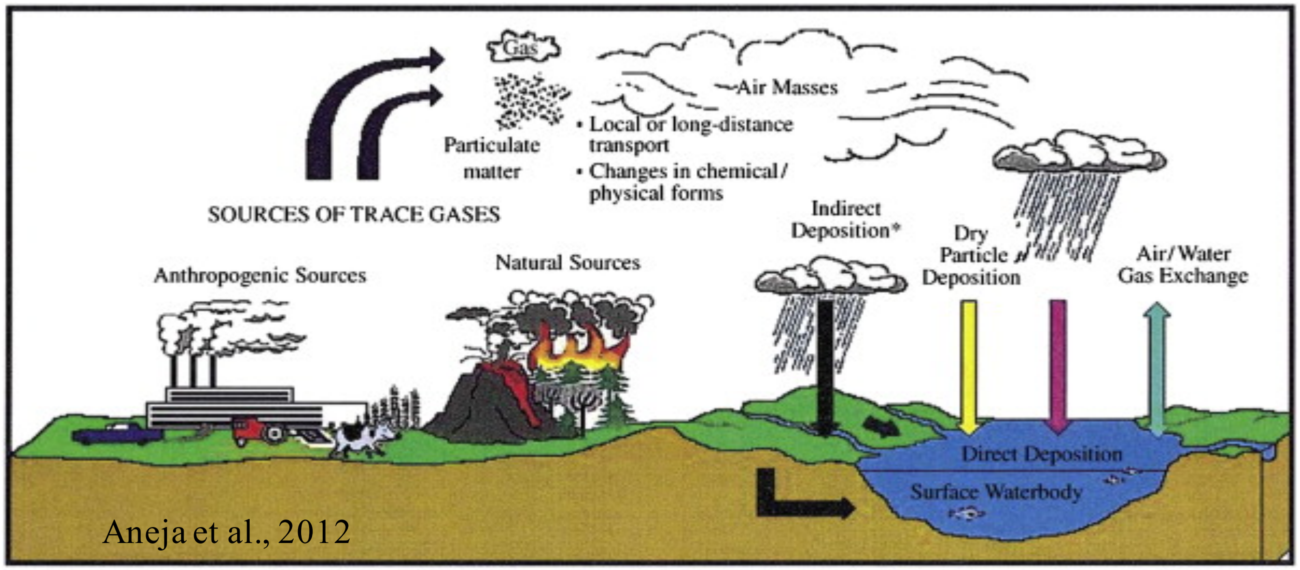
Why Ammonia (NH_3)

- 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 $PM_{2.5}$;

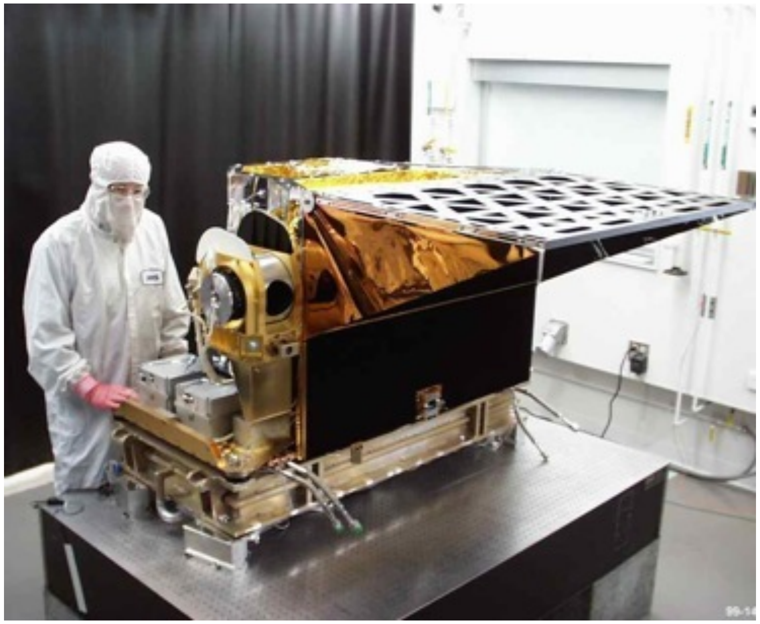
- Meteorological conditions (wind, rain, temperatures, etc.) affects the concentration of ammonia gases.

Why Satellite Remote Sensing

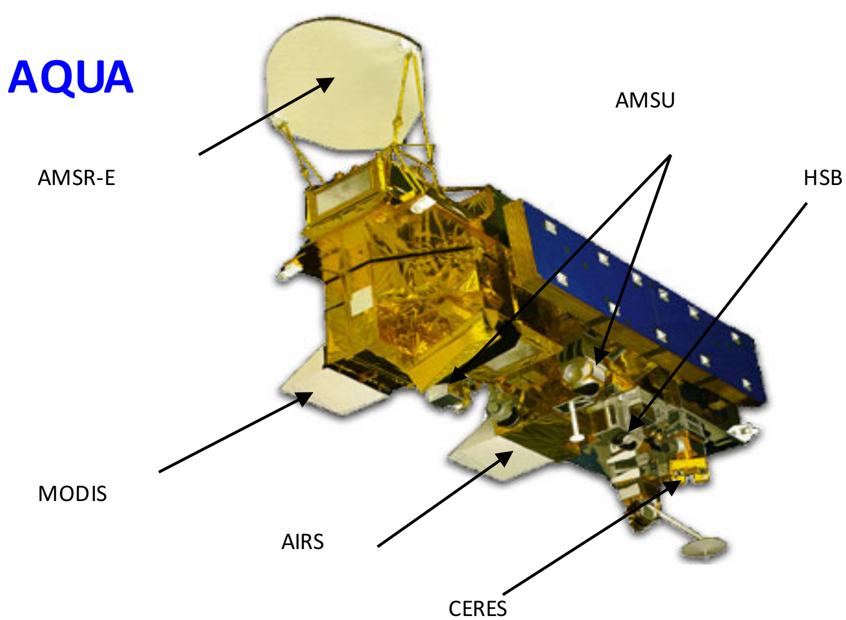
- ***Ammonia in situ measurements are rare, global coverage is impossible.***
- Satellite measurements with daily and large global coverage are challenging and have been lacking partly because ***the lifetime of NH_3 is relatively short*** and partly because it requires high sensitivity for the retrievals 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).

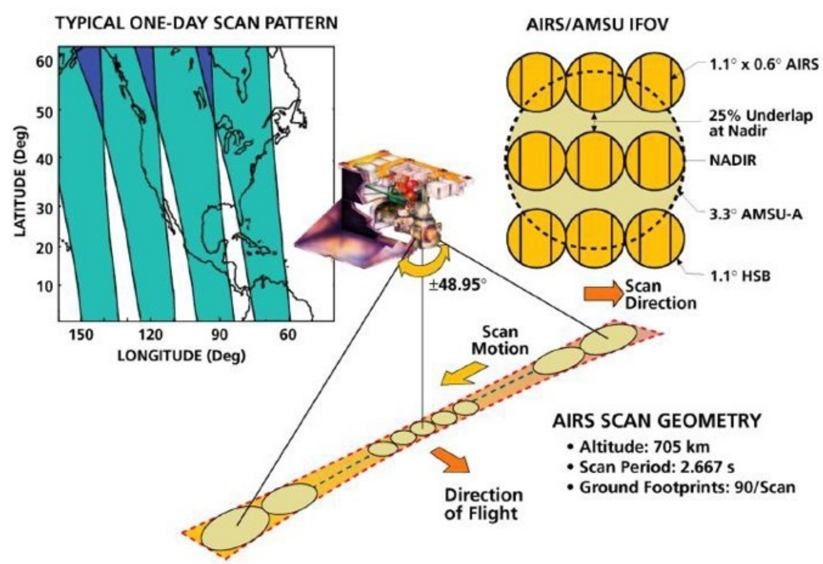
Atmospheric InfraRed Sounder (AIRS)

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



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

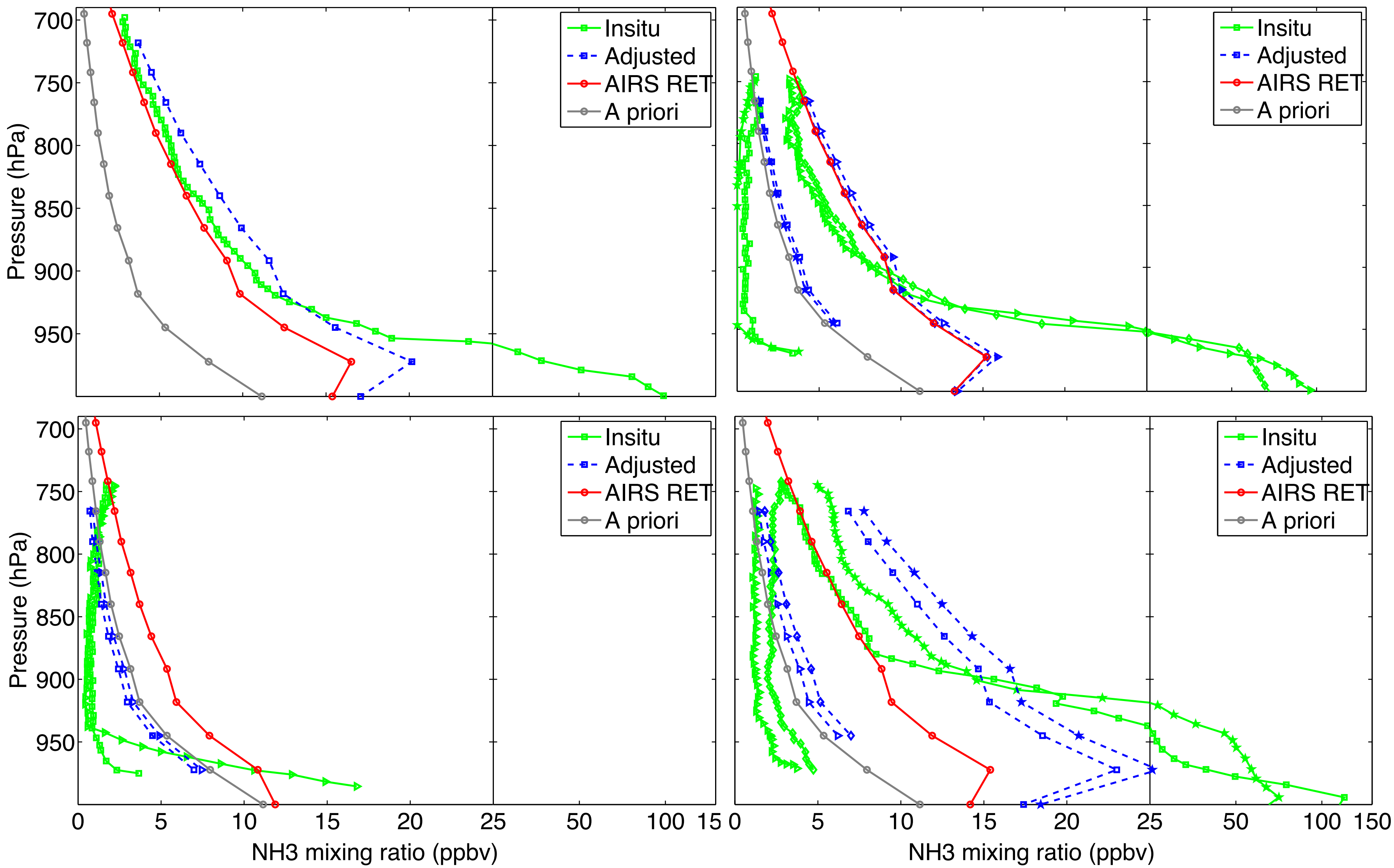




Validation vs CRDS/Picarro in DISCOVER-AQ CA

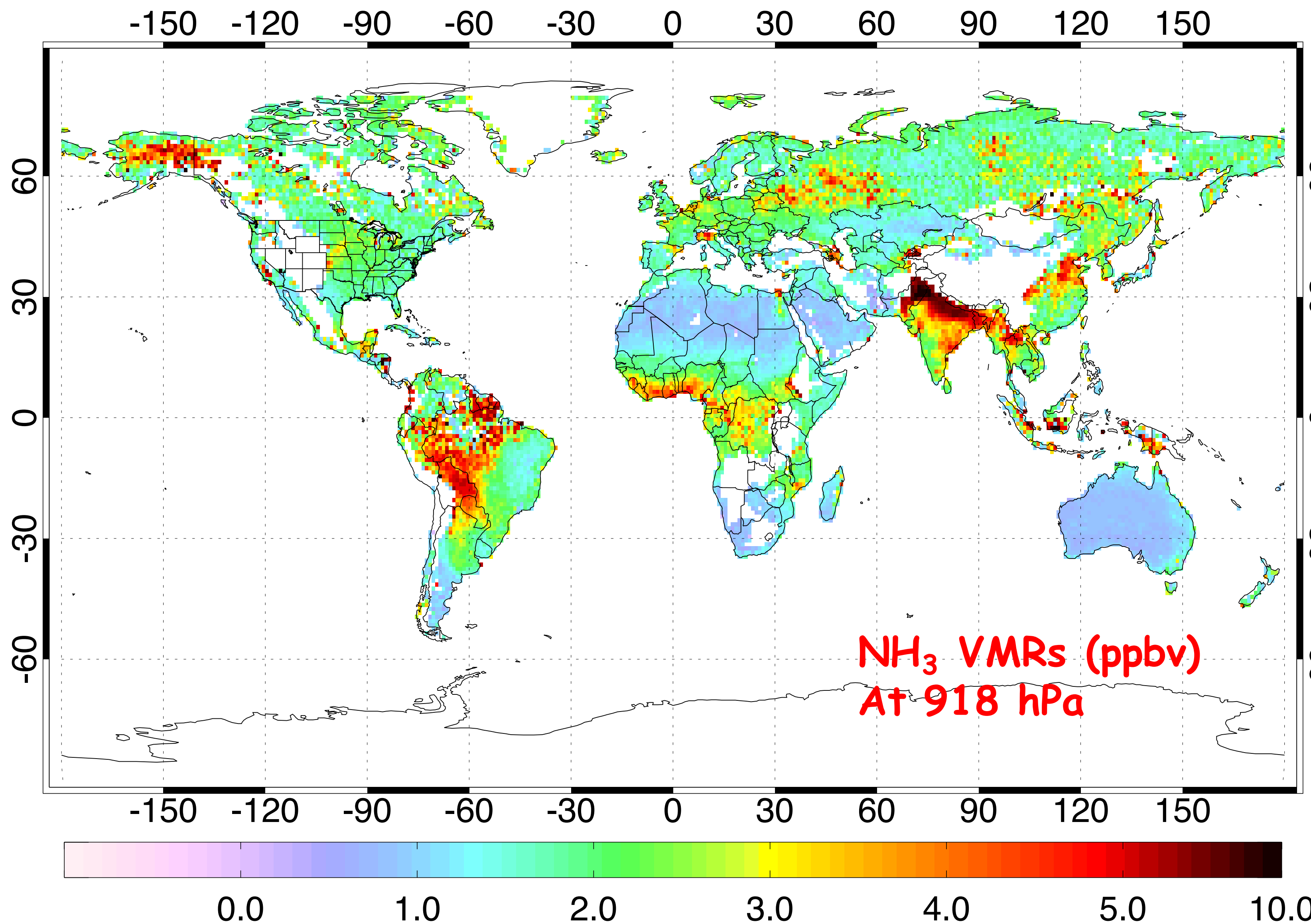
CRDS/Picarro Spiral Profiles Only - 01/16 to 02/06, 2013

(data courtesy of Co-author J. Nowak)



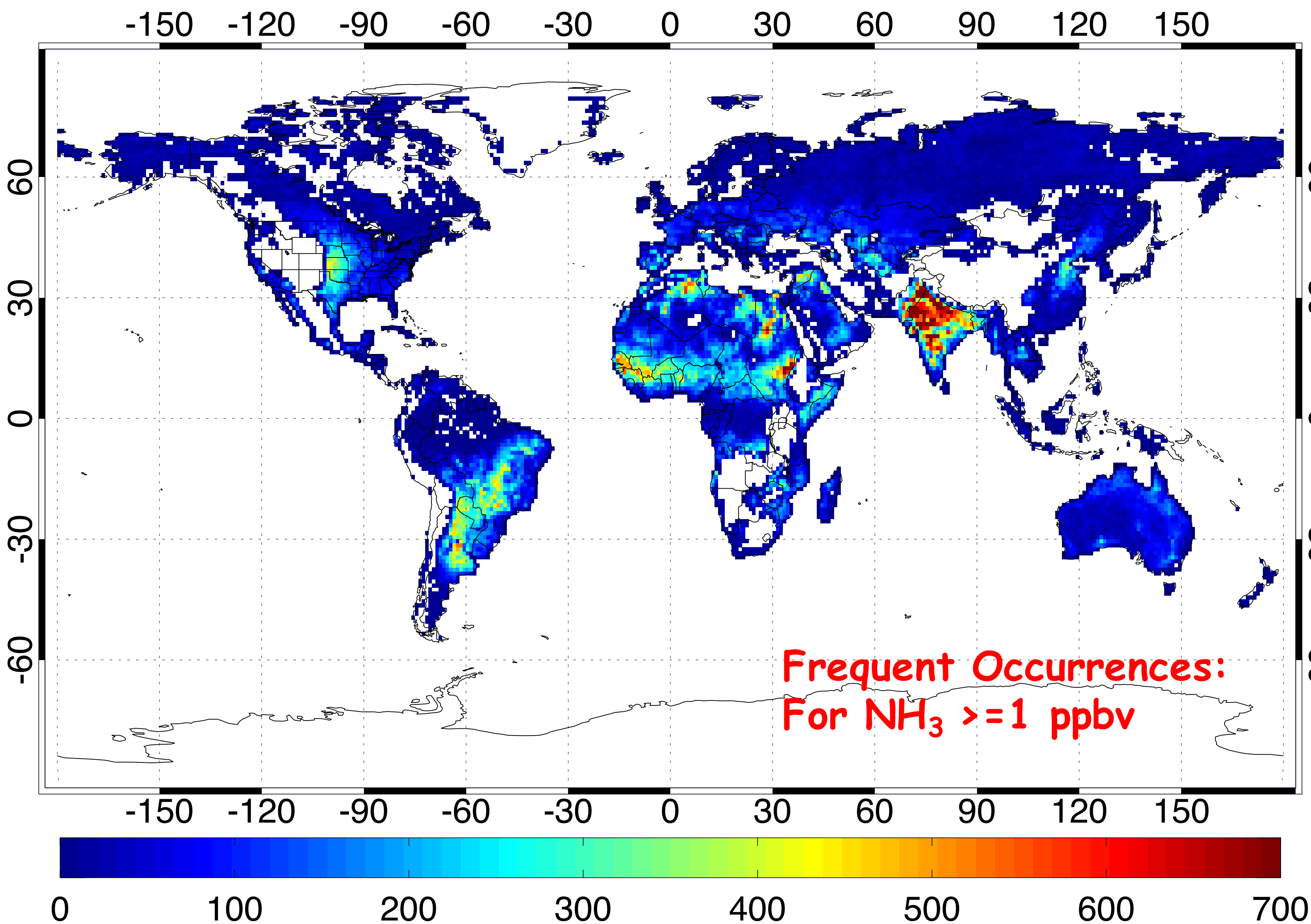
- Gray – a priori; Red – retrievals; Green solid – in situ; and Green dashed – convolved in situ.
- AIRS L2 pixel sizes are ~45 km^2, can coincide with multiple in situ profiles.
- AIRS NH_3 measurements are most sensitive at 850-950 hPa layer.

Global NH_3 in 2002-2015

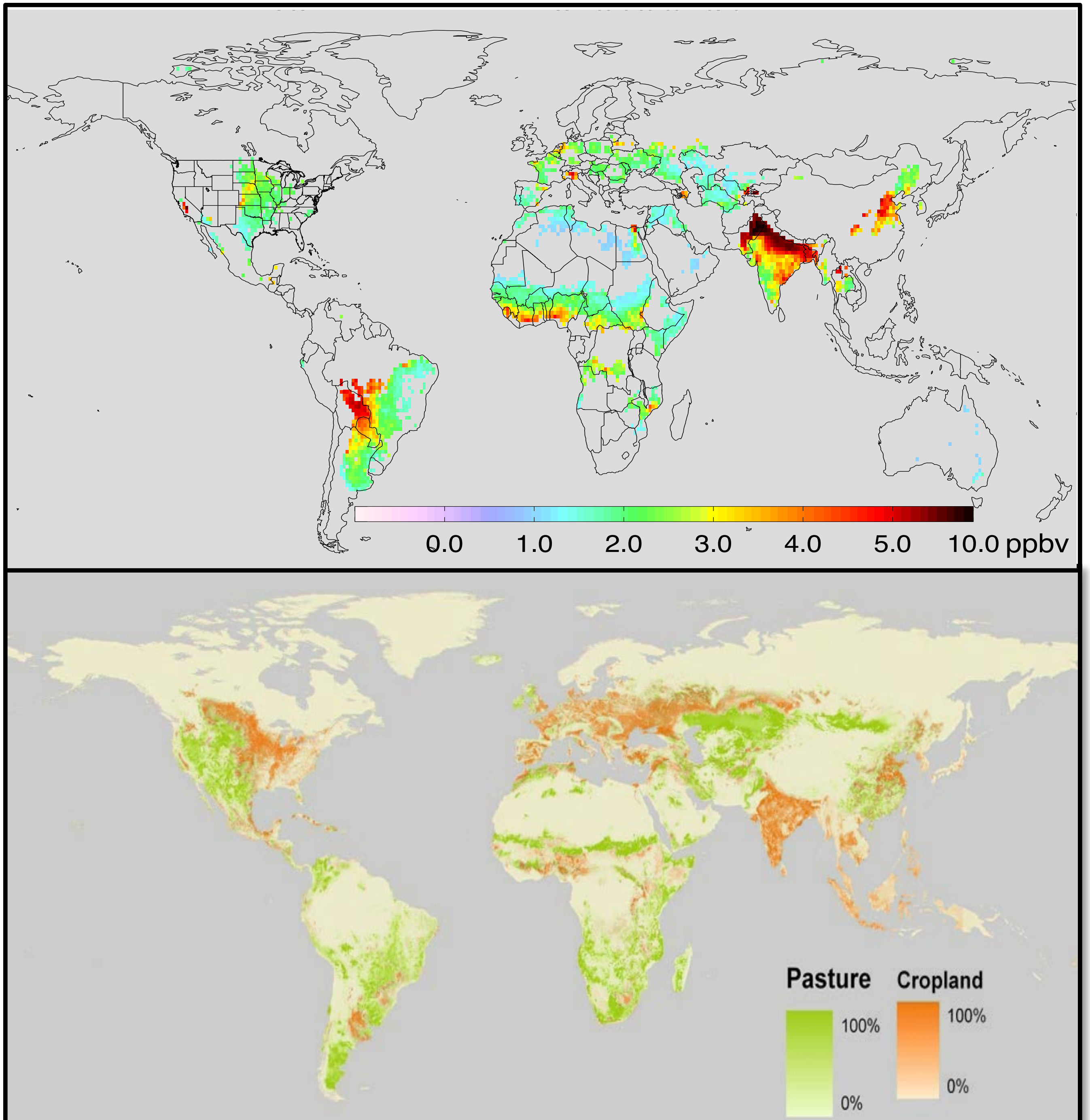


- High concentrations are mainly due to human activities and fires;
- Sources are seen in valleys (e.g., **San Joaquin Valley, California** in the U.S., the **Po Valley**, Italy, Fergana Valley, Uzbekistan, and the **Sichuan Basin** in China); Agricultural especially in irrigated lands (e.g., Azerbaijan,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



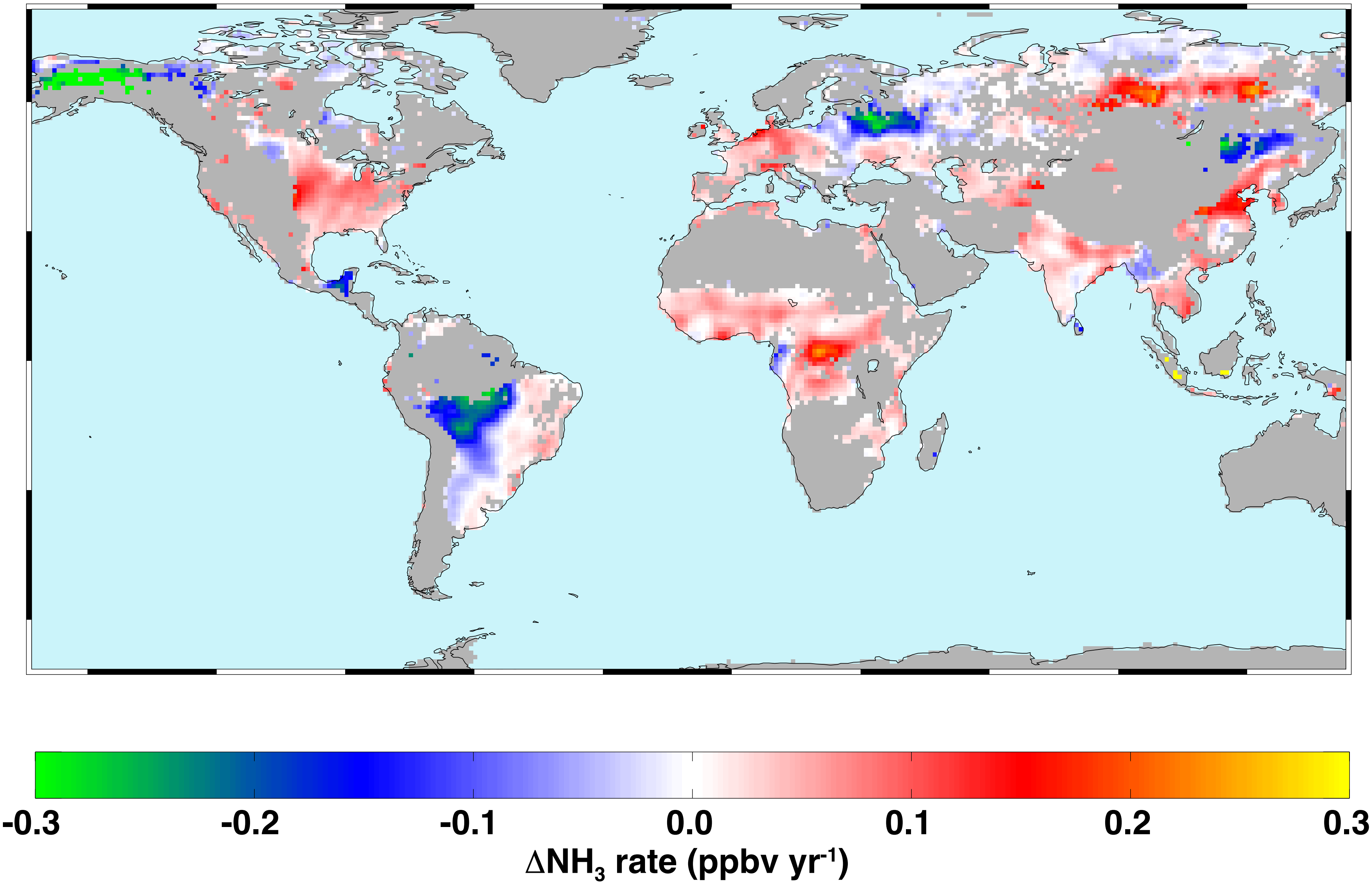
Use occurrences of higher emissions (lower) to distinguish between the two major sources: agricultural (high VMRs & high frequencies); BB emissions (high VMRs & low frequencies).



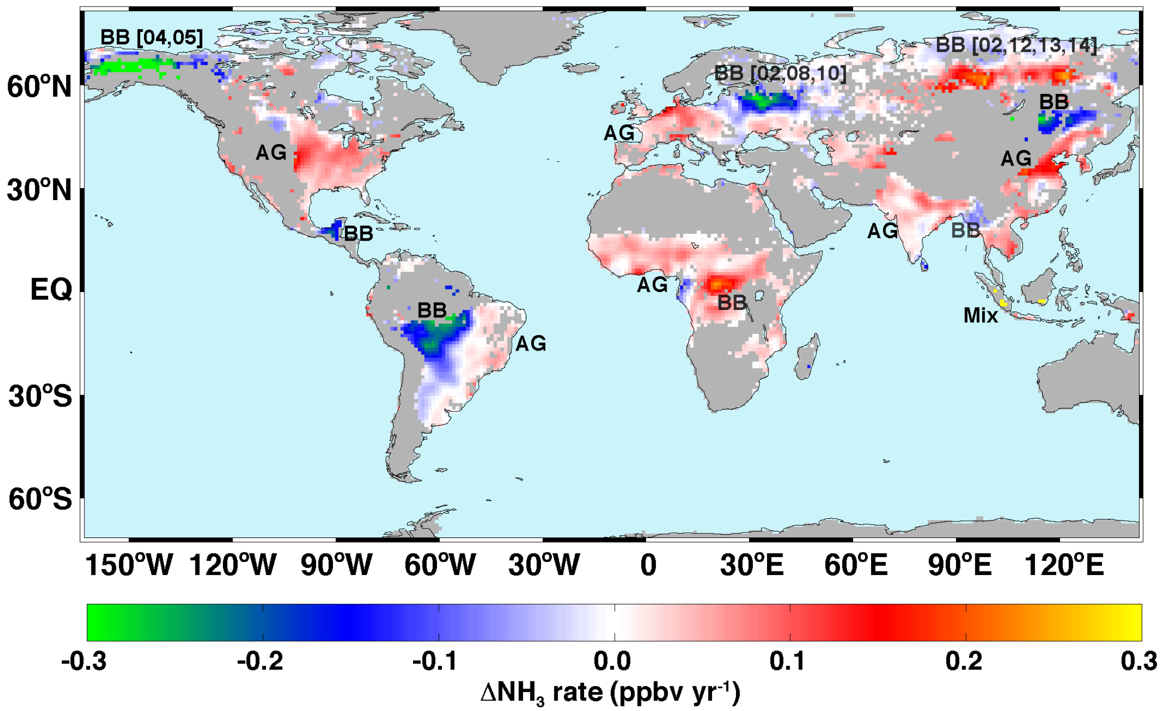
<u>Top panel:</u> The NH_3 VMRs from the persistent sources, i.e., ≥ 1.4 ppbv for more than 40 days;

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

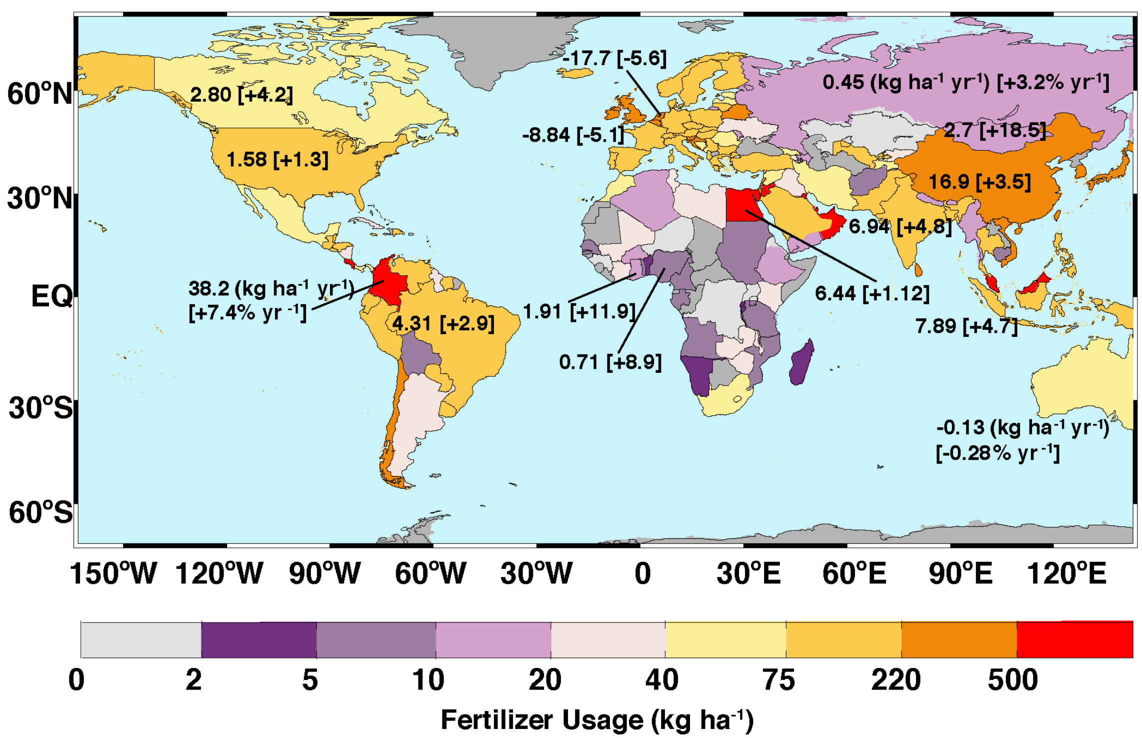
NH_3 Trends - Last 14 years



- 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



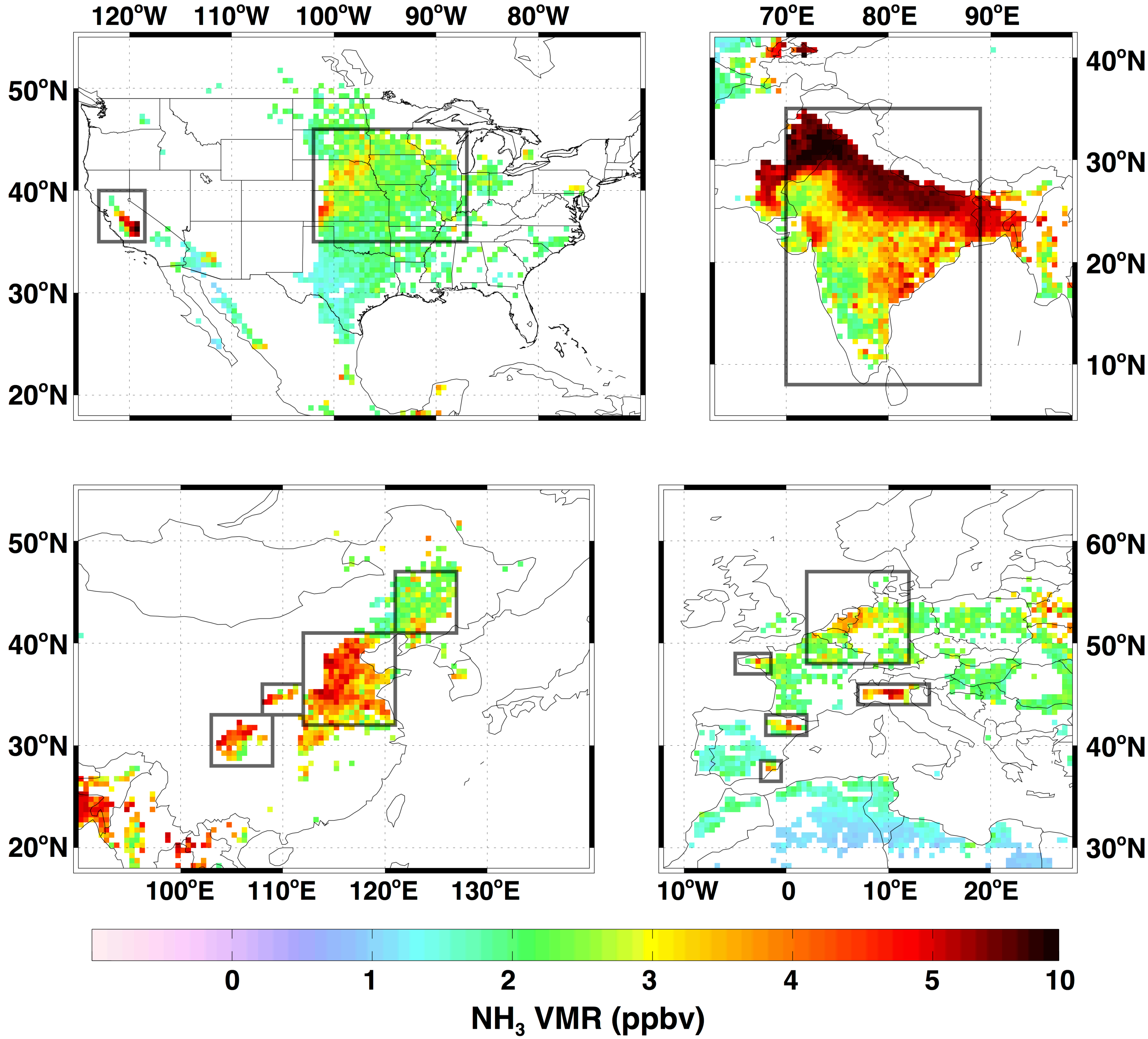
(top) Temporal trends; BB-biomass burning and AG-agricultural regions



(bottom) National averaged annual N fertilizer usage in 2002–2013 in kg ha^{-1} and trends (percentage changes)

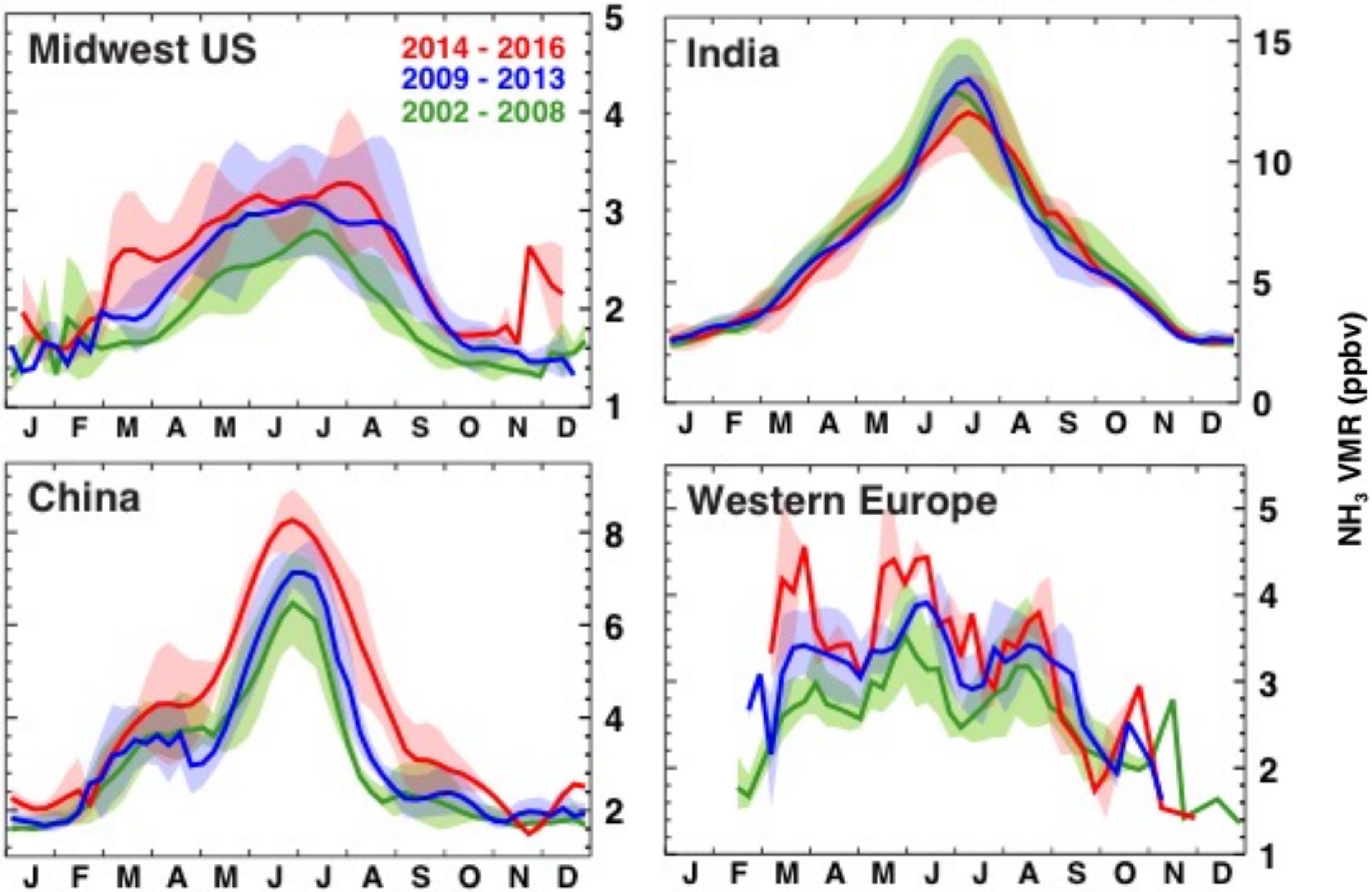
NH_3 over USA, China, India, and Europe

Using high concentration and high frequencies

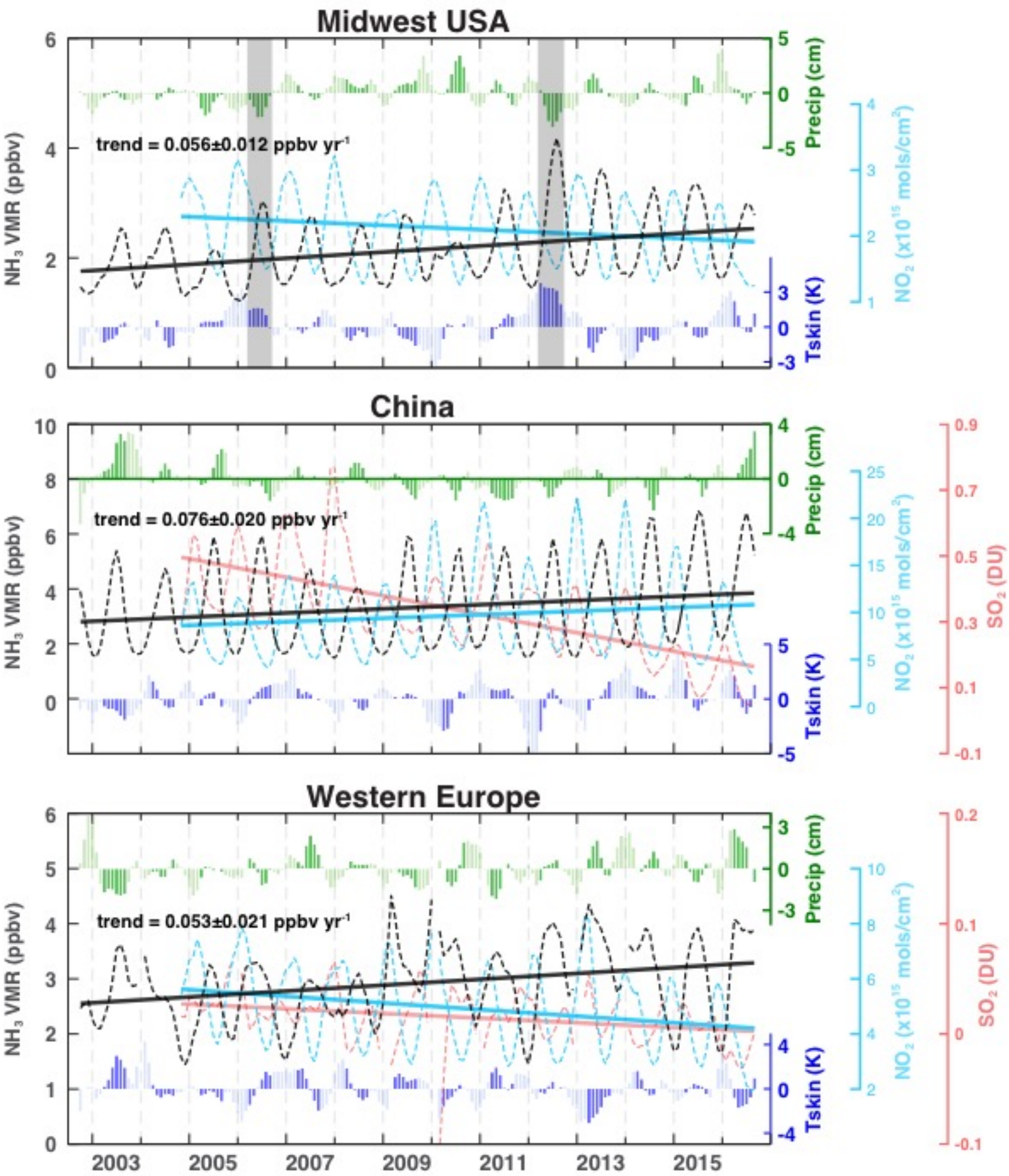


AIRS NH_3 Seasonal Variation

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



- The highest NH_3 concentrations in average occur in South Asia, and China. Note scales.
- NH_3 in India seasonal variation are broad and no obvious increasing/decreasing trends;
- NH_3 for USA, China and Europe have increased, with peaks in both spring and summer;



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.

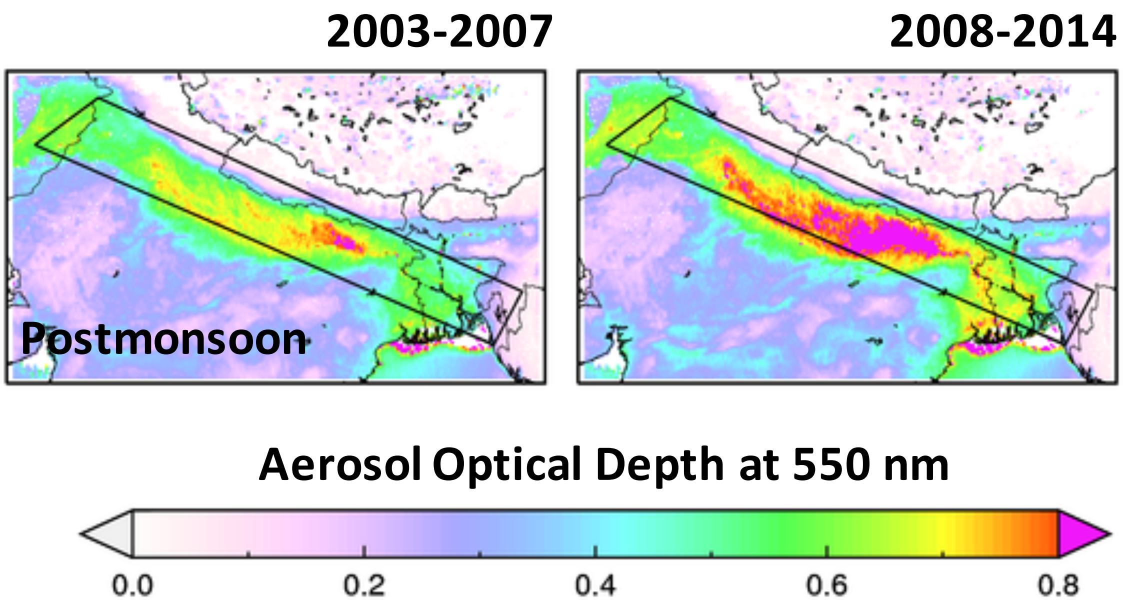
Decreased SO_2 largely explains the NH_3 increases in Midwest U.S. (not shown), China, and Europe.

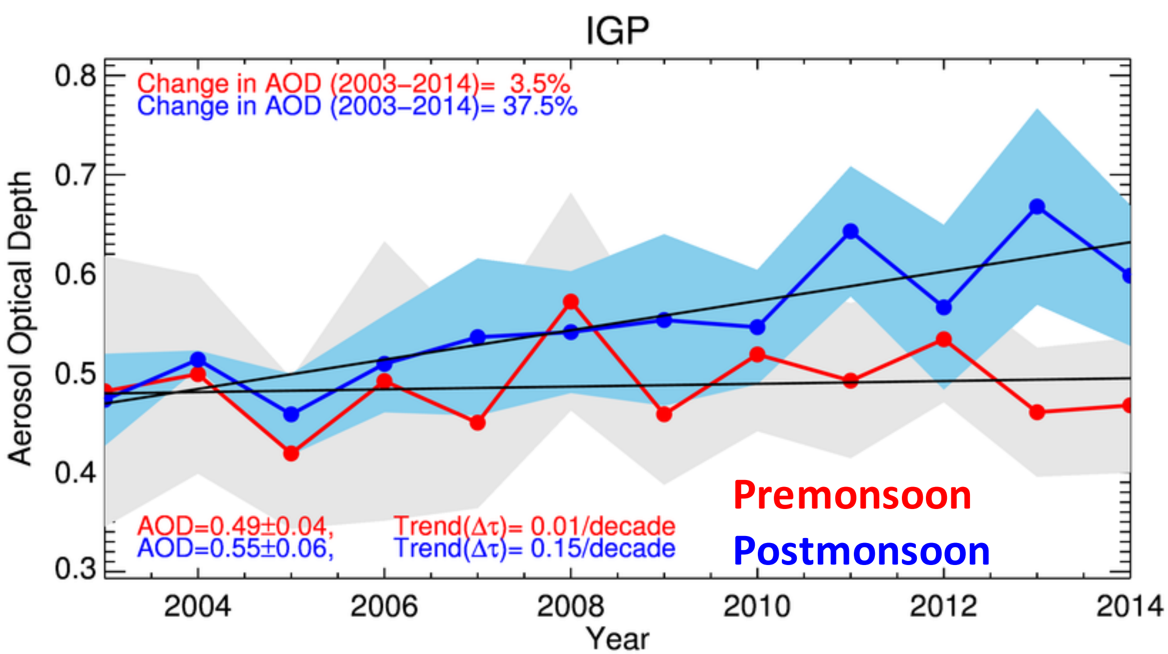
OMI NO_2 decreasing explains winter NH_3 increasing over the US and Europe.

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.

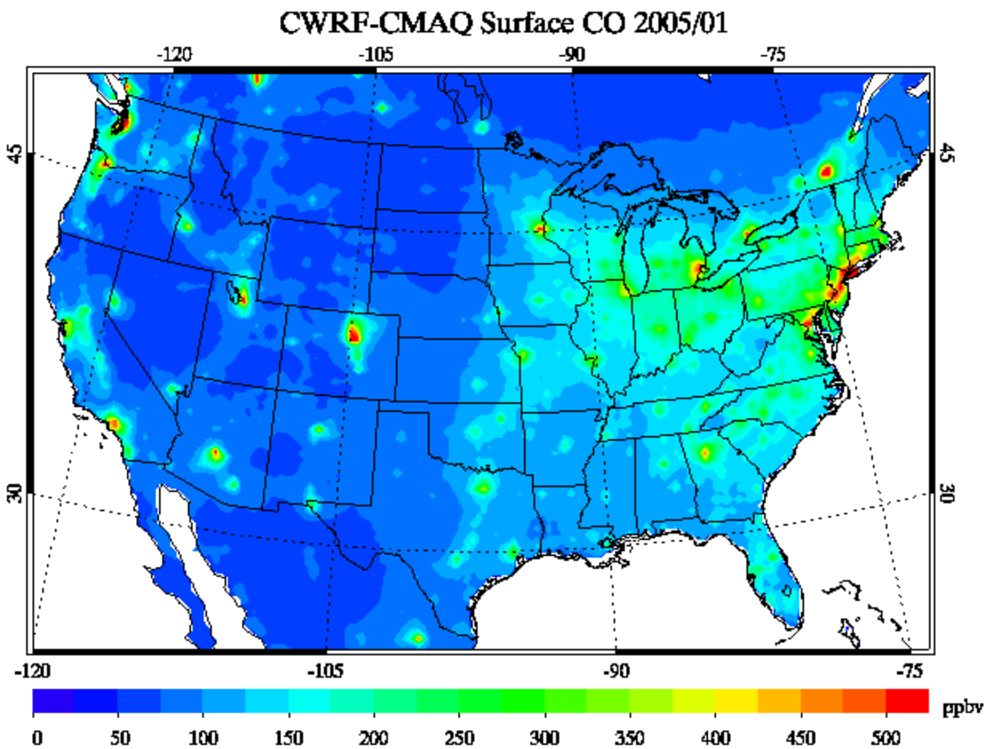
South Asia Aerosols Trends

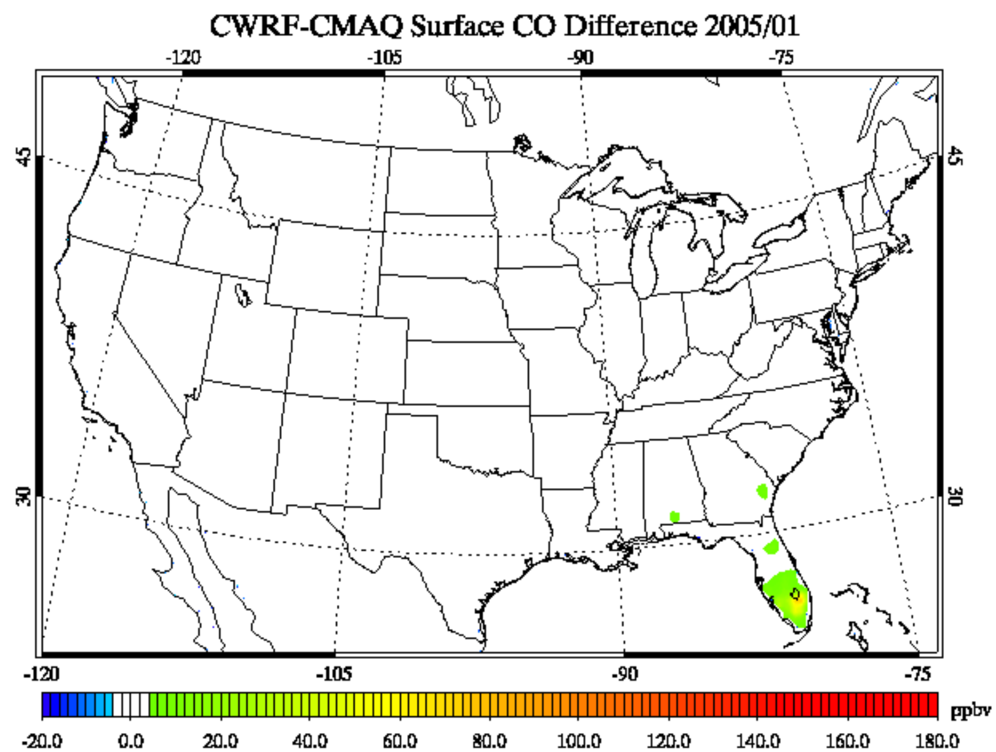




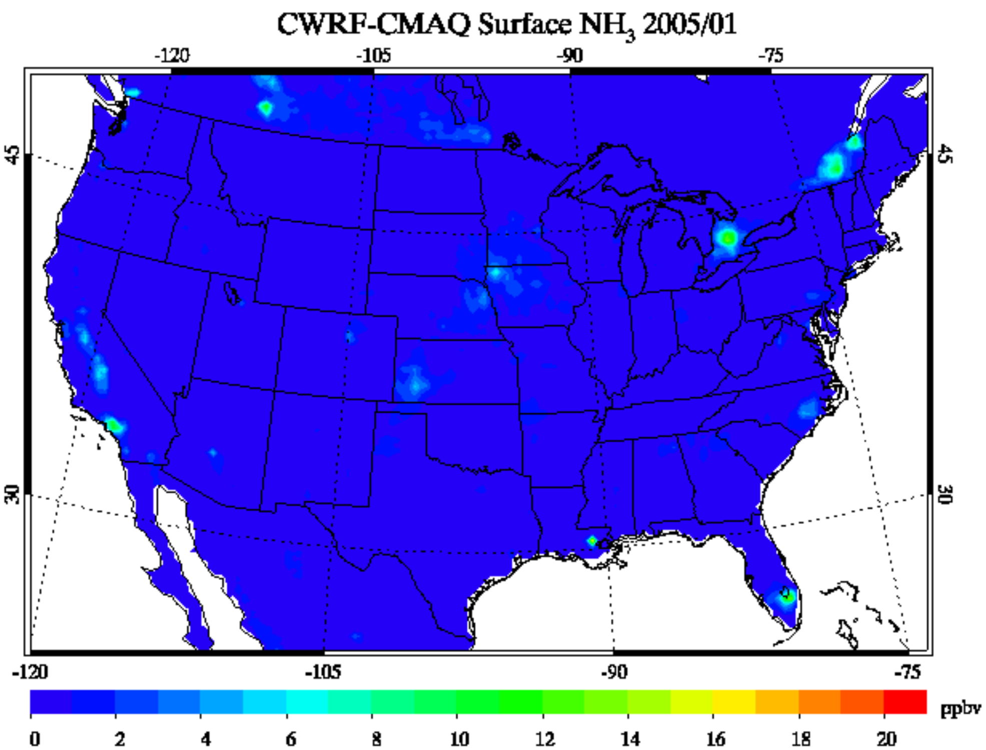
Courtesy of NASA MODIS team

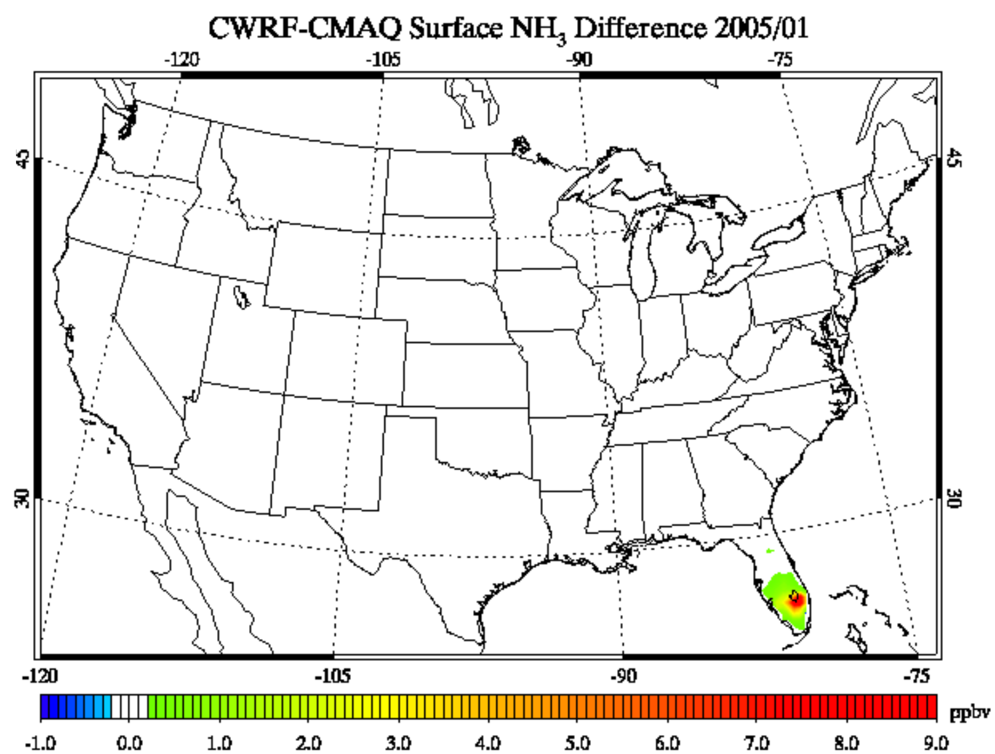
- No obvious NH_3 increased in the AIRS observations over South Asia, while the fertilizer usage has increased;
- Recent increases in SO_2 and NO_x from uncontrolled coal combustion and other sources;
- Greater conversion of gaseous NH_3 into particulate sulfates and nitrates.
- Dust influence in premonsoon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





Courtesy of Hao He - UMD





Courtesy of Hao He - UMD

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.