Observations of New Minor Gases with AIRS: NH_3 and HDO

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NH_3 Overview

- NH_3 major component of the global nitrogen cycle
- Global emissions primarily due to agriculture
- Environmental impact:
  1. Deposition of reactive nitrogen in sensitive ecosystems
  2. Enhanced creation of ammononium sulphate and ammonium nitrate aerosols (EPA PM2.5)
- In-situ measurements relatively sparse, especially in agricultural regions
- First observed with TES (Beer, et. al. GRL 2008). Global measurements using IASI (Clarisse et. al. Nature Geoscience 2009).
- Lifetime $<$8 hours, so observations are in the boundary layer
- Measurements are nominally only during daytime when hot surface allows one to sense absorption in the boundary layer
- *AIRS is probably more sensitive to NH_3 than IASI due to the 1:30 pm versus 9:30 am overpass time.*

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Approach

FOV Selection

- L2Sup: Total cloud cover < 0.3
- L2Sup: Qual.(Cloud_OLR,H2O,Surf,Temp_Profile_Bot) all <= 1
- L1b: calflag = 0 only
- L1b: additional scanline rejection done for undetected pops

NH_3 Channels

- Signal channels A: 930.44, 930.81, 931.18, 931.93 cm^{-1}
- Window channels A: 934.91, 935.28, 936.03, 936.41 cm^{-1}
- Signal channels B: 965.43, 966.23, 966.63, 967.03 cm^{-1}
- Window channels B: 969.04, 969.44, 970.24, 970.65 cm^{-1}

Output

- At present: $dBT = \langle(\text{Signal BT}) - (\text{Window BT})\rangle_{A,B}$

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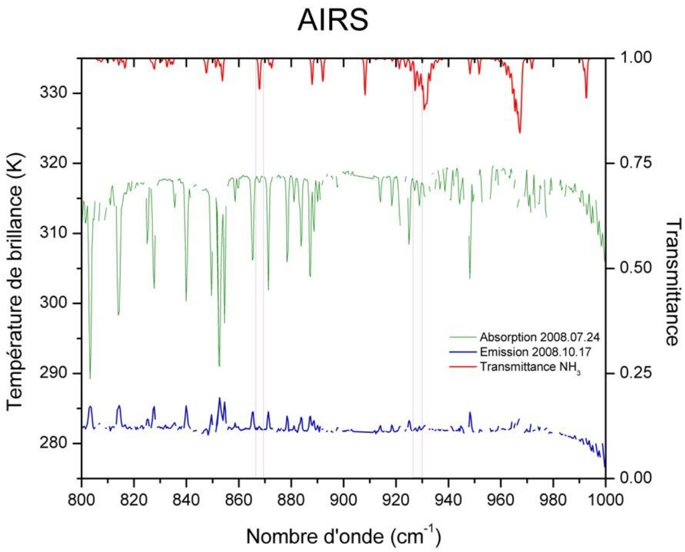
Spectrum of NH_3

Courtesy of Lieven Clarisse, Univ. Libre de Bruxelles



IASI World Map of NH_3

nature geoscience
LETTERS
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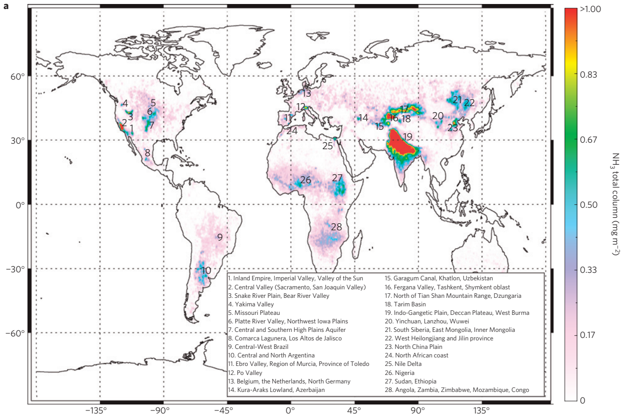
Global ammonia distribution derived from infrared satellite observations

Lieven Clarisse[1]*, Cathy Clerbaux[2], Frank Dentener[3], Daniel Hurtmans[1] and Pierre-François Coheur[1]



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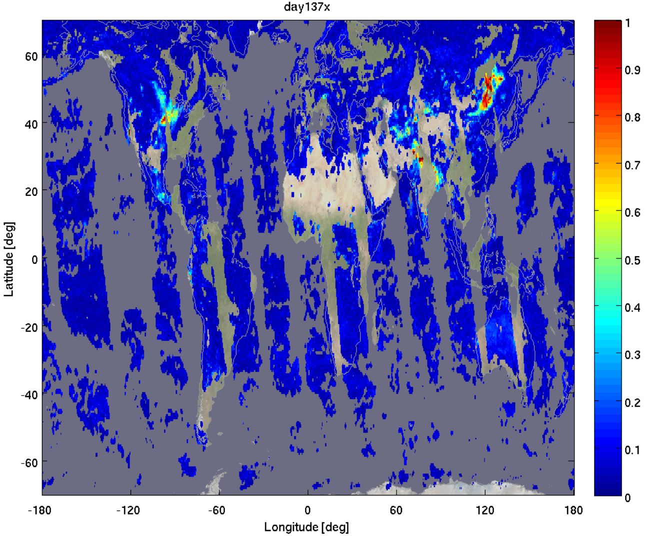
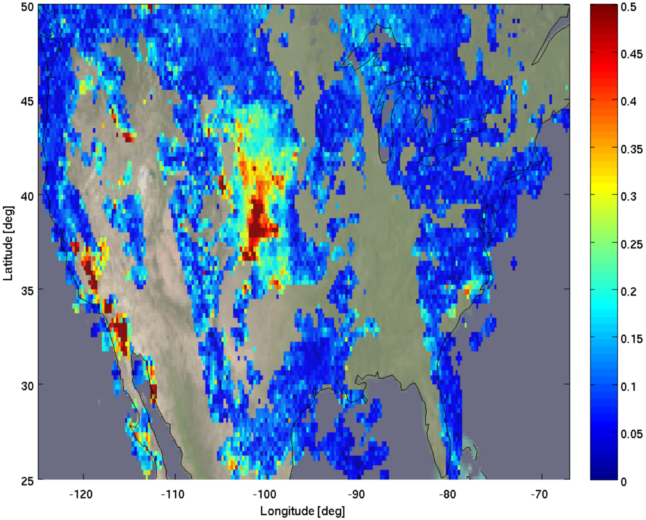
AIRS 1-Day World Map of NH_3

Single Day of NH_3 BT Signal



AIRS 1-Day USA Map of NH_3

Single Day of NH_3 BT Signal



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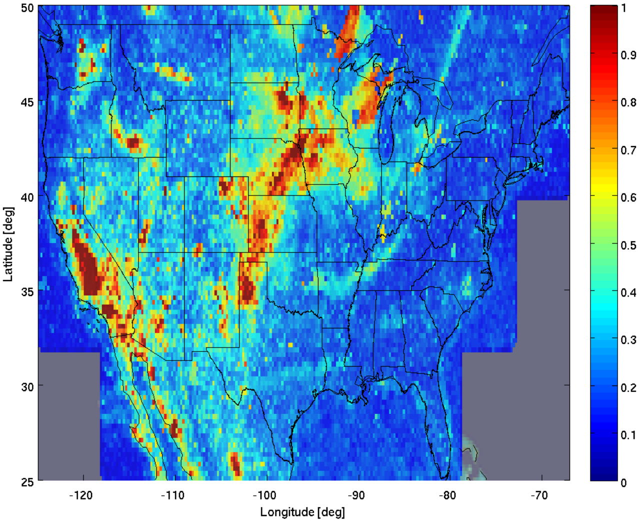
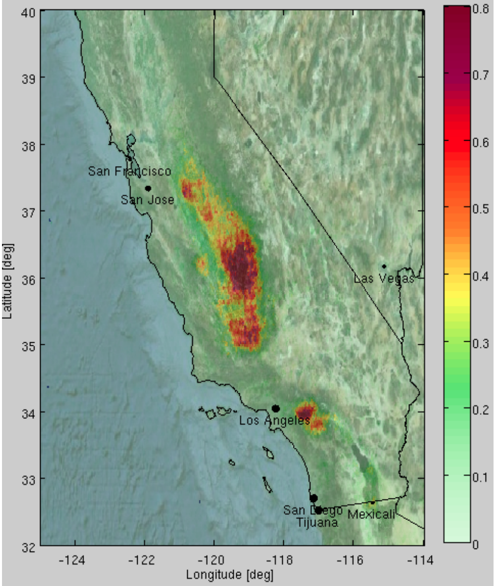
Max NH_3 for USA over 1-Year

Maximum per Pixel over 1-Year



High Resolution Map of NH_3 in California

Note San Joaquin Valley



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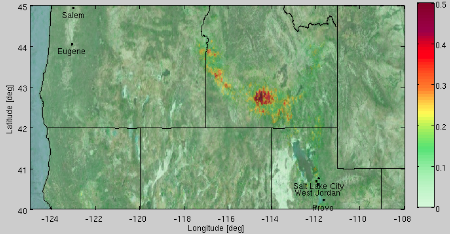
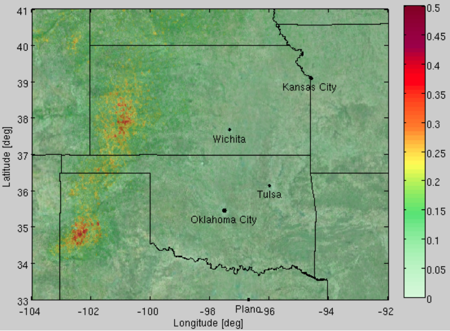
High Resolution Map of NH_3 in Idaho and Kansas





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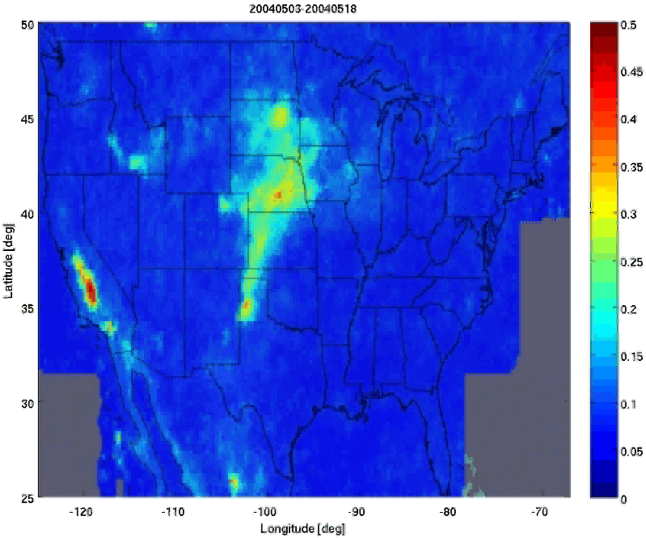
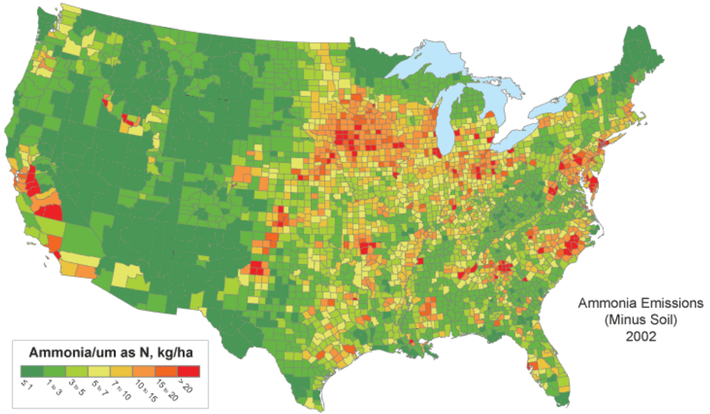
16-Day Average NH_3 in US

Keep features in mind for upcoming slides.

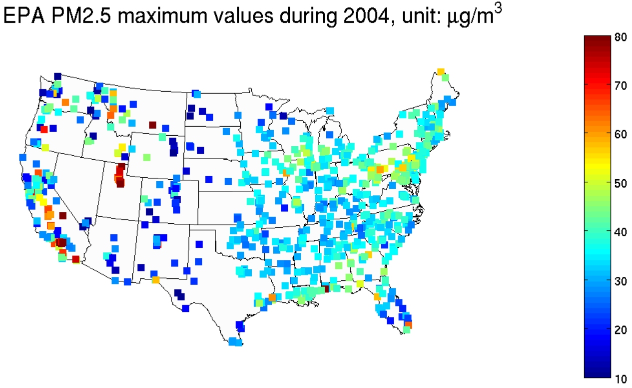


Model NH_3 Emissions (excluding soil)

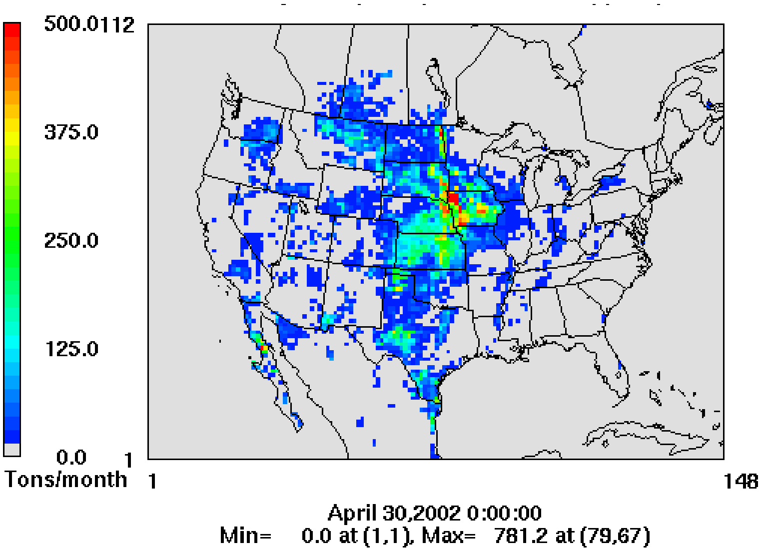


Map of EPA PM2.5 Max Values during 2004

PM2.5 is fine particle aerosol that produces poor air quality.



PM2.5 Estimates.. Source Uncertain



NH_3 Controls Cost-Effective for Improved Air-Quality

Ammonia Emission Controls as a Cost-Effective Strategy for Reducing Atmospheric Particulate Matter in the Eastern United States

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Current regulation aimed at reducing inorganic atmospheric fine particulate matter ($PM_{2.5}$) is focused on reductions in sulfur dioxide (SO_2) and oxides of nitrogen ($NO_x \equiv NO + NO_2$); however, controls on these pollutants are likely to increase in cost and decrease in effectiveness in the future. A supplementary strategy is reduction in ammonia (NH_3) emissions, yet an evaluation of controls on ammonia has been limited by uncertainties in emission levels and in the cost of control technologies. We use state of the science emission inventories, an emission-based regional air quality model, and an explicit treatment of uncertainty to estimate the cost-effectiveness and uncertainty of ammonia emission reductions on inorganic particulate matter in the Eastern United States. Since a paucity of data on agricultural operations precludes a direct calculation of the costs of ammonia control, we calculate the "ammonia savings potential", defined as the minimum cost of applying SO_2 and NO_x emission controls in order to achieve the same reduction in ambient inorganic $PM_{2.5}$ concentration as obtained from a 1 ton decrease in ammonia emissions. Using 250 scenarios of NH_3, SO_2, and NO_x emission reductions, we calculate the least-cost SO_2 and NO_x control scenarios that achieve the same reduction in ambient inorganic $PM_{2.5}$ concentration as a decrease in ammonia emissions. We find that the lower-bound ammonia savings potential in the winter is \$8,000 per ton NH_3; therefore, many currently available ammonia control technologies are cost-effective compared to current controls on SO_2 and NO_x sources. Larger reductions in winter inorganic particulate matter are available at lower cost through controls on ammonia emissions.

NH_3 Conclusions

- Much work to be done to turn BT signal into NH_3 amount
- Juying Warner has submitted a ROSES proposal to produce this NH_3 product using approach she used to obtain outstanding AIRS CO accuracies (Optimal Estimation).
- AIRS orbit time and high spatial coverage could make this product extremely important for EPA and our understanding of the nitrogen cycle.
- Hope we don't miss this opportunity!

My own contributions to atmospheric NH_3

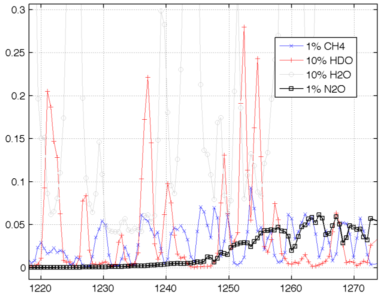
HDO Overview

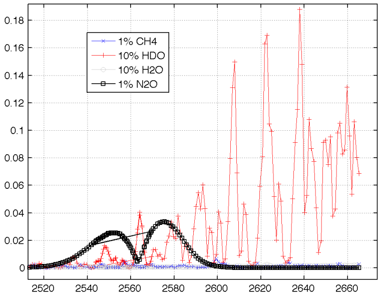
- H_2O preferentially evaporates while HDO preferentially condenses. The HDO/H_2O ratio gives information on water vapor sources, sinks.
- Accurate global HDO/H_2O ratios may provide strong test of climate model dynamics and water cycling
- The AIRS RTA uses a constant HDO/H_2O ratio. But, the H_2O retrieval uses a number of HDO lines!
- Consequently, the AIRS H_2O retrieval may have errors of 10-20+% in regions with a low HDO/H_2O ratio.
- Since AIRS has strong, well separated HDO spectra in the shortwave, an accurate HDO/H_2O ratio retrieval may be possible.

HDO vs H_2O in AIRS Spectrum

Shortwave AIRS is just HDO!

HDO is not a separate gas in the AIRS RTA

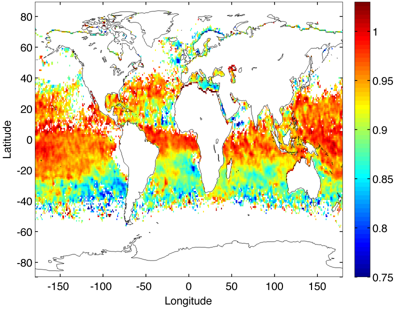


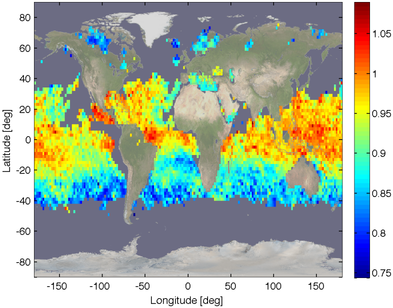


Two Approaches to HDO with AIRS (both column)

(Left) Use SW (HDO) versus LW (H_2O) to get HDO/H_2O ratio

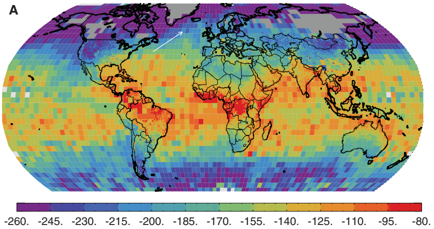
(Right) Ratio SW (HDO) AIRS amount to ECMWF model H_2O

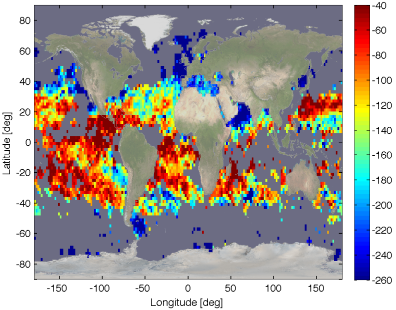




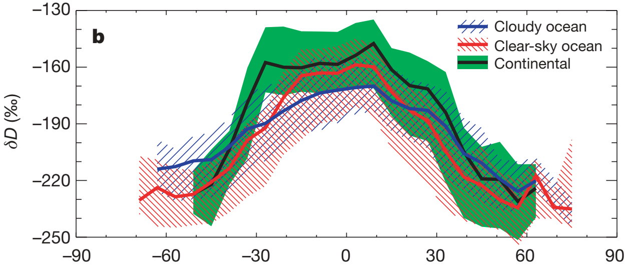
SCIAMACHY (left) vs AIRS (right) HDO

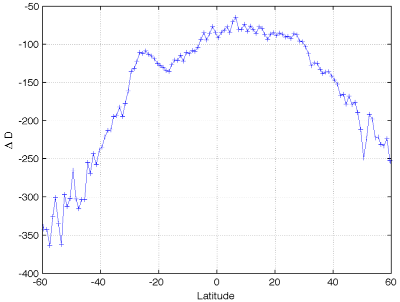
$\bar{\delta D} = 1000\% \times \left(\frac{VCD(HDO)/VCD(H_2O)}{R_s} - 1 \right)$ where VCD = Vertical Column Density, R_s is HDO/H_2O ratio in sea water.





TES (top plot) versus AIRS (bottom plot) HDO





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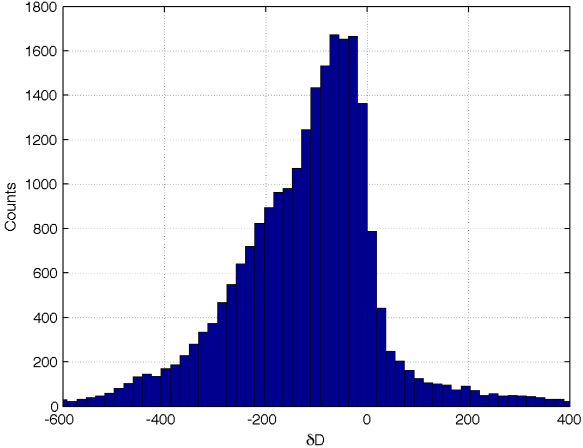
Histogram of δD Values

Shows sharp cutoff near zero where HDO to H_2O ratio reaches nominal sea water value.



HDO: Conclusions

- Very simple retrieval technques show that AIRS can detect very realistic HDO/H_2O ratios.
- At present, the AIRS radiative transfer algorithm (RTA) does not differentiate between HDO and H_2O. It uses a standard, constant value for that ratio.
- AIRS H_2O retrievals will be biased by 10-20+% in some regions (high latitudes) and times depending on how heavily the SW HDO channels are used in the retrieval
- A careful HDO retrieval with AIRS may yield important information on the water cycle
- HDO retrievals are also proposed in Juying Warner's ROSES proposal.