Ammonia from TES: Limits and Possibilities

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NH₃ Sources and Sinks

Long-range import

NH₄NO₃ ⇌ NH₃ + HNO₃

Bi-directional Flux

Emissions

Long-range export
Ammonia is an integral part of the nitrogen cycle

- Nitrogen in ammonia is deposited to the Earth’s surface and leads to:
  - Nutrient imbalances
  - Changes in ecosystem composition
  - Algal blooms and hypoxia (oxygen depletion)

Secondary Inorganic Aerosol Formation

- Ammonia (gas) reacts with sulfate and nitric acid
  - Produces ammonium sulfate and ammonium nitrate (aerosol-phase)

Air Quality

- Responsible for 10-20% of fine particulate matter (PM2.5)
  » Often exceeds recommended threshold (WHO, 2003)
- Exposure to aerosol concentration is associated with health issues
  » Cardiovascular disease, inhibited lung development, premature death

Climate

- Direct radiative forcing by ammonium aerosols
NH₃ Spectral Signature in the TES Observations

TES Obs. over Central Valley

TES - LBLRTM
initial guess NH₃

Windows selected to minimize H₂O interference

TES - LBLRTM with retrieved NH₃, SFCT, emissivity
TES NH$_3$ Averaging Kernel

TES NH$_3$
Averaging Kernels

- TES retrieval sensitivity at each level
- $\sim$1 DOFS (piece of information) but exact peak sensitivity is variable > multiple retrieval levels
- Peak retrieval sensitivity at $\sim$1.0km ($\sim$900mb)
- $\sim$2 km vertical resolution
Detectability test

- Simulated 540 spectra
- Defined NH$_3$ signal:
  \[ \frac{|BT_{NO\_NH3}-BT_{NH3}|}{NedT} \]
  - SNR > 1
  - SNR < 1
- Signal >1 @ ~1ppbv

TES NH$_3$ signal
TES NH\textsubscript{3} Validation: Transects over North Carolina

Region of intense livestock farming

- Hog farms are largest source

Transects started in early February 2009

- Will run through December 2010

- CAMNet NH\textsubscript{3} monitoring sites match-up with TES overpass

- Allows detection of spatial variability and seasonal trends

CHALLENGE

- **TES**: instantaneous profile over 5x8 km

- **CAMNet**: two week average at a surface point
Validation option: remove a dimension

Same spectrum - different \textit{a priori}

RVMR

Representative Volume Mixing Ratio

- Uses a transformation matrix derived from the AK
- Maps from retrieved levels to a reduced set determined by the amount of information (DOFS)

- Reduces effect of the \textit{a priori}

Payne et al., 2009
Correlation results

**Instantaneous RVMR vs surface two-week mean**

No correlation between all TES measurements and surface two week means. Correlation improves when only TES daytime observations are included.
What TES sees during the day

Summer maximum

Information content is at useful level

Sensitivity peaks between 900 and 700 mbar

Error due to noise less than 10%
Comparing daytime TES and CAMNeT

Monthly Means

Aggregation by source density

NH₃ (ppb)

April

May

July

August

October

CAMNet
TES RMVR

NH₃ (ppb)

<5

5–20

>20

number of livestock facilities within 10 km

373

23

290

31

389

24
What TES sees at night

Higher nighttime variability
Less information content
Sensitivity peaks close to surface

BL often becomes shallower and more stable at night

- NH3 concentration increases
- Lack of mixing leads to pooling and greater spatial variability
Barren North: low NH$_3$

Next Step: compare with appropriate land use measure

Dense agriculture south of Fresno:

high NH$_3$
TES NH3 over North America - April 2006

Retrieved NH3 Total Column Density, April 2008

NH3 Total Column Density ($10^{16}$ mol/cm$^2$)

0  5  10  15  20  25  30  >35
**Limits and possibilities**

TES can detect NH$_3$ in profiles with at least 1 ppbv
- Poor thermal contrast, temperature inversions and clouds raise this threshold

TES NH$_3$ has approximately 1 DOF

Useful Global Survey retrieval results are relatively sparse

TES NH$_3$ retrievals are sensitive enough to:
- Show distinct day/night differences and daytime seasonal cycle over North Carolina
- Detect spatial gradients associated with land use in the Central Valley
- Provide continental (and global) retrievals for assimilation in regional and global air quality models
  - goal is to reduce uncertainties in emission models

Retrieval algorithm and validation papers will be submitted this fall

NH$_3$ will be a TES L2 product in the next release
Current estimates of NH₃ profiles

- Obtained from GEOS-Chem monthly mean output for 2005
- Binned by lower tropospheric ammonia amounts
- Range over two orders of magnitude
- Concentration peaks low in the atmosphere

Binning Thresholds →

- Unpolluted: NH₃ < 1 ppbv
- Moderately Polluted: 1 < NH₃ < 5 ppbv (below 500 mb)
- Polluted: NH₃ > 5 ppbv (surface)
Simulated TES Retrieval Results

- TES - Truth (with AK and \textit{a priori} applied)
  - Std. : \(-0.5 \text{ ppbv}\) (red dashed line)
  - Mean diff : \(+0.5 \text{ ppbv}\) (red solid line)

- Avg. \(~1\) DOF (piece of information)
- Avg. peak sensitivity at \(~1.5 - 2\) km (\(~825\)mb)
- Avg. \(~2\) km vertical resolution

Statistics derived from retrieved values with SRAK > 0.5
Why Measure Ammonia from Space?

*In situ* (mostly surface) measurements are *sparse*

- Uncertainty in the *seasonal* and *spatial* variability
- Lack of direct NH$_3$ obs. leads to *large uncertainties* in modeled emissions
  - CMAQ (regional) : peak emissions during *fertilization* application in *spring* (April)
  - GEOS-Chem (global) : peak emissions with *high temperatures* in *summer* (July)

**Satellite measurements have potential to constrain the NH$_3$ emissions**

**US EPA Monitoring Network**

*(Gary Lear)*
TES NH₃ Sensitivity: Some different perspectives

Information content depends on
• NH₃ amount and distribution
• thermal contrast
• structure of the temperature profile

Elevated concentrations can be detected through some cloud
Validation: reconciling different views

One option - build a profile:
- add model (CMAQ) profile to surface value
- Apply TES AK

Another option: define a new representative metric derived from TES NH3 profile:
- Boundary Layer VMR (BLVMR)

Use the AK to build a mapping from the retrieved profile to a single value:
- 1 DOF > 1 value > 1 broad layer