Ammonia Research
NOAA
Air Resources Laboratory

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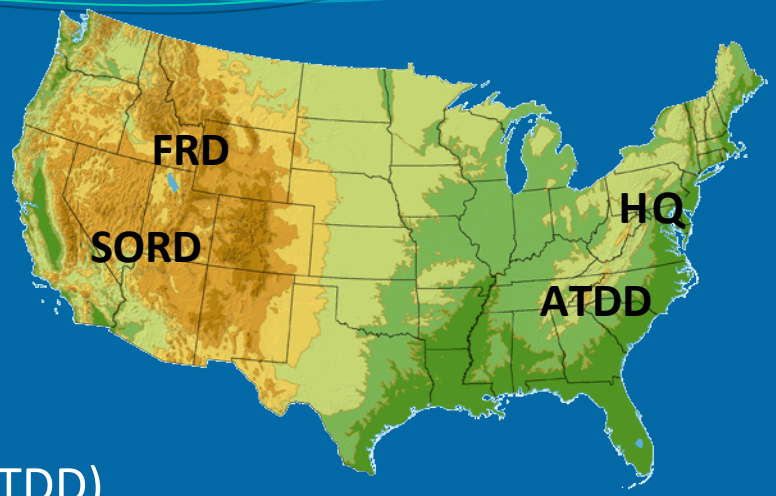
Air Resources Laboratory Headquarters
College Park MD

- National Weather Service
- National Environmental Satellite Data and Information Service
- **Oceanic & Atmospheric Research**
  - **Air Resources Laboratory**
    - Headquarters
      College Park, MD
    - Atmospheric Turbulence & Diffusion Division
      Oak Ridge, TN
    - Special Operations & Research Division
      Las Vegas, NV
    - Field Research Division
      Idaho Falls, ID
- National Ocean Service
- Office of Marine and Aviation Operations
- National Marine Fisheries Service



Headquarters (HQ)

- Atmospheric Dispersion and Boundary Layer Characterization
- Atmospheric Chemistry and Deposition
- Climate Observations and Analyses

Atmospheric Turbulence & Diffusion Division (ATDD)

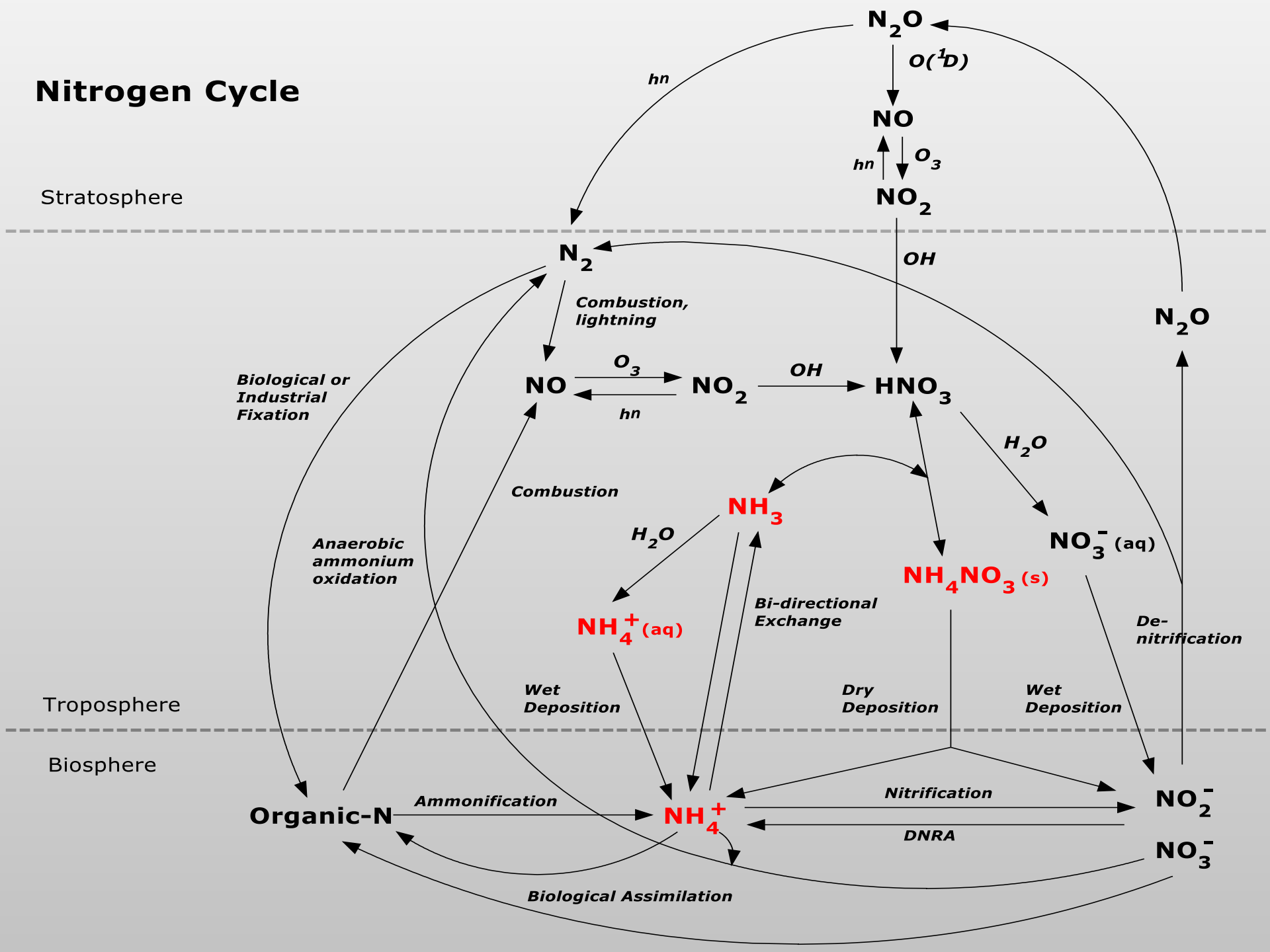
- Atmospheric Dispersion and Boundary Layer Characterization
- Atmospheric Chemistry and Deposition
- Climate Observations and Analyses

Field Research Division (FRD)

- Atmospheric Dispersion and Boundary Layer Characterization
- Substantial site support for DOE

Special Operations & Research Division (SORD)

- Atmospheric Dispersion and Boundary Layer Characterization
- Substantial site support for DOE


Nitrogen Cycle
Stratosphere
Troposphere
Biosphere
N_2O
$O(^1D)$
hn
NO
O_3
hn
NO_2
OH
N_2
Combustion, lightning
N_2O
Biological or Industrial Fixation
NO
O_3
NO_2
OH
HNO_3
hn
H_2O
Combustion
NH_3
H_2O
NO_3^- (aq)
Anaerobic ammonium oxidation
NH_4NO_3 (s)
Bi-directional Exchange
NH_4^+ (aq)
De-nitrification
Wet Deposition
Dry Deposition
Wet Deposition
Organic-N
Ammonification
NH_4^+
Nitrification
NO_2^-
DNRA
NO_3^-
Biological Assimilation

Sources of Atmospheric NH_3

Why Ammonia?

- Important component of global N cycle (Galloway, 2003)
- Only gaseous alkaline substance in the atmosphere
- At high concentrations can directly damage vegetation (Krupa, 2003)
- Deposition of NH_3, along with other reactive N, can alter the N status of aquatic and terrestrial ecosystems
- Participates in the production and growth of PM

National Air Quality Forecast Capability (NAQFC) for O_3 and $PM_{2.5}$

Meteorological Model

- North American Model (NAM) - 12 km

Emission projection

- Area sources use US EPA 2011 NEI v1
- Point sources use biennial CEM and latest DoE energy consumption outlook
- Mobile sources use US EPA 2012 Cross State Air Pollution Rule MOBILE6 output scaled by EPA AQS monitored trends
- BEIS3 v3.14 Biogenic Emissions
- Intermittent sources: dust and wildfire

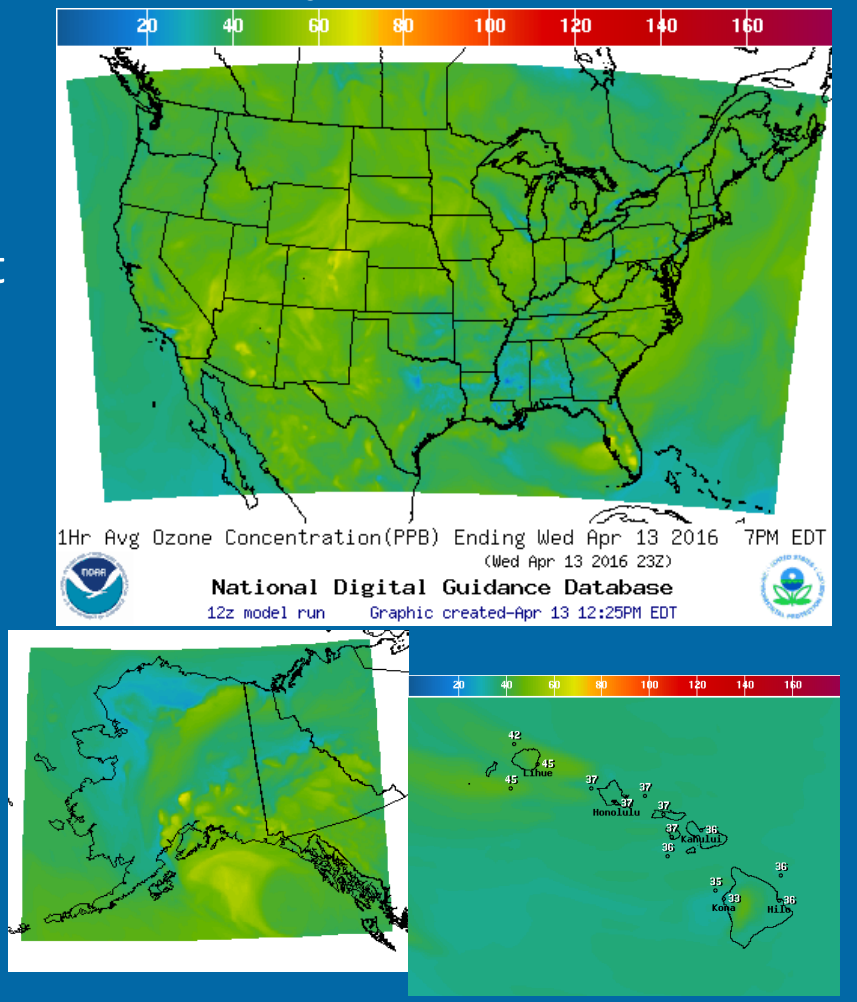
Air Quality chemistry-transport Model

- US EPA CMAQ v4.6 – 12 km

NAQFC 48 h forecast online:

- O_3 for CONUS, AK and HI
- $PM_{2.5}$ for CONUS

Surface O_3 concentration in ppb



airquality.weather.gov

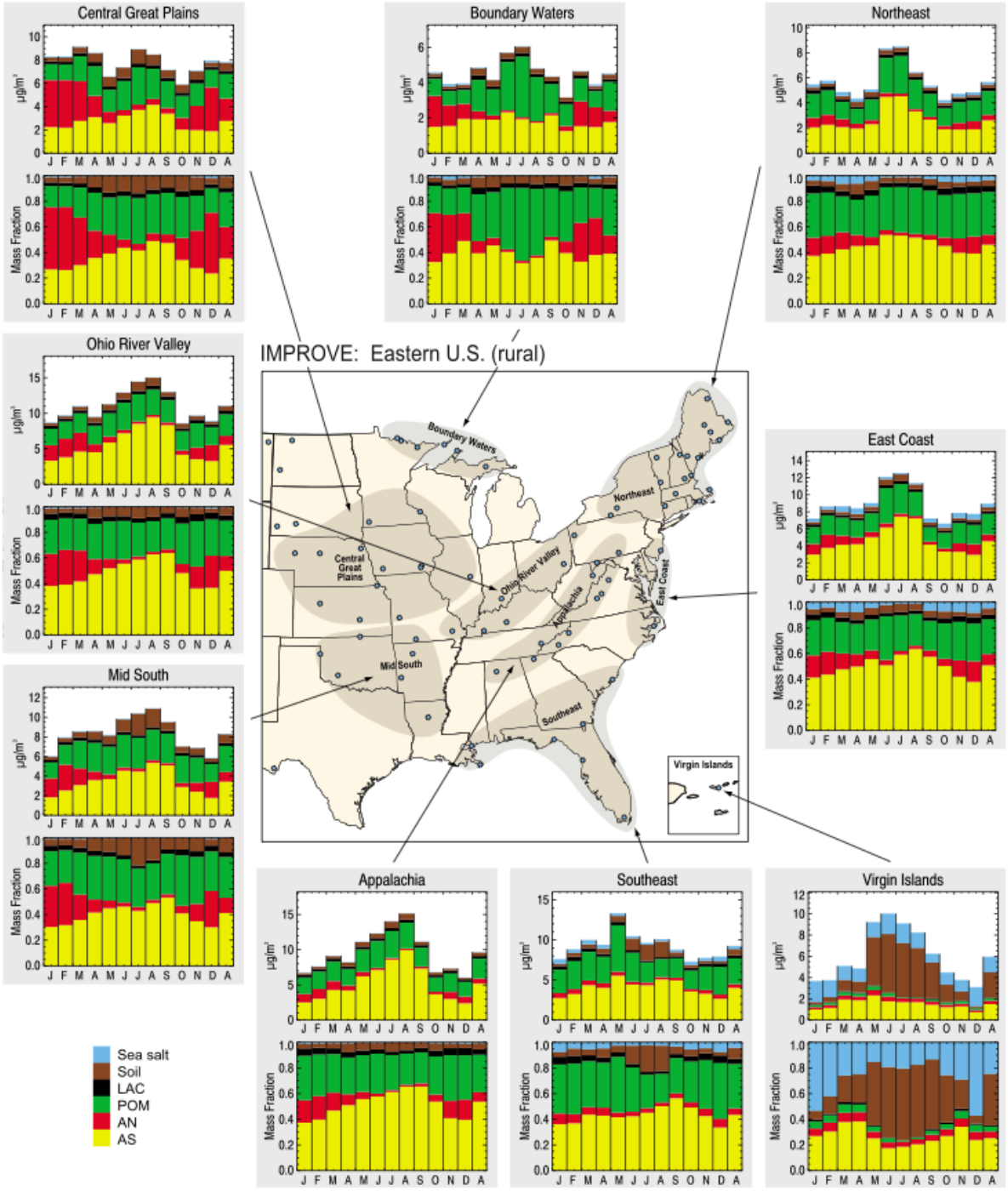
Ammonia reacts with strong acids in the atmosphere to form ammonium salts …

$NH_{3(g)} + H_2SO_{4(l)} \rightarrow NH_4HSO_{4(s,l)}$ (ammonium bisulfate)

$\rightarrow (NH_4)_3H(SO_4)_{2(s,l)}$ (letovicite)

$\rightarrow (NH_4)_2SO_{4\ (s,l)}$ (ammonium sulfate)

$NH_{3(g)} + HNO_{3(g)} \leftrightarrow NH_4NO_{3(s,l)}$ (ammonium nitrate)


Central Great Plains
Boundary Waters
Northeast
Ohio River Valley
IMPROVE: Eastern U.S. (rural)
East Coast
Mid South
Appalachia
Southeast
Virgin Islands
Sea salt
Soil
LAC
POM
AN
AS
µg/m³
Mass Fraction
J F M A M J J A S O N D A

Ammonia-Related Research Activities in the NOAA Air Resources Laboratory

- Measurements – increase knowledge base of NH_3 concentrations and flux measurements over diverse landscapes and in a variety of environmental conditions

- Data analyses – increase our understanding of NH_3 spatial and temporal variations and trends

- Process modeling – use specialized models in conjunction with measurements to increase our understanding of controlling processes

- 3-D air quality modeling – accurately simulate the large-scale distribution of NH_x (better $PM_{2.5}$ forecasts)

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Evaluating ammonia (NH_3) predictions in the NOAA National Air Quality Forecast Capability (NAQFC) using *in situ* aircraft, ground-level, and satellite measurements from the DISCOVER-AQ Colorado campaign

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HIGHLIGHTS

- *In situ* aircraft measurements in summer 2014 suggest the NAQFC CMAQ model underestimated NH_3 in NE Colorado by a factor of 2.7.
- Ground-level monitors and satellite retrievals produced a similar results.
- The underestimation of NH_3 vapor was not accompanied by a comparable underestimation of particulate NH_4^+.
- Seasonal patterns measured at an AMoN site in the region suggest that the underestimation of NH_3 is not limited to summer.

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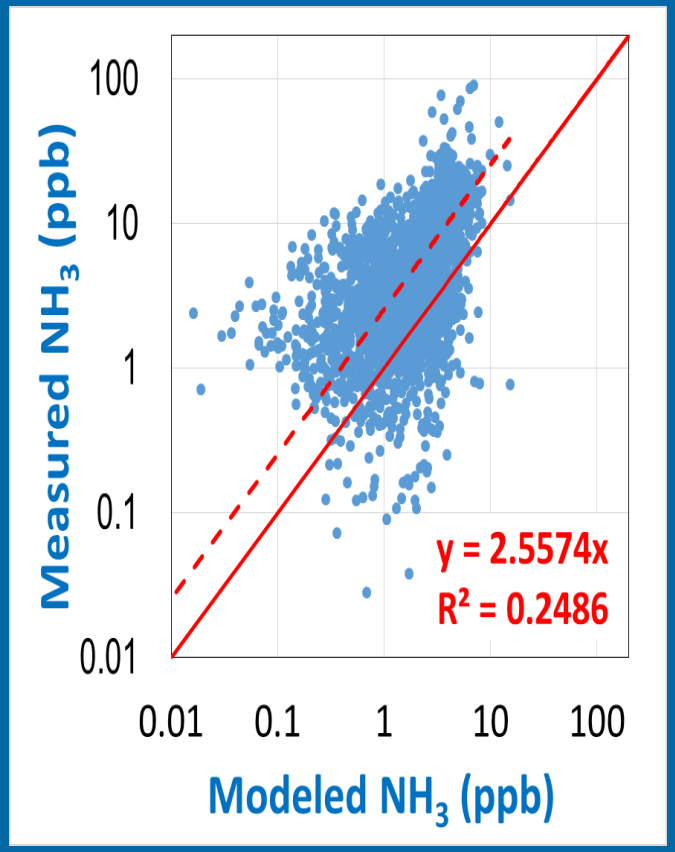
ABSTRACT

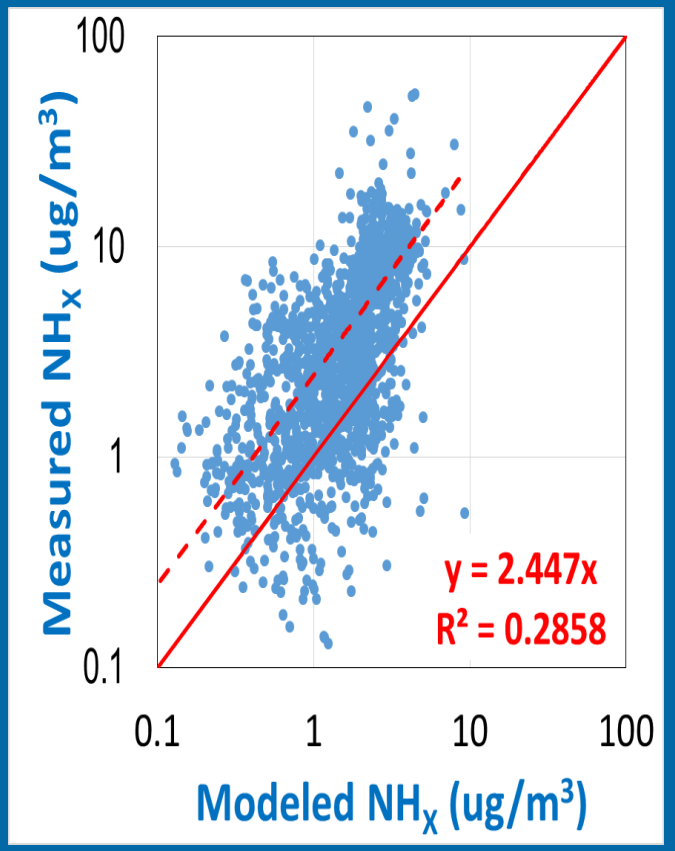
The U.S. National Oceanic and Atmospheric Administration (NOAA) is responsible for forecasting elevated levels of air pollution within the National Air Quality Forecast Capability (NAQFC). The current research uses measurements gathered in the DISCOVER-AQ Colorado field campaign and the concurrent Front Range Air Pollution and Photochemistry Experiment (FRAPPE) to test performance of the NAQFC CMAQ modeling framework for predicting NH_3. The DISCOVER-AQ and FRAPPE field campaigns were carried out in July and August 2014 in Northeast Colorado. Model predictions are compared with measurements of NH_3 gas concentrations and the NH_4^+ component of fine particulate matter concentrations measured directly by the aircraft in flight. We also compare CMAQ predictions with NH_3 measurements from ground-based monitors within the DISCOVER-AQ Colorado geographic domain, and from the Tropospheric Emission Spectrometer (TES) on the Aura satellite.

In situ aircraft measurements carried out in July and August of 2014 suggest that the NAQFC CMAQ model underestimated the NH_3 concentration in Northeastern Colorado by a factor of ~2.7 (NMB = −63%). Ground-level monitors also produced a similar result. Average satellite-retrieved NH_3 levels also exceeded model predictions by a factor of 1.5–4.2 (NMB = −33 to −76%). The underestimation of NH_3 was not accompanied by an underestimation of particulate NH_4^+, which is further controlled by factors including acid availability, removal rate, and gas-particle partition. The average measured concentration of NH_4^+ was close to the average predication (NMB = +18%).

Seasonal patterns measured at an AMoN site in the region suggest that the underestimation of NH_3 is not due to the seasonal allocation of emissions, but to the overall annual emissions estimate. The underestimation of NH_3 varied across the study domain, with the largest differences occurring in a region of intensive agriculture near Greeley, Colorado, and in the vicinity of Denver. The NAQFC modeling framework did not include a recently developed bidirectional flux algorithm for NH_3, which has shown to considerably improve NH_3 modeling in agricultural regions. The bidirectional flux algorithm, however,

NAQFC predictions compared with *in situ* aircraft measurements (DISCOVER-AQ Colorado, summer 2014, <1 km altitude)





Solid line = 1:1 slope

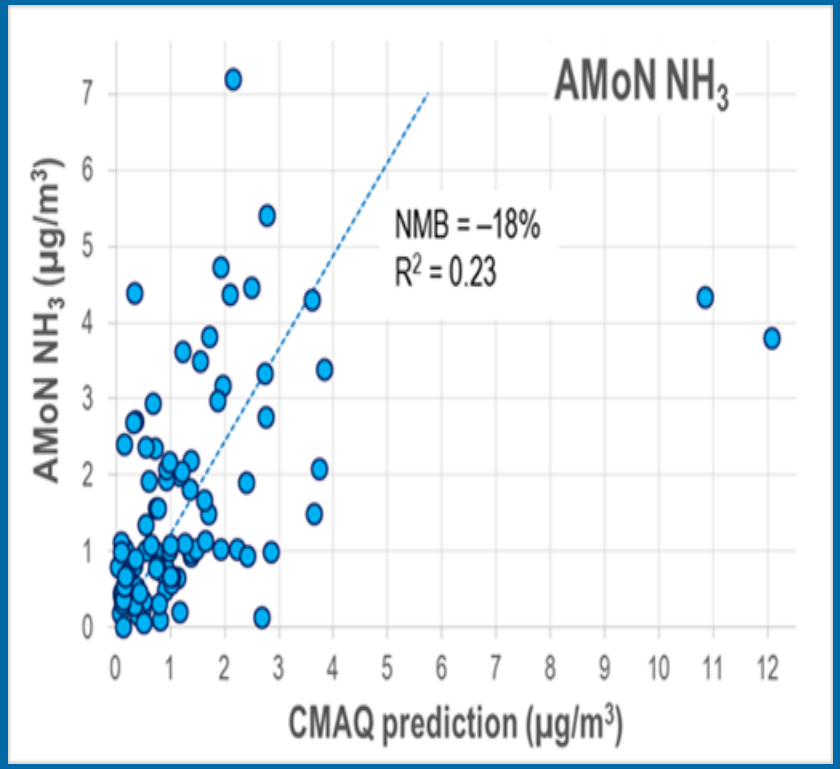
Dotted line = 1:1 line displaced by mean bias

NH_X = total ammonium (NH_3 & NH_4^+)

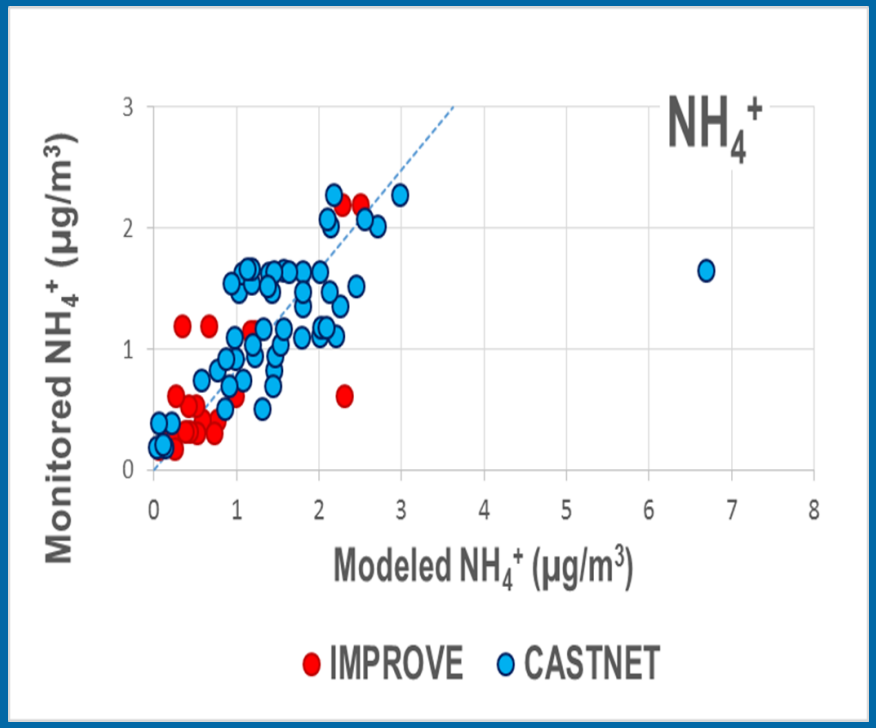
(Source: Battye et al, 2016)

NAQFC predictions compared with ground level measurements

AMoN NH_3



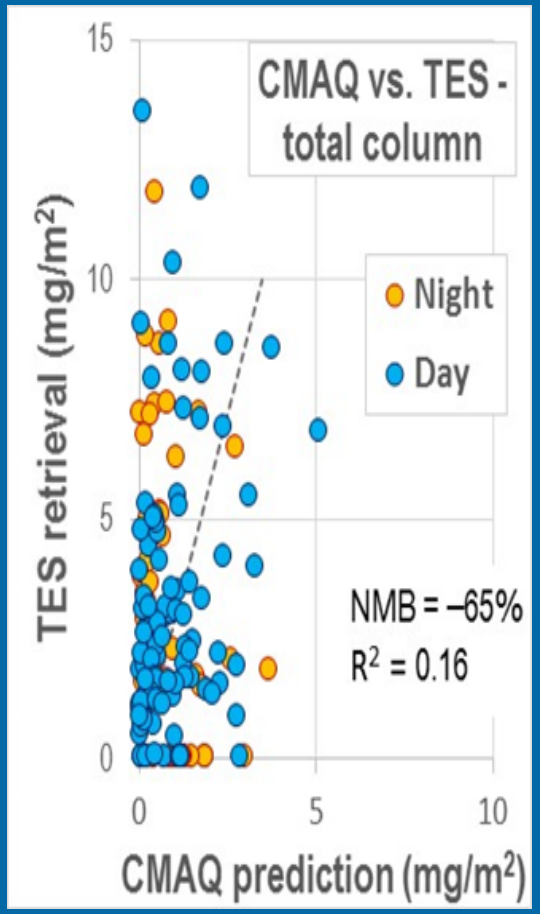
CASTNet and IMPROVE NH_4^+



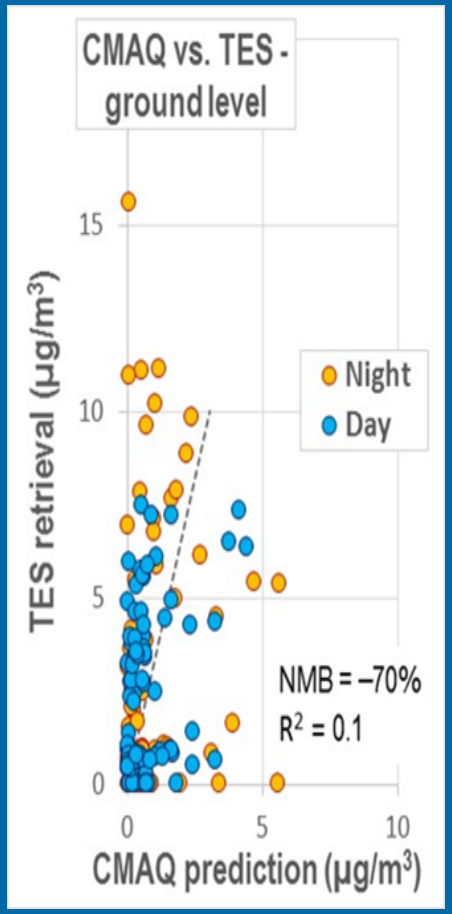
Source: Battye et al

NAQFC predictions compared with TES retrievals

Total atmospheric column



Ground-level concentration



Source: Battye et al

Findings from Battye et al. (2016)

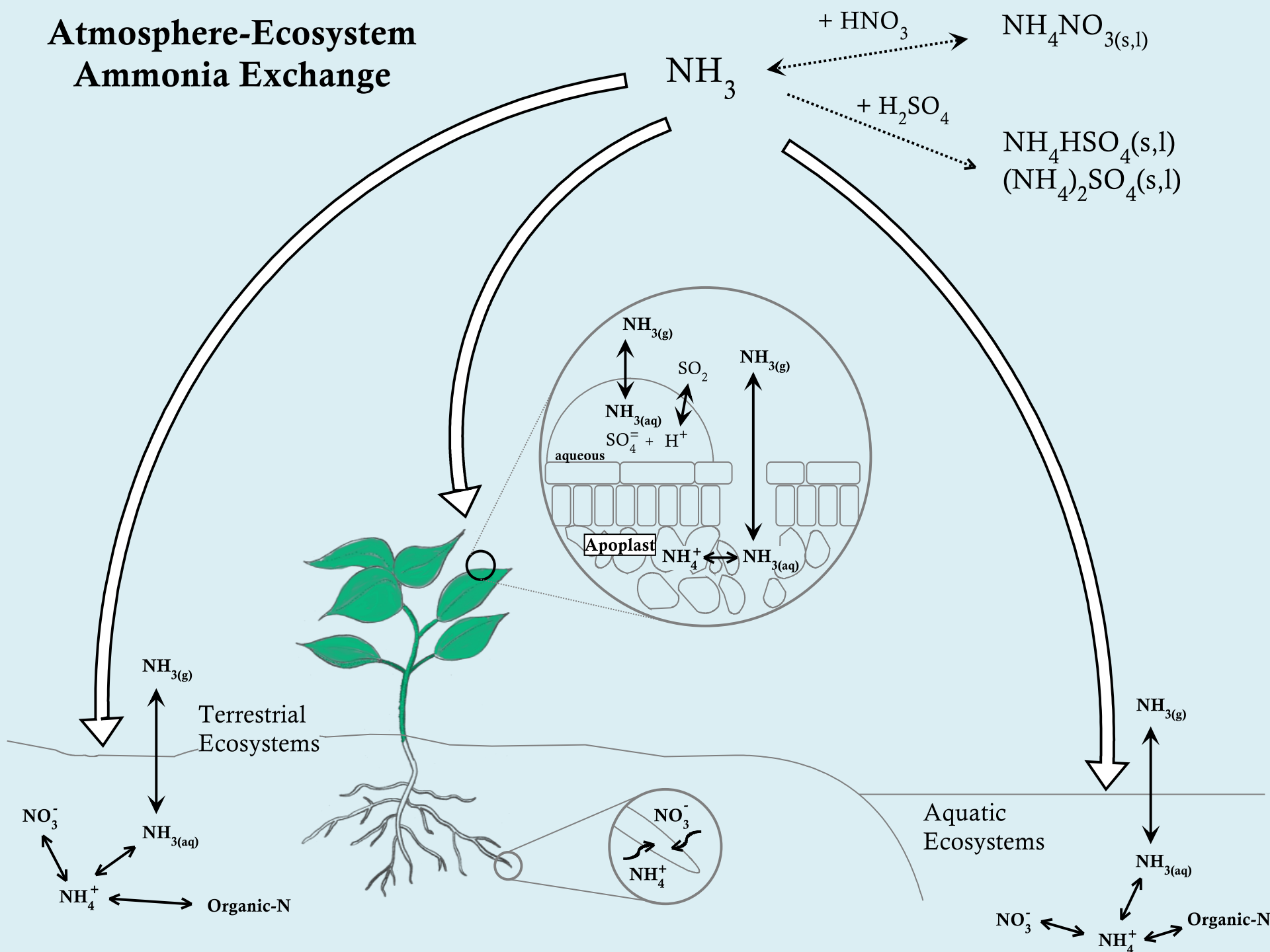
- Aircraft measurements suggest NAQFC-CMAQ underestimates NH_3 in agricultural regions of Colorado and California
- Measured spatial and temporal variations in NH_3 are larger than the variations in model predictions
- Ground-based measurements and TES retrievals were too sparse to evaluate the model for the period analyzed (July 2011)

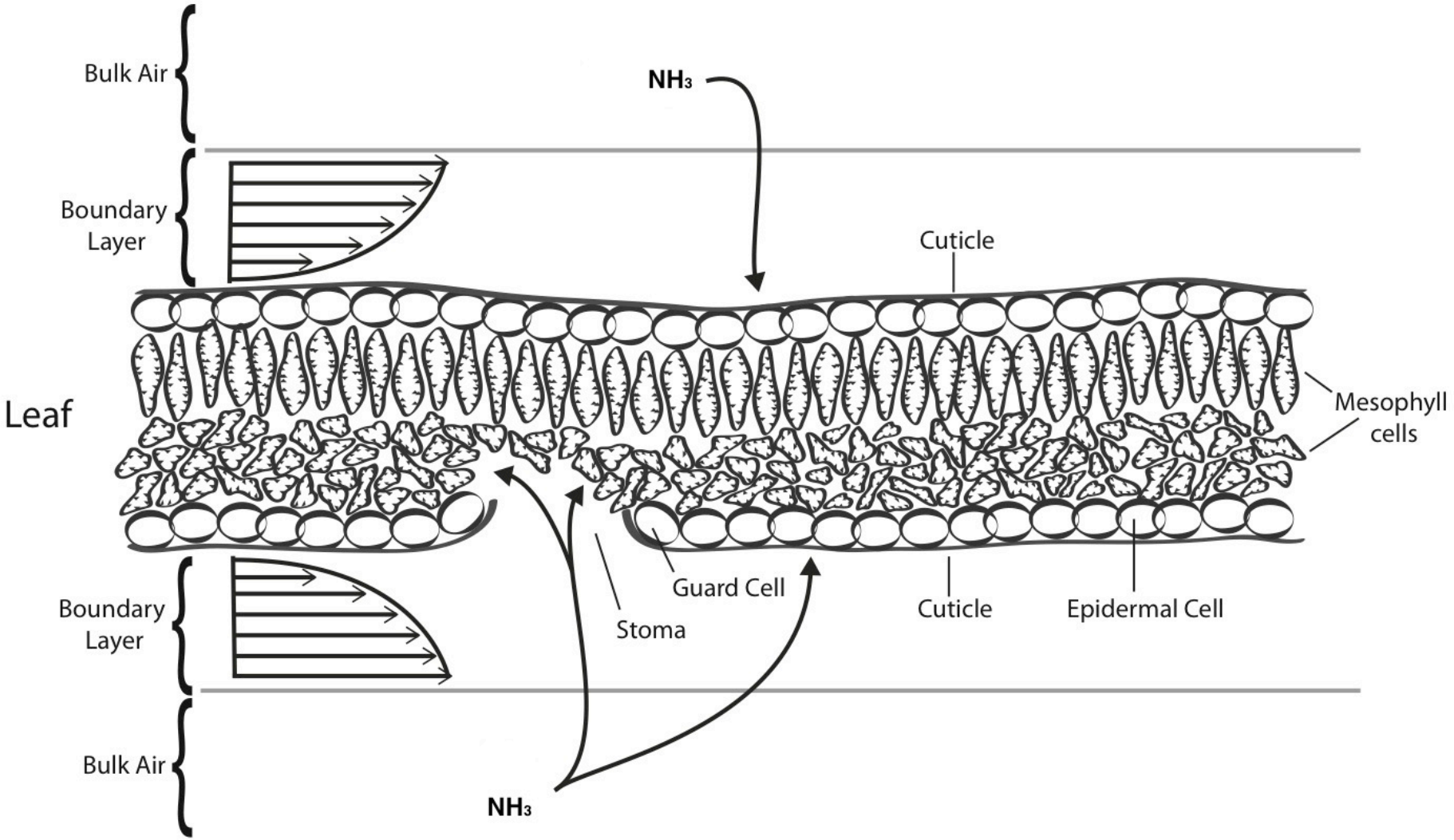
Future work

- AIRS or IASI satellite retrievals may provide a method of filling in the gaps

Challenges of Measuring NH_3

- Concentrations generally near or less than 1 ppbv, except near sources.
- Adsorbs onto surfaces, especially those that are wetted or even partially covered with water molecules, potentially resulting in memory effects.
- Partitions between gas-aerosol-hydrometeor phases, so that multiphase measurements are necessary to fully characterize.
- Reduced nitrogen species are usually not as abundant as oxidized nitrogen species (NO_y = NO, NO_2, HNO_3, etc.), making it difficult to detect NH_3 against the NO_y background.


Atmosphere-Ecosystem
Ammonia Exchange
NH_3
+ HNO_3
$NH_4NO_{3(s,l)}$
+ H_2SO_4
$NH_4HSO_4(s,l)$
$(NH_4)_2SO_4(s,l)$
$NH_{3(g)}$
SO_2
$NH_{3(aq)}$
$SO_4^= + H^+$
aqueous
Apoplast
NH_4^+
$NH_{3(aq)}$
Terrestrial
Ecosystems
NO_3^-
Organic-N
Aquatic
Ecosystems


Bulk Air
Boundary Layer
NH3
Cuticle
Leaf
Mesophyll cells
Guard Cell
Stoma
Cuticle
Epidermal Cell
Boundary Layer
Bulk Air
NH3

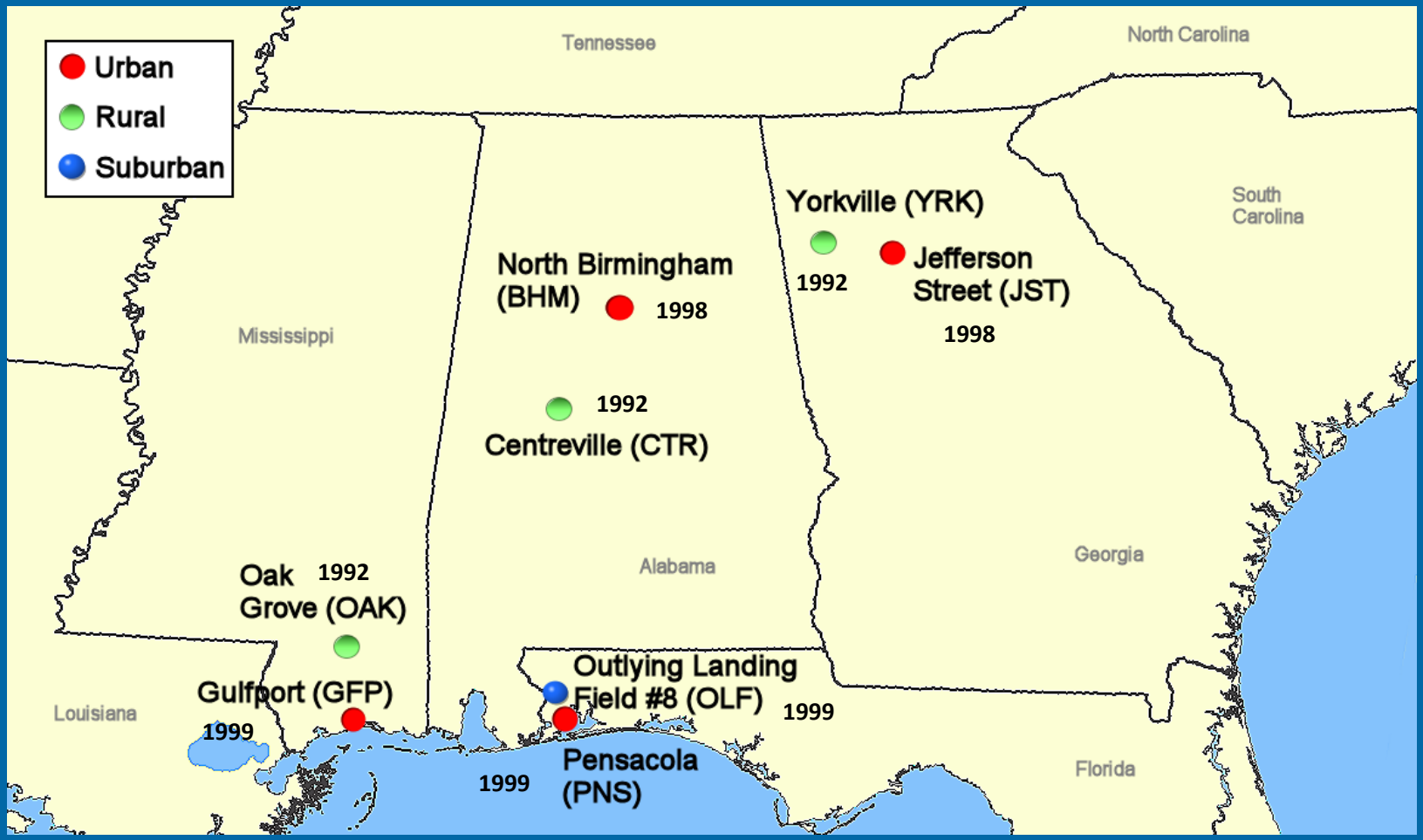
SEARCH

SouthEastern Aerosol Research and CHaracterization Study

SOUTHERN COMPANY
Energy to Serve Your World℠

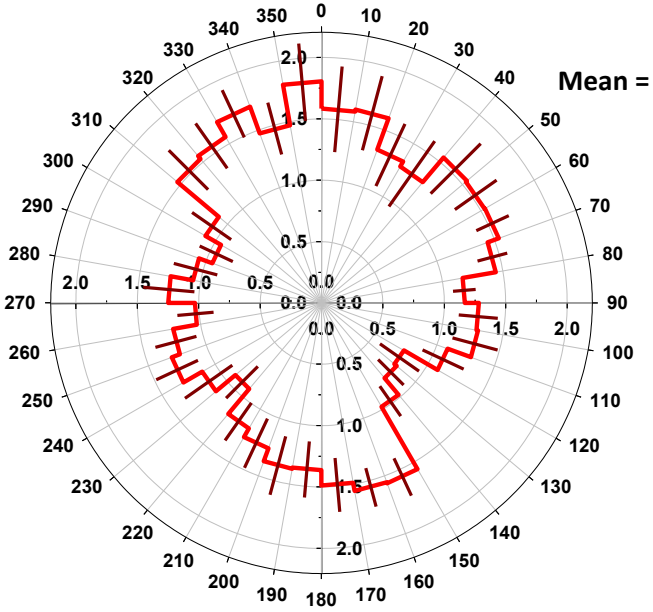
EPRI ELECTRIC POWER RESEARCH INSTITUTE

SEARCH Measurement Network

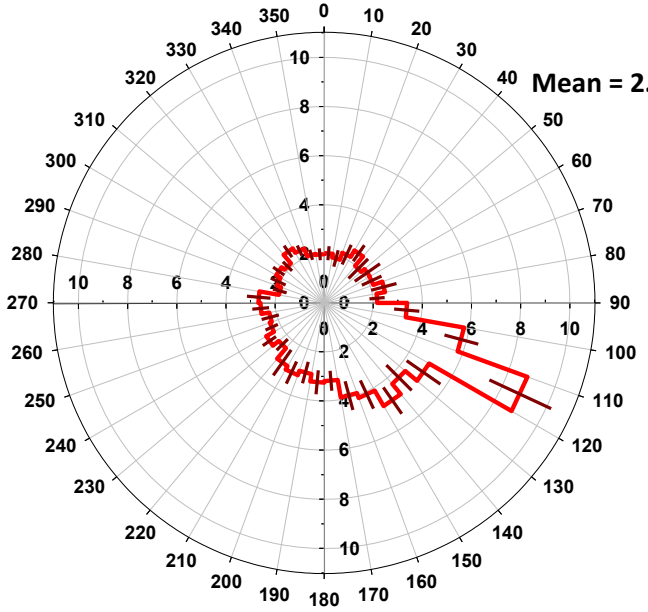


SEARCH Measurements

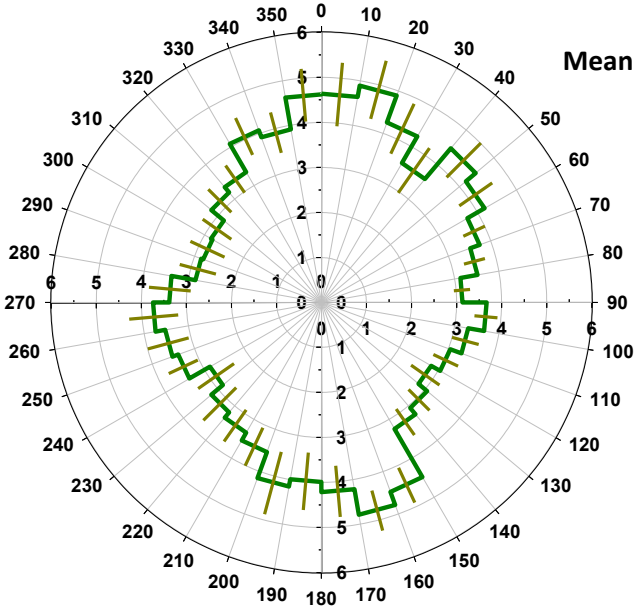
- **Filter-Based Particles and Gases (24-hour)**
  - FRM: $PM_{2.5}$
  - PCM and Dichot: $PM_{2.5}$, $PM_{10-2.5}$ mass and speciation (TC, OC, BC, NH_4^+, NO_3^-, SO_4^{2-})
  - NH_3 (citric acid denuder)
- **Continuous Particles (5-min to 1-hr)**
  - TEOM: $PM_{2.5}$ mass
  - Sunset Labs: OC/EC/TC
  - Aethelometer: BC
  - SEARCH/ARA: NH_4^+, NO_3^-
  - Modified HSPH: SO_4^{2-}
- **Trace Gases (5-min)**
  - O_3, NO, NO_2, NO_y, HNO_3, SO_2, CO, CO_2
  - NH_3 (3 sites)
- **Meteorology (5-min)**
  - WS, WD, T, RH, BP, SR, rainfall
- **Mercury**
  - Continuous Hg, Hg^P, RGM (3 sites)
  - Weekly or daily wet deposition (5 sites)



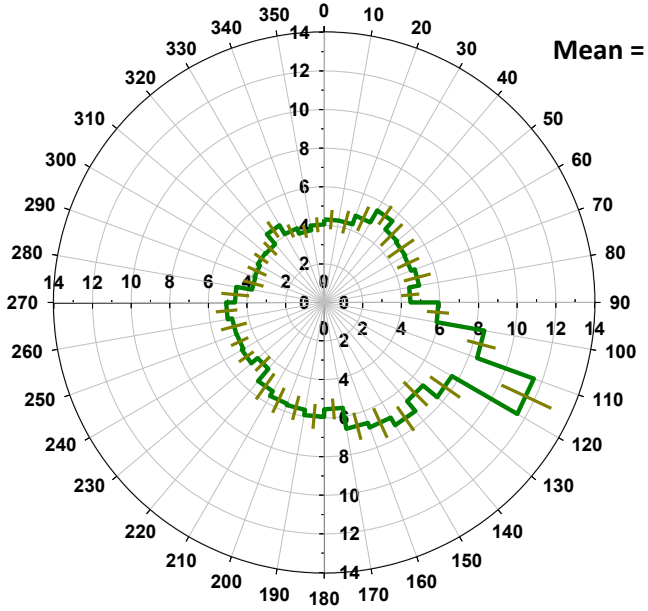
JST NH_3 (ppbv)



YRK NH_3 (ppbv)



JST $NH_3 + NH_4^+$ (ppbv)



YRK $NH_3 + NH_4^+$ (ppbv)

SEARCH

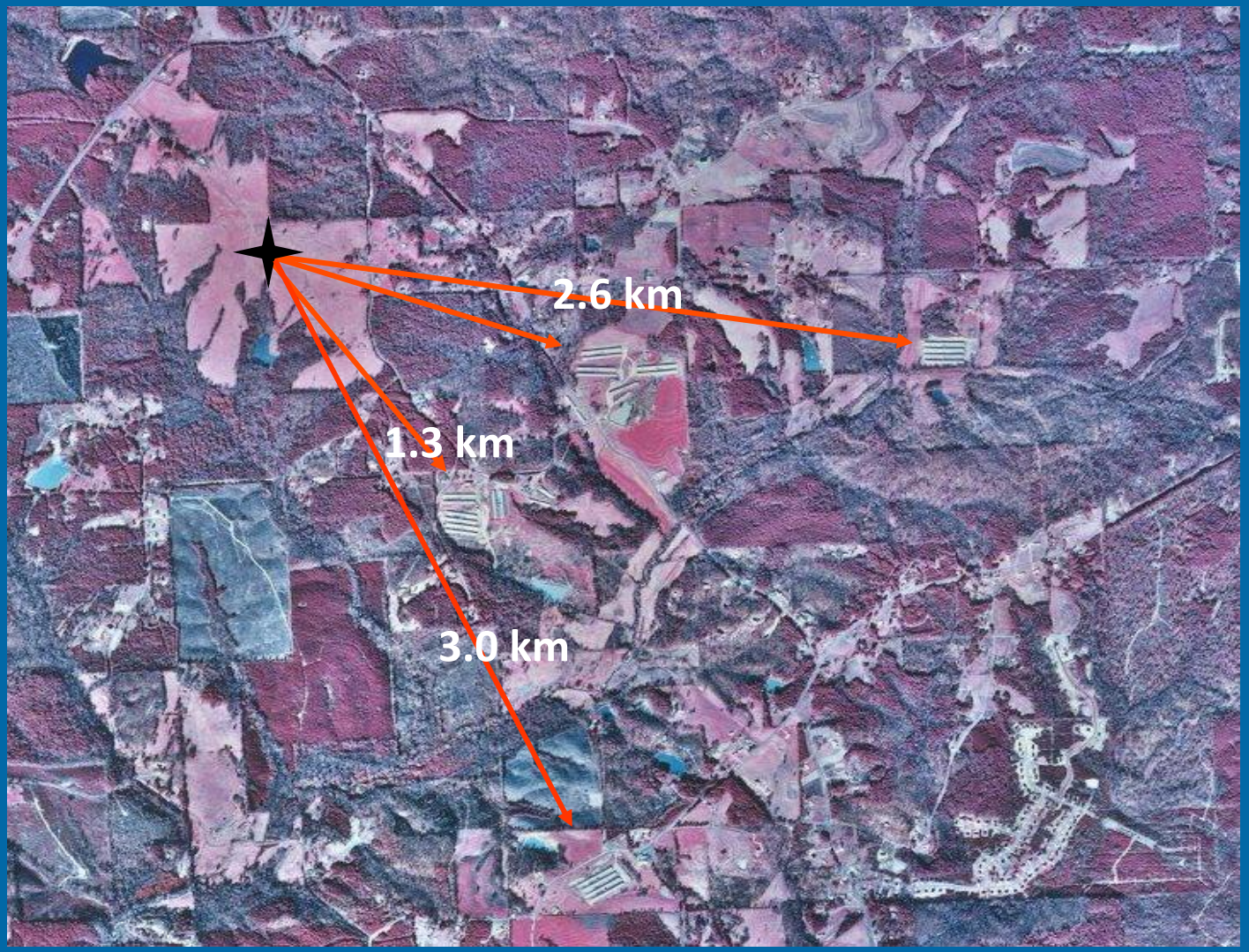
Hourly-Avg NH_3 Values > 30 ppbv at YRK

Datetime	NH_3 (ppbv) YRK	NH_4^+ (ppbv) YRK	WindDir (deg) YRK	NH_3/NH_x (mol/mol) YRK		NH_3 (ppbv) JST	NH_4^+ (ppbv) JST	NH_3/NH_x (mol/mol) JST
11/29/2007 07:00	46.3	1.4	139.7	0.971		1.8	0.7	0.724
7/14/2007 05:00	41.6	3.3	115.3	0.926		1.5	2.5	0.377
10/14/200 7 20:00	39.2	5.8	117.8	0.871		1.2	3.7	0.247
7/14/2007 06:00	38.3	3.5	112.1	0.917		1.5	2.7	0.354
10/15/2007 18:00	36.7	2.8	110.2	0.929		< DL	2.5	0.020
10/8/2007 00:00	32.0	3.7	113.5	0.896		1.9	1.5	0.558
8/24/2007 07:00	32.0	3.6	126.5	0.899		3.8	2.5	0.598
10/15/2007 19:00	31.9	2.6	115.8	0.925		0.4	2.1	0.170
8/27/2007 04:00	31.7	4.7	110.4	0.872		2.7	2.4	0.532

SEARCH

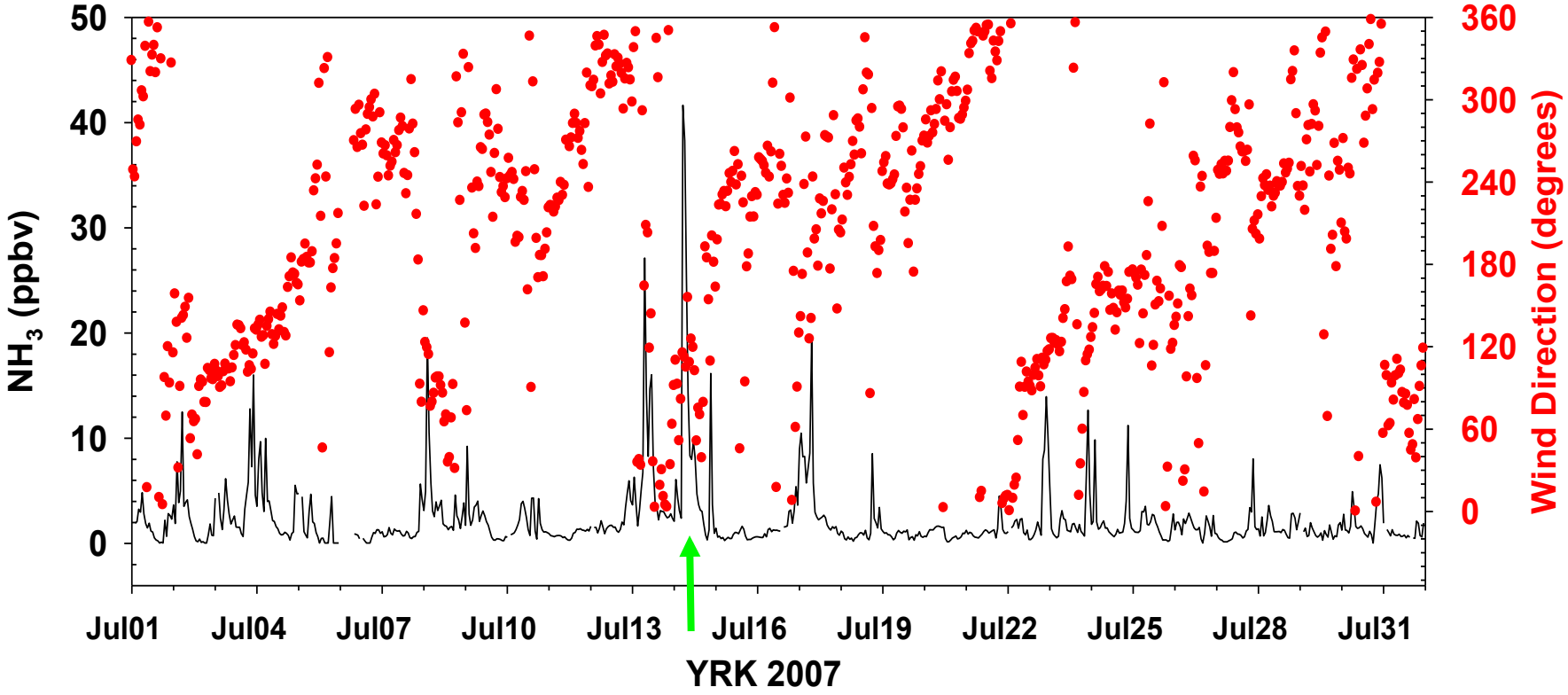
Atmospheric Research & Analysis

Poultry Houses near YRK



SEARCH

Hourly-Averaged NH_3 and Wind Direction
YRK July 2007



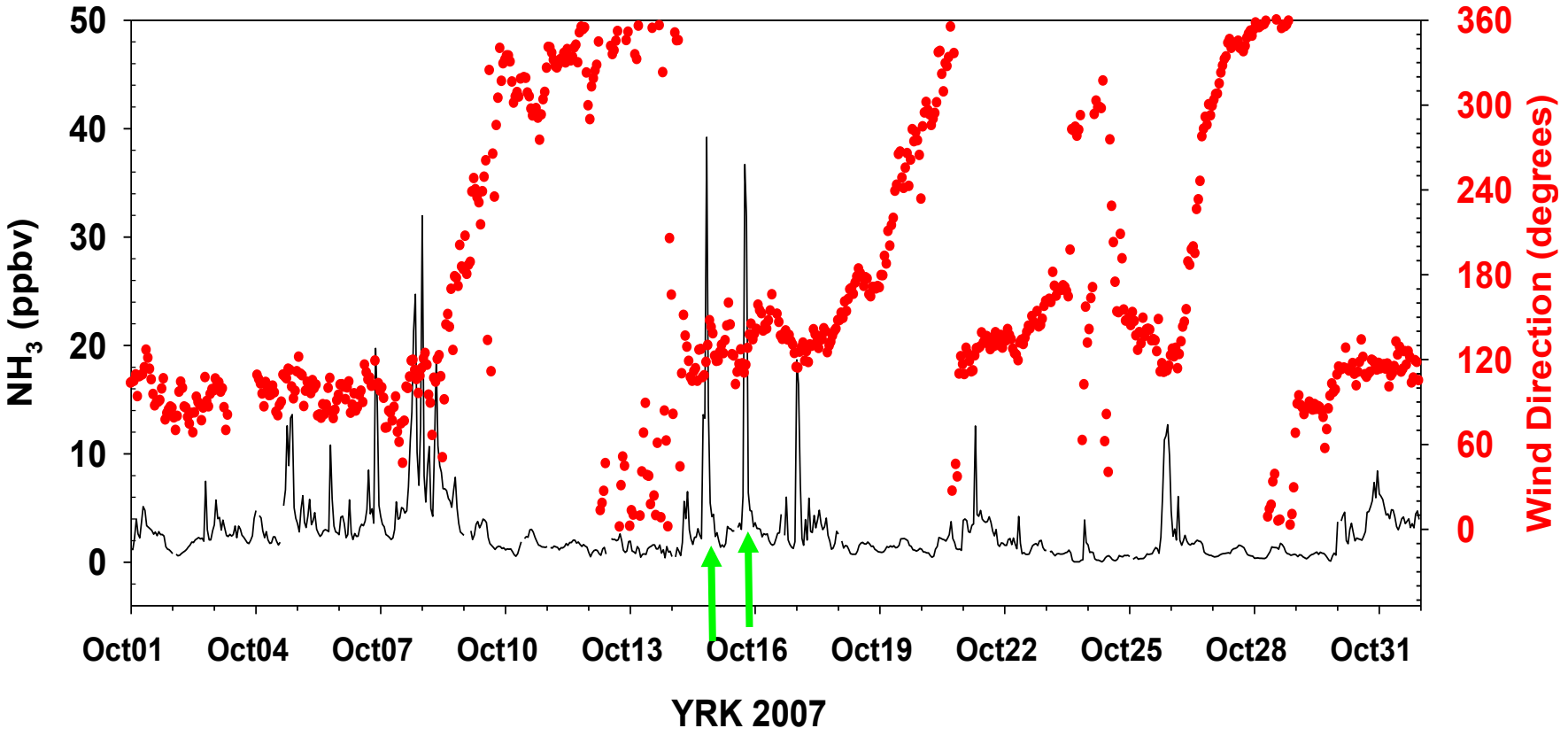
SEARCH

Atmospheric Research & Analysis

HYSPLIT Back Trajectory July 14, 2007

HYSPLIT Back Trajectory July 14, 2007 - Zoom

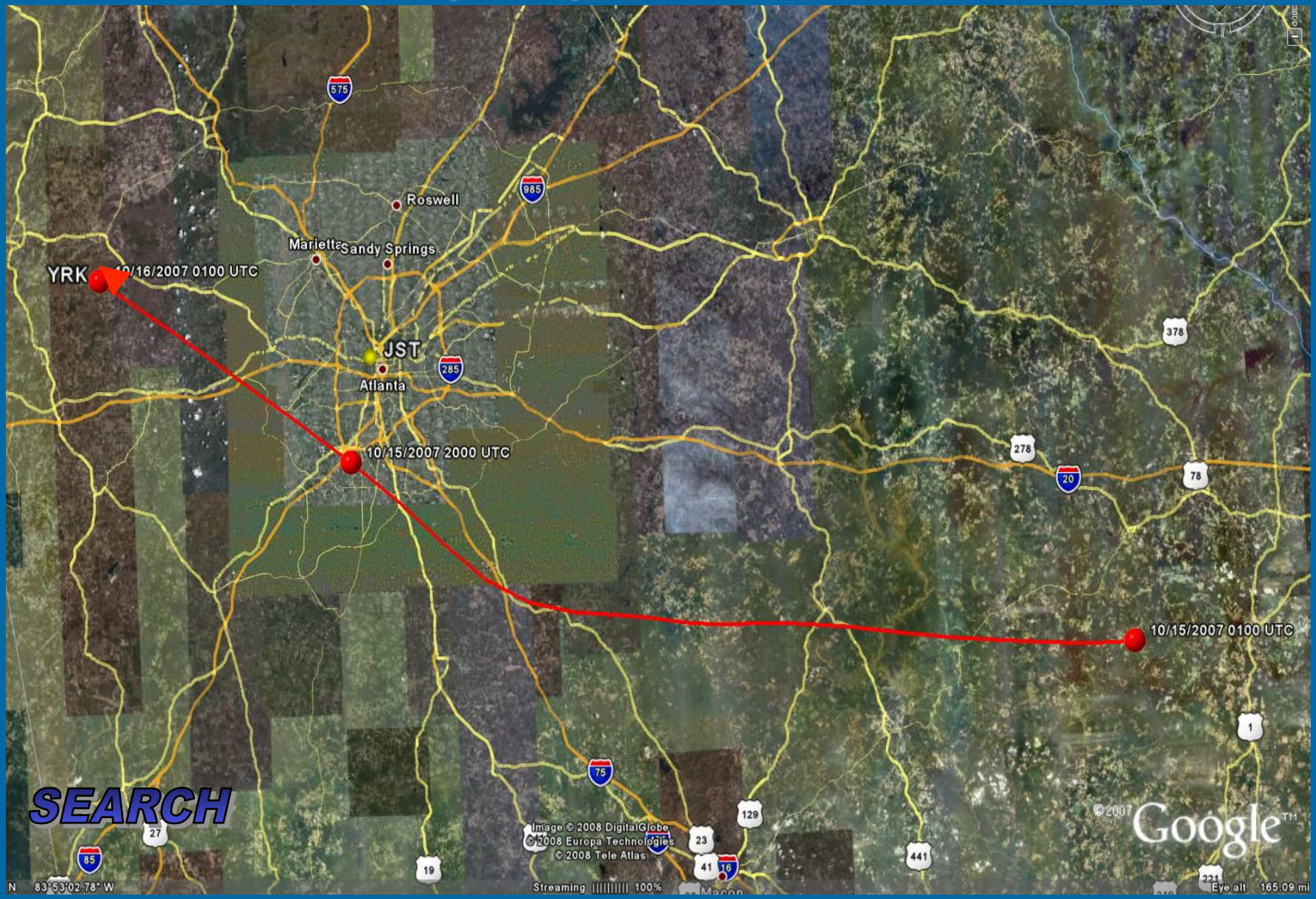
Hourly-Averaged NH_3 and Wind Direction
YRK October 2007



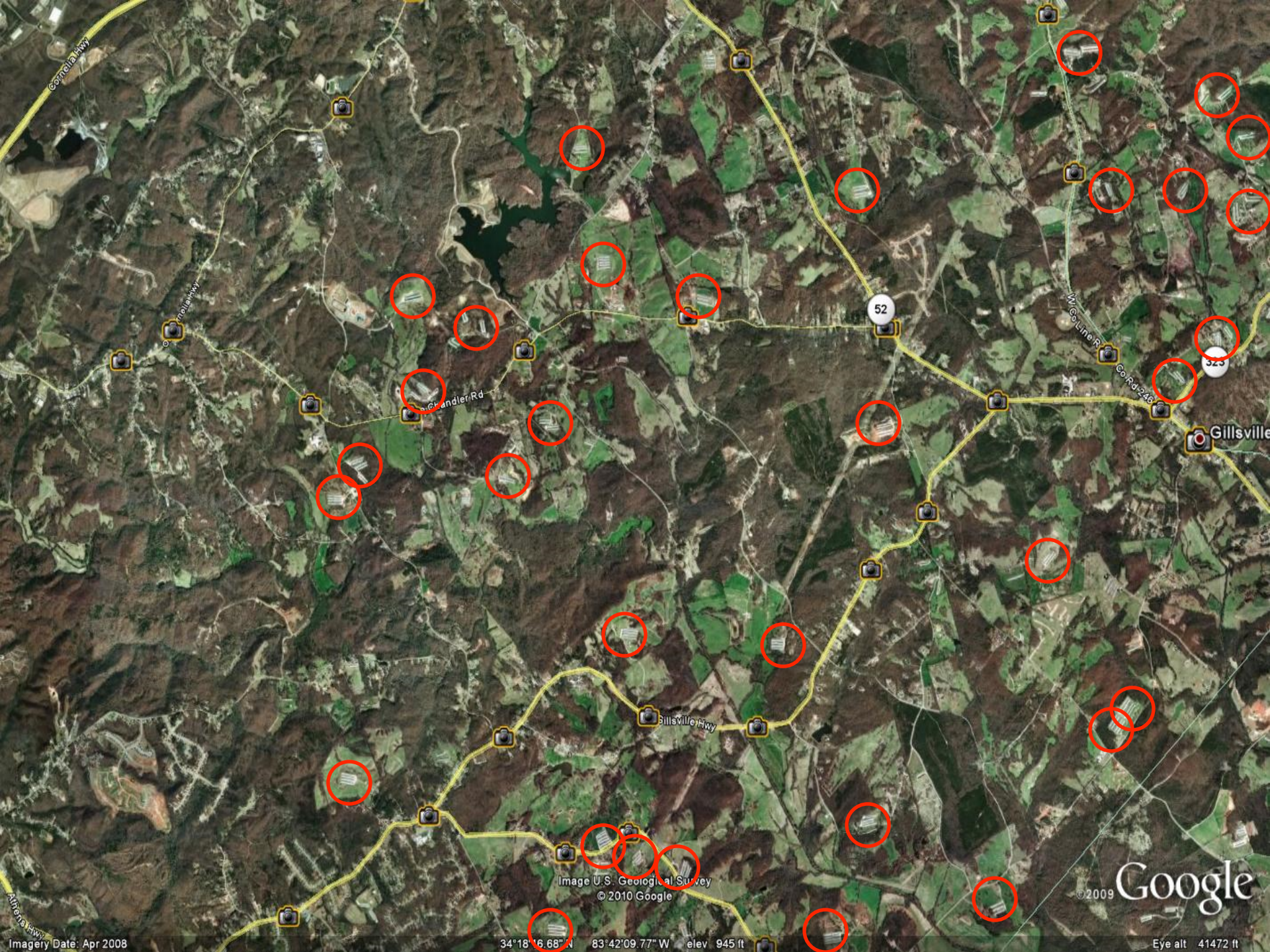
SEARCH

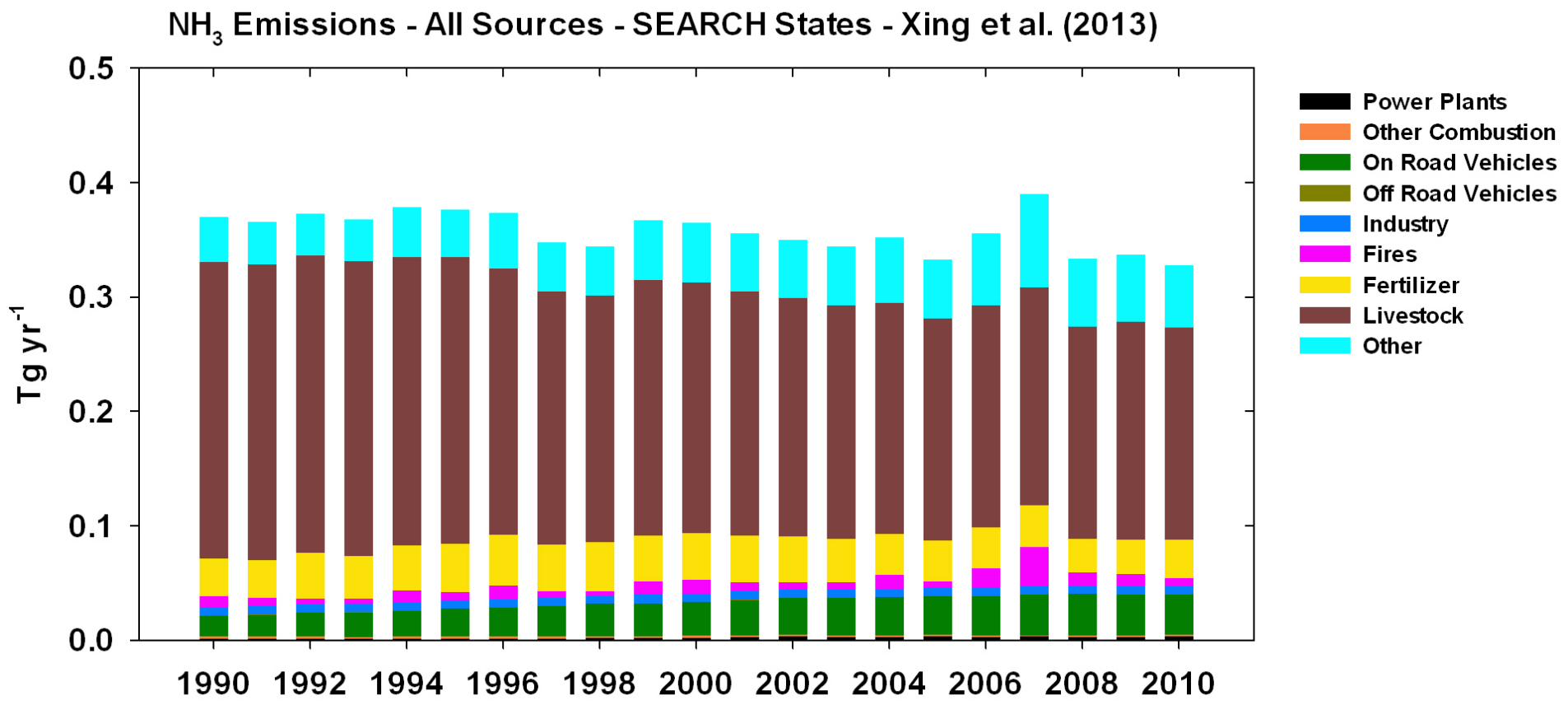
Atmospheric Research & Analysis

HYSPLIT Back Trajectory October 15, 2007

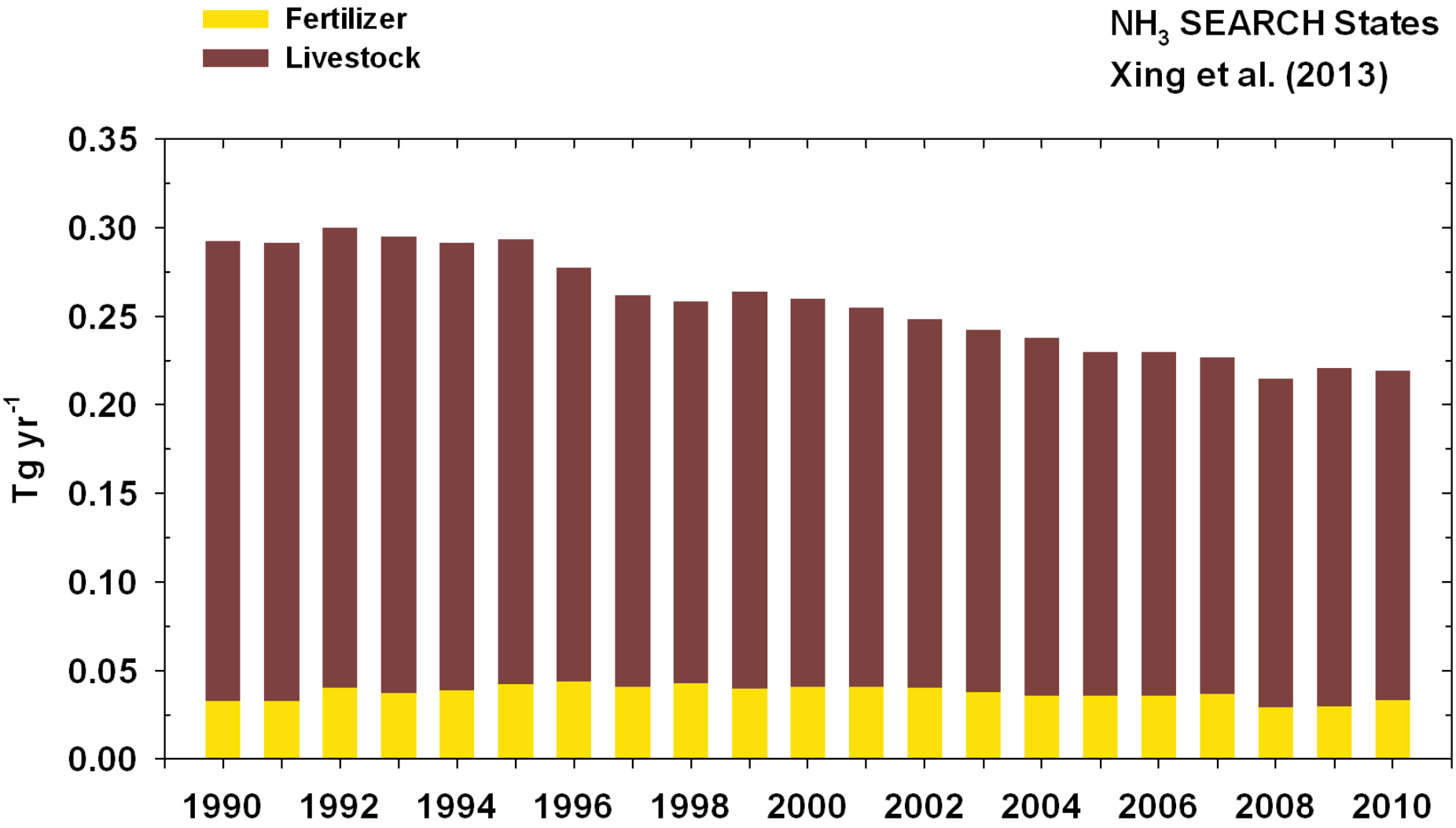


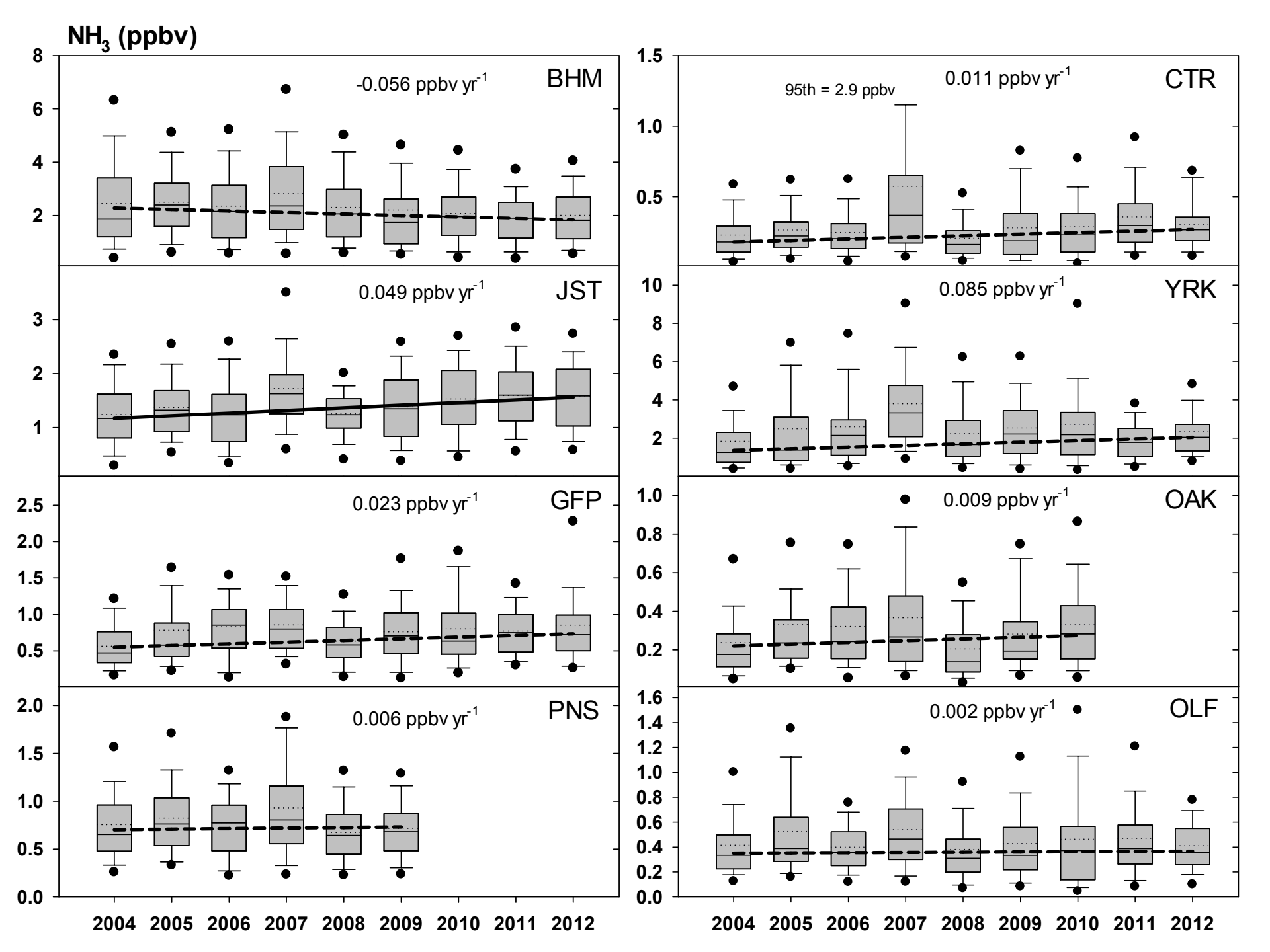
HYSPLIT Back Trajectory Oct 15, 2007 - Zoom

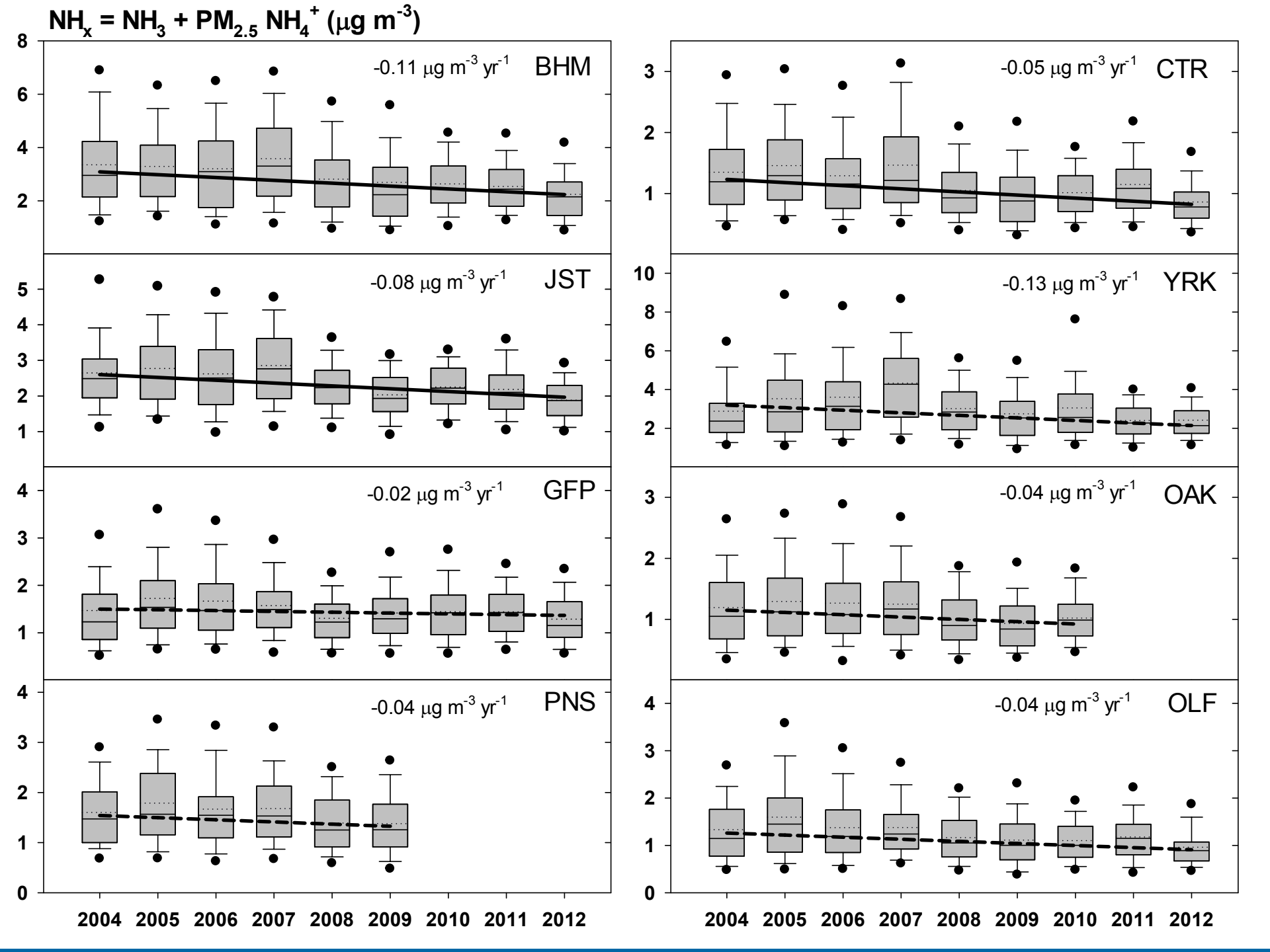

Cornelia Hwy
Chandler Rd
52
W Co Line Rd
Co Rd 246
323
Gillsville
Gillsville Hwy
Athens Hwy
Image U.S. Geological Survey
© 2010 Google
©2009 Google
Imagery Date: Apr 2008
34°18'16.68" N 83°42'09.77" W elev 945 ft
Eye alt 41472 ft

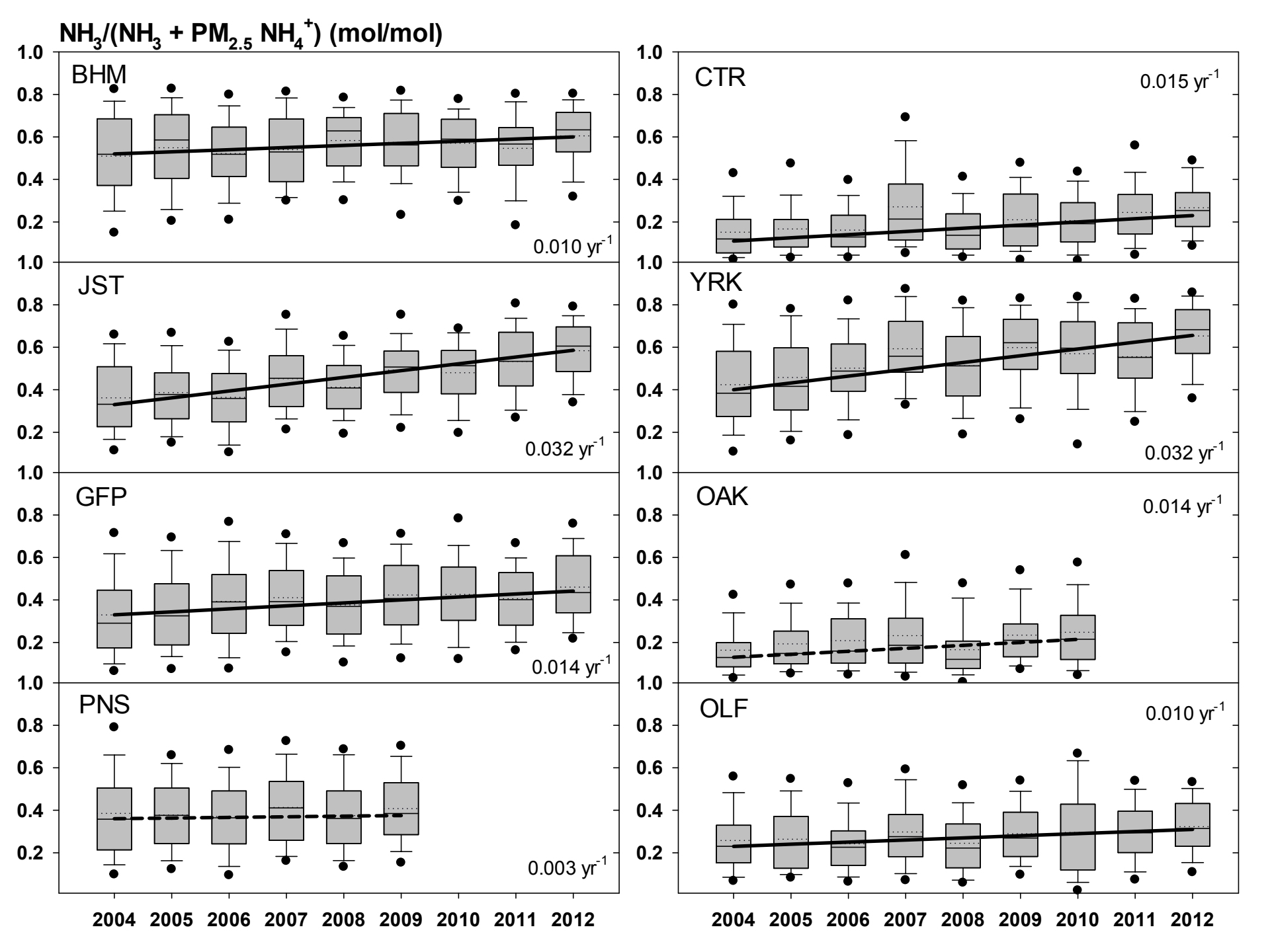


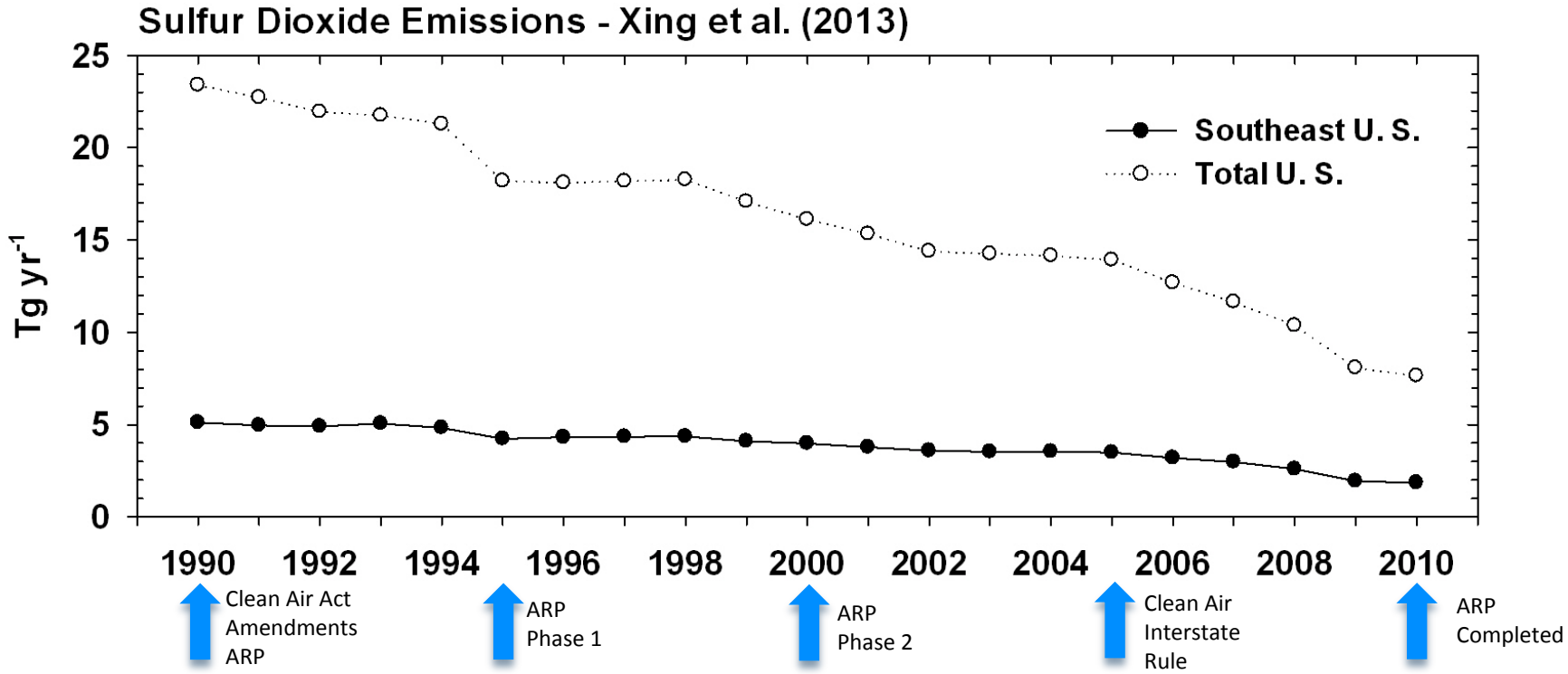
Xing et al. (2013) Historical gaseous and primary aerosol emissions in the United States from 1990 to 2010, Atmos. Chem. Phys., 13, 7531-7549.

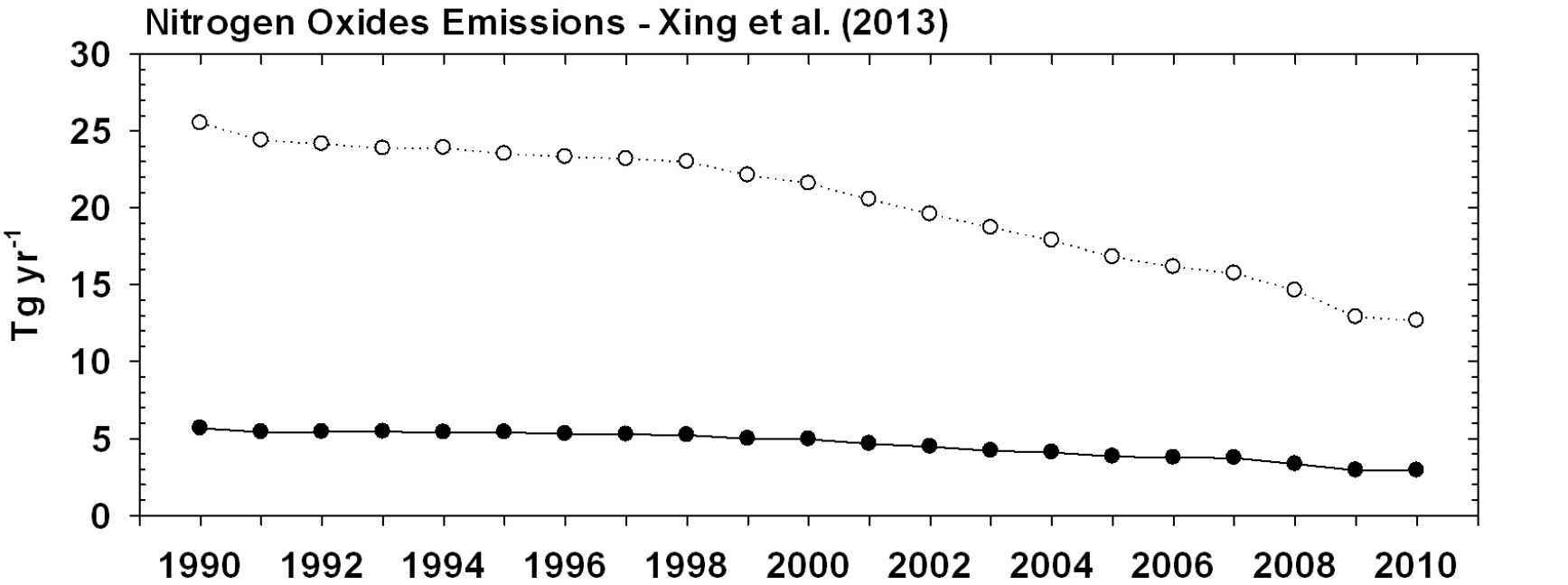

Fertilizer
Livestock
NH3 SEARCH States
Xing et al. (2013)
Tg yr-1
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0.00
1990
1992
1994
1996
1998
2000
2002
2004
2006
2008
2010

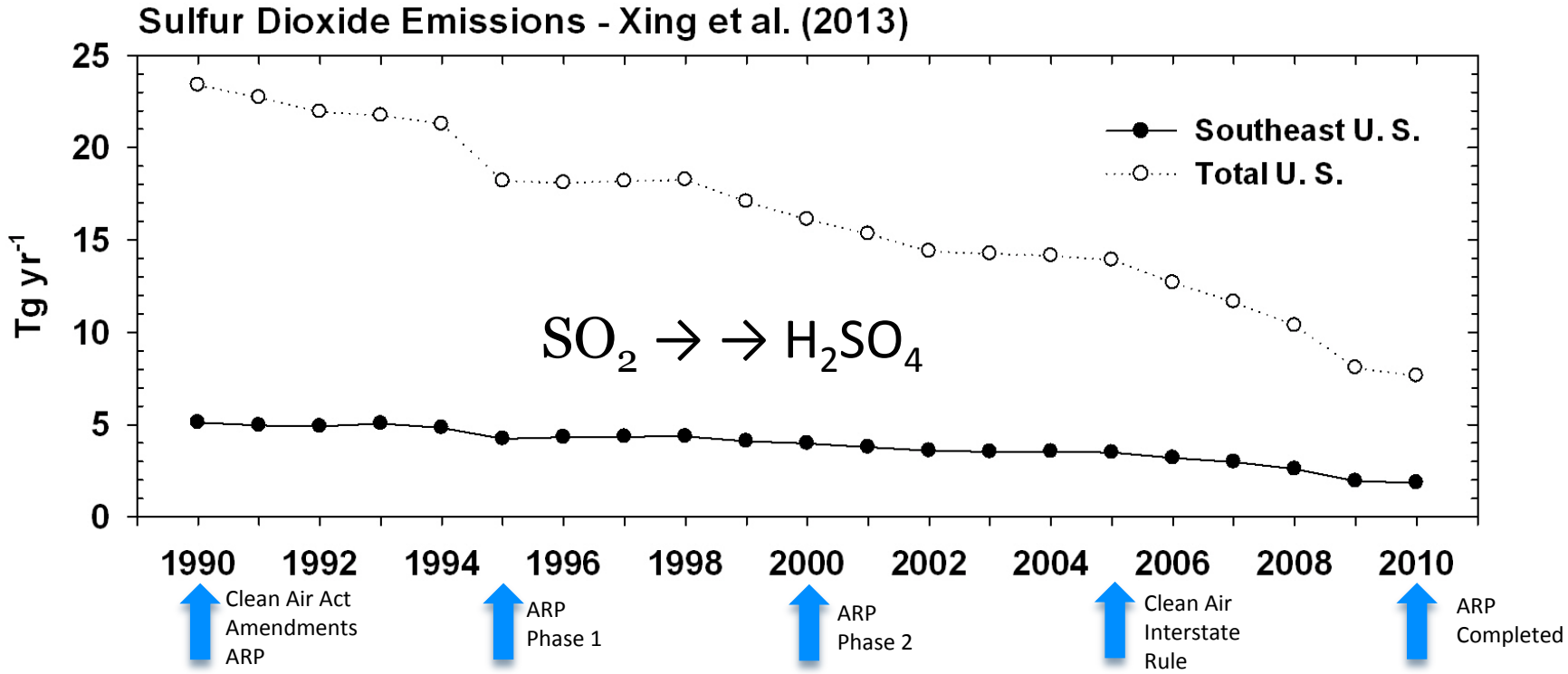

NH3 (ppbv)
BHM
-0.056 ppbv yr-1
JST
0.049 ppbv yr-1
GFP
0.023 ppbv yr-1
PNS
0.006 ppbv yr-1
CTR
95th = 2.9 ppbv
0.011 ppbv yr-1
YRK
0.085 ppbv yr-1
OAK
0.009 ppbv yr-1
OLF
0.002 ppbv yr-1
2004
2005
2006
2007
2008
2009
2010
2011
2012

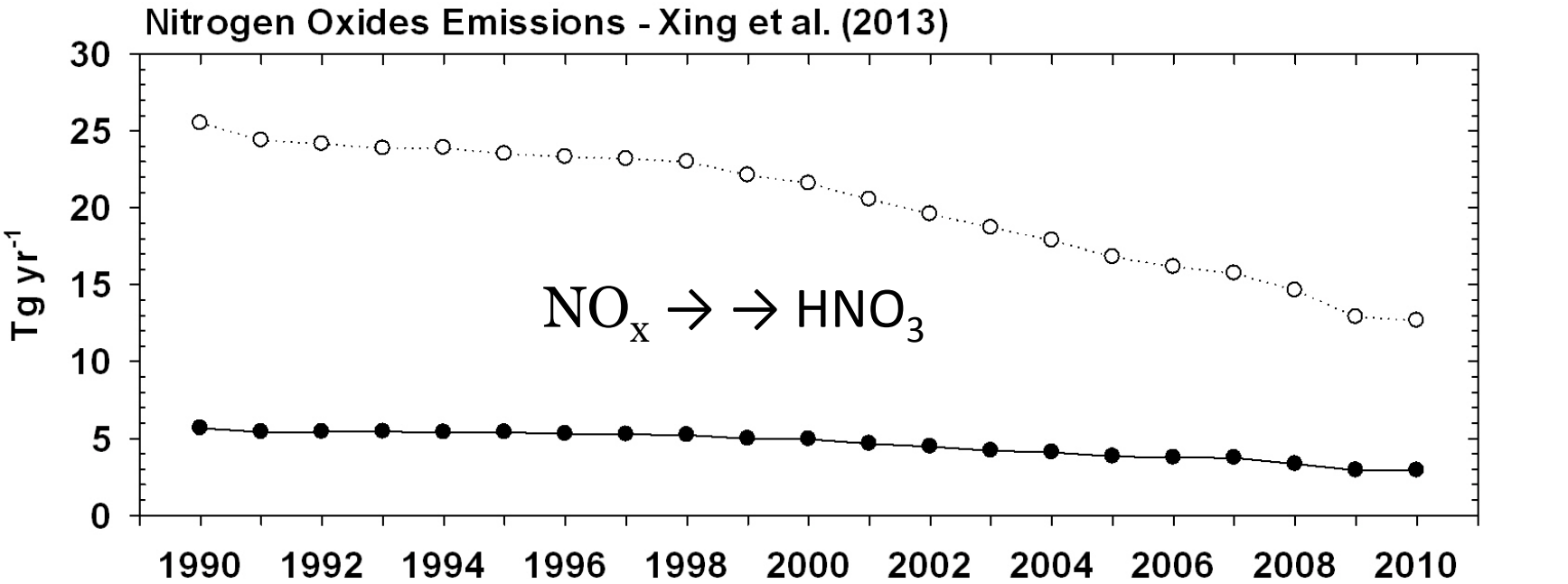

$NH_x = NH_3 + PM_{2.5}\ NH_4^+$ (μg m^{-3})
-0.11 μg m^{-3} yr^{-1} BHM
-0.05 μg m^{-3} yr^{-1} CTR
-0.08 μg m^{-3} yr^{-1} JST
-0.13 μg m^{-3} yr^{-1} YRK
-0.02 μg m^{-3} yr^{-1} GFP
-0.04 μg m^{-3} yr^{-1} OAK
-0.04 μg m^{-3} yr^{-1} PNS
-0.04 μg m^{-3} yr^{-1} OLF
2004 2005 2006 2007 2008 2009 2010 2011 2012

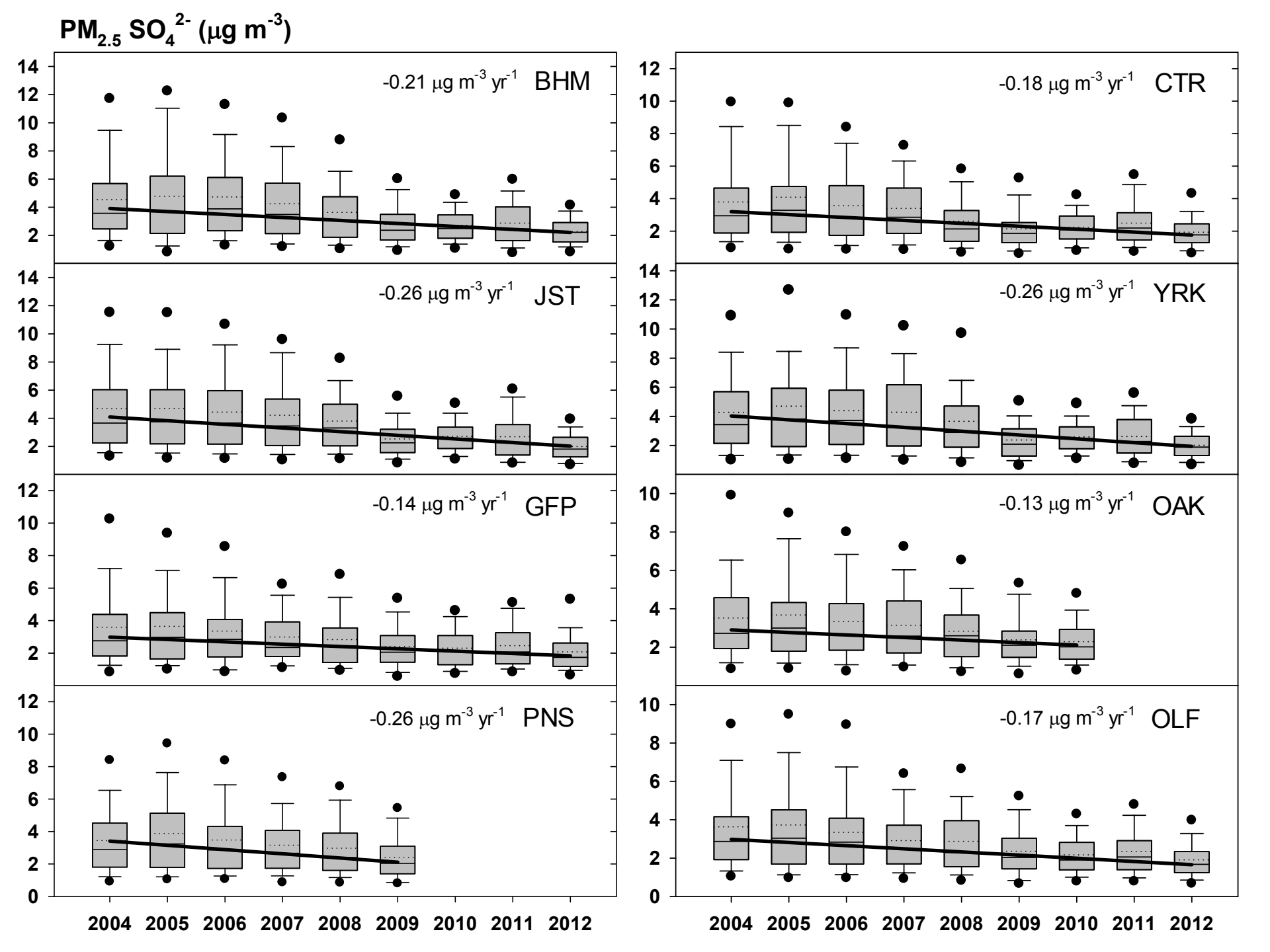

NH3/(NH3 + PM2.5 NH4+) (mol/mol)
BHM
0.010 yr-1
CTR
0.015 yr-1
JST
0.032 yr-1
YRK
0.032 yr-1
GFP
0.014 yr-1
OAK
0.014 yr-1
PNS
0.003 yr-1
OLF
0.010 yr-1
1.0
0.8
0.6
0.4
0.2
2004
2005
2006
2007
2008
2009
2010
2011
2012

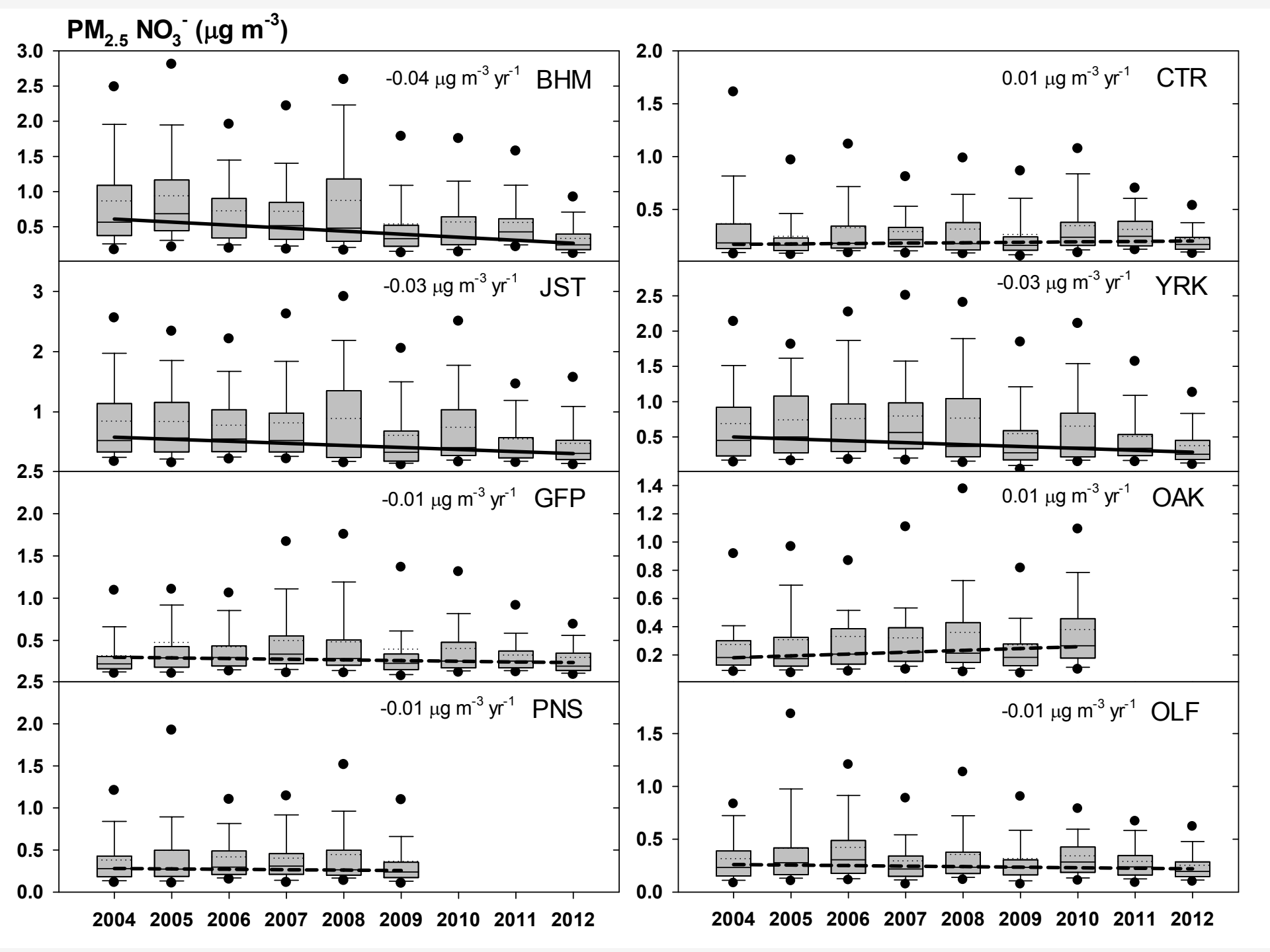

Sulfur Dioxide Emissions - Xing et al. (2013)
Tg yr-1
25
20
15
10
5
0
Southeast U. S.
Total U. S.
1990
1992
1994
1996
1998
2000
2002
2004
2006
2008
2010
Clean Air Act Amendments ARP
ARP Phase 1
ARP Phase 2
Clean Air Interstate Rule
ARP Completed

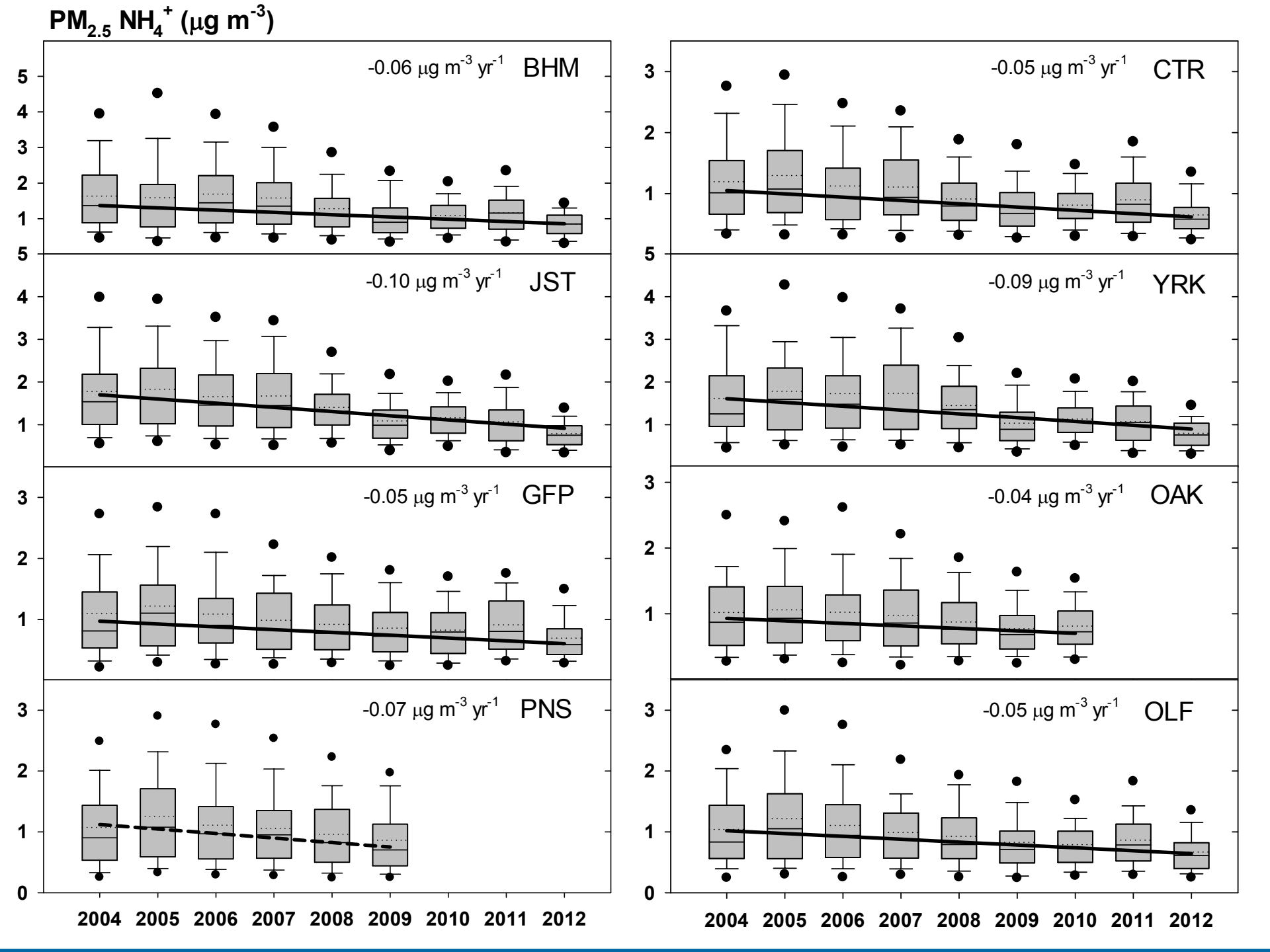

Nitrogen Oxides Emissions - Xing et al. (2013)
Tg yr-1
30
25
20
15
10
5
0
1990
1992
1994
1996
1998
2000
2002
2004
2006
2008
2010

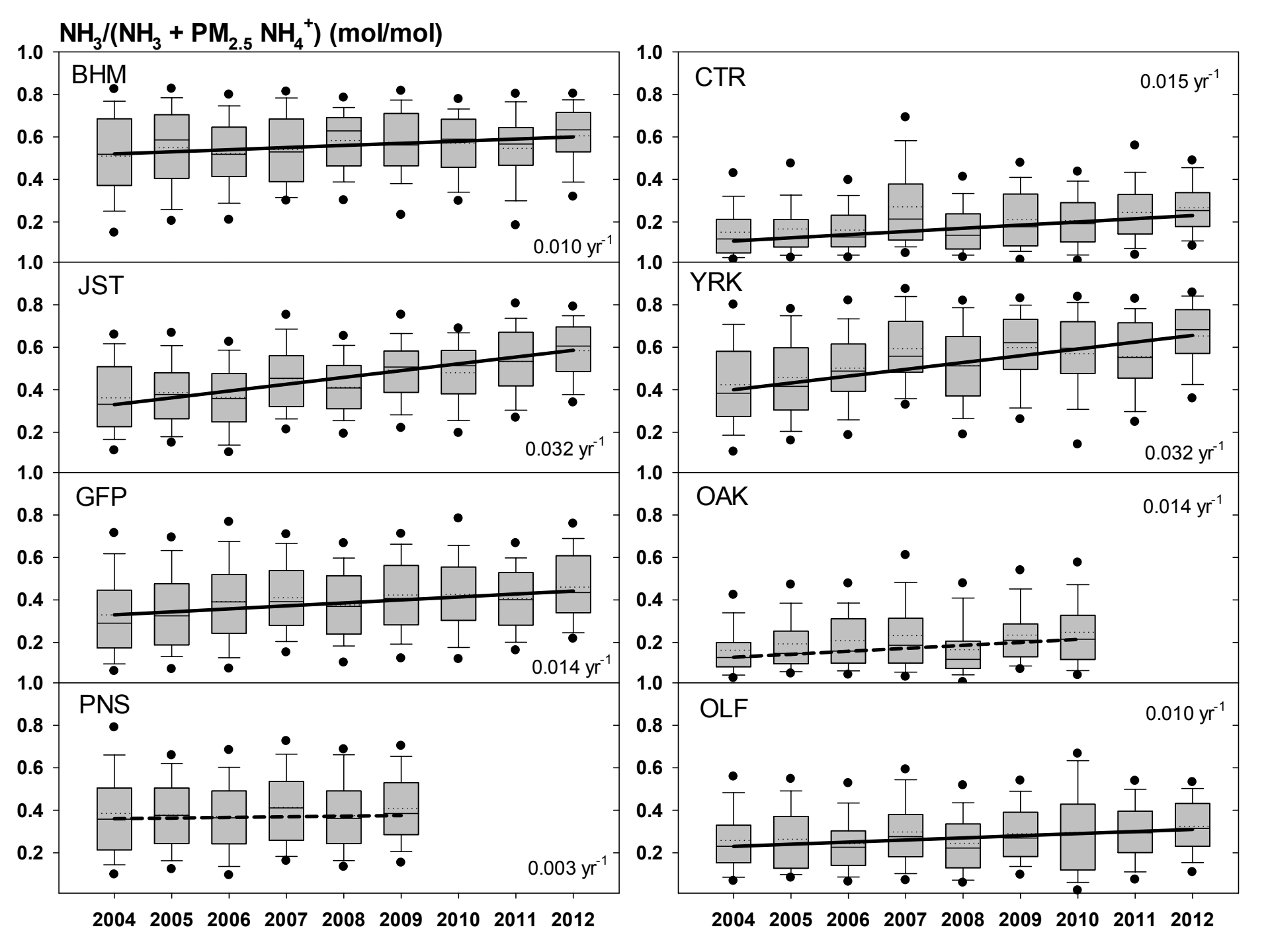

Sulfur Dioxide Emissions - Xing et al. (2013)
Tg yr-1
25
20
15
10
5
0
Southeast U. S.
Total U. S.
SO2 → → H2SO4
1990
1992
1994
1996
1998
2000
2002
2004
2006
2008
2010
Clean Air Act Amendments ARP
ARP Phase 1
ARP Phase 2
Clean Air Interstate Rule
ARP Completed


Nitrogen Oxides Emissions - Xing et al. (2013)
Tg yr-1
30
25
20
15
10
5
0
NOx → → HNO3
1990
1992
1994
1996
1998
2000
2002
2004
2006
2008
2010


PM2.5 SO4 2- (μg m-3)
-0.21 μg m-3 yr-1 BHM
-0.18 μg m-3 yr-1 CTR
-0.26 μg m-3 yr-1 JST
-0.26 μg m-3 yr-1 YRK
-0.14 μg m-3 yr-1 GFP
-0.13 μg m-3 yr-1 OAK
-0.26 μg m-3 yr-1 PNS
-0.17 μg m-3 yr-1 OLF
2004 2005 2006 2007 2008 2009 2010 2011 2012


PM2.5 NO3- (μg m-3)
-0.04 μg m-3 yr-1 BHM
-0.03 μg m-3 yr-1 JST
-0.01 μg m-3 yr-1 GFP
-0.01 μg m-3 yr-1 PNS
0.01 μg m-3 yr-1 CTR
-0.03 μg m-3 yr-1 YRK
0.01 μg m-3 yr-1 OAK
-0.01 μg m-3 yr-1 OLF
2004 2005 2006 2007 2008 2009 2010 2011 2012

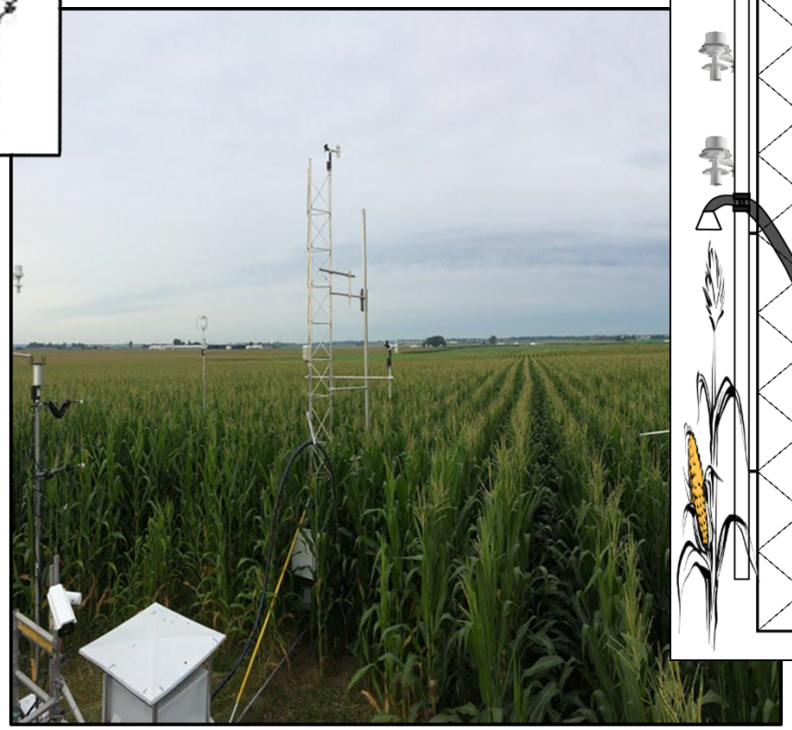

PM2.5 NH4+ (μg m-3)
-0.06 μg m-3 yr-1 BHM
-0.05 μg m-3 yr-1 CTR
-0.10 μg m-3 yr-1 JST
-0.09 μg m-3 yr-1 YRK
-0.05 μg m-3 yr-1 GFP
-0.04 μg m-3 yr-1 OAK
-0.07 μg m-3 yr-1 PNS
-0.05 μg m-3 yr-1 OLF
2004 2005 2006 2007 2008 2009 2010 2011 2012

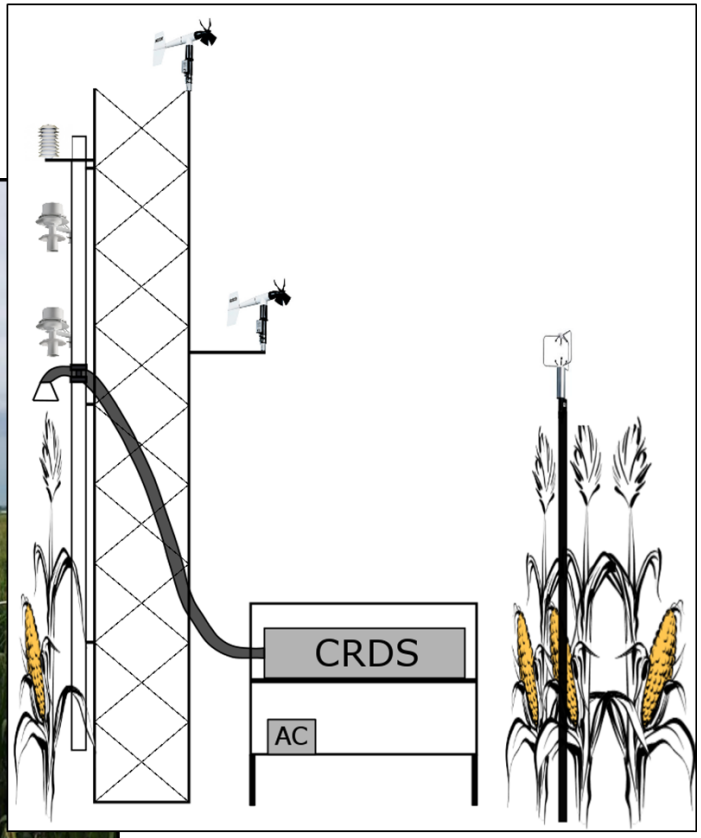

NH3/(NH3 + PM2.5 NH4+) (mol/mol)
BHM
0.010 yr-1
CTR
0.015 yr-1
JST
0.032 yr-1
YRK
0.032 yr-1
GFP
0.014 yr-1
OAK
0.014 yr-1
PNS
0.003 yr-1
OLF
0.010 yr-1
1.0
0.8
0.6
0.4
0.2
2004
2005
2006
2007
2008
2009
2010
2011
2012

2014 Illinois NH_3 Study - NSF

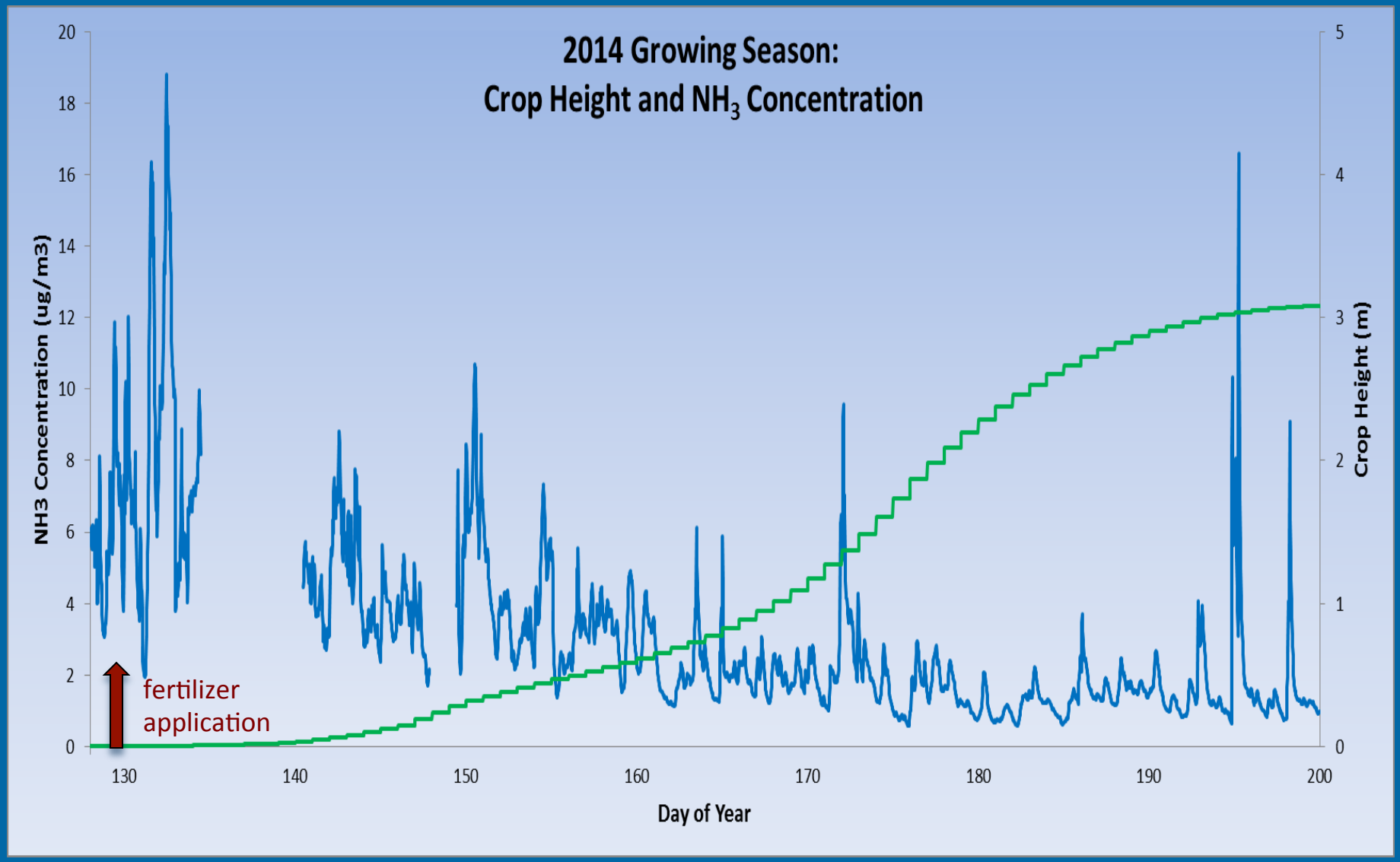
Dr. LaToya Myles (ATDD) and Dr. Sotiria Koloutsou-Vakakis (U. Illinois)

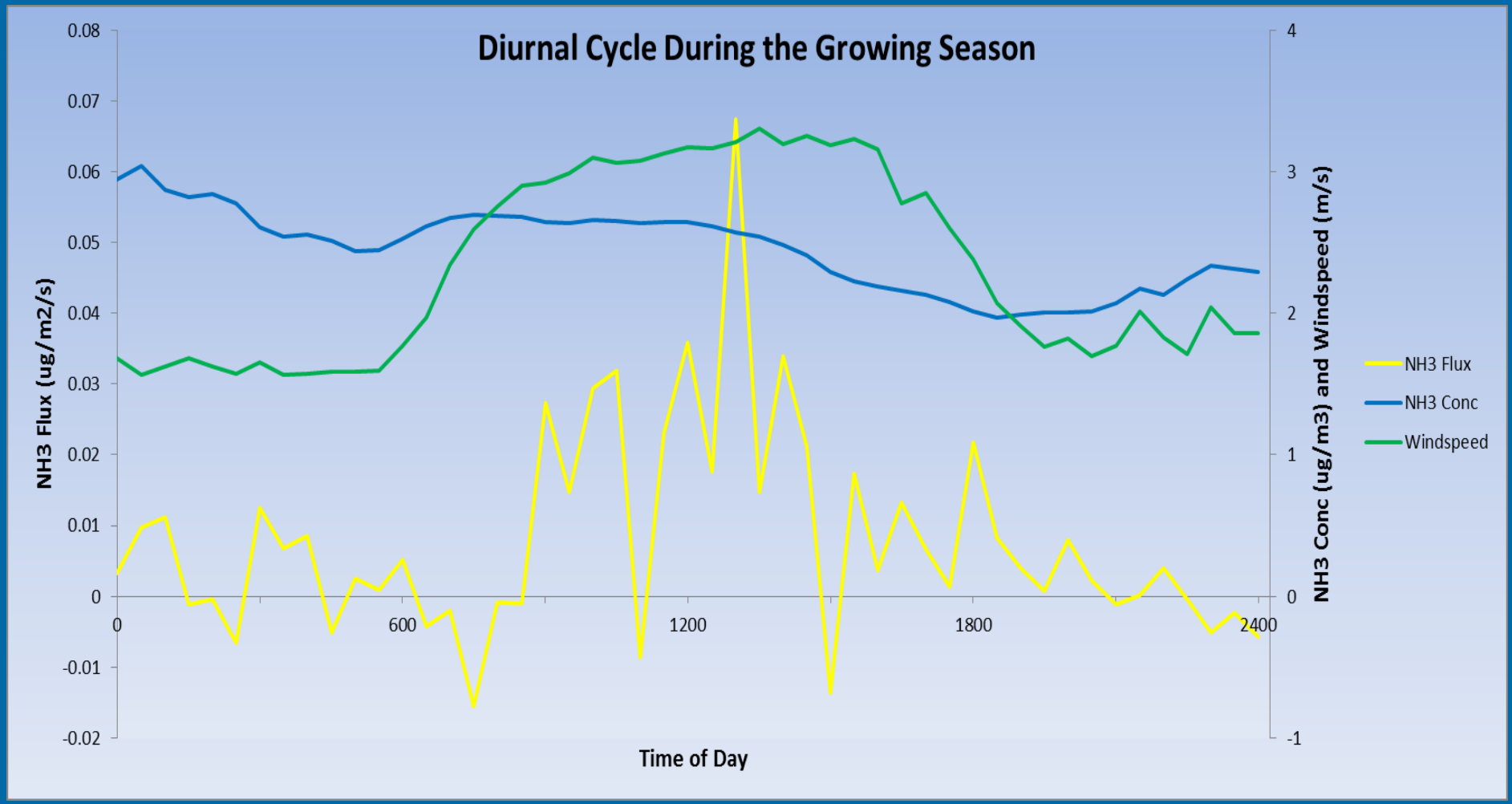
Ambient NH3 concentrations	Cavity Ring-Down Spectroscopy
Air temperature	Platinum Resistance Thermometers
Dewpoint	Humidity and Temperature Probe
Wind speed and direction	Propeller Anemometer
Pressure	Barometer





Instruments in 200 m^2 Zea mays plot at UIUC Energy Biosciences Institute Farm in Urbana, IL (July 2014).
Photo Credit: A. Nelson


2014 Growing Season:
Crop Height and NH3 Concentration
NH3 Concentration (ug/m3)
Crop Height (m)
Day of Year
fertilizer application
0
2
4
6
8
10
12
14
16
18
20
0
1
2
3
4
5
130
140
150
160
170
180
190
200


Diurnal Cycle During the Growing Season
NH3 Flux (ug/m2/s)
NH3 Conc (ug/m3) and Windspeed (m/s)
Time of Day
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0
-0.01
-0.02
4
3
2
1
0
-1
0
600
1200
1800
2400
NH3 Flux
NH3 Conc
Windspeed

Atmospheric Chemistry and Canopy Exchange Simulation System for Ammonia (ACCESS-NH3)

Final Governing Equation:

$$\frac{\partial \chi(z,t)}{\partial t} = \frac{\partial}{\partial z}\left(\rho(z,t) K_v(z,t) \frac{\partial \chi(z,t)/\rho(z,t)}{\partial z} \right) - v_c(z,t)\left(\chi(z,t) - \chi_c(z,t)\right) \cdot LAD(z)$$

Initial Condition:

$$\chi(z,t) = \chi_0(z) \qquad @\ t = 0$$

Boundary Conditions:

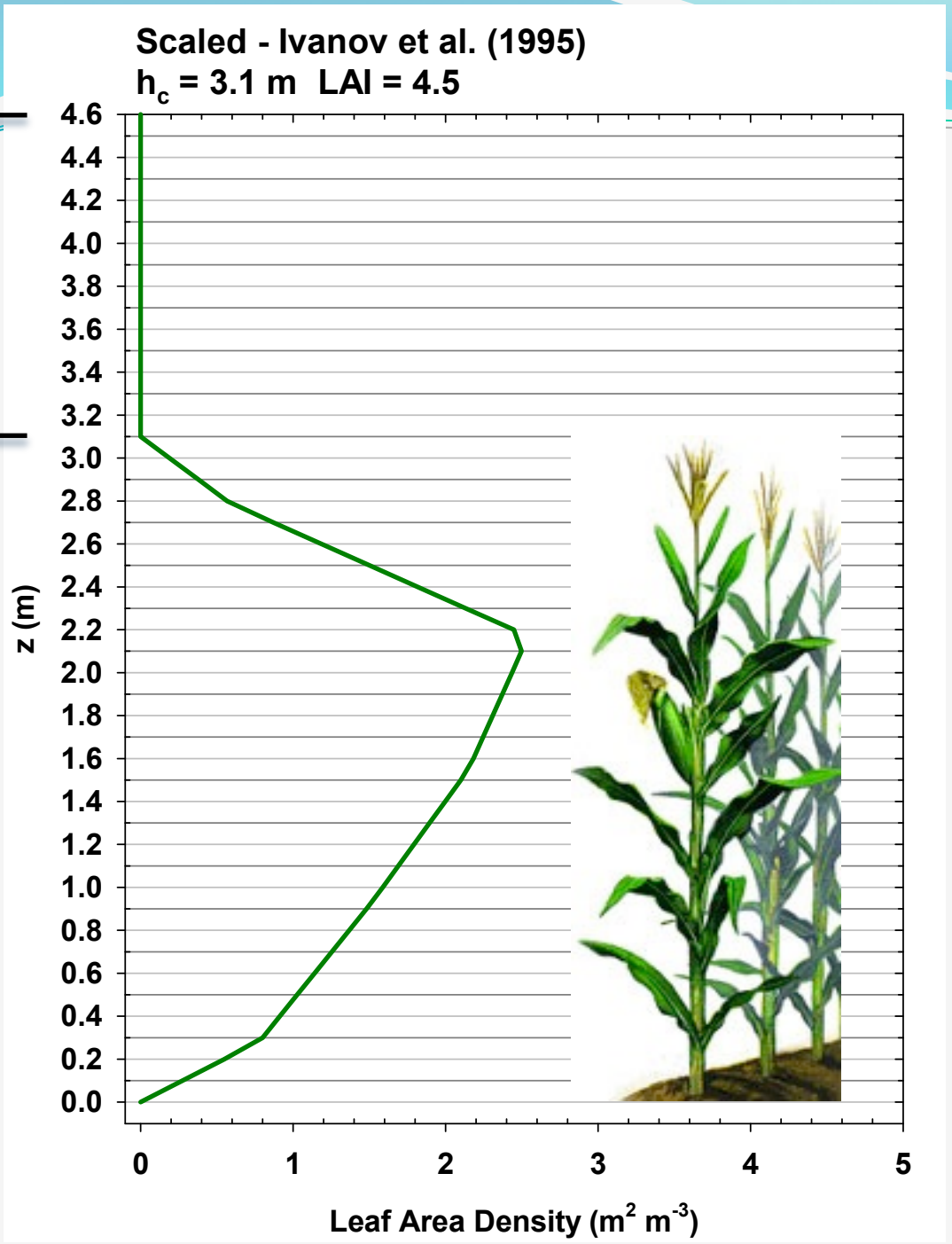
$$-\rho(0,t) K_v(0,t) \frac{\partial \chi(0,t)/\rho(0,t)}{\partial z} = -v_s(t)\left(\chi(0,t) - \chi_g(t)\right) \qquad @\ z = 0$$

$$\chi(H,t) = \chi_a(t) \qquad @\ z = H$$

where,

$\chi_g(t)$ = soil NH_3 compensation point

$\chi_a(t)$ = NH_3 concentration at $z = H$



h

h_c

- 1-D column model
- Surface to 1.5 m above canopy top
- 46 vertical layers
- 0.1 m (10 cm) resolution throughout domain
- LAD scaled from data of Ivanov et al. (1995) for a maize canopy

Atmospheric Chemistry and Canopy Exchange Simulation System for Ammonia (ACCESS-NH3)

Input Variables

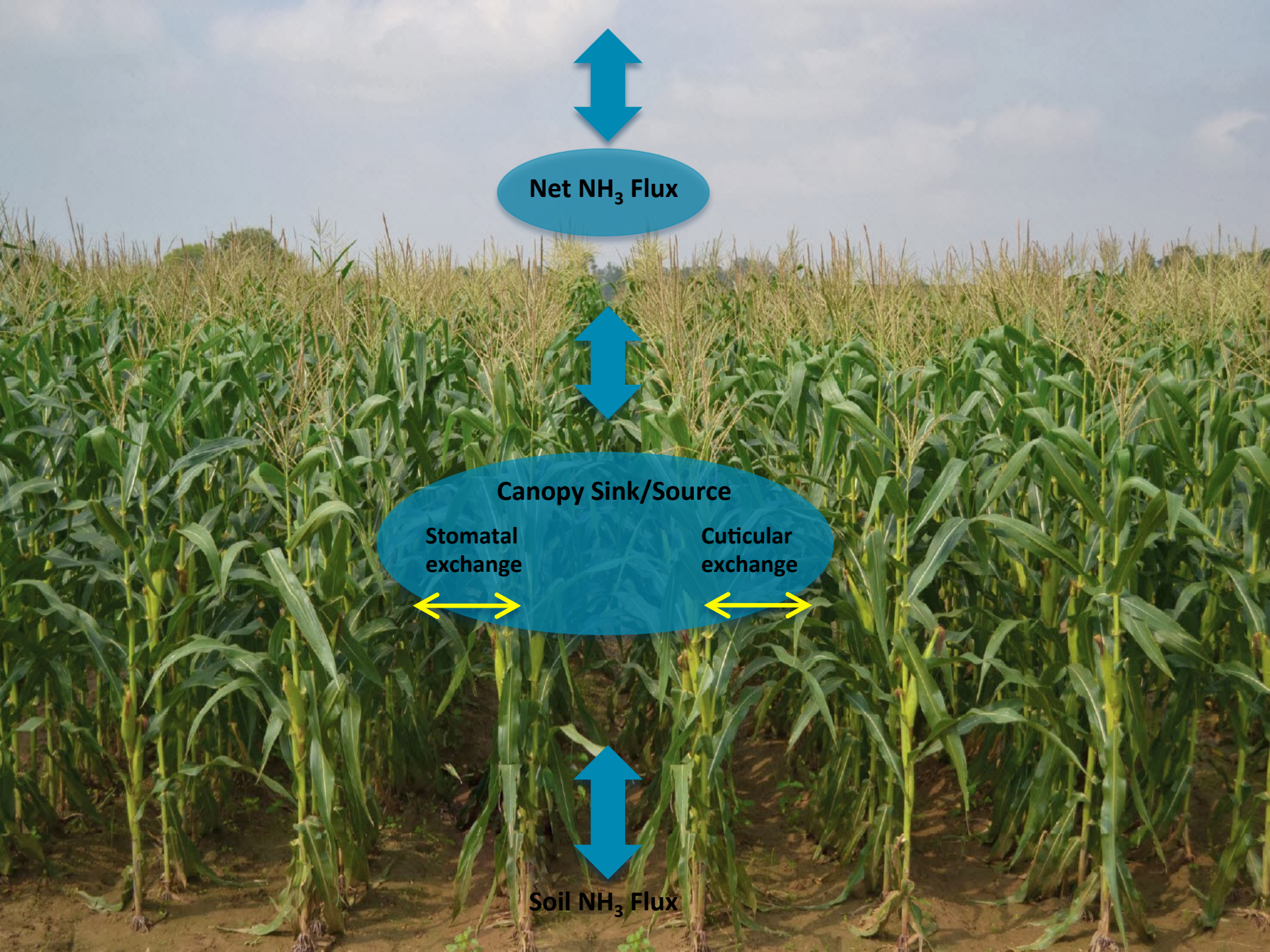
- Latitude/Longitude; Month, Day, Time
- Canopy morphology (canopy height, h_c; leaf area density profile $LAD\ (z)$)
- Soil data (soil type; topsoil depth, d_s; volumetric water content, θ)

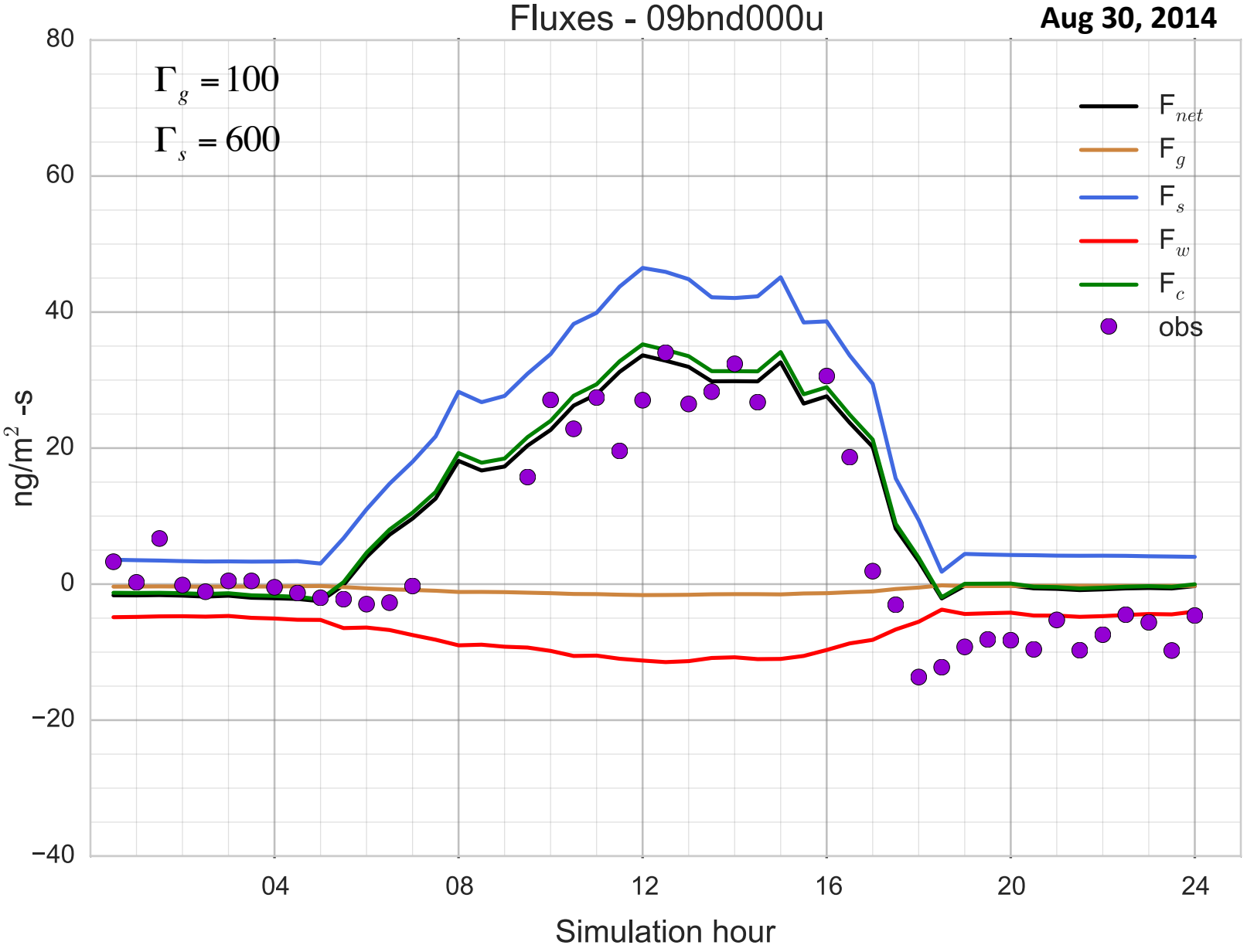
- NH_3 Concentration @ $z = H$ ($H = h_c$ + 1.5 m = 4.6 m)

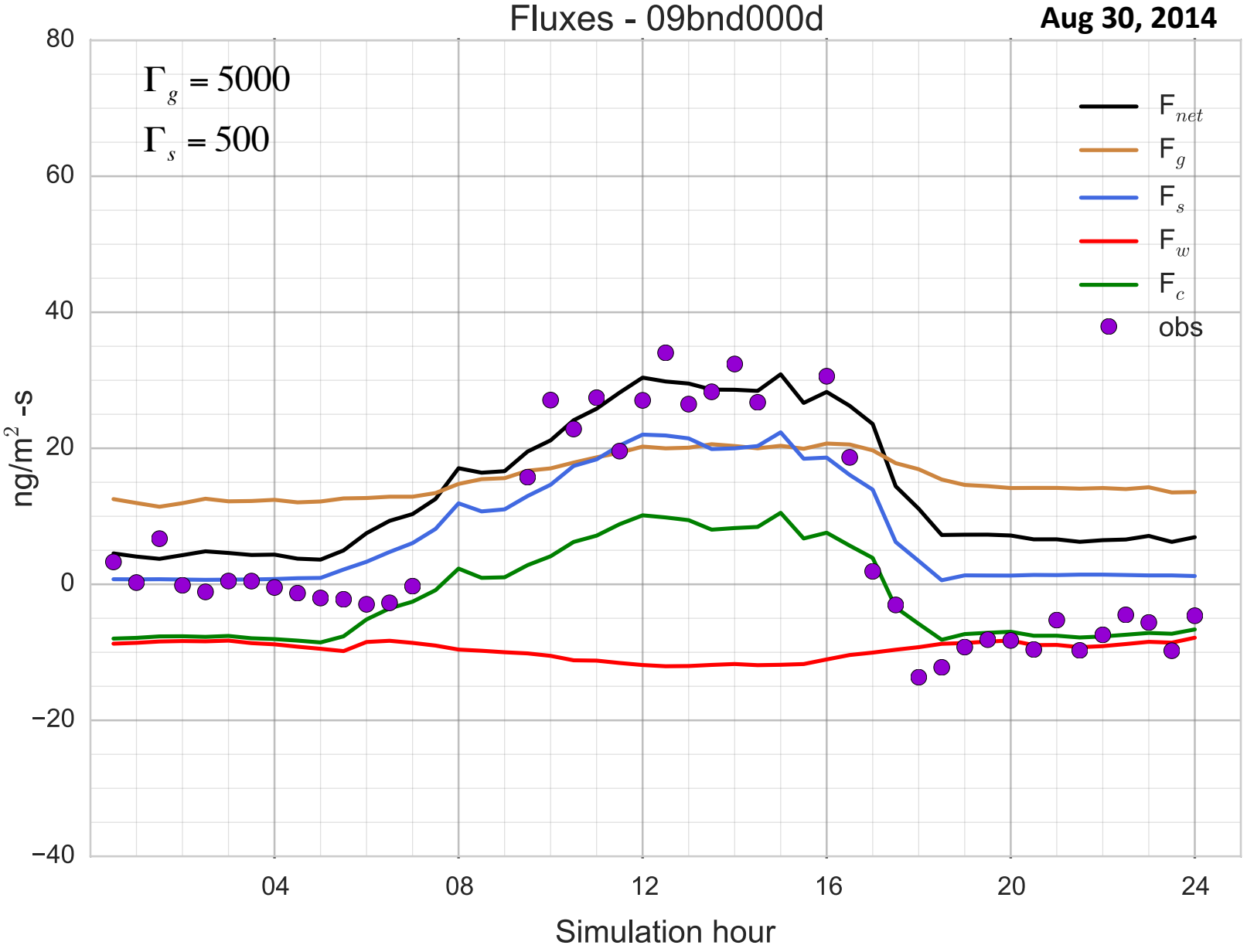
- Air temperature @ 3.95 m, soil temperature, pressure @ 0.8 m, relative humidity @ 3.95 m

- Mean wind speed, $\overline{u}$, shortwave radiation, and PPFD @ 3.95 m

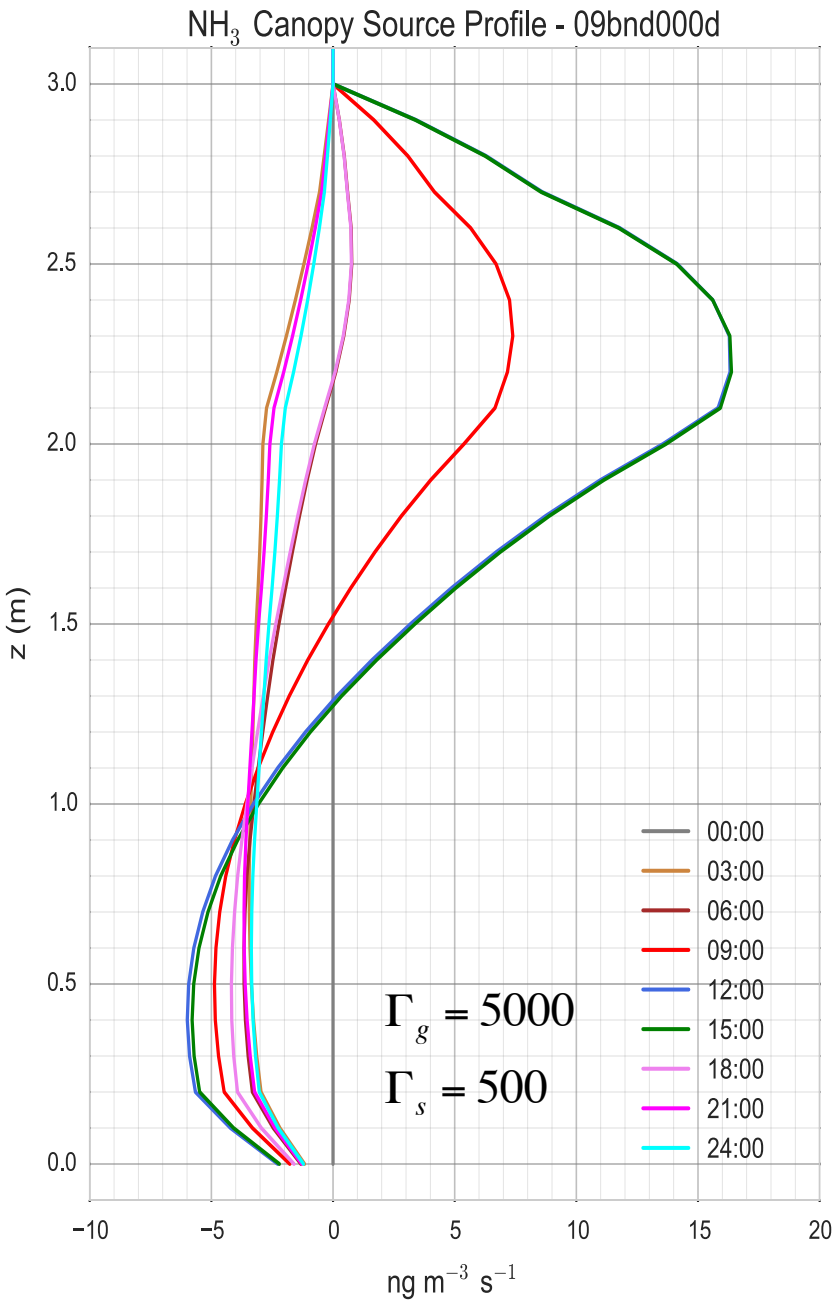
- Stomatal Emission Potential … $\Gamma_s = [NH_4^+]_s / [H^+]_s$
- Soil Emission Potential … $\Gamma_g = [NH_4^+]_g / [H^+]_g$

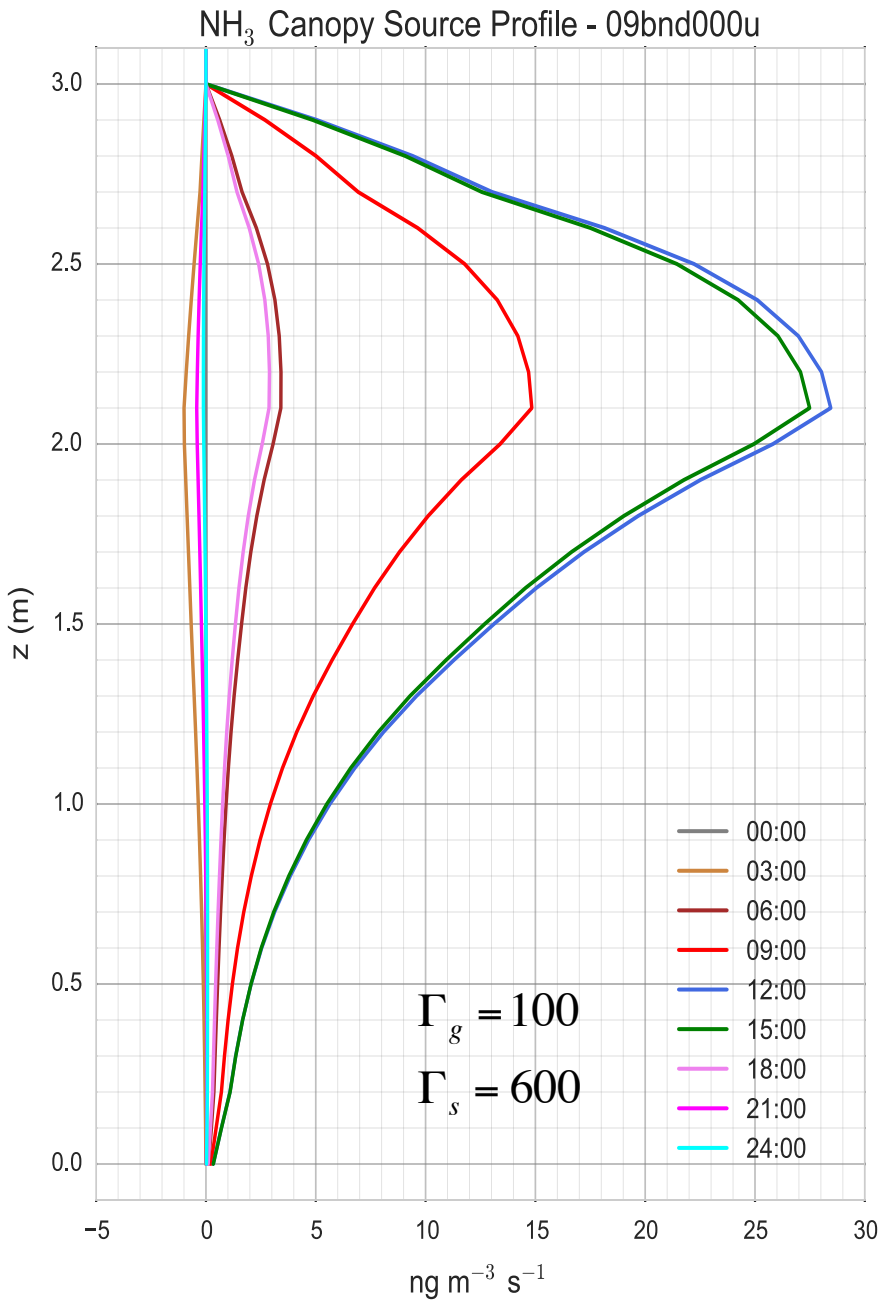

Net NH_3 Flux
Canopy Sink/Source
Stomatal exchange
Cuticular exchange
Soil NH_3 Flux


Fluxes - 09bnd000u
Aug 30, 2014
$\Gamma_g = 100$
$\Gamma_s = 600$
F_{net}
F_g
F_s
F_w
F_c
obs
80
60
40
20
0
−20
−40
ng/m^2 -s
04
08
12
16
20
24
Simulation hour

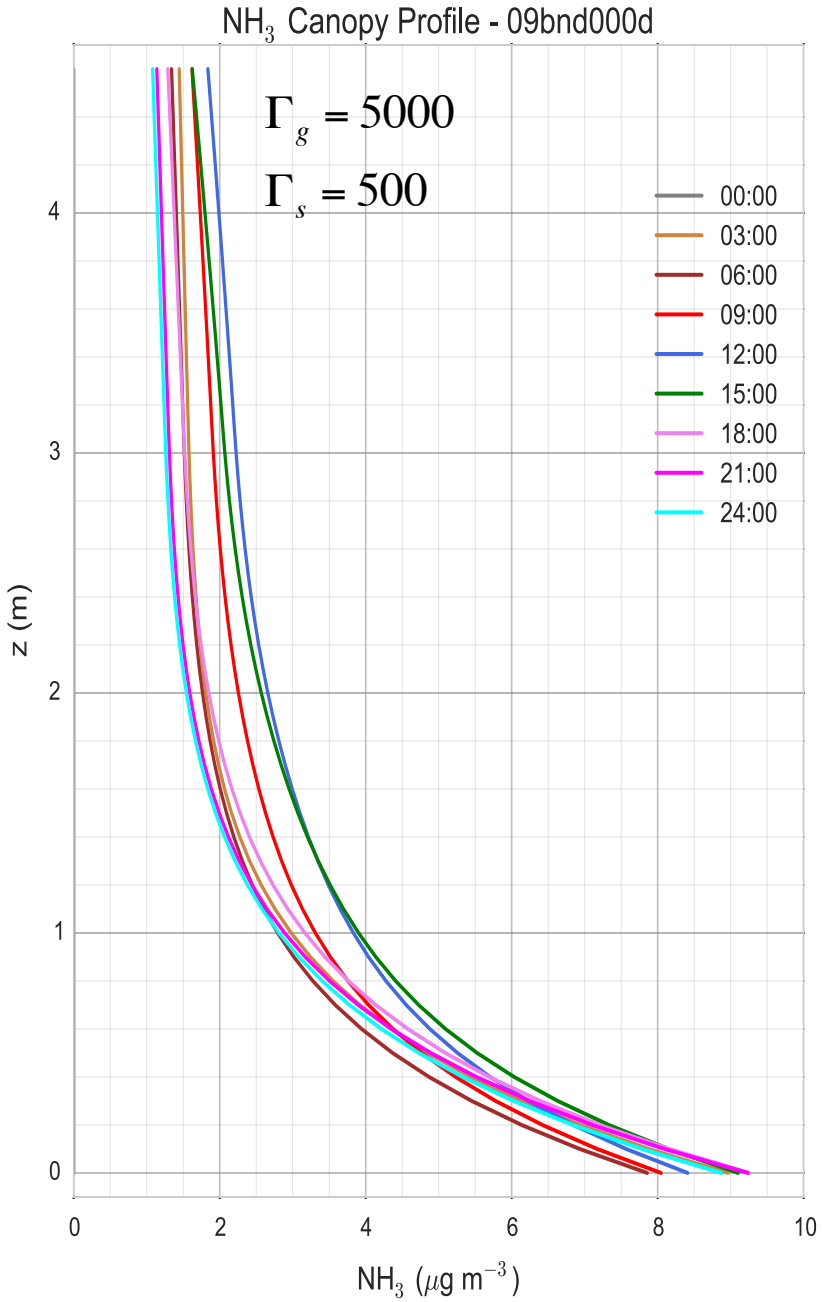

Fluxes - 09bnd000d
Aug 30, 2014
$\Gamma_g = 5000$
$\Gamma_s = 500$
F_{net}
F_g
F_s
F_w
F_c
obs
80
60
40
20
0
−20
−40
ng/m^2 -s
04
08
12
16
20
24
Simulation hour

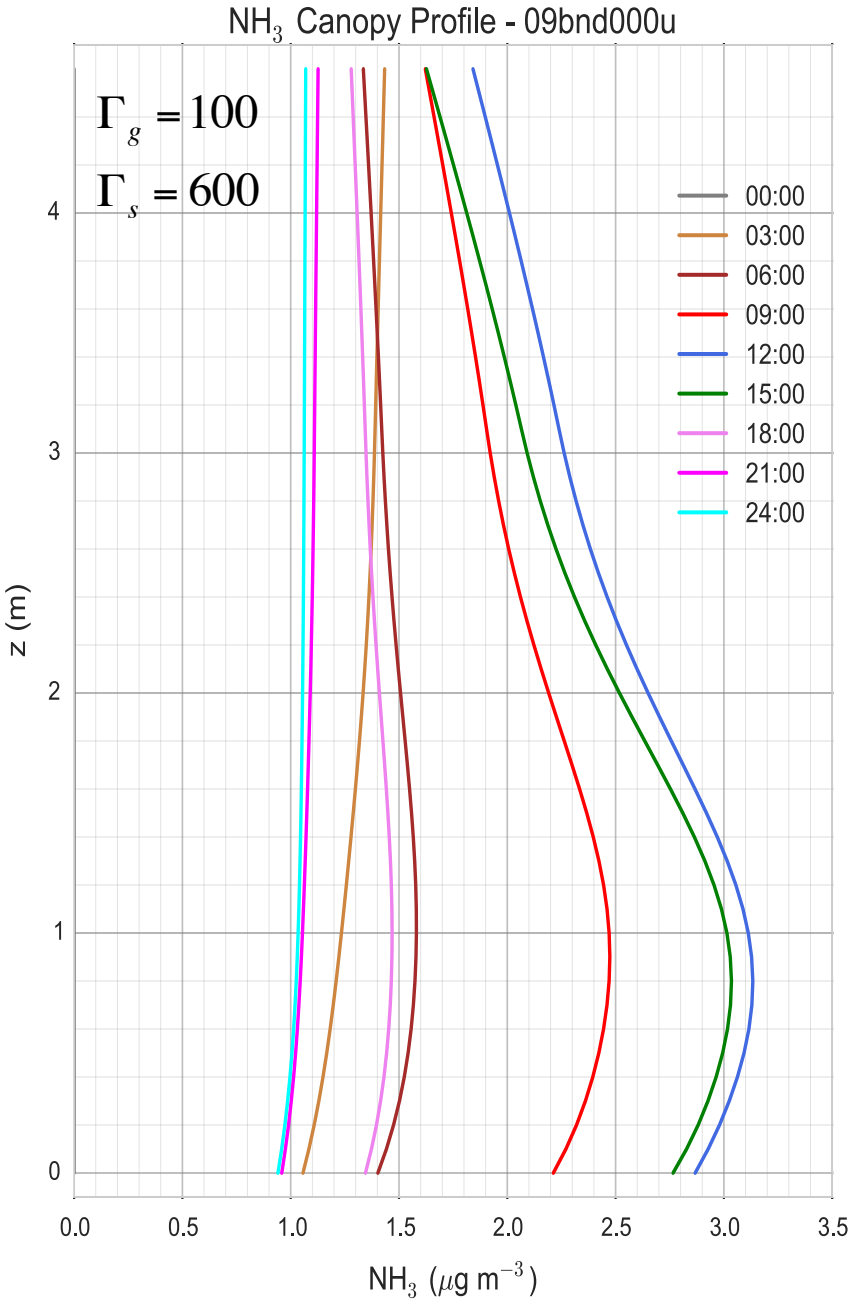
Aug 30, 2014


NH3 Canopy Source Profile - 09bnd000d
z (m)
ng m−3 s−1
Γg = 5000
Γs = 500
00:00
03:00
06:00
09:00
12:00
15:00
18:00
21:00
24:00


NH3 Canopy Source Profile - 09bnd000u
z (m)
ng m−3 s−1
Γg = 100
Γs = 600
00:00
03:00
06:00
09:00
12:00
15:00
18:00
21:00
24:00

Aug 30, 2014


NH3 Canopy Profile - 09bnd000d
Γg = 5000
Γs = 500
00:00
03:00
06:00
09:00
12:00
15:00
18:00
21:00
24:00
z (m)
0
1
2
3
4
0
2
4
6
8
10
NH3 (μg m−3)


NH3 Canopy Profile - 09bnd000u
Γg = 100
Γs = 600
00:00
03:00
06:00
09:00
12:00
15:00
18:00
21:00
24:00
z (m)
0
1
2
3
4
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
NH3 (μg m−3)

Future Directions

Measurements

- ✓ Intercomparisons between CRDS and other laser-based techniques, e.g. open path tunable diode laser (OPTDL), tunable diode laser absorption spectroscopy (TDLAS)
- ✓ Field measurements of fluxes in more complex ecosystems, including coastal marshes, where nutrient enrichment can affect vegetation and carbon exchange
- ✓ Field measurements of concentrations downwind from prescribed burns and/or wildfires (contribution to NOAA biennial study: FIREX)

Modeling

- ✓ Continued use of ACCESS-NH3 (and other NH_3 flux models) to better understand environmental controls of NH_3 fluxes from/to agricultural fields and coastal marshes (limited resources!).
- ✓ Evaluation of NH_3 emissions used in 3-D air quality models (esp. NAQFC) using AMoN and satellite data.

Research Needs

- ✓ U.S. ammonia emissions inventory remains highly uncertain.
  - Lack of information about agricultural emissions from various crops in different locations.
  - Lack of understanding about processes that drive NHx exchange with soil, vegetation, and surface waters under different environmental conditions.
  - Lack of long-term measurements with adequate spatial and temporal resolution.
- ✓ More robust continuous measurement techniques for field applications.
- ✓ Better algorithms for simulation of bi-directional exchange within 3-D air quality models.

Thank you!

Questions?