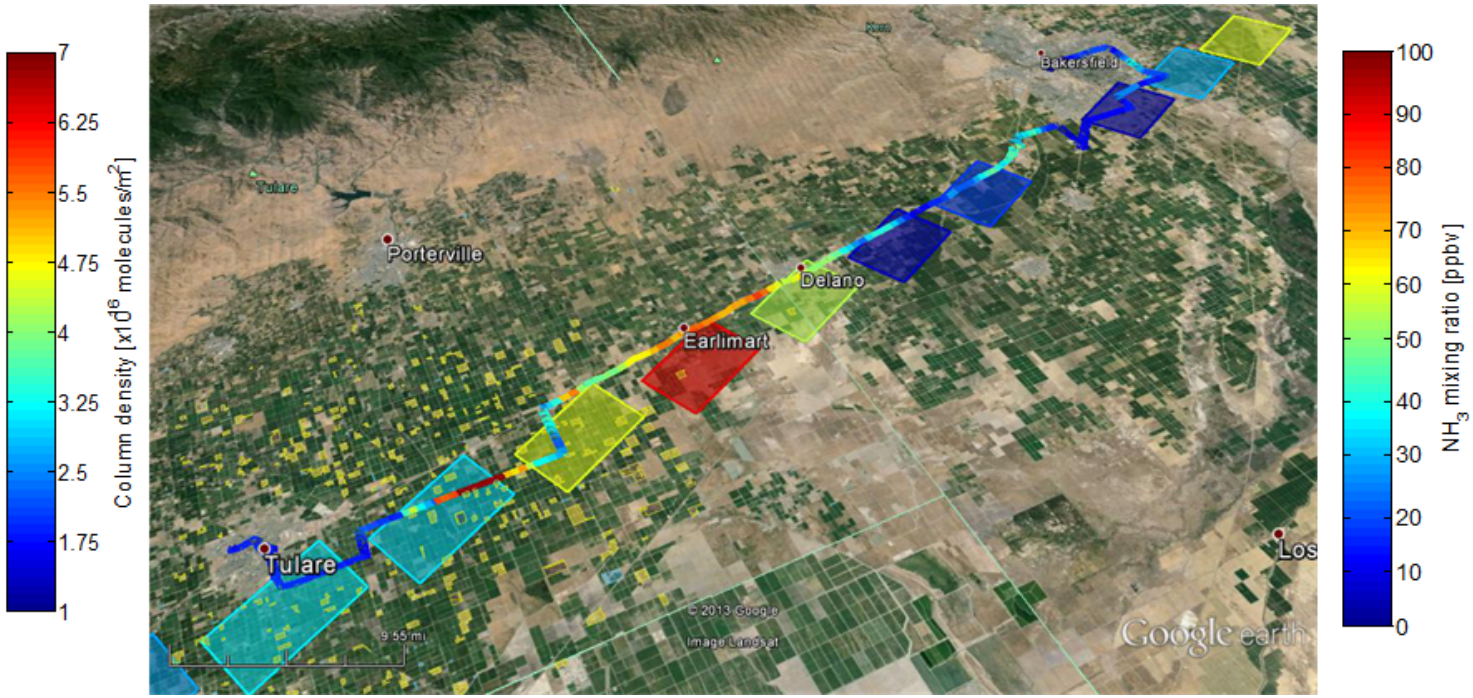
# Validation of Satellite Ammonia Retrievals Using Ground-based Mobile Measurements





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[1] Princeton University, Princeton, NJ; [2] AER, Inc. Lexington, MA; [3] UPMC Univ., Paris, France; [4] Université Libre de Bruxelles, Brussels, Belgium; [5] ARI, MA; [6] University of Innsbruck, Austria



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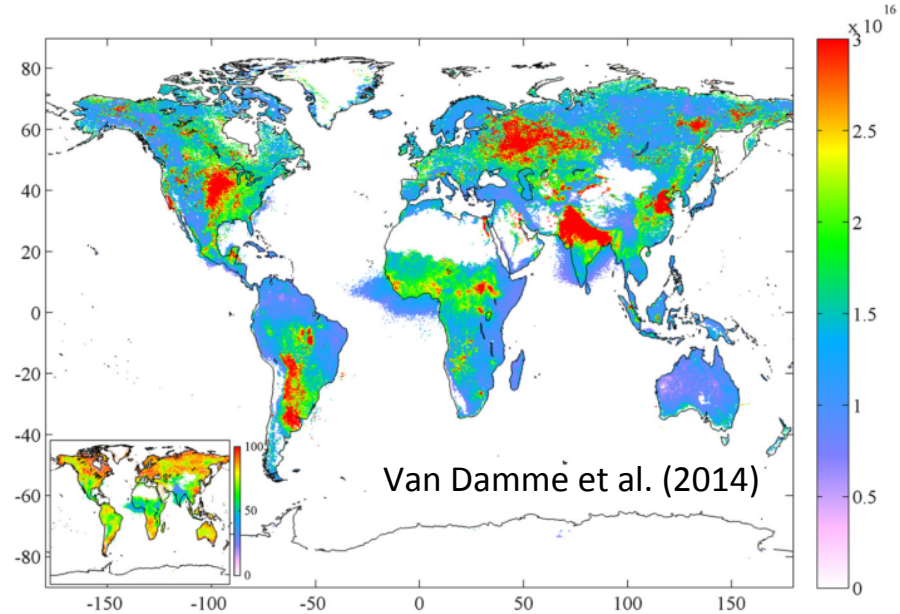
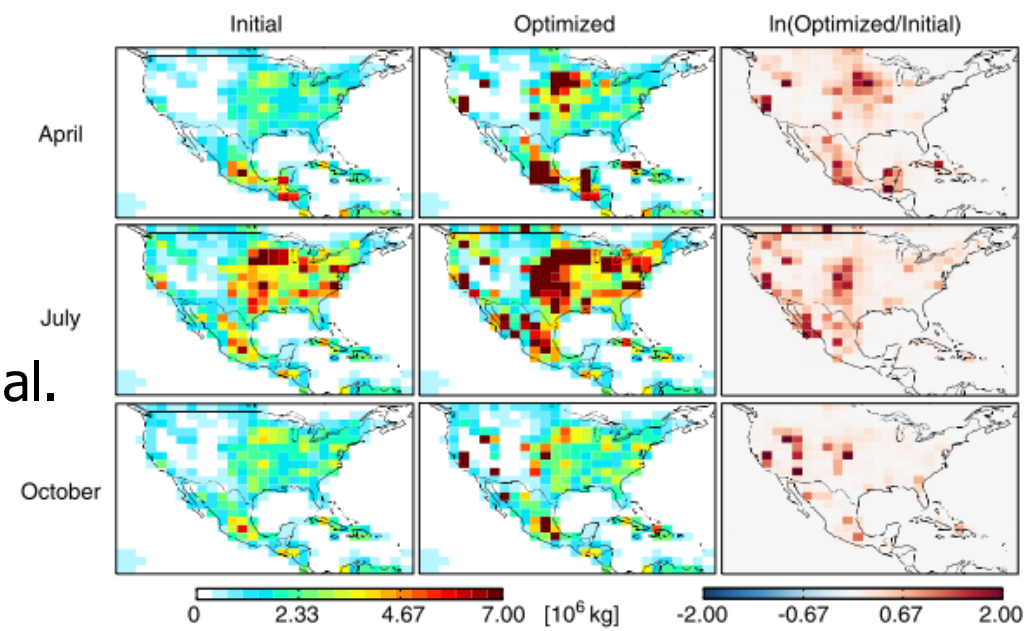
NASA Sounder Science Team Meeting, Oct. 1, 2014

# Introduction

- Ammonia ($NH_3$) is a key precursor to $PM_{2.5}$
- Observing $NH_3$ from space (TES, IASI, AIRS, CrIS)
- Satellites provide observational constraints on $NH_3$ emissions
- Current $NH_3$ inventories are underestimated globally (Zhu et al. 2013; Heald et al. 2012; Clarisse et al. 2009; Shephard et al. 2011)

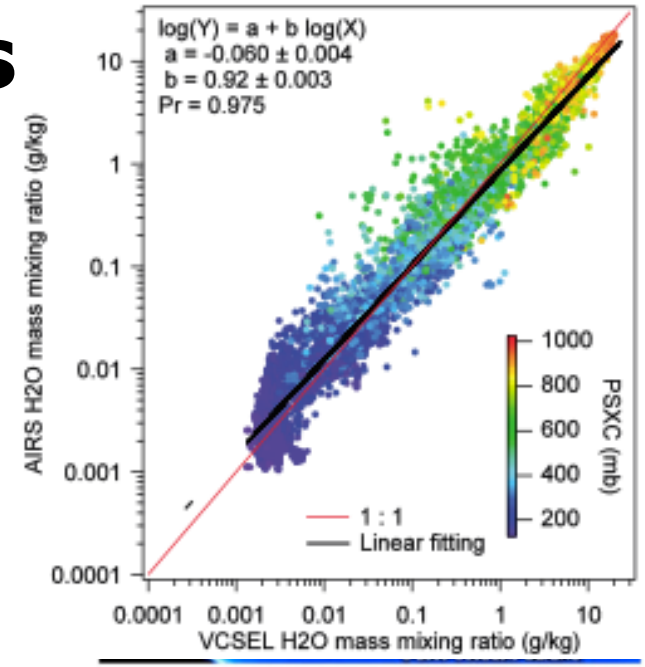


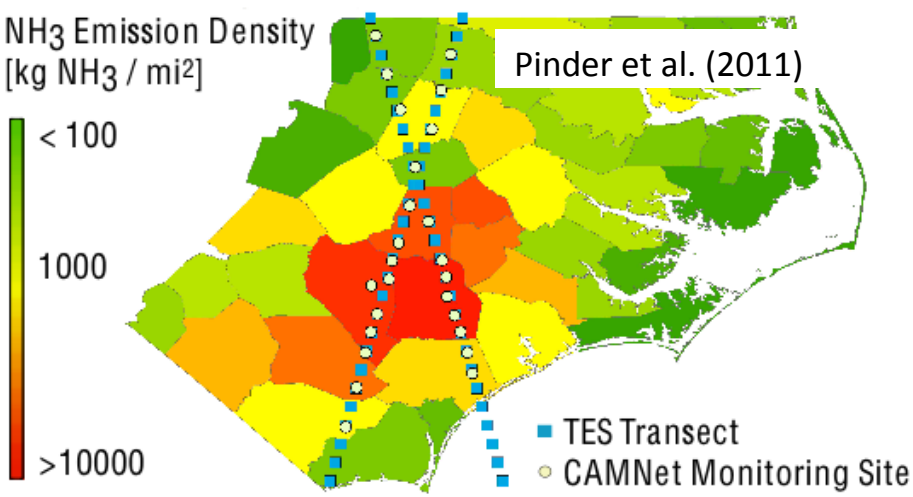

Zhu et al. (2013) $NH_3$ emissions from GEOS-Chem before and after the assimilation.

# Validation of $NH_3$ retrievals

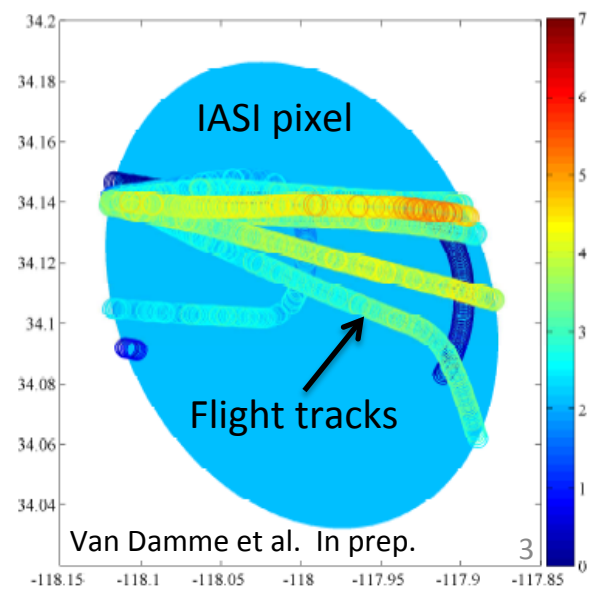
- Importance of $NH_3$ validation
  - Weak signal, concentrated near surface
  - Strong dependence on thermal contrast
- Conventional satellite validation
  - Statistical analyses from large dataset
  - Assuming intra-pixel homogeneity
- TES was validated by biweekly surface measurements
- IASI/AIRS validation using aircraft data




Diao et al. (2013)

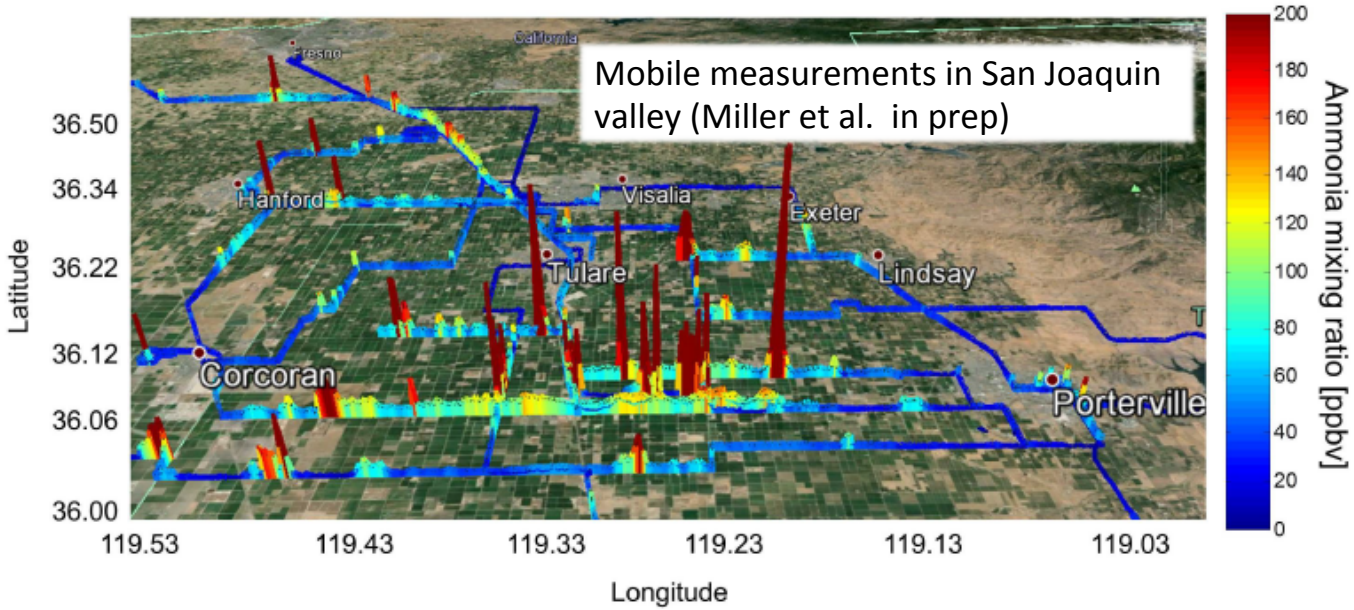



Pinder et al. (2011)




Van Damme et al. In prep.

# Validation of $NH_3$ retrievals (continued)



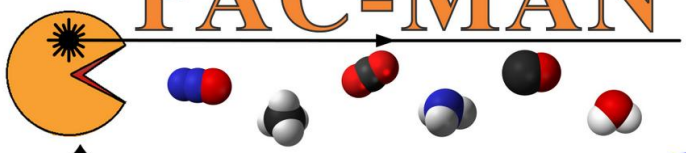

- Challenges of $NH_3$ validation
  - Extreme heterogeneity/variation near sources
  - Large dynamic range
  - Few *in-situ* measurements, limited retrievals (TES)
- Questions:
  - Can we validate $NH_3$ under heterogeneous surface conditions?
  - Can we validate $NH_3$ with limited number of pixels?

# Mobile sensing setup

| Species | Prec. | Mass | Power | Make |
|---|---|---|---|---|
| $NH_3$ | 0.15 ppbv | 15 kg | 50 W | ref 1-3 |
| $N_2O$ | 0.07 ppbv | 10 kg | 40 W | ref 4 |
| CO | 0.2 ppbv | - | - | ref 4 |
| $CH_4$ | 2 ppbv | 4 kg | 15 W | LICOR |
| $H_2O$ | <1% | 2 kg | 5 W | LICOR |
| $CO_2$ | 0.1 ppmv | - | - | LICOR |
| met. data (T, p, q, winds) | | | | Vaisala |

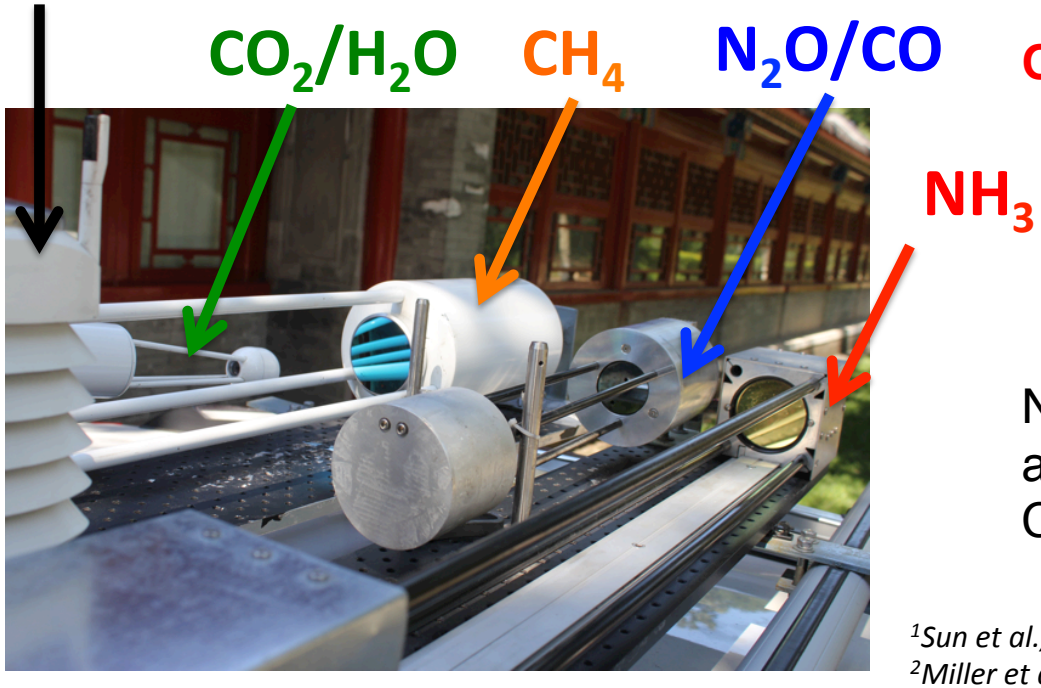
**P**rinceton **A**tmospheric **C**hemistry
**M**obile **A**cquisition **N**ode

**PAC-MAN**



PRINCETON
School of Engineering and Applied Science
http://zondlo.princeton.edu/mobile

MIRTHE




**Open-path** design critical for:

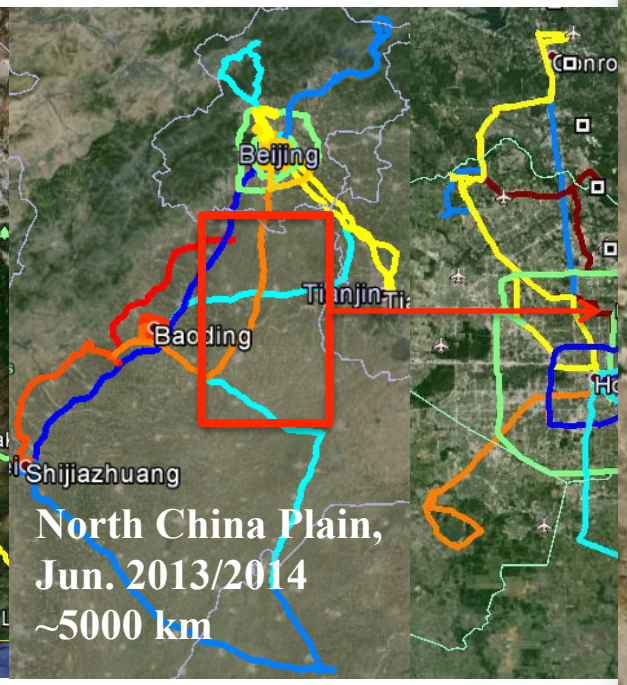
- fast, high-resolution
- compact, low power sensor
- avoiding sampling biases
- enhancing response time

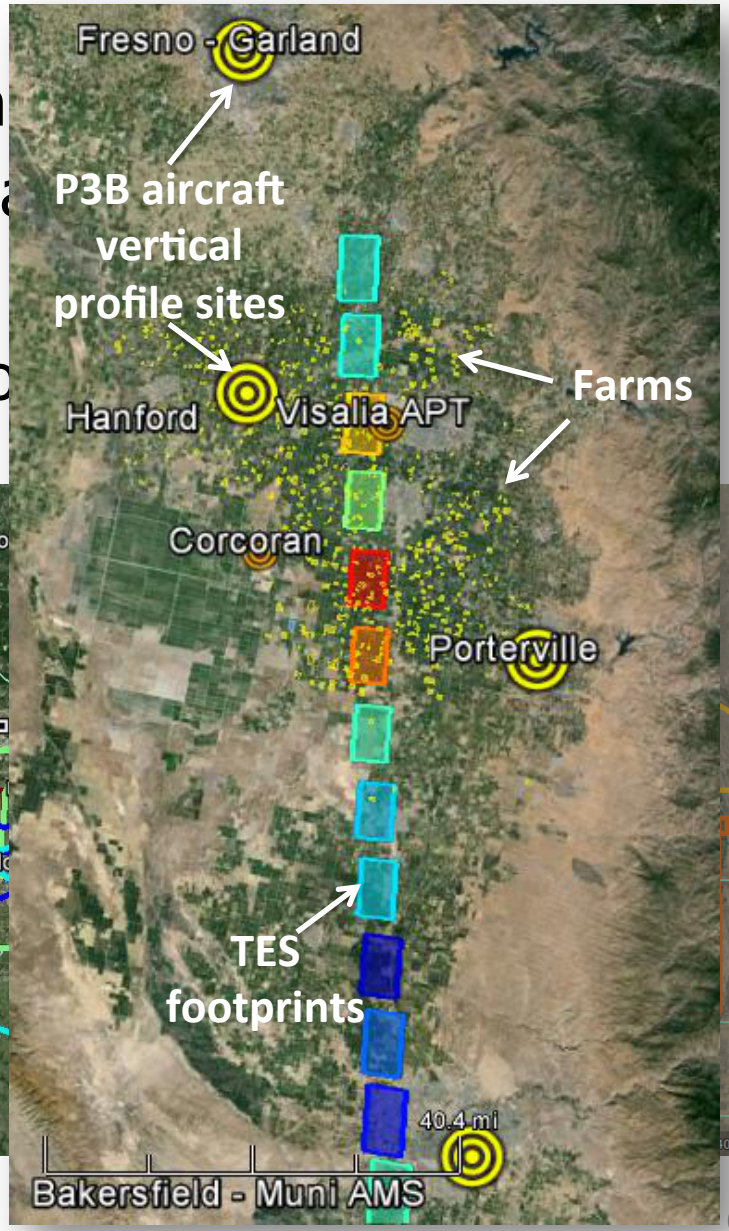
$NH_3$ calibrated by inline reference cell and direct absorption (ref 1-2); $CO_2$, CO, $CH_4$ calibrated by **NOAA standard**


[1]*Sun et al., Appl. Phys. B, 2013*
[2]*Miller et al., AMT, 2014*
[3]*Sun et al., Envi. Sci. Technol, 2014*
[4]*Tao et al., Optics Exp., 2012*

# Spatial coverage

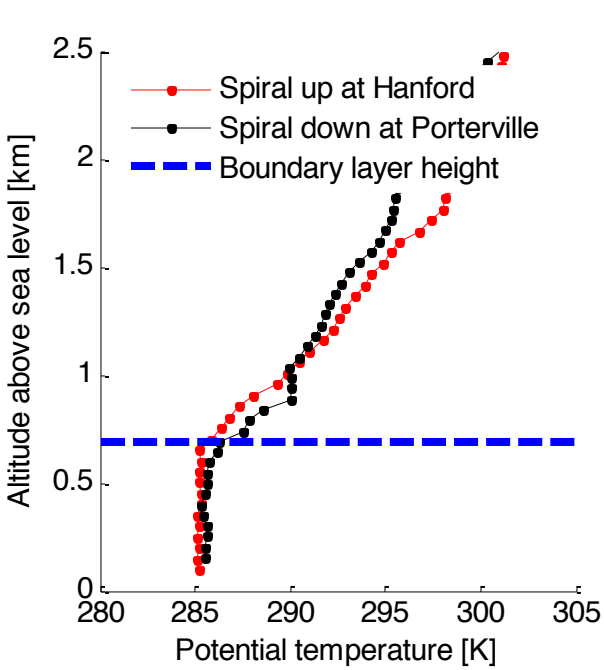
- NASA DISCOVER-AQ in Californ
- CAREBeijing/NCP in North China
- ~ 16,000 km, 300 hours
- Major urban/agricultural $NH_3$ so

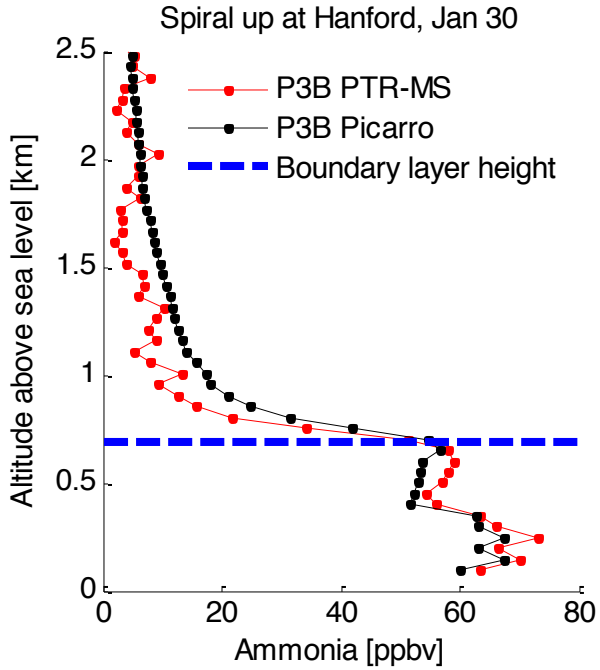



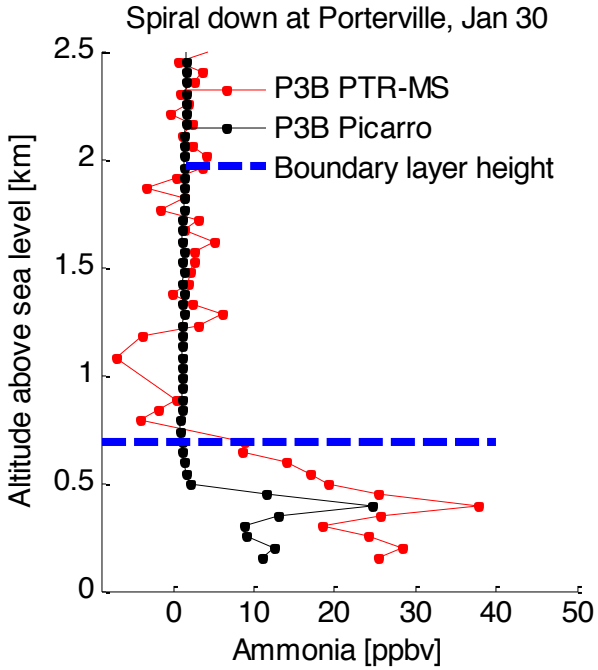



# $NH_3$ measurements at DISCOVER-AQ SJV

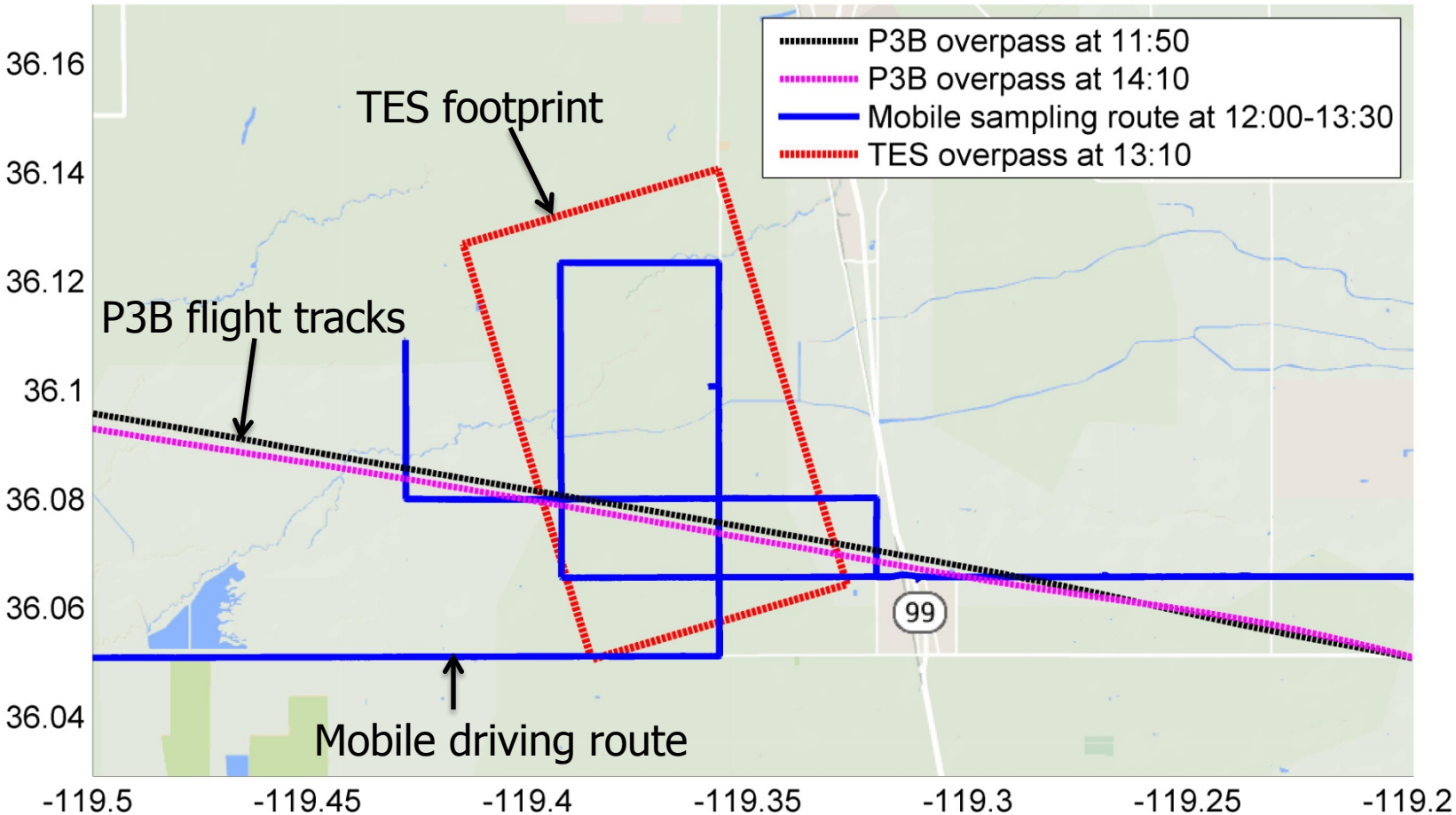
- TES (Tropospheric Emission Spectrometer) on Aura Satellite
  - Local daytime overpass at 13:00 – 13:30; 5.3 km x 8.3 km footprint
  - Sensitivity: 1 ppbv $NH_3$
  - Degrees of freedom (DOFS) ~ 1
- PTR-MS and Picarro G2103 on NASA P3-B aircraft
  - PTR-MS (Dr. Armin Wisthaler): low sensitivity (~10 ppbv), better response tim (~ 12 s)
  - Picarro (Dr. John Nowak): high sensitivity (0.34 ppbv), slow response (1 min)



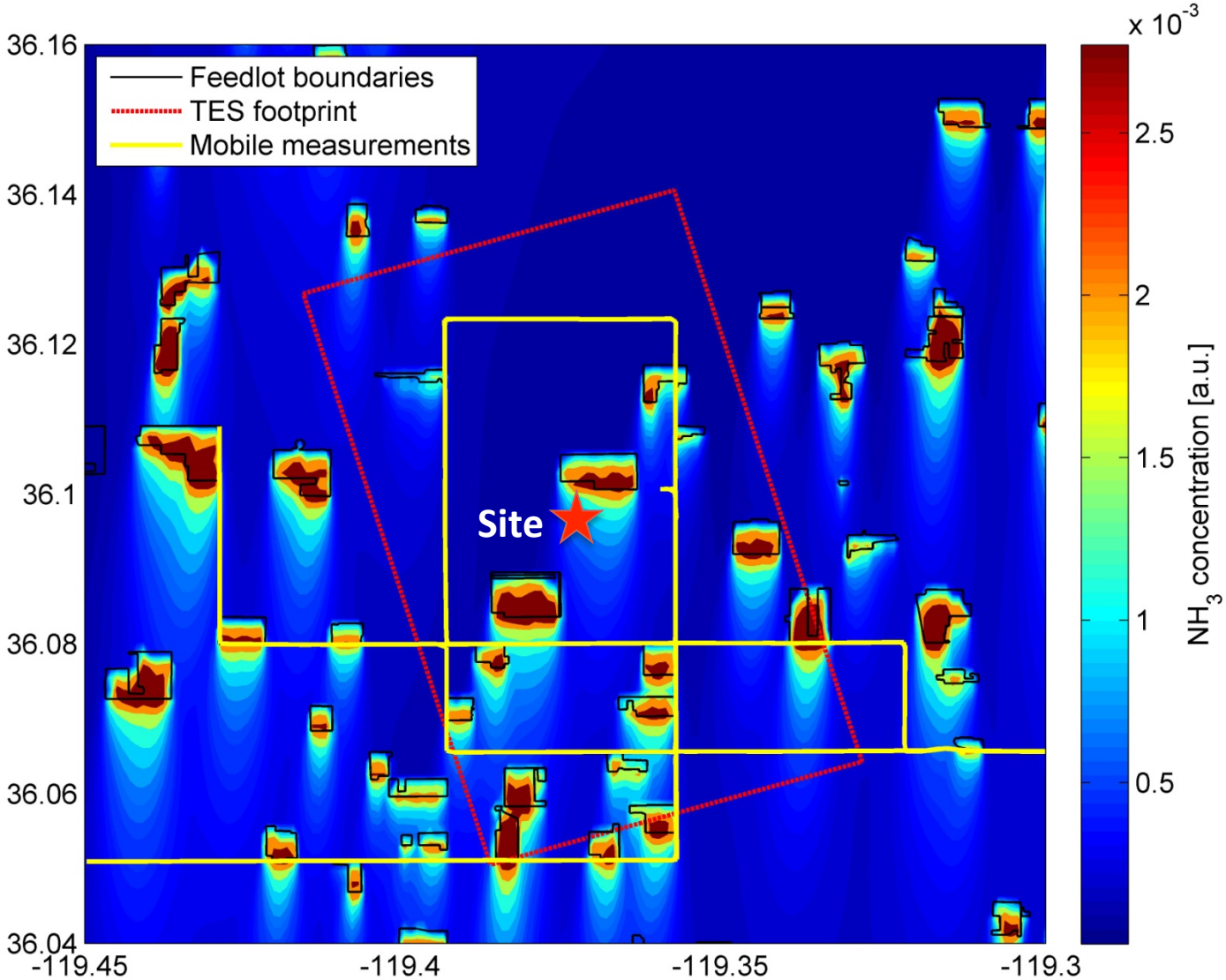



# Intra pixel surface/airborne measurements



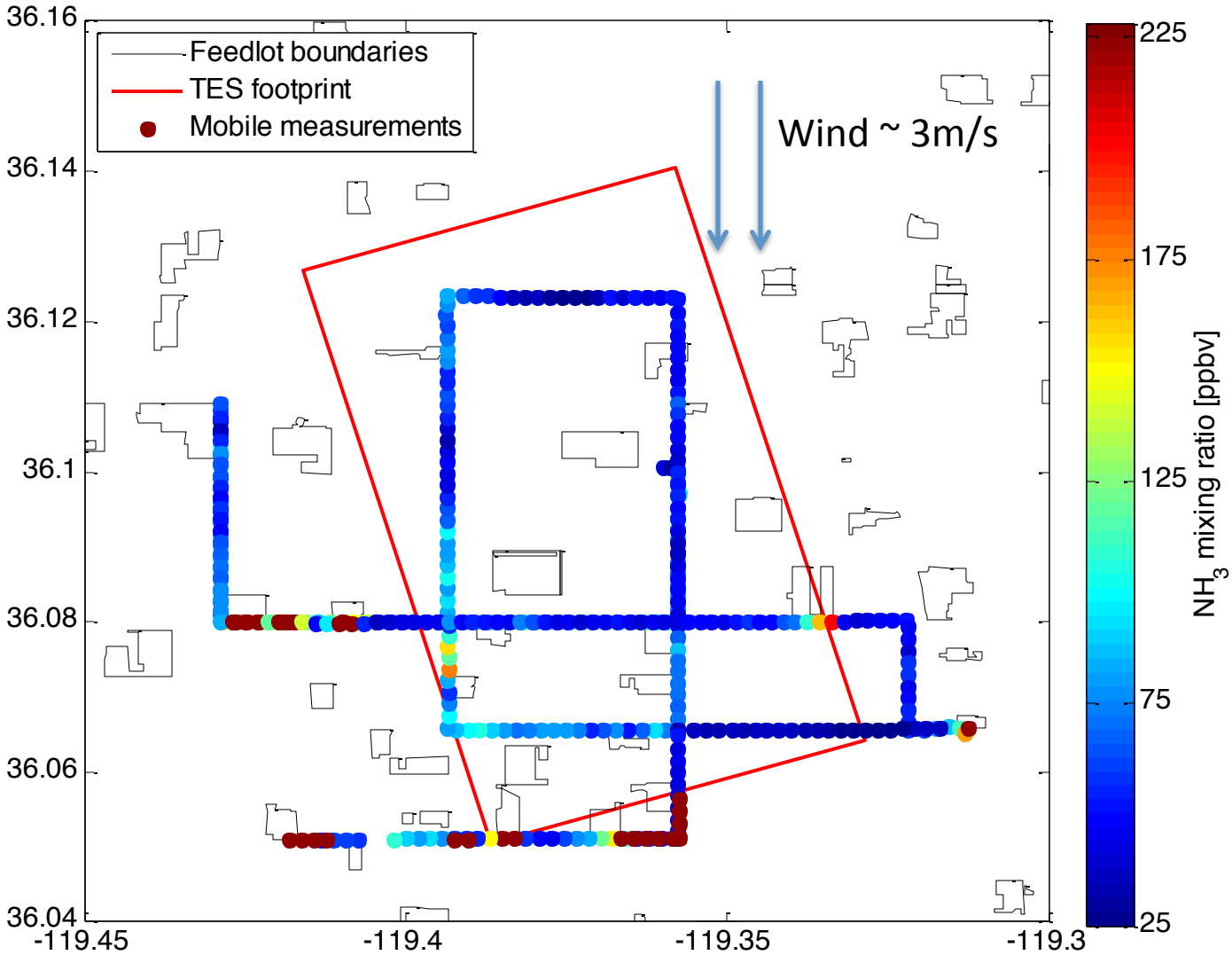

- TES footprint on Jan. 21, 2013 in the San Joaquin Valley

# Intra pixel $NH_3$ spatial variation



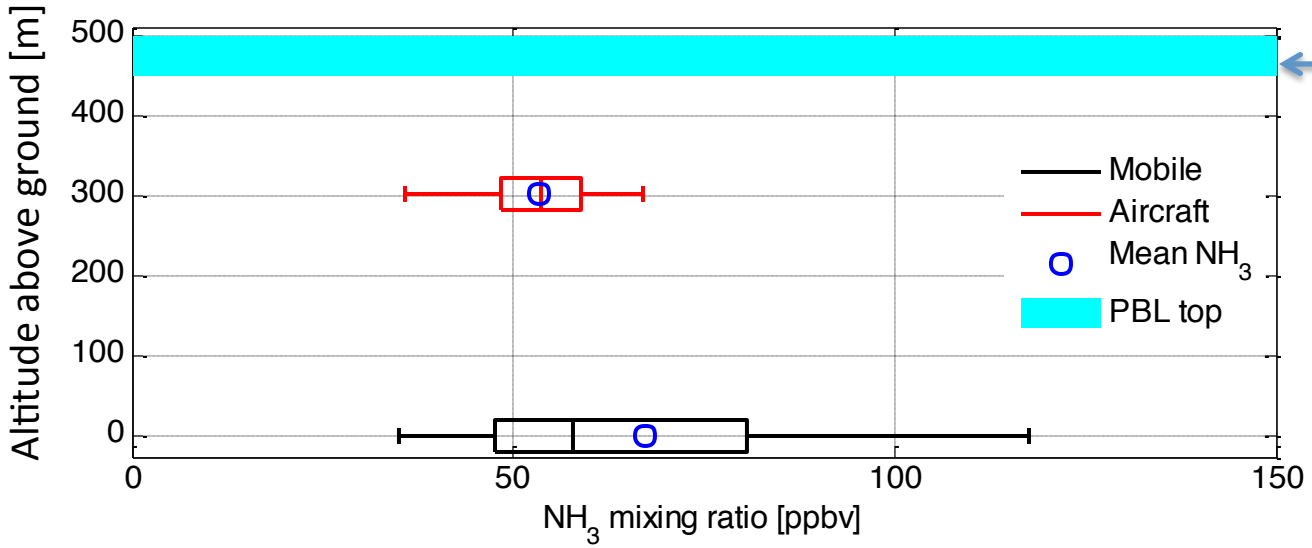

- Area-source Gaussian plume model using observed wind

# Intra pixel $NH_3$ spatial variation (cont.)




- Mobile sampling data spatially averaged to 50 m

# Surface/PBL variation

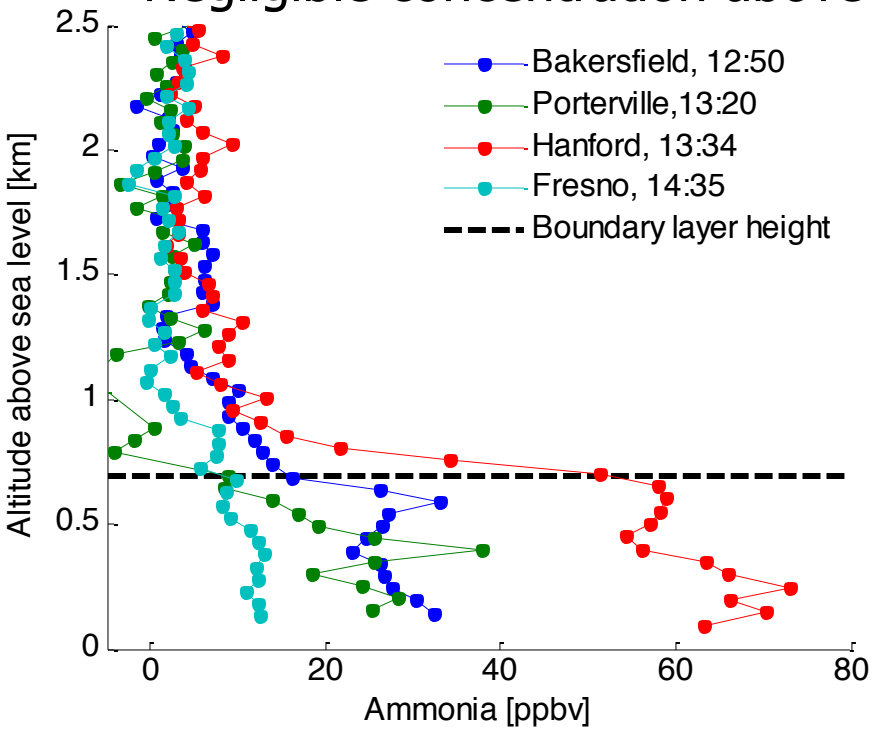


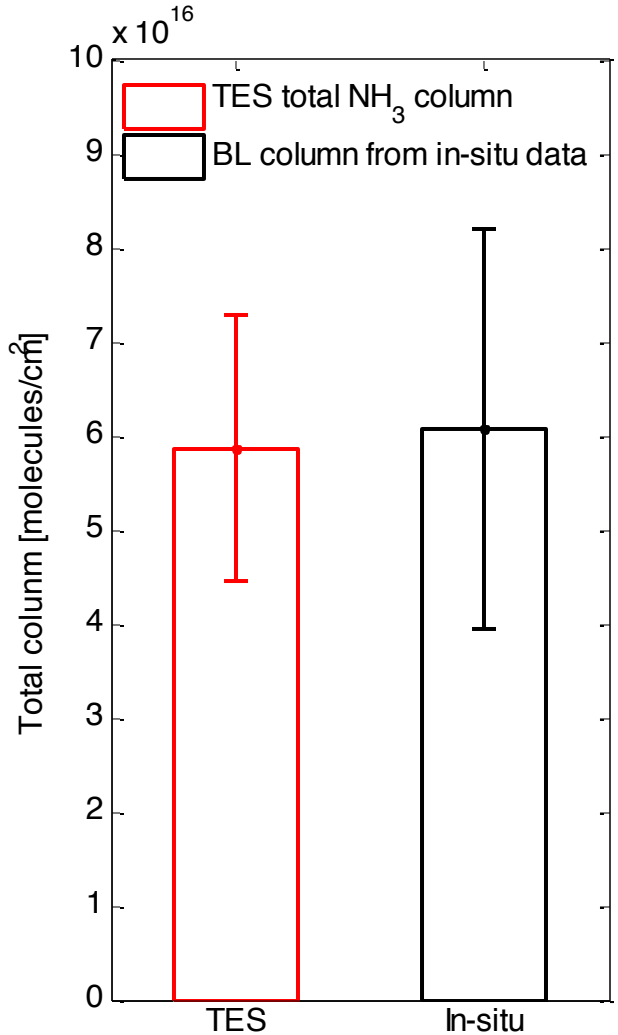

PBL height measured by airborne High Spectral LIDAR concurrently

- Surface data shows skewed distribution with large variance, due to local sources
- Two aircraft transects ± 1 hour from TES overpass show consistent concentrations (51 ± 10 vs. 55 ± 4 ppbv)
- Comparable median aircraft/surface concentrations: 52 vs. 57 ppbv
- Vertically uniform PBL structure

# Total column intercomparison

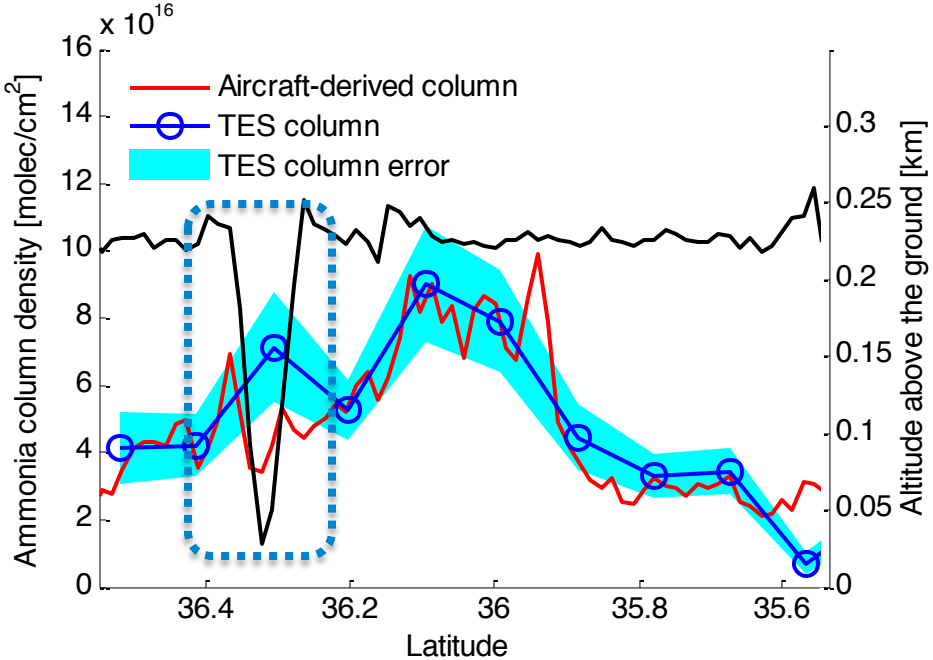
- Observational total $NH_3$ column was constructed assuming
  - Vertical uniformity in the PBL
  - Negligible concentration above



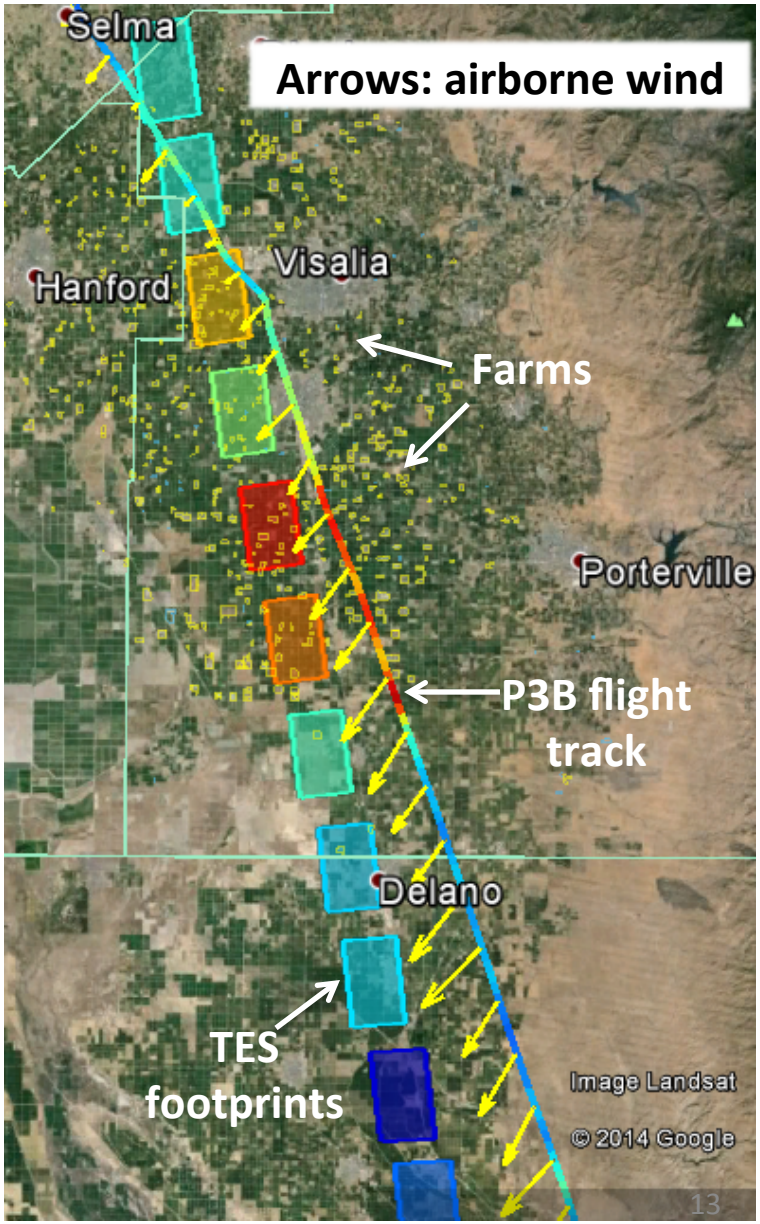




- TES and observational total columns within measurement/retrieval uncertainties at single pixel

# TES and aircraft-derived column data (Jan 30)

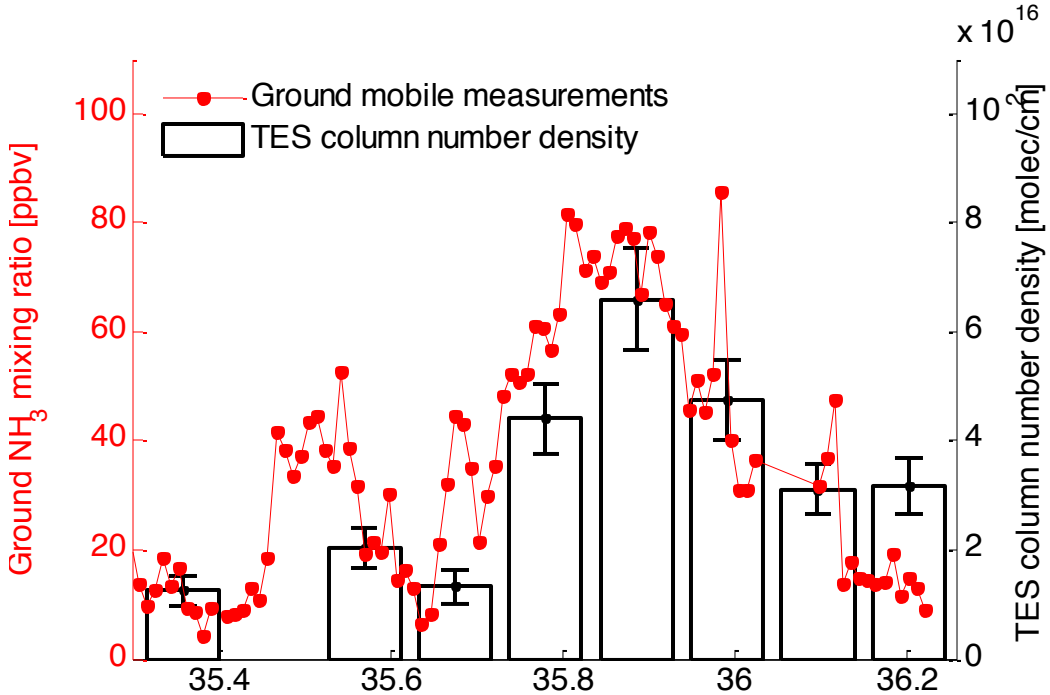


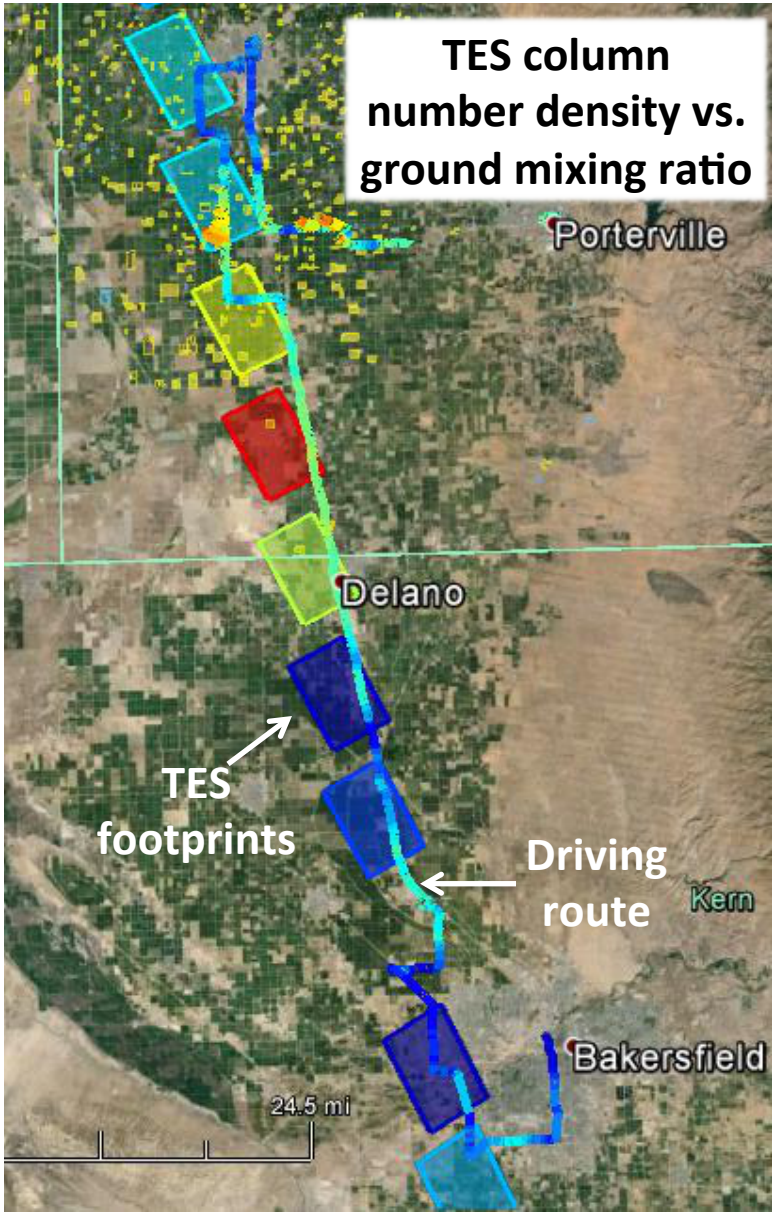

- TES ammonia column number densities agree well with column number densities derived from aircraft PBL measurements
- Discrepancies at missed approach due to less mixing at lower altitude



# TES and ground mobile data (Jan 28)

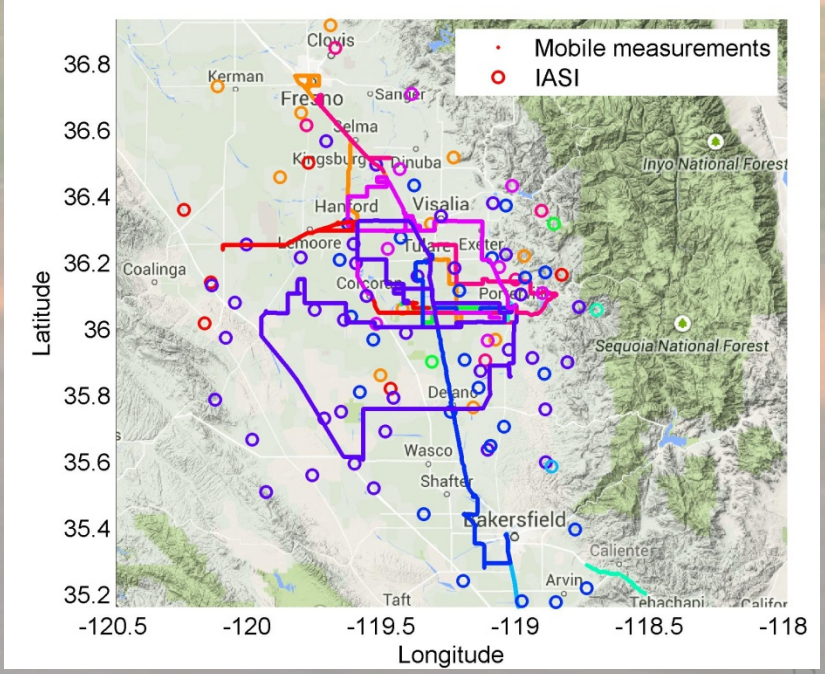
- No P3-B flight in SJV on Jan 28
- Ground mobile measurements along the TES transect
- Minimized the spatial and temporal difference from TES transect



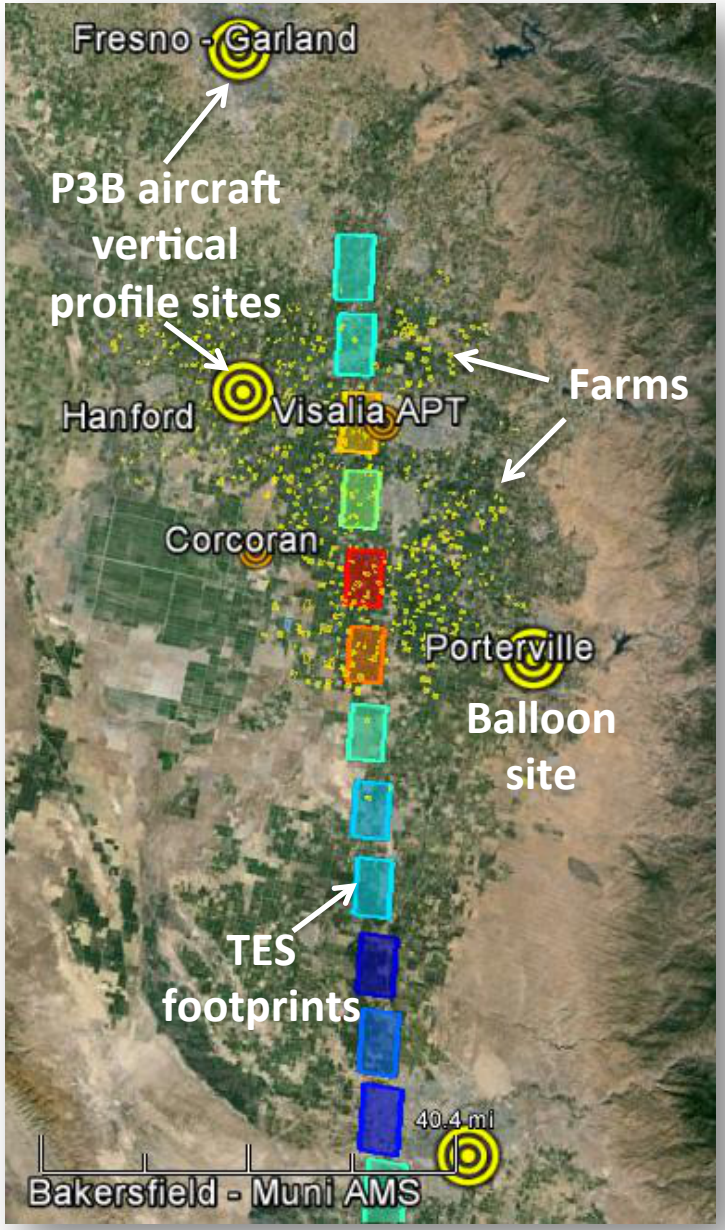
# Summary & ongoing work

- Developed methods to validate satellite $NH_3$ retrievals under highly heterogeneous surface conditions
  - Intra-pixel $NH_3$ variations characterized by spatial survey
  - Vertical uniformity of PBL supported by aircraft data
- TES $NH_3$ column densities capture ground level spatial variations and agree with *in-situ* validation
- Intercomparison with IASI
  - SJV, California
  - Front Range, Colorado



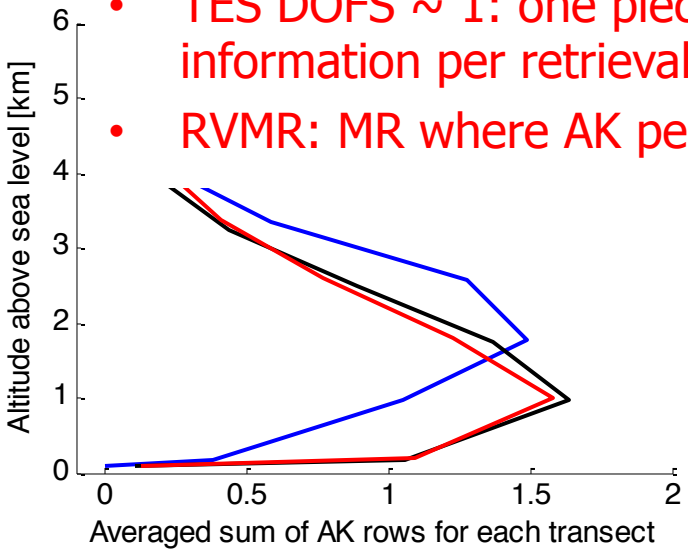
# Outline

- Introduction
- Experimental methods
- Ammonia from agriculture
  - Open-path ammonia eddy covariance flux measurements, manuscript in preparation.
  - Validation of TES ammonia in the San Joaquin Valley, California, manuscript in preparation.
- Ammonia from urban areas
- Future work

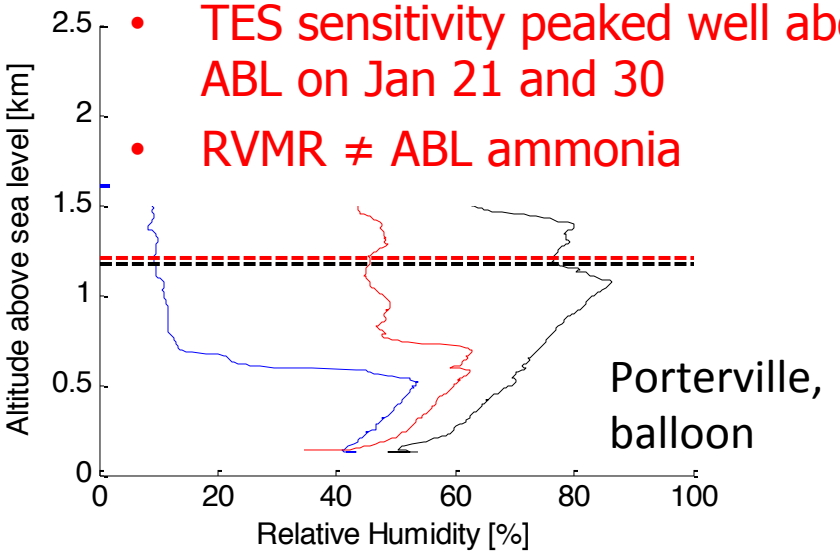


# TES retrieval in the boundary layer (ABL)

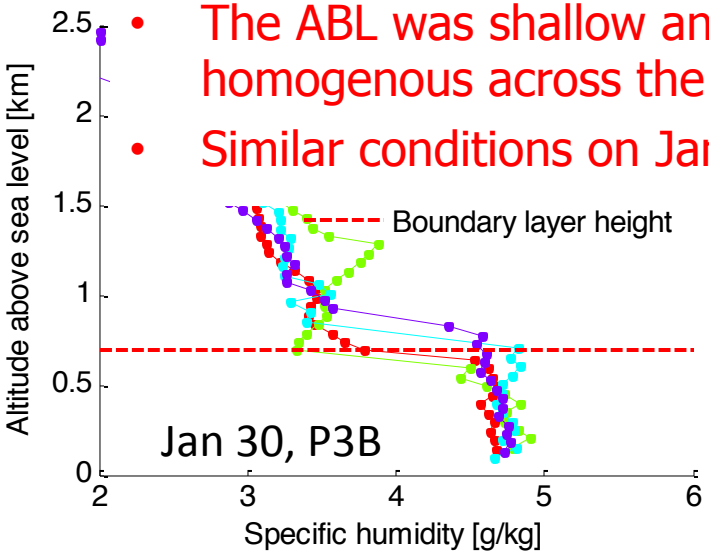
- TES DOFS ~ 1: one piece of information per retrieval
- RVMR: MR where AK peaks



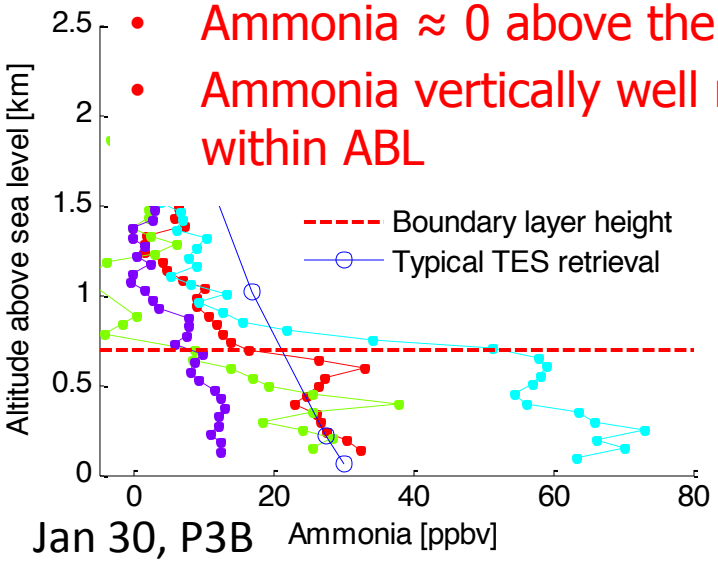

- TES sensitivity peaked well above ABL on Jan 21 and 30
- RVMR ≠ ABL ammonia




- The ABL was shallow and near homogenous across the valley
- Similar conditions on Jan 21



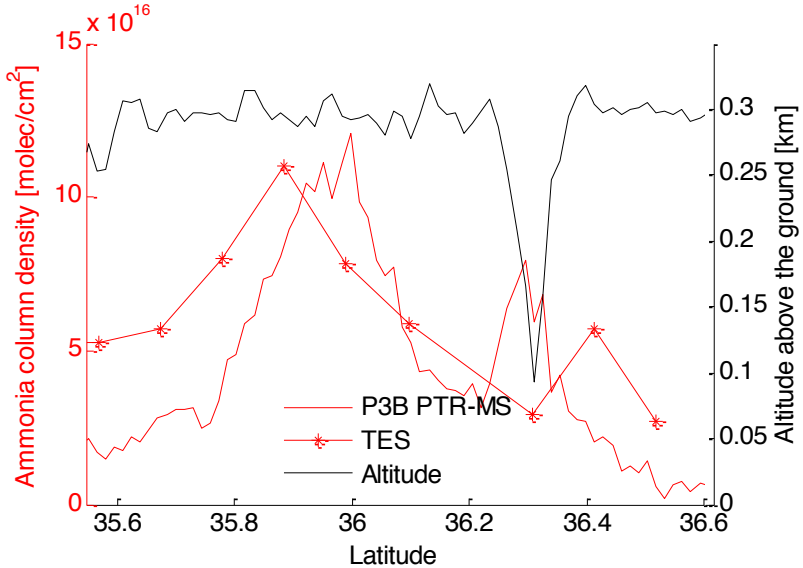

- Ammonia ≈ 0 above the ABL
- Ammonia vertically well mixed within ABL



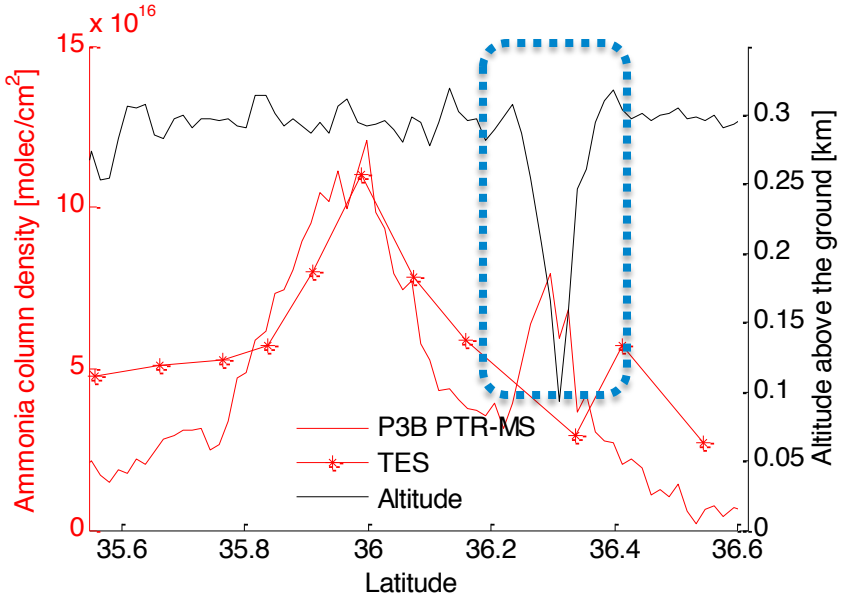



Data courtesy: TES – Karen Cady-Pereira; balloon – Anne Thompson; P3-B – Armin Wisthaler, John Nowak, Gao Chen

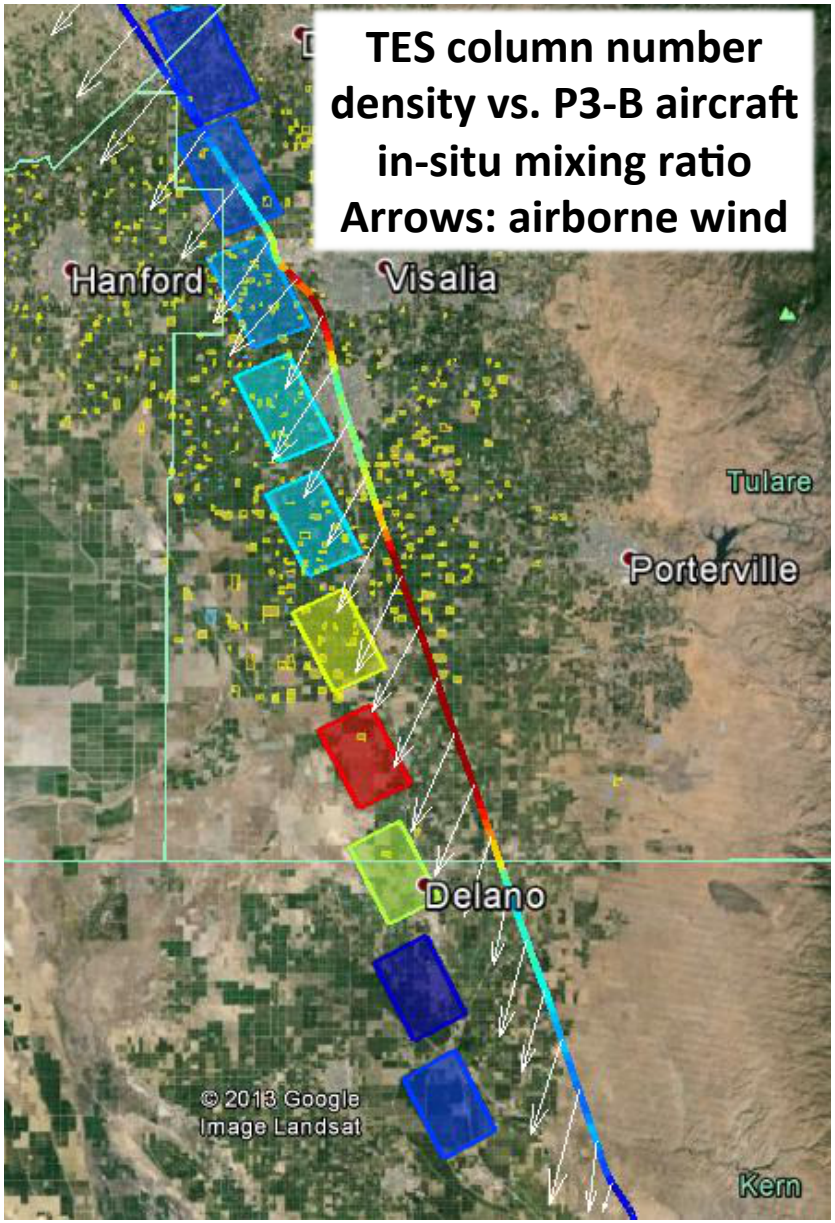
# TES and aircraft-derived column data (Jan 21)




Assuming well-mixed, homogenous ABL

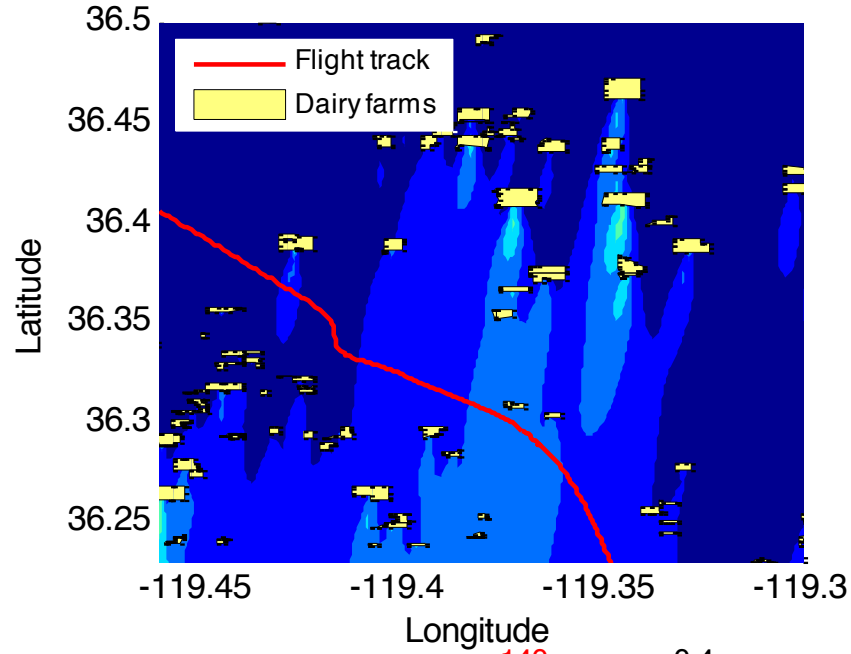


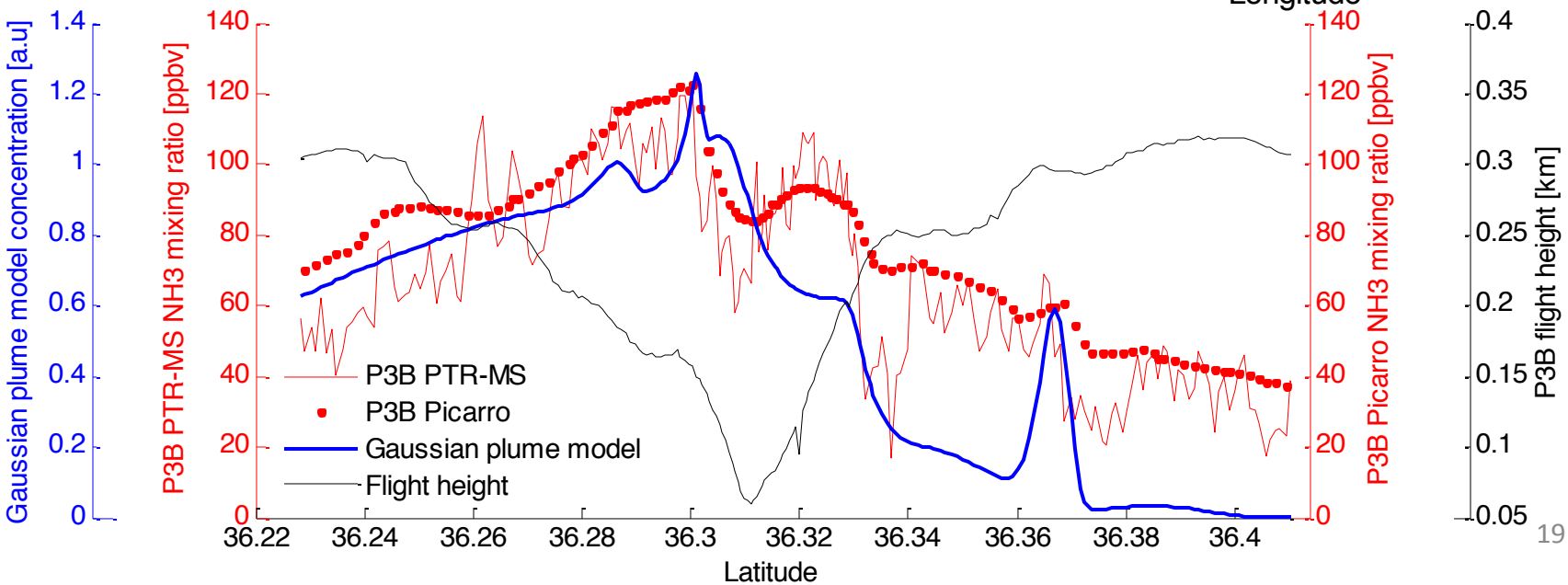

After latitude alignment



# Influences from local sources at Visalia

- Gaussian plume modeling
  - Constrained by observational wind, ABL height, and ABL stability
  - Assuming emissions are proportional to farm areas
- P3-B flew downwind of farm emissions during Visalia missed approach



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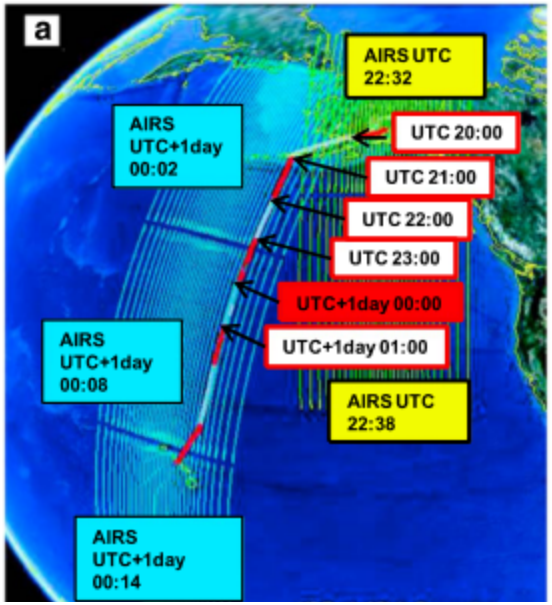
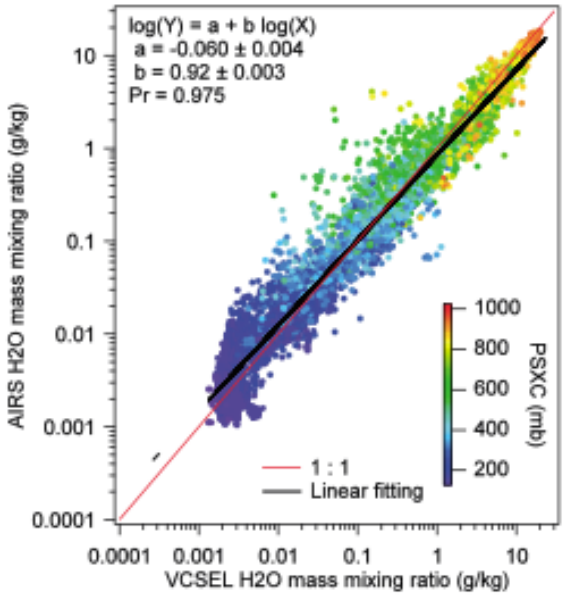
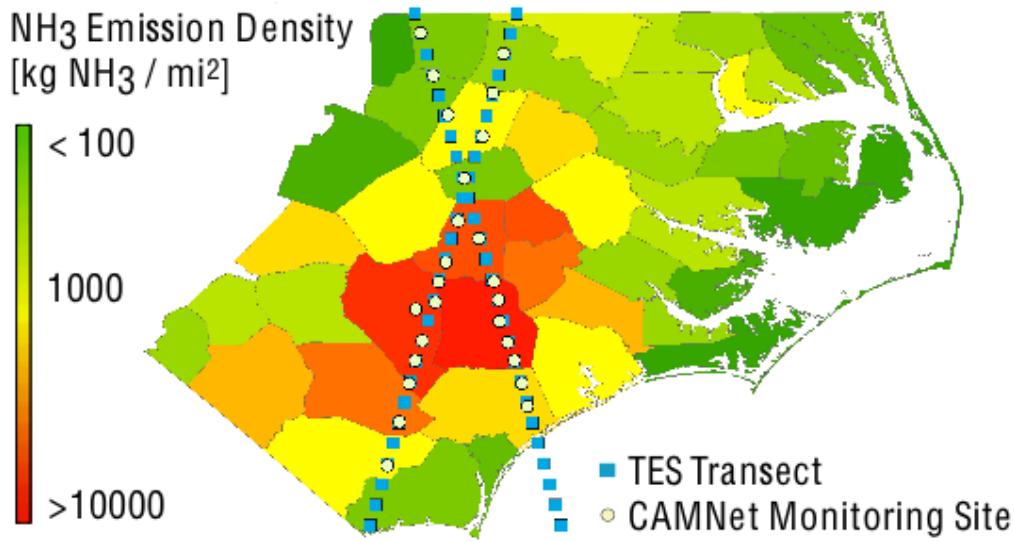



Diao et al. (2013)



# Validation of $NH_3$ retrievals (continued)

- TES was validated using biweekly surface measurements
- TES and surface measurements are qualitatively well correlated (Pinder et al. 2011)
- IASI validation using ground networks and aircraft data (Van Damme et al. in prep.)
- Questions:
  - Can we validate $NH_3$ under heterogeneous surface conditions?
  - Can we validate $NH_3$ with limited number of pixels?

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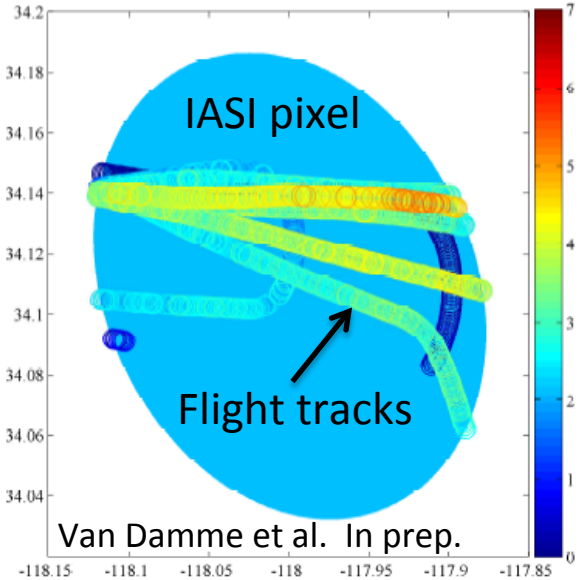


Van Damme et al. In prep.