Utah Winter Fine Particulate Study

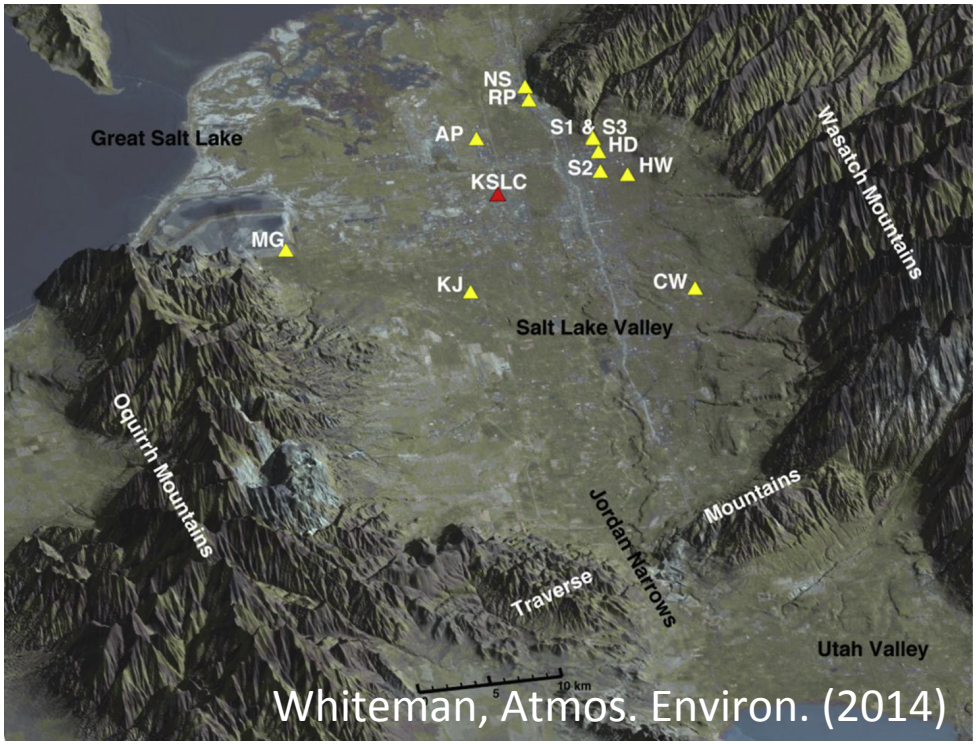
January 15 – February 14, 2017, Salt Lake City and adjacent air basins

A twin otter aircraft investigation of the factors governing high PM2.5 events in mountain basins of northern Utah

Winter Particulate Matter in Northern Utah

Ogden - Salt Lake City – Provo urban area has a population of 2.4 million (80% of Utah's total) in a 120 mile corridor

PM2.5 in this region exceeds the NAAQS (35 μg m^{-3}, 24 hours) an average of 18 days per year, exclusively during Nov 15 – Feb 15



Whiteman, Atmos. Environ. (2014)

Meteorology leading to high winter PM events has been well studied

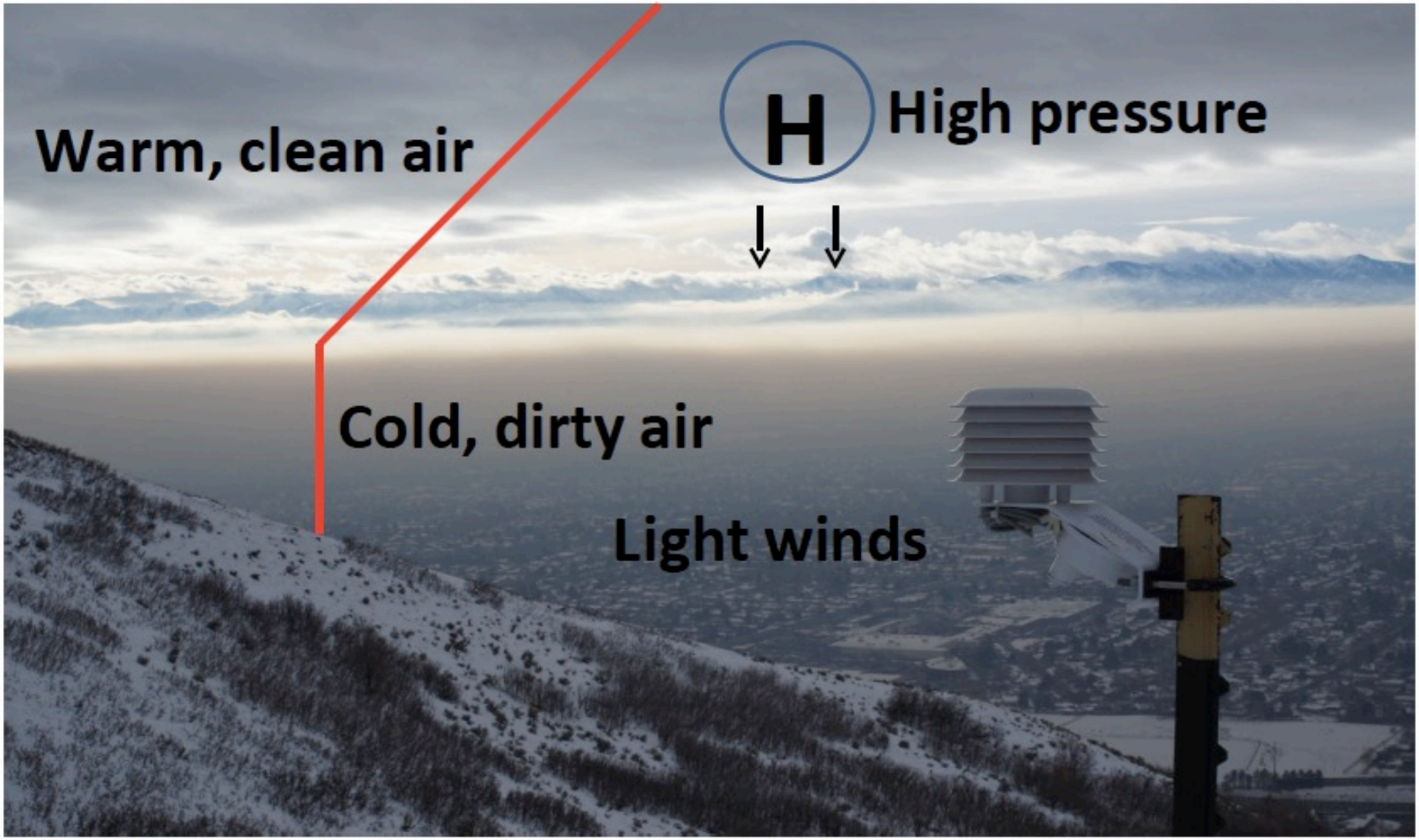
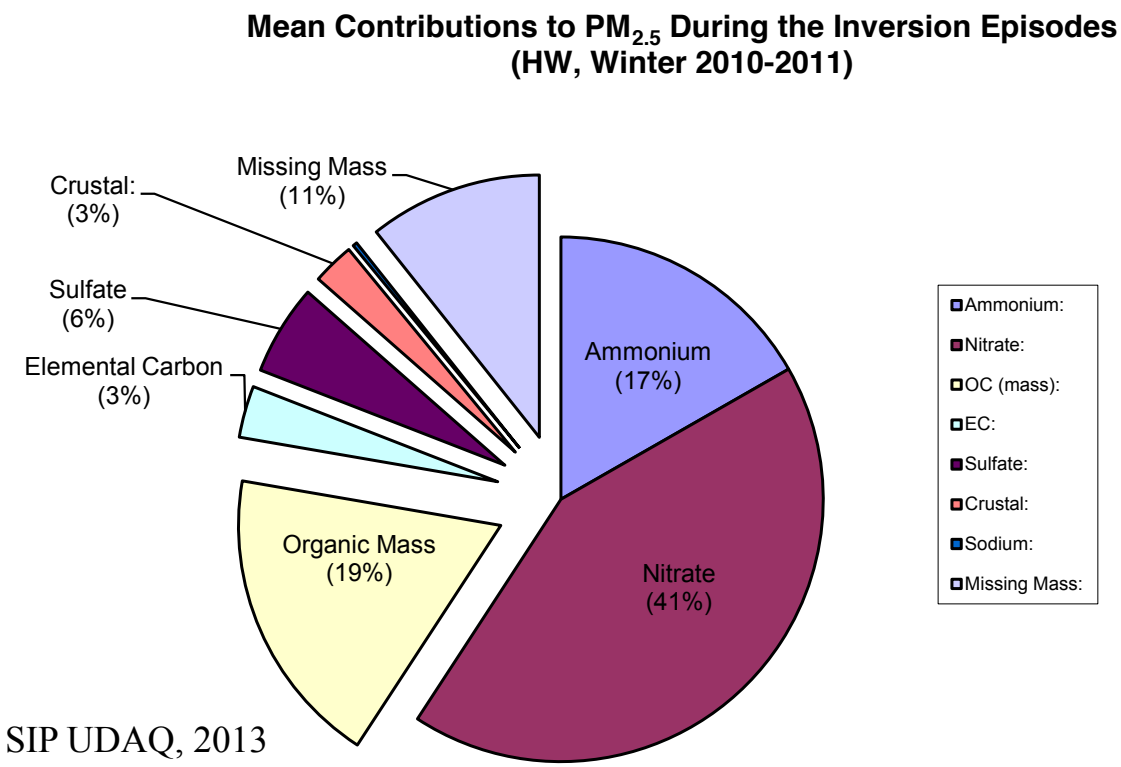


Photo & Diagram: Erik Crosman, University of Utah

Major constituent of $PM_{2.5}$ during pollution episodes



- Secondary sources dominate
- Dominated by secondary NH_4NO_3 (50 – 75% of the total)
- Secondary NH_4Cl may also a be significant contributor (10-15% of the total $PM_{2.5}$) (Kelly et al., 2013)

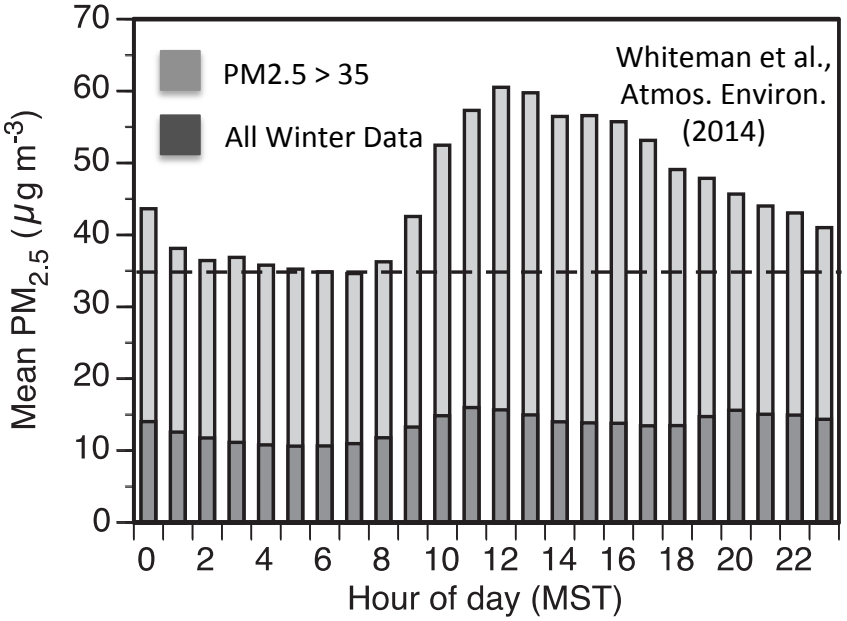
Emissions and the interaction of chemical mechanisms with boundary layer dynamics that leads to formation of NH_4NO_3 not well understood

Contribution of organic aerosol from residential wood combustion also poorly characterized

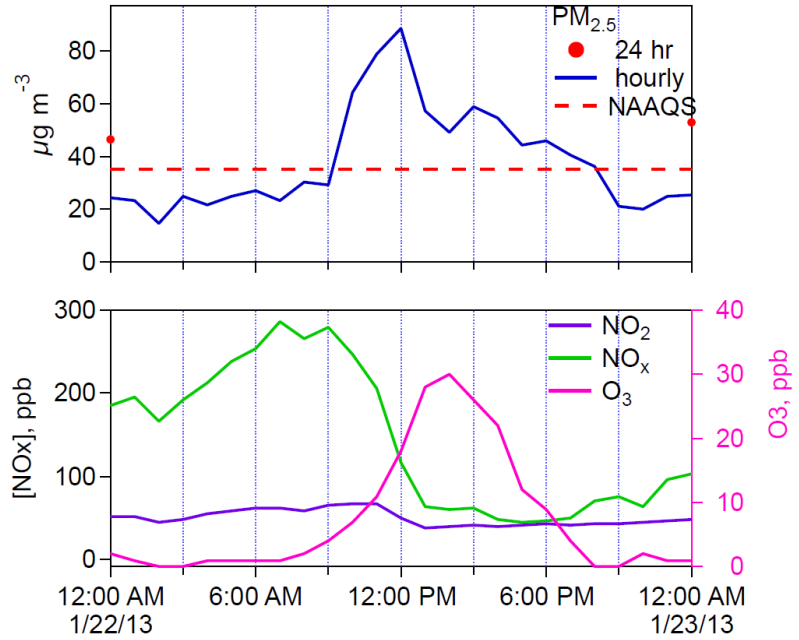
Secondary Aerosol and Boundary Layer Dynamics

Near surface measurements are consistent with secondary PM formation in upper layer of inversion, with entrainment to surface

Average Winter PM2.5, 2009-2014



One Day Event from Hawthorne Site



At night

- O_3 is depleted
- High "NO_x", CO (!!)
- PM constant or slowly decreasing

Morning Hours

- $PM_{2.5}$ and O_3 both show an increase
- Sharp decrease in "NO_x", CO
- PM2.5 decrease in afternoon

No secondary chemistry at surface at night (no O_3)
Daytime PM growth = photochemistry + residual layer mixing

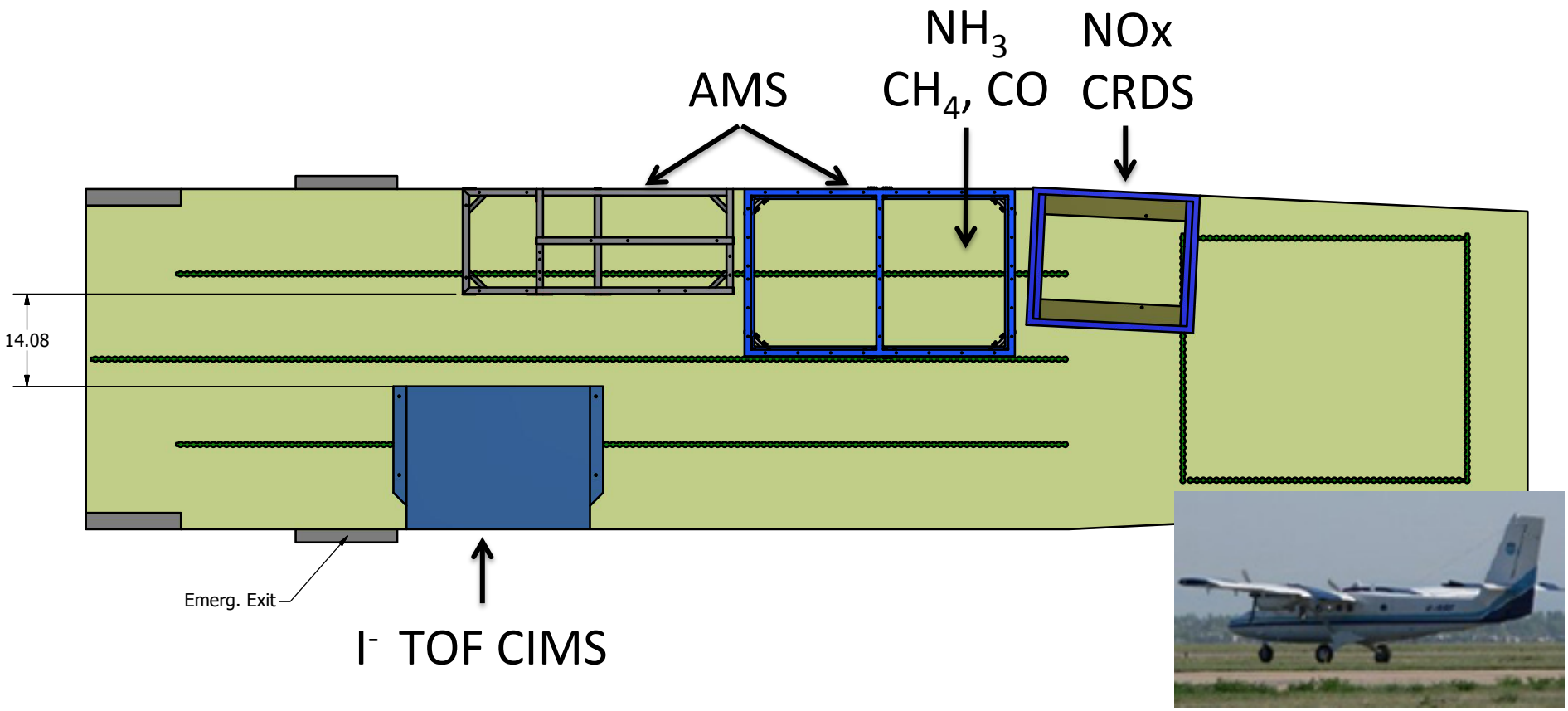
Science Questions

For details, please see
http://esrl.noaa.gov/csd/groups/csd7/measurements/2017uwfps/whitepaper.pdf

- What is the spatial distribution of key trace gases and aerosols related to PM formation?
- What are the limiting and excess reagents in ammonium nitrate formation, and what are the key source regions?
- What are the limiting and excess reagents in oxidant and nitric acid formation? Do these limitations and / or sources vary significantly across the region?
- How do these distributions and the associated chemistry vary as a function of time of day?
- What is the role of the Great Salt Lake and Utah Lake, both chemically and meteorologically, in regional air quality?
- Are there significant aerosol sources other than ammonium nitrate? What is the role of residential wood combustion as a source for organic aerosol?
- What are the key emission sectors for aerosol precursors? What is the role of agricultural, industrial, urban, home heating, and natural emissions?

Atmospheric Chemistry Instrument Payload

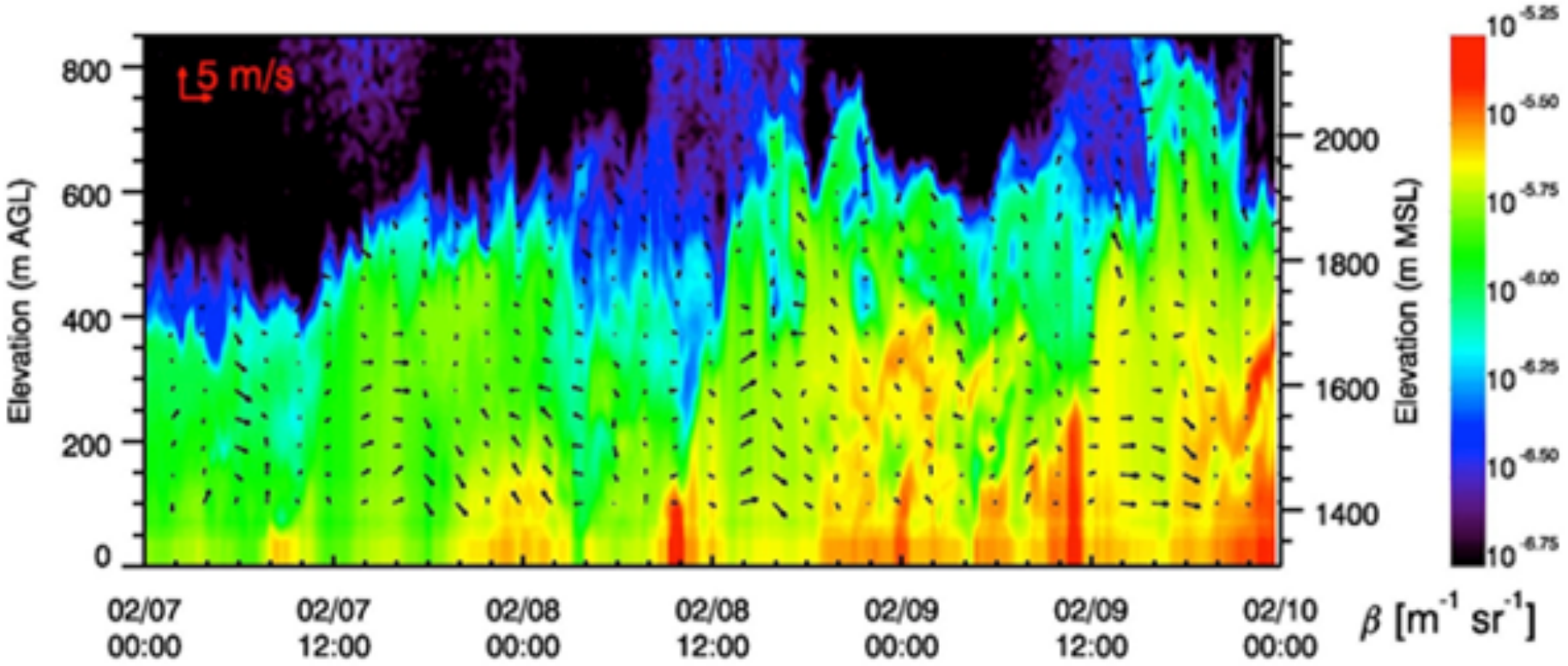
Measurement	Instrument	Investigator
Aerosol Composition	Aerosol Mass Spectrometer	Ann Middlebrook, NOAA
Acid Gases	Iodide TOF CIMS	Joel Thornton, U. Washington
NO_x, NO_y, O_3	Custom CRDS	Steve Brown, NOAA
NH_3	Infrared QCL absorption	Jennifer Murphy, U. Toronto
CO, CH_4	Picarro CRDS	Loaned from Colm Sweeney, NOAA
PM distributions	UHSAS	Loaned from Jon Abbatt, U. Toronto



Flight Planning Logistics

- Twin Otter to be based at TAC Aviation at Salt Lake International Airport
- Aircraft endurance / flight time constraints
  - Payload = ~1500 lbs of instruments + 2 scientific operators and 2 pilots
  - Aircraft endurance (Payload + Passangers + Fuel) = 2 hours 45 minutes
- Survey Northern Utah region using two back to back flights with 1 hour refueling stop at Salt Lake International, total duration (flight time + refueling) of 6.5 hours
- Total flight hours available for research flights in Salt Lake City 78-80
  - 5.5 hours per flight day = 14.5 research flight days / 29 flights
  - Total available flight days during study period = 27
- Takeoff times will be staggered day to day to capture early morning, midday and nighttime periods
- Weather conditions expected to be ~80% clear, but fog may be a limitation for some flight days, especially during the later stages of inversion periods
- Inversion days will have low boundary layer heights
  - Aircraft cruise altitude is 1000’ AGL; can request lower during daylight hours
  - Make use of missed approaches to airfields to probe boundary layer structure

Boundary Layer Depth



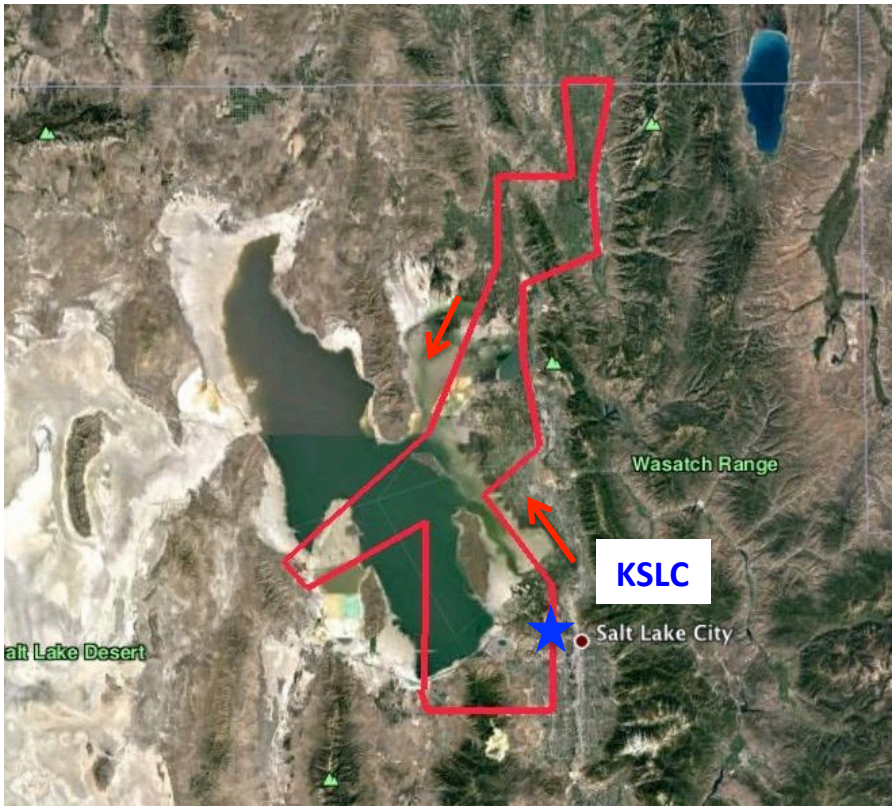
Ceilometer data suggest 400 – 600 m BL depths during periods when inversions are building

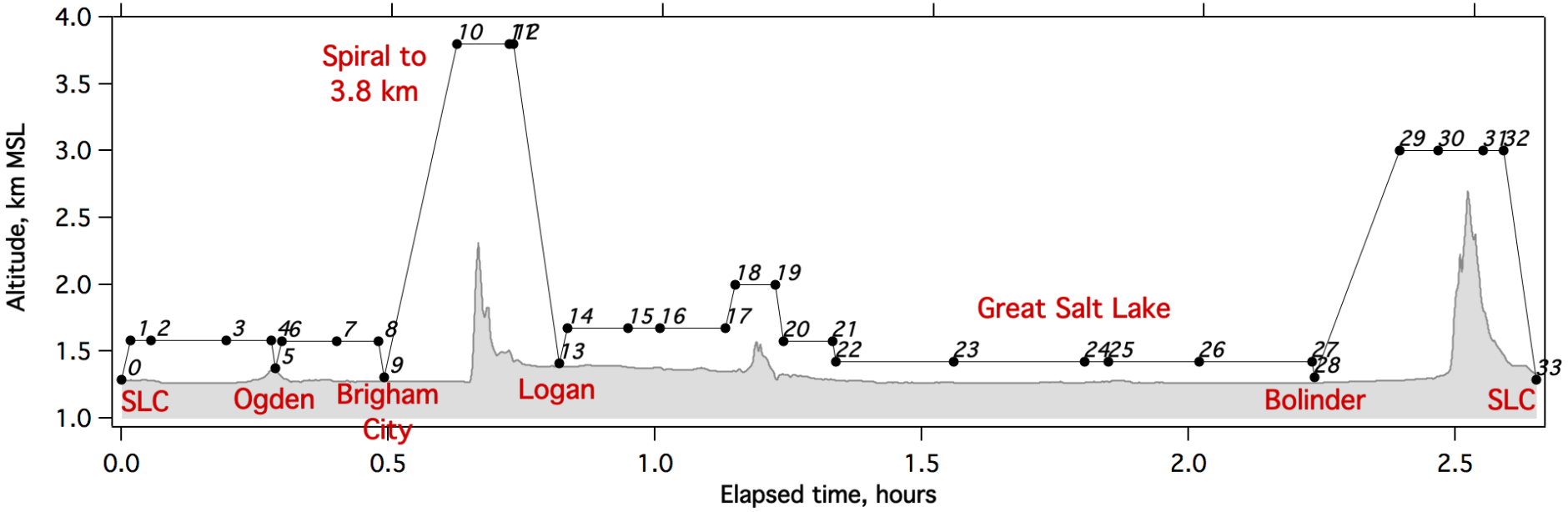
Consistent with aircraft cruise altitude of 1000' AGL, and possibly lower during daylight hours

Probe vertical structure of boundary layer with missed approaches to airfields to ~20 m AGL

Flight Plan #1

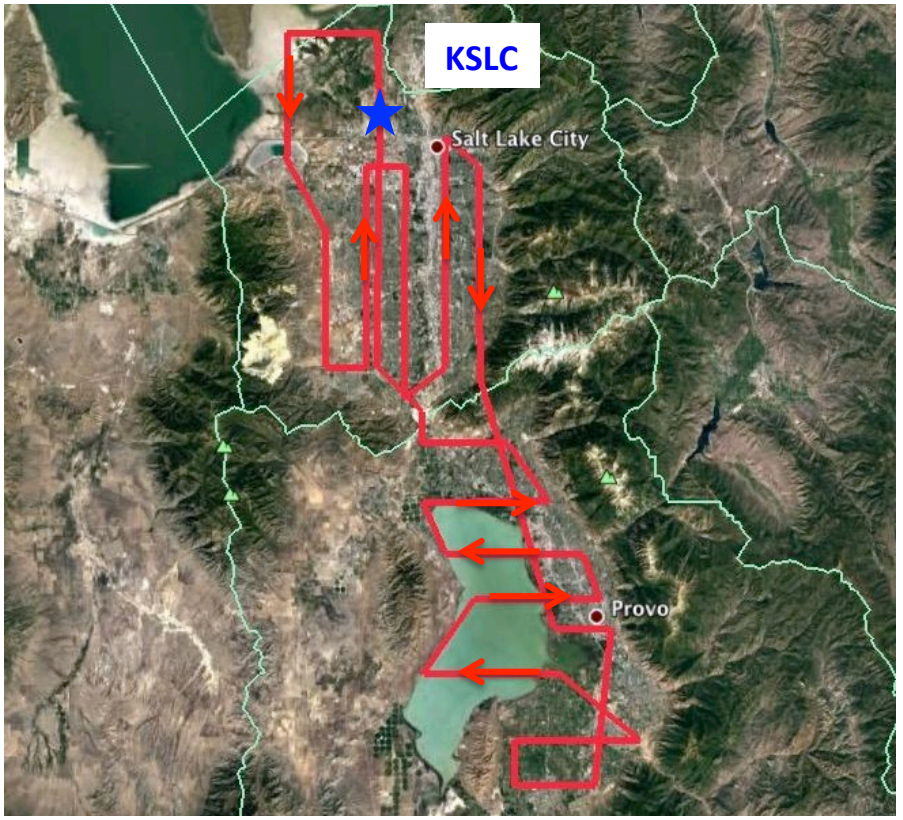
Survey flight to the north of Salt Lake city including Ogden, Cache Valley, Beaver River Valley, Great Salt Lake and Tooele Valley

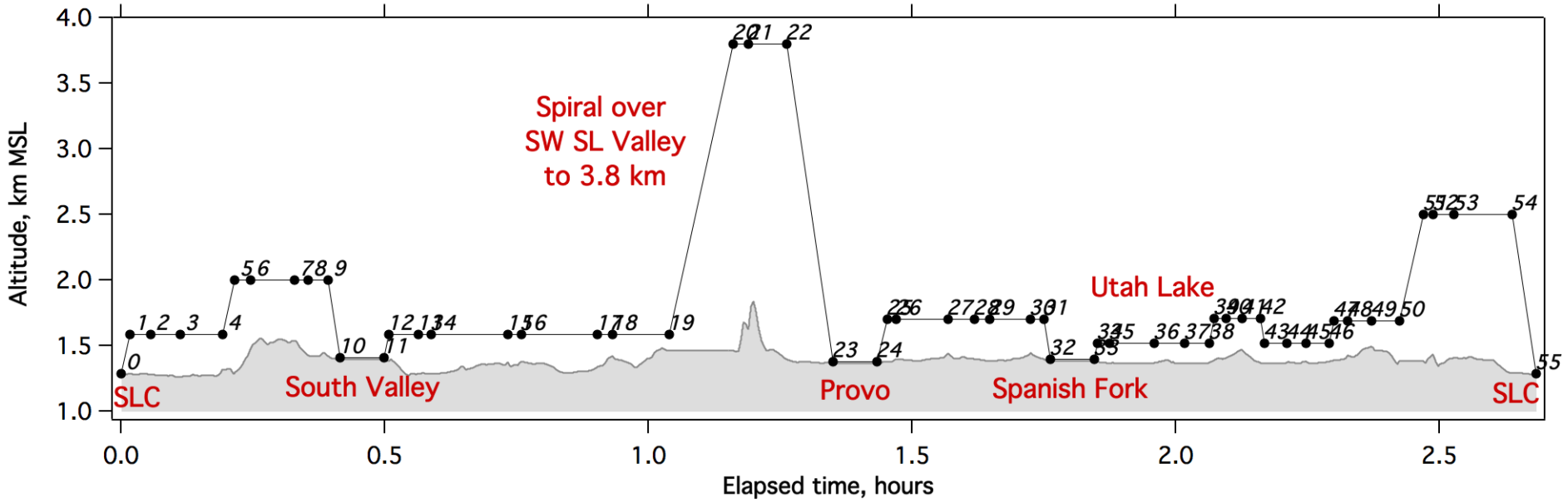




Flight Plan #2

Focused survey of urban areas of Salt Lake and Utah Valleys





Current Aircraft Schedule

January 2: Twin Otter arrives at NCAR Research Aviation Facility (RAF), Broomfield CO

January 3 – 14: Integration and test flights

January 15: Transit to Salt Lake City. Twin Otter based at TAC Air, Salt Lake City International Airport

January 17 – February 12: Research flights in Great Salt Lake basin

27 Flight days, approximately 78-80 flight hours

February 13: Transit back to Colorado

February 14: De-installation at RAF

February 15: Twin Otter departs for next mission

Winter (Dec – Feb) 2015 - 2016

- Overview of 2015 – 2016 study
- Plans for Ground Based Observations

Rooftop measurements of chemistry and met parameters

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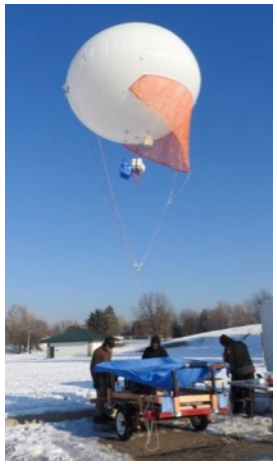
MiniVol $PM_{2.5}$ samplers on WBB roof

Spatial measurements

Vertical measurements

- Aerosol back scatter
- 3-D fields of ws and wd, evolution



Rooftop Measurements:

CO_2, CH_4, NO_3, N_2O_5, NOx,
O_3, CO, $PM_{2.5}$, H_2O,
Particle Size Distribution, particle composition
Isotopes ($^{13}C^{18}O_2$, $^{2}H_2{}^{18}O$), met observations

Measurements at Valley Floor and Higher Elevations

- Detailed observation of chemical and met parameters

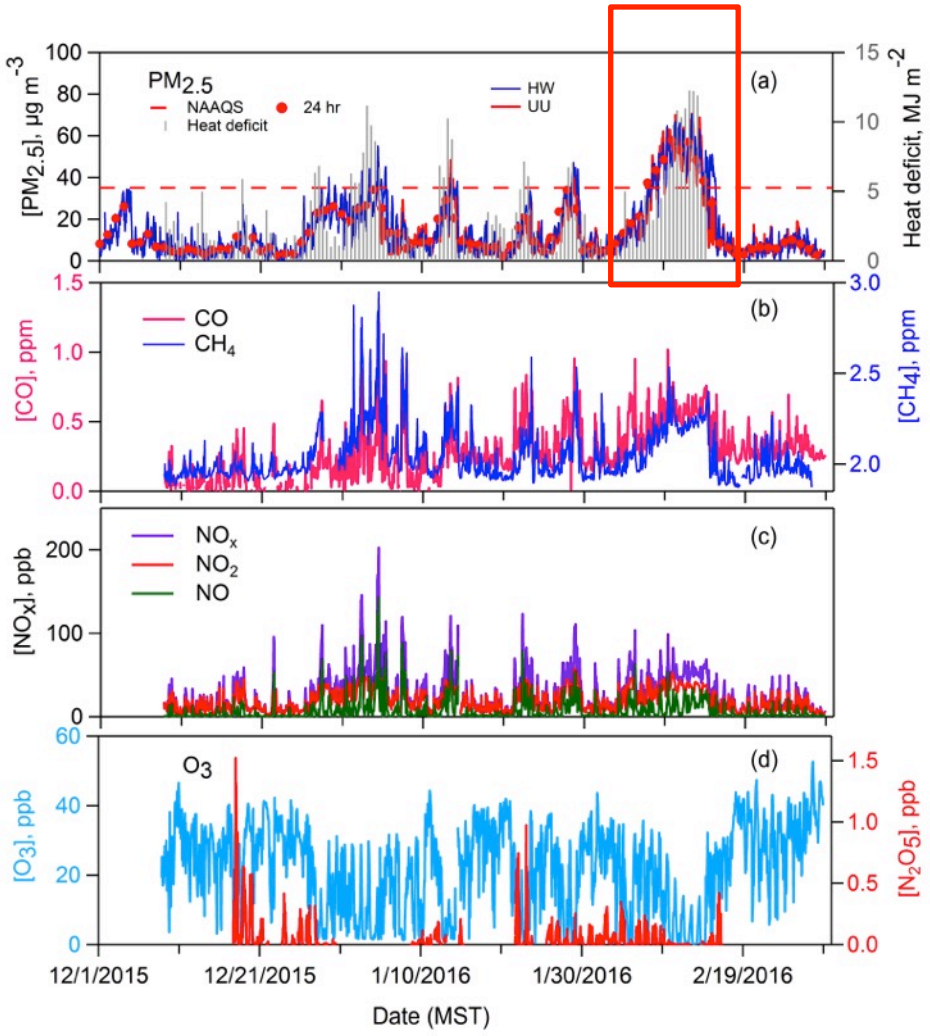
Winter (Dec – Feb) 2015 - 2016

O3

Church Office Building

UU WBB

Time Series of $PM_{2.5}$, Heat deficit, O_3 , NOx, N_2O_5: A Close Correlation Between $PM_{2.5}$ Episodes and Atmospheric Stability



$\underline{PM_{2.5}}$:

- $PM_{2.5}$ varies from 0 to 76 ug/m^3
- ~ 6 CAPs events
- PM enhancements are closely associated with heat deficit.
- 8 exceedances; all occurred during Feb 7 – 14 episodes

Primary pollutants:

- Enhanced during pollution events
- NOx: <10 -200 ppb; max CO 1 ppm

$\underline{O_3}$:

- Low, especially during the PM pollution episodes.

$\underline{N_2O_5}$

- detectable most night. max 1.5 ppb; average 0.076 ppb

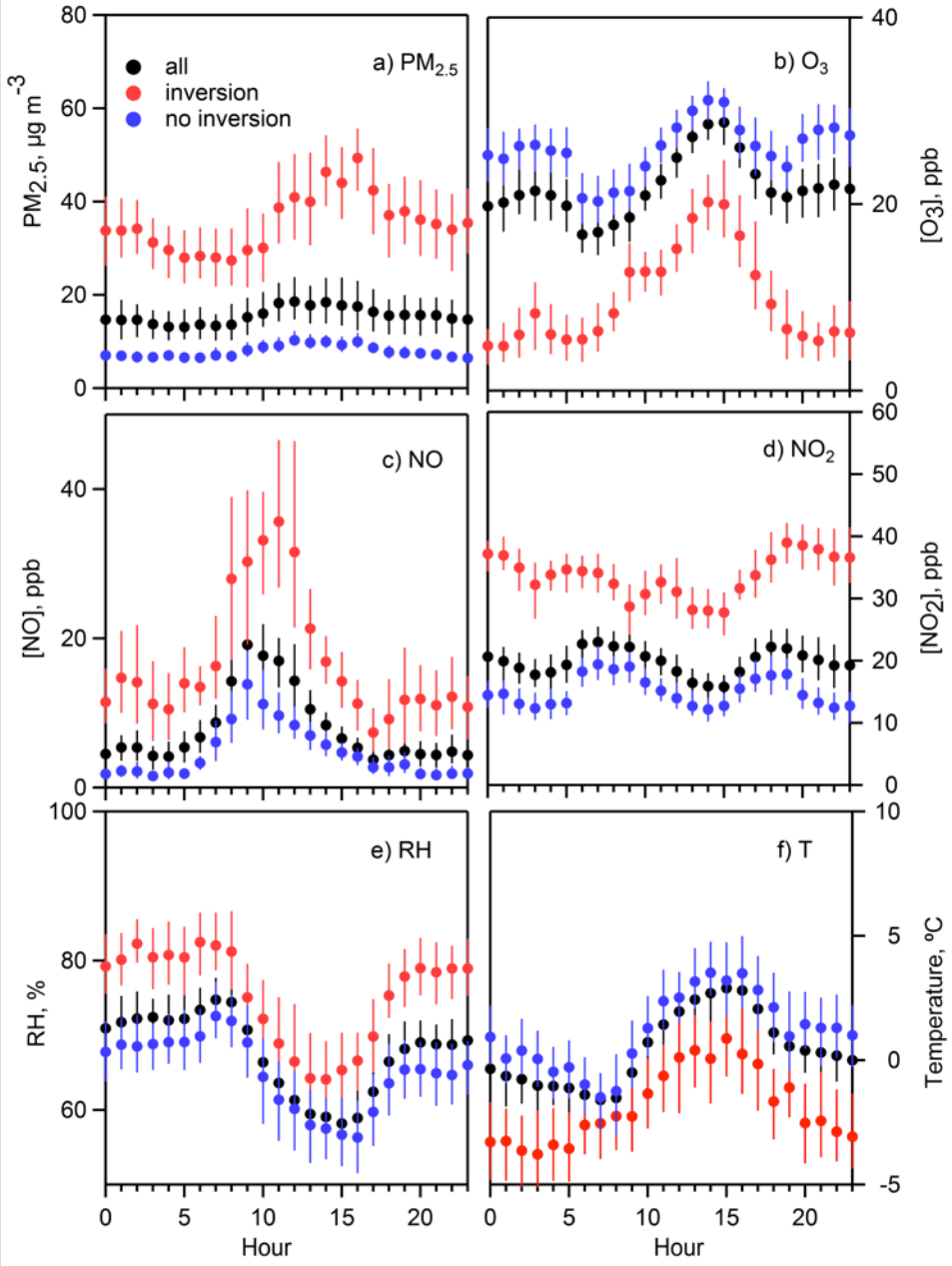
Conditions During Pollution Episodes

$PM_{2.5}$
- Daytime high

O_3
- Titrated at night

NOx
- Morning peak ~10 AM due to transport
- A sharp decrease coincides with increase in PM
- NO_2 is high and persists through out the day. ~ 35 ppb

RH & T
- Average RH: ~ 75 %
- Low T <0



UU WBB

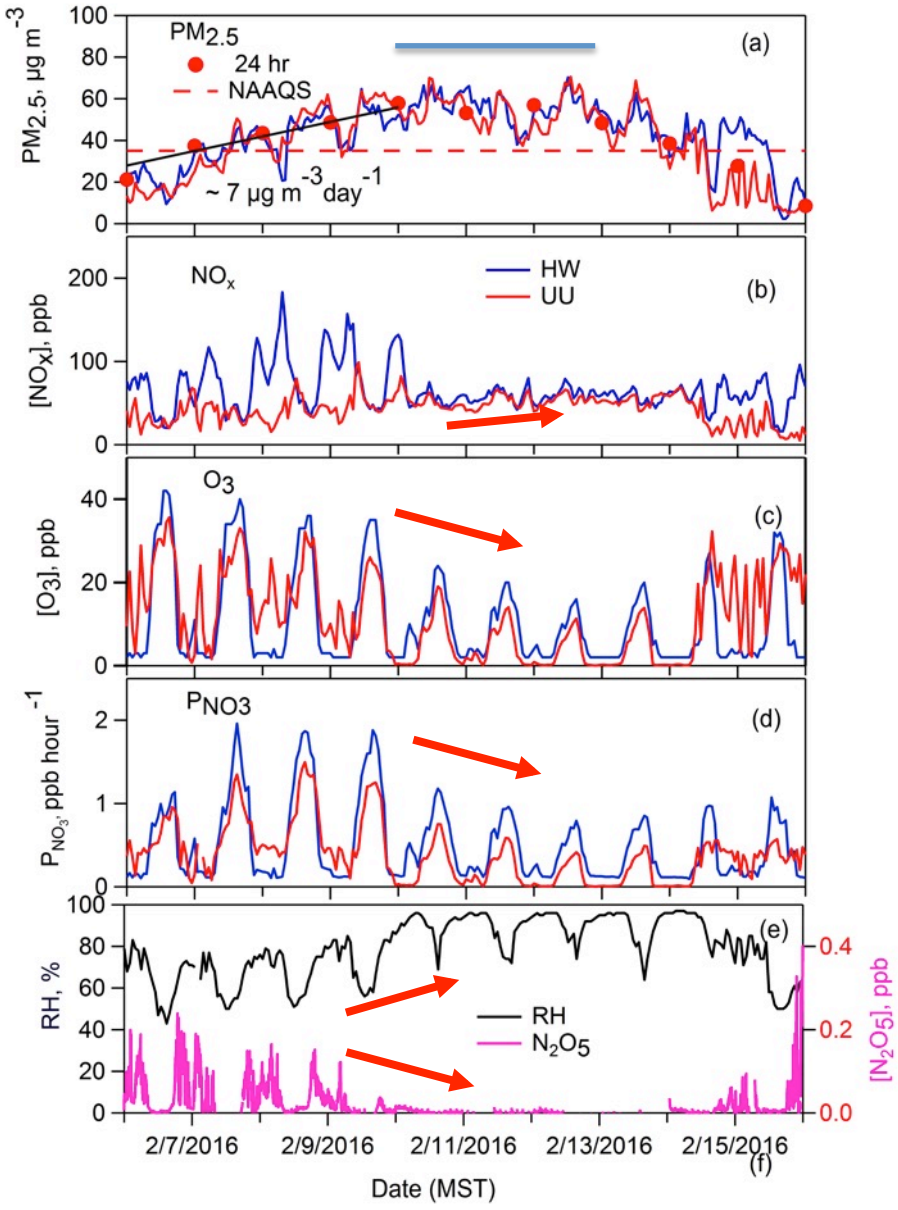
$PM_{2.5}$ episodes are characterized by:
- High PM
- Low O3
- High NOx
- High RH
- Low T <0

Conditions During February 6 – 16 Episode

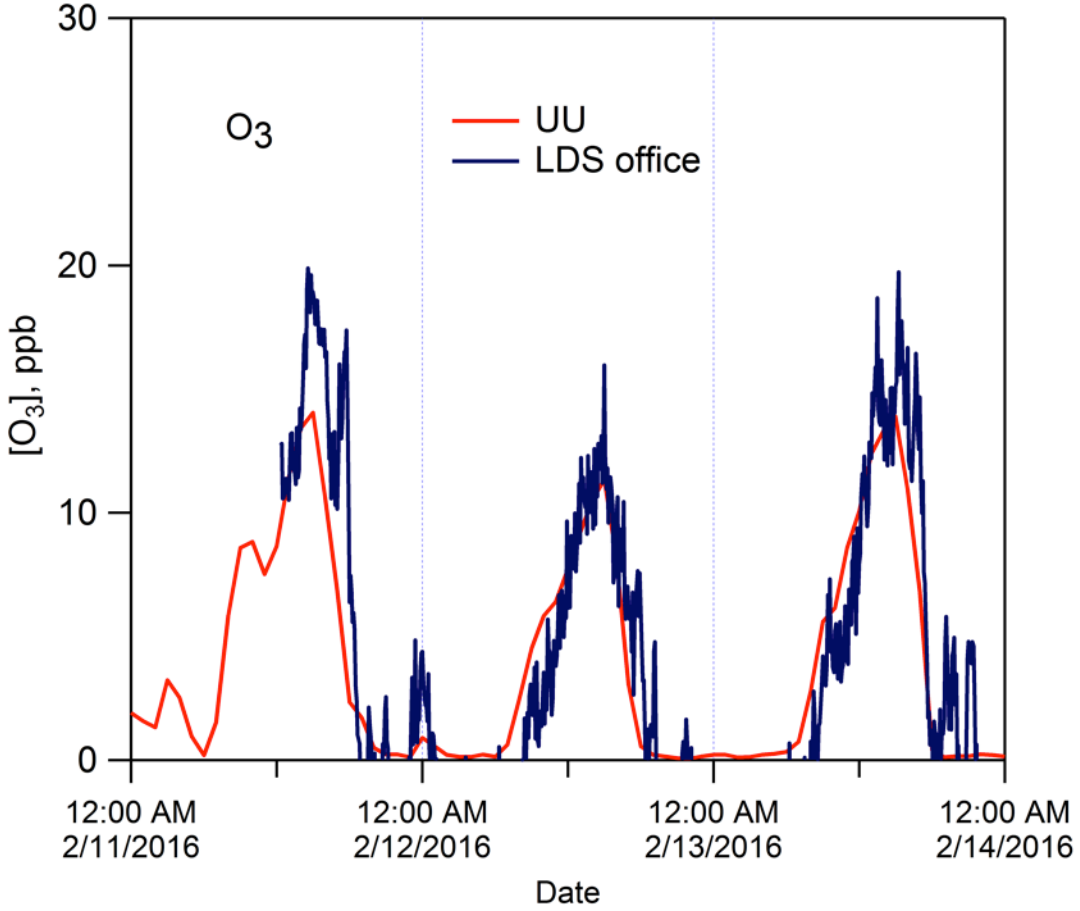
8 Exceedances

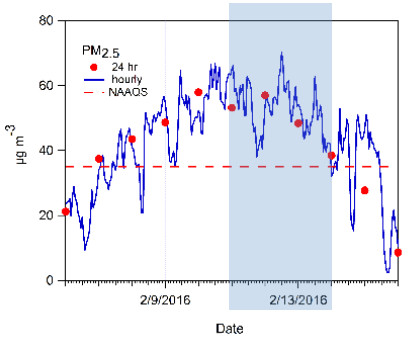
Middle of the episode

- $PM_{2.5}$ increase rate~ 7 ug/m3
- Reaches a plateau, ~ 60 ug/m3 Same levels at both UU and HW



What is the Altitude to Which the Surface Level O3 Titration Persists?

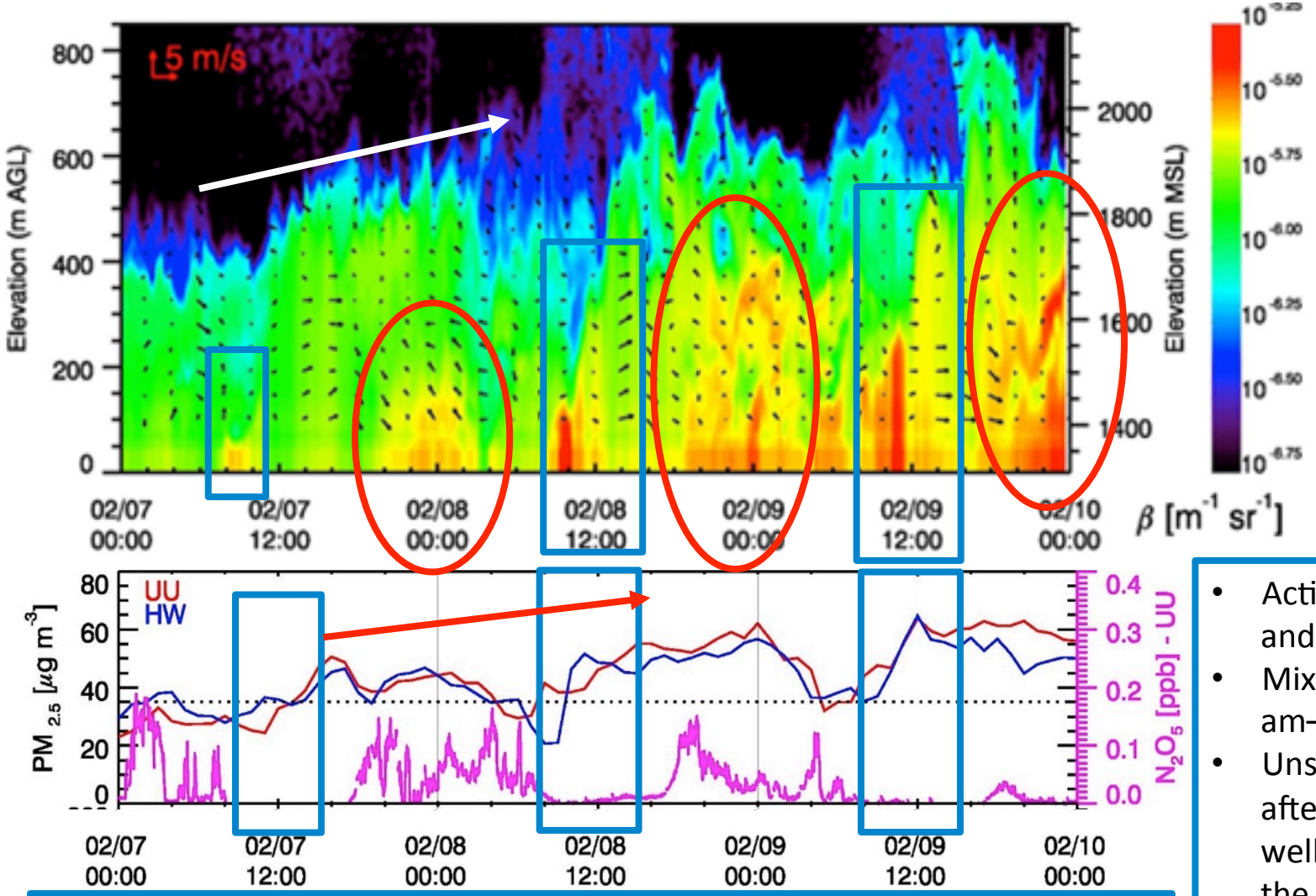


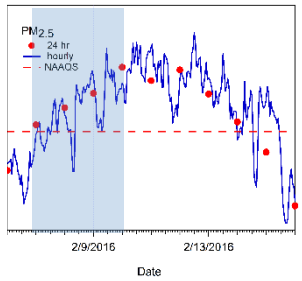


Day 6 - 8

- Consistent O3 levels at U and top of LDS office building ~ 100 m agl
- Complete titration at 100 m agl
- Occasional spikes likely due to drainage flows from City Creek Canyon.

Time Evolution of Aerosol Layer During Feb 6 –16 Event: Morning and Nighttime Chemistry Aloft and Daytime Mixing



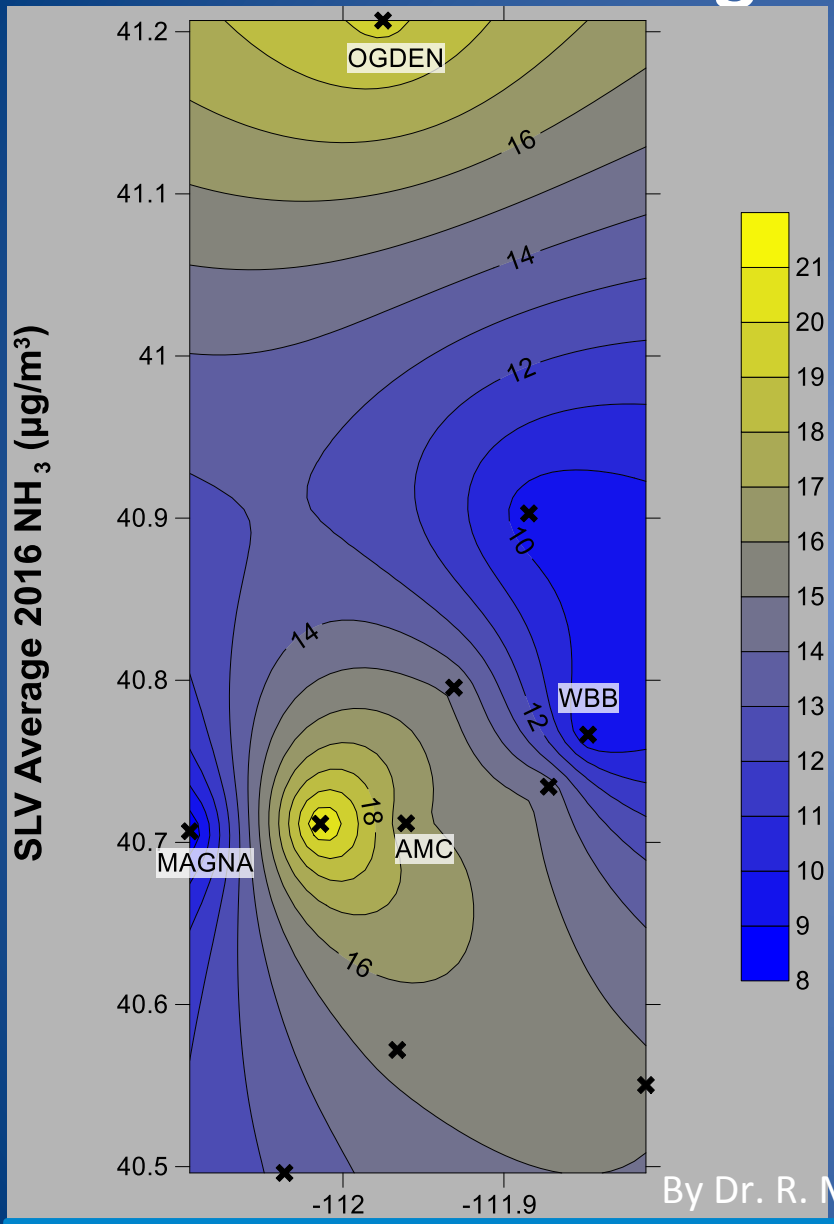


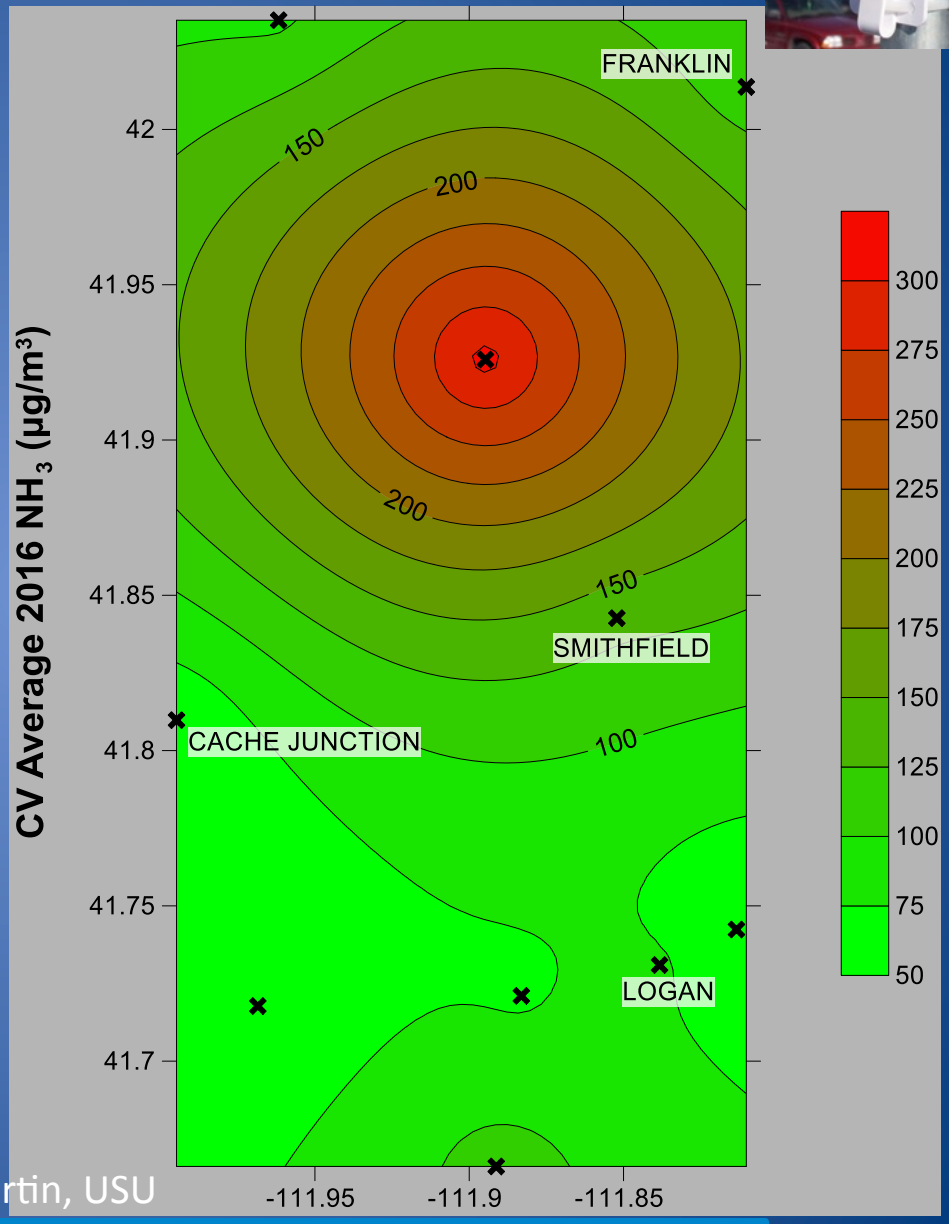
beginning of the episode

- Depth increases with time
- Stable @ night; unstable during the day within lowest few 100 m's.
- But capping inversion is still present.

- Activities at night and early morning
- Mixing happens ~ 10 am– 12 noon.
- Unstable in the afternoon; aerosol well mixed within the inversion layer.

Winter 2016 Average Ambient Ammonia

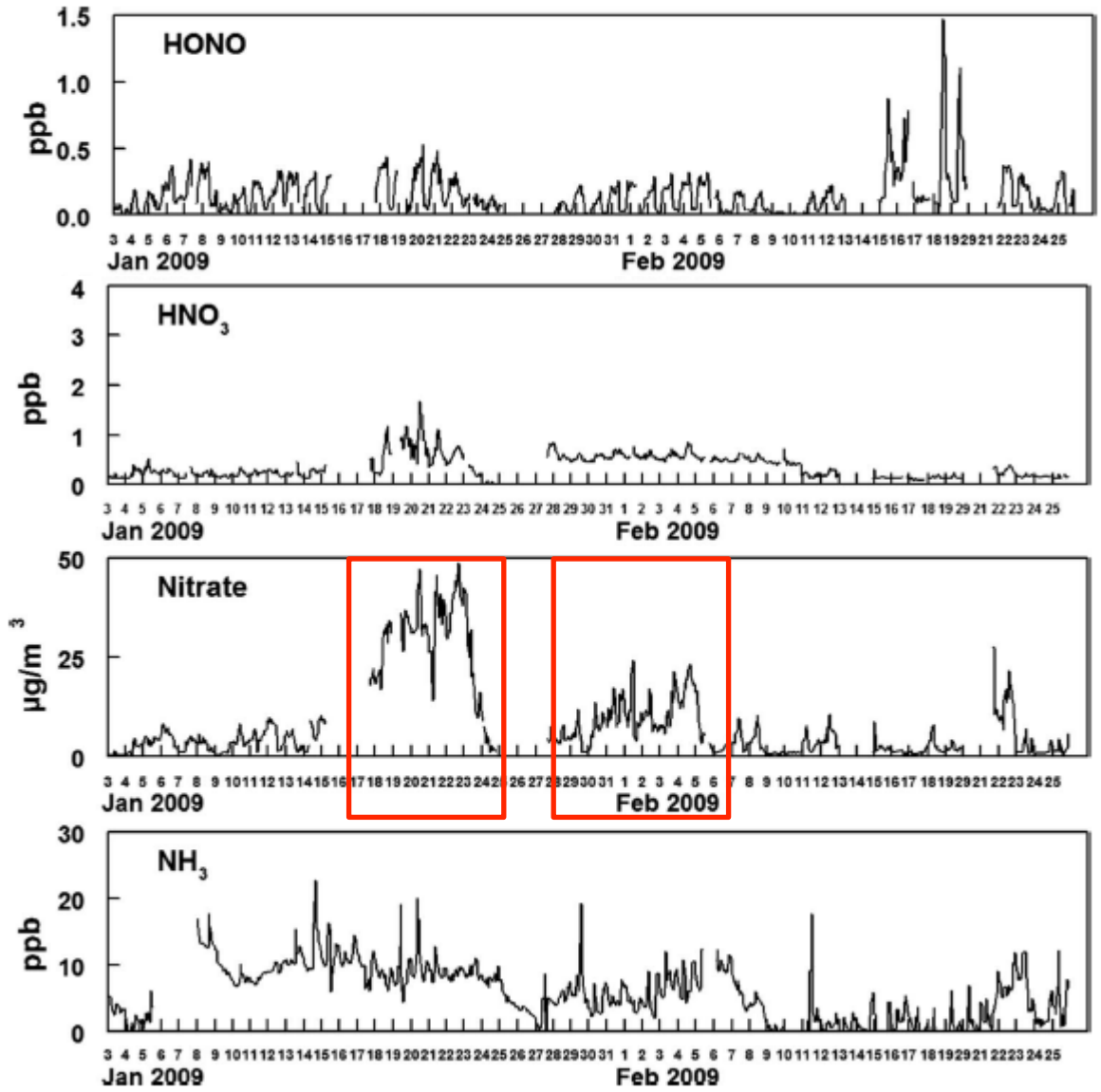




By Dr. R. Martin, USU

- very different chemical condition with high ammonia and low NOx in Cache

Levels of HNO3, NH3, and HONO at HW



Jan 2009 – Feb 2009

Near Surface Measurements

- HONO<0.5 ppb
- HNO3<1 ppb
- NH3 in 10's of ppb

Kuprov et al. 2014

Ground Site Measurements: Plan A

Atmospheric Sciences Building

Cloud Physics Lab

Atmos. Chem. Lab

Instrument	Species Measured	PI
VAPs--Aerosol Mass Spectrometer	Speciated PM 1 ; speciated organics	Dr. Brent Williams (Washington University in St. Louis)
Iodide Time of Flight Chemical Ionization Mass Spectrometer	HONO, HNO_3, N_2O_5, $ClNO_2$, other species	Dr. Hans Osthoff (University of Calgary)
Proton Transfer Reaction Time of Flight Mass Spectrometer	Volatile Organic Compounds (aromatics, carbonyls etc)	Dr. Dylan Millet (University of Minnesota)
Nitrogen Oxide CRDS	NO, NO_2, NO_3, N_2O_5, NO_y, O_3	Dr. Steve Brown (NOAA)
Others	$PM_{2.5}$, CO, CO_2, CH_4	Munkh/Lin group (University of Utah)
Doppler wind lidar, ceilometers, radiosondes and Hobos	Depth, dynamics and time evolution of CAPs, vertical structure, forecasting	Dr. Sebastian Hoch, Dr. Erik Crossman (University of Utah)
AIM-IC	PM inorganics, HNO3, NH3	Jen Murphy, U Toronto?
> 6		EPA ORD

Ground Site Measurements: Plan A

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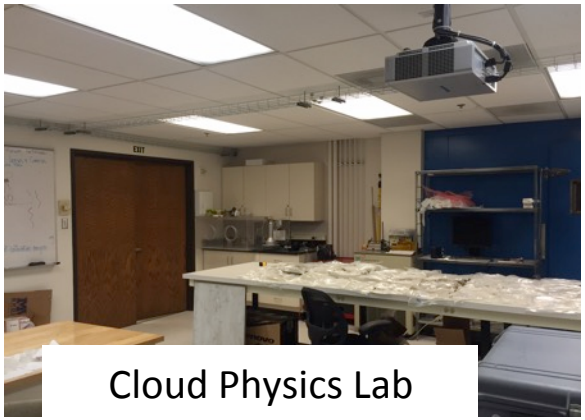
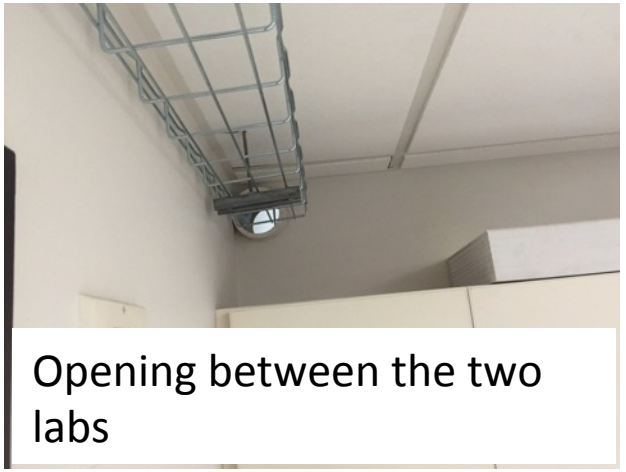
Roof

Cylinder storage with connection lines



Cloud Physics Lab



Opening between the two labs

Plan B: Ground Site Measurements

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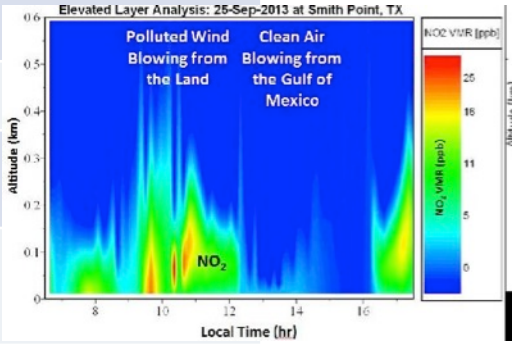
Instrument	Species Measured	PI
TEOM	PM2.5, O_3, NO_x, CO	DAQ/UU
LGR CRDS	CO_2, CH_4	University of Utah
Depth and time evolution of CAPs, vertical structure	ceilometers, and Hobos	University of Utah
AIM-IC	PM inorganics, HNO3, NH3	Jen Murphy, U Toronto?
> 6		EPA ORD

PM mass concentration by TEOM

Back scattering by ceilometer

EPA Office of Research and Development: Ground-Based Observations (Plan A & B)

Instrument	Species Measured
CRDS, UV Abs	NO2, O3
Chemiluminesence (?)	NOy
QCL (Aerodyne?)	HCHO
TSI OPC	$PM_{2.5}$ mass and size
3 x ceilometer	time evolution of aerosol layer
2 - 3 x PANDORA	-Total column measurements of HCHO, NO2, and O3, -Altitude profiles



Ideas:

- Co-located continuous measurements of NO2, NOy, HCHO, O3 and PM to study contribution of daytime component in Cache
- Remote sensing devices: inter-valley comparison of chemical conditions and aerosol layer
- In conjunction with UofU met observations, they can be used to study transport patterns:
  - Lake effects; drainage flows
  - Intrusion of cleaner air from the residual layer in 3 valleys
- Comparison of HCHO, and PM2.5 measurements; Pandora retrieval vs. aircraft

Mobile Laboratory Measurements: Plan A

Funding for mobile laboratory is part of the Targeted Air Shed Grant and to be decided

Science Questions:

1. What is the contribution of emissions from wood stoves to VOCs and fine particles?
2. What are the emission sources of ammonia?

Other objectives:

1. Sample in the same basins on the flight days of the NOAA Twin Otter to provide perspective
2. Provide vertical and regional perspective by taking various roads out of the basin

Dates: January 15 – February 5 (3 weeks)

Mobile Laboratory Measurements: Plan A

Instrument	Species Measured	Investigators
H_3O^+ ToF-CIMS	Volatile Organic Compounds	Matt Coggon Bin Yuan Carsten Warneke Joost de Gouw (NOAA & CIRES)
LAS	Particle size (90nm-10μm)	
LGR CRD	CO and N_2O	
PSAP	Absorption	
LGR CRD	NH_3	Munkh Baasandorj (UDEQ; UofU)

Comments:

- CO_2/CH_4: would be good, but space and power may be too limited. Can be overcome by co-locating stationary measurements with Salt Lake City CO_2 network, or by coordinated drives with "Nerdmobile"
- Wish list: filter samples for aerosol composition during stationary measurements
- Wish list: Sunset Laboratory filter or semi-continuous OC/EC analyzer during stationary measurements

Mobile Laboratory Measurements: Plan A

Sampling strategy:

- Combination of drives and stationary measurements to determine diurnal variations
- Drives: sample in residential, industrial, business areas and along traffic corridors, and other targets of interest to UDEQ, UofU, Twin Otter, etc.
- Stationary measurements: select a few locations for the mobile laboratory in consultation with UDEQ and UofU to be parked at multiple times during the study and construct a diurnal variation
  (For example: mobile lab storage at UofU, Rose Park, Magna range from east to west in the SLC basin, not too far from base of operations)

Analysis:

- Use the drives to characterize specific emission sources
- Use the stationary measurements for source attributions of VOCs, fine particle volume, ammonia, BC and CO (using PMF, linear regression etc., and using the composition of individual sources for comparisons)