Impacts of Oil & Natural Gas Operations and Urban Emissions on Air Quality in Rocky Mountain National Park during FRAPPÉ

Barkley C. Sive
Air Resources Division

ARD: Tony Prenni, Jim Cheatham, Bret Schictel, John Vimont

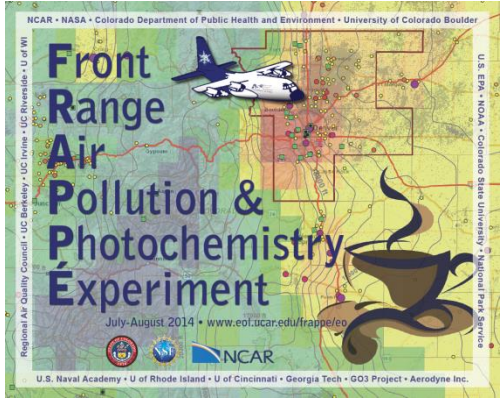
CSU/CIRA: Yong Zhou, Katie Benedict, Ashley Evanoski-Cole, Emily Fischer, Derek Day, Sara Callahan, Amy Sullivan, Jeff Collett

NCAR: Eric Apel, Becky Hornbrook

UCI: Stacey Hughes

SUNY-ESF: Huiting Mao, Ying Zhou

Air Resource Specialists, Inc.



15 July - 18 August 2014
Colorado Front Range

PIs: Gabriele Pfister and Frank Flocke

National Center for Atmospheric Research (NCAR)

Funding Sources

FRAPPÉ: National Science Foundation (NSF)
State of Colorado

DISCOVER-AQ: NASA

Others: NOAA, GO_3 Project, NPS, EPA

https://www2.acd.ucar.edu/frappe

FRAPPÉ AND DISCOVER-AQ

- Two major field campaigns - FRAPPÉ and DISCOVER-AQ - merged to study air quality in the Colorado Front Range in summer 2014 and fill measurement gaps.
- Measurements collected from surface stations, upward looking lidars and profilers, mobile vans, balloons and sondes, and four aircraft.
- Together with satellite data and model analysis provides the most comprehensive characterization of air quality ever conducted in the region.

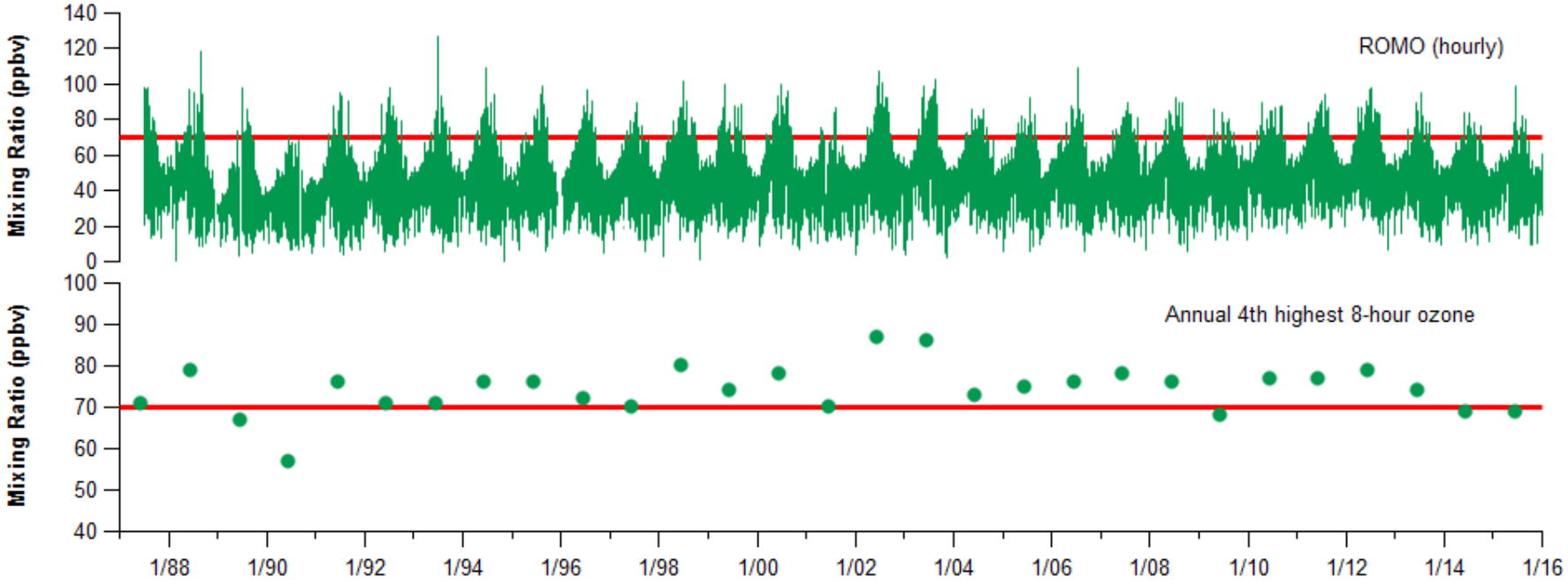
- Improve development & evaluation of emission control strategies
- Allow better modeling of present and future air quality for decision making
- Identify optimal locations for surface monitoring sites making the network more efficient and more representative
- Refine and verify satellite data for air quality planning in the Front Range.

Question: Is there a measureable impact from O&G operations at ROMO?

- Historical ozone record at ROMO
- Ozone at 2 sites in ROMO during FRAPPÉ
- VOC distributions and source characterization
- 2 case studies – upslope and stratospheric intrusion
- Box modeling results & calculations to determine O_3 production from O&G

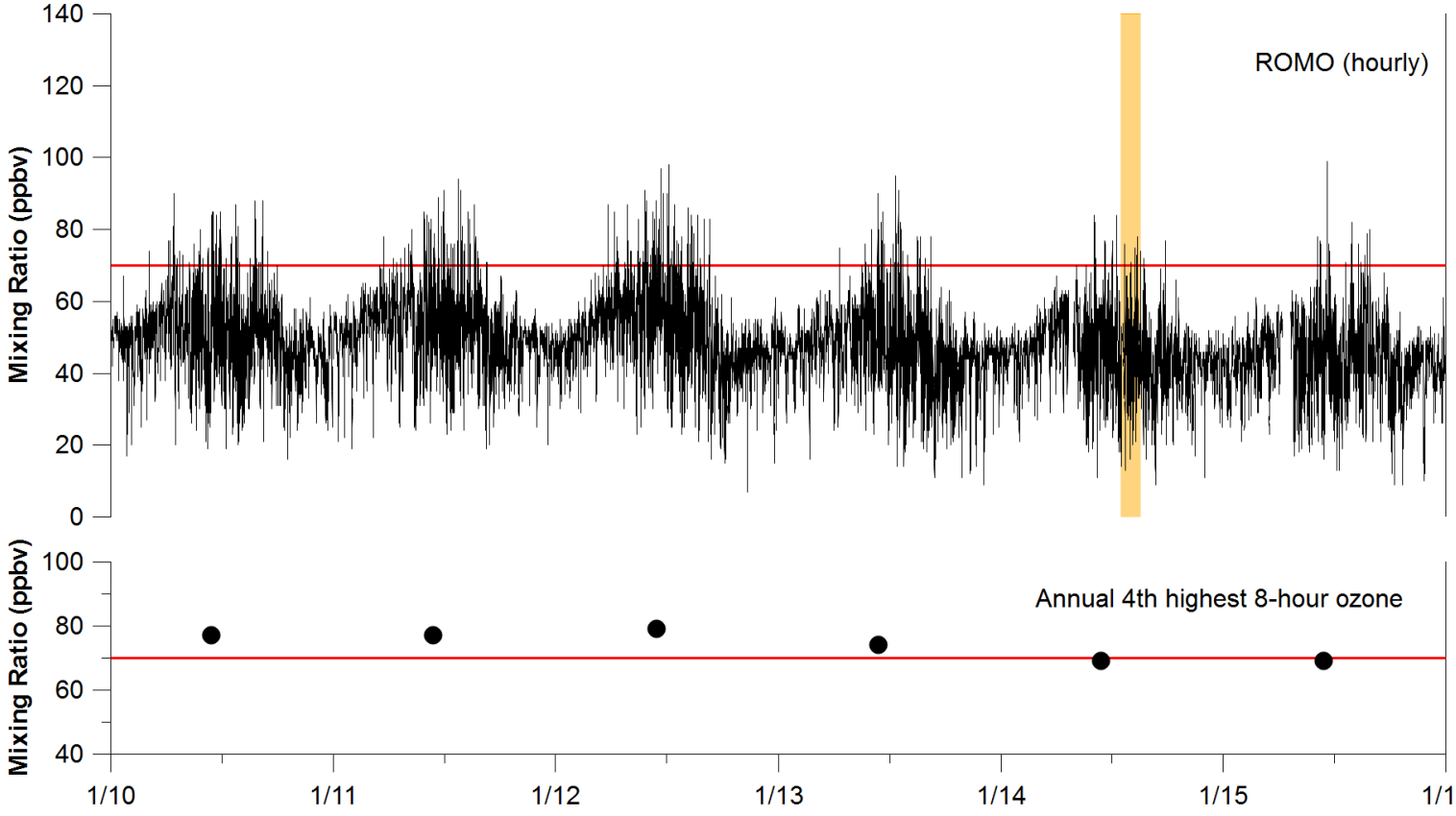
Rocky Mountain National Park, CO Site: Longs Peak

Historical Perspective of ROMO for Summer 2014

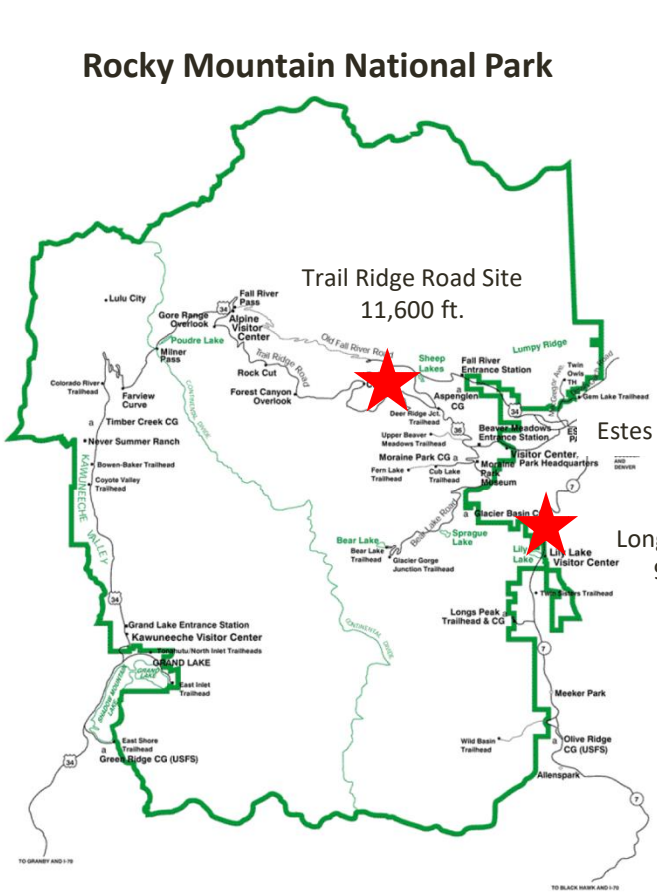


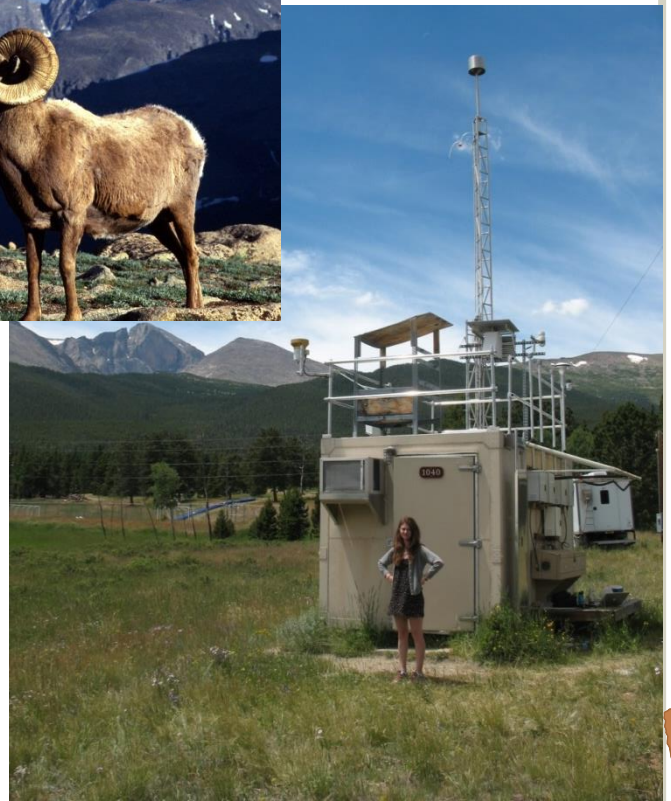
Rocky Mountain National Park, CO Site: Longs Peak

Historical Perspective of ROMO for Summer 2014



ROMO is a Class I area and suffers from multiple air quality problems including elevated ozone and harmful levels of nitrogen deposition.





Rocky Mountain National Park Measurements

Objective: Supplement continuous monitoring occurring at ROMO during FRAPPÉ intensive period.

Key areas of NPS interest: Oil & gas impacts, N deposition, O_3

Ongoing measurement programs:
IMPROVE, AMoN, NADP, CASTNet (O_3, met, filter packs)

Additional Measurements during FRAPPÉ

VOC GC
PTR-MS
PAN GC
CO, NH_3, NO_x, NO_y
MARGA
Spatial sampling:
VOCs with canisters
URG annular denuder system
Portable O_3 - Trail Ridge Road

Alkanes
ethane
propane
i-butane
n-butane
i-pentane
n-pentane
cyclopentane
n-hexane
n-heptane
n-octane
n-nonane

Alkenes
ethene
propene
t-2-butene
1-butene
i-butene
c-2-butene

Alkynes
ethyne

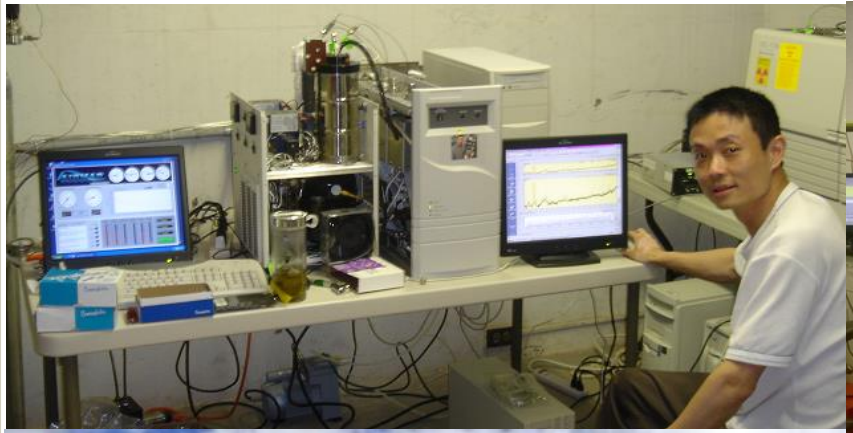
Biogenics
isoprene
α-pinene
β-pinene

OVOCs
methanol
acetaldehyde
MEK
MVK+MACR
acetic acid

Aromatics
benzene
toluene
ethylbenzene
m+p-xylene
o-xylene

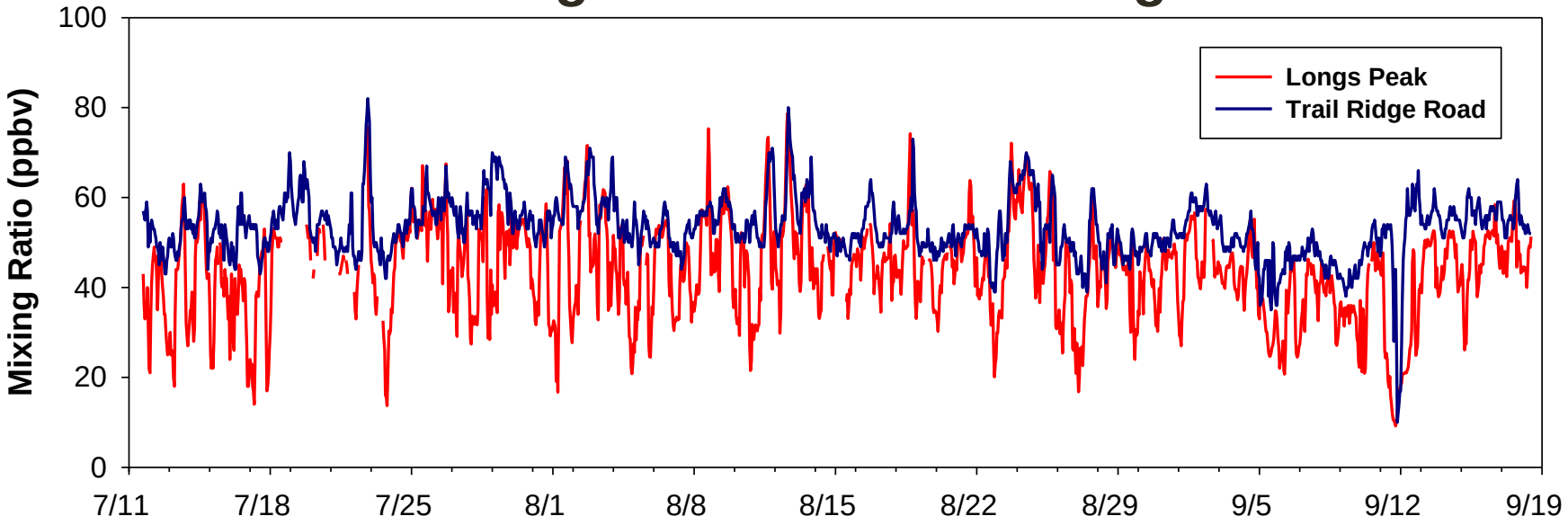
Alkyl Nitrates
MeONO2
EtONO2
i-PrONO2
n-PrONO2
2-BuONO2
3-PenONO2
2-PenONO2

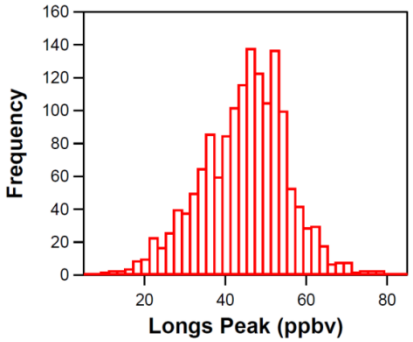
Halocarbons
C2HCl3
C2Cl4
CH3I
CH2Br2
CHBrCl2
CHBr3



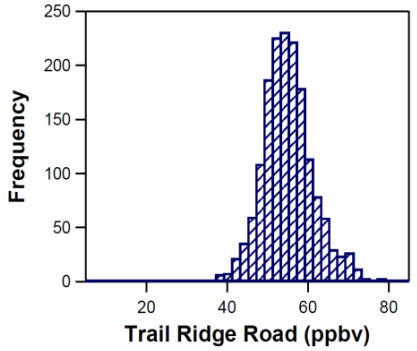

USGS
Wahoo's

Ozone: Longs Peak and Trail Ridge Road

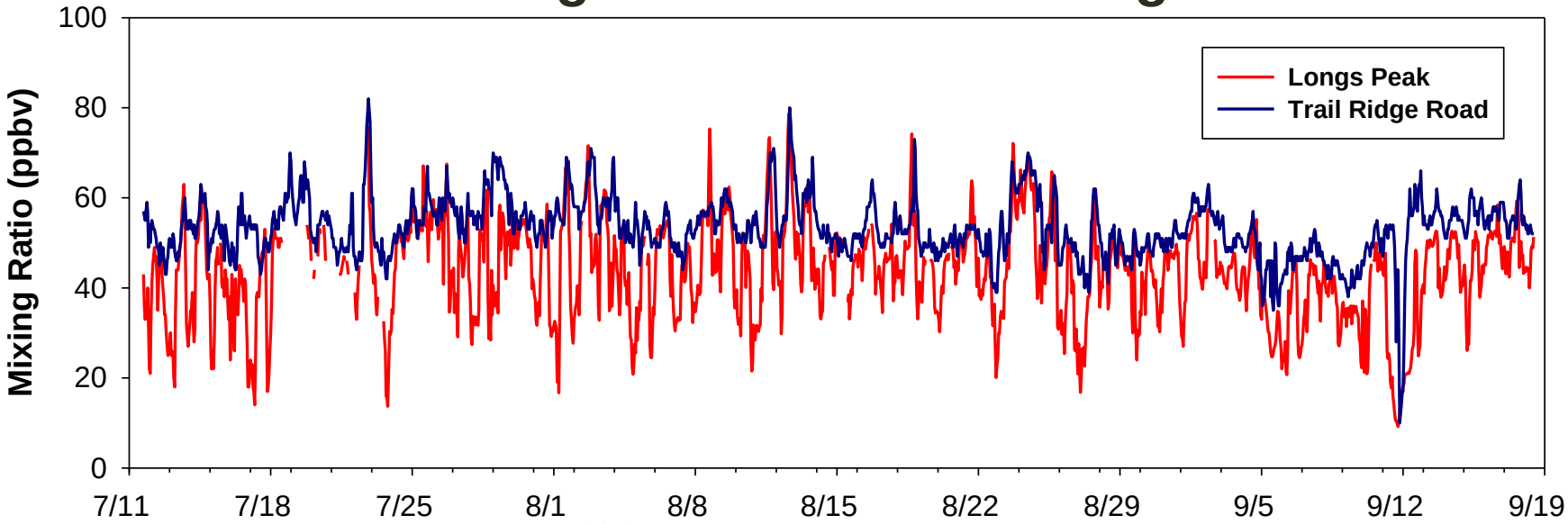


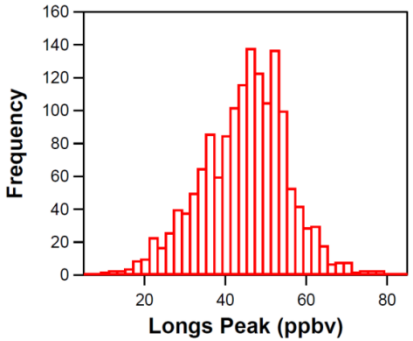


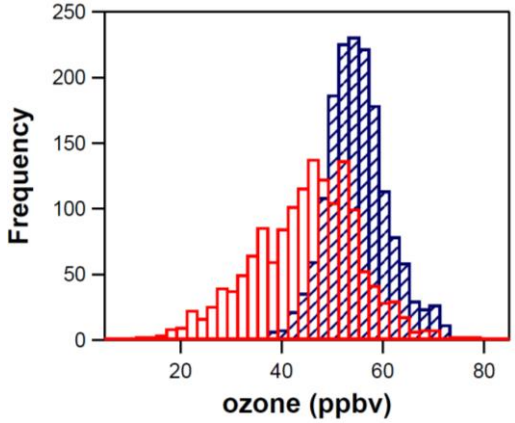
	Longs Peak	Trail Ridge Road
Mean	43	53
Med	45	53
Max	79	82
Min	9	10
25th	36	49
75th	51	57

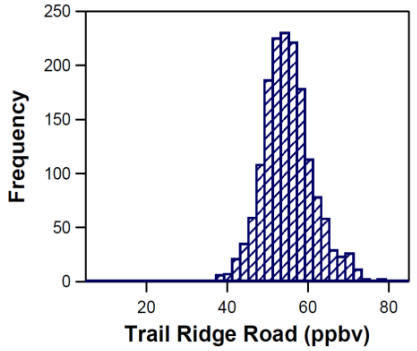


Ozone: Longs Peak and Trail Ridge Road

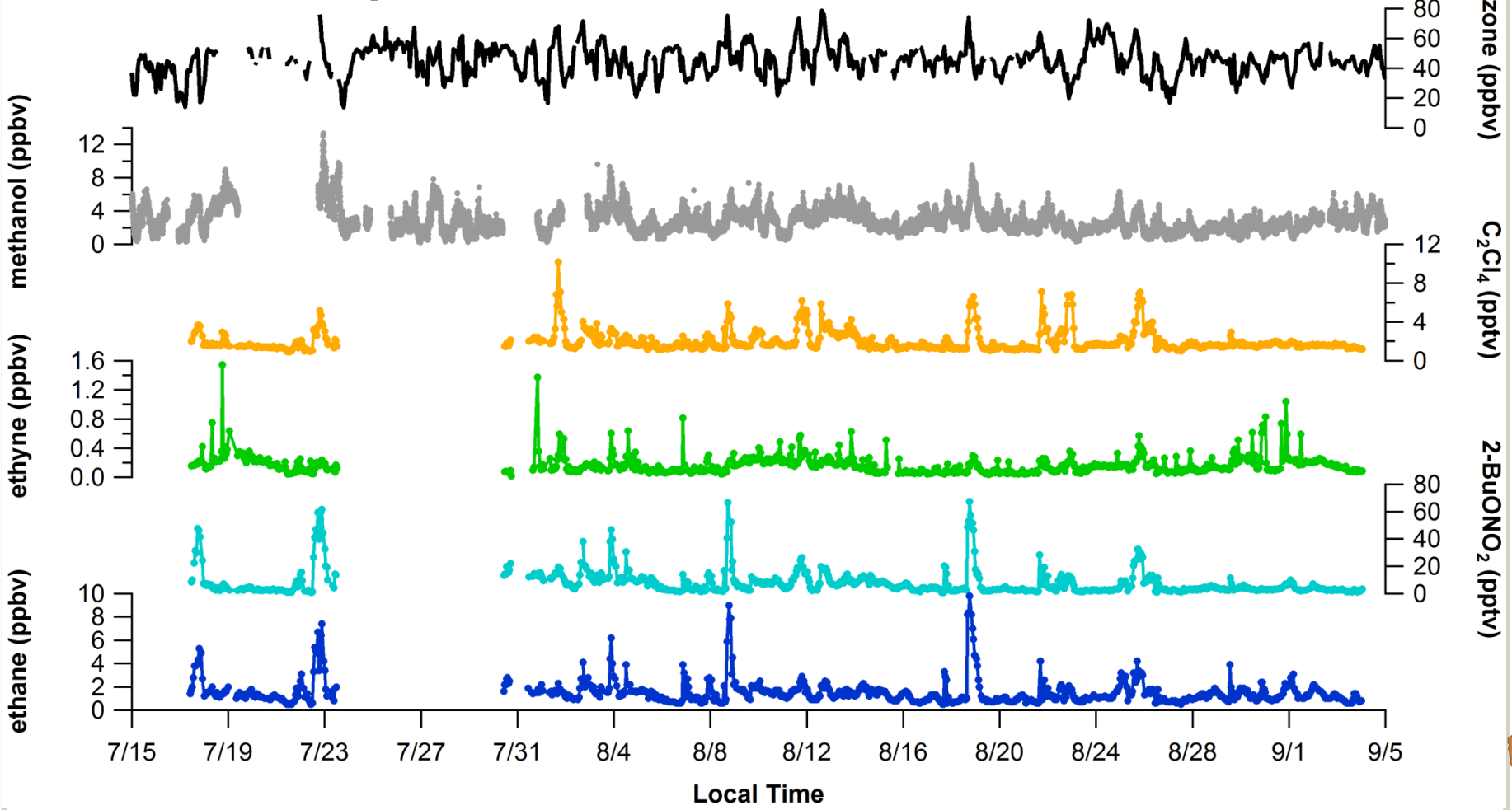








Temporal Distributions of VOCs at ROMO



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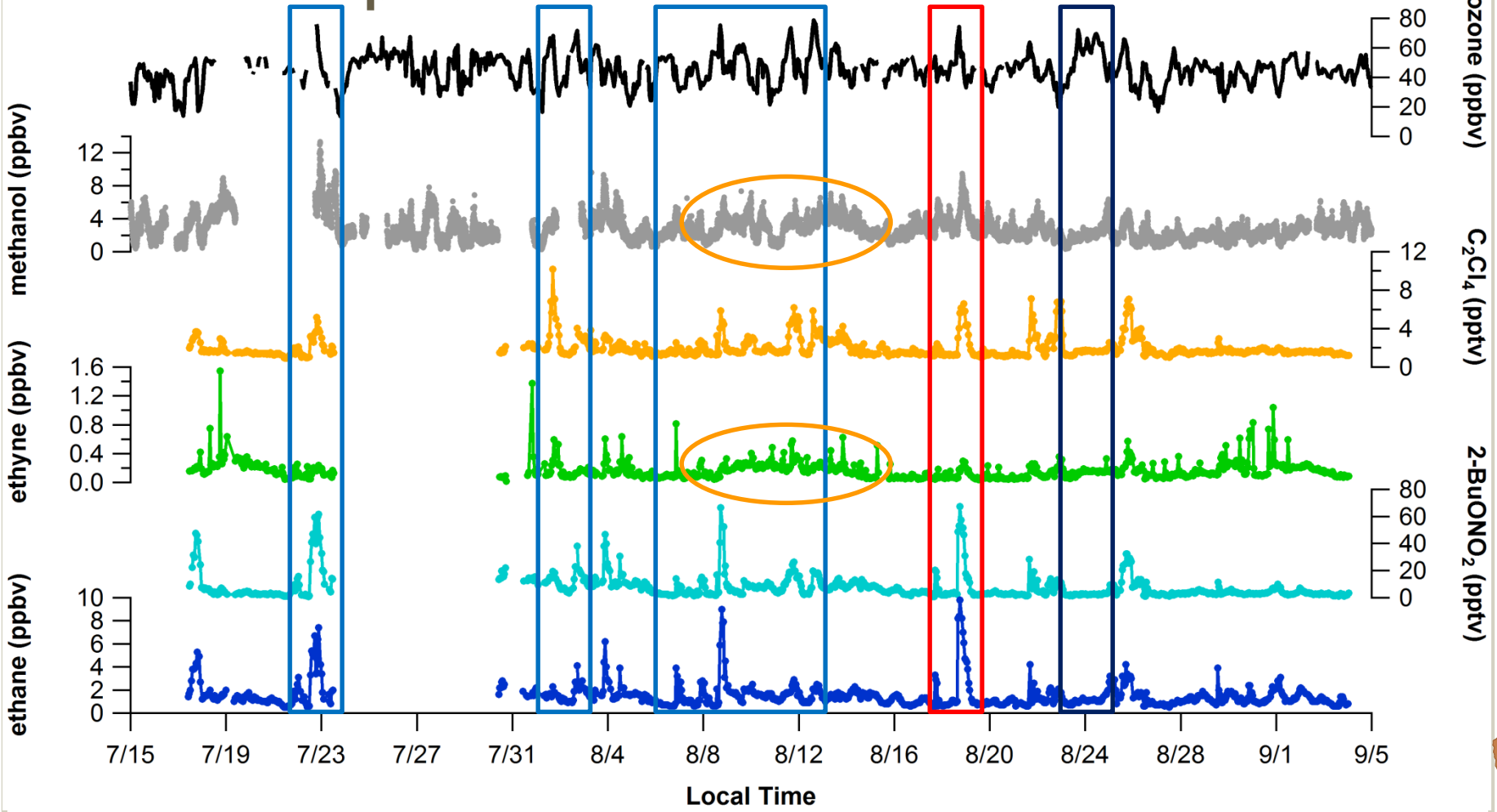
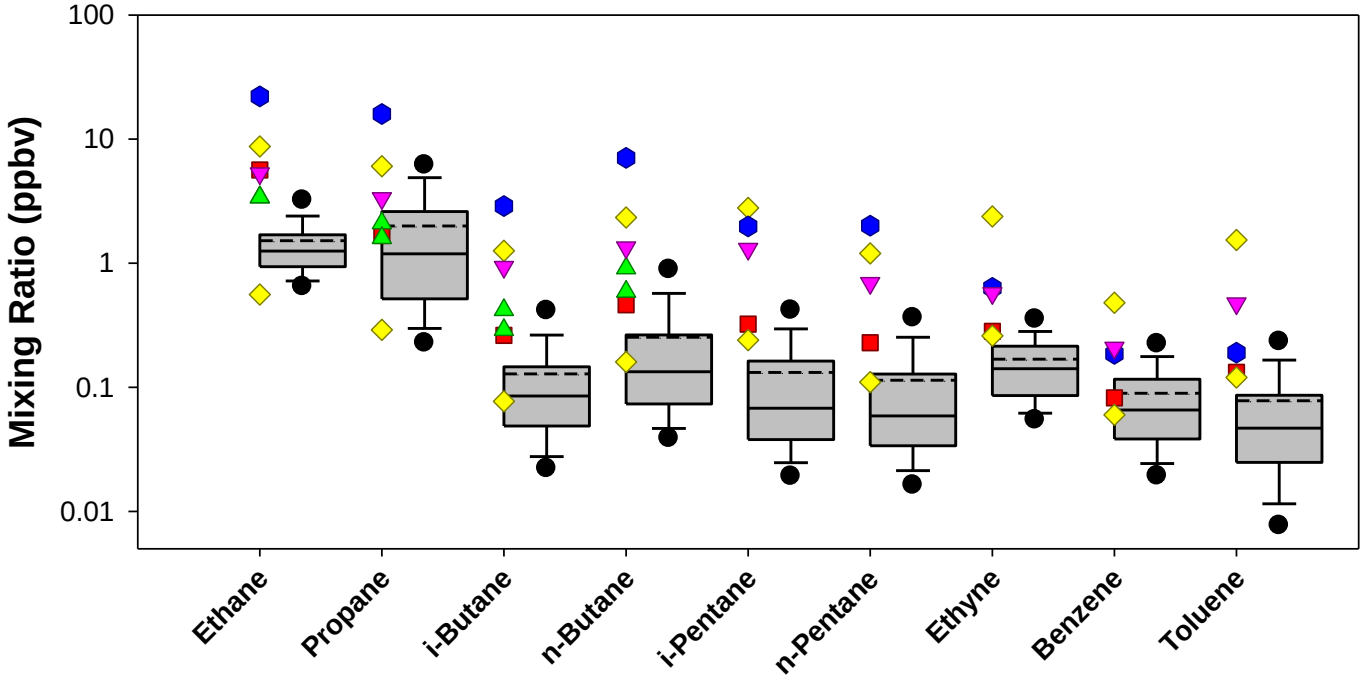


Urban Study Comparison of Light NMHCs

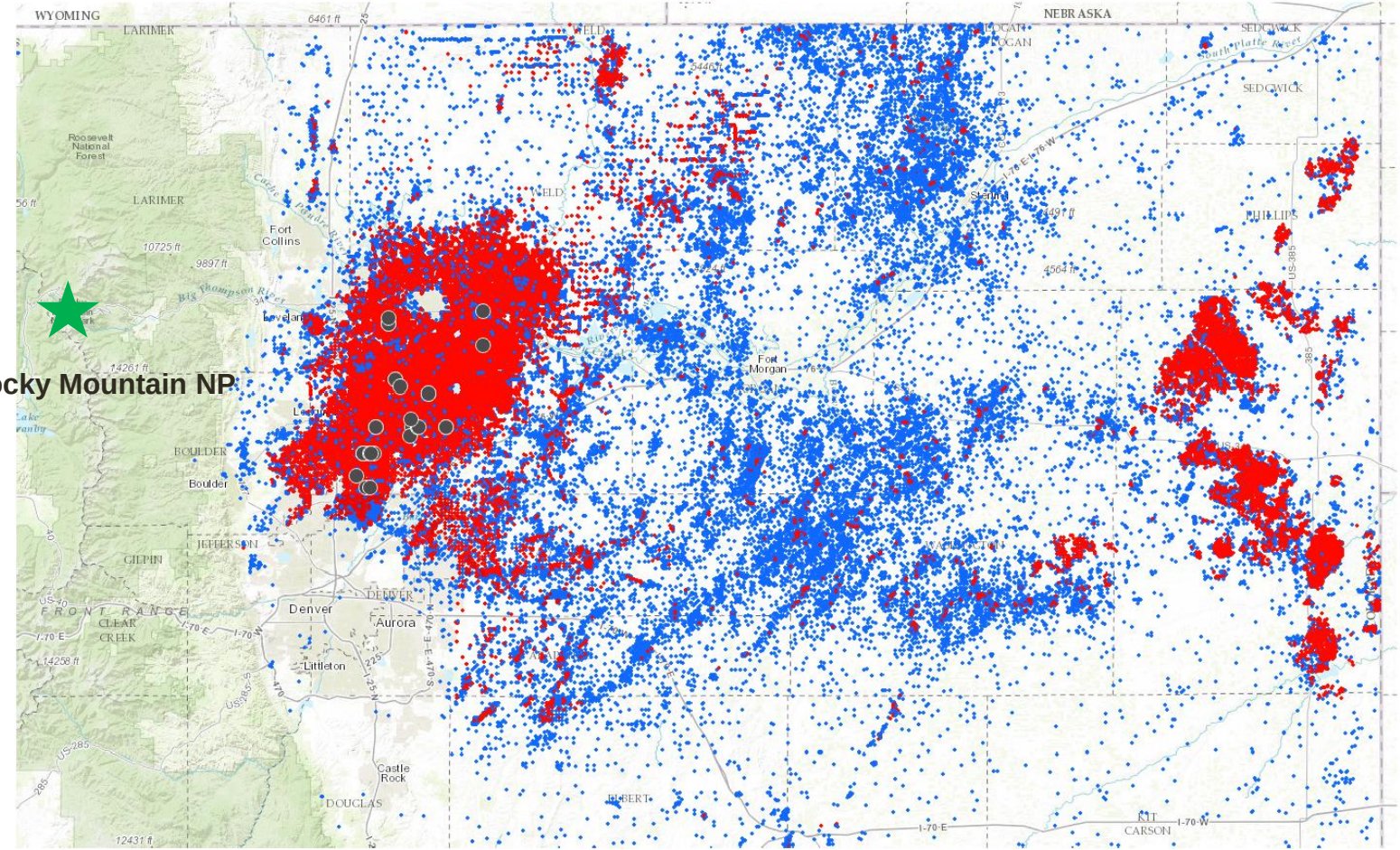


1916 Organic Act – NPS Mission Established

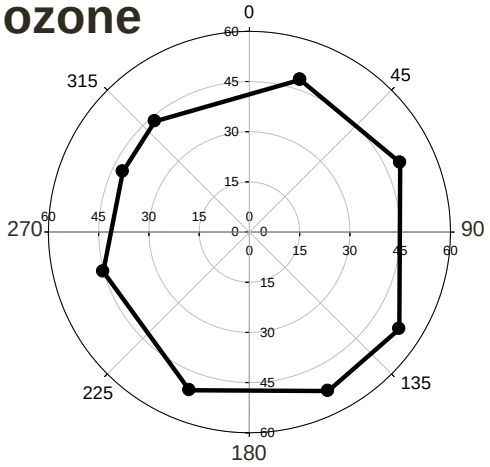
Clean Air Act – Importance of Clean "Pristine" Air in these Areas a National Goal

1) Swarthout et al., 2015; 2) Baker et al., 2008; 3) Katzenstein et al., 2003; 4) Swarthout et al., 2013.

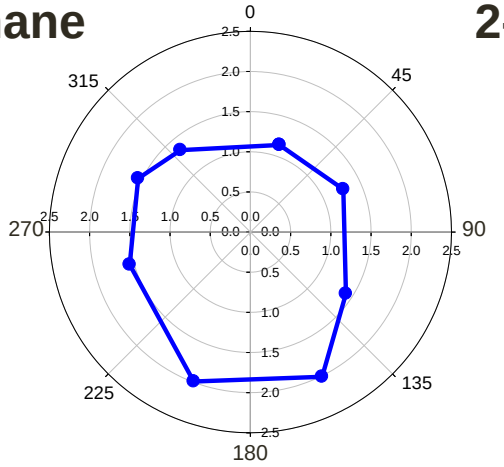
Oil and Gas Wells



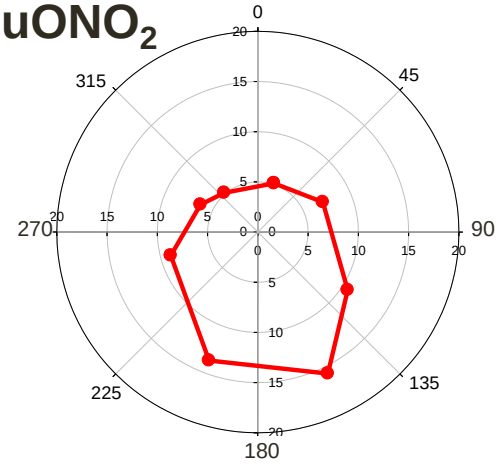
ozone



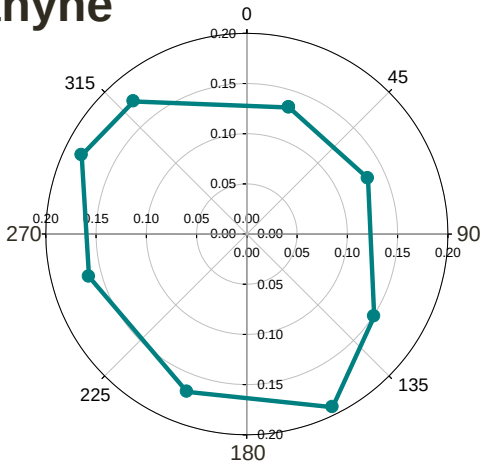
ethane



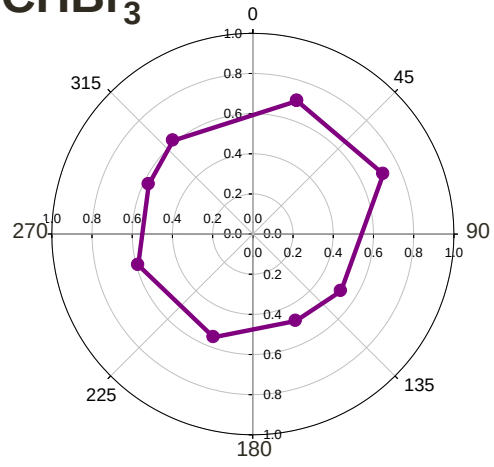
2-BuONO$_2$



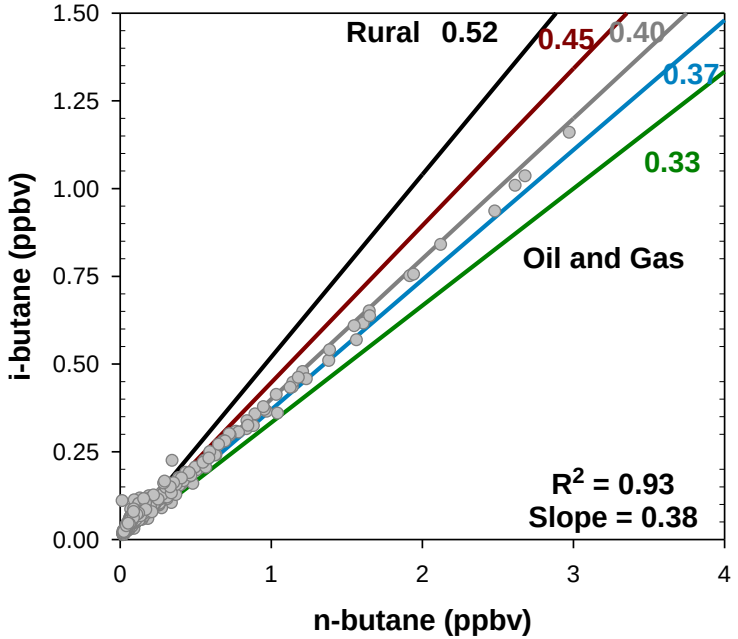
ethyne

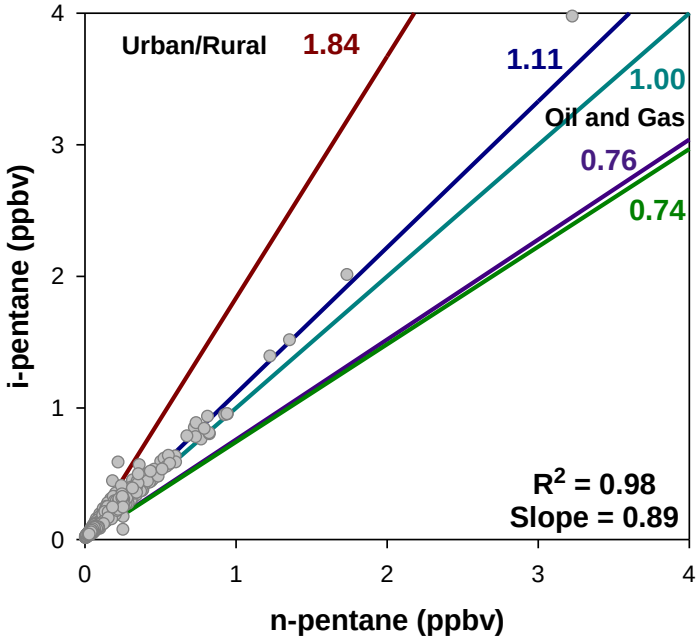


CHBr$_3$



Oil & Gas Emissions Tracers
The Butane and Pentane Ratios





Swarthout et al., 2013 JGR (CO)

Swarthout et al., 2015 ES&T (PA)

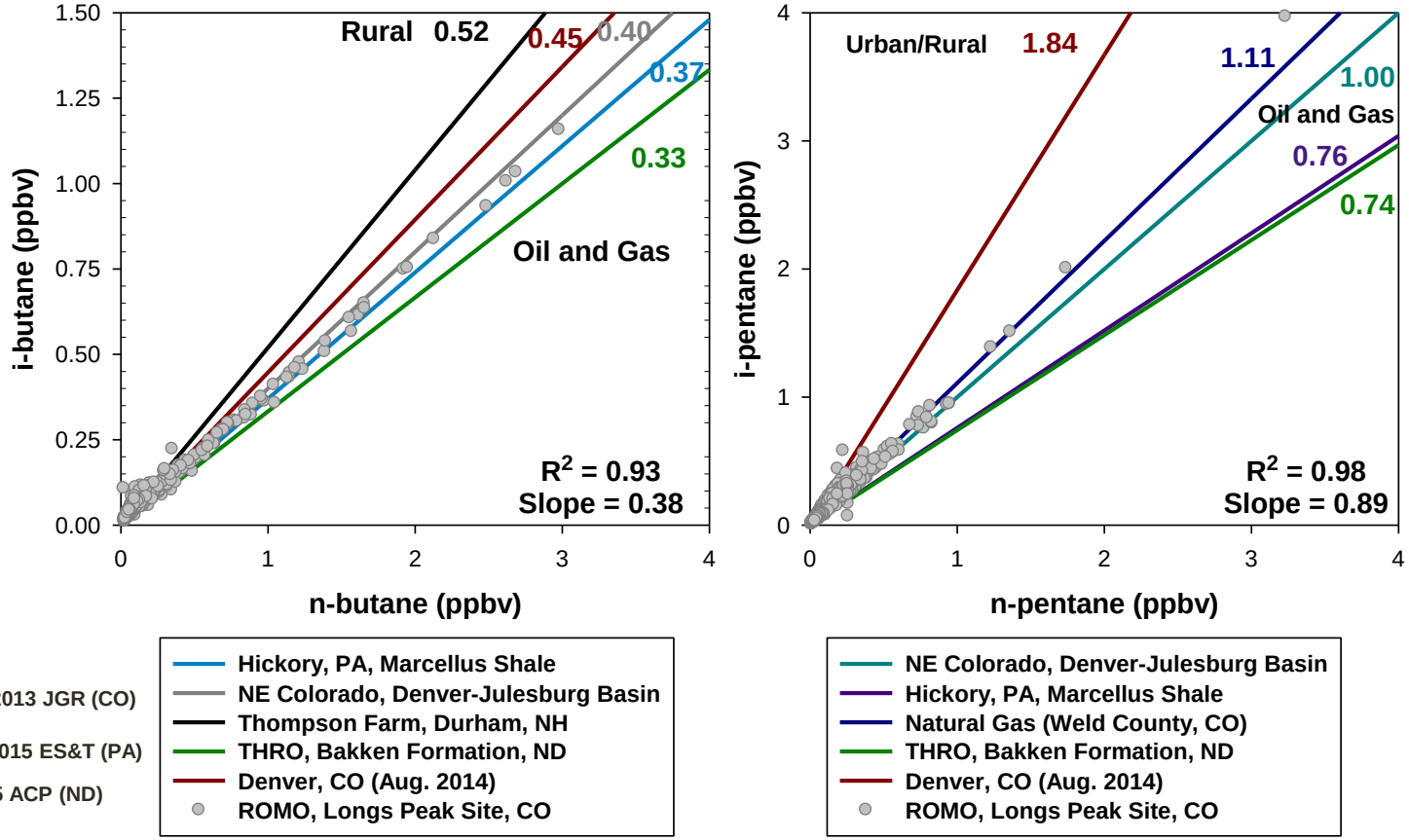
Prenni et al., 2015 ACP (ND)

- Hickory, PA, Marcellus Shale
- NE Colorado, Denver-Julesburg Basin
- Thompson Farm, Durham, NH
- THRO, Bakken Formation, ND
- Denver, CO (Aug. 2014)
- ROMO, Longs Peak Site, CO

vehicular exhaust ~ 2.2-3.8
gasoline ~ 1.5-3
fuel evaporation ~1.8-4

Oil & Gas Emissions Tracers

The Butane and Pentane Ratios



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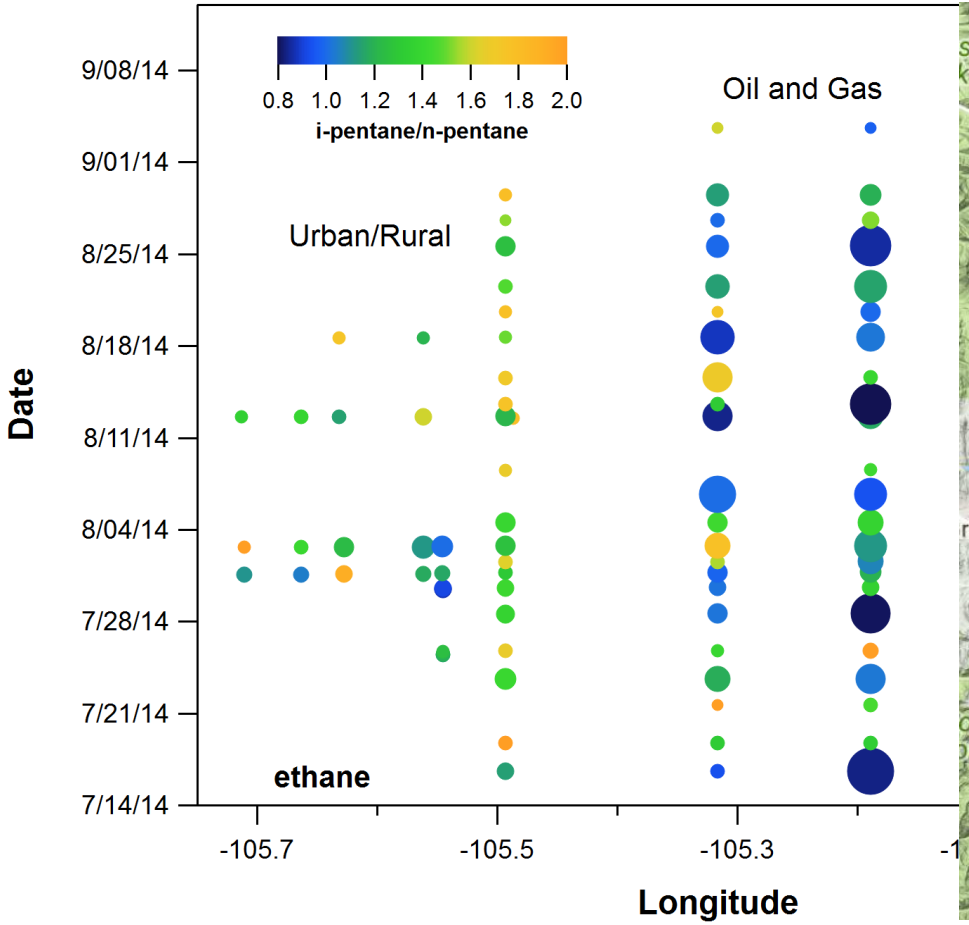
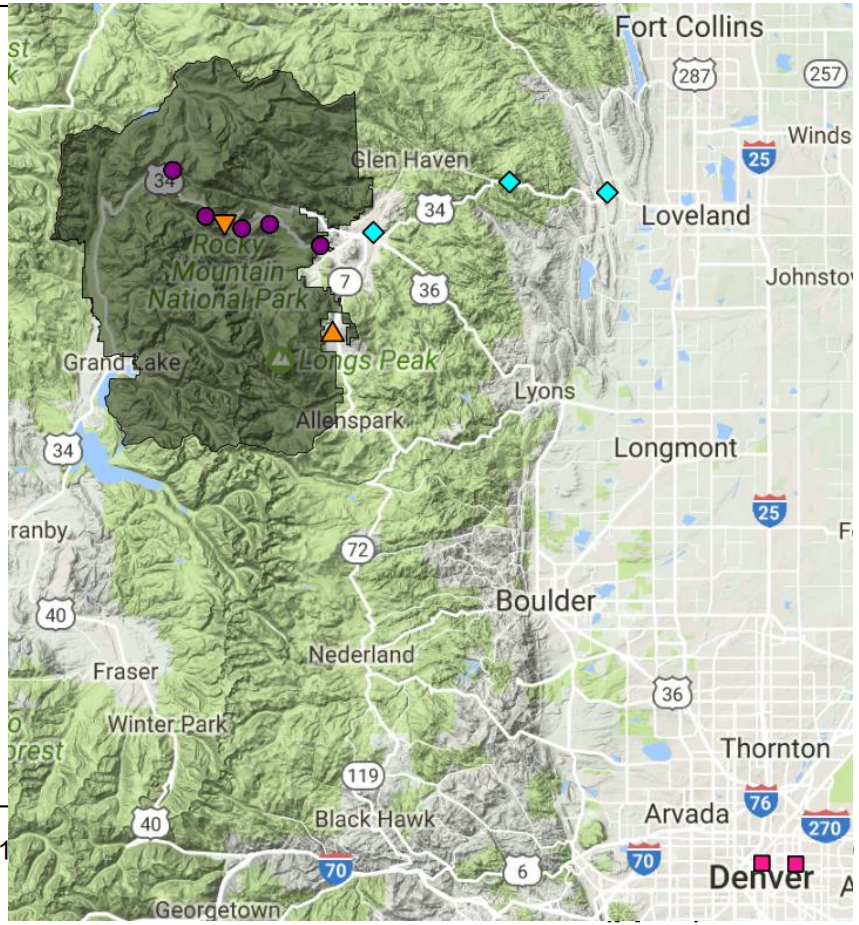
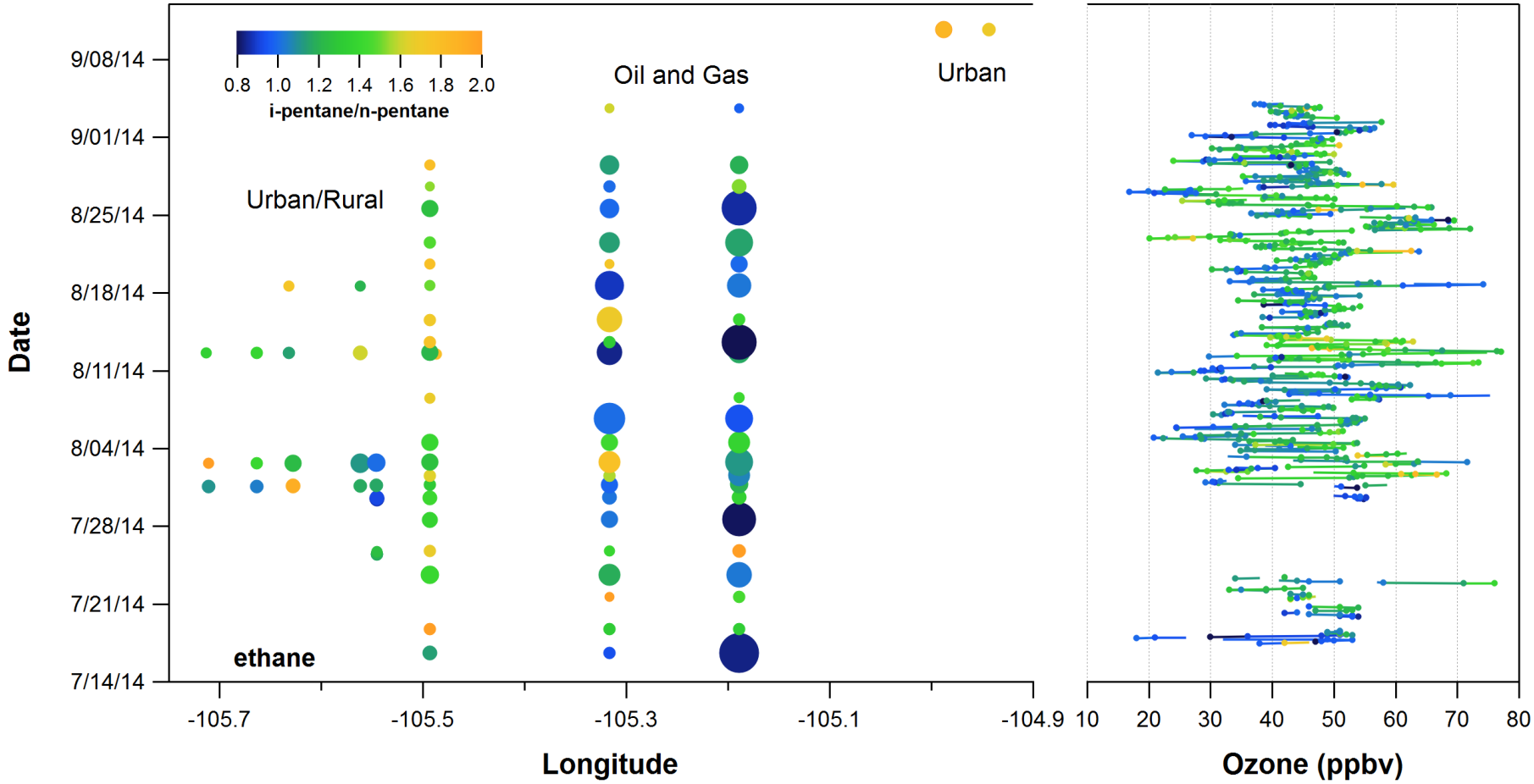
- NE Colorado, Denver-Julesburg Basin
- Hickory, PA, Marcellus Shale
- Natural Gas (Weld County, CO)
- THRO, Bakken Formation, ND
- Denver, CO (Aug. 2014)
- ROMO, Longs Peak Site, CO

Transect Samples

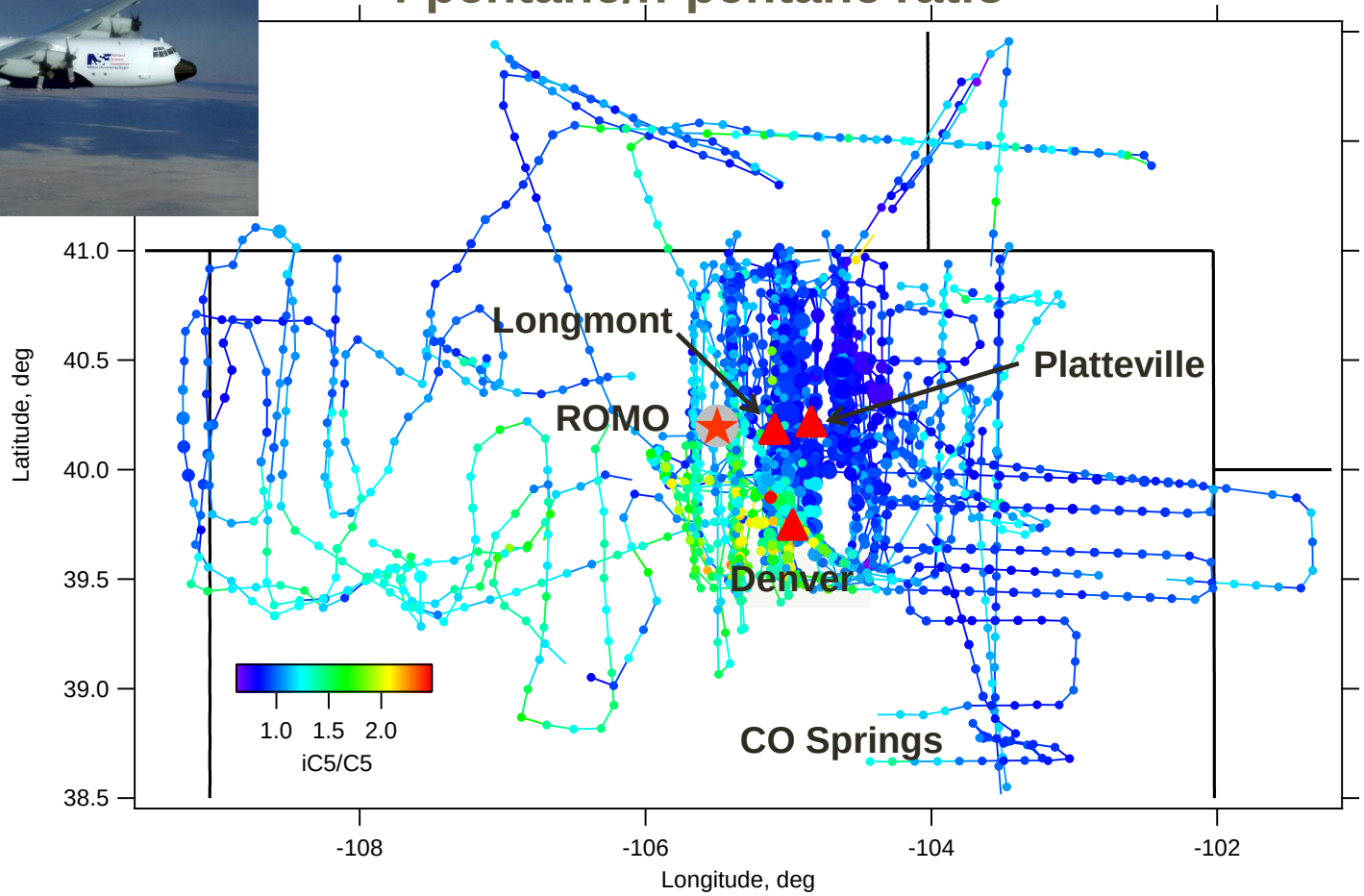




Transect Samples



TOGA C-130
i-pentane/n-pentane ratio



Upslope & Stratospheric Intrusion Events

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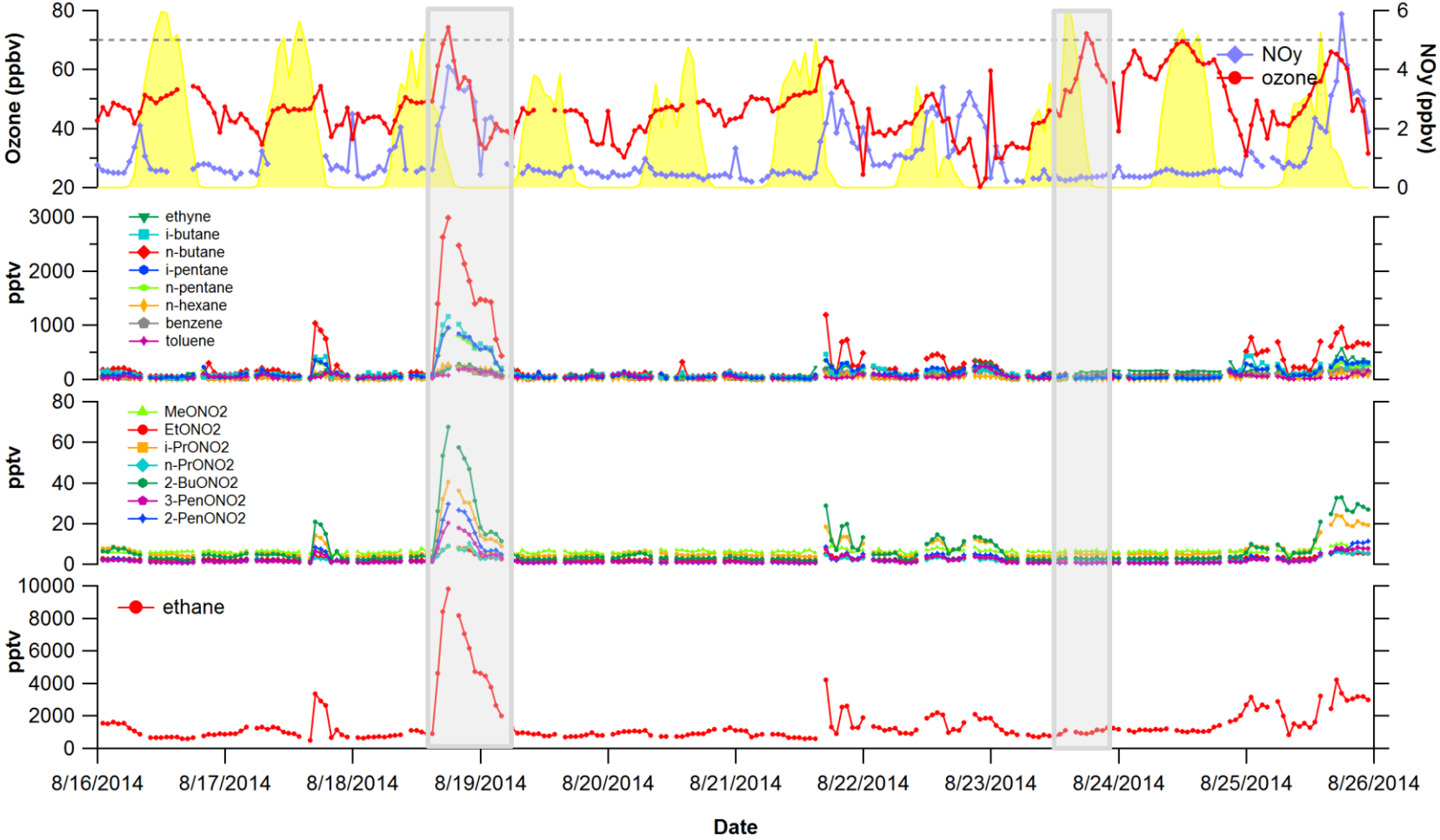


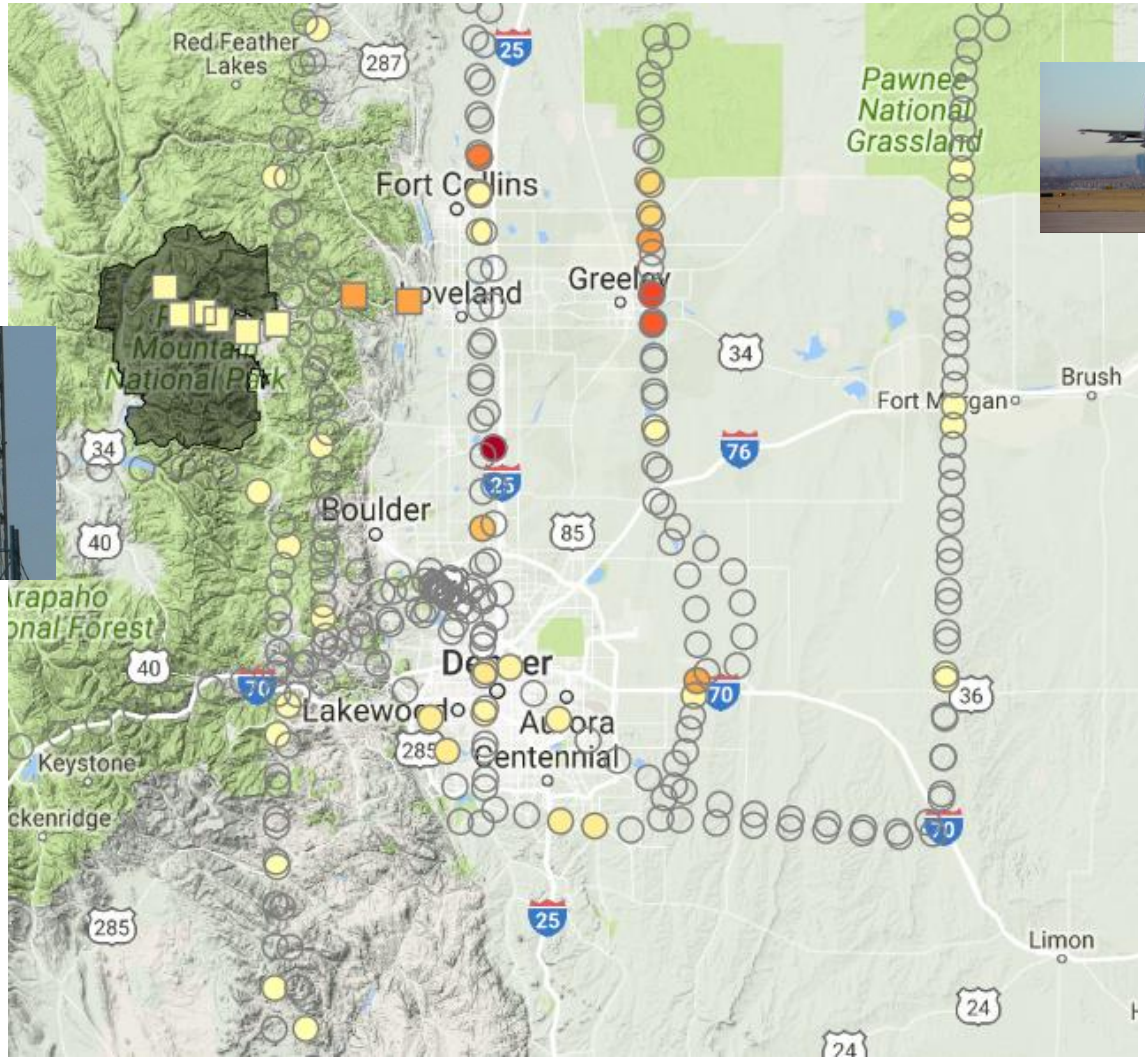
RF15

8/18/2014

Upslope Event

3 PM

10 AM



RF15

8/18/2014

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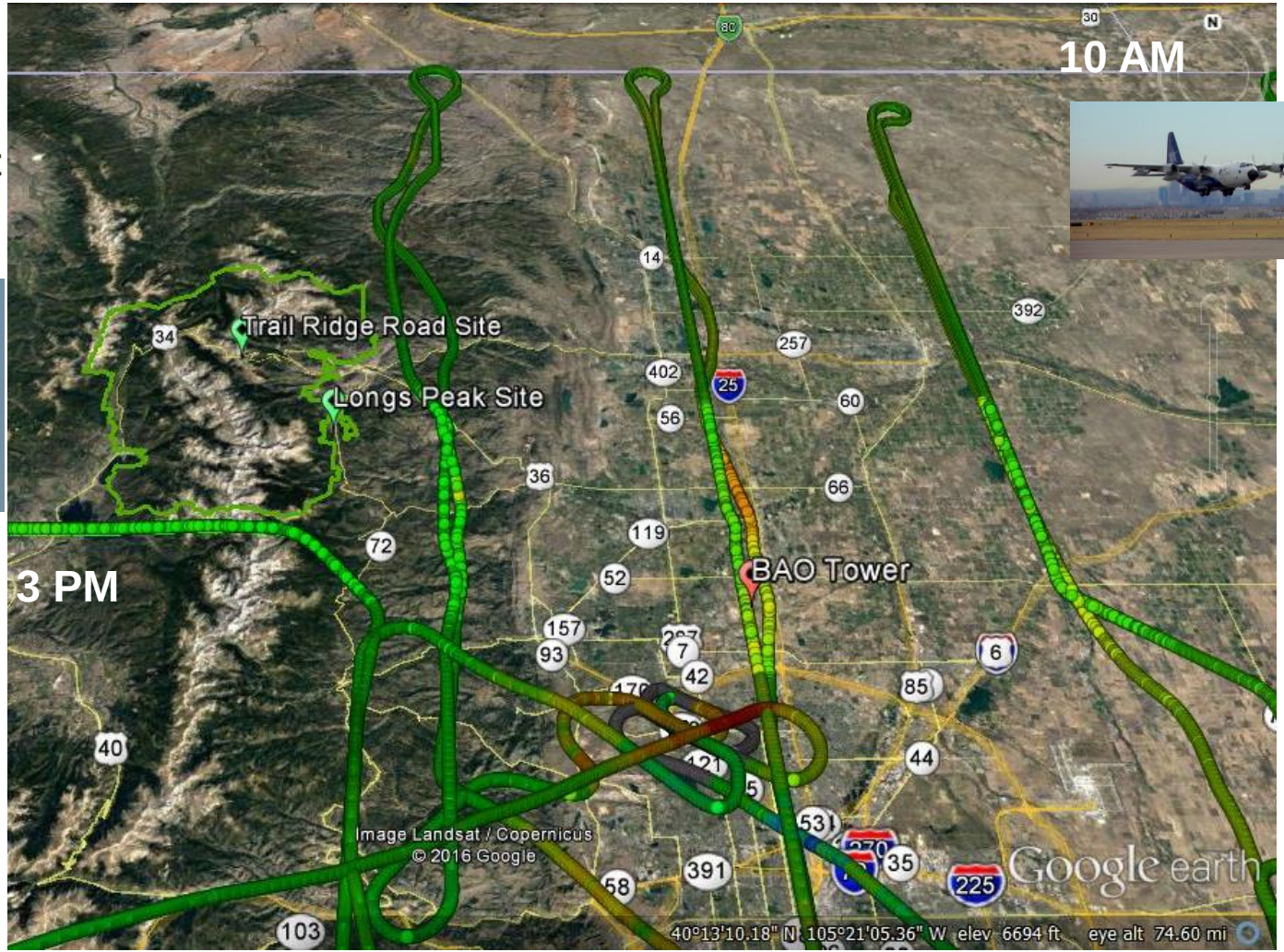
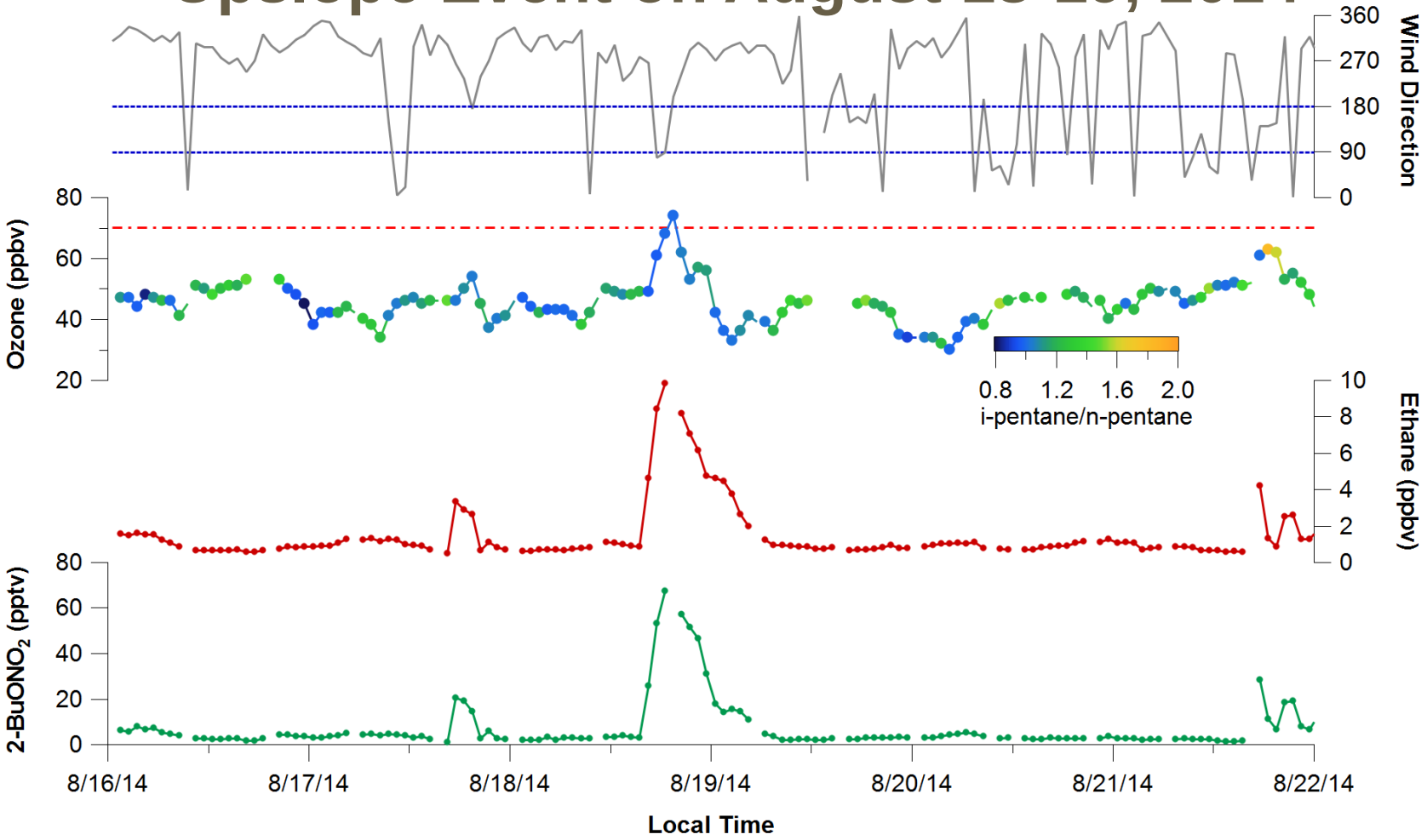


Picture: Samuel Hall (NCAR)

Upslope Event on August 18-19, 2014



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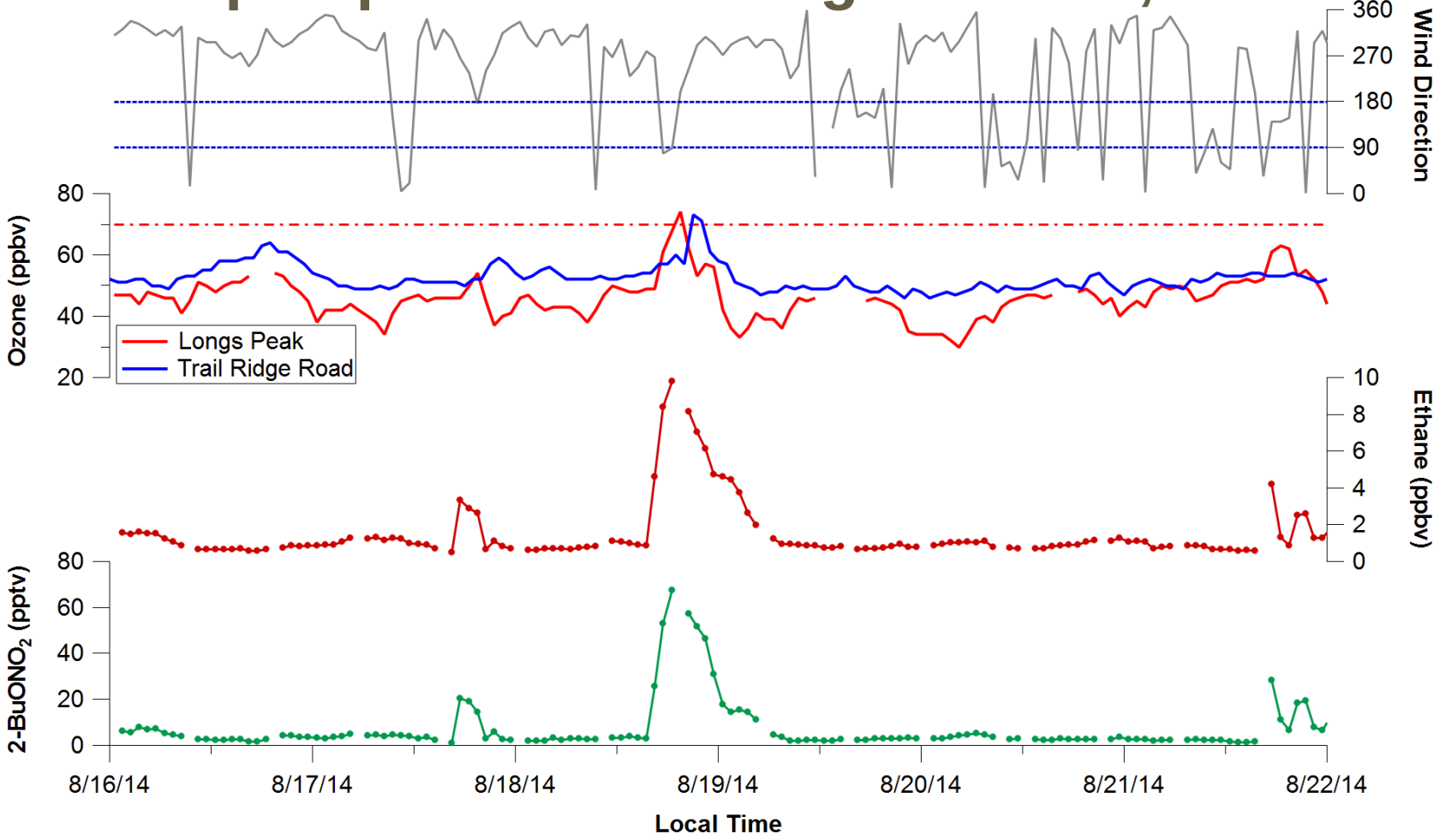
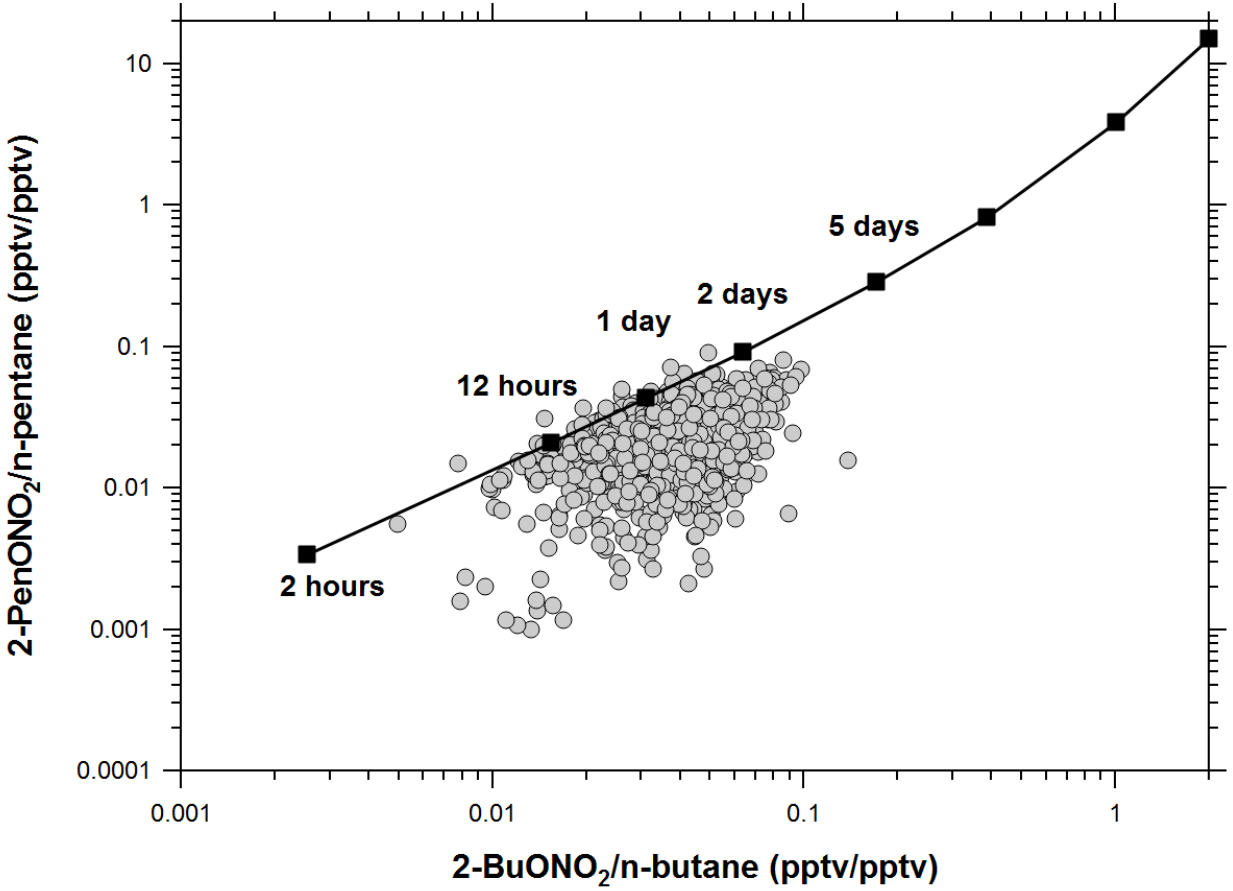


Photochemical Age using Alkyl Nitrates



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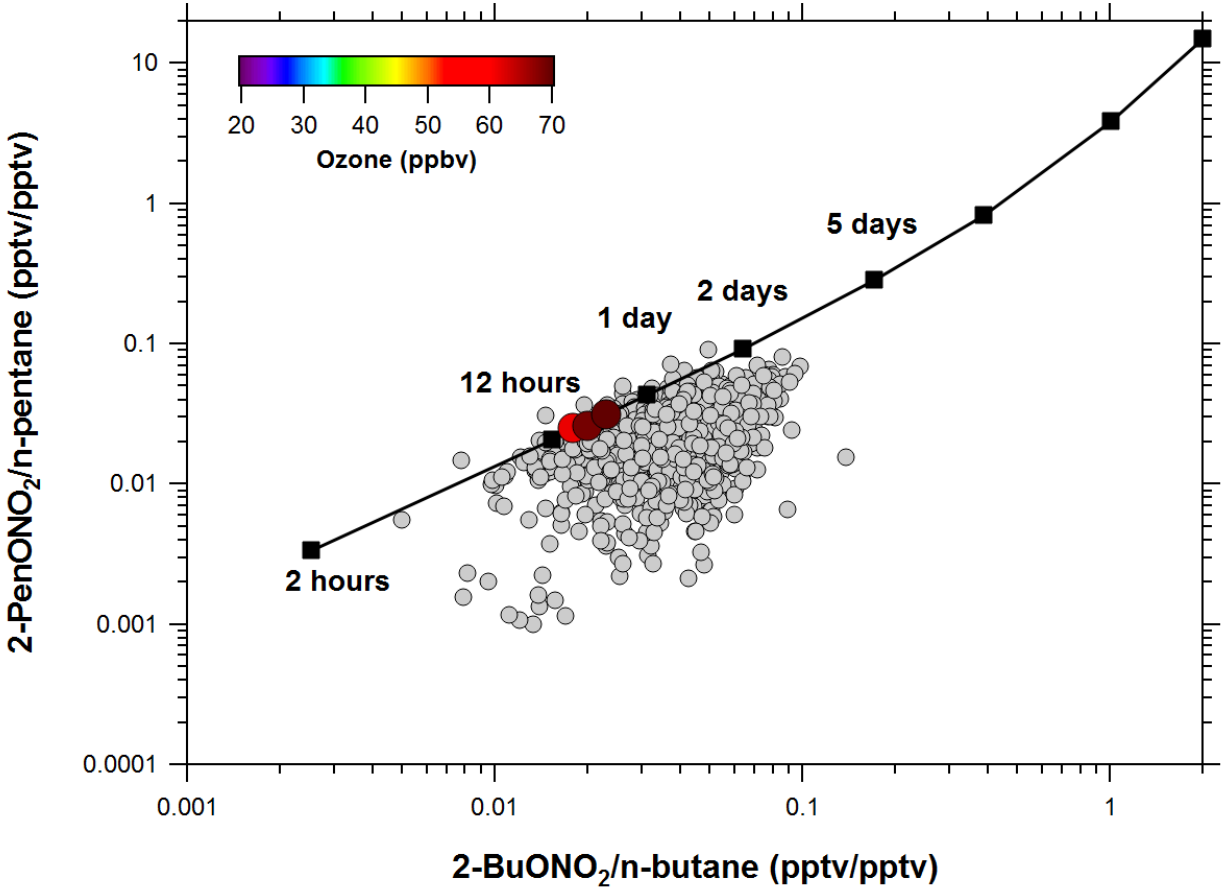
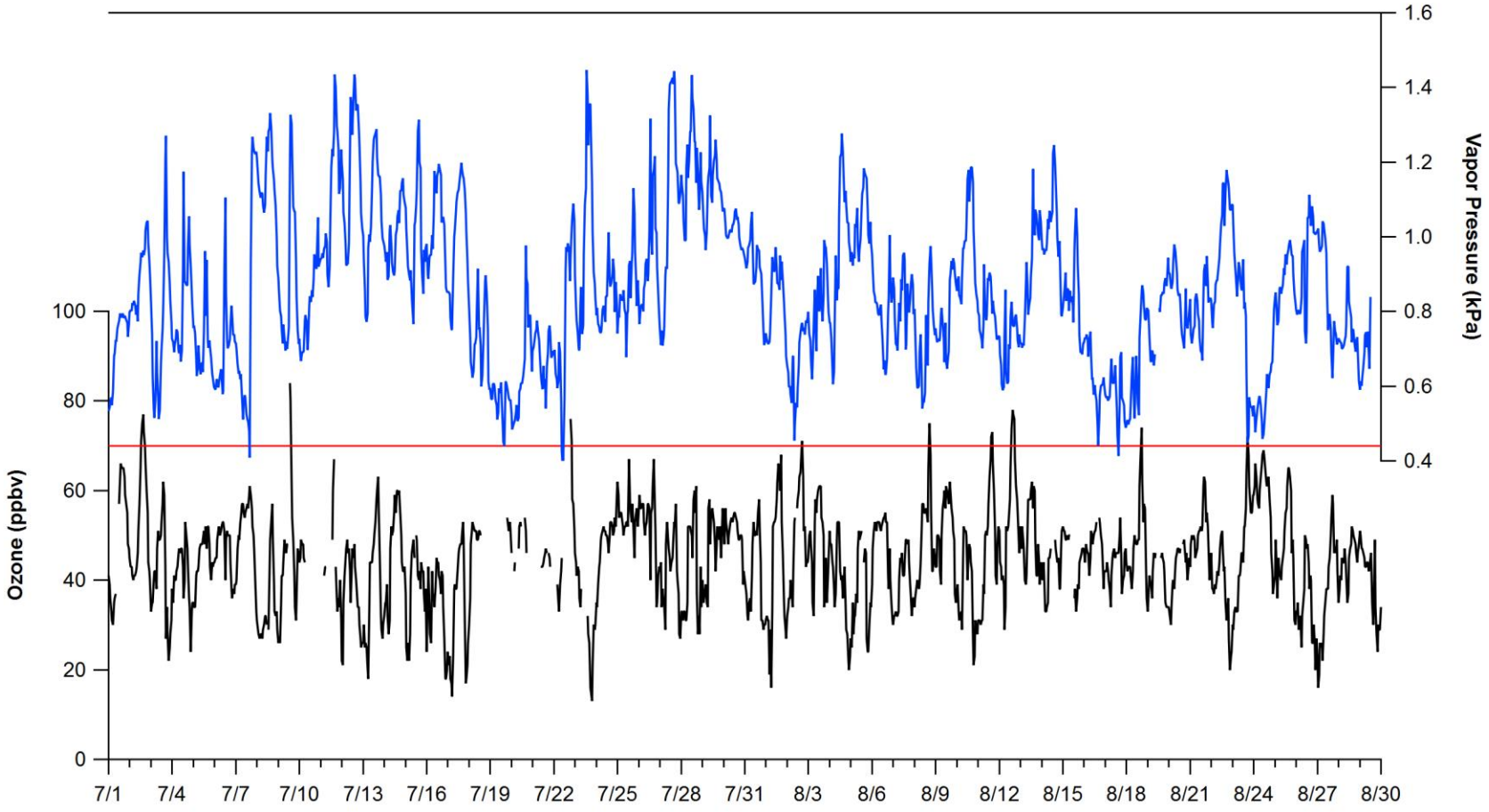
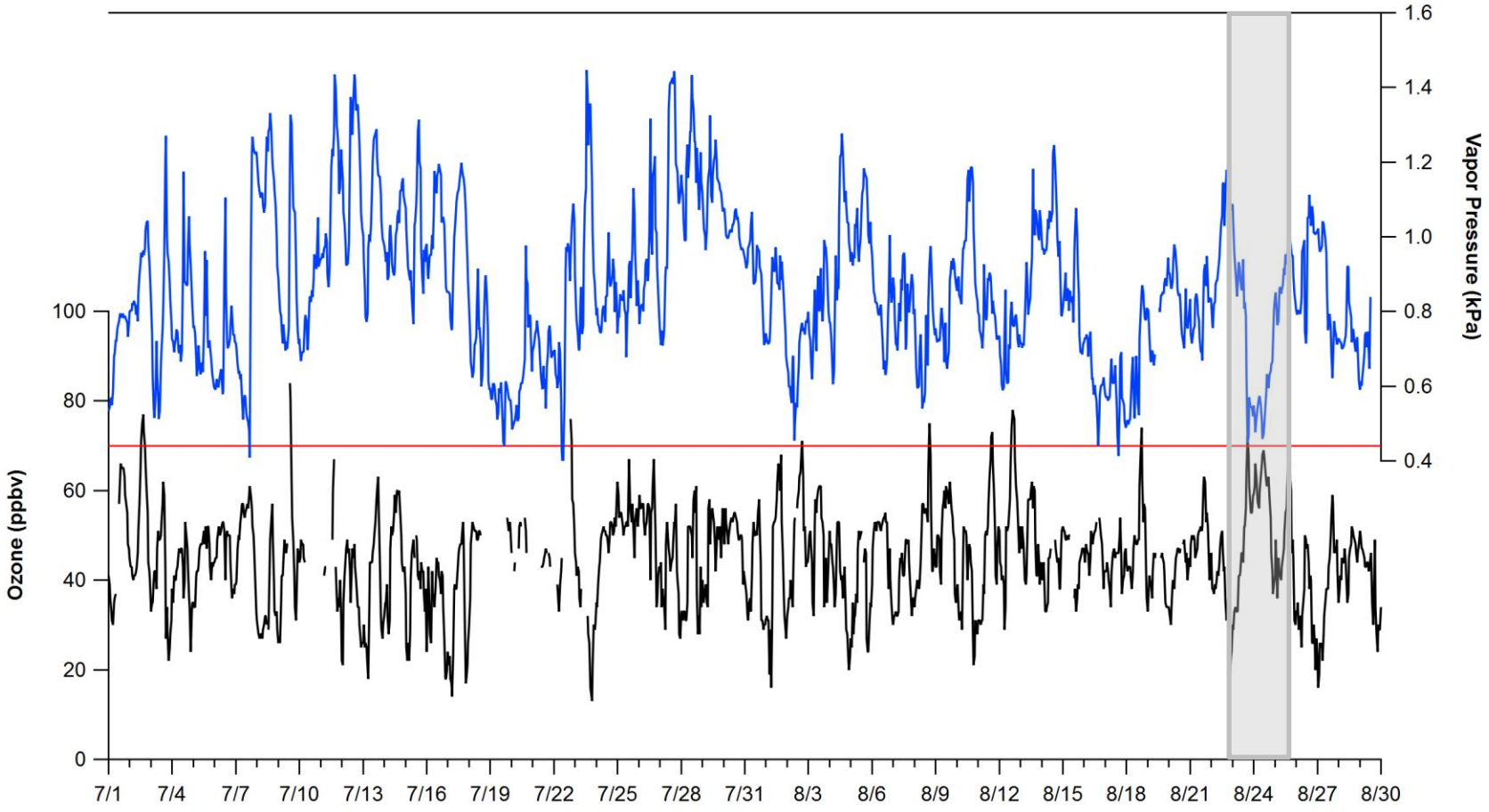


Stratospheric Intrusion Event on August 23, 2014



Stratospheric Intrusion Event on August 23, 2014



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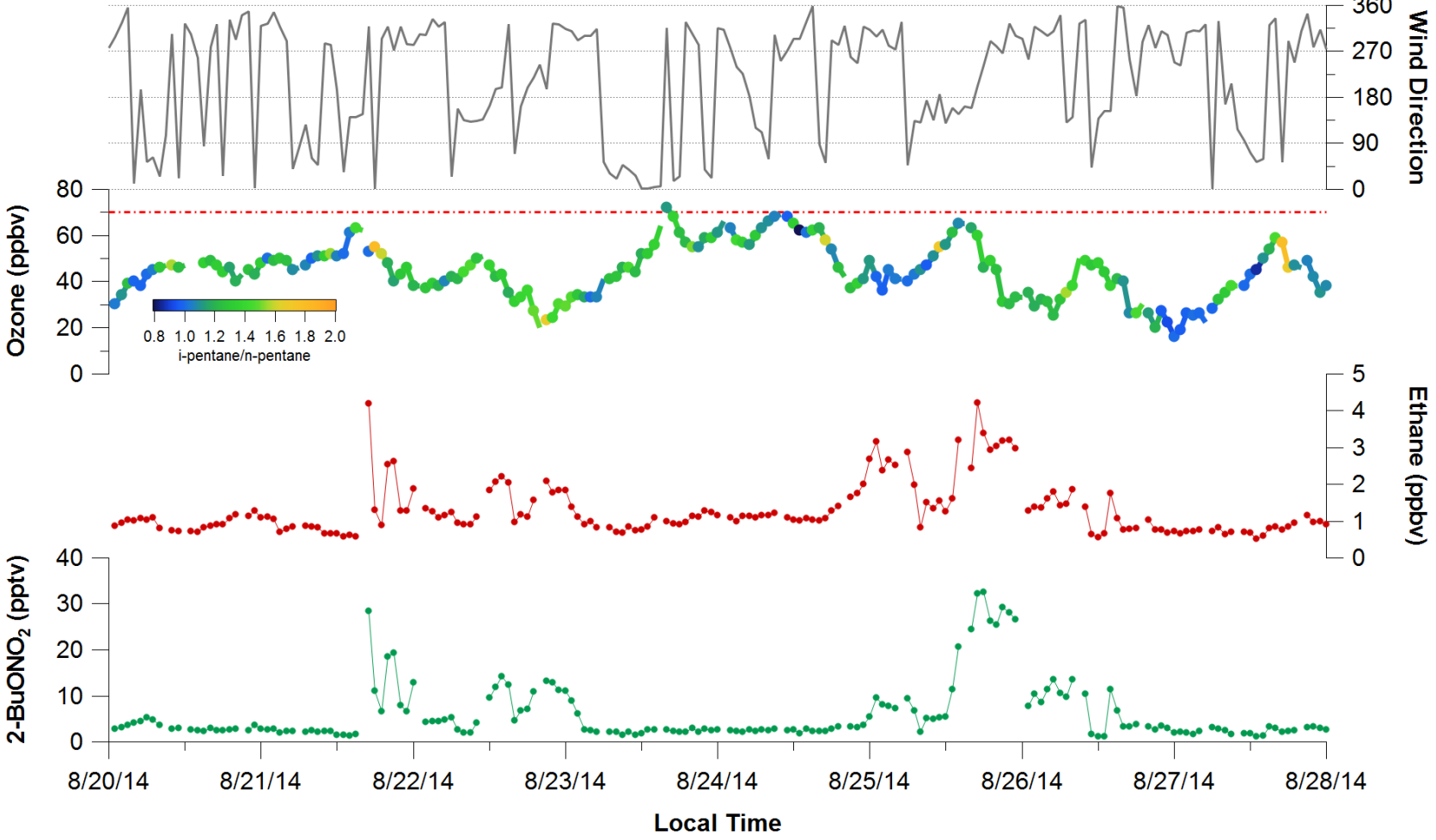

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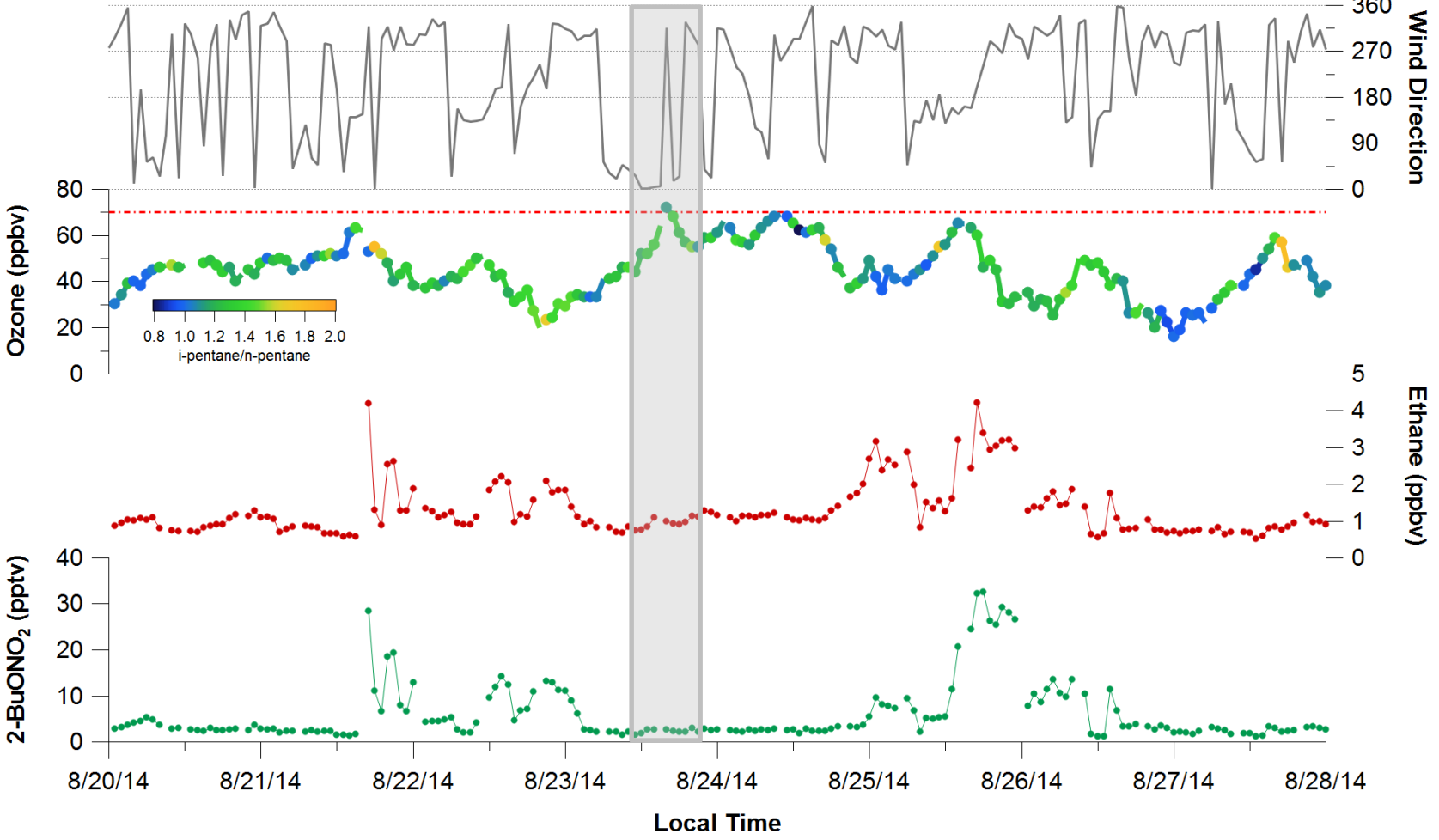

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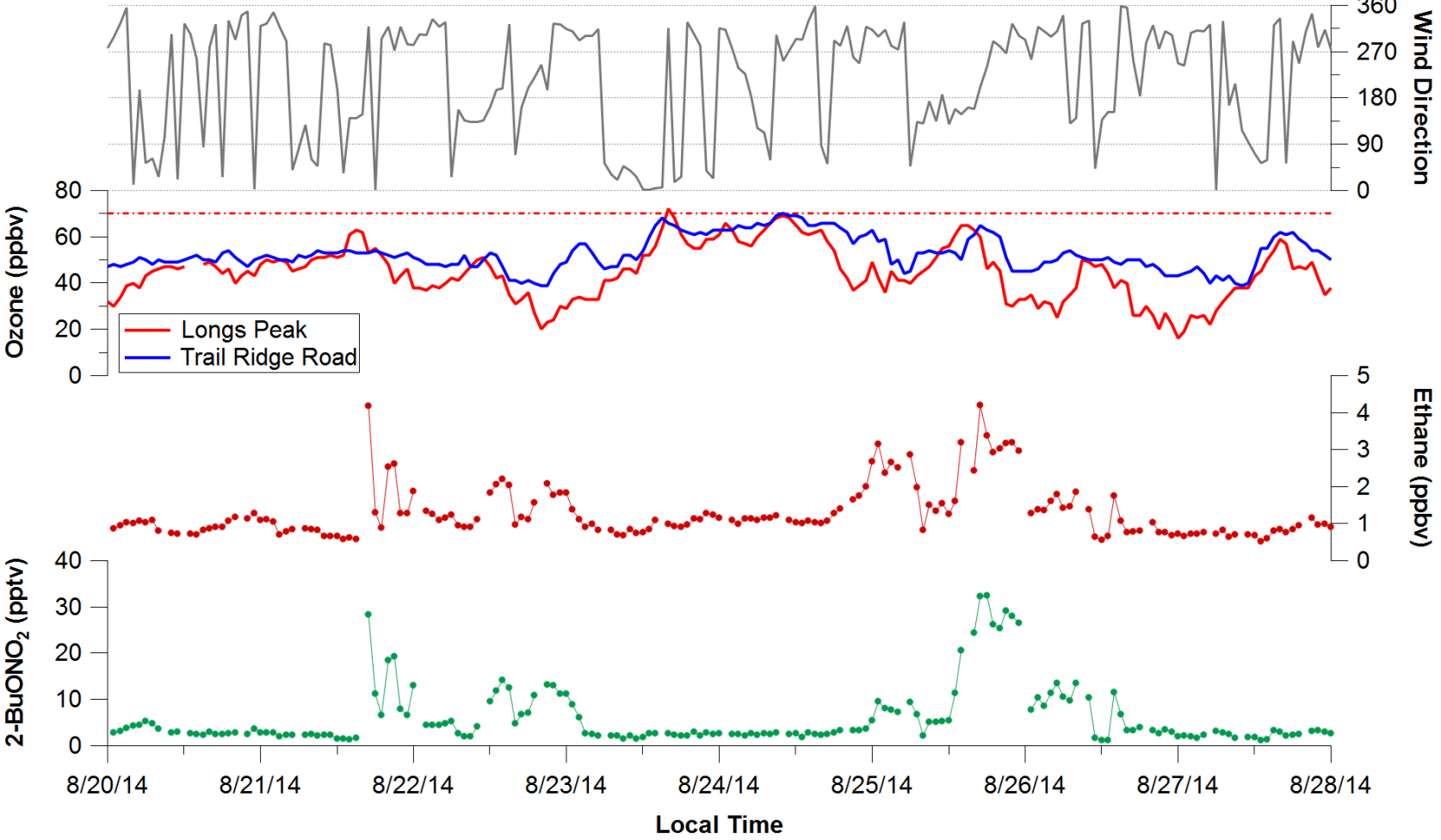
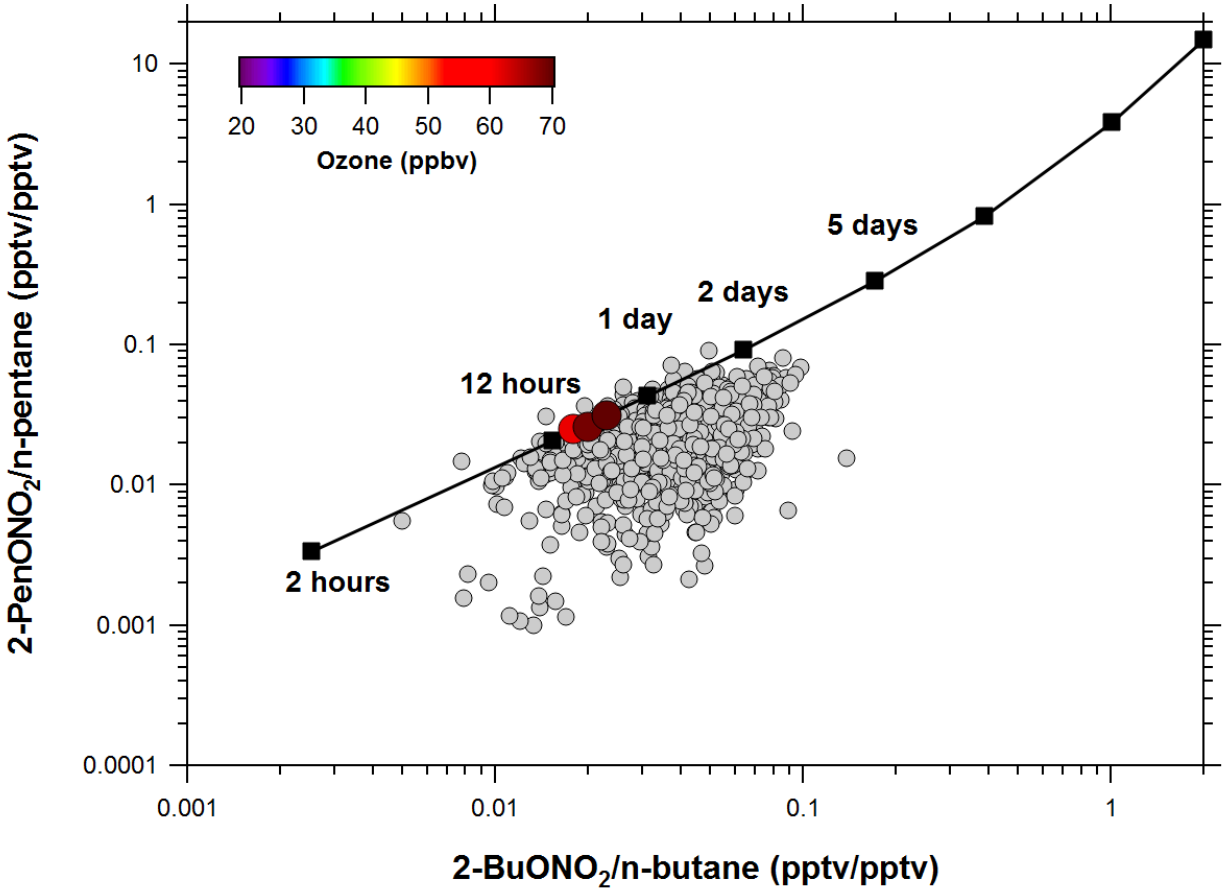


Photochemical Age using Alkyl Nitrates



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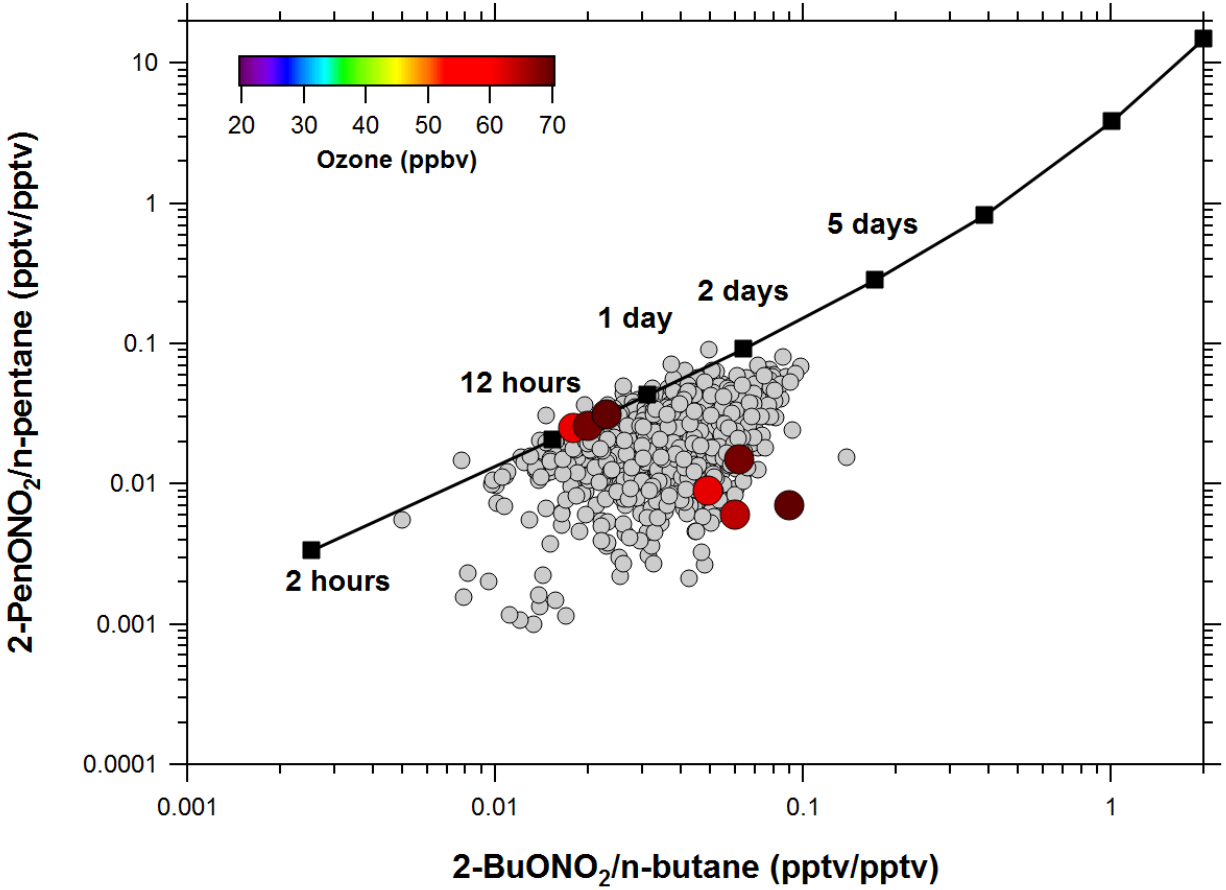
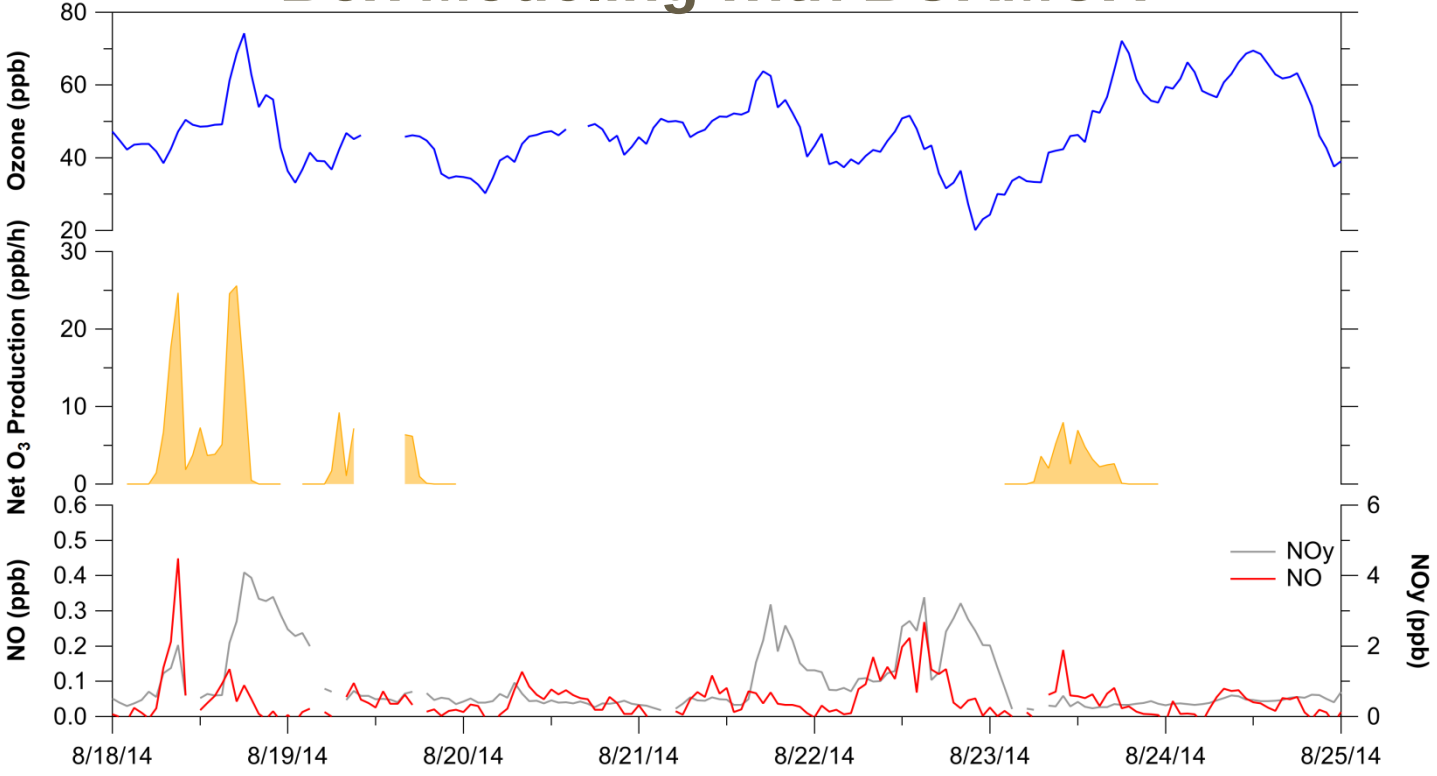
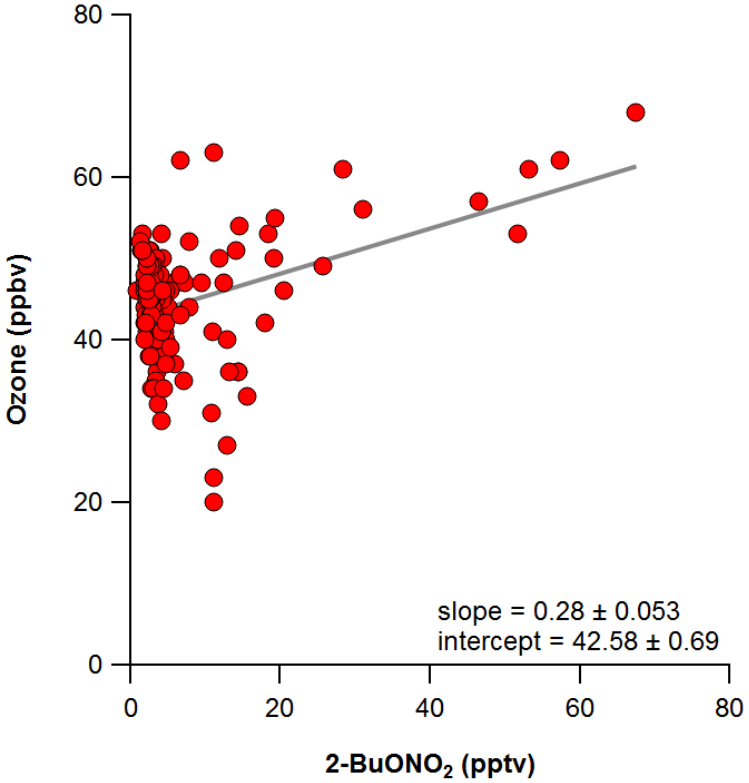


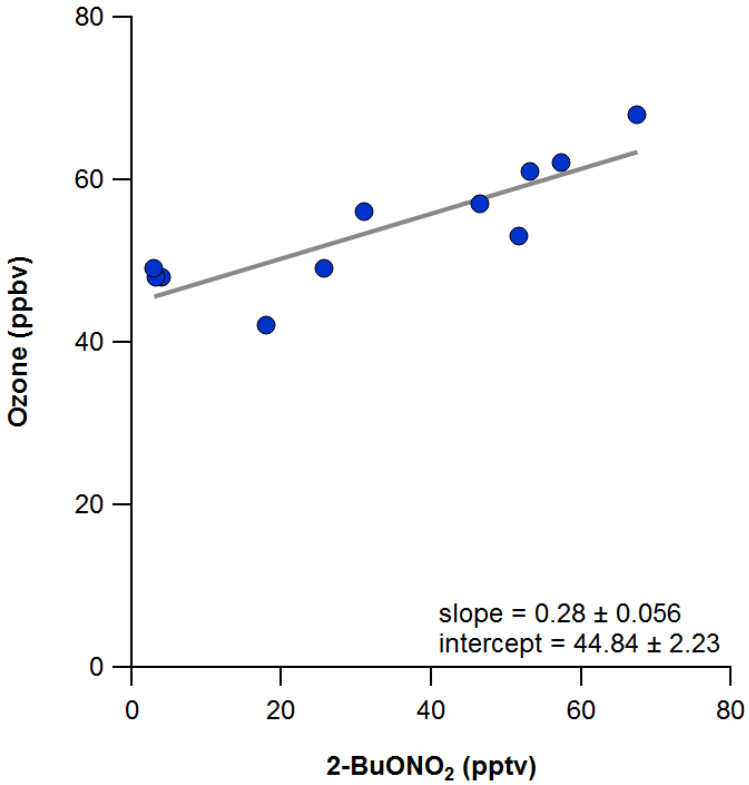
Upslope and Stratospheric Intrusion Events
Box Modeling with BOXMOX



Net ozone production rates ~25 ppb/h during upslope

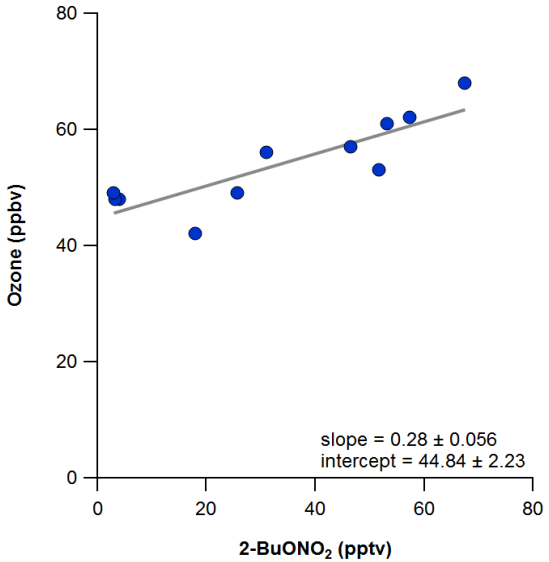
Ozone Production from O&G during an Upslope Event





Ozone Production from O&G during an Upslope Event

Compound	XS O_3 Production (ppbv)
$EtONO_2$	18.4
i-$PrONO_2$	17.9
n-$PrONO_2$	19.8
2-$BuONO_2$	18.1
3-$PenONO_2$	18.1
2-$PenONO_2$	16.5
Average	**18.2 ± 1.1**



Ozone Production from O&G during an Upslope Event

O_3/$RONO_2$ Method

XS O_3 Produced: 18.2 ppbv

Peak 1 hr O_3 = 74	XS O_3 (ppbv)	% of XS O_3	% O_3 from O&G
BGD1 O_3 = 50	24	76%	**25%**
BGD2 O_3 = 44	30	61%	

$RONO_2$ Diurnal Cycle Method

XS O_3 Produced: 14.9 ppbv

Peak 1 hr O_3 = 74	XS O_3 (ppbv)	% of XS O_3	% O_3 from O&G
BGD1 O_3 = 50	24	62%	**20%**
BGD2 O_3 = 44	30	49%	

Net ozone production rates ~25 ppb/h during upslope

~15-18 ppbv excess ozone at ROMO from O&G

Summary

- ROMO is a Class I area and afforded the highest level of air quality protection under the law. Parks should be the cleanest areas in the U.S. (CAA and NPS Organic Act).
- Trail Ridge Road and Longs Peak sites tracked well; highest O_3 levels at high elevation.
- Mixed signature of urban and oil and gas emissions observed at Longs Peak site.
- NMHC distributions similar to summertime measurements in SW PA; mixed urban and oil and gas operations.
- Elevated ozone and VOCs during upslope events, transport from the E and SE.
- Highest levels of alkanes associated with oil and gas operations based on i-pentane/n-pentane ratio (i-butane/n-butane).
- Net ozone production rates of ~25 ppb/h during the Aug 18-19 upslope event.
- Upwards of ~18 ppbv excess ozone at ROMO during this event.

Is there a measureable impact from O&G production operations?

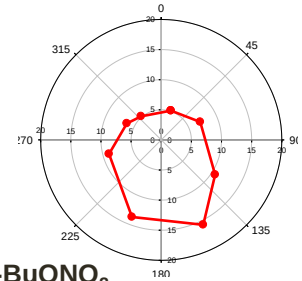
Because O&G emissions are often coupled with urban emissions, this results in a significant ozone production potential for ROMO during upslope events (~20-35%).

EXTRAS

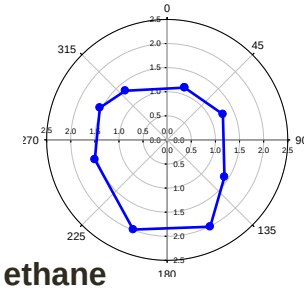
Future O&G Developments to the West of ROMO?

- Studies have demonstrated that oil and gas emissions are a significant contributor to pollutant loading (& ozone formation) during upslope events.

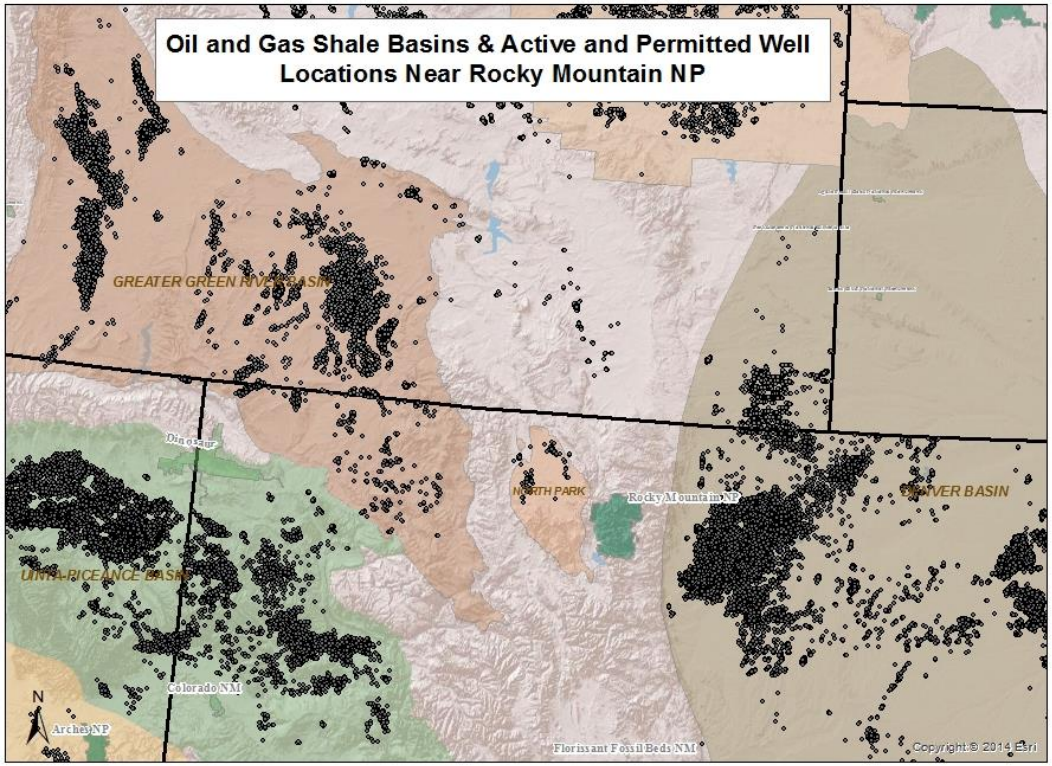
- Currently, air masses coming from the west/northwest are relatively “clean” in comparison. If the western side of the park is also allowed to degrade, this will only exacerbate an ongoing problem.



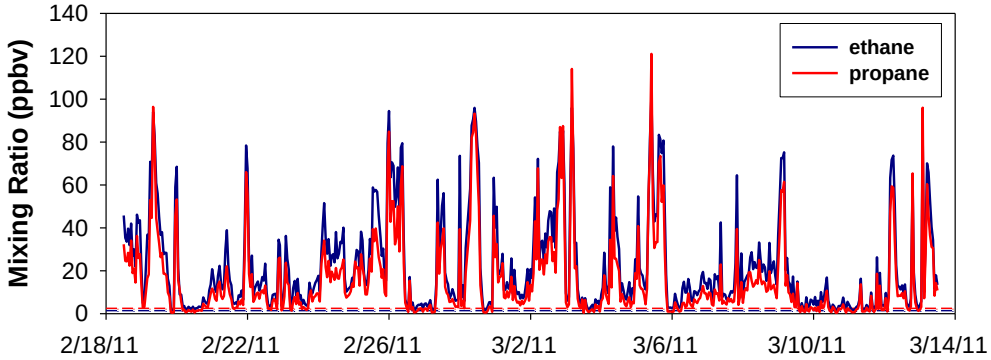
2-BuONO$_2$



ethane



Perspective on Potential Impacts



Data from BAO Tower in Weld Co.
- Winter 2011

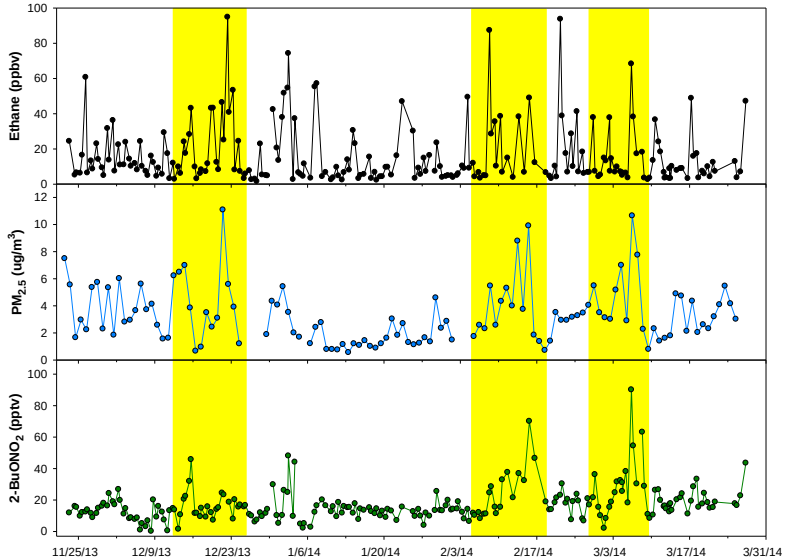
Extremely high levels VOCs
- Ozone precursors
- Local and downwind impacts

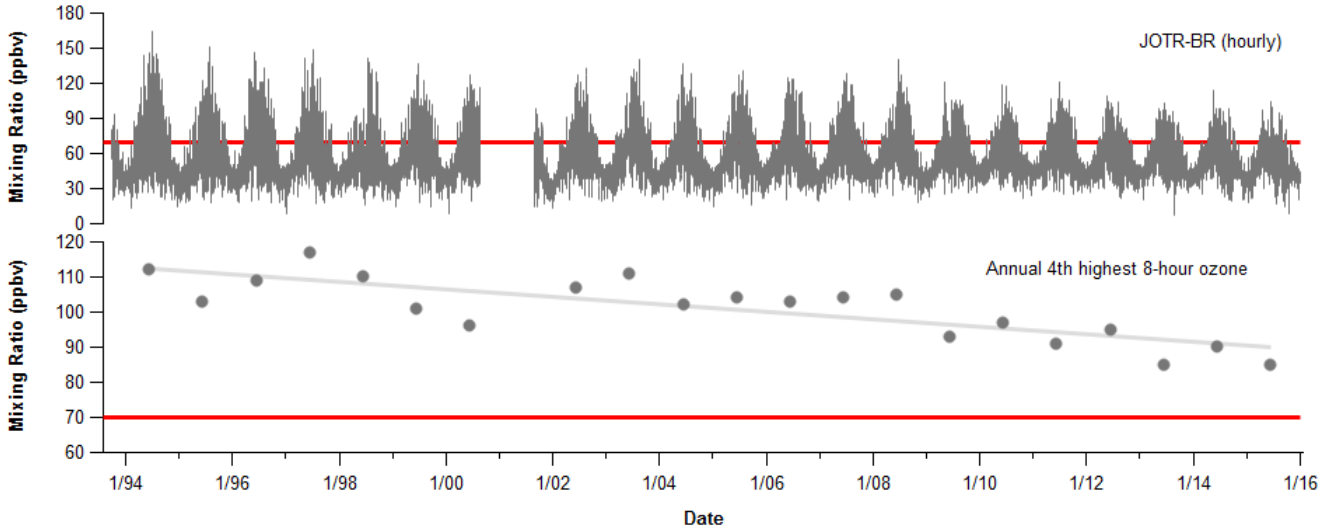
Data from THRO in ND
- Fall 2013 - Winter 2014

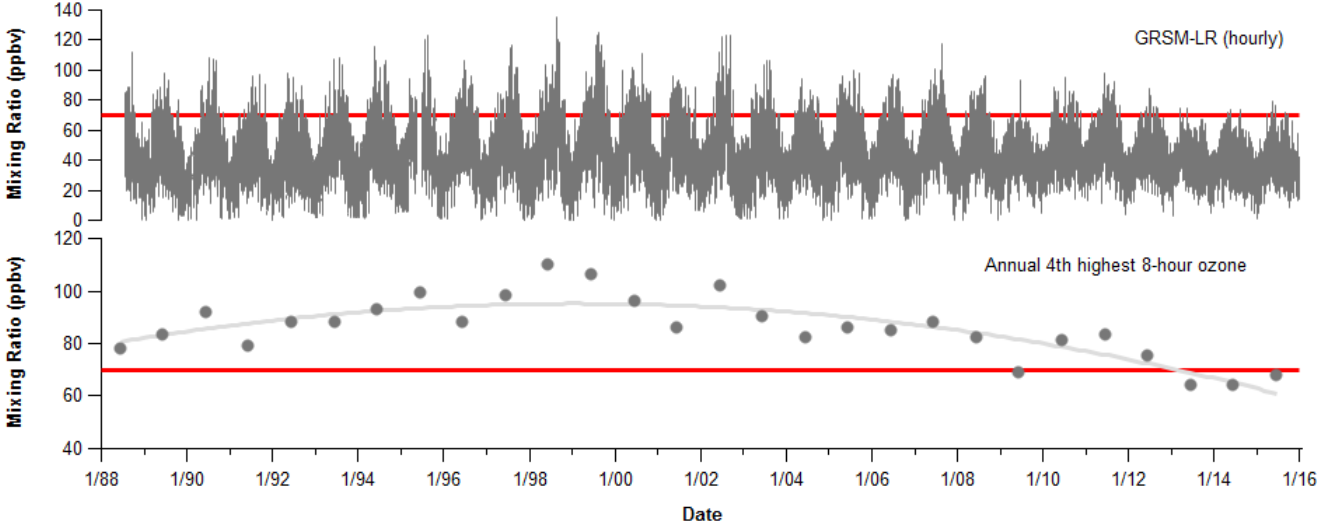
Extremely high levels VOCs
- Secondary chemistry marker (2-BuONO$_2$)

Haze events from O&G emissions ($PM_{2.5}$)
- "Photochemical Clock" for verification
- Local and fresh emissions from O&G

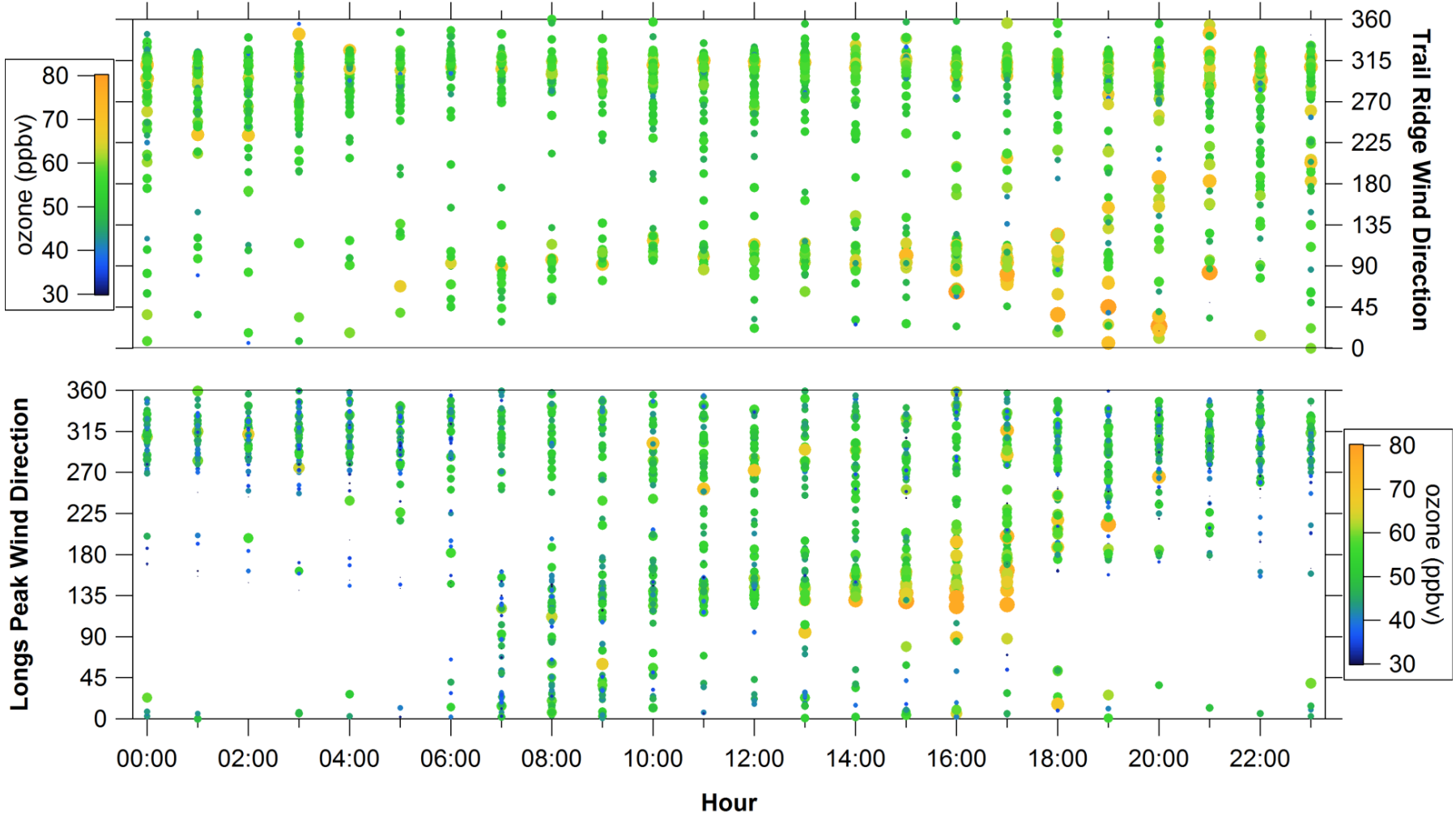
Potential to behave like Uintah and Upper Green River Basins – Wintertime ozone



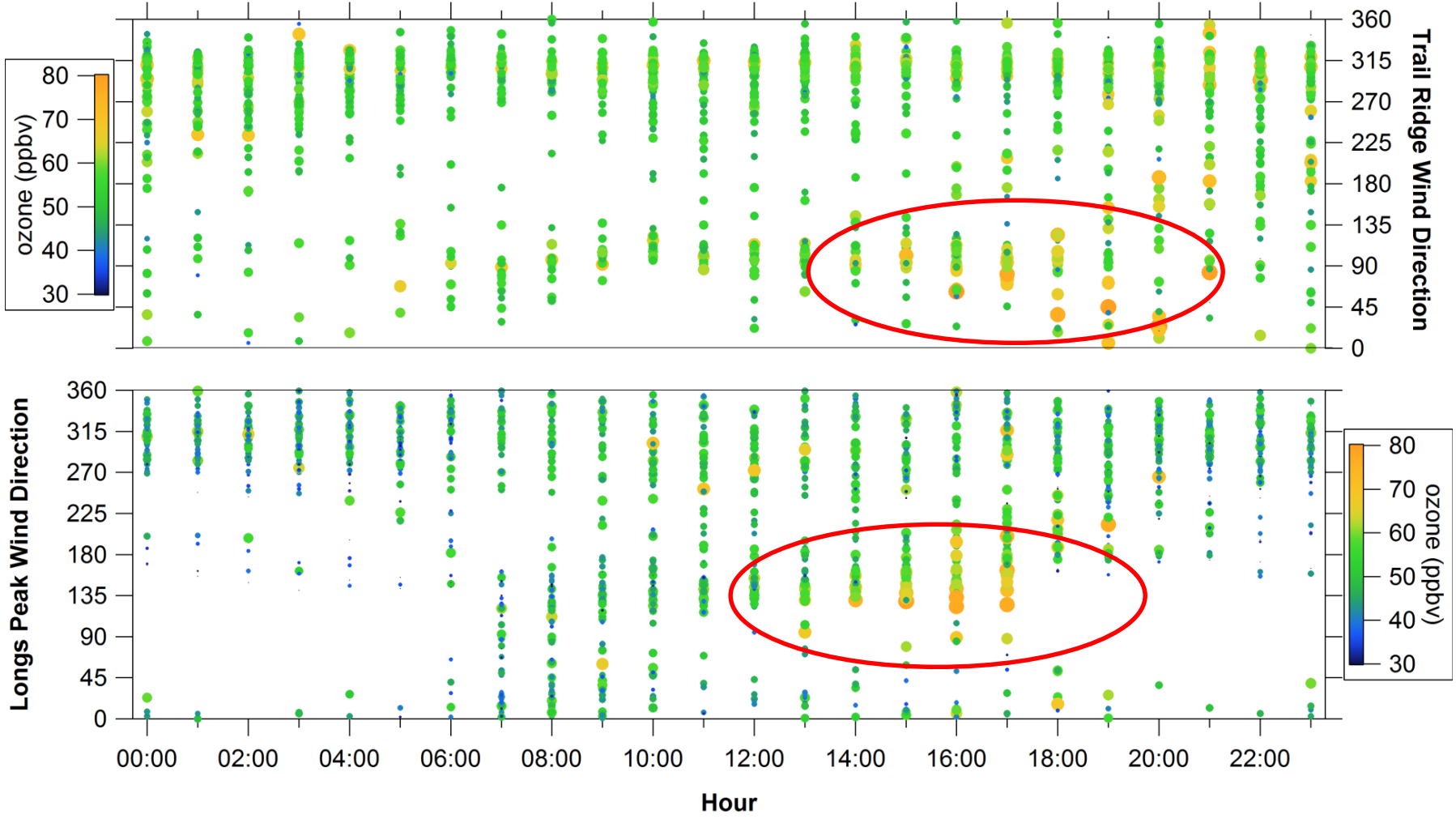

JOTR-BR (hourly)
Mixing Ratio (ppbv)
180
150
120
90
60
30
0
Annual 4th highest 8-hour ozone
Mixing Ratio (ppbv)
120
110
100
90
80
70
60
1/94
1/96
1/98
1/00
1/02
1/04
1/06
1/08
1/10
1/12
1/14
1/16
Date


GRSM-LR (hourly)
Mixing Ratio (ppbv)
140
120
100
80
60
40
20
0
Annual 4th highest 8-hour ozone
Mixing Ratio (ppbv)
120
100
80
60
40
1/88
1/90
1/92
1/94
1/96
1/98
1/00
1/02
1/04
1/06
1/08
1/10
1/12
1/14
1/16
Date

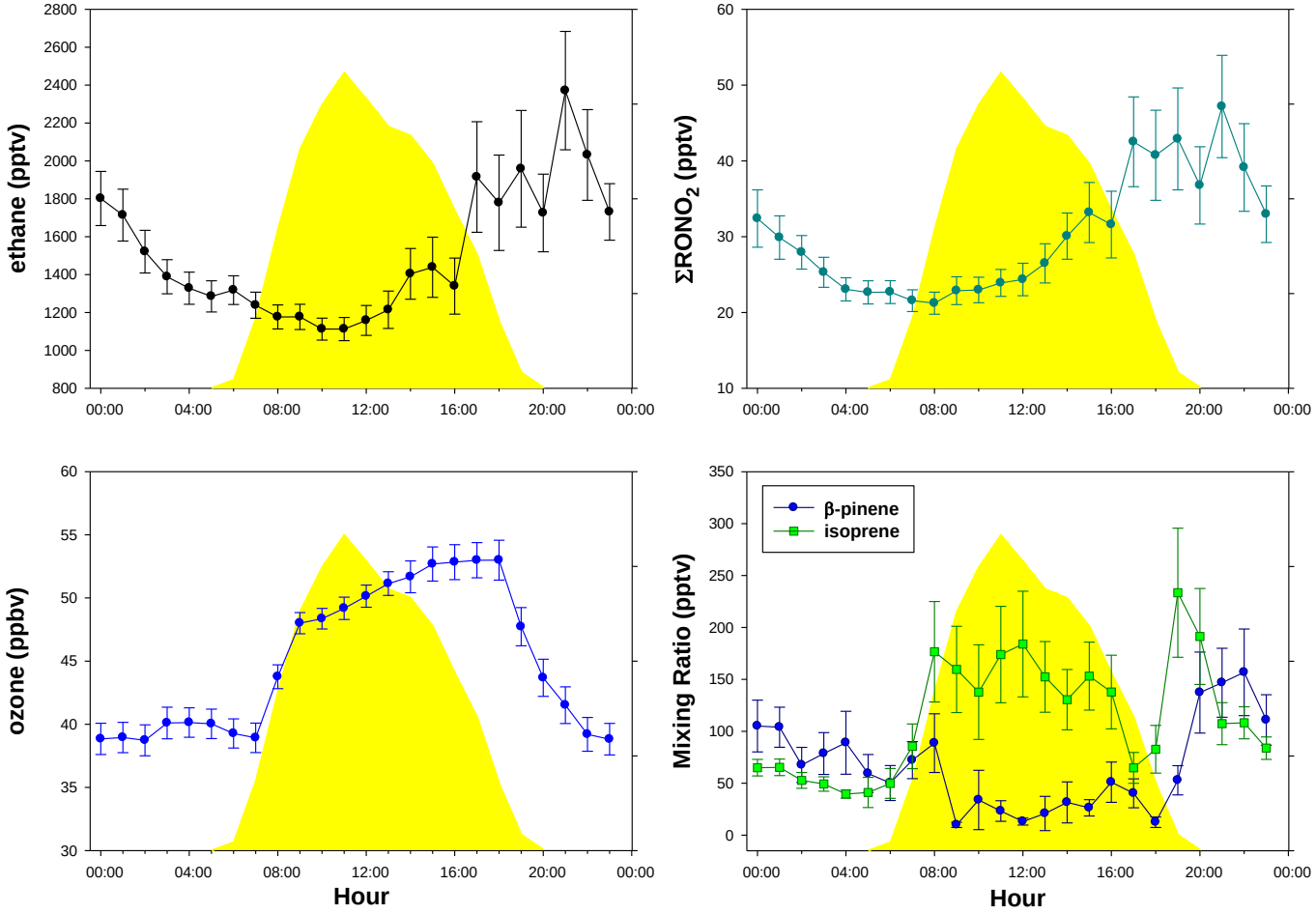
Ozone and Wind Direction – Timing of Events at ROMO



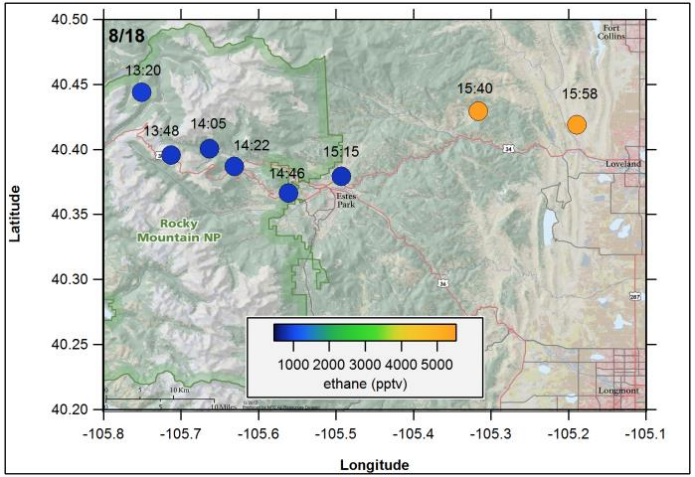
Ozone and Wind Direction – Timing of Events at ROMO

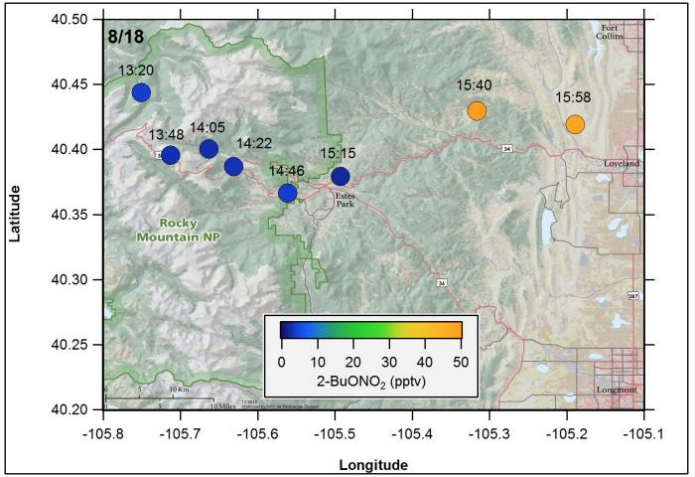


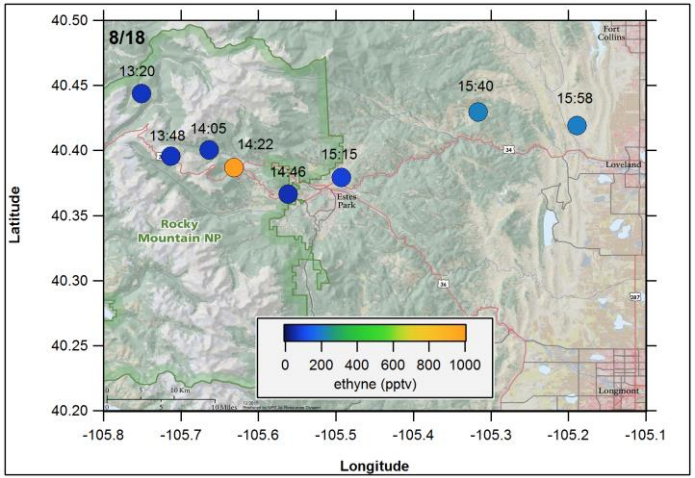
Diurnal Profiles from ROMO

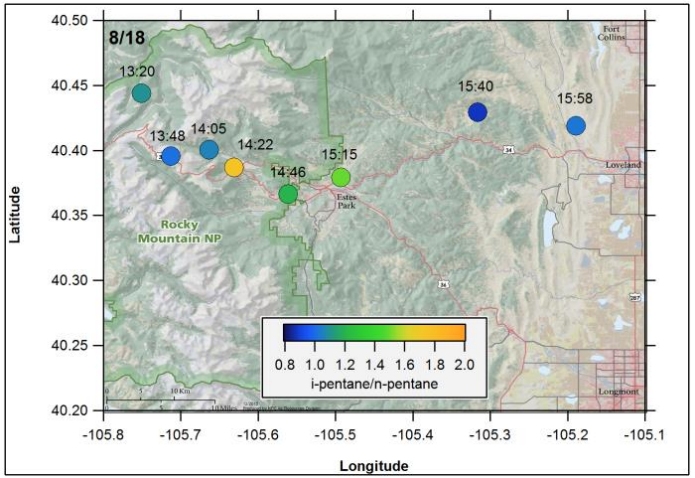


Transect Samples on August 18, 2014









RF15

8/18/2014

Upslope Event

3 PM

10 AM

ACTIVE OIL AND GAS WELLS in METRO AREA OCT 2014

Ft. Collins

Greeley

Boulder

DIA

Denver

Highlands Ranch

iC_5/C_5

2.0 — Urban/ Vehicular

1.8

1.6

1.4

1.2

1.0 — Oil and Gas

0.8

Points sized by n-pentane

Map Data from The Colorado Oil and Gas Conservation Commission (COGCC) WELLS shapefile.
Well status mapped include: AC-Active,DG-Drilling, DM-Domestic Well, IJ-Injecting, PR-Producing, WO-Waiting on Completion, XX- Permitted Location, UN - Unknown