What drives high wintertime ozone in the oil and natural gas fields of the western U.S.?

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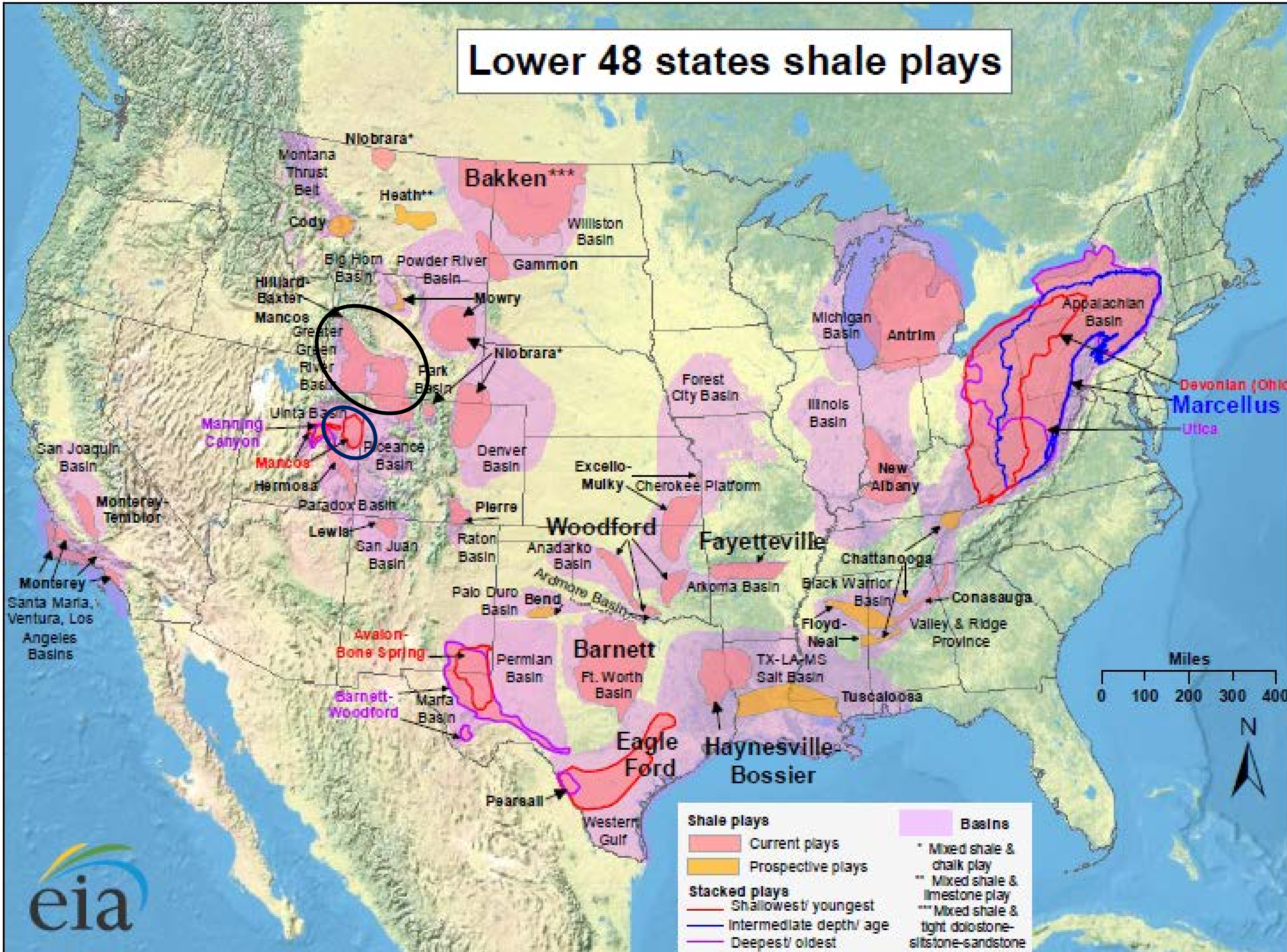


Source: Energy Information Administration based on data from various published studies.
Updated: May 9, 2011

www.eia.gov

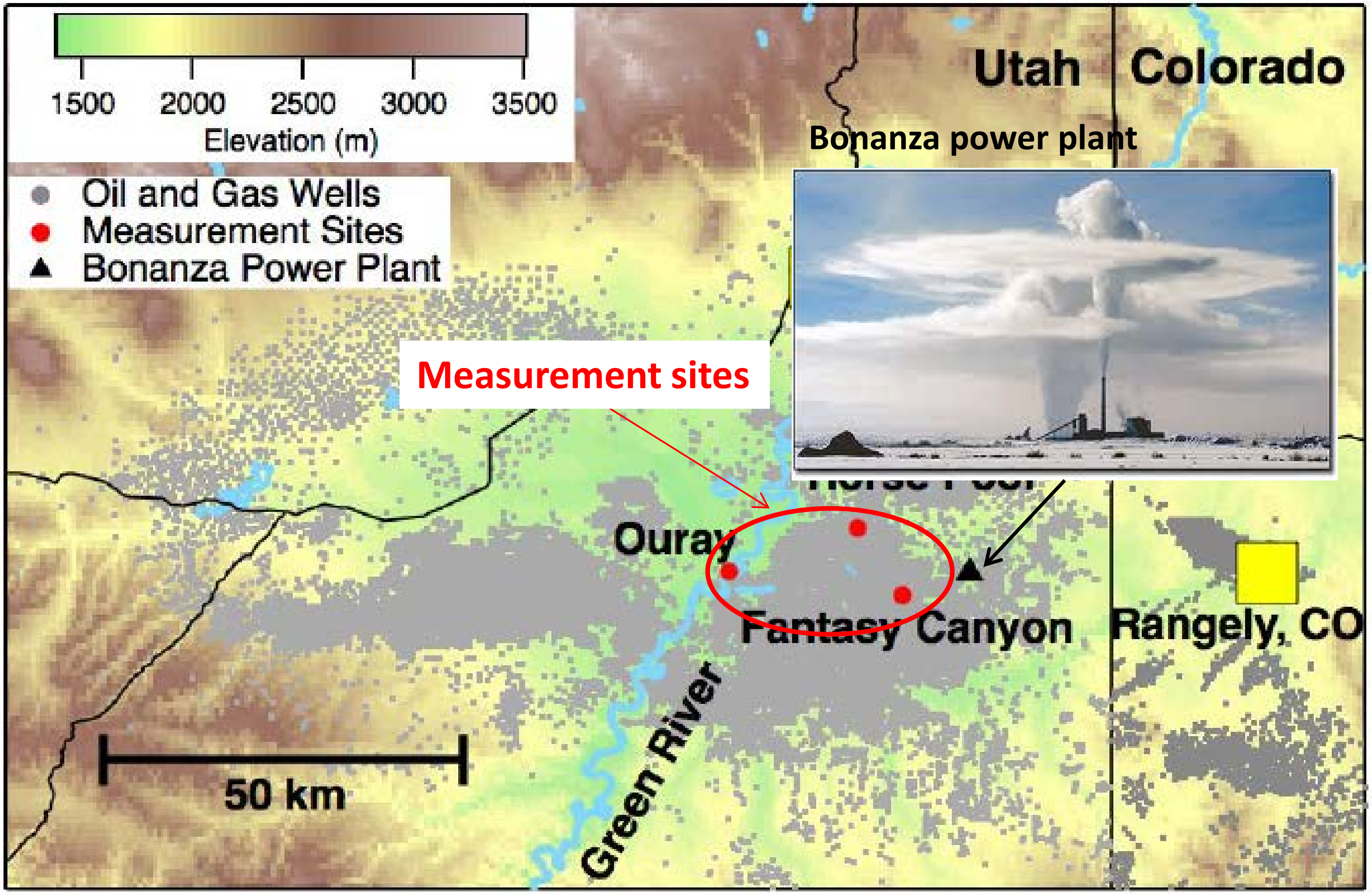
Background

- During some winters over rural areas with high oil and natural gas production in Wyoming and Utah high O_3 episodes were observed (*Schnell et al., 2009; Oltmans et al., 2014).*

- *Carter and Seinfeld (2012)* and *Edwards et al. (2014)* used detailed chemical mechanisms in box models to study high wintertime O_3 production observed in Wyoming and Utah, respectively. The authors stressed the need for full 3D air quality models to address the high wintertime O_3 episodes.

- NOAA/ESRL and other groups conducted two intensive field campaigns - Uinta Basin Winter Ozone Study (UBWOS) in January-February, 2012 (warmer, little or no snow conditions) and 2013 (colder and snowy) to study meteorology, oil/gas emissions and atmospheric chemistry in the Uinta Basin. In 2013 the highest O_3 concentration in the U.S. was observed in the Uinta Basin during winter!

Topography of the Uinta Basin, Utah



The region is sparsely populated (~50,000 people). The urban VOC and NO_x emissions are not high.

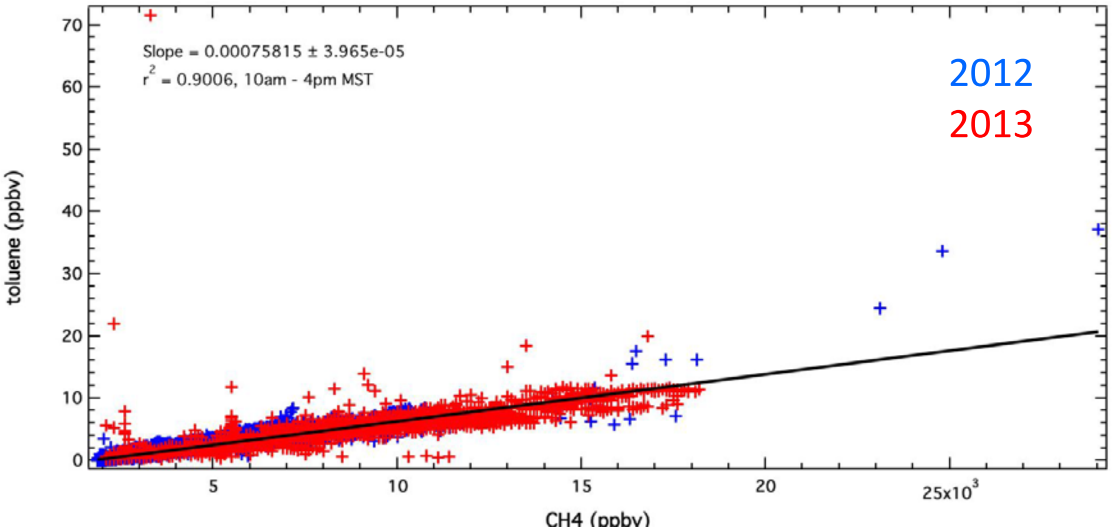
Objectives of our modeling study

- Model the wintertime meteorological conditions in 2012 and 2013 over the Uinta Basin (UB), Utah; Focus on cold pool type stagnations during 2013;
- Estimate emissions of NO_x and VOCs for the oil/gas sector in the UB using the atmospheric measurements from the UBWOS field campaigns;
- Conduct air quality simulations using both bottom-up (EPA NEI-2011) and top-down emission scenarios;
- Investigate the major driving factors of high the wintertime ozone in the UB;

A high resolution meteorology-chemistry modeling using WRF-Chem (with RACM gas chemistry) was conducted for January – February, 2012 and 2013.

The dry deposition and photolysis schemes in WRF-Chem were modified to take into account effect of snow cover.

Examples of CH_4 regressions, VOC/NO_y measurements at the Horse Pool site – The basis of the Top-Down inventory

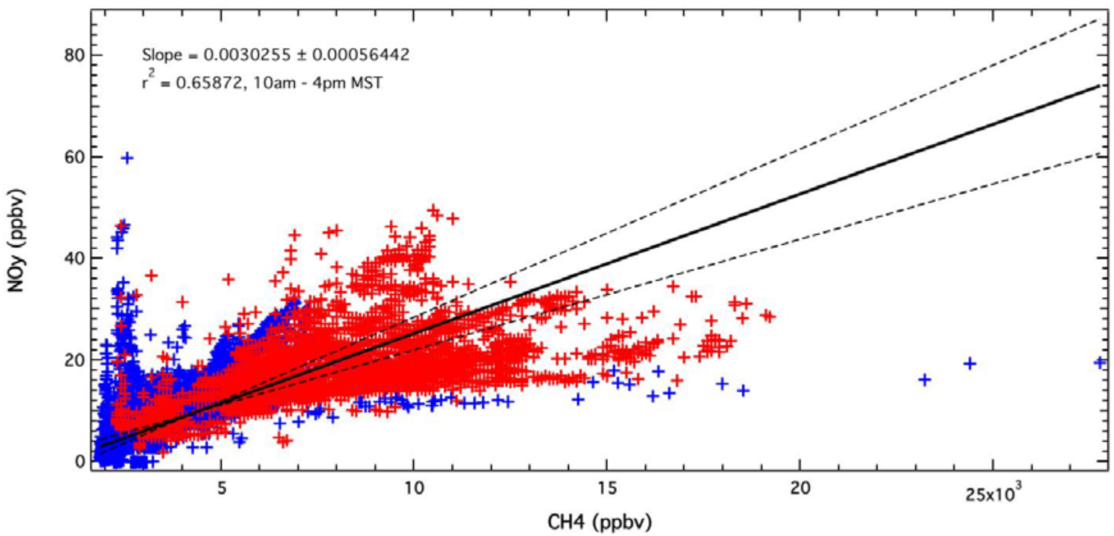


Daytime CH_4 regressions for:

- **49** Primary VOCs (GC and PTRMS)
- 10 Oxygenated VOCs
- NOy

Primary VOC regressions are:

- Very robust ($0.85 < r^2 < 0.98$)
- The same for 2012 and 2013



NO_y – CH_4 regression:

- Combine 2012/2013 data
- $r^2 = 0.66$
- Slope used as "Best Guess" in the top-down inventory

Anthropogenic emission scenarios used in the WRF-Chem model: Emission totals for the oil and gas sector in the Uinta Basin

Emission inventories	Inventory source	CH_4 (tons/year)	VOC (tons/year)	NO_x (tons/year)
Bottom-up	EPA NEI-2011	110,539	111,536	18,131
Top-down	Regression analysis	531,457	203,389	4,583

Total CH_4 flux estimate is from *Karion et al., 2013*

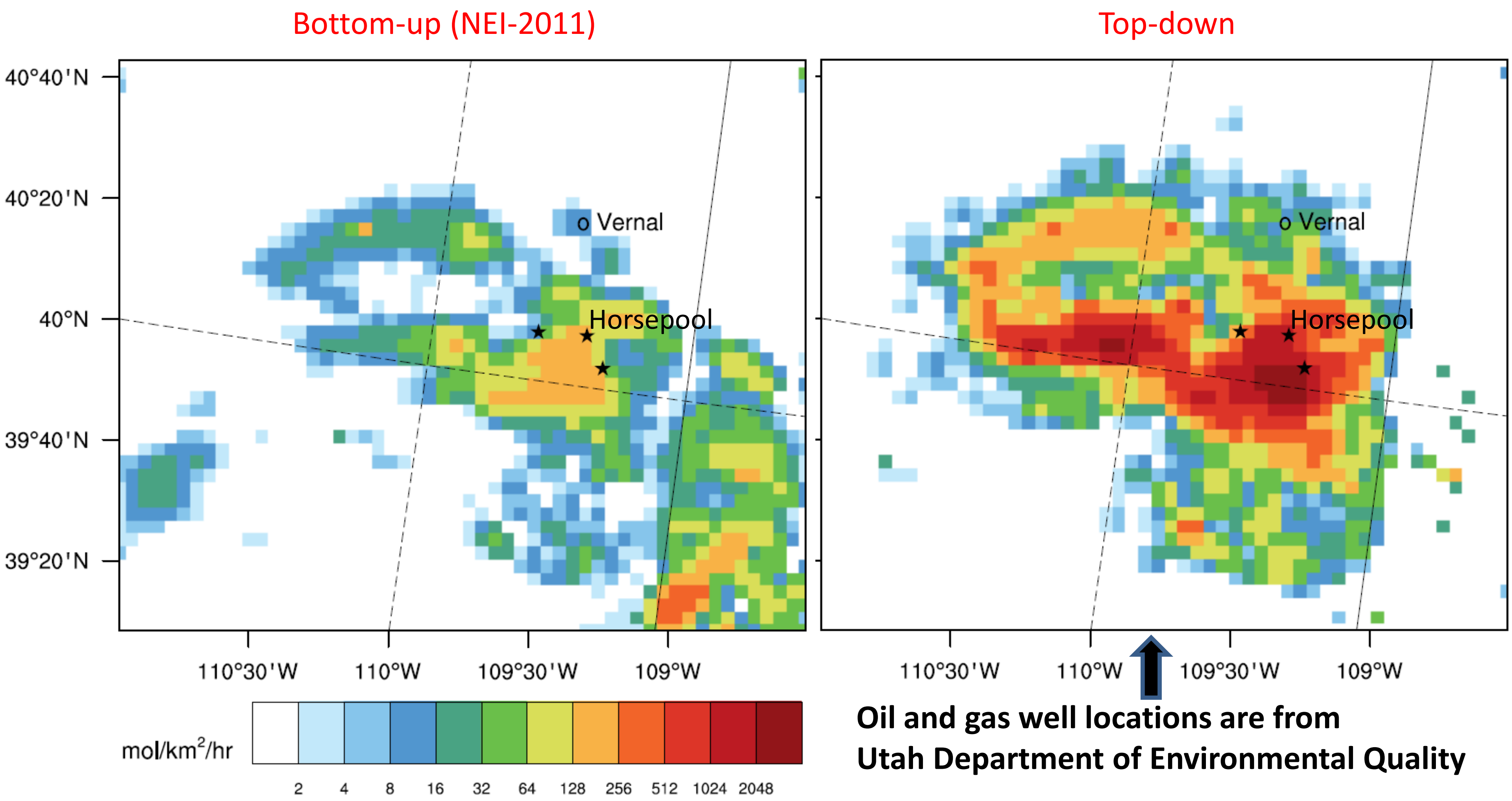
Top-down: Using NO_y/CH_4 and VOC/CH_4 ratios from surface observations during winters of 2012 and 2013

Total CH_4 and VOC emissions in NEI-2011 are lower by a factor of 4.8 and 1.8 than in the top-down estimates respectively!

Conversely, NO_x emissions are 4.0 times higher in the NEI-2011 inventory!

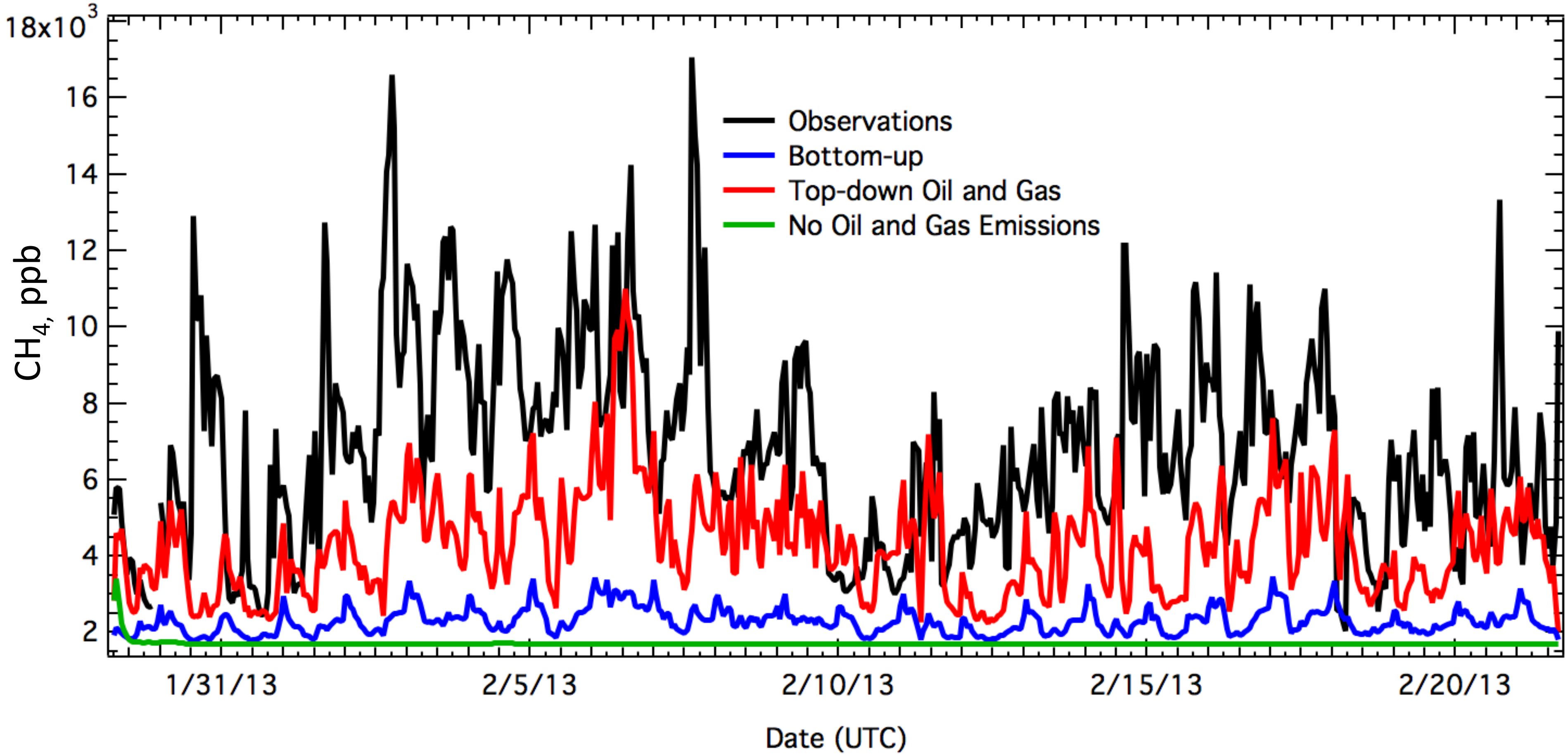
Ahmadov et al. (2014), ACPD

Anthropogenic methane emissions in the 4km resolution grid over the Uinta Basin (two inventories)



Oil and gas well locations are from Utah Department of Environmental Quality

Observed and modeled methane time series at the Horse Pool site in 2013

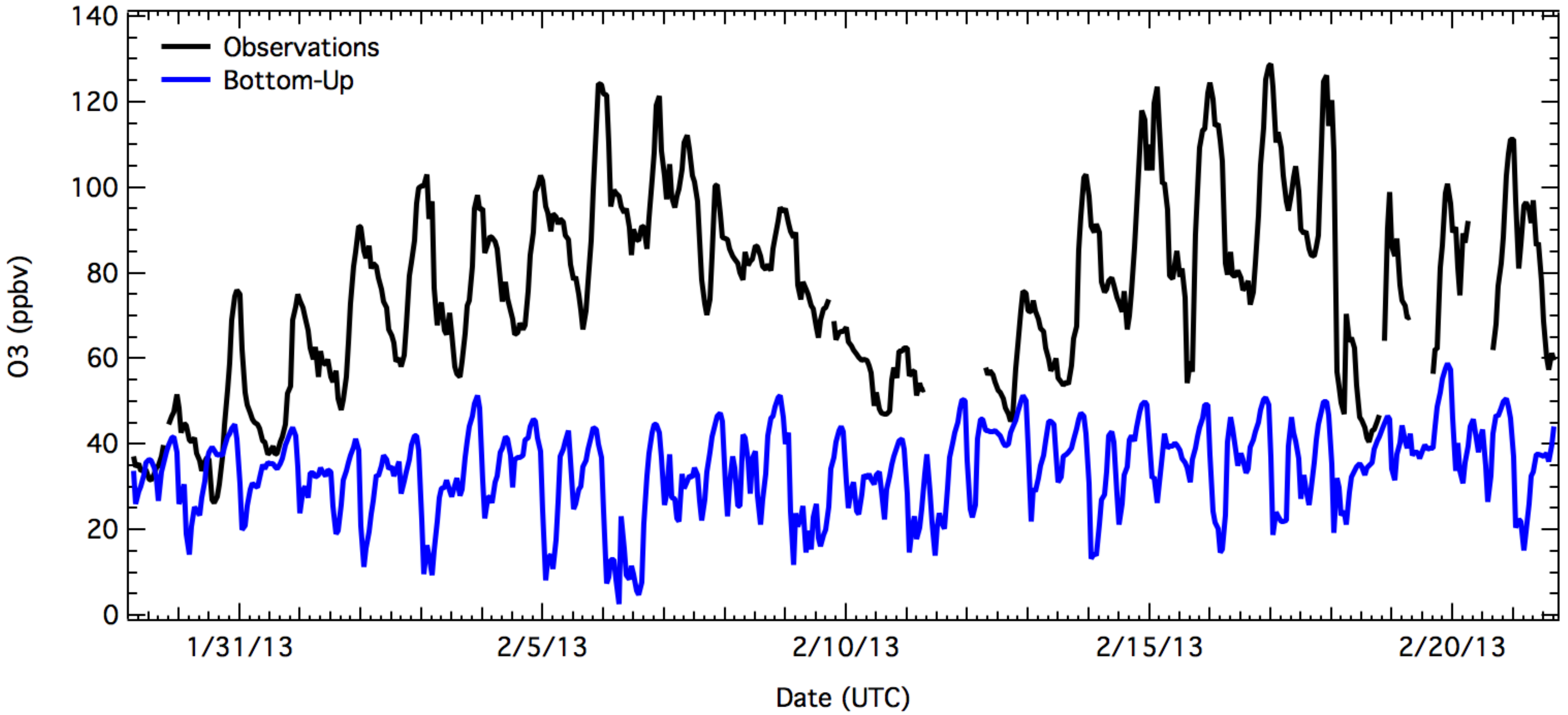


Daytime (9-17MST) statistics:

Bottom-up case: *r= 0.29, med. bias= -5.1 ppm, med. (mod./obs.)= 0.31*

Top-down case: *r= 0.37, med. bias= -2.9 ppm, med. (mod./obs.)= 0.61*

Observed and modeled ozone time series at the Horsepool site

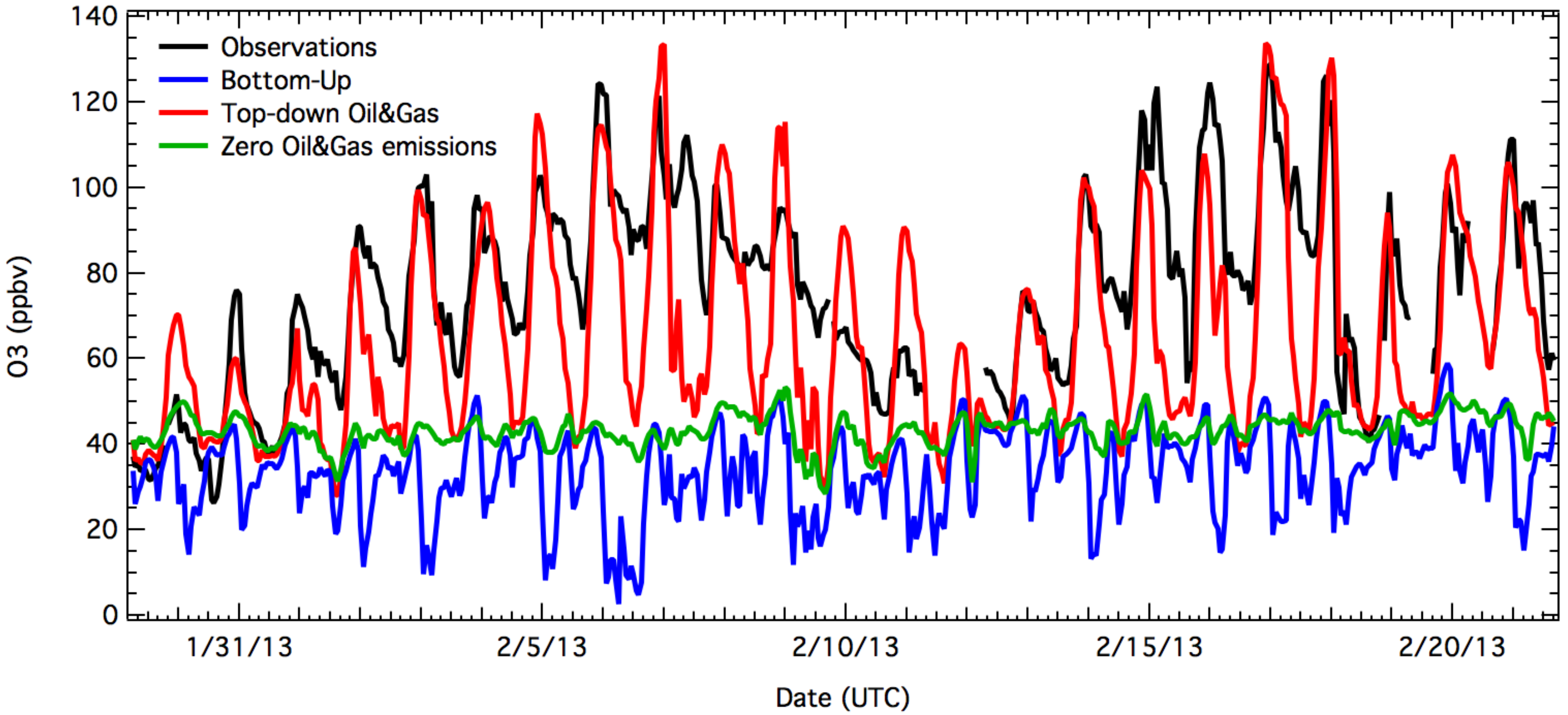


Observed and modeled ozone time series at the Horsepool site, 2013

Daytime (9-17MST) statistics:

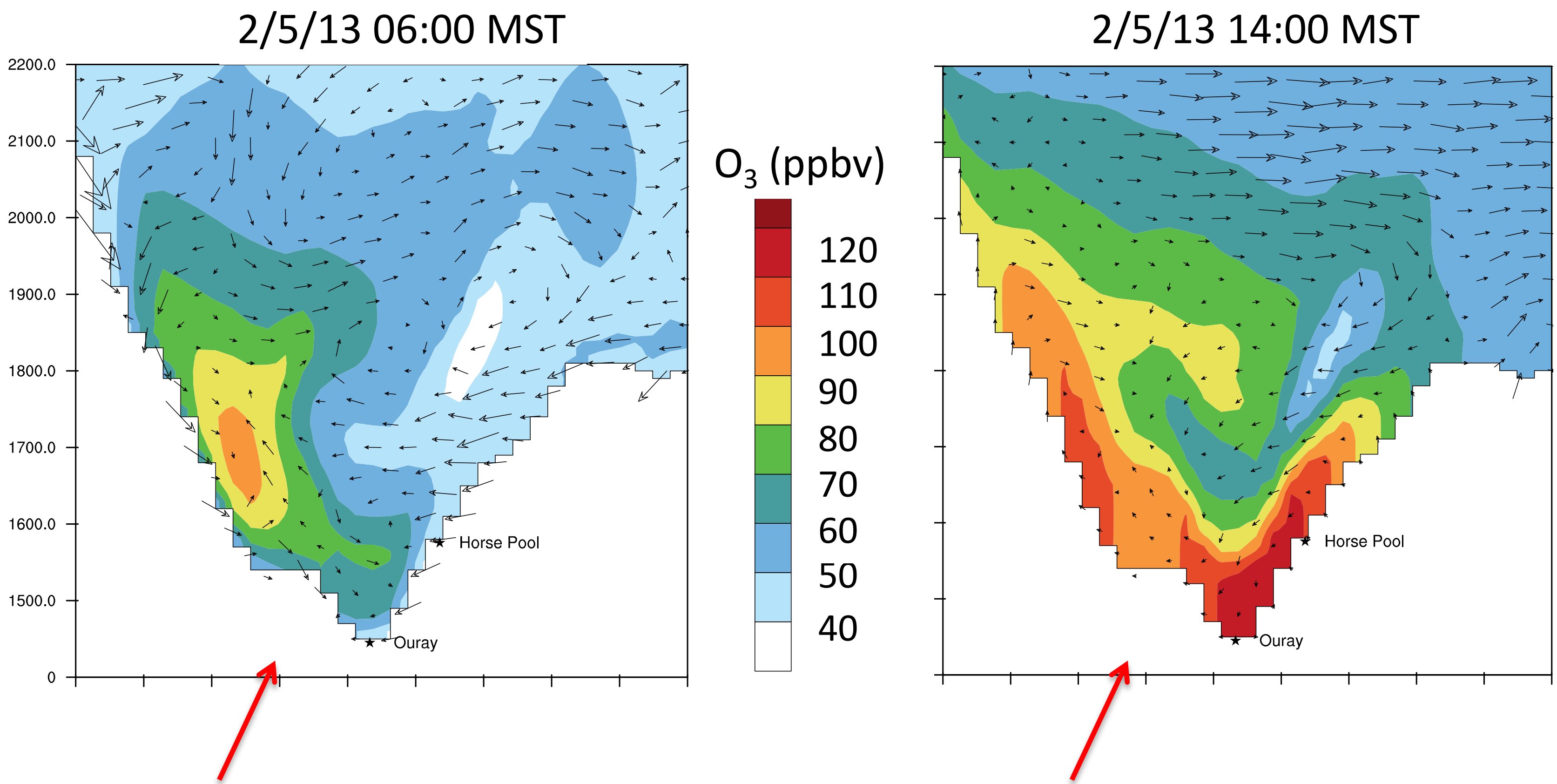
Bottom-up case: *r= 0.33, med. bias= -39.8 ppb, med. (mod./obs.)= 0.51*

Top-down case: *r= 0.85, med. bias= -5.3 ppb, med. (mod./obs.)= 0.93*



Ahmadov et al. (2014), ACPD

West-East Cross-section through the Uinta Basin



<u>Nighttime and Early Morning</u>

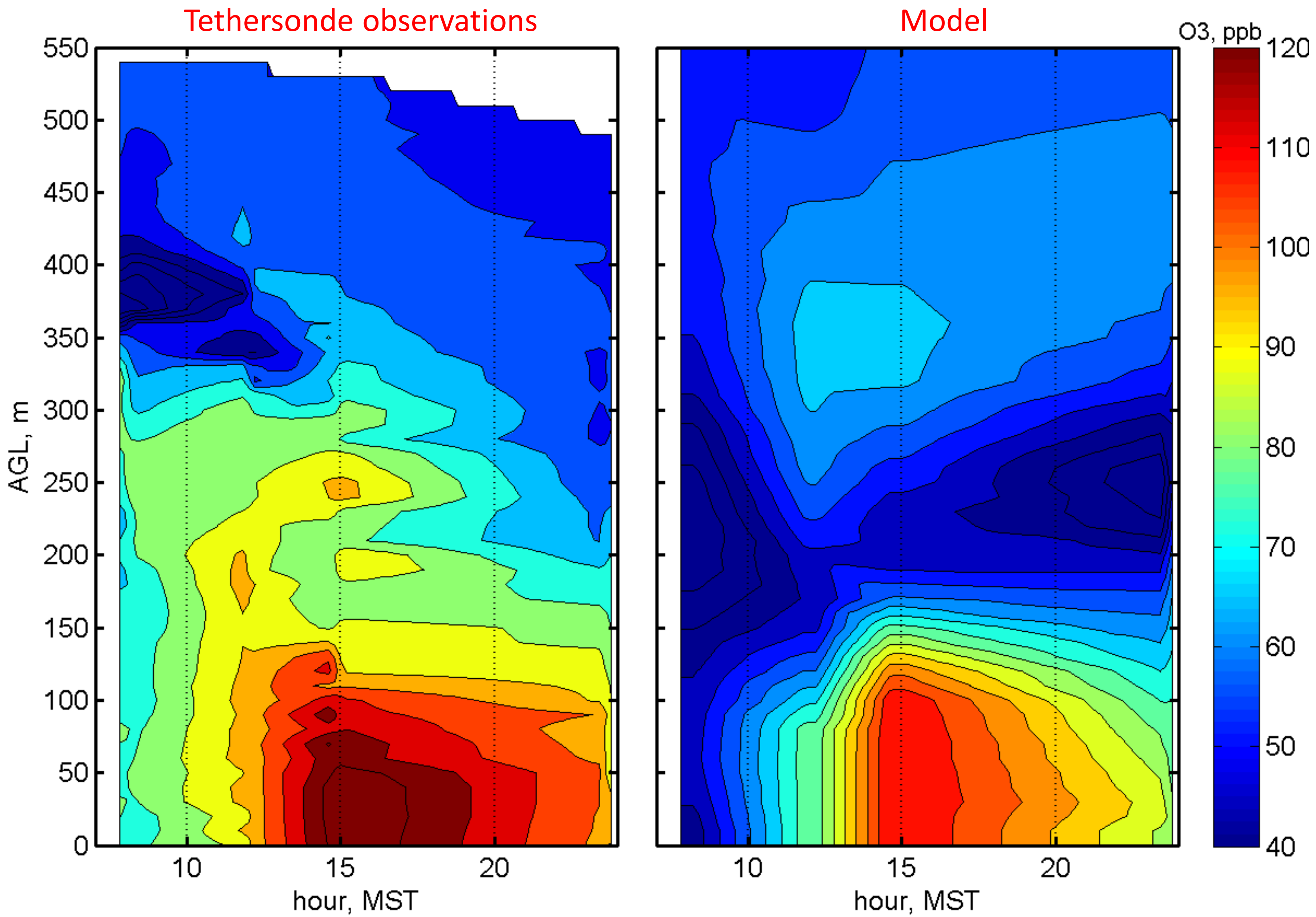
- Strong drainage flow
- Complicated circulation within Basin
- O_3 from previous day trapped

<u>Daytime</u>

- Light winds within Basin
- Low Mixing Heights
- Significant O_3 buildup in shallow layers

Ahmadov et al., ACPD, 2014

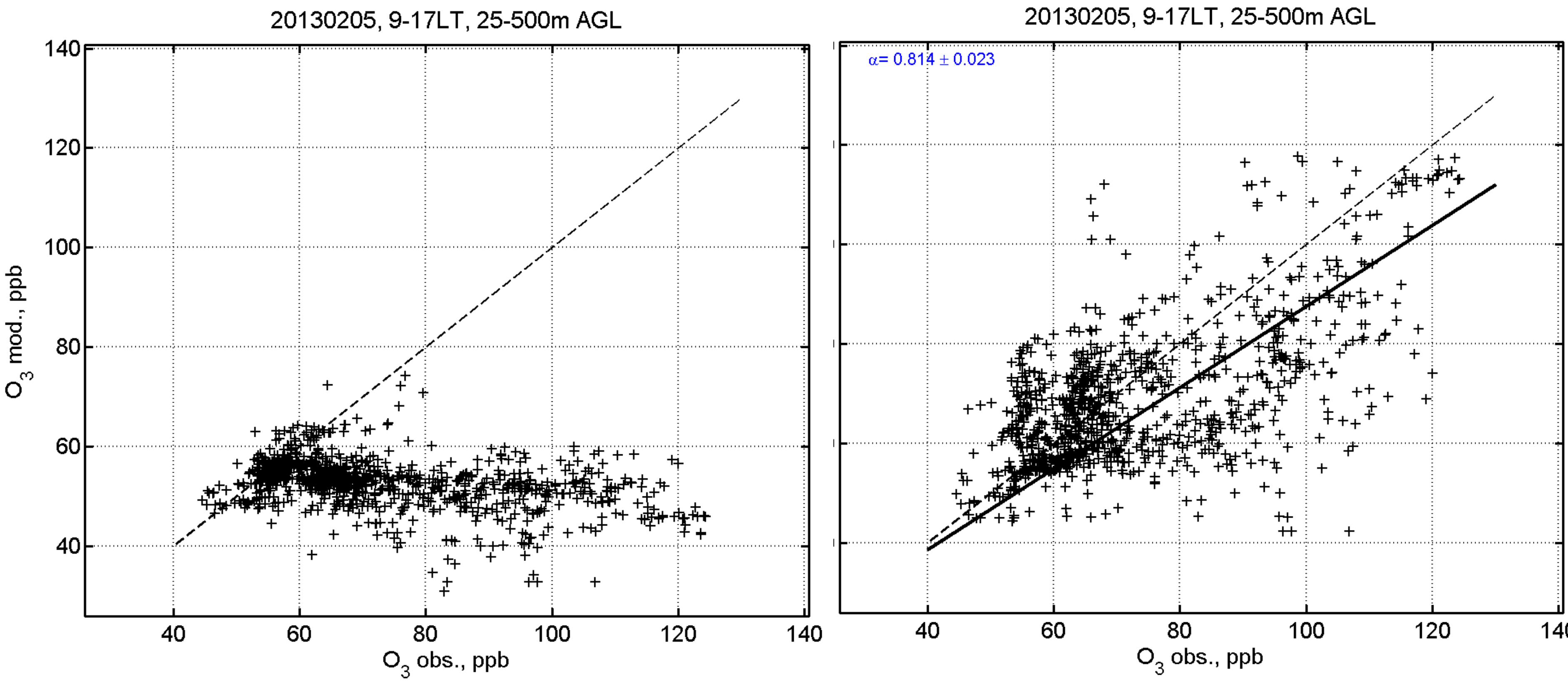
O_3 distribution over Horse Pool on February 5th, 2013



Model O_3 comparisons against the aircraft measurements (Feb. 5, 2013)

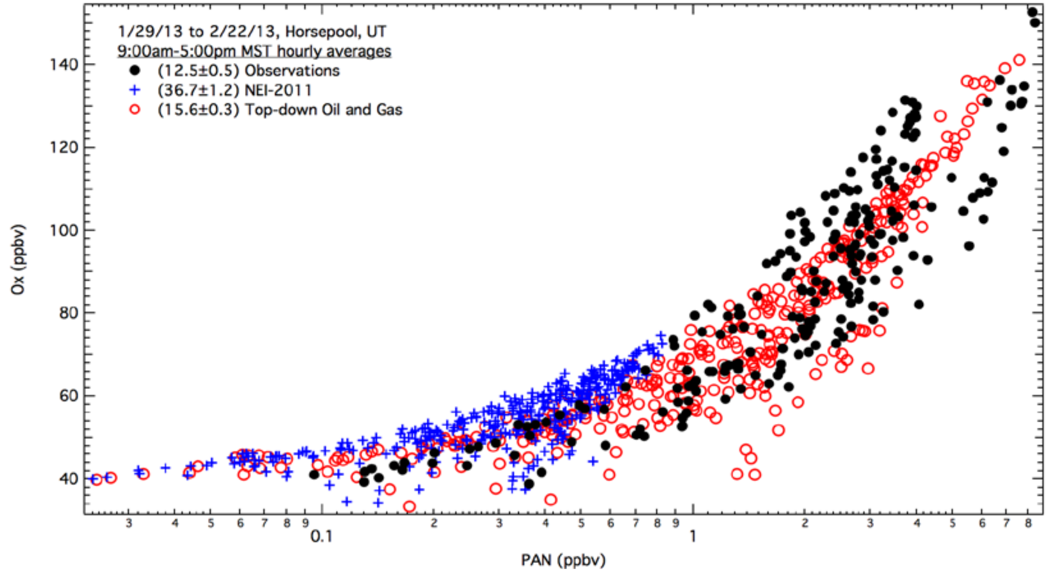
Bottom-up (NEI2011)

Top-down



Horse Pool measurements used for model/inventory verification

O_x versus PAN at the Horsepool site, 2013



O_x – PAN relationship
Depends on:
VOC/NO_x ratios
Photochemical mechanism

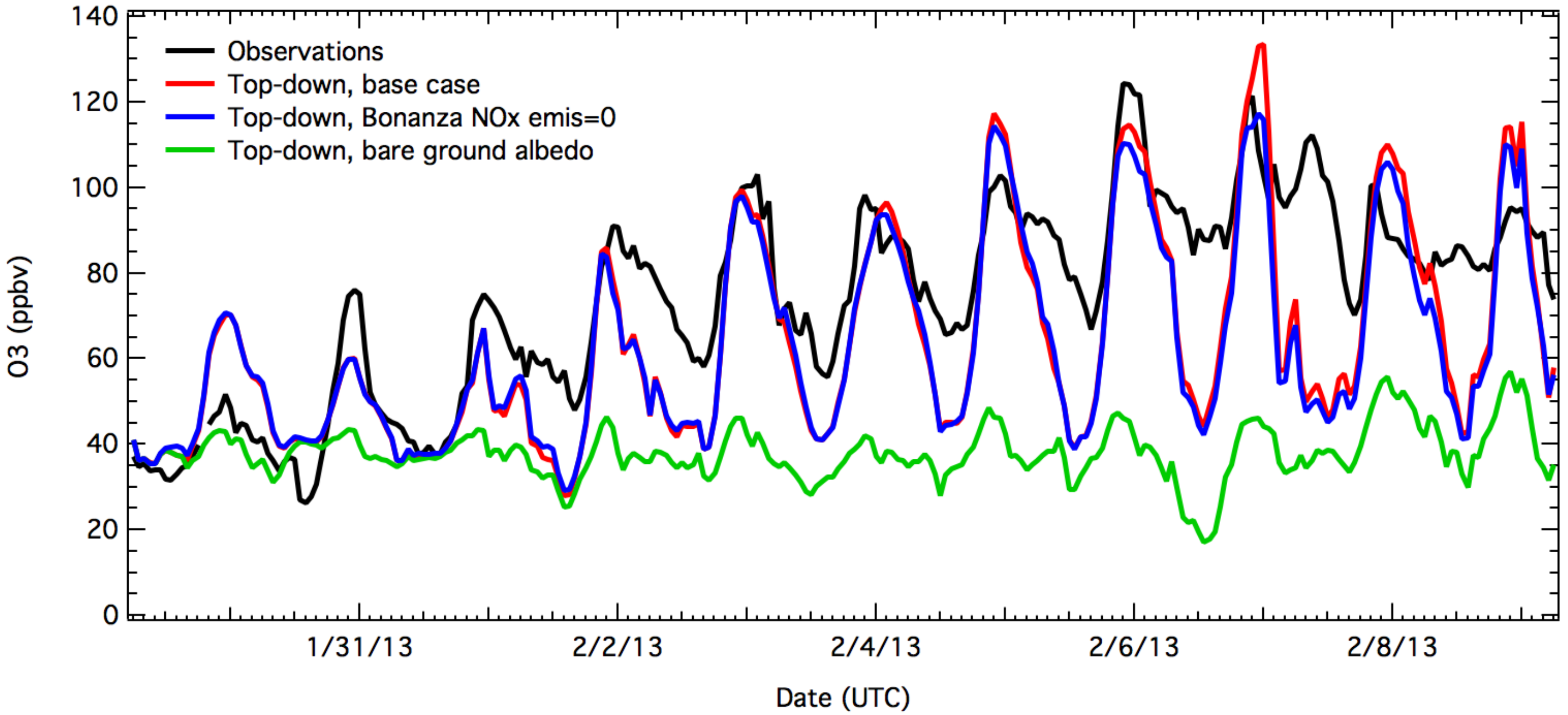
NO_x emission inventory assessment

	NO_x	Top-Down		Bottom-up (NEI-2011)	
	Observed Median (ppbv)	**Median Mod/Obs Ratio**	**r coefficient**	**Median Mod/Obs Ratio**	**r coefficient**
2012	4.81	0.70	0.64	1.55	0.67
2013	17.16	0.75	0.46	1.86	0.35

Ahmadov et al., ACPD, 2014

Is O_3 photochemistry sensitive to Bonanza power plant emissions and snow albedo?

Bonanza power plant: No
Snow albedo: Yes



Highlights of perturbation/sensitivity analysis

Physical Processes - Perturbation Case	Impact on model O_3 from oil/gas
Bare ground surface albedo (no snow)	104%
Bare ground O_3 surface deposition	48%

Snow is essential for high O_3

NO_x Emission Perturbation Case	Impact
Top-Down Oil&Gas NOx Emission Reduced 30%	1%
Top-Down Oil&Gas NOx Emission Reduced 67%	14%
Top-Down Oil&Gas NOx Emission Reduced 100%	45%

High O_3 events are insensitive to NO_x reductions

VOC Emission Perturbation Case	Impact
Top-Down Oil&Gas VOC emis. Reduced 30%	33%
>C-2 Alkane VOC emis. set to zero	44%
Aromatic VOC emis. set to zero	37%

Top-down Aromatic/(>C-2 alkane) flux ratio = 0.10

O_3 is VOC limited

Aromatics have a disproportionate influence

Ahmadov et al., ACPD, 2014

Model O_3 sensitivity to emissions of radical precursors

(Horse Pool site, Jan 29 to Feb 9, 2013, daytime)

Base Case NO_x emissions:

NO: 90%

NO_2: 8%

HONO: 2%

The model can predict high O3 concentrations without primary HONO emissions!

	Impact Percentage
All NO_x emissions were included as NO	5%

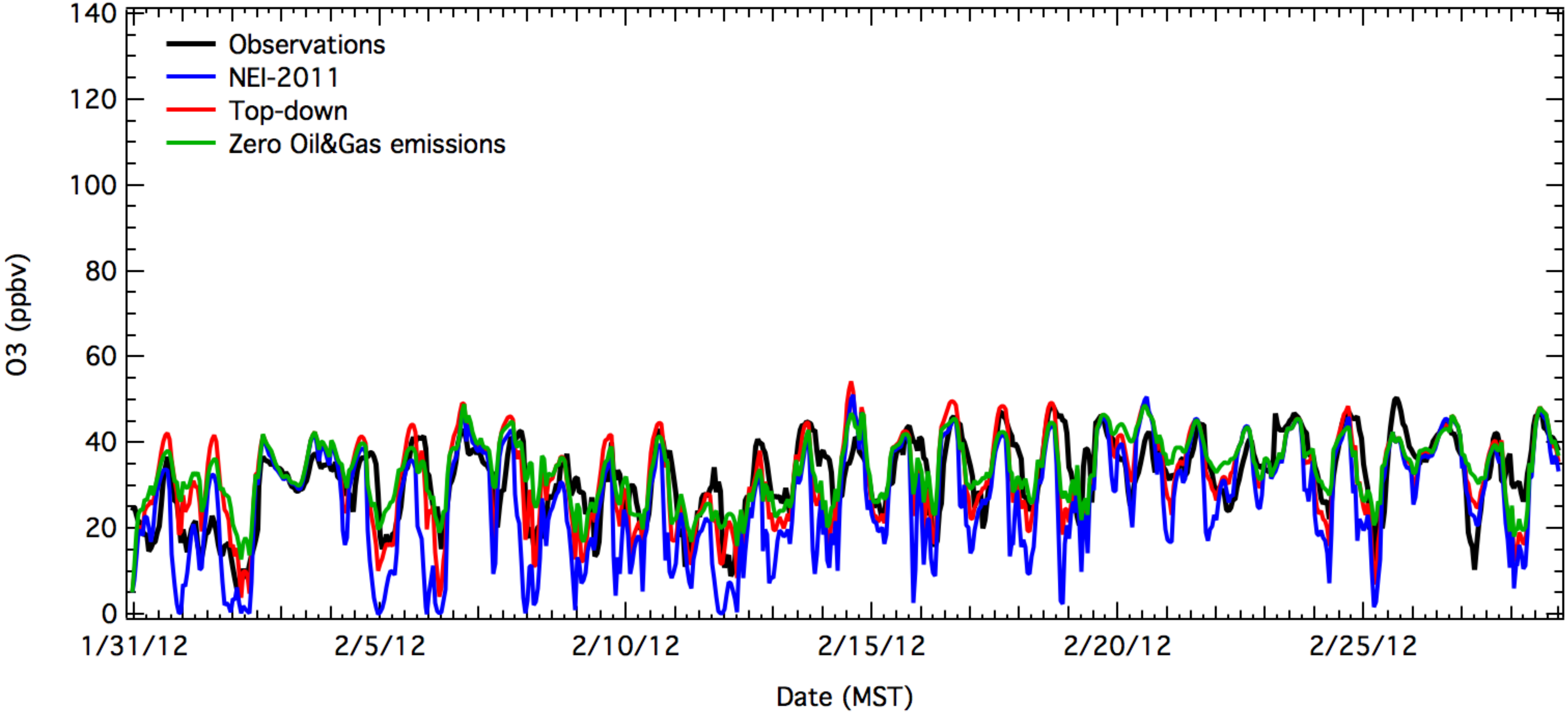
CH_2O Statistics: Median Model/Observed Ratio = 0.53

	Impact Percentage
CH_2O primary emissions set to zero	18%

CH_2O Median Model/Observed Ratio = 0.36 after emissions removal

The primary formaldehyde emissions need to be considered!

Observed and modeled ozone time series at the Horsepool site, 2012



The same model settings and emissions for the 2012 and 2013 cases were used!

Ahmadov et al. (2014), ACPD

Summary

- The emission inventories (CH_4, VOCs, NO_x) for the oil/gas sector can be significantly improved by using the top-down emission estimates.
- The model is able to simulate high O_3 episodes in winter of 2013 using the top-down inventory, but not the bottom-up (NEI-2011) inventory.
- The sensitivity simulations show reducing the VOC emissions would be an efficient way to mitigate wintertime O_3 problem in the Uinta Basin.
- High ozone in the Uinta Basin are primarily caused by the very high VOC versus NO_x emissions from the oil/gas sector, persistent stagnation episodes and high surface albedo and reduced deposition effect due to snow cover.

Thank you for your attention!

Uintah Basin, 2013
Photo by S.Sandberg