Back Trajectory & Meteorological Analyses of Reactive Nitrogen Measured at Rocky Mountain National Park, Colorado

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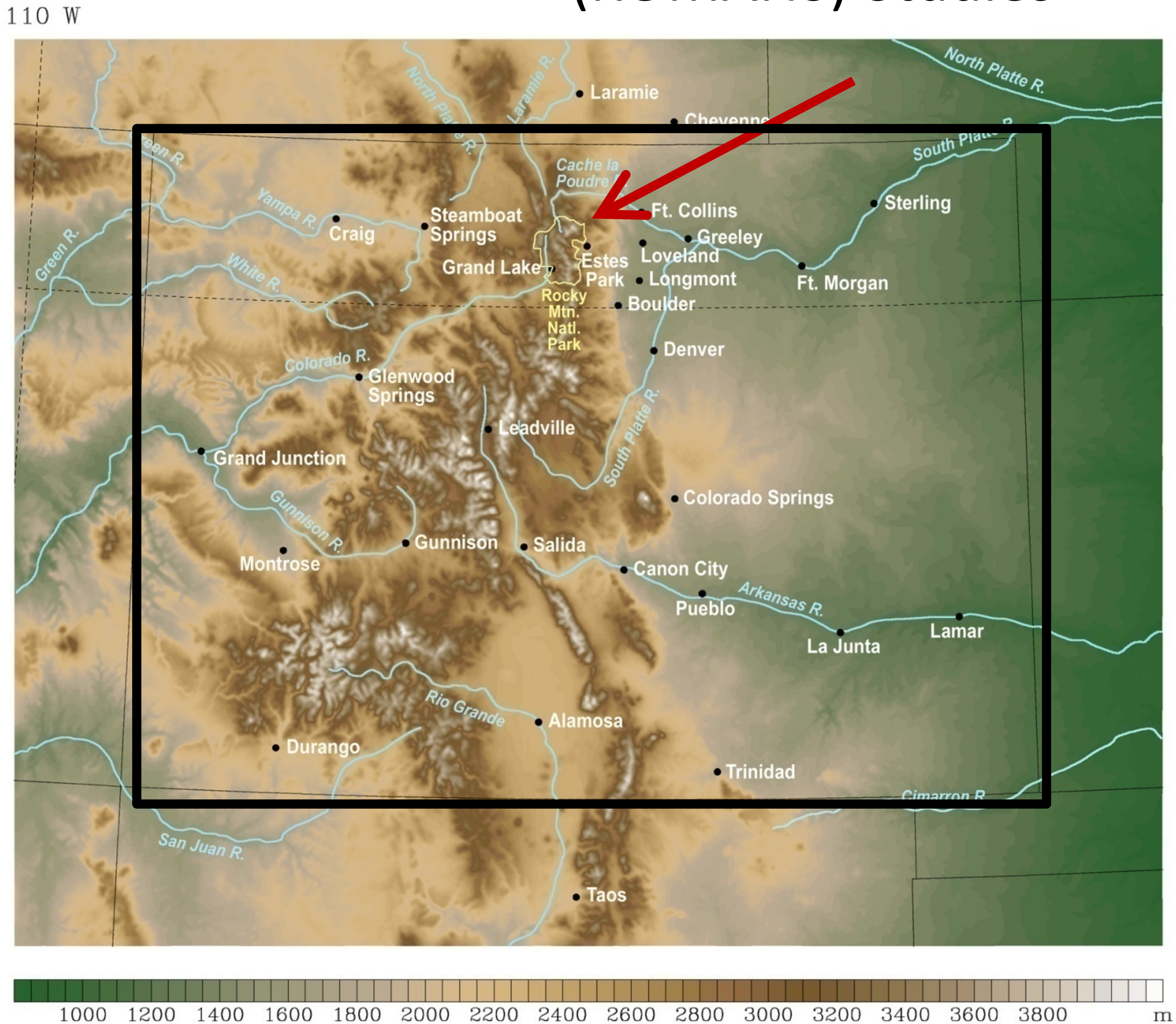
View of The Loch from the Lake of Glass, July 2008

National Acid Deposition Program Annual Meeting

Providence, RI 27 Oct 2011

Rocky Mountain Atmospheric Nitrogen and Sulfur (ROMANS) Studies



What are the N species? Where does N come from? Why the trends?

2005
Scoping Study

2006
April and July

2009
Full year
(Nov 2008 to Nov 2009)

2011
Another site
(Grand Teton, WY)

Source Apportionment Strategy
(Weight of Evidence)

- Multiple approaches building from simple to complex. Reconciliation of differences

Qualitative

  - Concentration gradients.
  - Which way is the wind coming from?
  - Simple back trajectories.
  - Frequency with which the air mass passes over source areas before it arrives at the receptor - residence time analyses.

Quantitative

  - Trajectory receptor models.
  - Other receptor models.
  - Chemical transport model (CAMx).
  - Hybrid Models.

ROMANS I & II Meteorological Goals

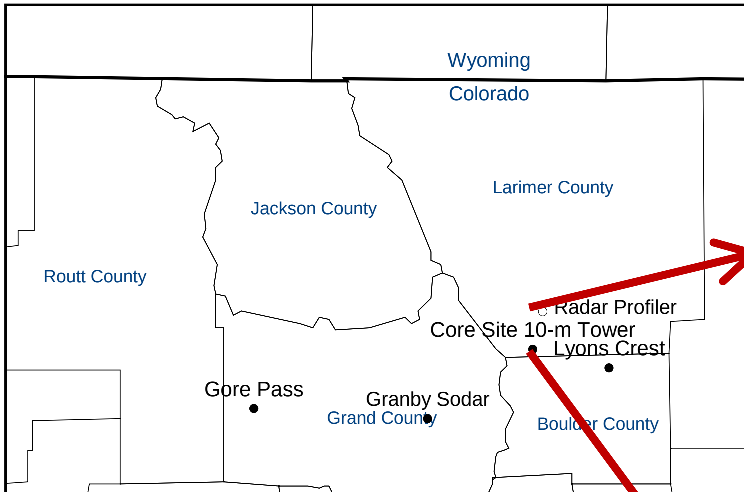
- Generate a meteorological data set suitable for chemical transport modeling, trajectory analyses, and formation of a conceptual model of source-receptor relationships.
- Generate accurate wind fields for accurate source apportionment.
- Generate accurate moisture, cloud, and precipitation fields for chemistry and deposition calculations.
- Evaluate suitability of coarse-domain meteorological data for simple source apportionment like back trajectories and for use in historical analyses.

Known Meteorological Issues

Complex Terrain = complex meteorology & small scale inhomogeneity

- Complex diurnal and seasonal mountain circulation patterns
- Inversions & stagnation in valleys
- Orographic Precipitation & isolated convective storms
- Fewer observations in remote mountainous areas

Meteorology Monitoring Locations - ROMANS Study



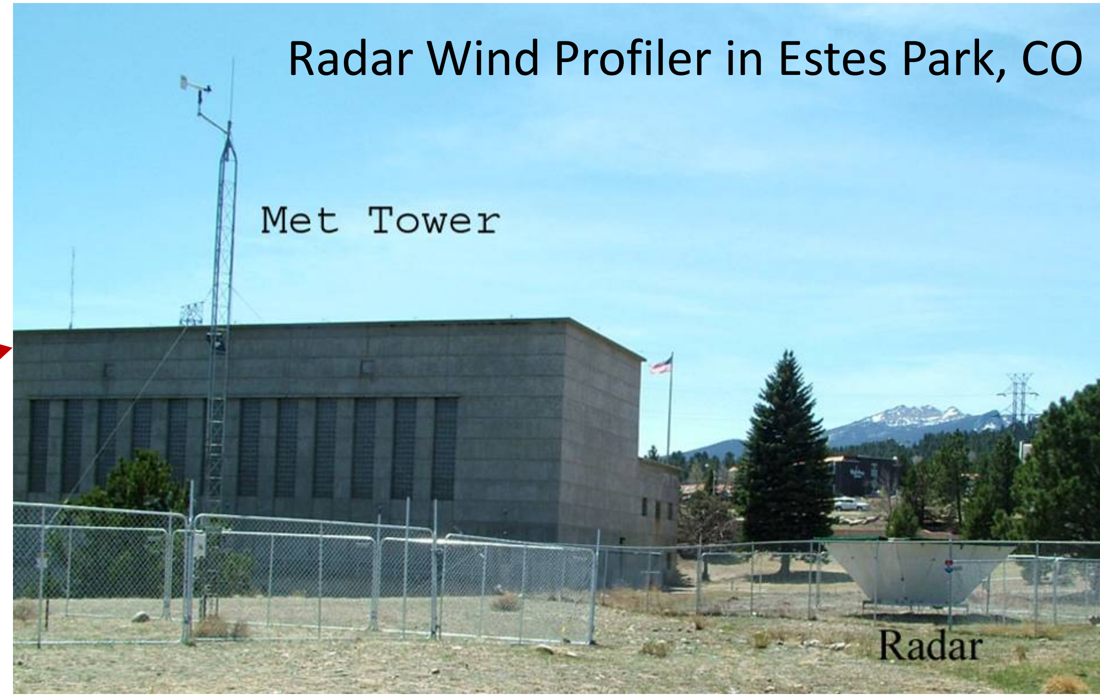
Distances from Core Site:

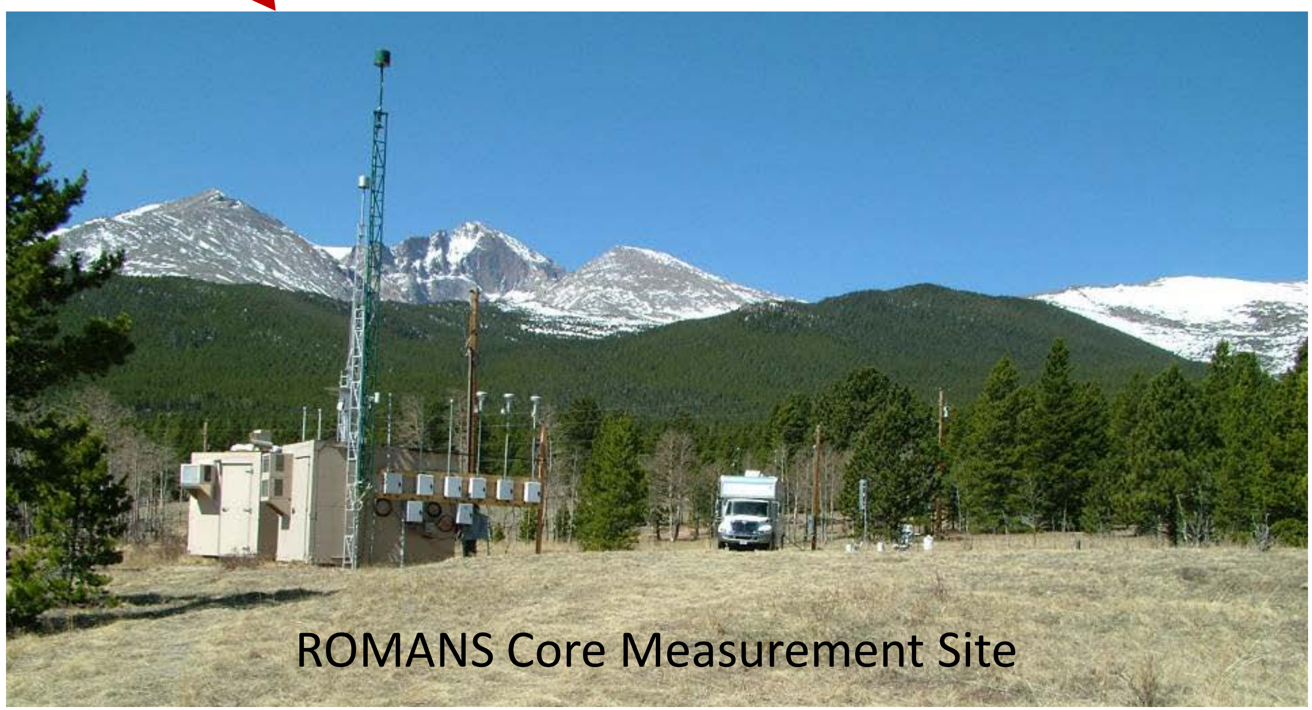
to Estes Park Radar Profiler = 12 Km

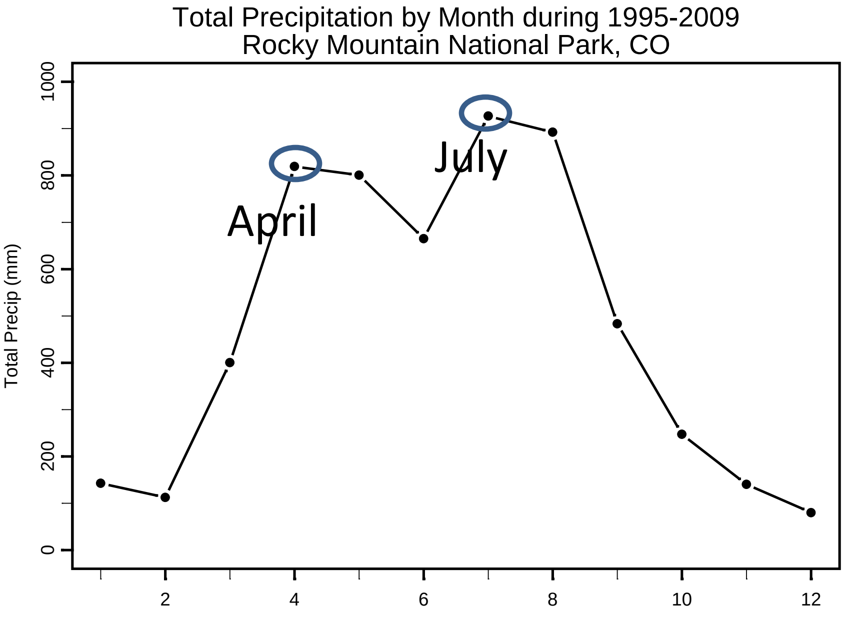
to Lyons = 24 Km

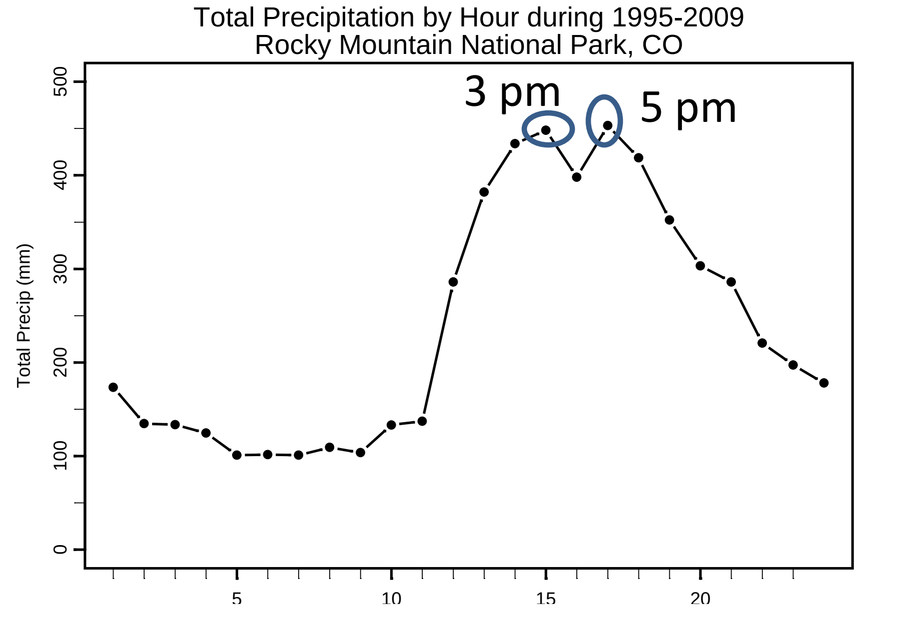
to Granby SODAR = 37 Km

to Gore Pass = 86 Km



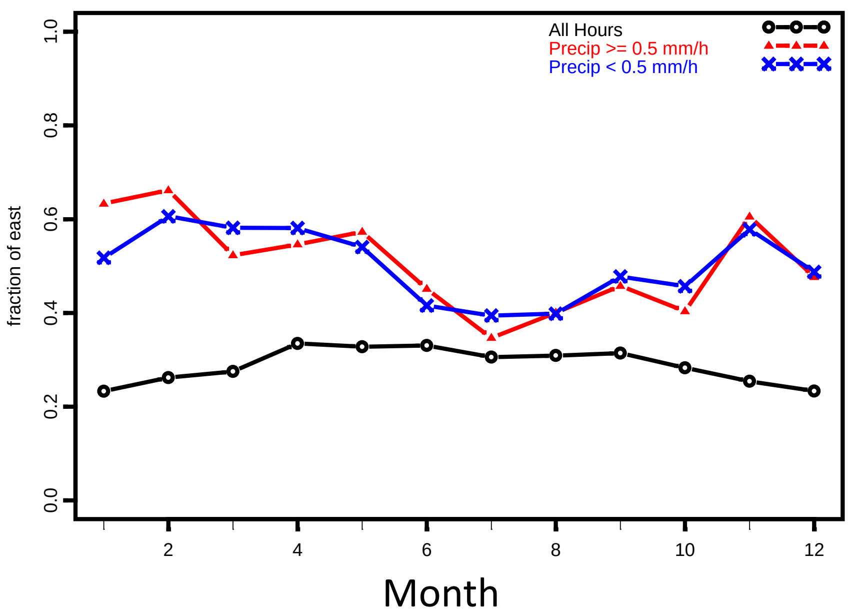




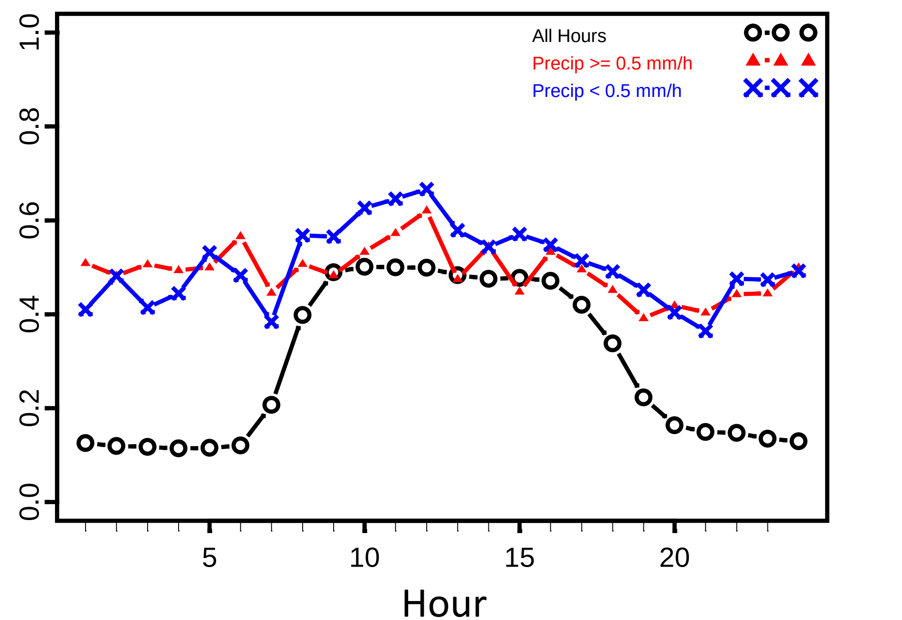


More Easterlies during Precipitation Events

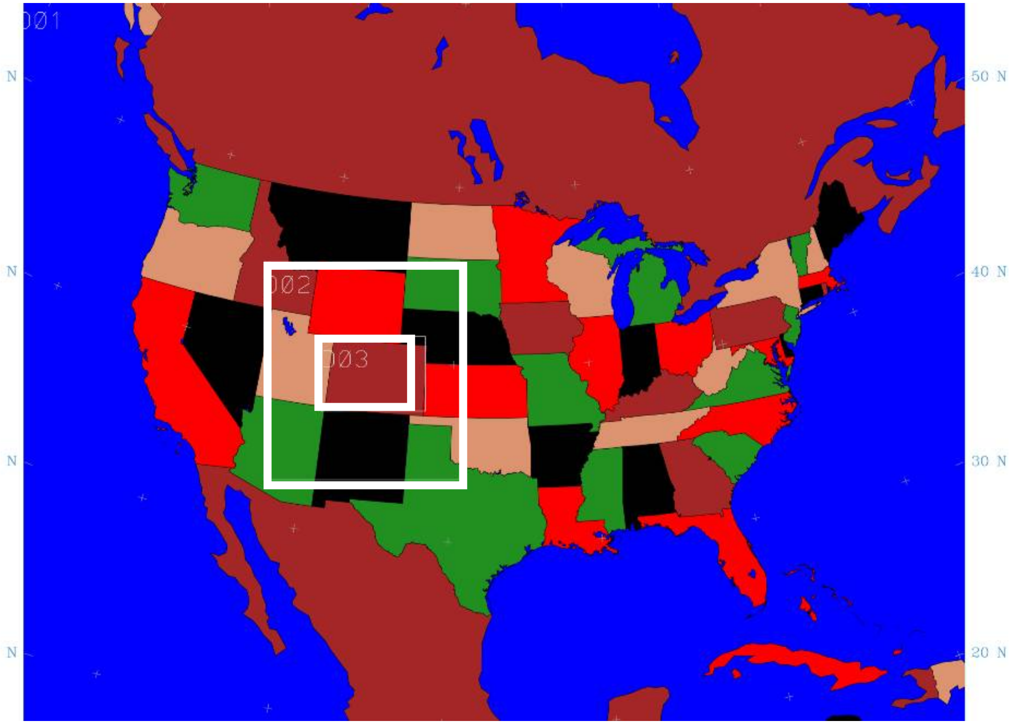
Fraction of Winds from the East 1995-2009



Fraction of Winds from the East 1995-2009



WRF Mesoscale Meteorological Modeling



Domain 1
36 km, 165 x 129
(WRAP* Domain)

Domain 2
12 km, 103 x 115

Domain 3
4 km, 163 x 118

34 layers

*Western Regional Air Partnership

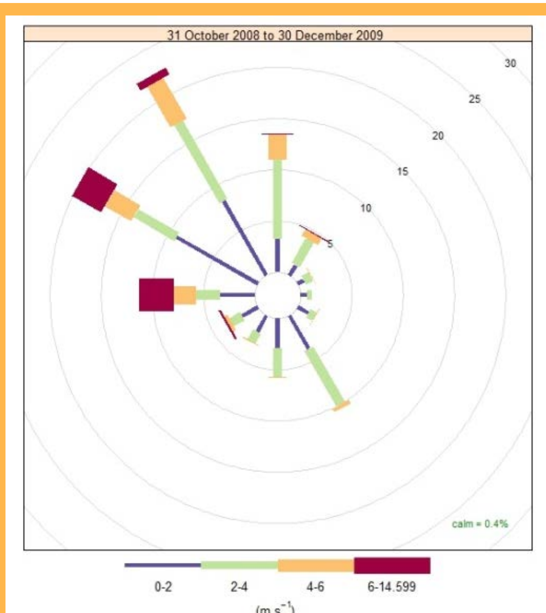
Several Runs for Nov 2008 – Nov 2009

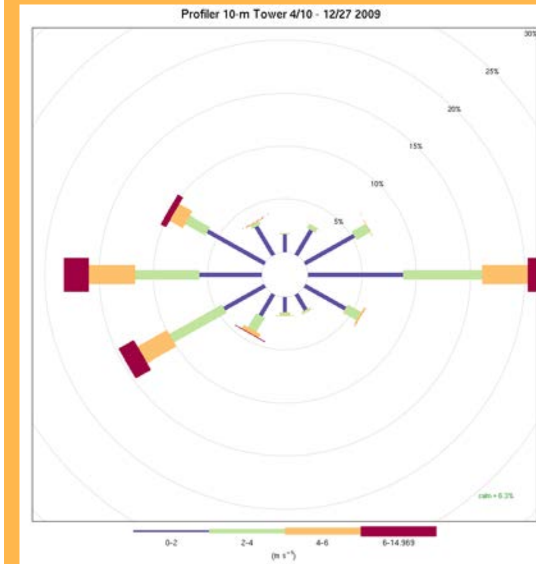
1. Simple physics , get it running with new hardware & software.
2. Added observational nudging on fine domain.
3. “Final” physics options
4. Ran MM5 for comparison.
5. Updated to most recent version of model, tested higher nudging coefficients.
6. Next …. Add more observational data in CO.
7. Upcoming (if needed) finer scale input data, add 1.3 km domain.

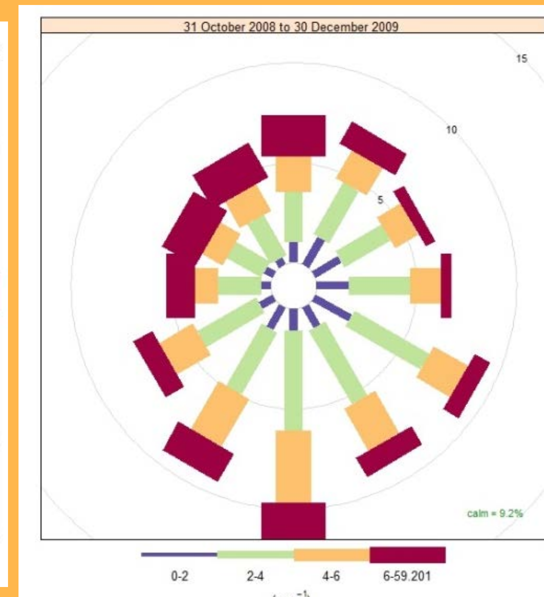
How Good is WRF? Surface Winds 2009

RMNP – ROMANS Core Site | **Estes Park – 12 km away** | **N. Front Range (7 sites)**

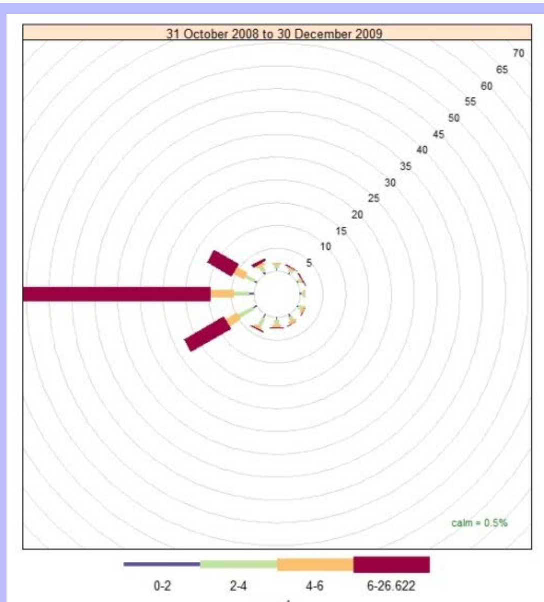
Obs.

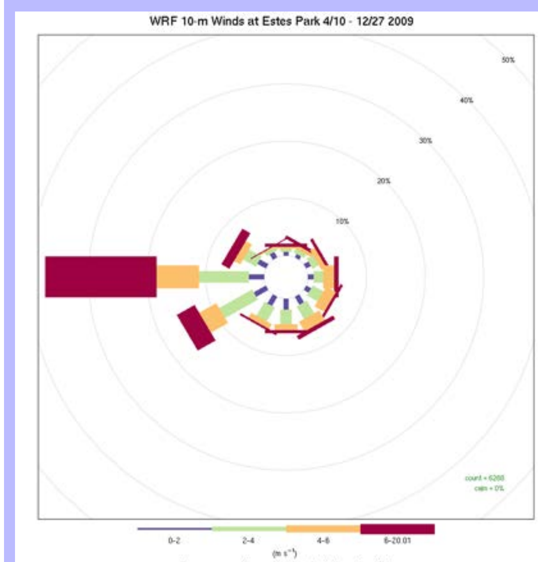


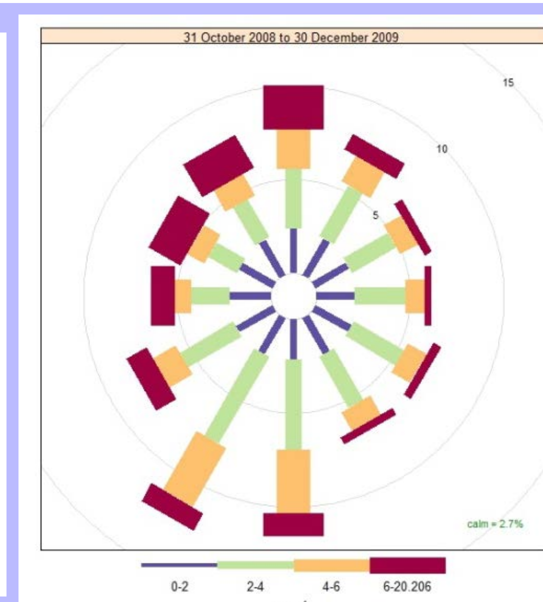




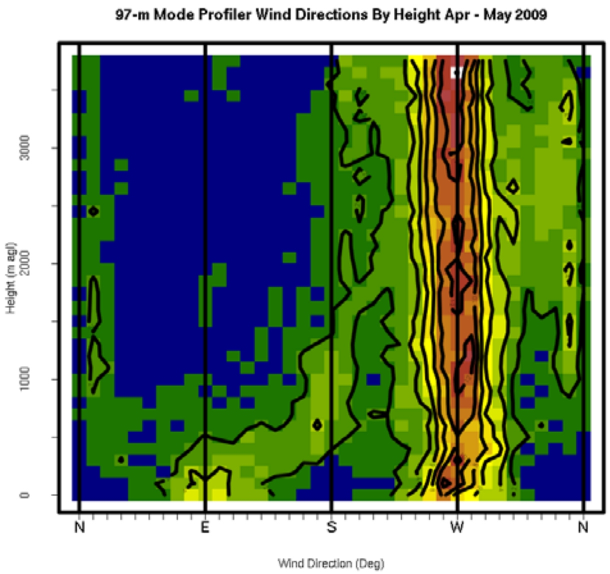
Model

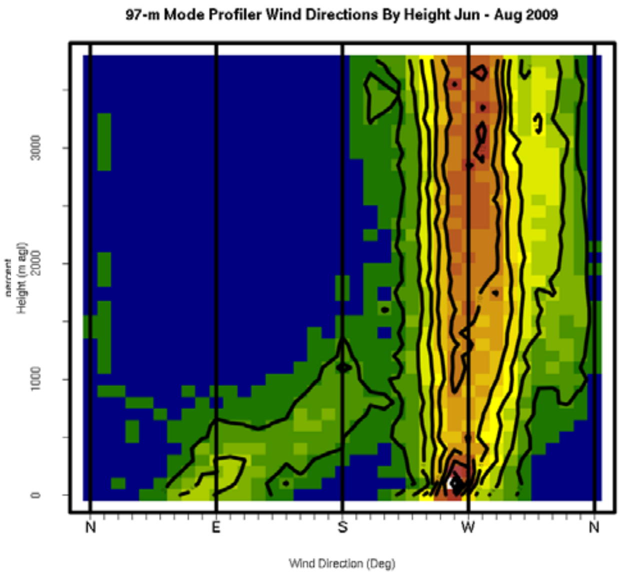


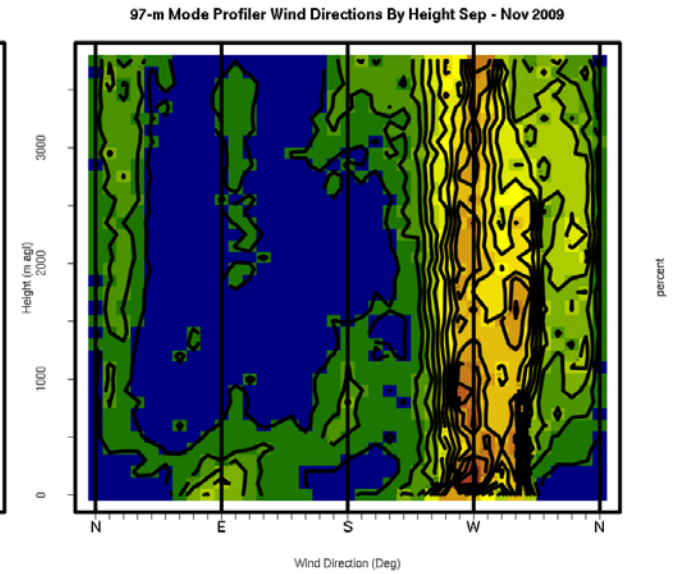




How good is WRF? Upper Air Winds, Top - Radar Wind Profiler 2009





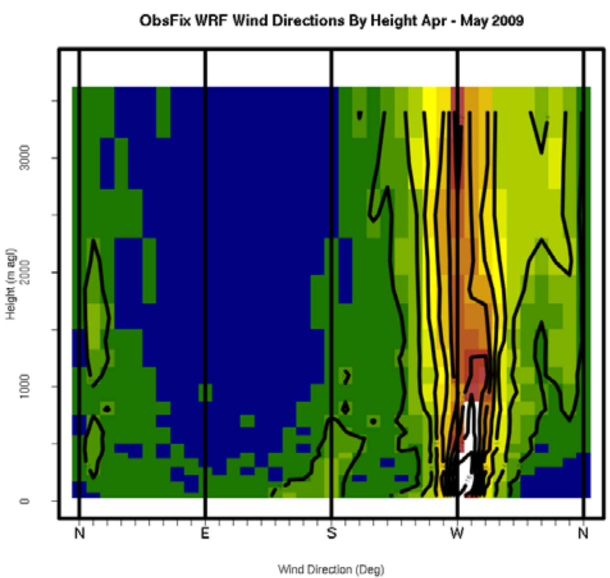


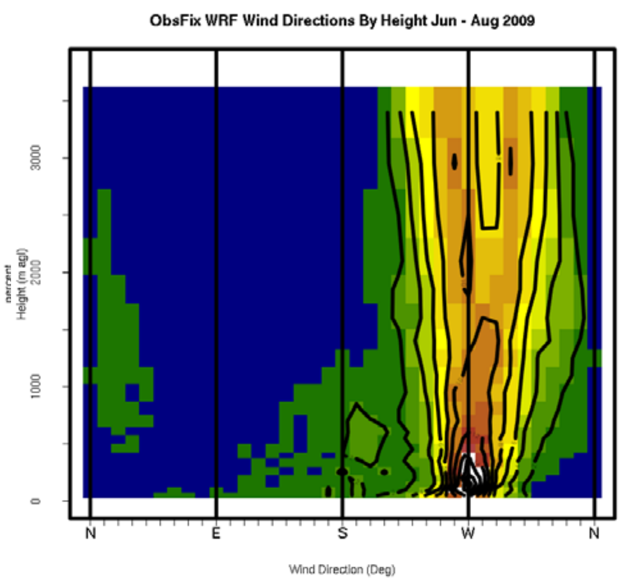
Spring

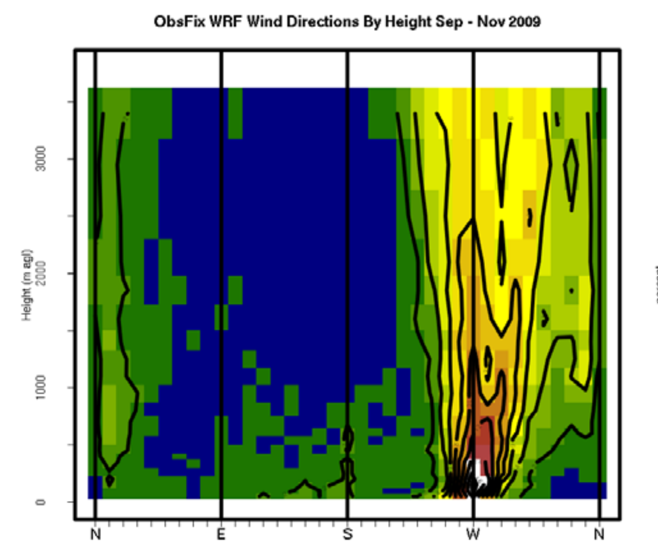
Summer

Fall

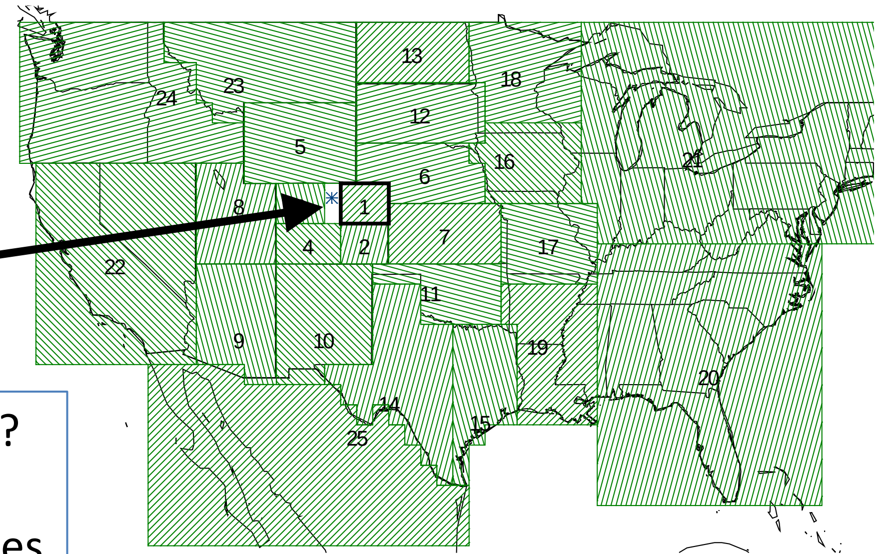
Bottom - Modeled with WRF 2009



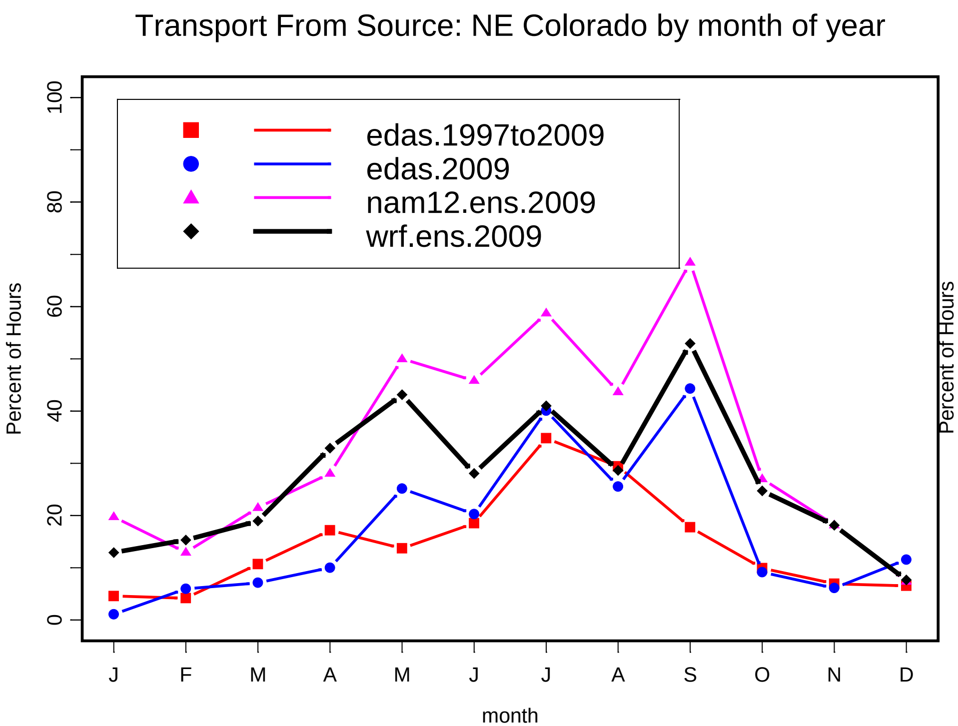


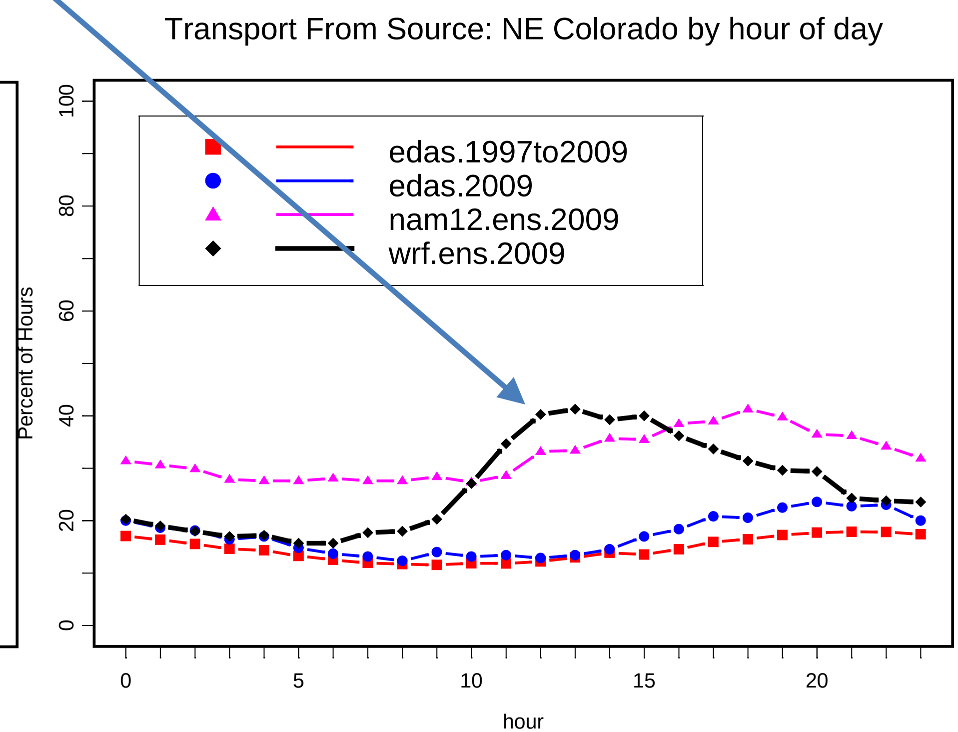


Transport from Northeastern Colorado 2009

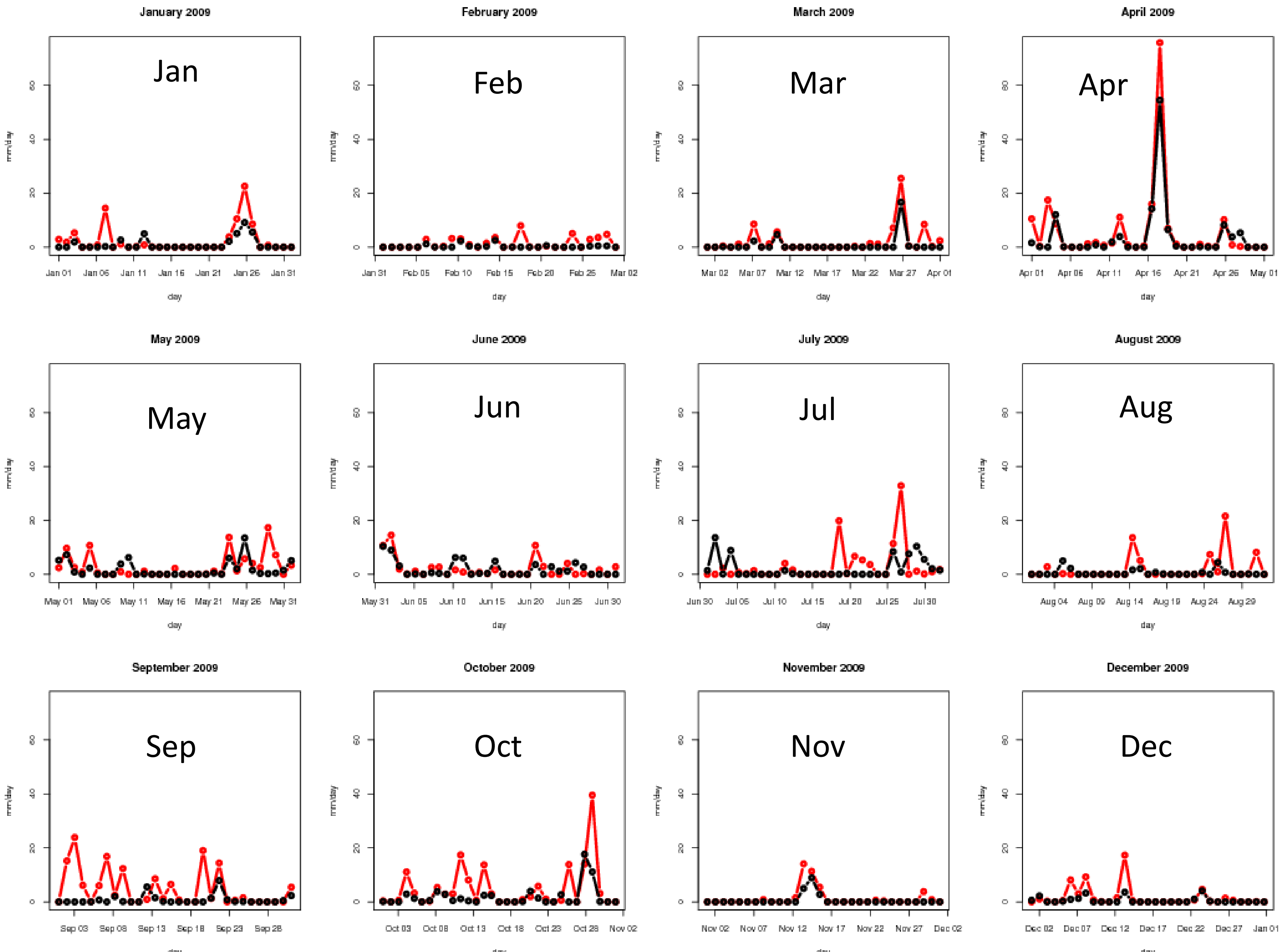


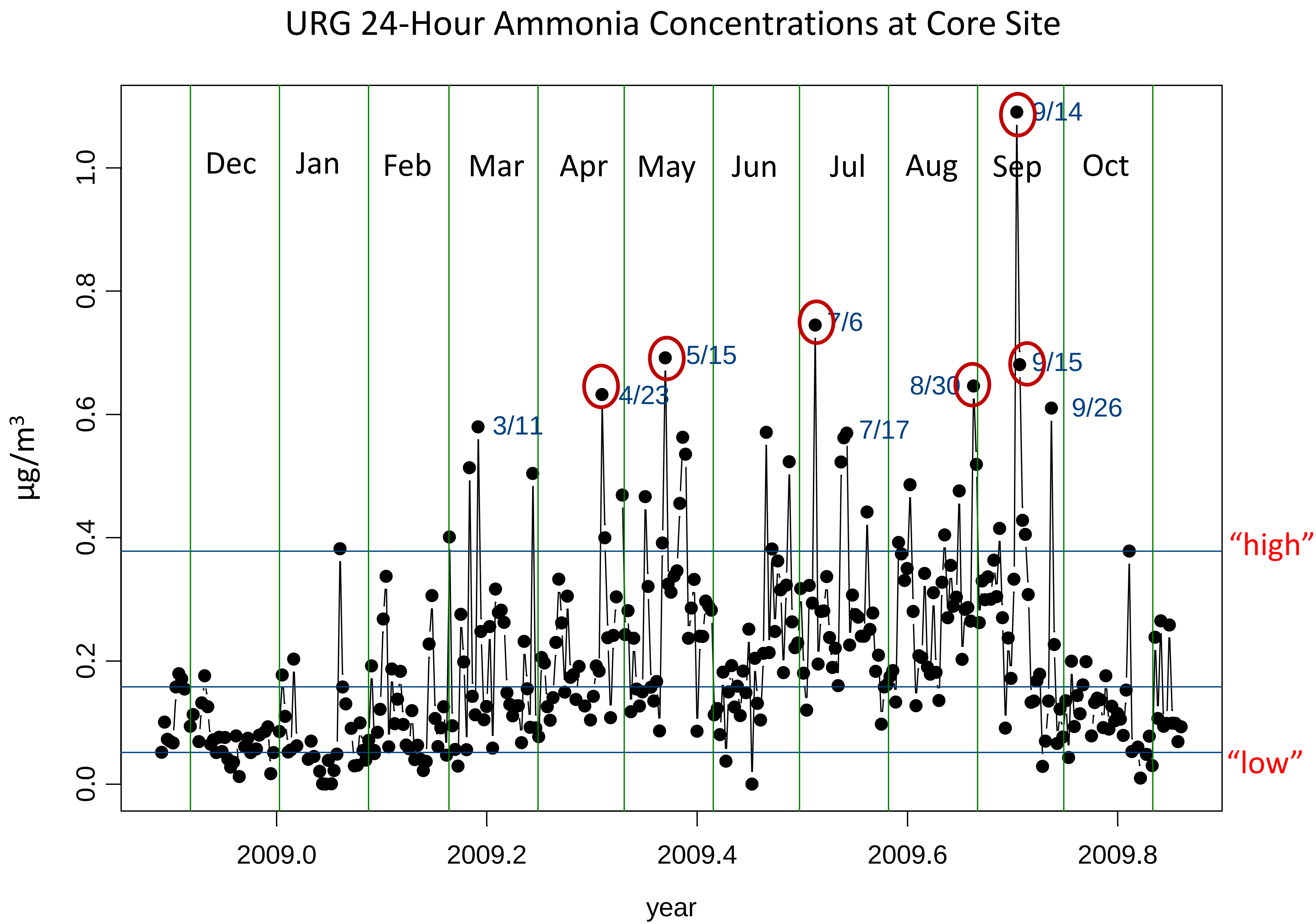
How Good it WRF?
Best at capturing afternoon easterlies



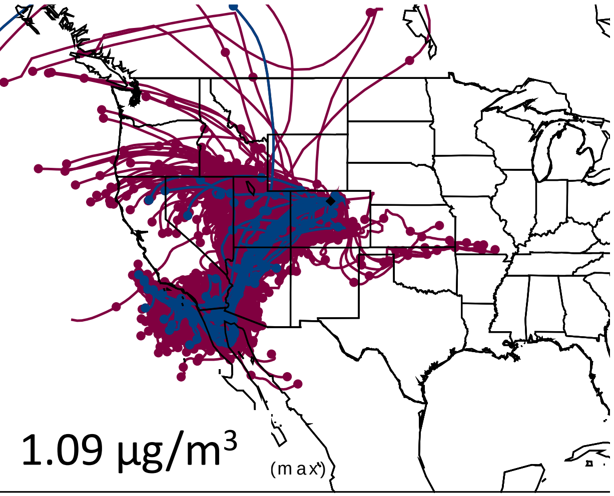


How Good is WRF? Precipitation, Black=Measured, Red=Model

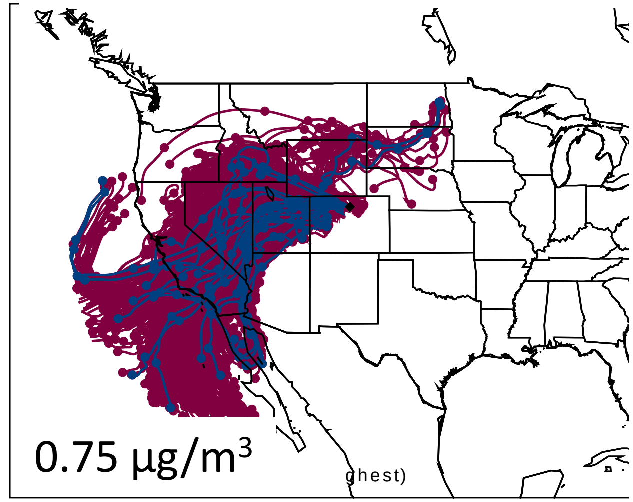



URG 24-Hour Ammonia Concentrations at Core Site
Dec
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
9/14
7/6
5/15
9/15
8/30
4/23
9/26
3/11
7/17
“high”
“low”
µg/m³
0.0
0.2
0.4
0.6
0.8
1.0
2009.0
2009.2
2009.4
2009.6
2009.8
year

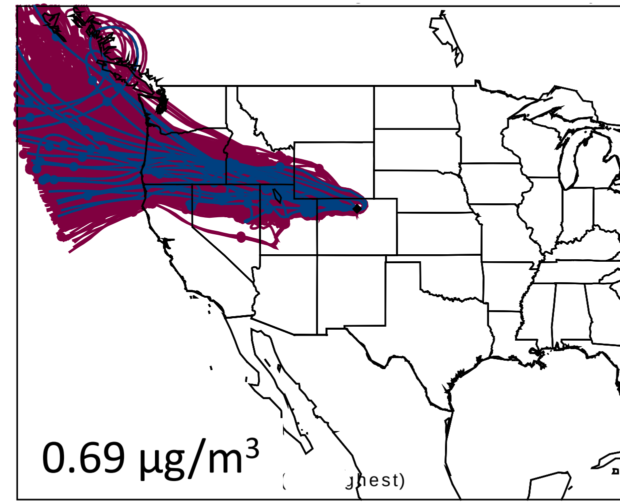
September 14, 2009



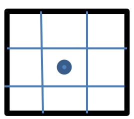
July 6, 2009



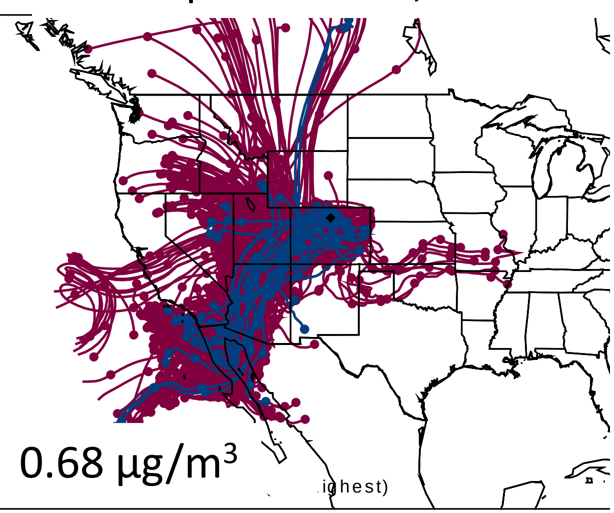
May 15, 2009



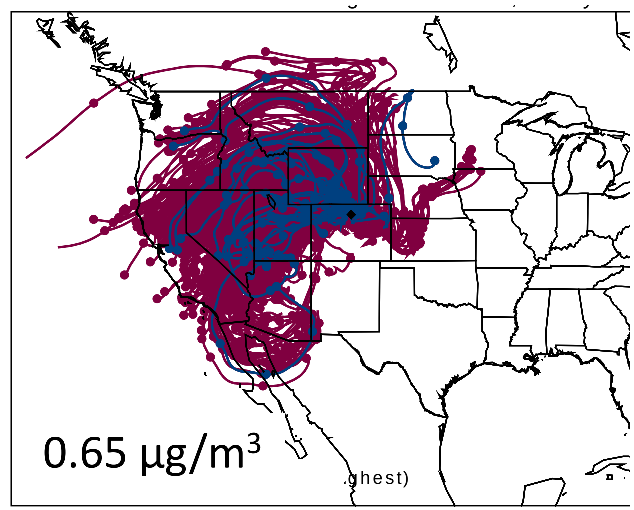
Hysplit ver 4.9 Ensemble Trajectories, 6 highest ammonia days, 100m start, wrf input



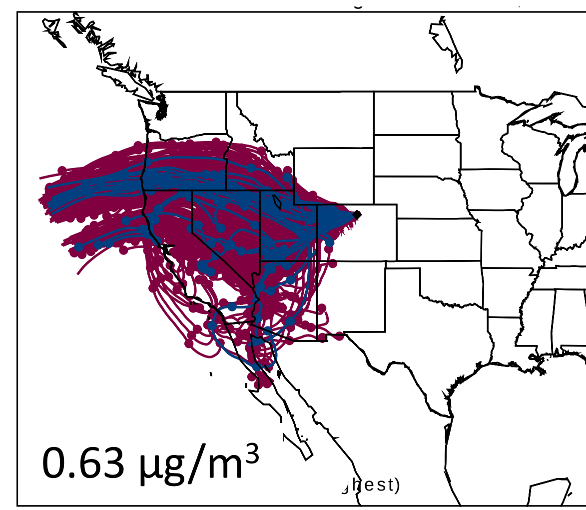
September 15, 2009



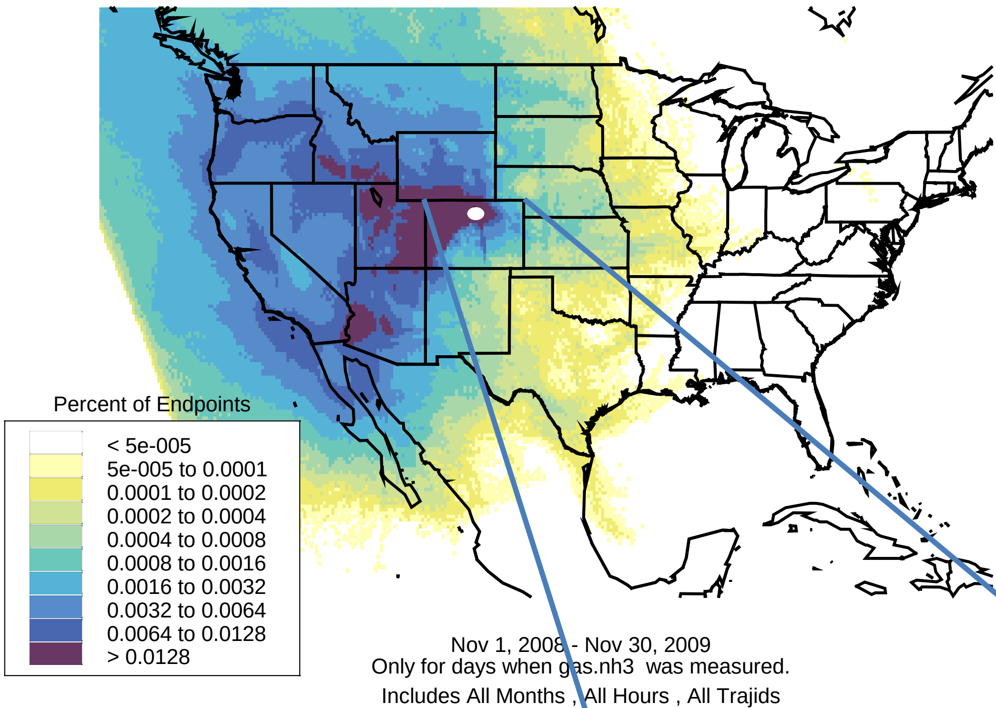
August 30, 2009



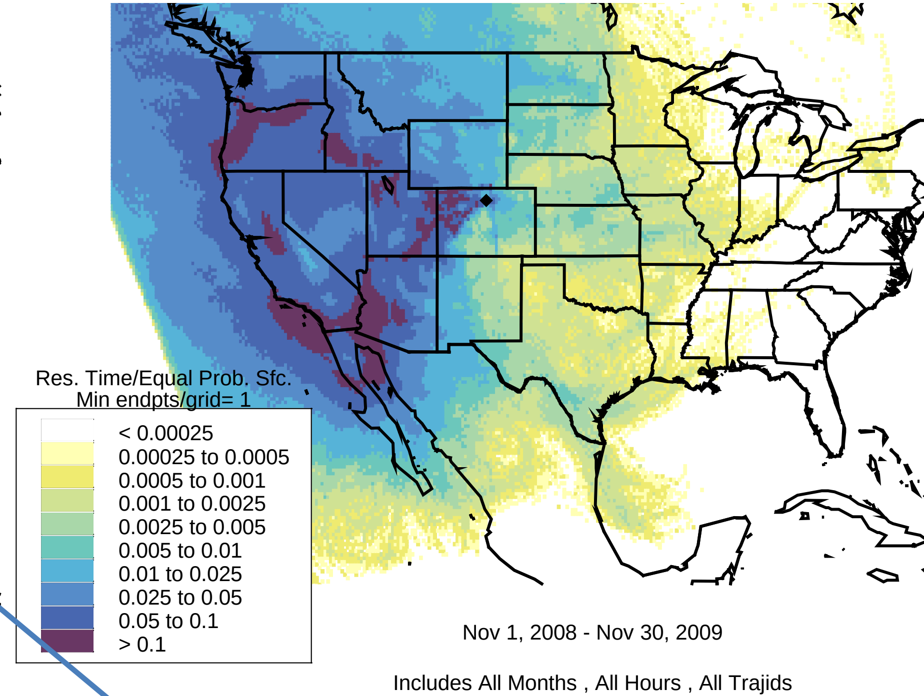
April 23, 2009



Overall Residence Time

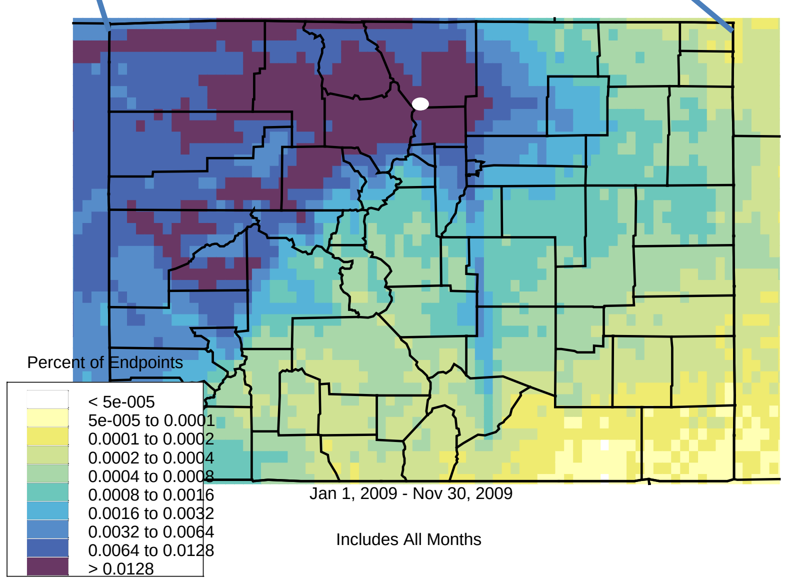


Overall Source Contribution Function



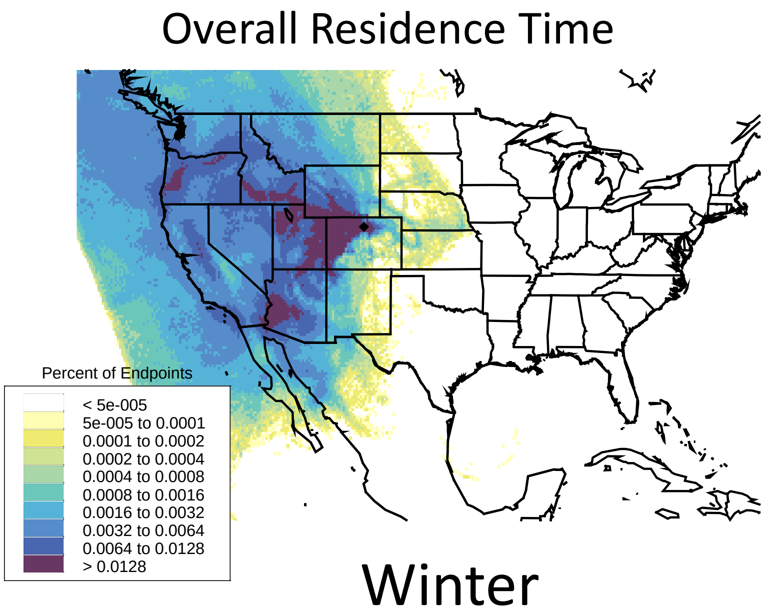
Top left and bottom:
Overall Residence Time
Nov 2008 – Nov 2009

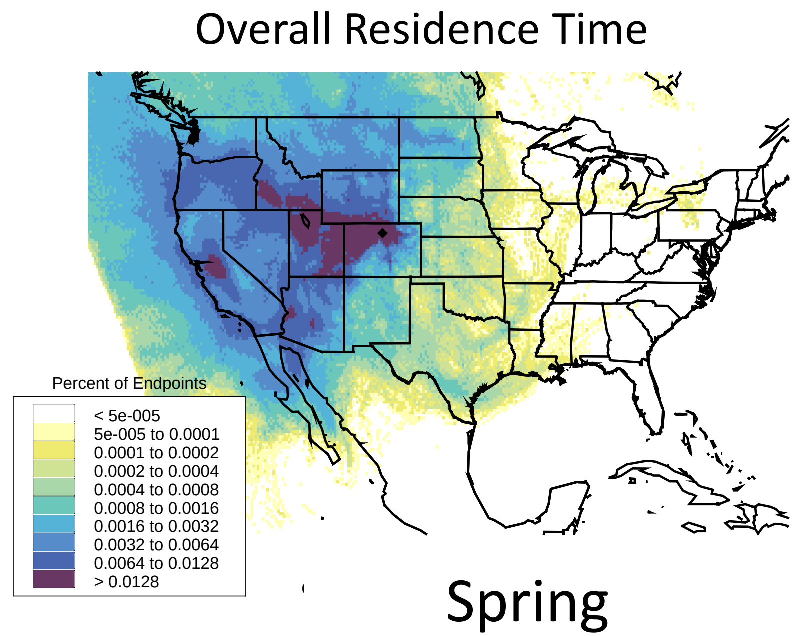
All Months
All Hours



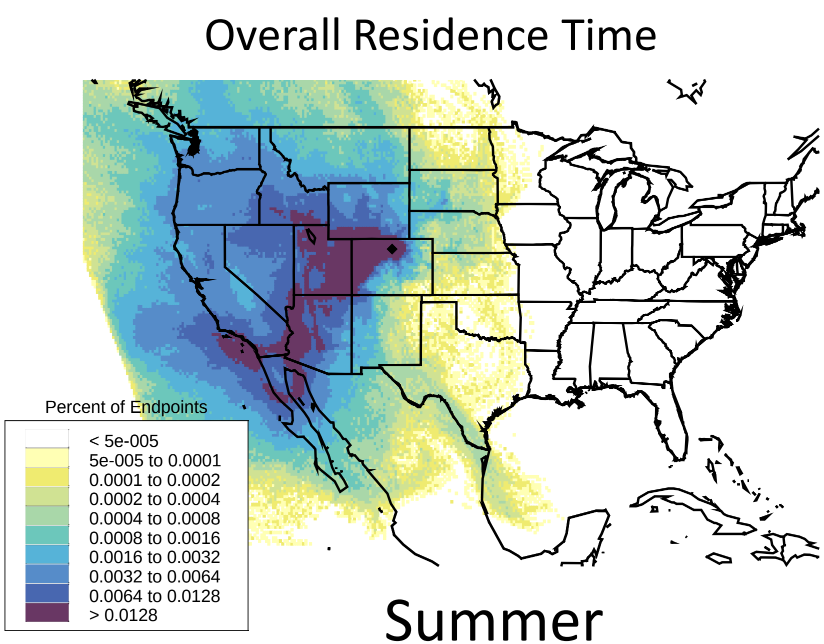
Top right:
Overall Source
Contribution Function
(ORT with central
peak removed)

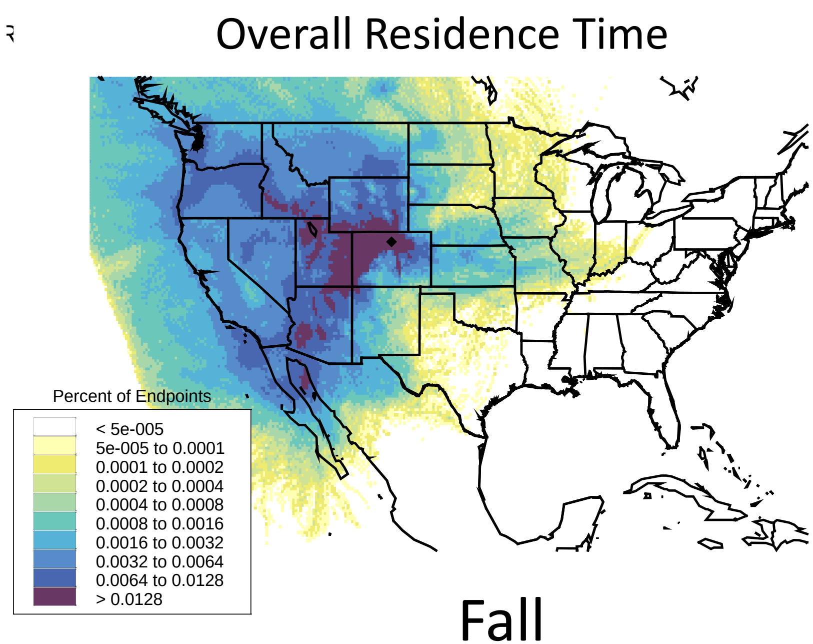
All Months
All Hours





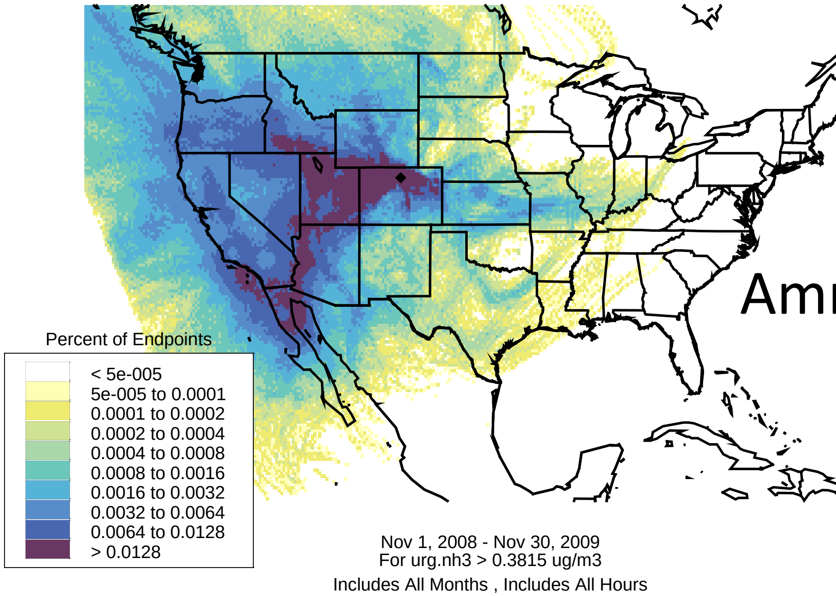
By Season For Nov 2008 – Nov 2009



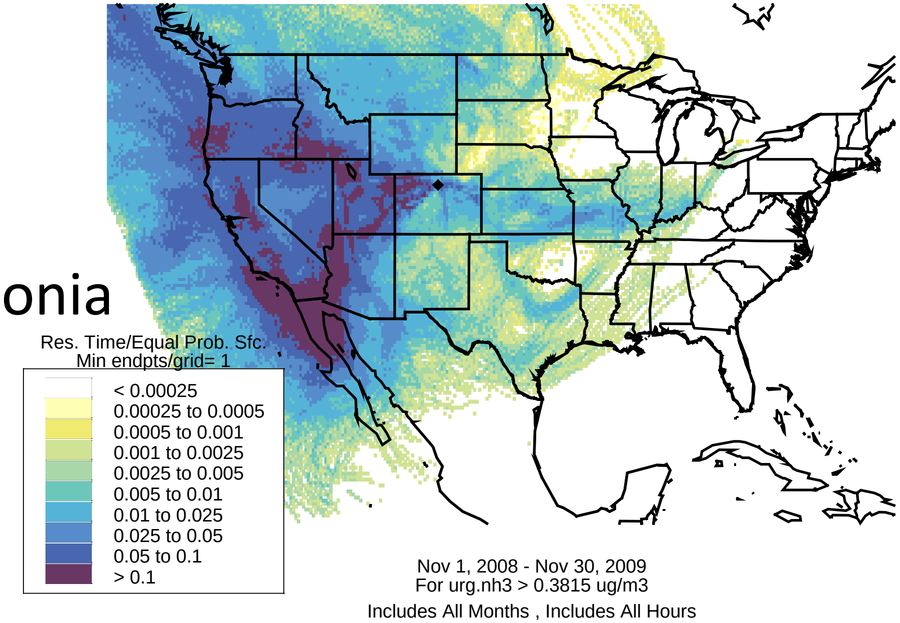


Ammonia

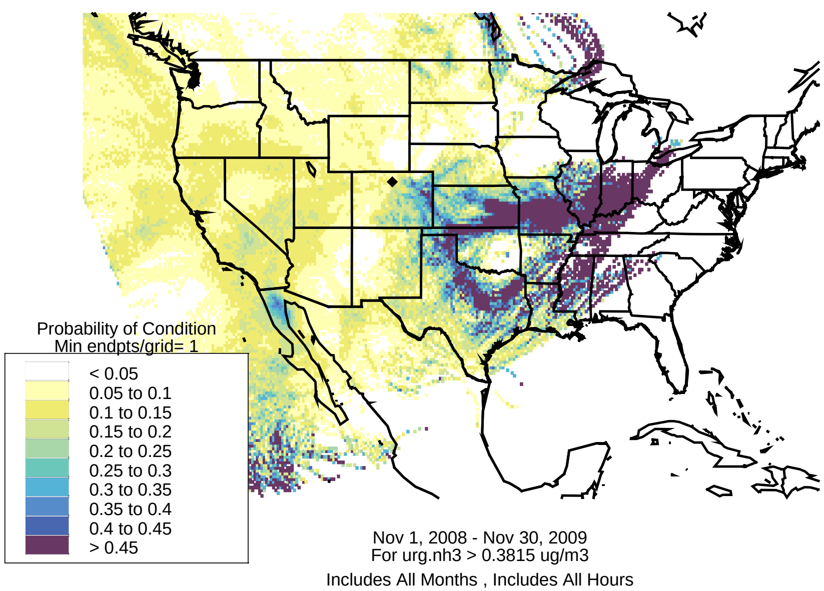
High Concentration Residence Time



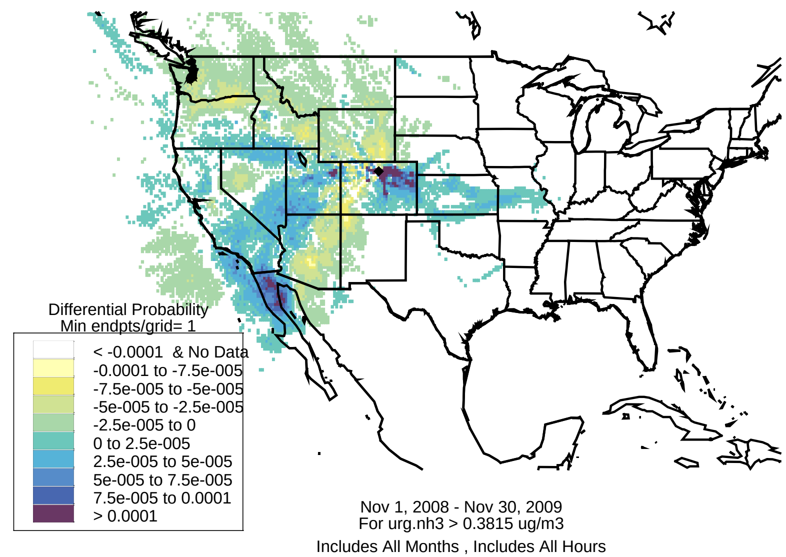
High Concentration Source Contribution Function

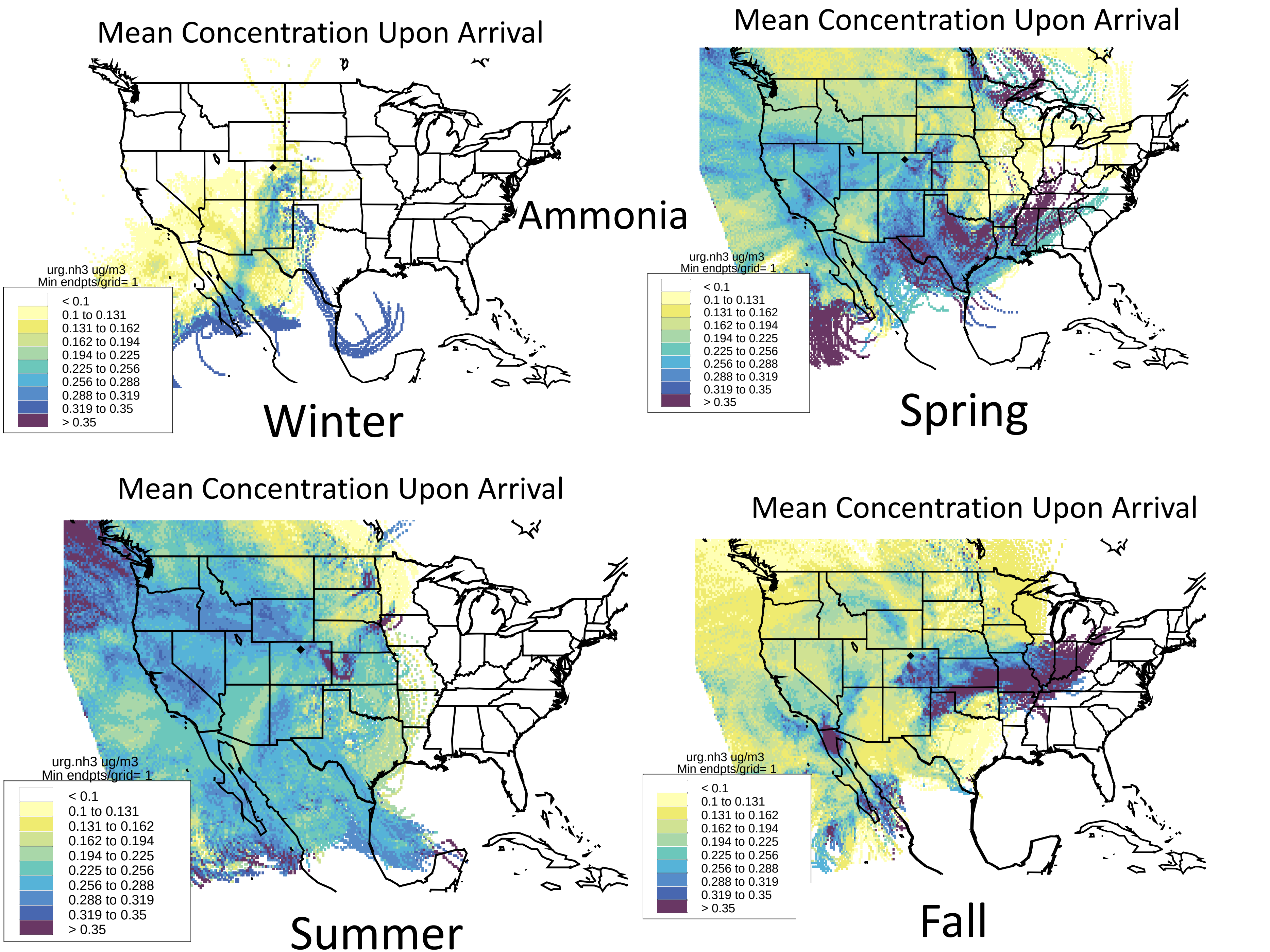


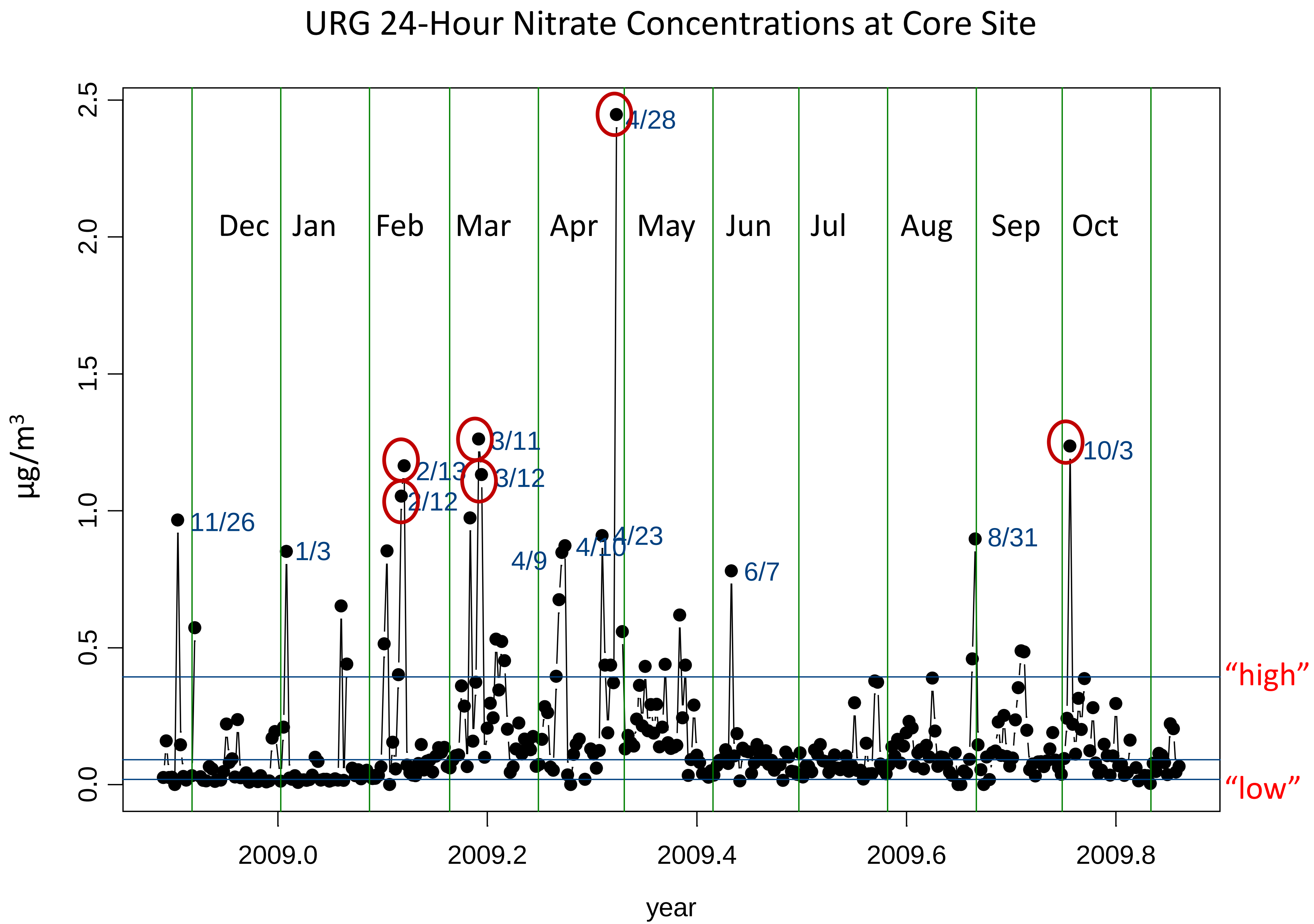
High Concentration Conditional Probability



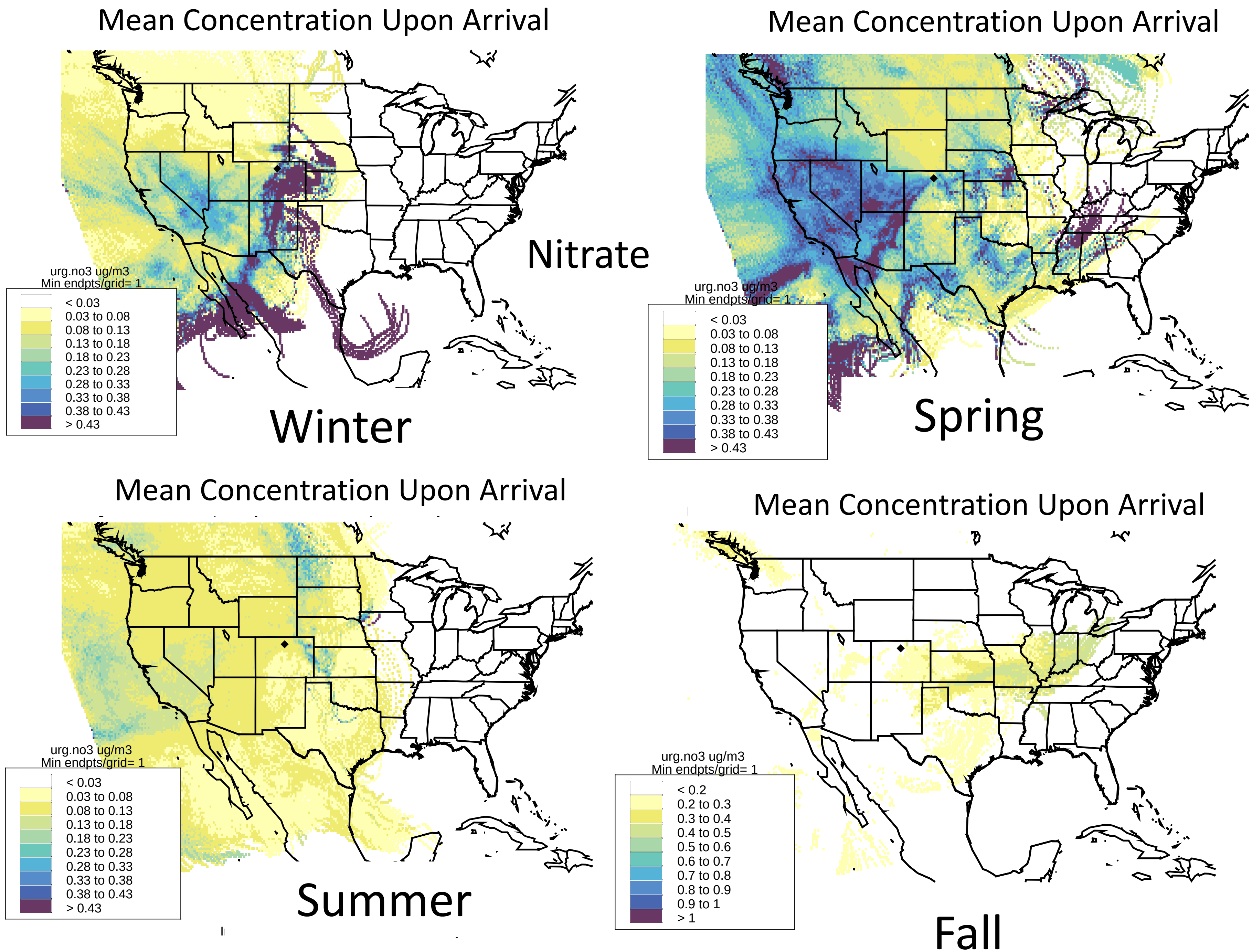
High Concentration Differential Probability




Mean Concentration Upon Arrival
urg.nh3 ug/m3
Min endpts/grid= 1
< 0.1
0.1 to 0.131
0.131 to 0.162
0.162 to 0.194
0.194 to 0.225
0.225 to 0.256
0.256 to 0.288
0.288 to 0.319
0.319 to 0.35
> 0.35
Winter
Ammonia
Mean Concentration Upon Arrival
urg.nh3 ug/m3
Min endpts/grid= 1
< 0.1
0.1 to 0.131
0.131 to 0.162
0.162 to 0.194
0.194 to 0.225
0.225 to 0.256
0.256 to 0.288
0.288 to 0.319
0.319 to 0.35
> 0.35
Spring
Mean Concentration Upon Arrival
urg.nh3 ug/m3
Min endpts/grid= 1
< 0.1
0.1 to 0.131
0.131 to 0.162
0.162 to 0.194
0.194 to 0.225
0.225 to 0.256
0.256 to 0.288
0.288 to 0.319
0.319 to 0.35
> 0.35
Summer
Mean Concentration Upon Arrival
urg.nh3 ug/m3
Min endpts/grid= 1
< 0.1
0.1 to 0.131
0.131 to 0.162
0.162 to 0.194
0.194 to 0.225
0.225 to 0.256
0.256 to 0.288
0.288 to 0.319
0.319 to 0.35
> 0.35
Fall



URG 24-Hour Nitrate Concentrations at Core Site
µg/m³
year
2.5
2.0
1.5
1.0
0.5
0.0
2009.0
2009.2
2009.4
2009.6
2009.8
Dec
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
11/26
1/3
2/13
2/12
3/11
3/12
4/9
4/10
4/23
4/28
6/7
8/31
10/3
“high”
“low”


Mean Concentration Upon Arrival
Nitrate
urg.no3 ug/m3
Min endpts/grid= 1
< 0.03
0.03 to 0.08
0.08 to 0.13
0.13 to 0.18
0.18 to 0.23
0.23 to 0.28
0.28 to 0.33
0.33 to 0.38
0.38 to 0.43
> 0.43
Winter
Mean Concentration Upon Arrival
urg.no3 ug/m3
Min endpts/grid= 1
< 0.03
0.03 to 0.08
0.08 to 0.13
0.13 to 0.18
0.18 to 0.23
0.23 to 0.28
0.28 to 0.33
0.33 to 0.38
0.38 to 0.43
> 0.43
Spring
Mean Concentration Upon Arrival
urg.no3 ug/m3
Min endpts/grid= 1
< 0.03
0.03 to 0.08
0.08 to 0.13
0.13 to 0.18
0.18 to 0.23
0.23 to 0.28
0.28 to 0.33
0.33 to 0.38
0.38 to 0.43
> 0.43
Summer
Mean Concentration Upon Arrival
urg.no3 ug/m3
Min endpts/grid= 1
< 0.2
0.2 to 0.3
0.3 to 0.4
0.4 to 0.5
0.5 to 0.6
0.6 to 0.7
0.7 to 0.8
0.8 to 0.9
0.9 to 1
> 1
Fall

Regression Techniques of Source Apportionment

Assumption: The concentration measured at the receptor is some linear combination of the contributions of several sources.

$$\textbf{Concentration} = a_1\ \textbf{Source}_1 + a_2\ \textbf{Source}_2 + \ldots$$

TrMB (Trajectory Mass Balance)

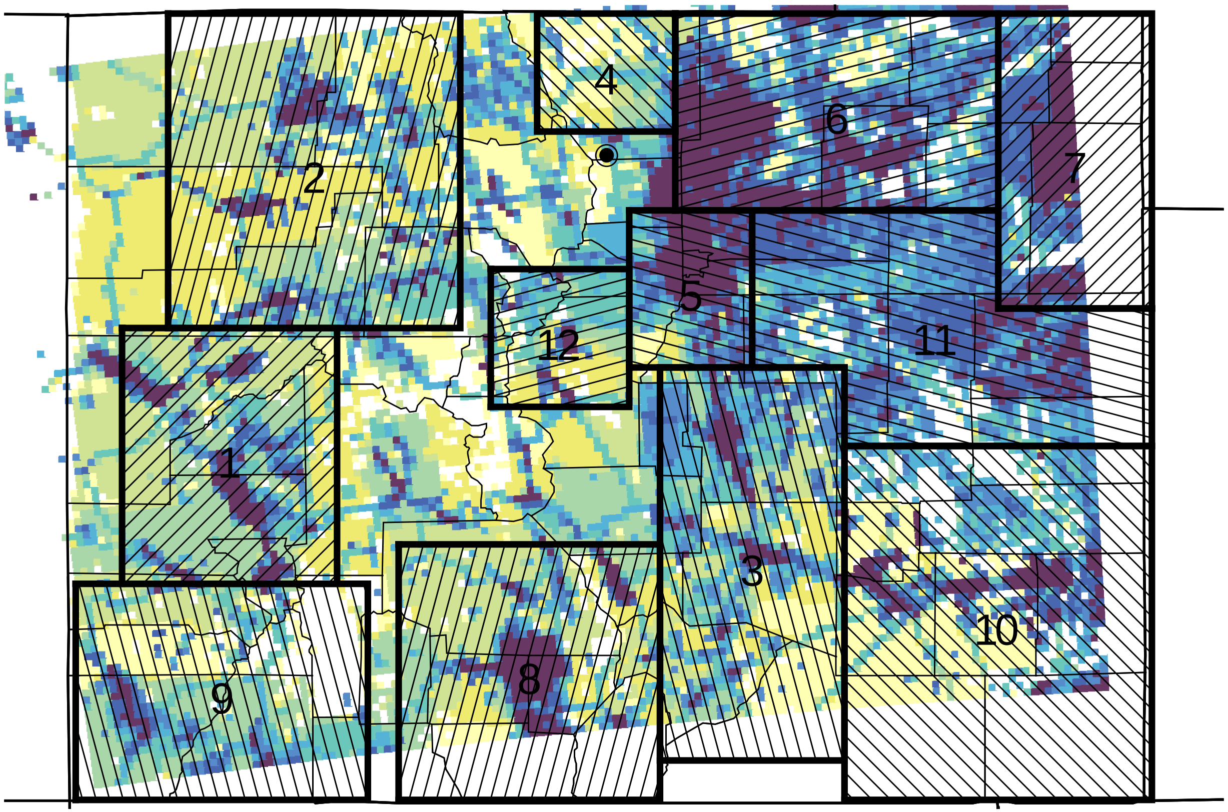
Use many concentrations of 1 species and (most simply) counts of trajectory endpoints in source regions to predict average attributions over a long period.

More Sensitive To:

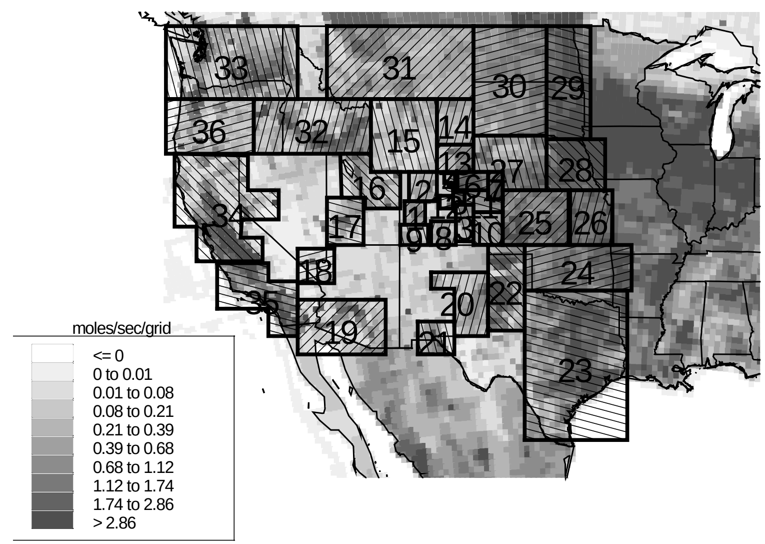
Choice of source areas, input met data, trajectory model, and including all relevant areas.

Less Sensitive To:

Trajectory length, trajectory height.



2006 TrMB Source Areas Overlaid on 2009 Ammonia Emissions



TrMB Attributions of Ammonia Concentrations 2006 (final) and 2009 (PRELIMINARY!)

	Colorado (%)	Eastern U.S. (%)	Western U.S. (%)	Concentration ($\mu g/m^3$)
Spring 2006	56 ± 5	8 ± 2	36 ± 4	0.14
Summer 2006	50 ± 7	21 ± 3	29 ± 5	0.35
Winter 2008/09	37	44	20	0.09
Spring 2009	32	6	62	0.24
Summer 2009	30	10	61	0.27
Fall 2008/09	23	10	66	0.19

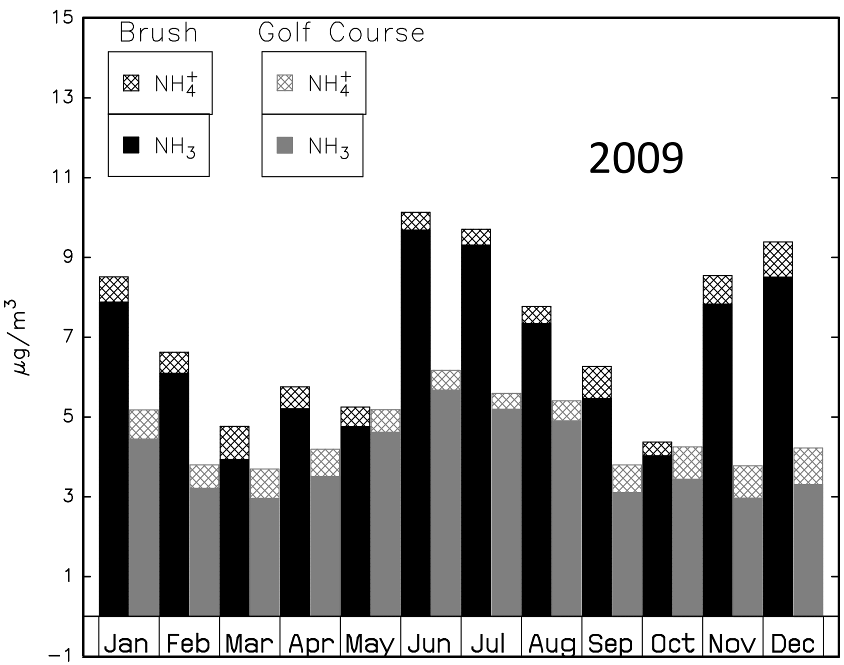
<u>Upcoming work</u>:

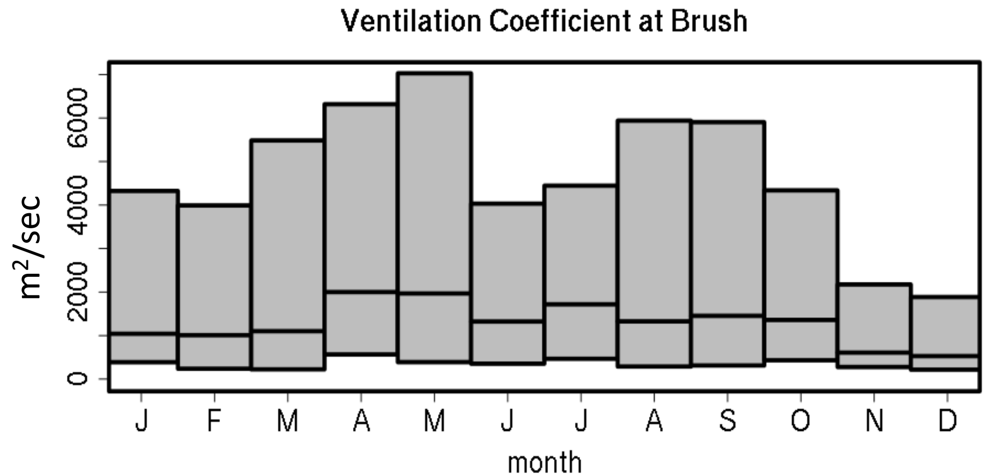
1. Run wrf again with more observational nudging.
2. Re-select source areas (currently using those from 2006) to better reflect 2009 emissions and reduce collinearities between source areas.
3. Try an eigenvector technique to automate source area choices.

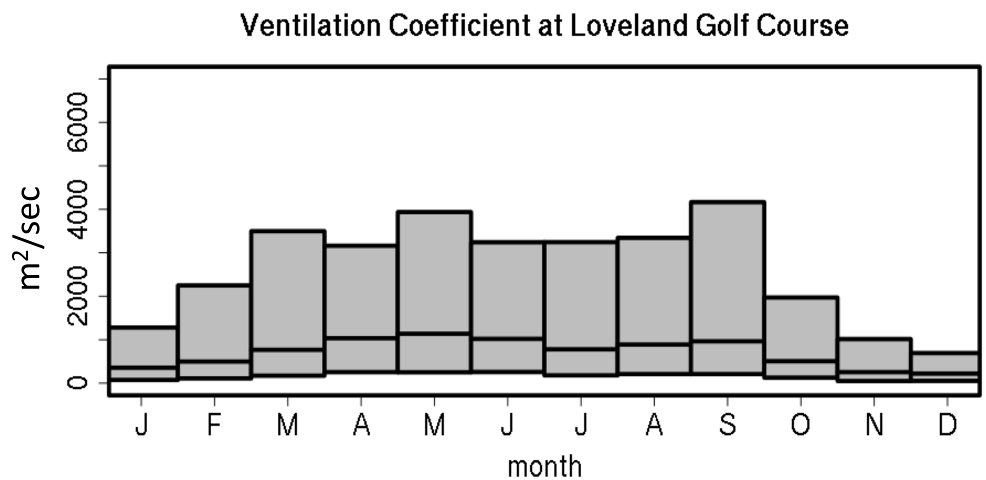
CAFO ammonia emissions near Brush are about twice as high in the summer as in the winter. Why such high reduced N concentrations in the winter?

A probable meteorological answer: Wintertime stagnation.

Ventilation coefficient is the mixing height multiplied by the wind speed.







Summary

1. ROMANS II as a follow up to ROMANS I - Enhanced techniques to better measure reactive nitrogen. ROMANS II was a full year while ROMANS I was April and July only. New emissions data, new met model, tweaks to AQ model, ensemble trajectories.

2. Challenges – Reactive N is hard to measure and hard to model. Complex terrain adds complexity. WRF's wind speeds are too high, it has too much precipitation, and WRF has trouble with wind directions in small valleys. Yet, it's still better than the alternative wind fields and improvements in nudging are planned.

3. Preliminary back trajectory findings:
   - There are seasonal and diurnal trends in transport. Upslope easterly flow is more likely in the afternoon, somewhat more likely in summer. Easterly flow is more likely during precipitation than during dry periods.
   - Predominant wind flow is westerly, so simple trajectory methods attribute the highest *mean* fraction to sources to the west.
   - However, when there is easterly transport, the likelihood of high concentrations is high.
   - There is evidence of low winter mixing heights and low wind speeds affecting concentrations near sources.

These results are preliminary and only part of a weight-of-evidence analysis. These are (so far) attributions of concentrations, not of deposition.