

A WRF Application to Support Nitrogen Deposition Modeling for Rocky Mountain National Park



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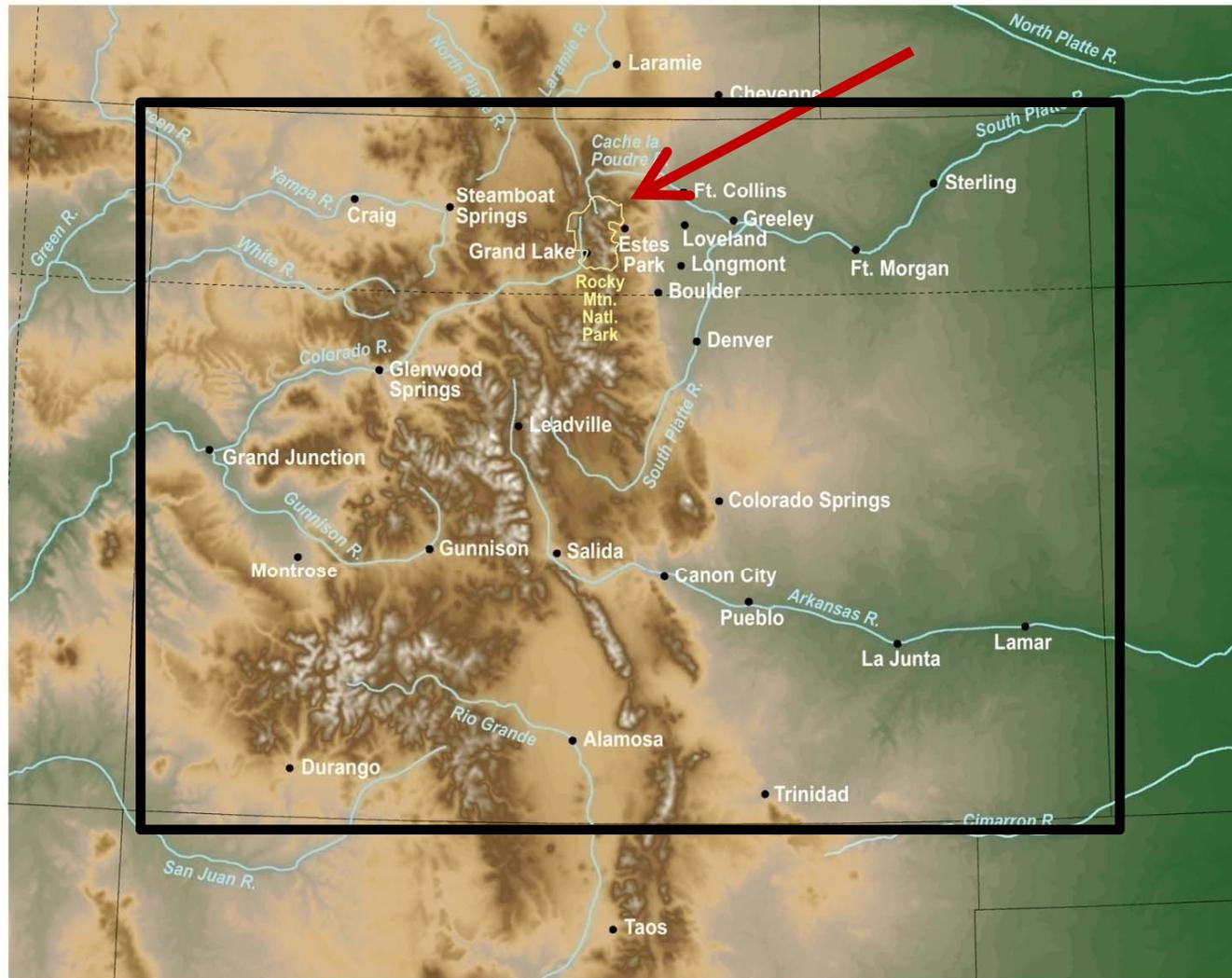
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Atmosphere
Fort Collins, CO
(now at AECOM)



11th Ad-Hoc Meteorological Modeling Group Meeting
28-29 June 2012, Boulder, CO

Rocky Mountain Atmospheric Nitrogen and Sulfur (ROMANS) Studies

110 W



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

Multiple approaches from simple to complex with reconciliation of differences. (Weight of Evidence)

- 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 models.
 - Hybrid Models.



ROMANS II Meteorological Goals

- Produce 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. (Largest fraction of N deposition is wet deposition.)

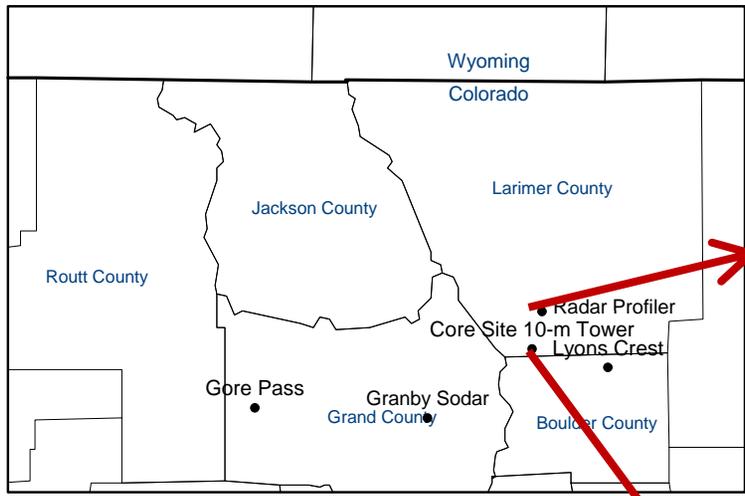
Known Meteorological Issues

Complex Terrain = complex meteorology & fine scale inhomogeneity

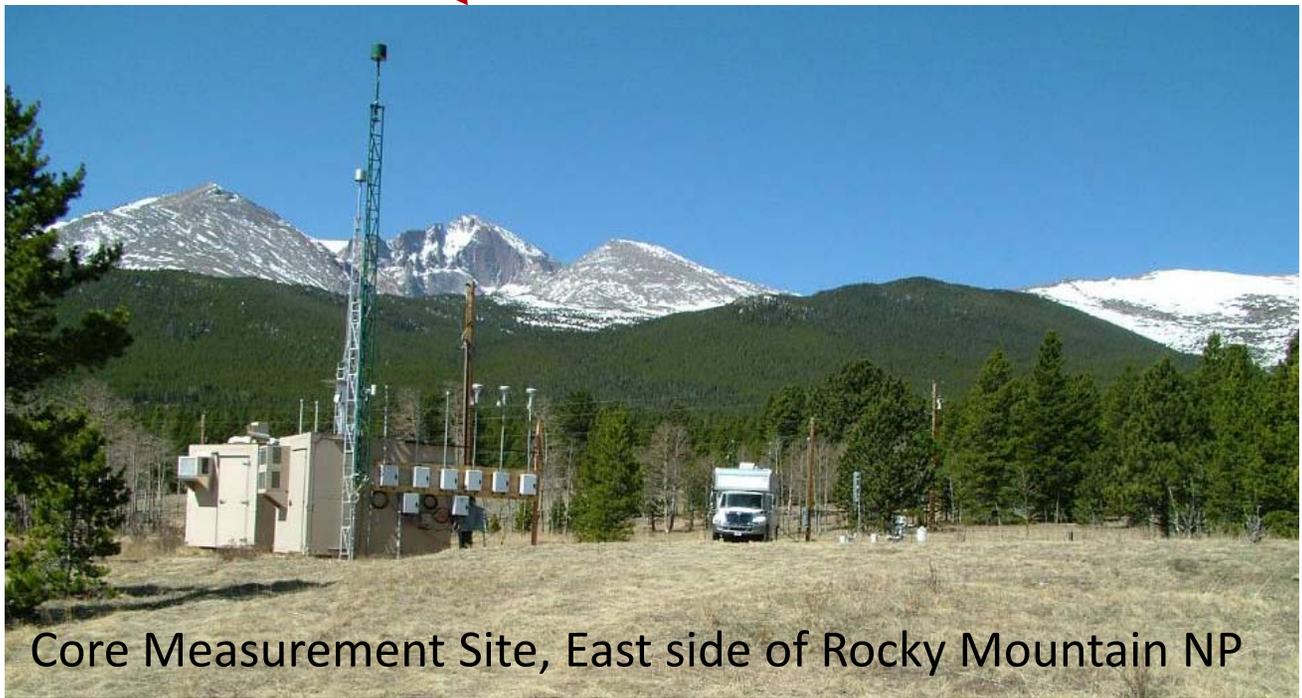
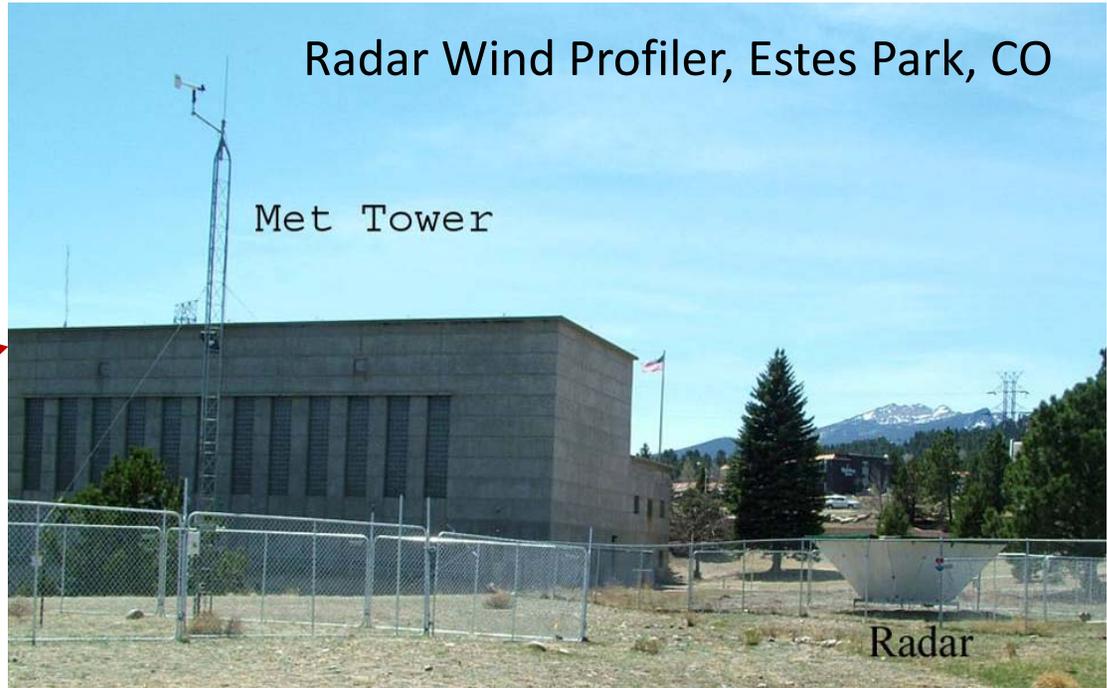
- Complex diurnal and seasonal mountain circulation patterns
- Inversions & stagnation in valleys
- Orographic precipitation & isolated convective storms
- Fewer observations in remote mountainous areas



Meteorology Monitoring Locations - ROMANS Study



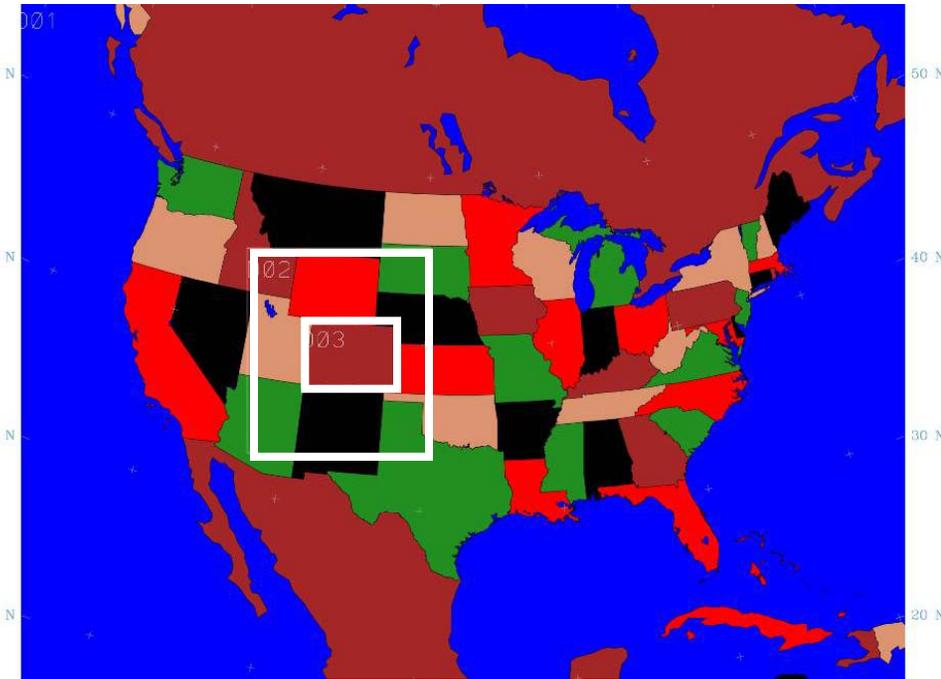
Distances from Core Site:
to Estes Park Radar Profiler = 12 Km
to Lyons = 24 Km
to Granby SODAR = 37 Km
to Gore Pass = 86 Km



Core Measurement Site, East side of Rocky Mountain NP

Profiler for
Apr-Dec,
2009 only

WRF Mesoscale Meteorological Modeling



Domain 1
36 km, 165 x 129

Domain 2
12 km, 103 x 115

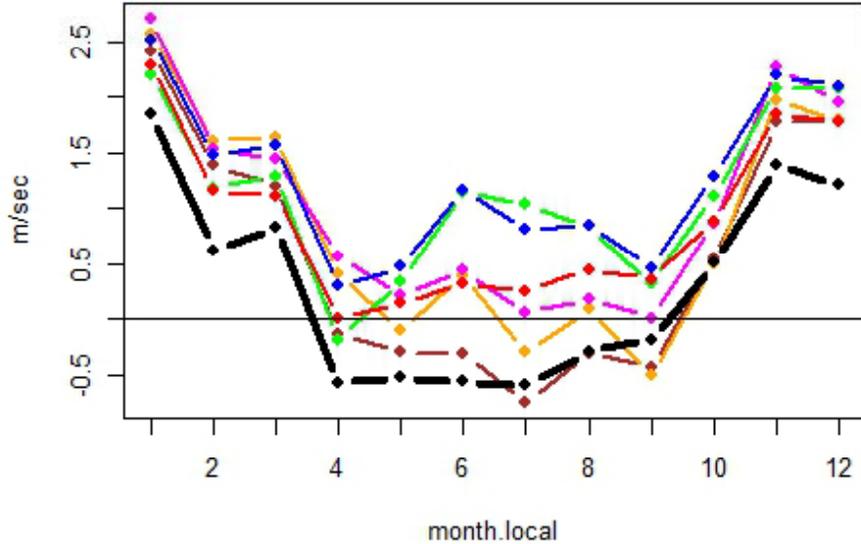
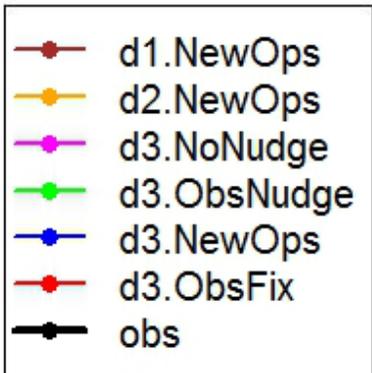
Domain 3
4 km, 163 x 118

34 layers

Several Runs for Nov 2008 – Nov 2009

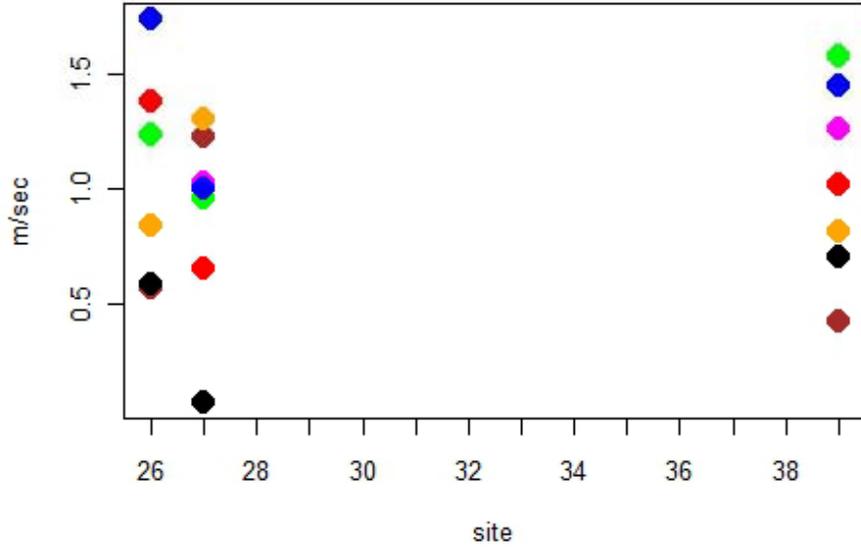
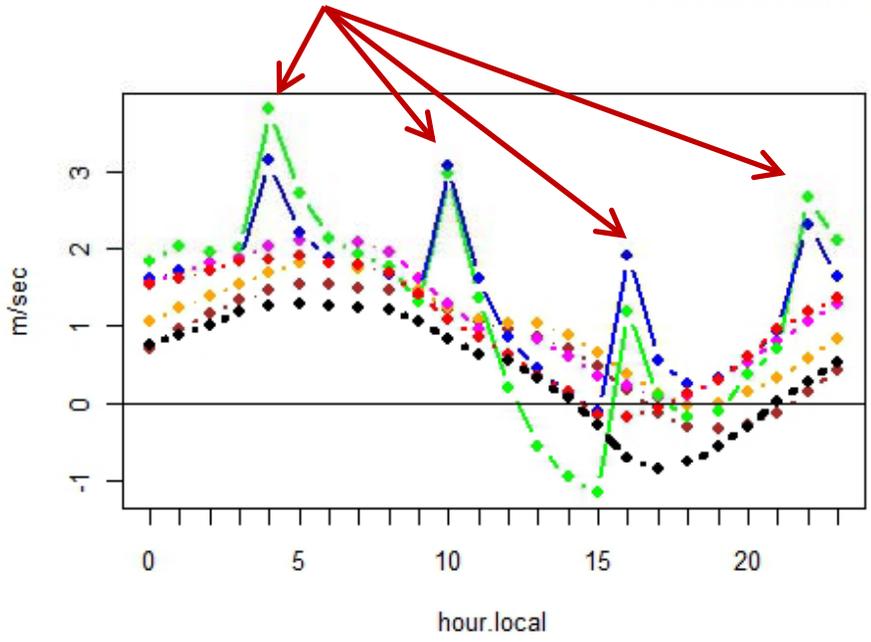
1. First run with simple physics with new hardware & software. (Get it running)
2. Added observational nudging on fine domain.
3. Put more thought into physics options.
4. Removed satellite data from observational nudging. (See next slide)
5. Ran MM5 for comparison.
6. Updated to most recent version of model (3.3.1 from 3.2.1)
7. Changed observational data in CO from NCAR to MADIS.
8. Removed aircraft data from MADIS.
9. Experimented with different obs nudging coefficients & radius of influence
10. Would like to try smaller grid size over CO **but No More Time!!!**

Easterly Wind Component



WHAT is happening every six hours ? ...

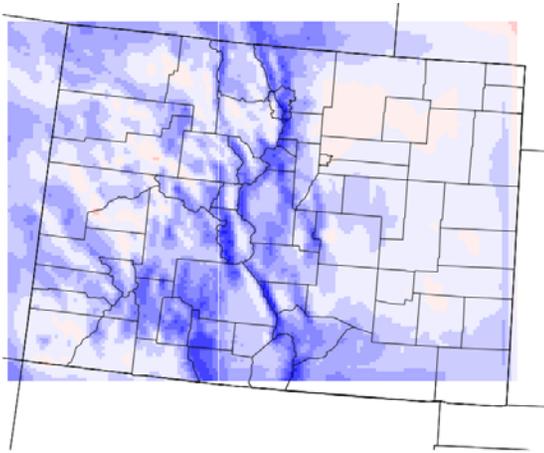
Northeast Plains (26,27,39)



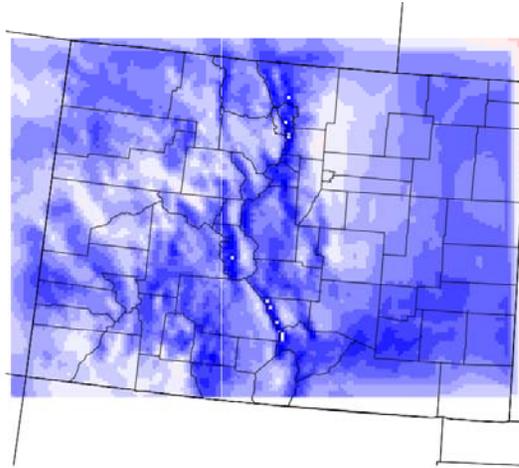
Contours of U10 in Colorado for June 2009 (Lots of Easterlies at Estes Park)

Effect of Different Observational Data for Nudging

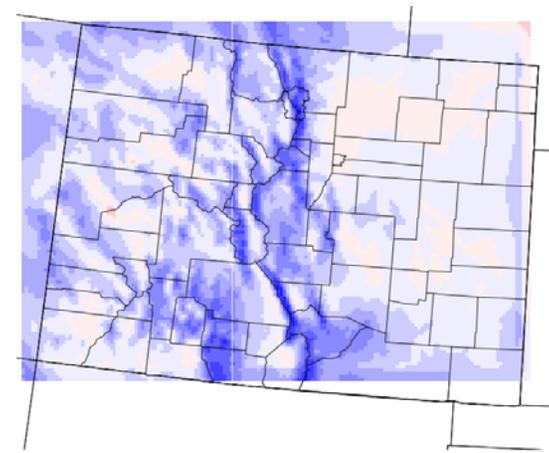
NCAR DS461.0, DS351.0



MADIS with ACARS

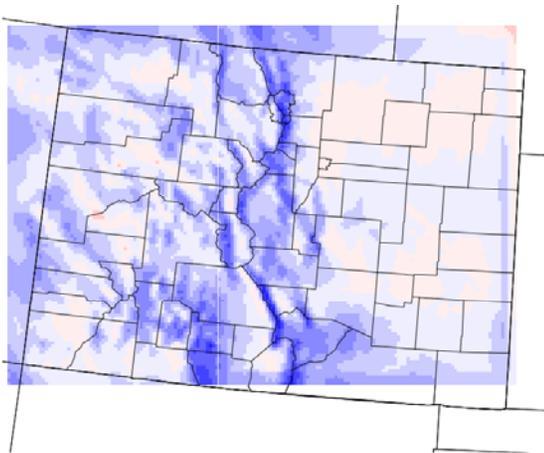


MADIS with No ACARS

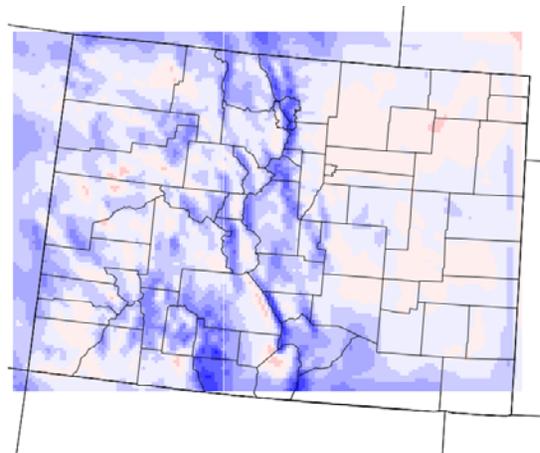


Effect of Different Nudging Coefficients for Winds (Default = $6e-04$ 1/s)

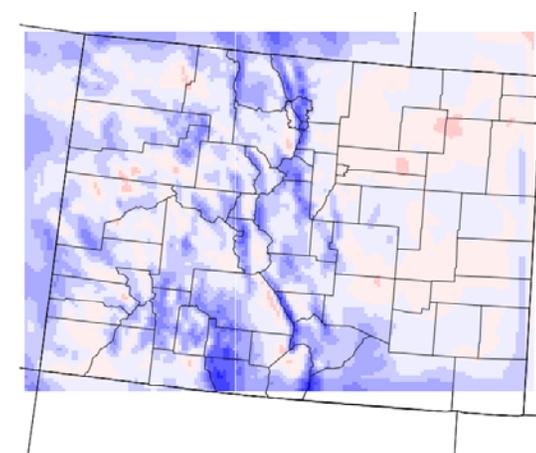
$1e-03$ 1/s



$3e-03$ 1/s



$6e-03$ 1/s

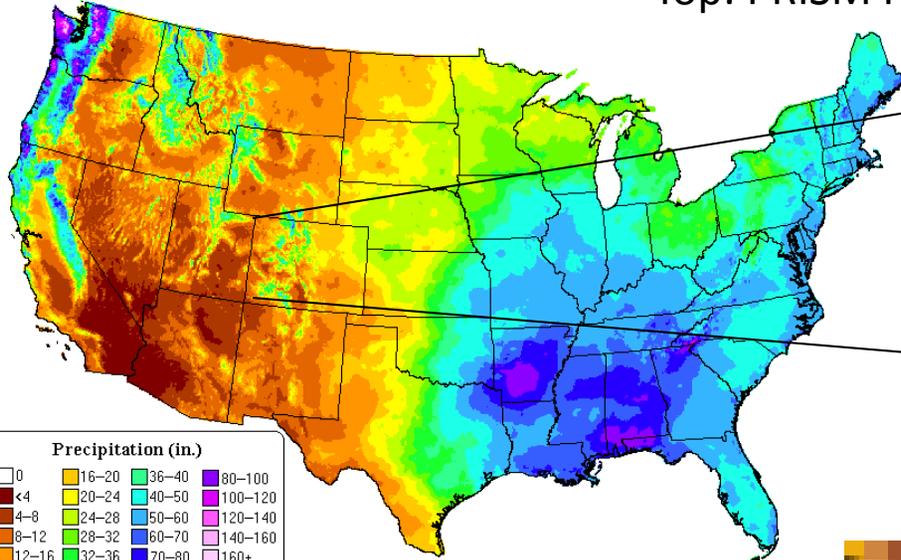


Final WRF Modeling Choices

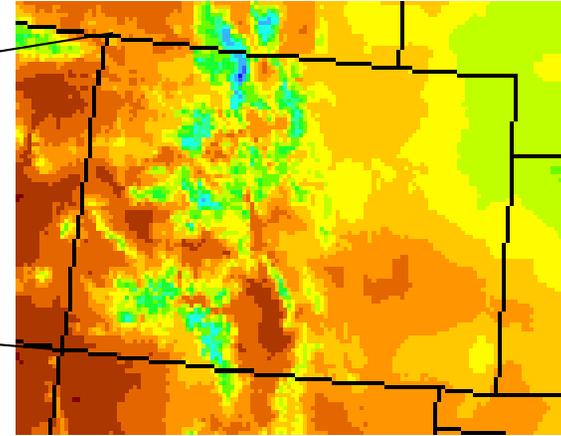
Parameter	Choice
Vertical Layers	34 layers (WRAP)
Forecast Length	3.5 day duration with 12-hour spinup overlap
Initial/Boundary Conditions and Obs nudging data	NARR – 3 hrs, 32 Km resolution MADIS, Estes Park profiler, Core tower
Nudging	Analysis on 36 km, obs on 4 km obs_rinx = 60 km (default=200) obs_coef_wind = 3e-3 1/s (default=6e-4)
Radiation	RRTMG
Microphysics	wrf single moment 5-class
Cumulus Parameterization	Kain-Fritsch (new) on 4 km Domain
PBL Scheme/Land Surface Model	Yonsei University/ 5-layer thermal diffusion

Precipitation: Annual 2009
Final Data

Top: PRISM Precipitation 2009 Total

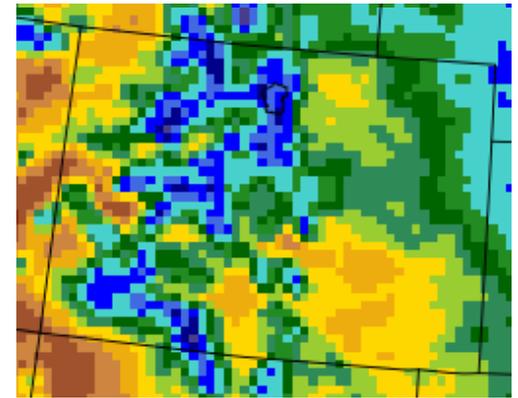
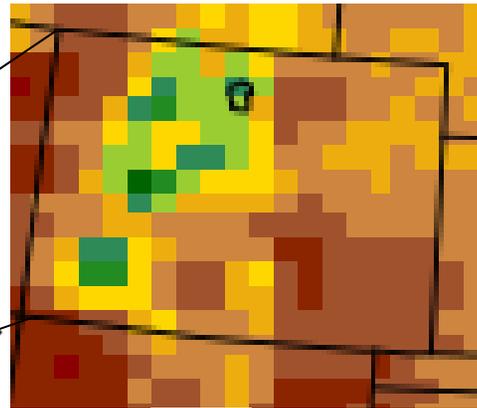


Copyright (c) 2010, PRISM Climate Group, Oregon State University
<http://prism.oregonstate.edu> - Map created Jun 08 2010

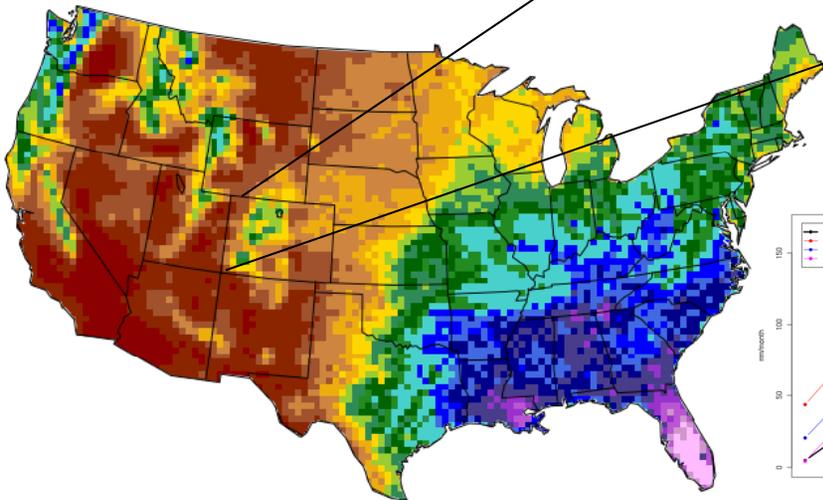


WRF 36-km Domain

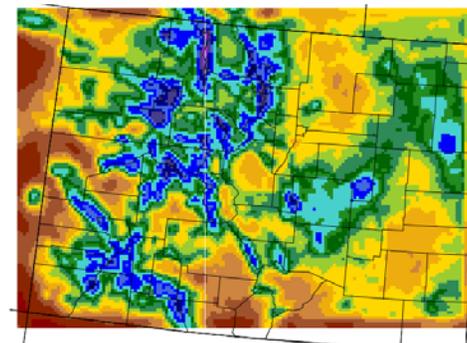
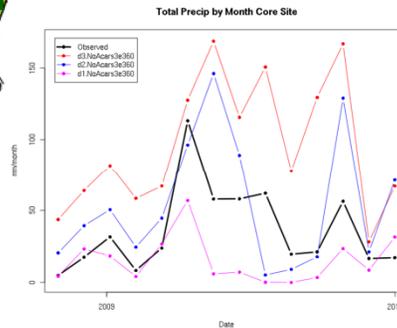
WRF 12-km Domain



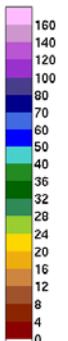
WRF 36-km Domain 2009 Total



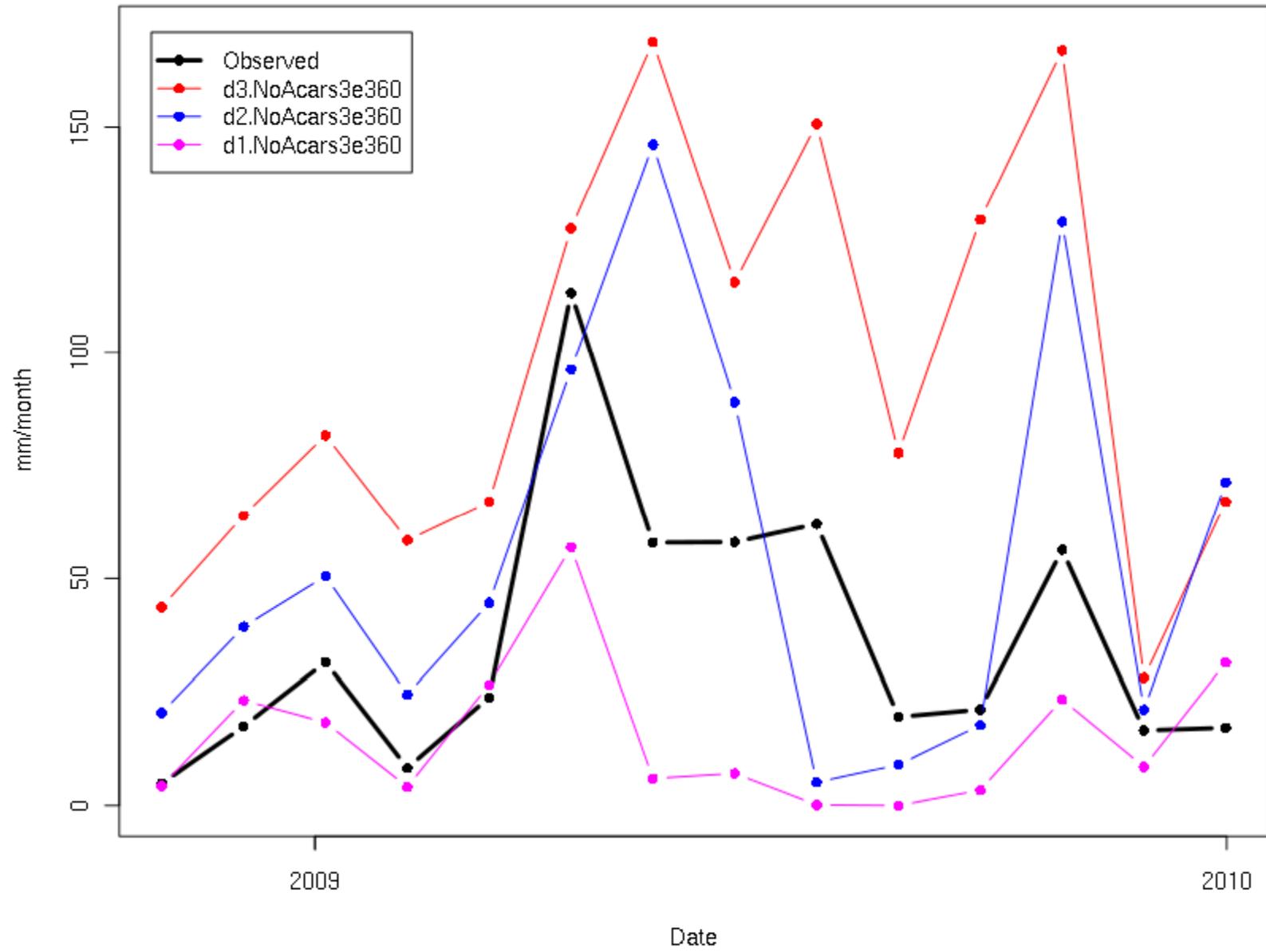
WRF 4-km Domain



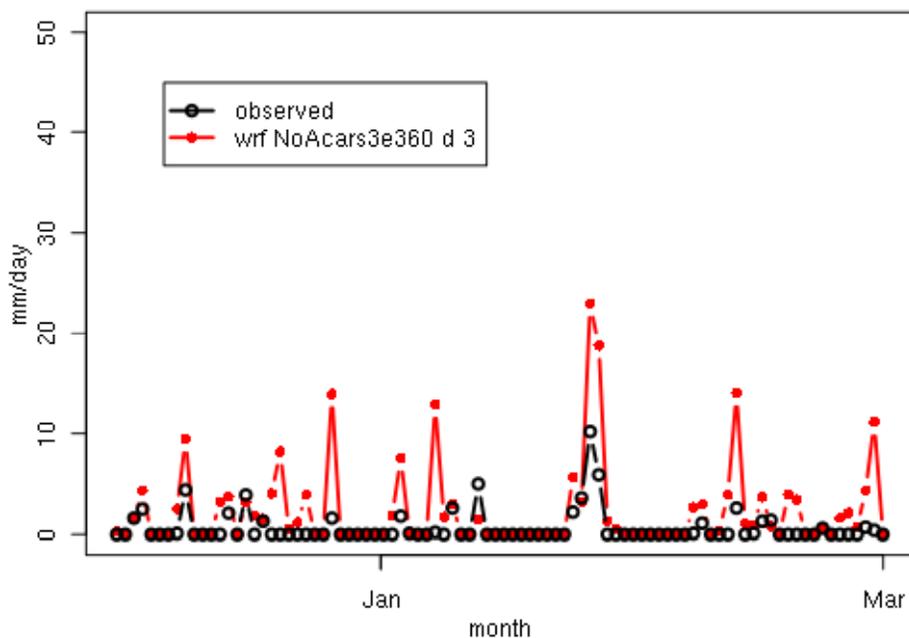
in/year



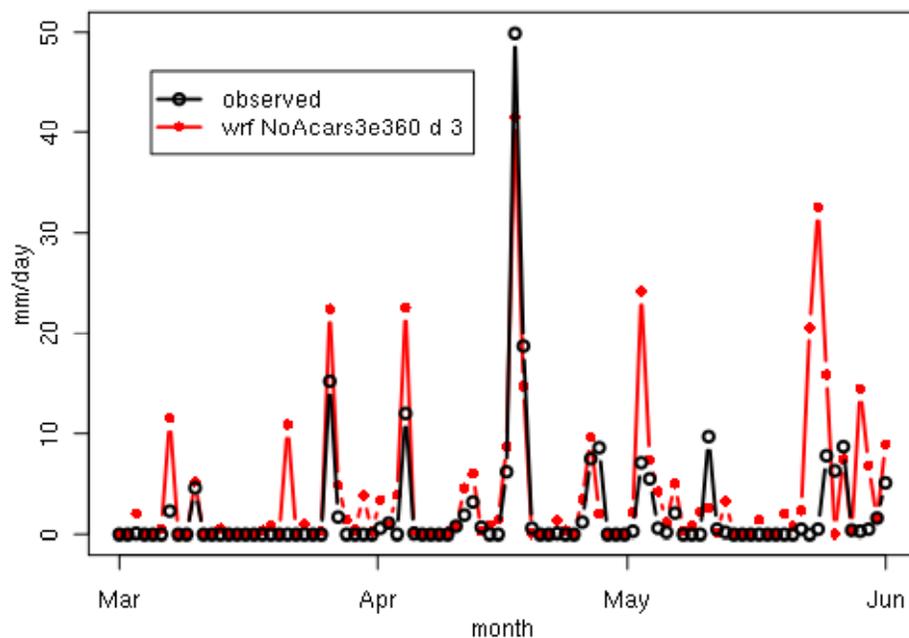
Total Precip by Month Core Site



winter 2009



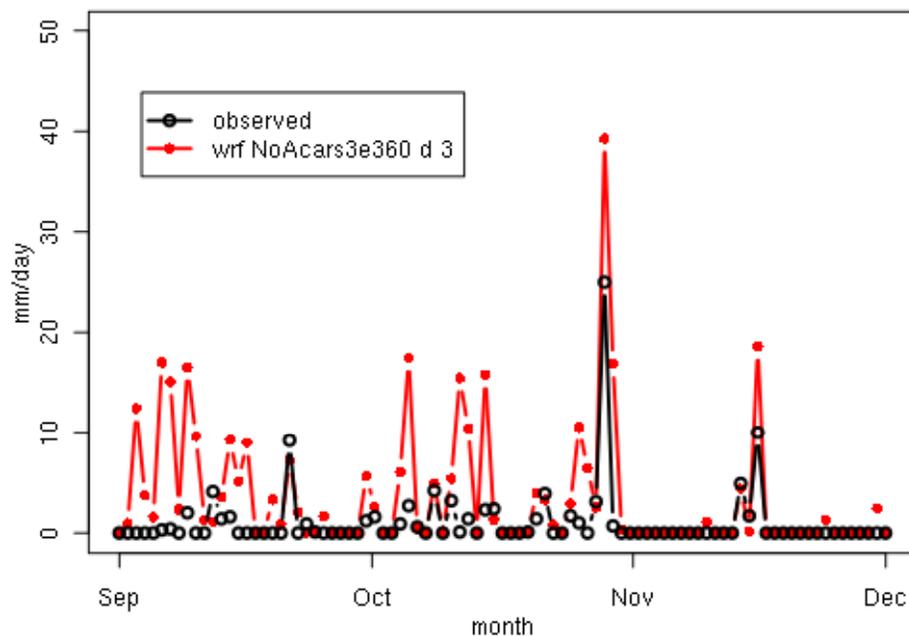
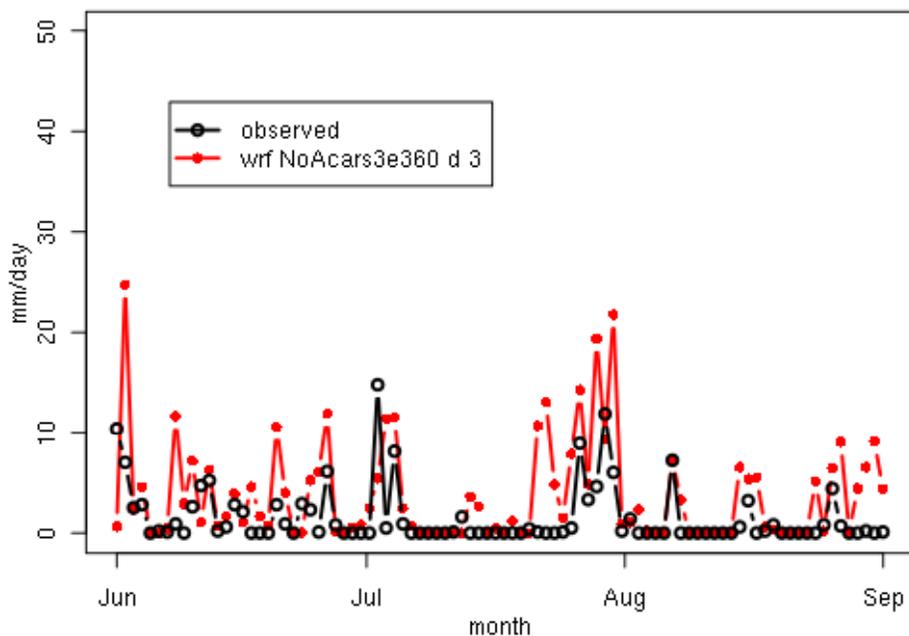
spring 2009



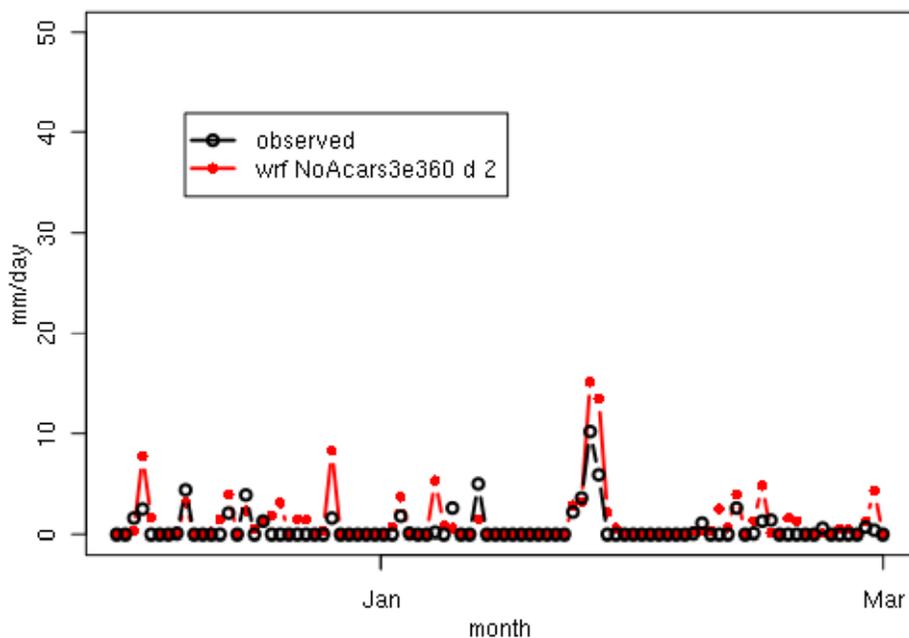
summer 2009

Daily Precip – ROMANS Core Site d3

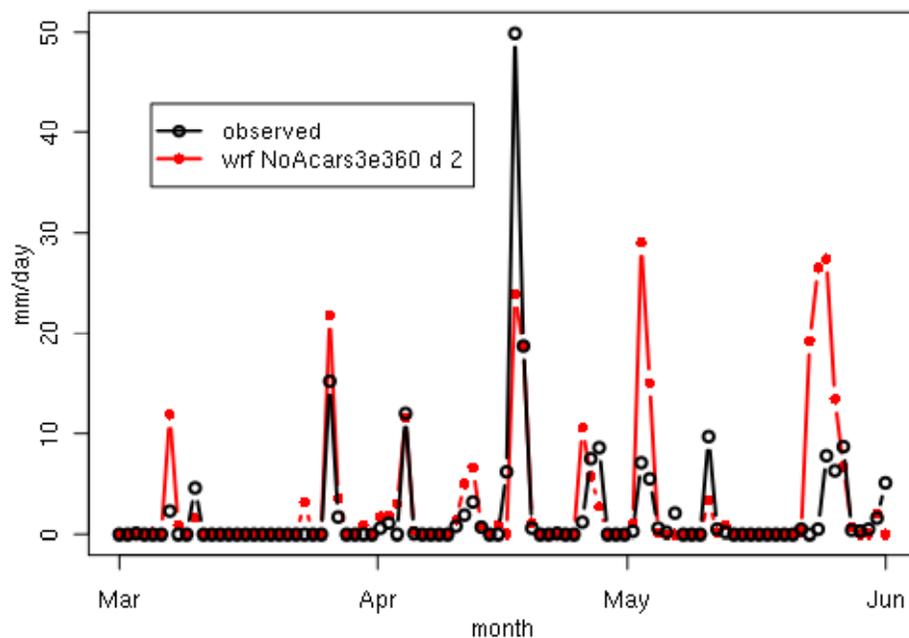
fall 2009



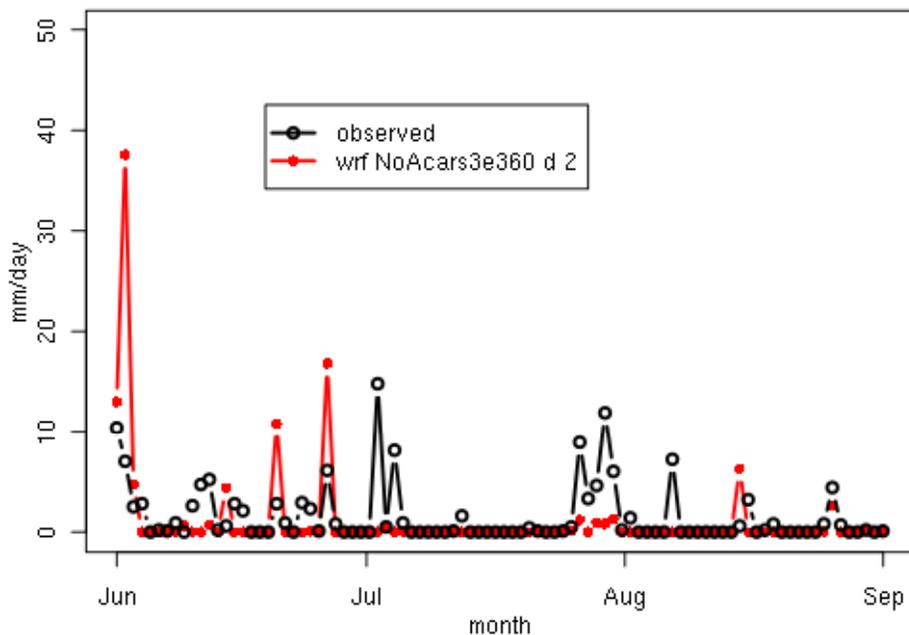
winter 2009



spring 2009

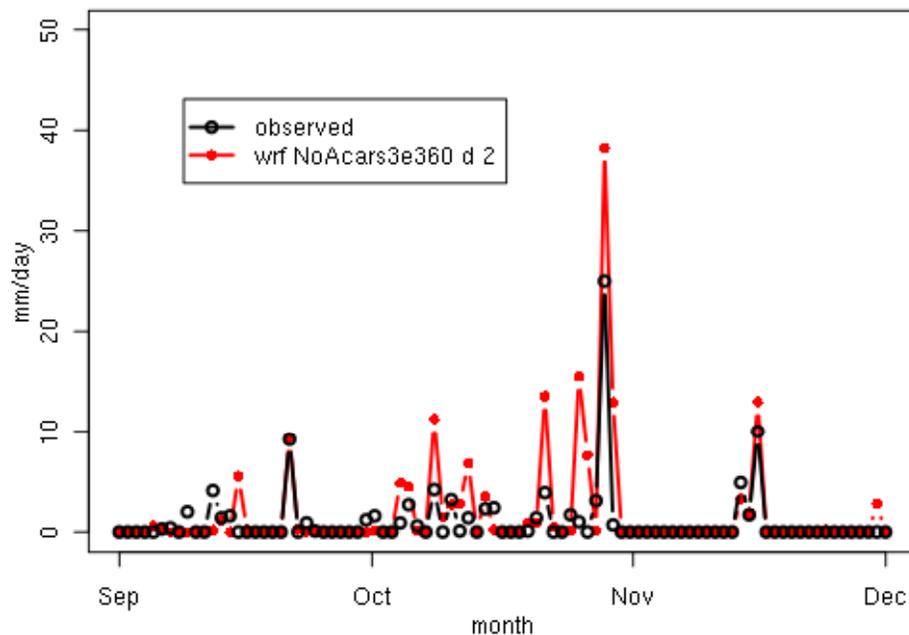


summer 2009

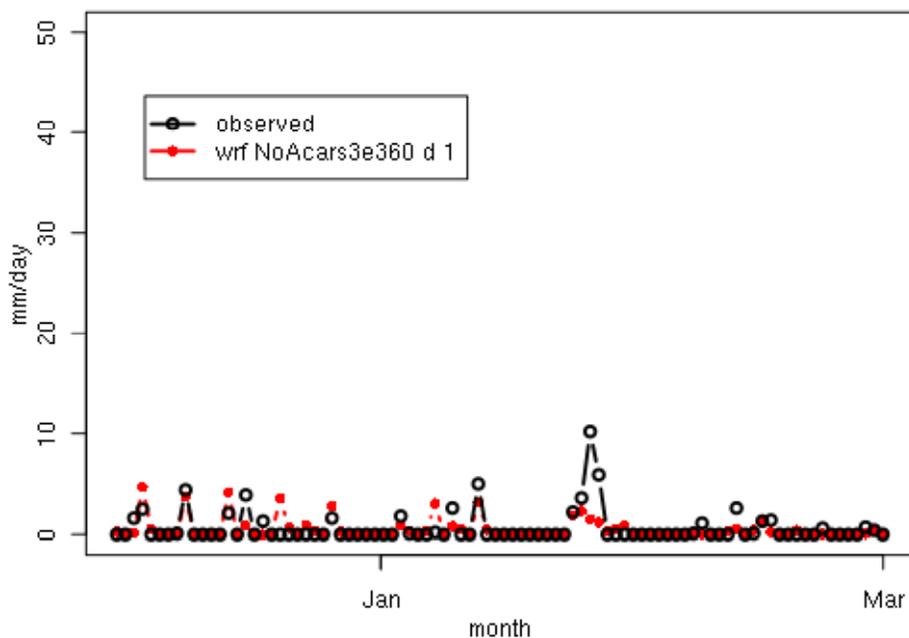


Daily Precip – ROMANS Core Site d2

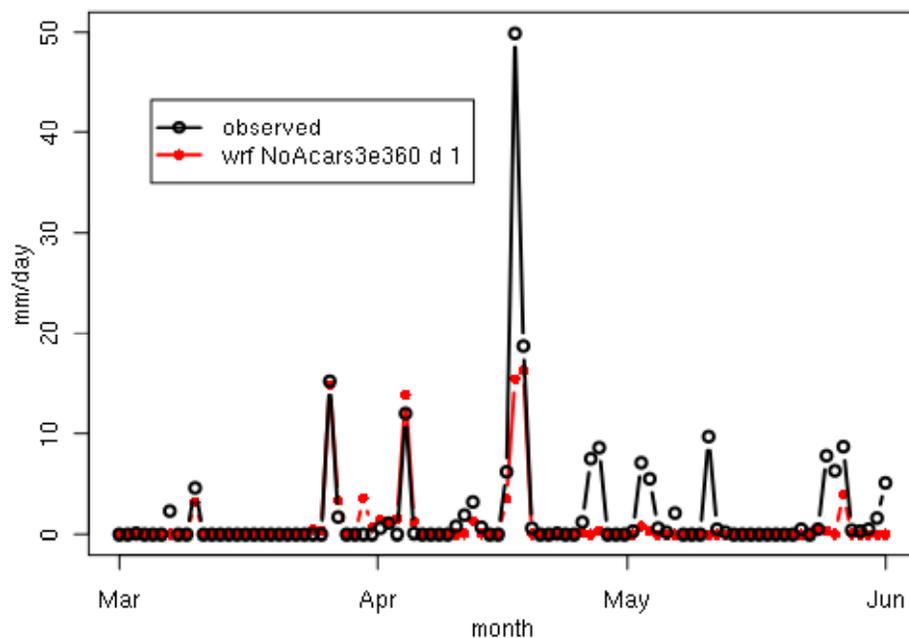
fall 2009



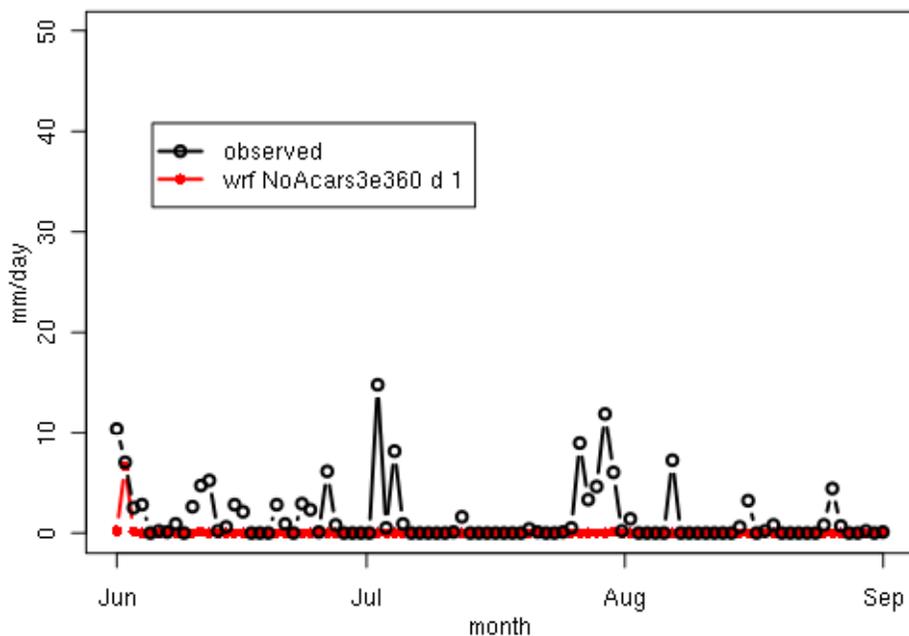
winter 2009



spring 2009

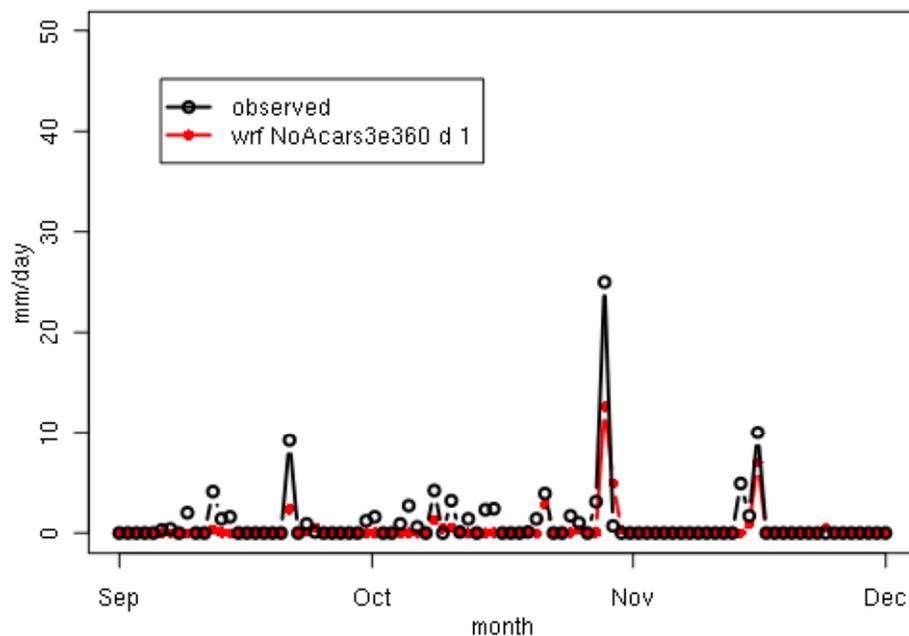


summer 2009



Daily Precip – ROMANS Core Site d1

fall 2009



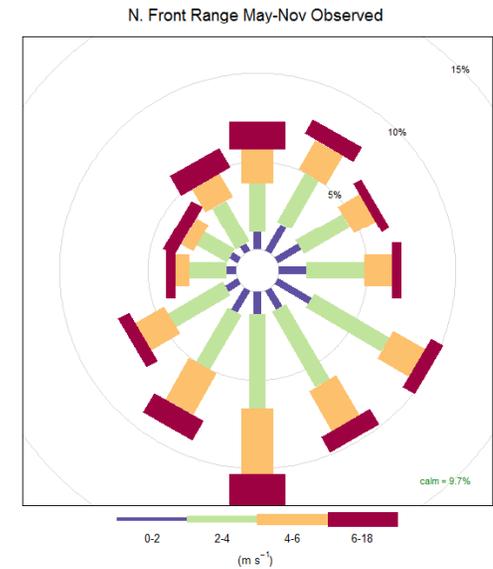
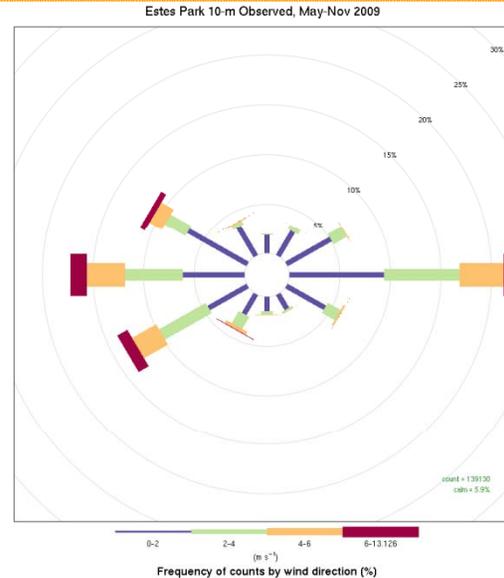
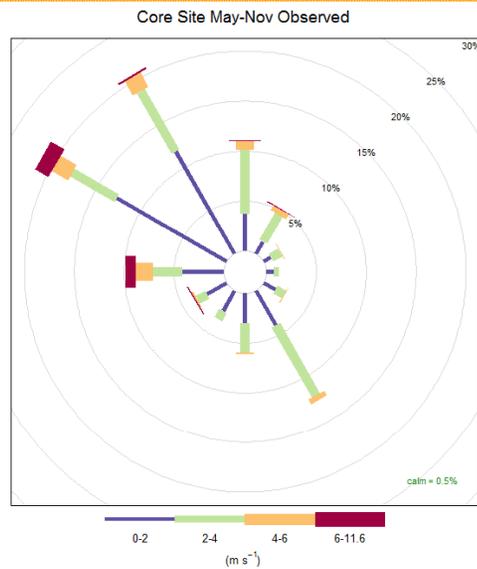
10-m Wind Roses May-Nov 2009

RMNP – ROMANS Core Site

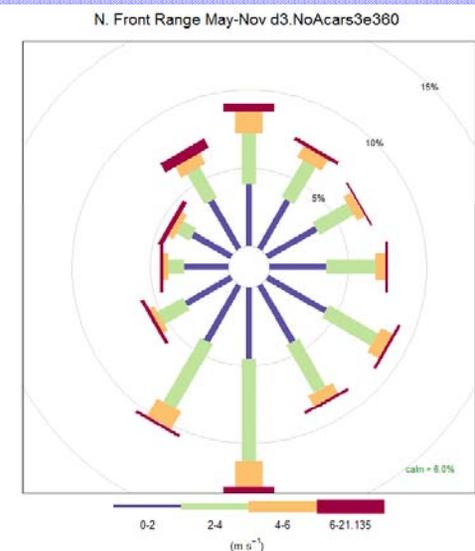
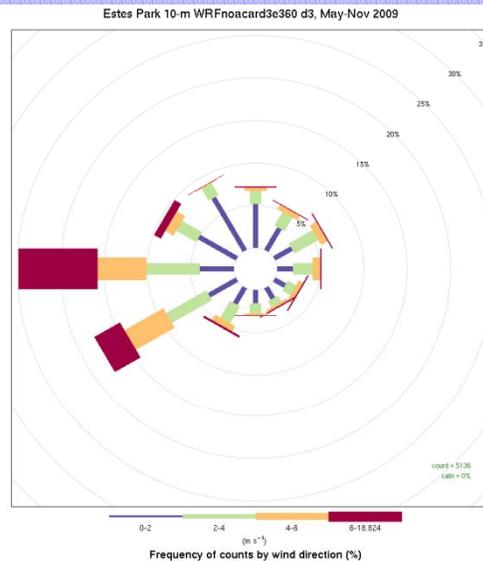
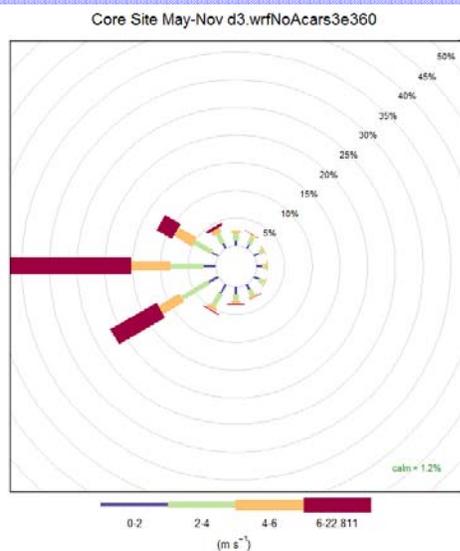
Estes Park – 12 km away

N. Front Range (7 sites)

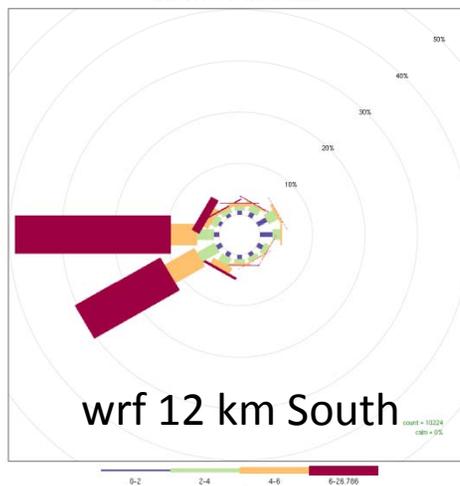
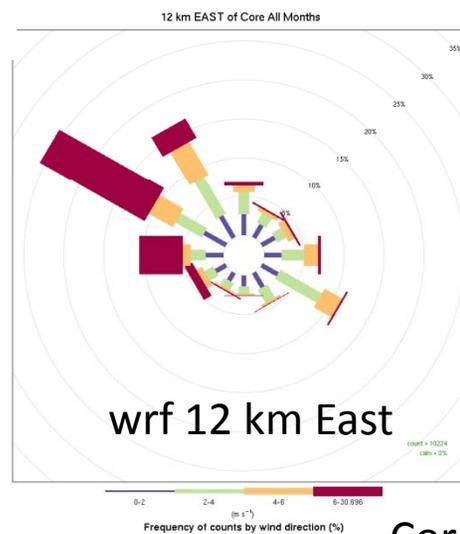
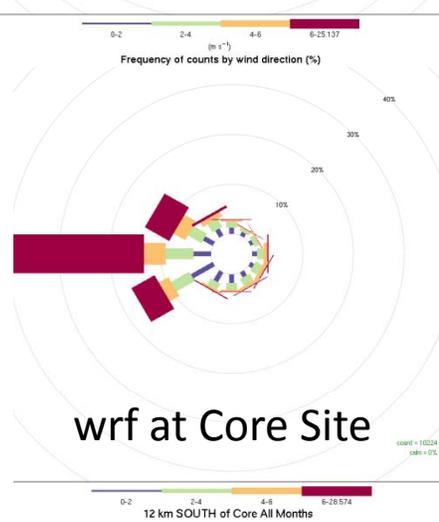
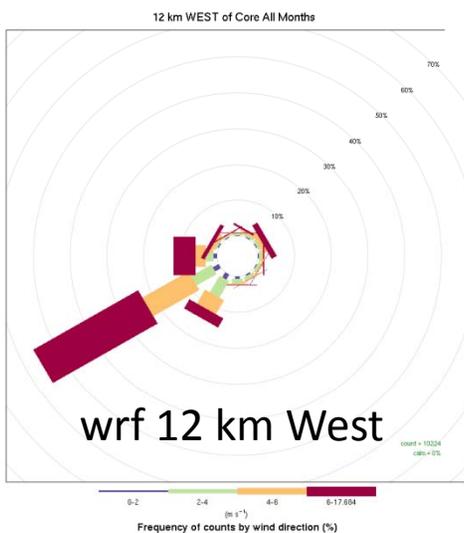
Obs.



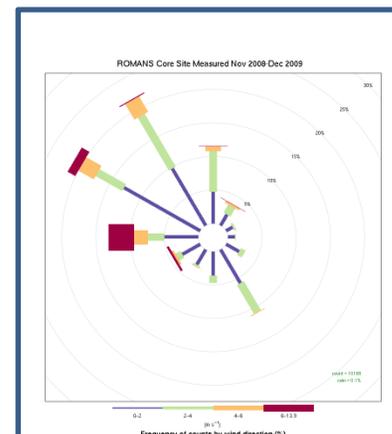
Model



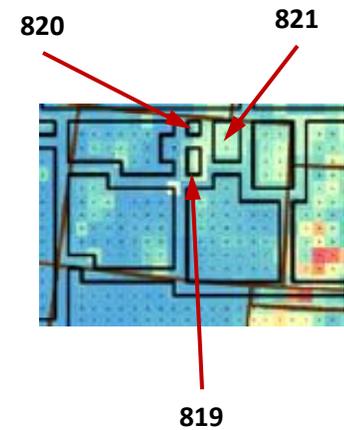
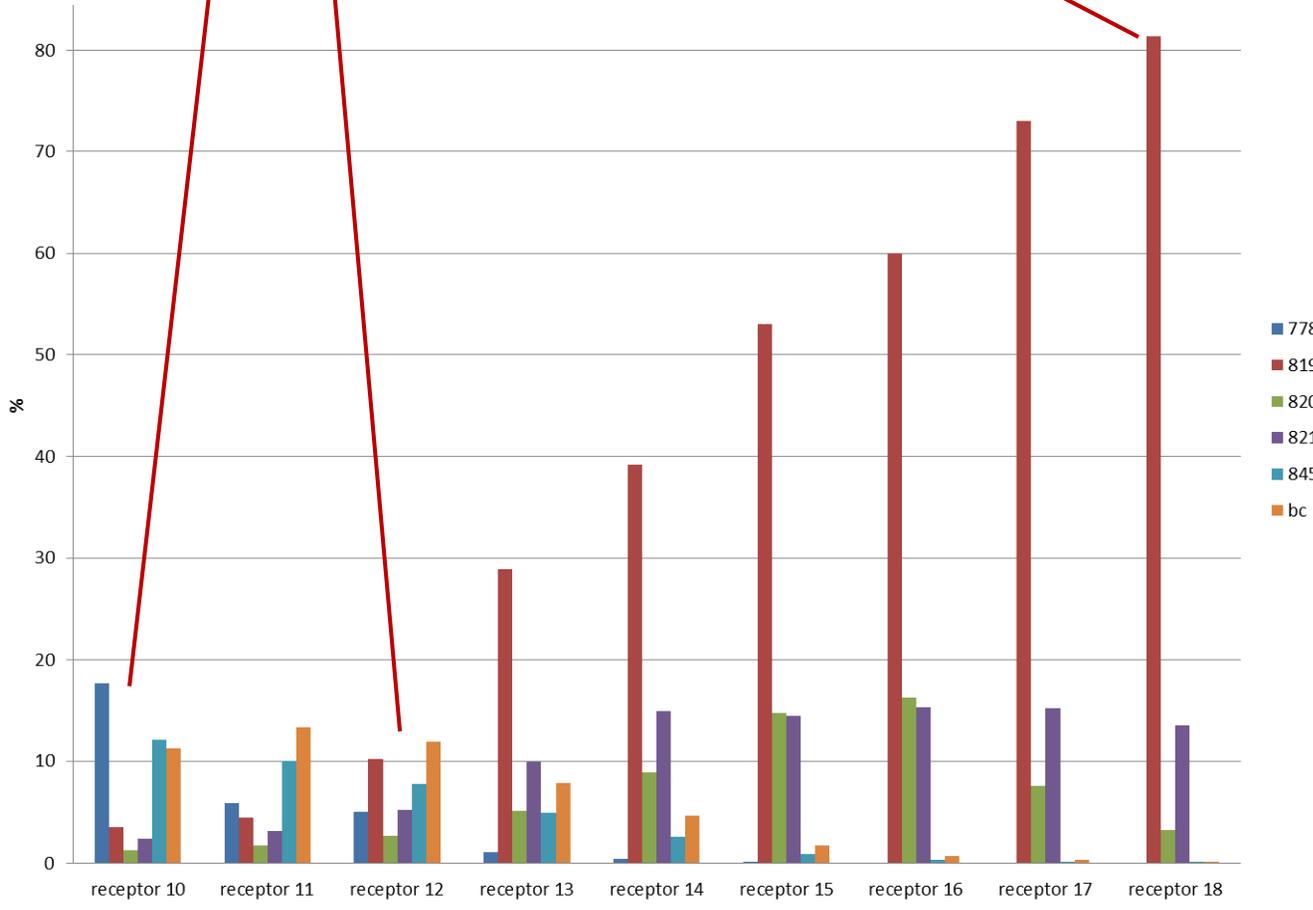
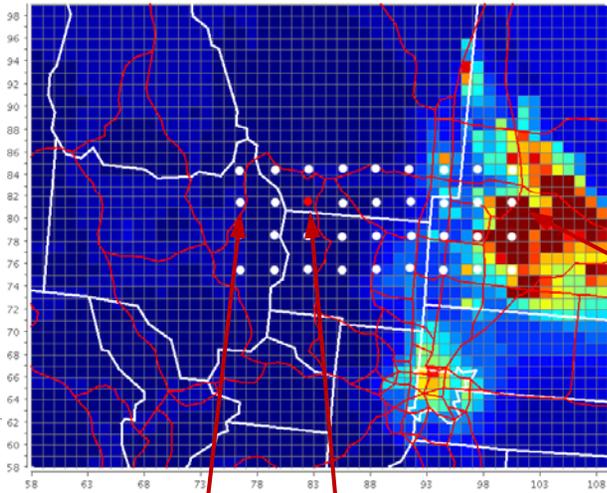
WRF 10-m Wind Roses
at and near
ROMANS I & II Core
Measurement Site
Nov 2008 – Dec 2009



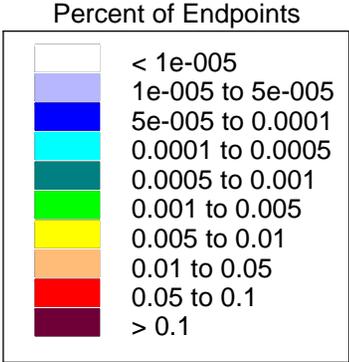
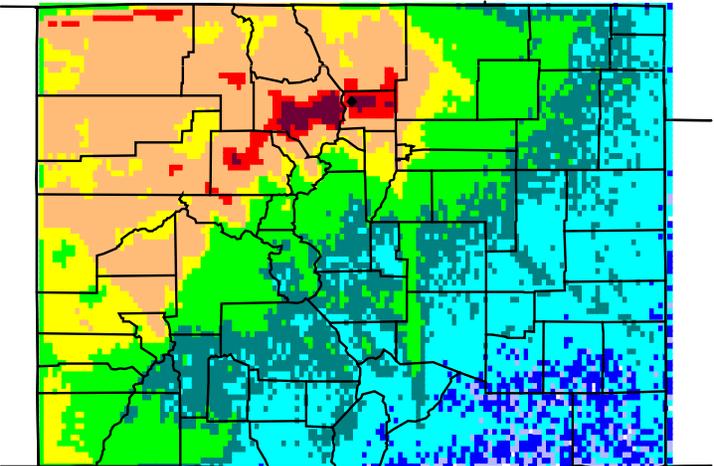
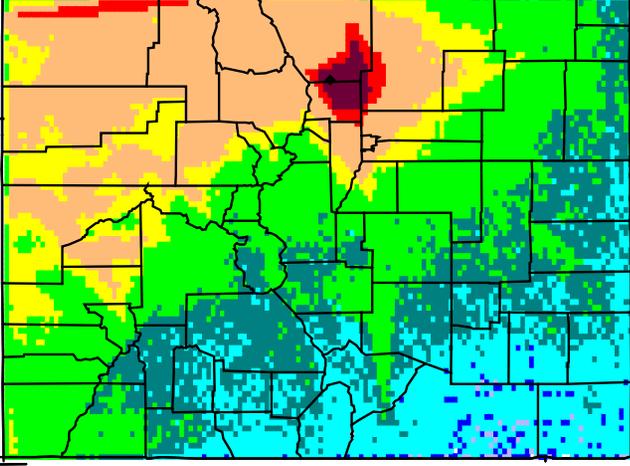
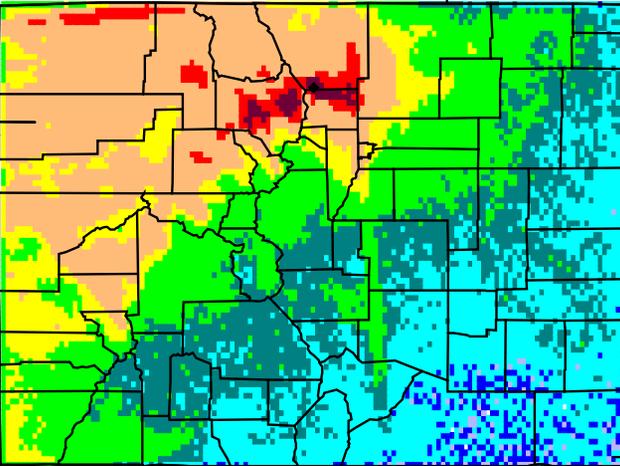
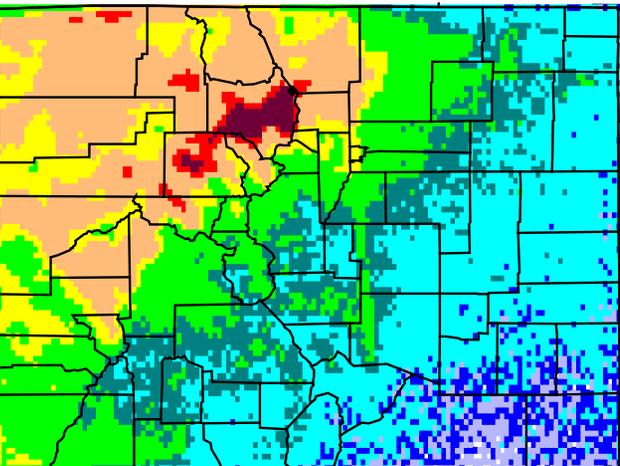
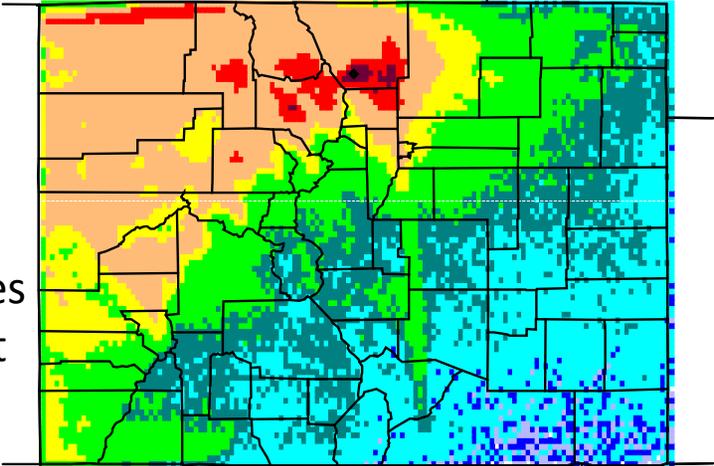
Core Observed



CAMx Annual NH₃ Source Apportionment receptor transect

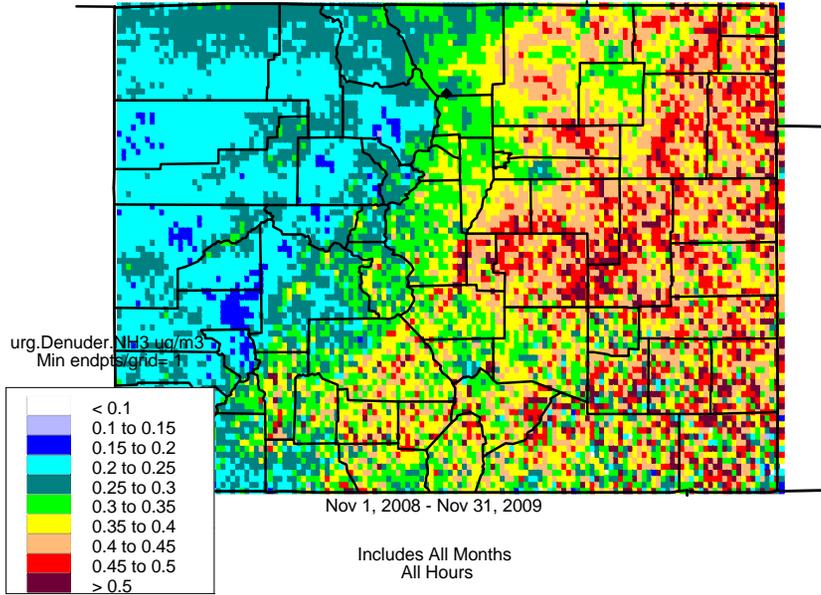


Overall Residence Time
Nov 2008 – Nov 2009
Hysplit Ensemble Trajectories
WRF input 10-m start height



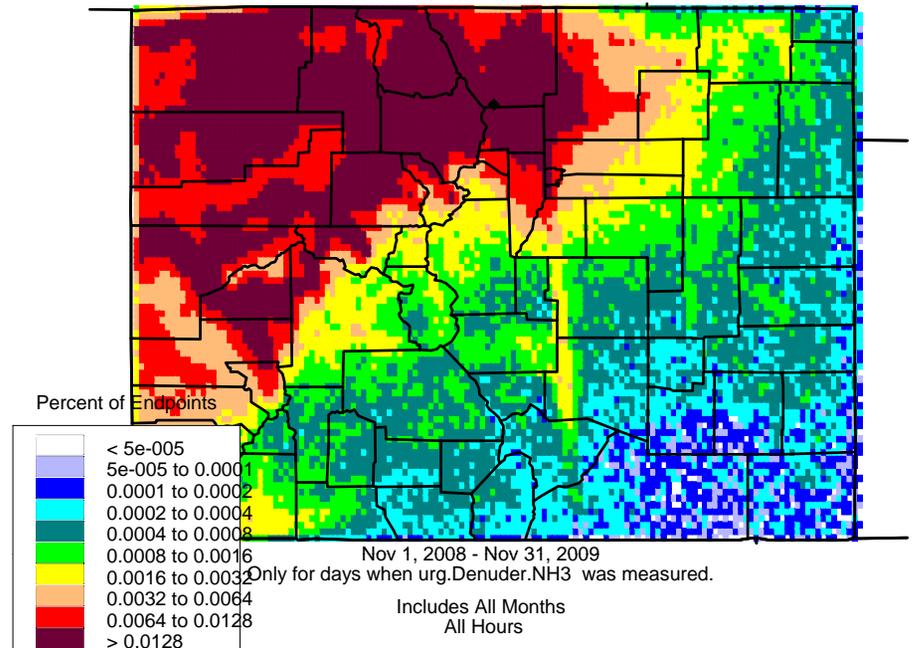
Rocky Mountain National Park Mean Concentration

Heights = 0 - 10703 m, input = Hy49 WRFnoacars3e360 , Traj Len = 5 days, 10 m start



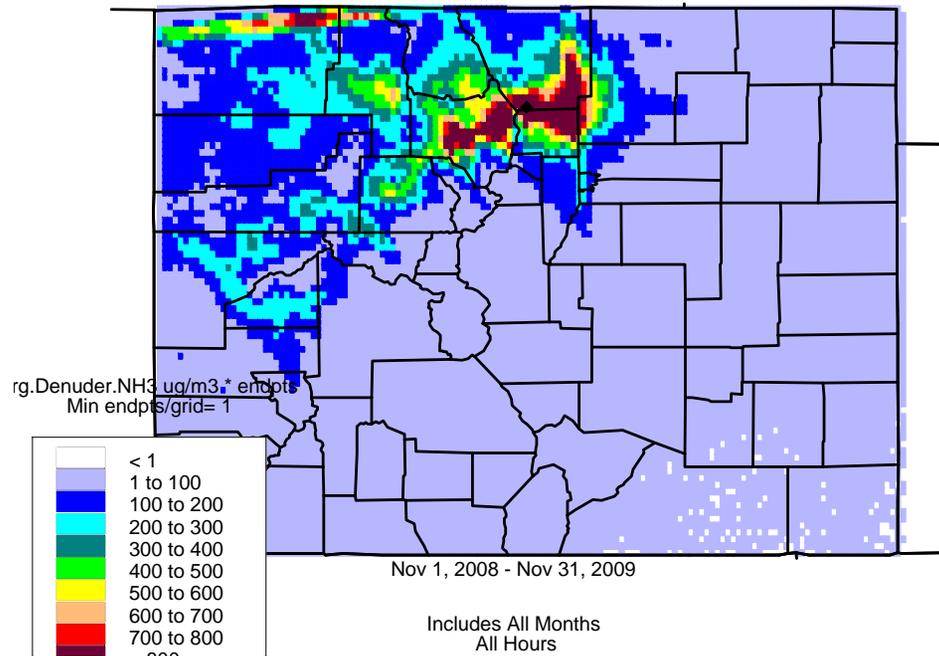
Rocky Mountain National Park Overall Residence Time for Measurement

Heights = 0 - 5853 m, input = Hy49 WRFnoacars3e360 , Traj Len = 5 days, 10 m start



Rocky Mountain National Park Sum Concentration

Heights = 0 - 10703 m, input = Hy49 WRFnoacars3e360 , Traj Len = 5 days, 10 m start



Regression Techniques of Source Apportionment

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

$$\text{Concentration} = a_1 \text{Source}_1 + a_2 \text{Source}_2 + \dots$$

TrMB (Trajectory Mass Balance)

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

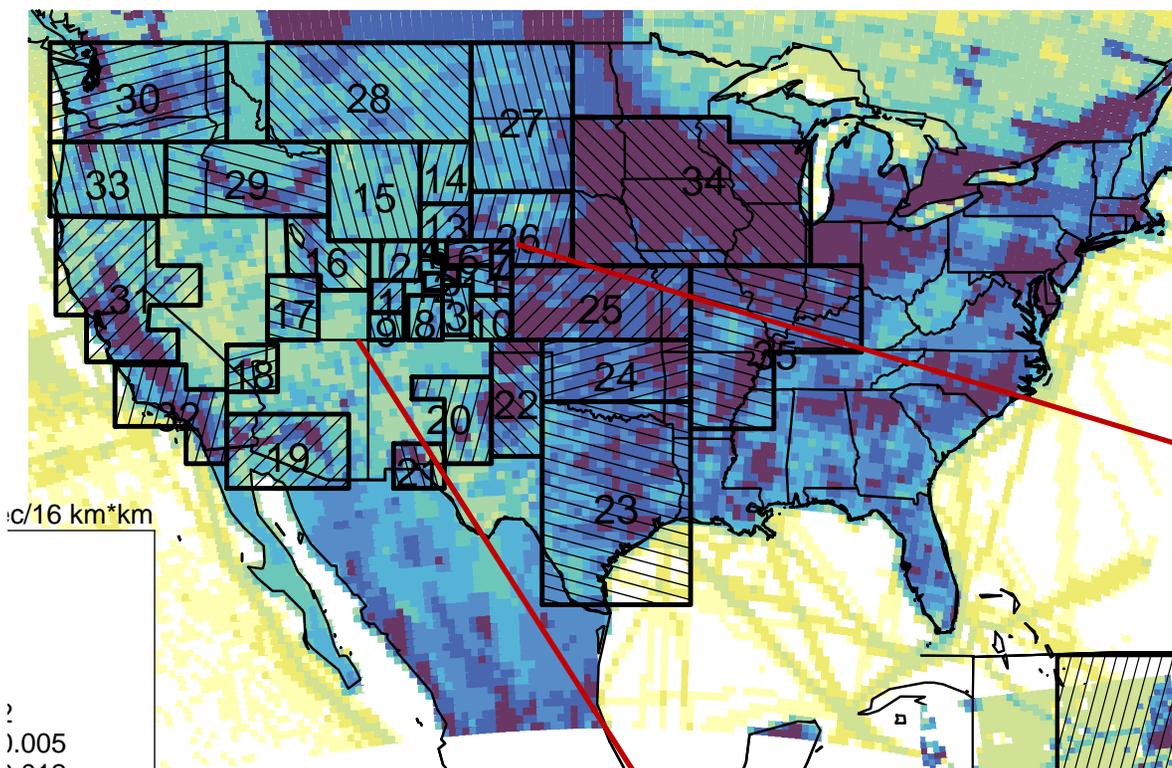
Sensitive to:

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

Not Sensitive to:

Trajectory length, trajectory height, cap on upwind height.

source set 12 NH3

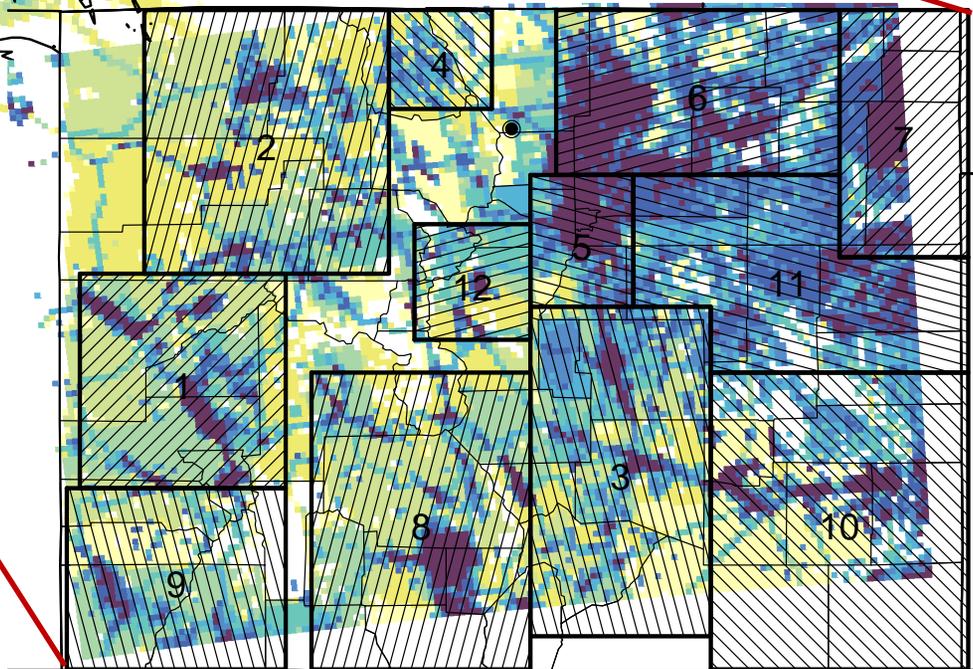


ROMANS II
TrMB Source Areas
For NH₃ and NH₄

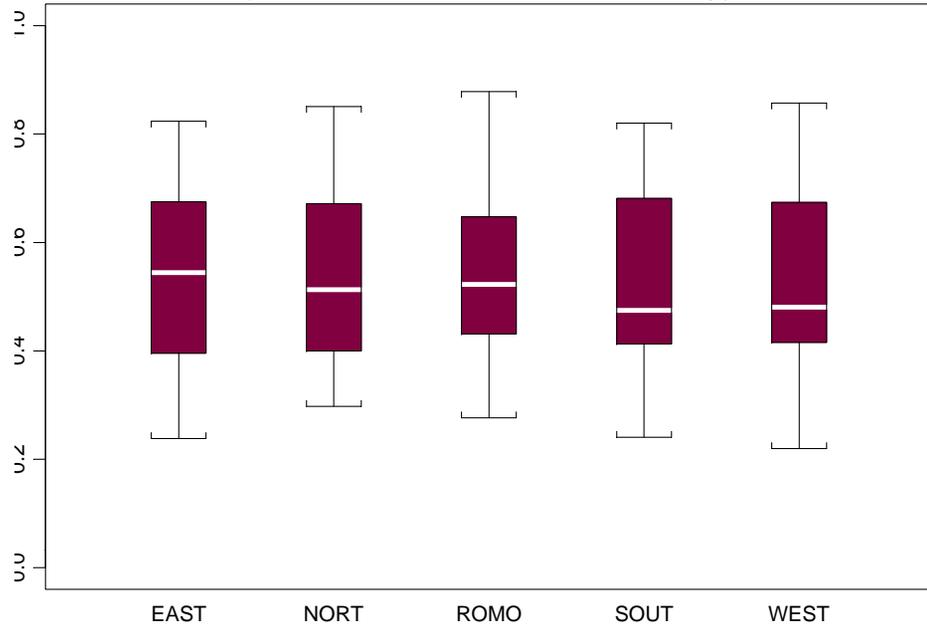
16 km*km

0.005
0.012
0.025

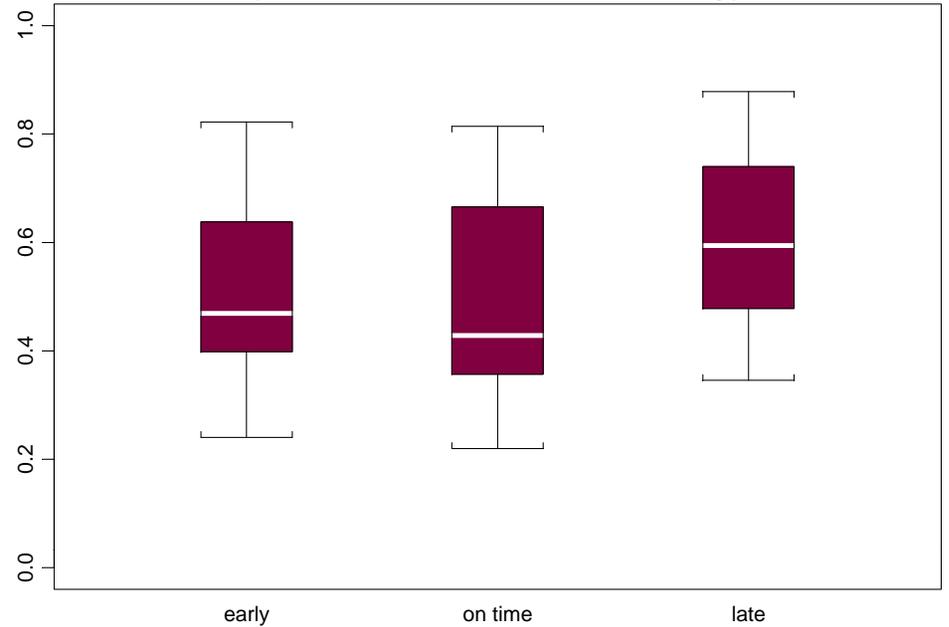
source set 12 NH3



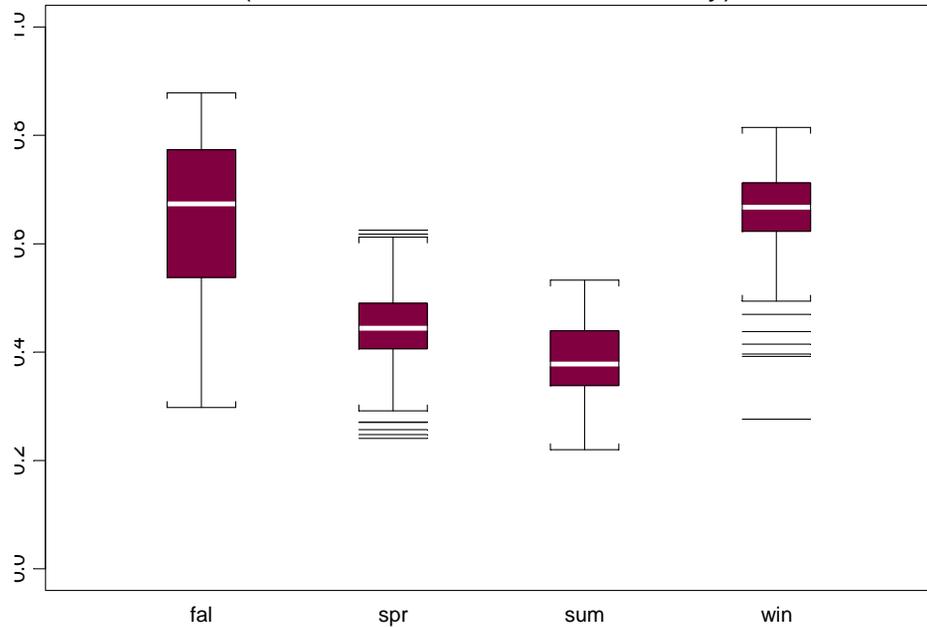
R Squares by Horizontal Start Location
(24-Hour Ammonia run seasonally)



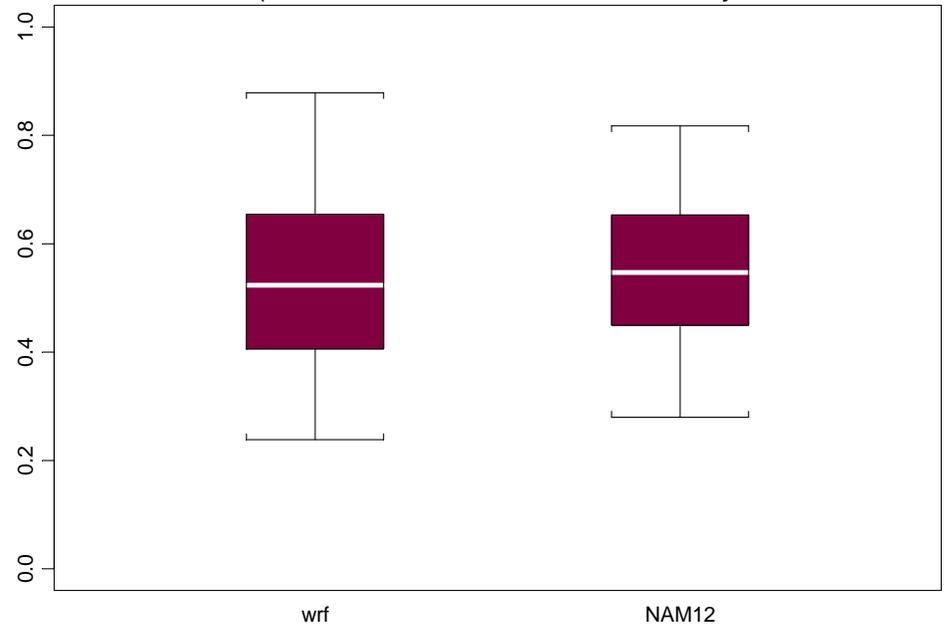
R Squares by Concentration Time
(24-Hour Ammonia run seasonally)



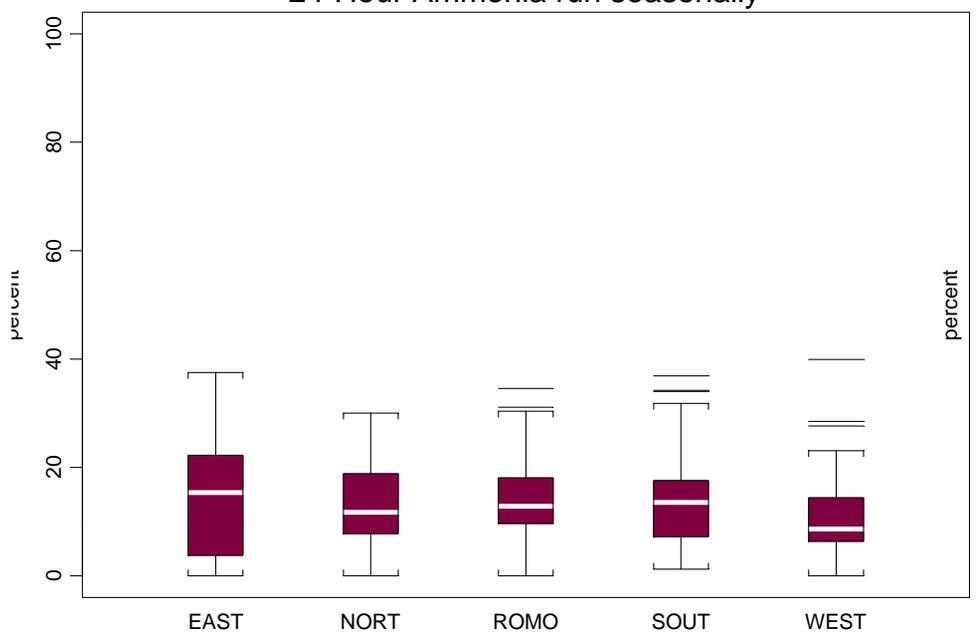
R Squares by Season
(24-Hour Ammonia run seasonally)



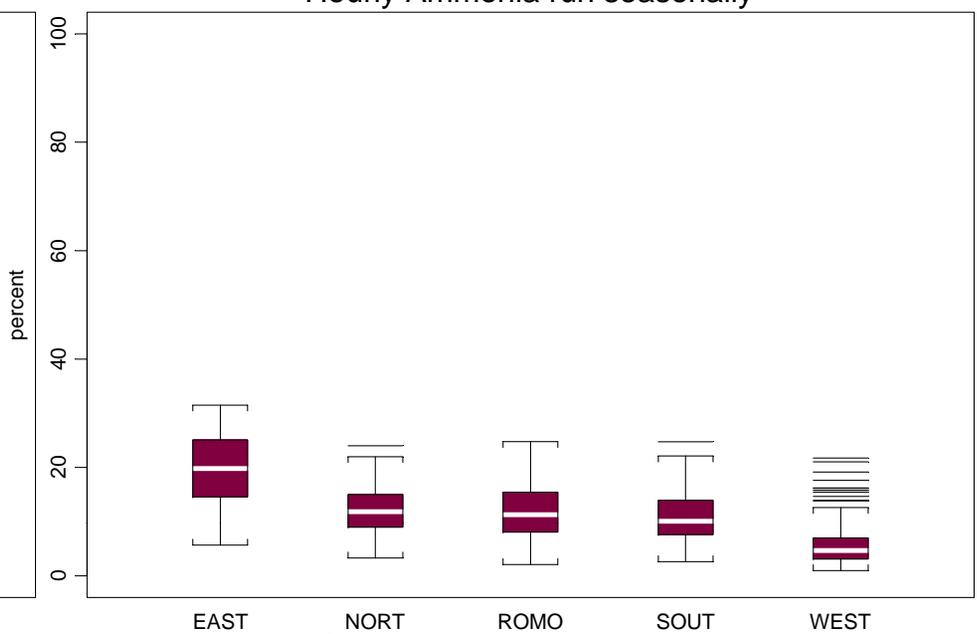
R Squares by Model Input (ROMO & EAST only)
(24-Hour Ammonia run seasonally)



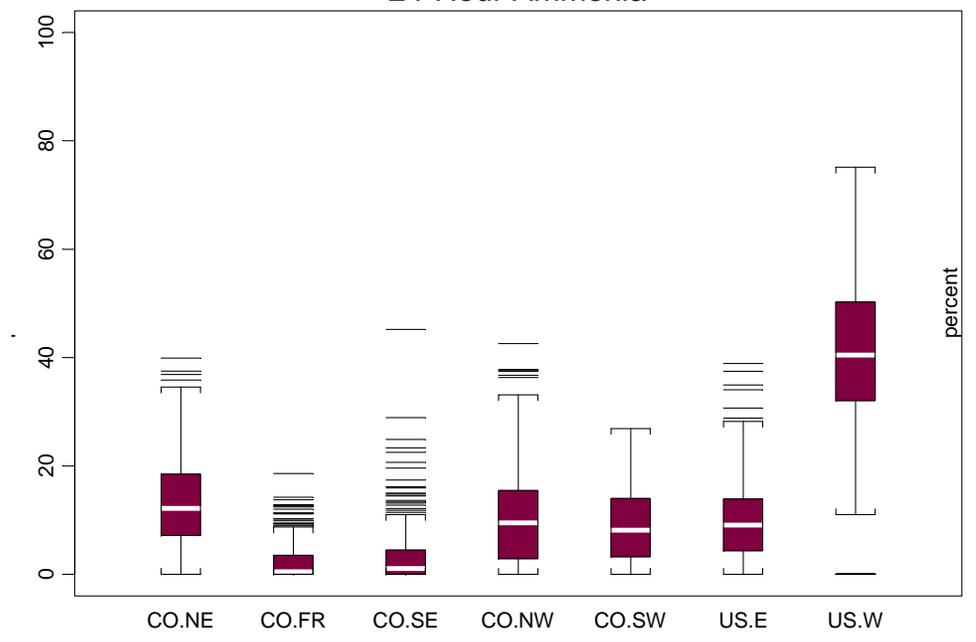
Attribution to Northeast CO by Horizontal Start Location
24-Hour Ammonia run seasonally



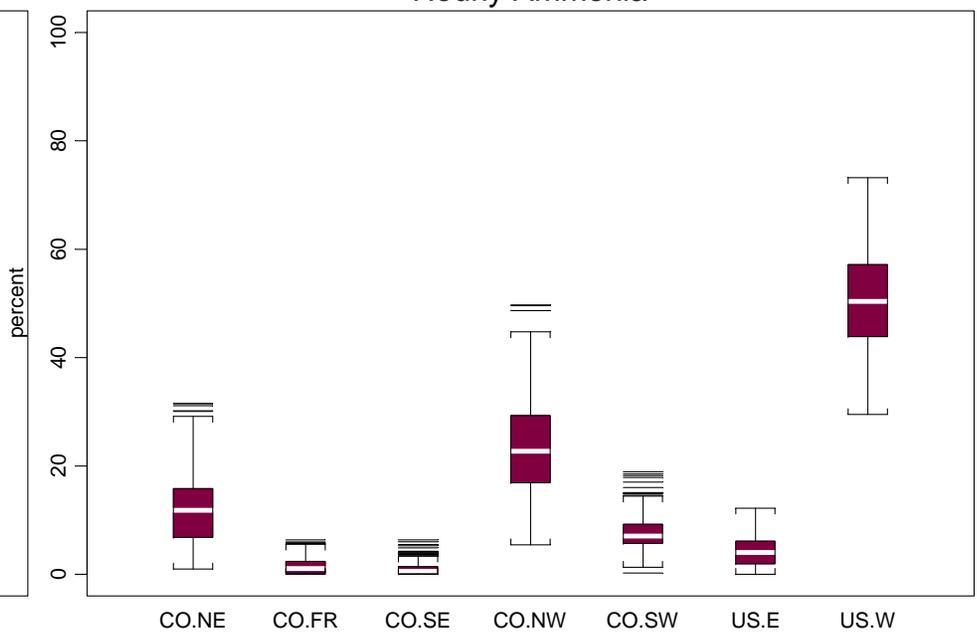
Attribution to Northeast CO by Horizontal Start Location
Hourly Ammonia run seasonally



Source Attributions by Region
24-Hour Ammonia



Source Attributions by Region
Hourly Ammonia



Summary - Where are we now with WRF for ROMANS II?

In General:

Time has run out. We have to finish up the source apportionment part of the study with the wrf output we have now and move on.

Precipitation:

Spatially, on an annual average, the 36-km wrf precip matches PRISM quite well. 12-km and 4-km precip are both too high (annual average compared to PRISM). At the Core Site, wrf (4-km) often predicts precip when none was observed, especially in the fall. When wrf gets the day right, it often over-predicts the amount. At the other extreme, 36-km wrf almost never predicted precip in the summer – totally missing convective storms. In the middle: At 12-km some observed precip in summer was not predicted and amounts were overpredicted, especially in the spring.

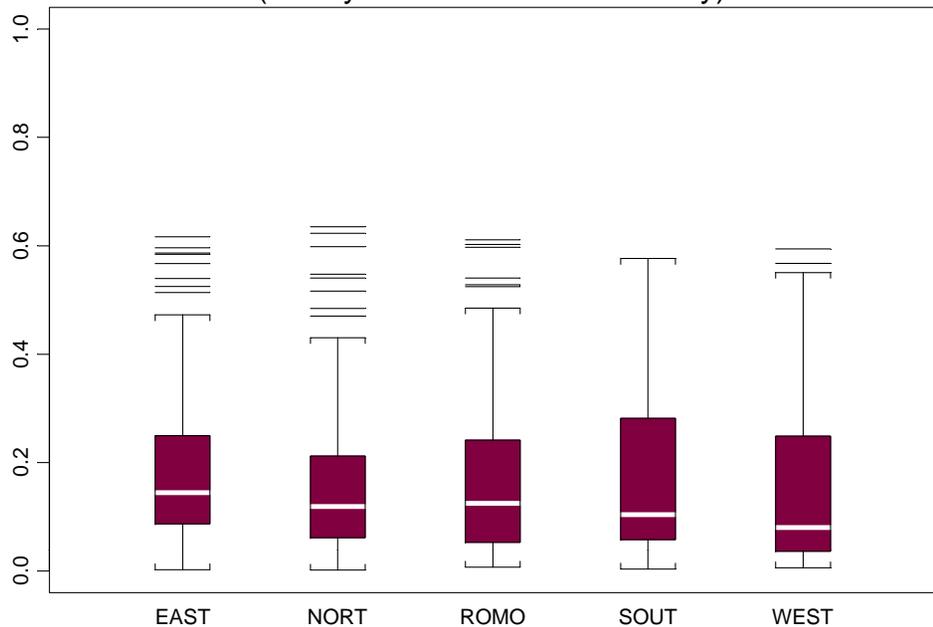
Winds:

Why can't we get the winds right at the core site and at Estes Park, even with obs nudging?

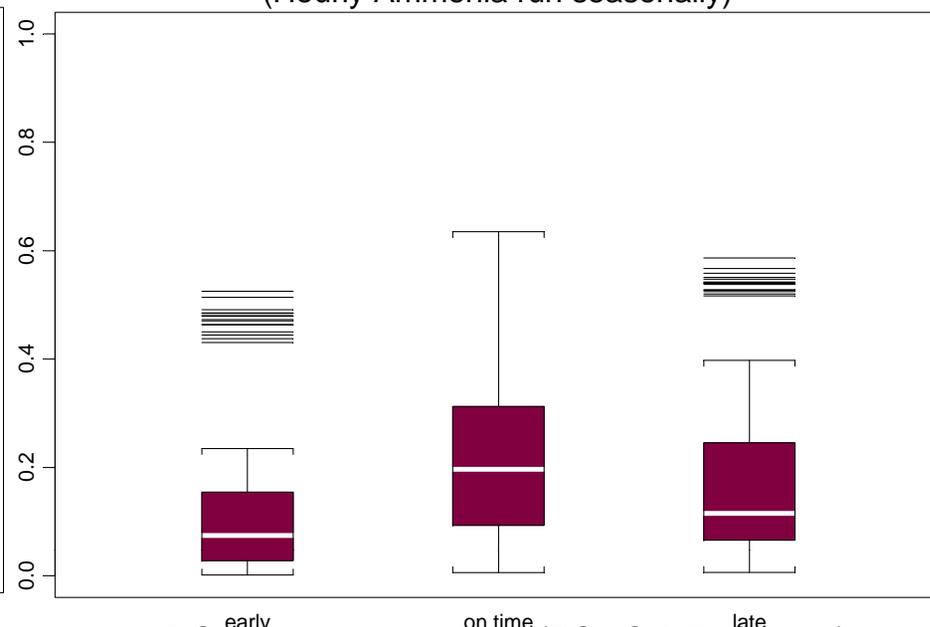
Is a body of "best practices" developing for obs nudging, especially in complex terrain in the West i.e. areas of influence, nudging coefficients, input data?

EXTRAS AFTER HERE

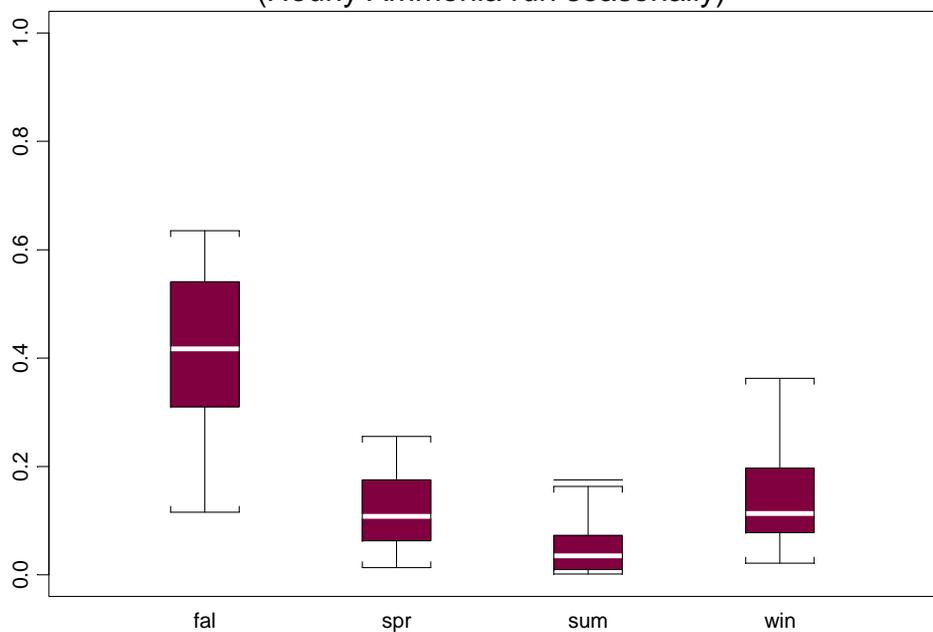
R Squares by Horizontal Start Location
(Hourly Ammonia run seasonally)



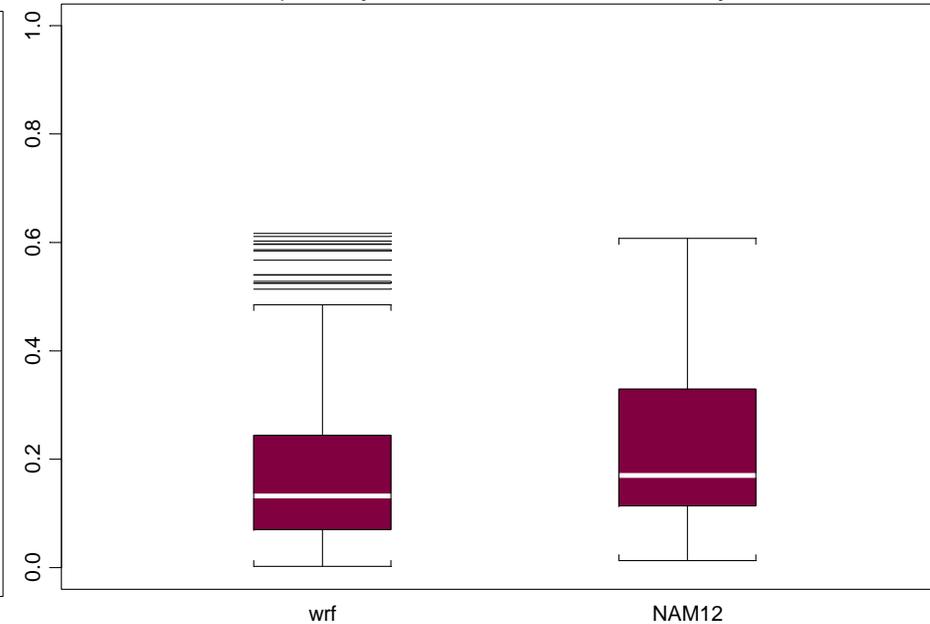
R Squares by Concentration Time
(Hourly Ammonia run seasonally)



R Squares by Season
(Hourly Ammonia run seasonally)



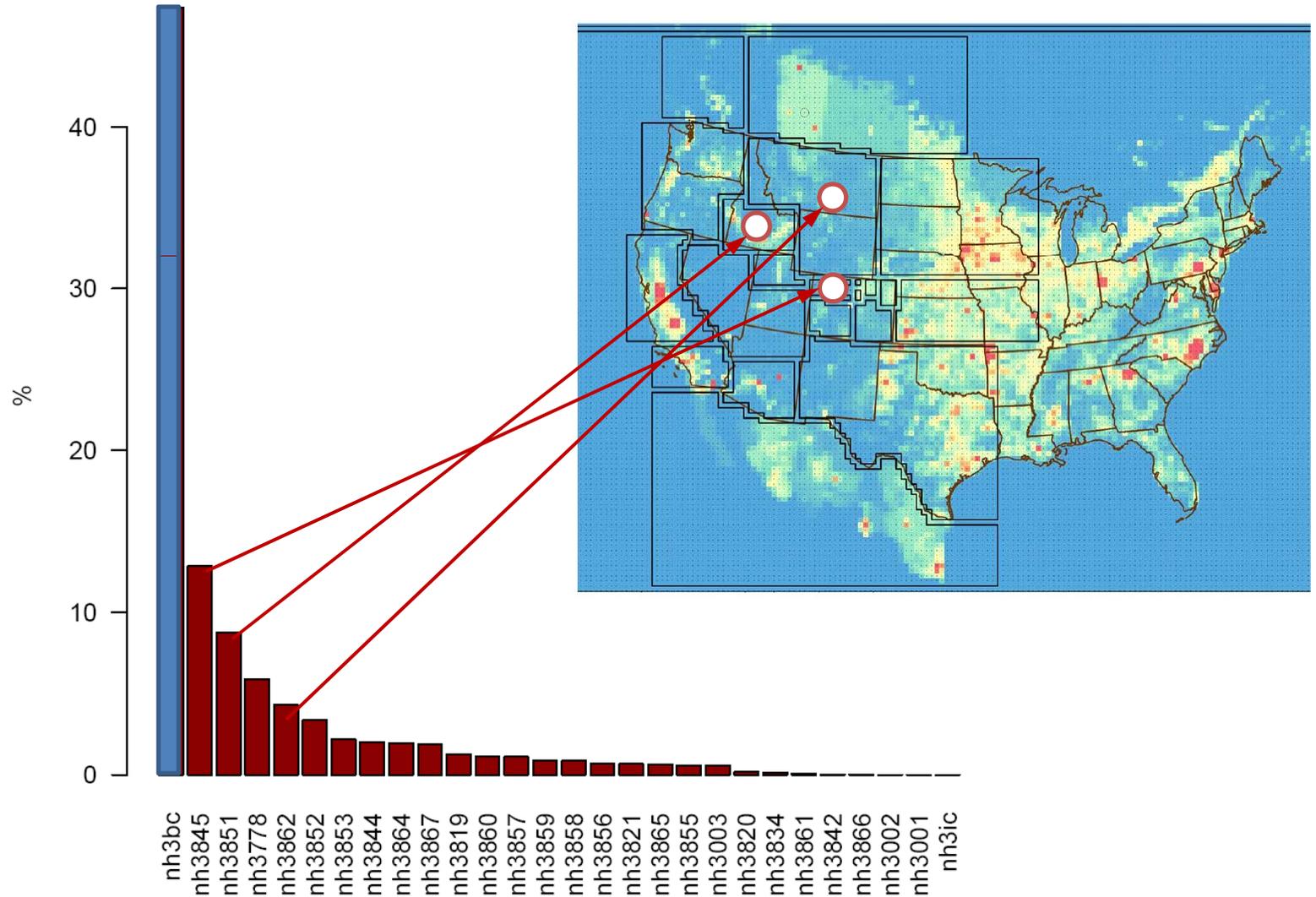
R Squares by Model Input (ROMO & EAST only)
(Hourly Ammonia run seasonally)



PSAT Results January Ammonia

Model Mean = 0.018 $\mu\text{g}/\text{m}^3$
Model Max = 0.057 $\mu\text{g}/\text{m}^3$

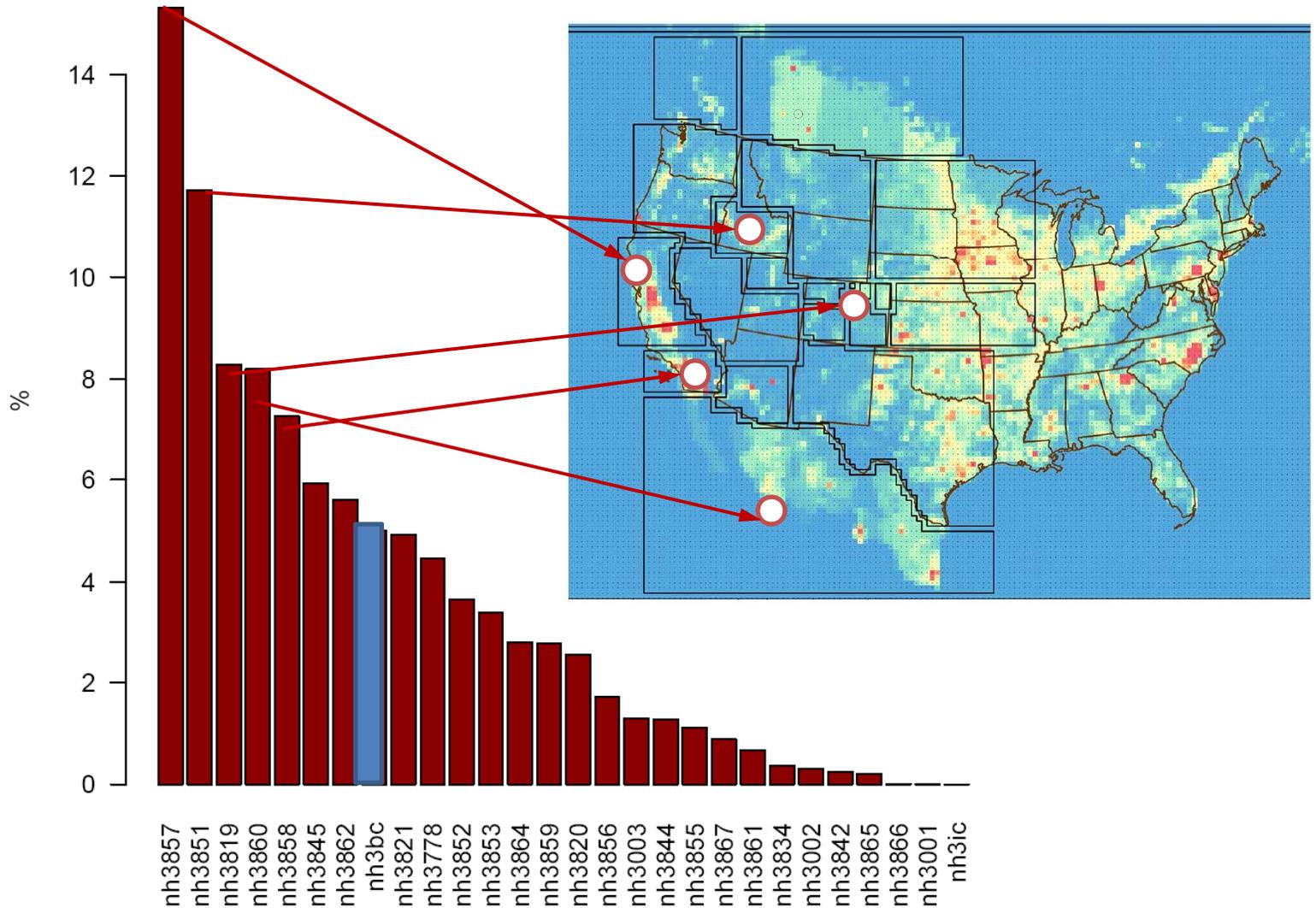
Average contribution by source region



PSAT Results July Ammonia

Model Mean = 0.200 $\mu\text{g}/\text{m}^3$
Model Max = 1.865 $\mu\text{g}/\text{m}^3$

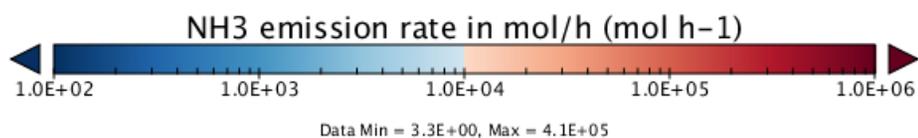
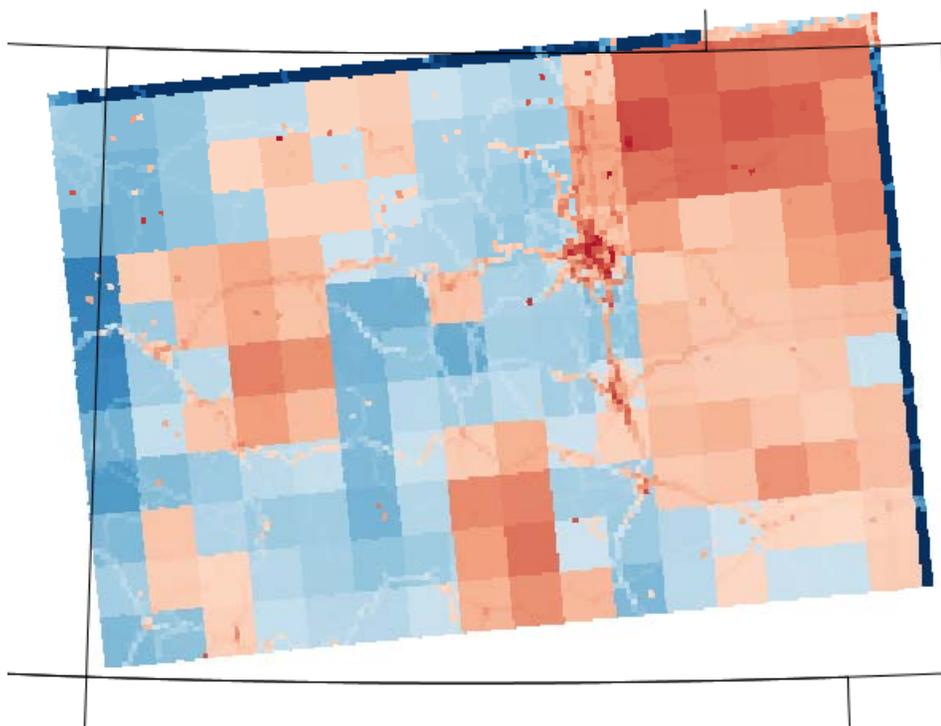
Average contribution by source region



NH₃ Emissions 4km Domain RoMANS

April 2006

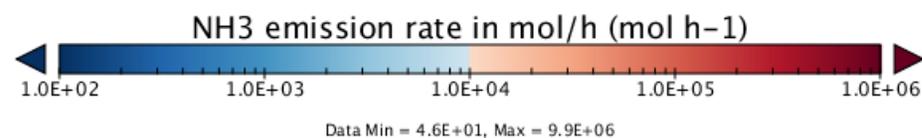
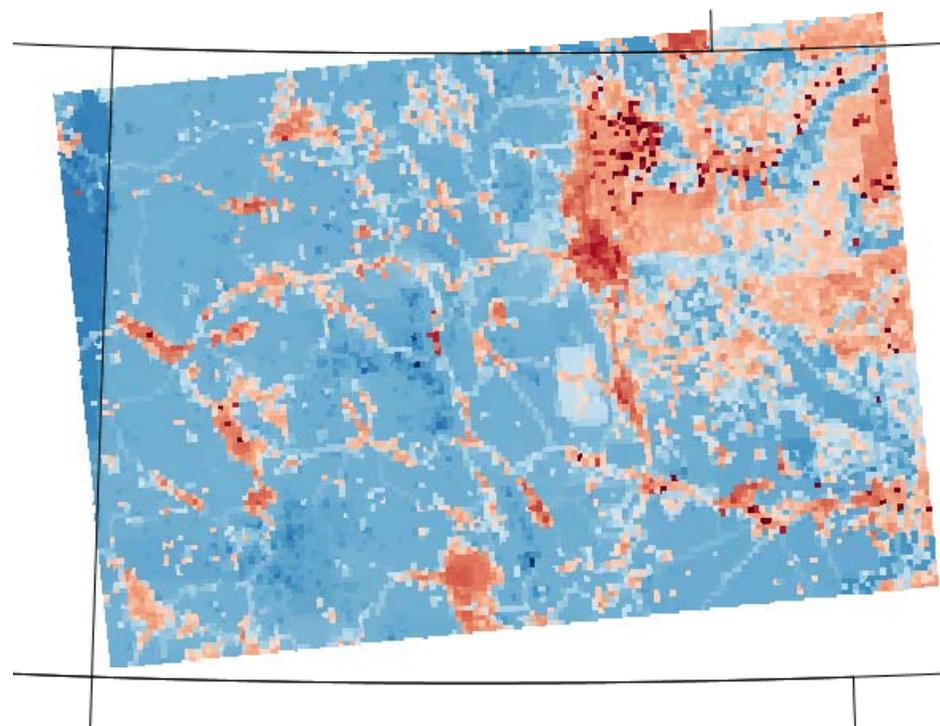
NH₃ emission rate in mol/h



Total: 2.8279e+08 mol

April 2009

NH₃ emission rate in mol/h

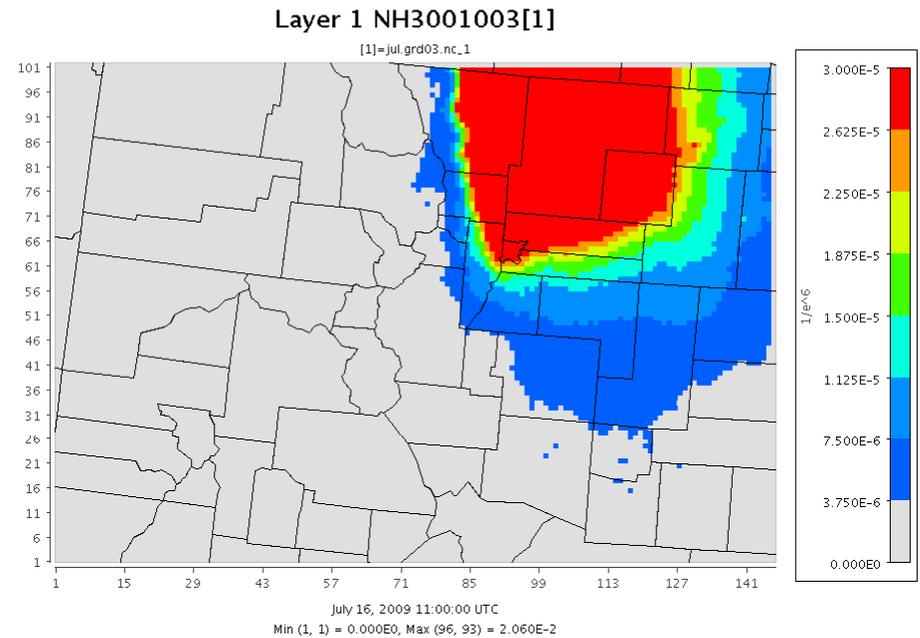
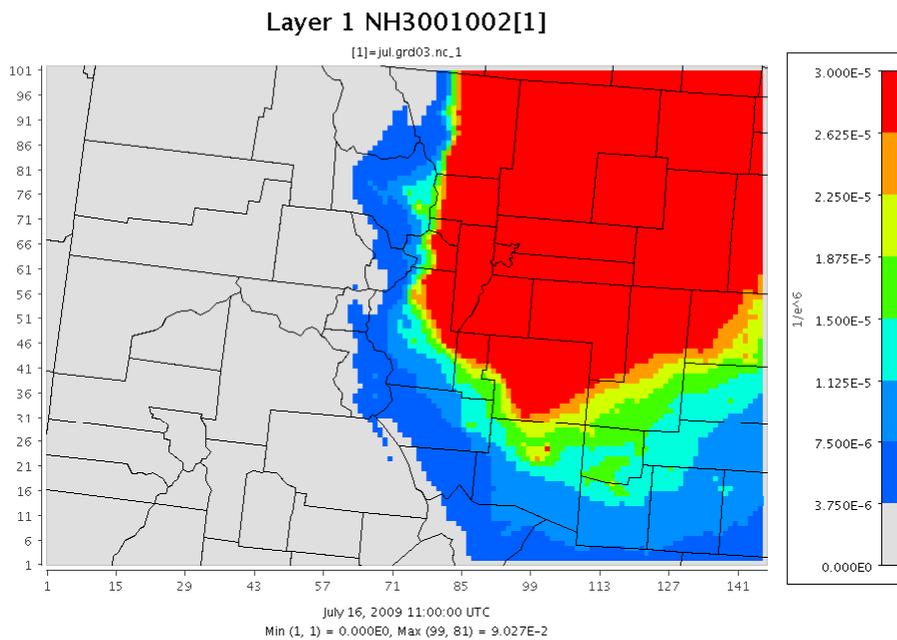


Total: 3.1554e+08 mol

July 2009 Average Tracer Concentrations by Region (footprint or area of influence)

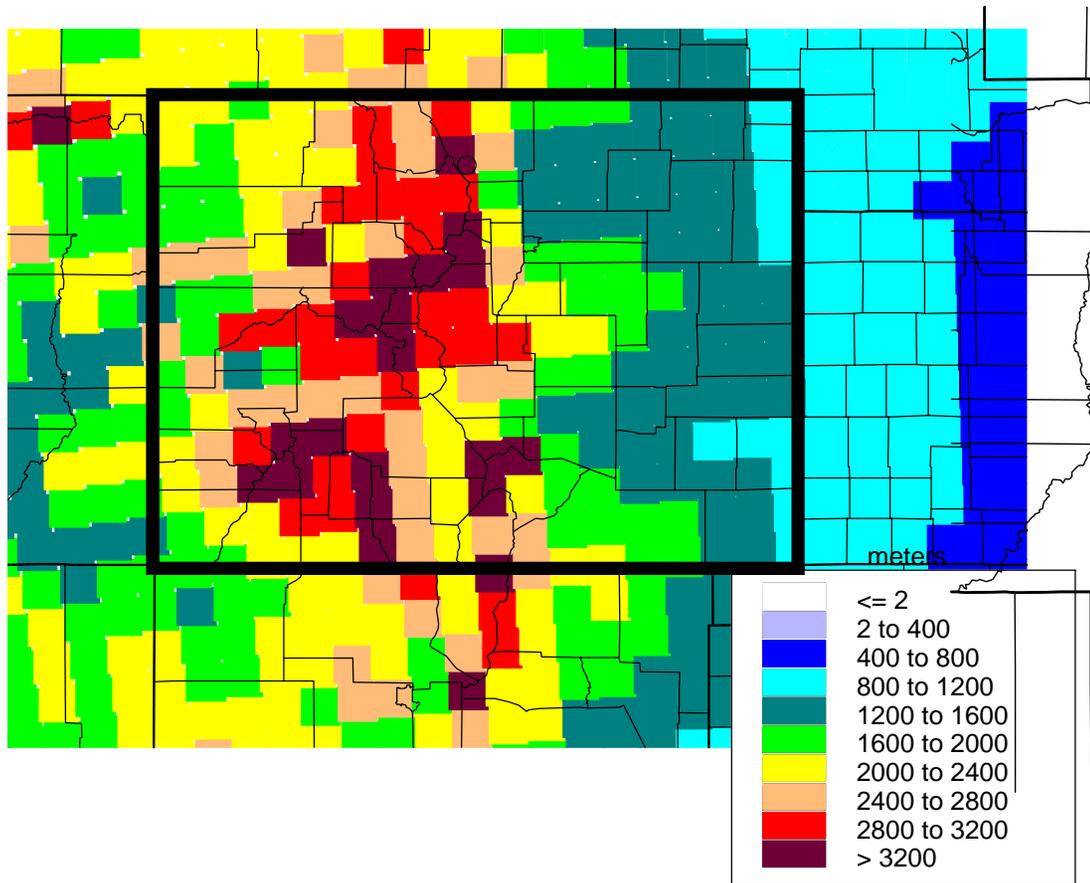
Region 819 South Front Range, CO

Region 820 North Front Range, CO

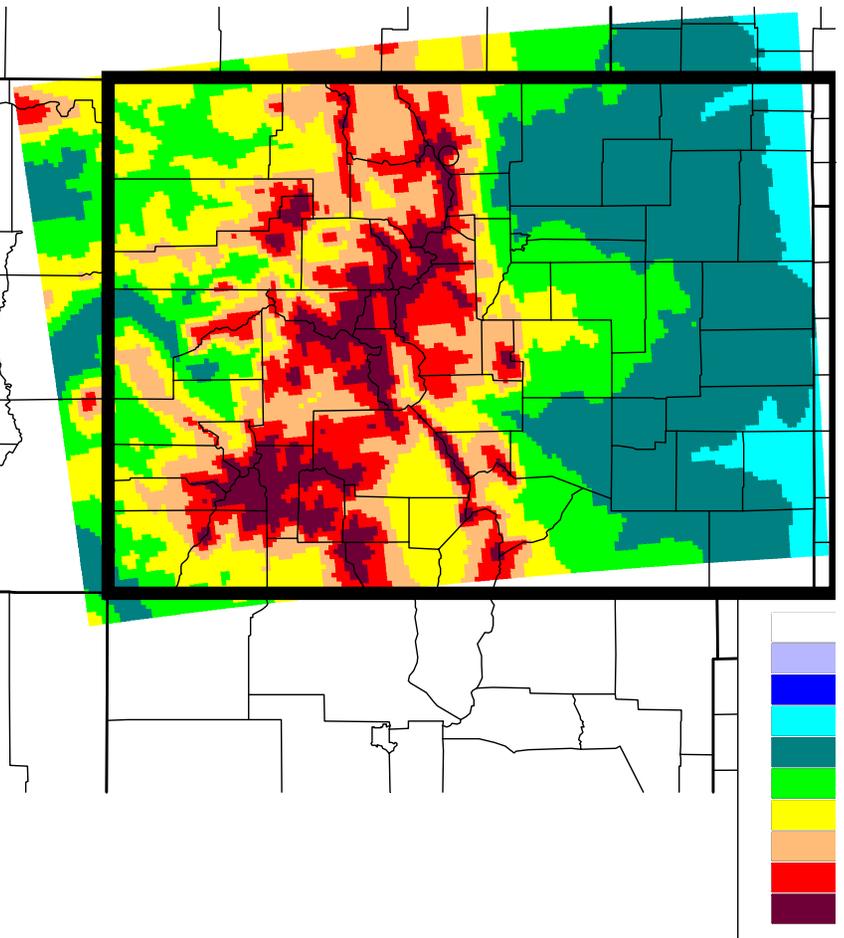


36 km vs 4 km Terrain Over Colorado

36 km Domain



4 km DOMAIN



More Easterlies During Precipitation Events

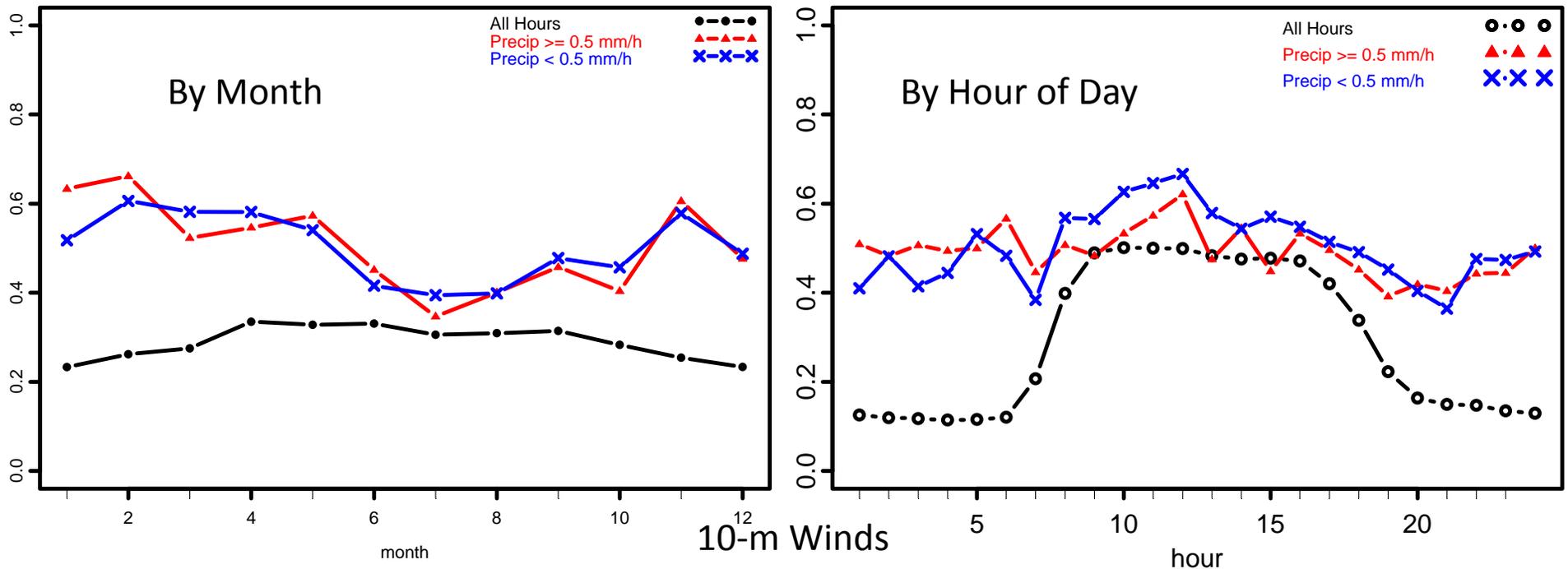
Fraction of hours during each month of the year (left) and hour of day (right) when 10-m wind is from the east.

Black is all hours

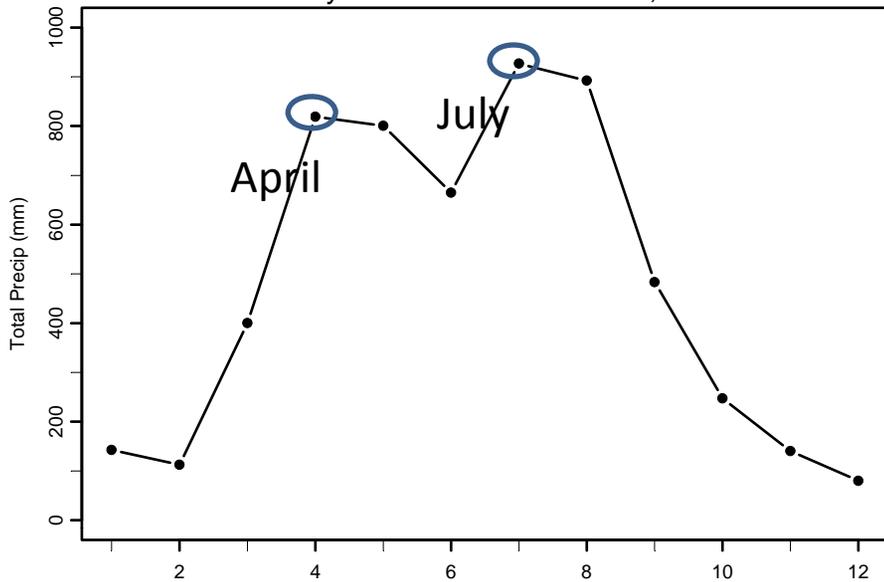
Red is hours with precipitation > 0.5 mm/hr

Blue is hours with precipitation < 0.5 mm/hr.

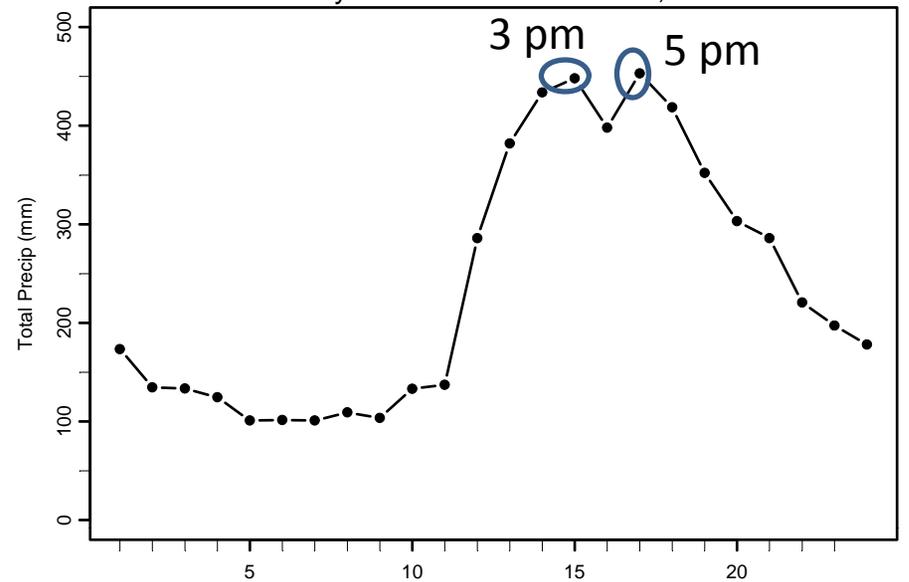
Fraction of Hours With Winds From the East 1995-2009



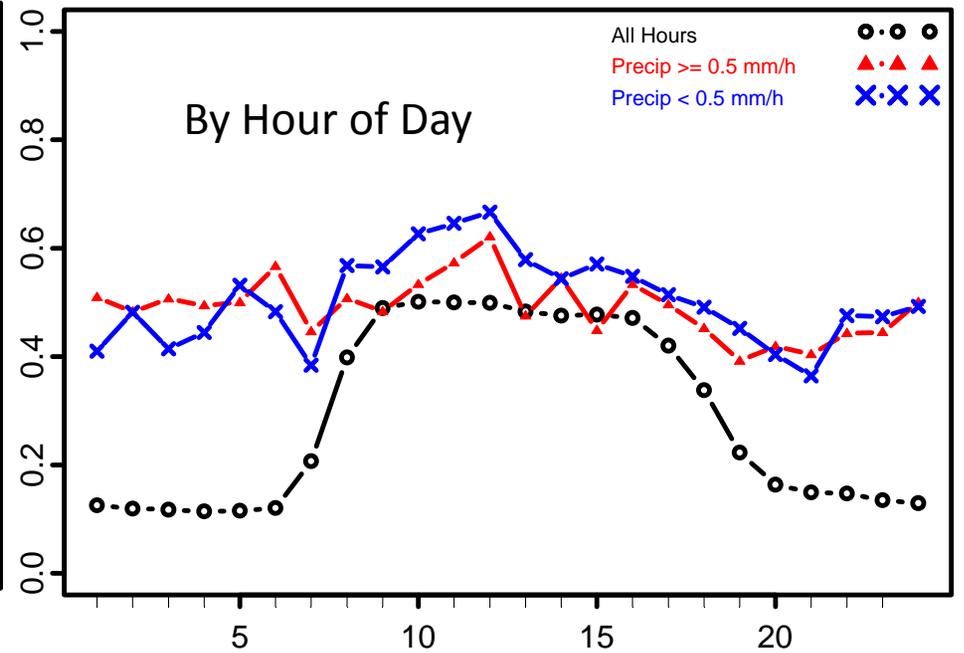
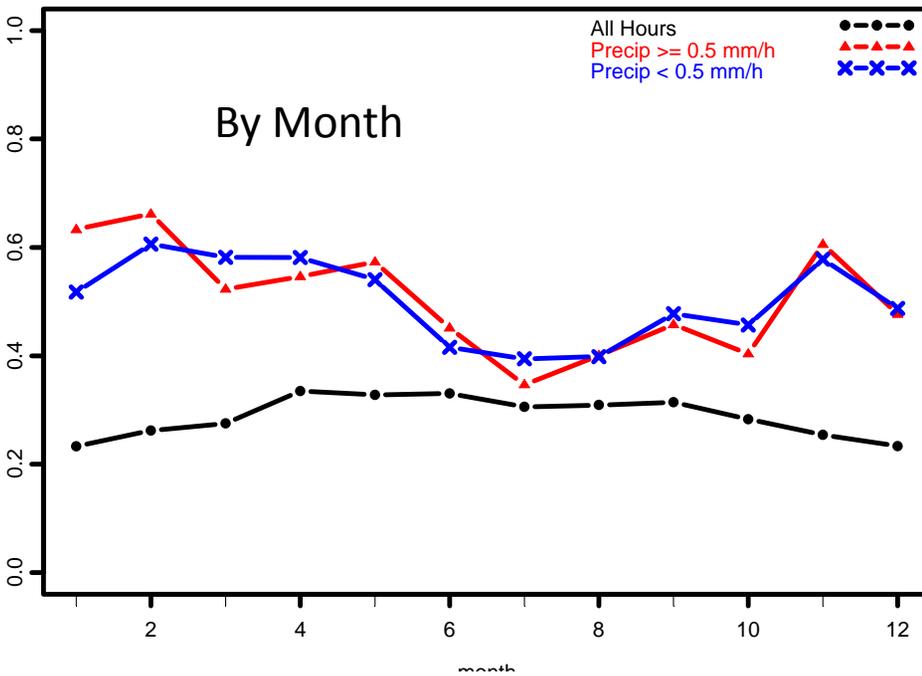
Total Precipitation by Month during 1995-2009
Rocky Mountain National Park, CO



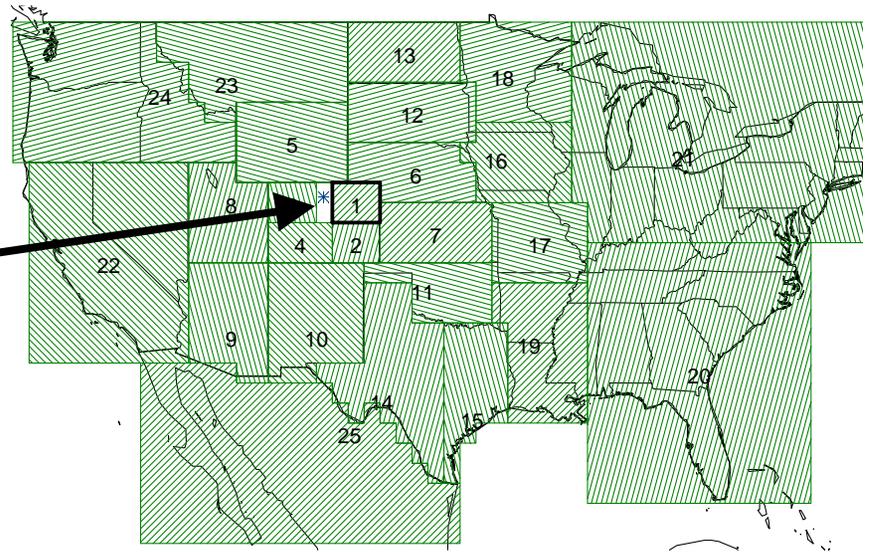
Total Precipitation by Hour during 1995-2009
Rocky Mountain National Park, CO



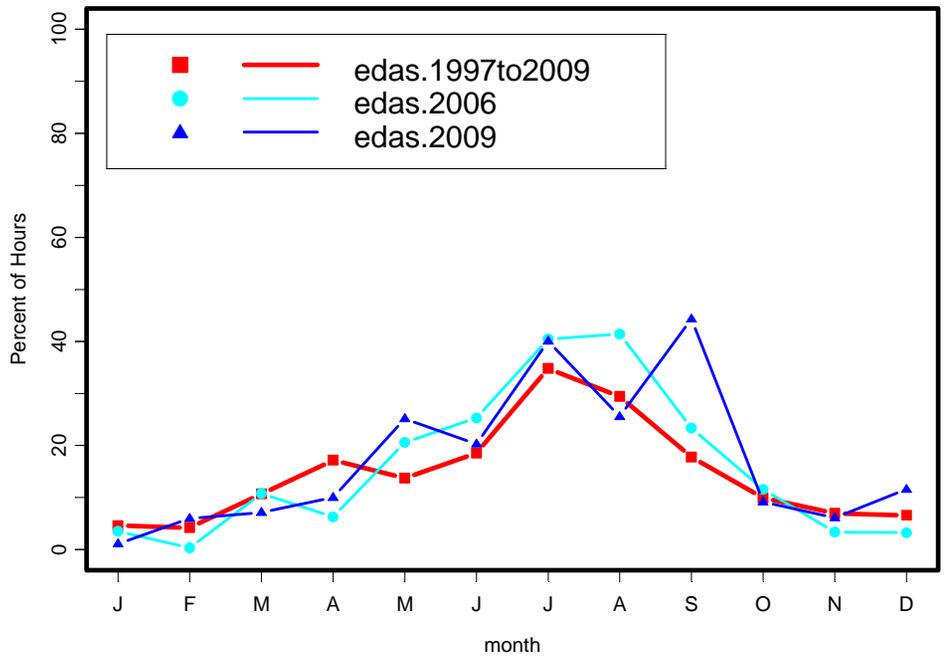
Fraction of Hours With Winds From the East 1995-2009



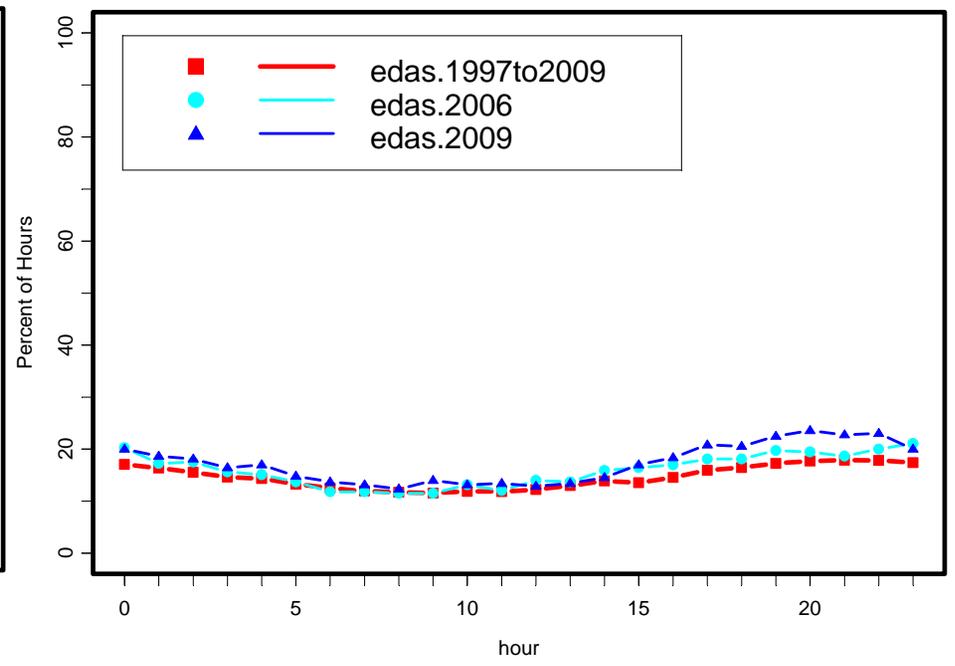
Transport from
Northeastern
Colorado
EDAS historic,
2006 & 2009



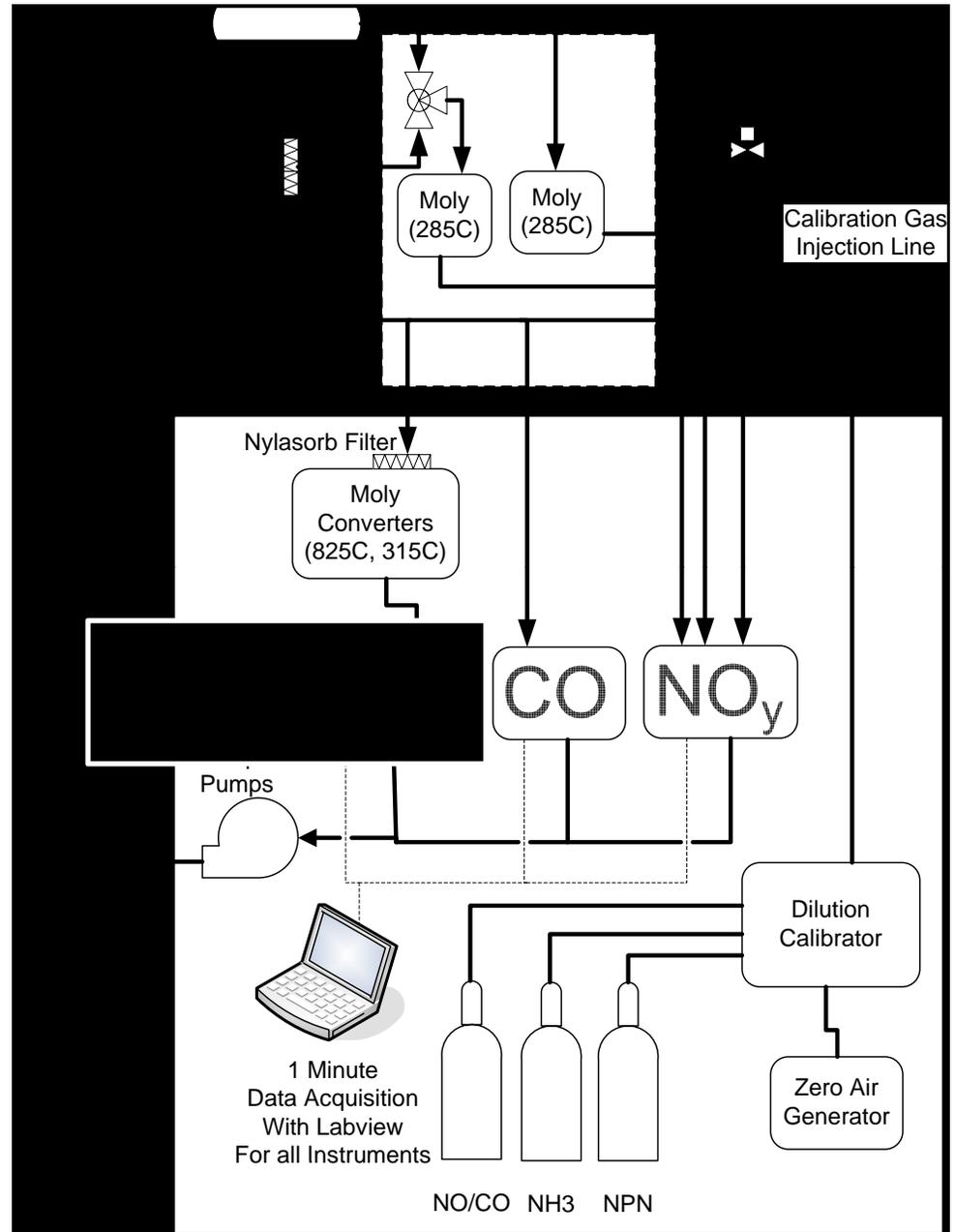
Transport From Source: NE Colorado by month of year



Transport From Source: NE Colorado by hour of day



Chemiluminescence Nitrogen Gas Samplers



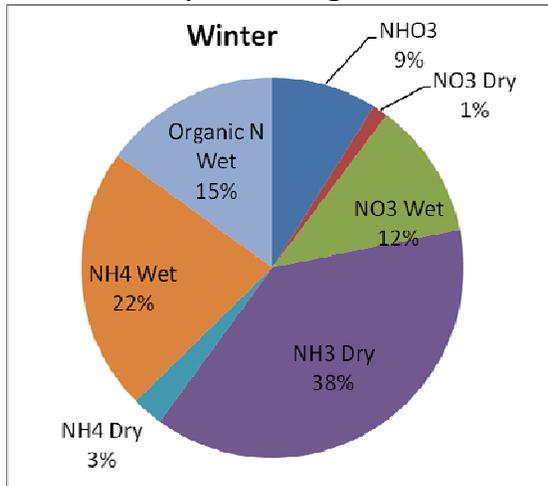
Continuous Gas Analyzers-ROMO 09

Para-meter	Instrument
NO	Chemiluminescence (no converter, Nylasorb filter)
NO _x	Chemiluminescence (315C converter, Nylasorb filter)
NO _y	Chemiluminescence (285C converter, no filter)
NO _y ' = (NO _y – HNO ₃)	Chemiluminescence (285C converter + denuder)
NO _y '' = (NO _y – HNO ₃ – pNO ₃)	Chemiluminescence (285C converter + Nylasorb filter)
Total N – HNO ₃ – pNO ₃	Chemiluminescence (825 converter, Nylasorb)
NH ₃	Ion Mobility

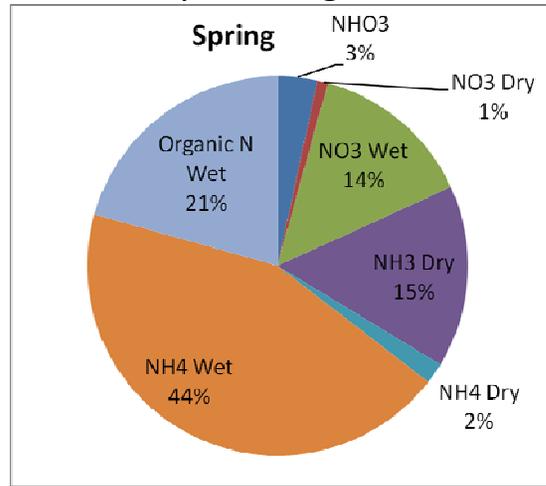
Para-meter	Instrument
Reduced N	Total N – HNO ₃ – pNO ₃ – NO _x
R-NH _x (reduced ON)	Total N – HNO ₃ – pNO ₃ – NO _x – NH ₃
NO ₂ + R-NO _x	NO _x – NO
HNO ₃	NO _y – NO _y '
pNO ₃	NO _y ' – NO _y ''

Seasonal N Deposition – 2009

Dec-Feb, 2009
N dep=3.2 mg/m²/wk

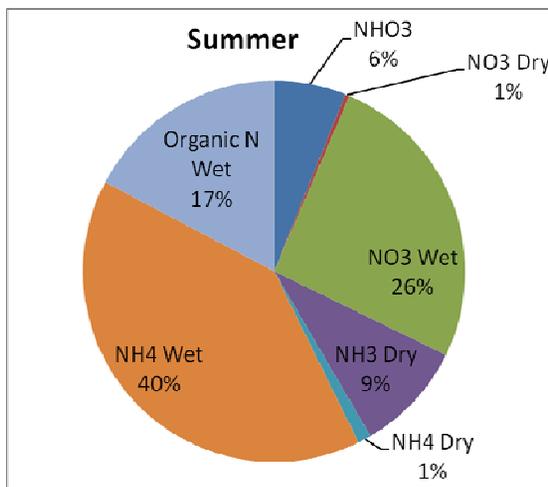


Mar-Apr, 2009
N dep=9.2 mg/m²/wk

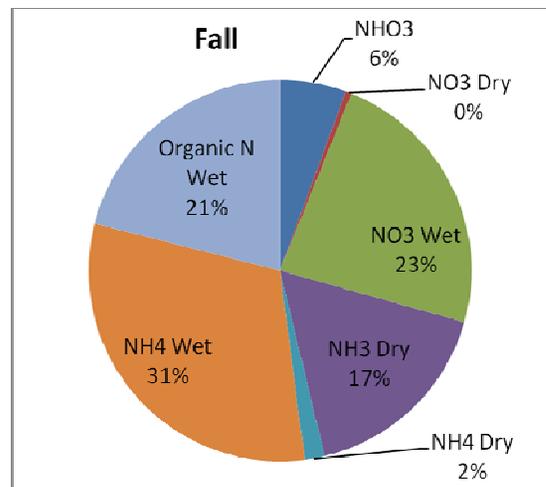


- Winter has different deposition composition, but the lowest deposition rates
- In general, RoMANS I was representative of 2009

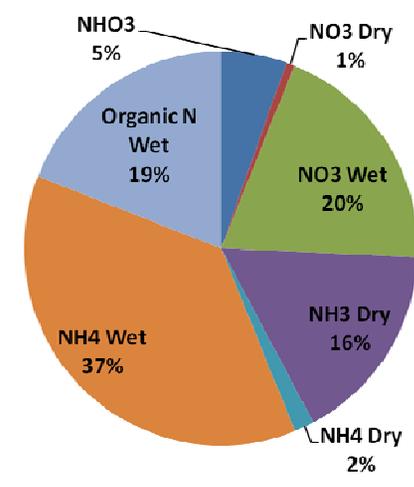
Jun-Aug, 2009
N dep=8.7 mg/m²/wk



Sep-Nov, 2009
N dep=6.8 mg/m²/wk



Annual
N dep=2.9 kg/ha/yr



Surface Met Data (Little_R) Sites in Colorado

