Twist on a Back Trajectory Technique to Examine Wet Deposition Events

Met Tower, radar profiler site, ROMANS I, Estes Park, CO, 2006

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Kristi Morris, John Vimont

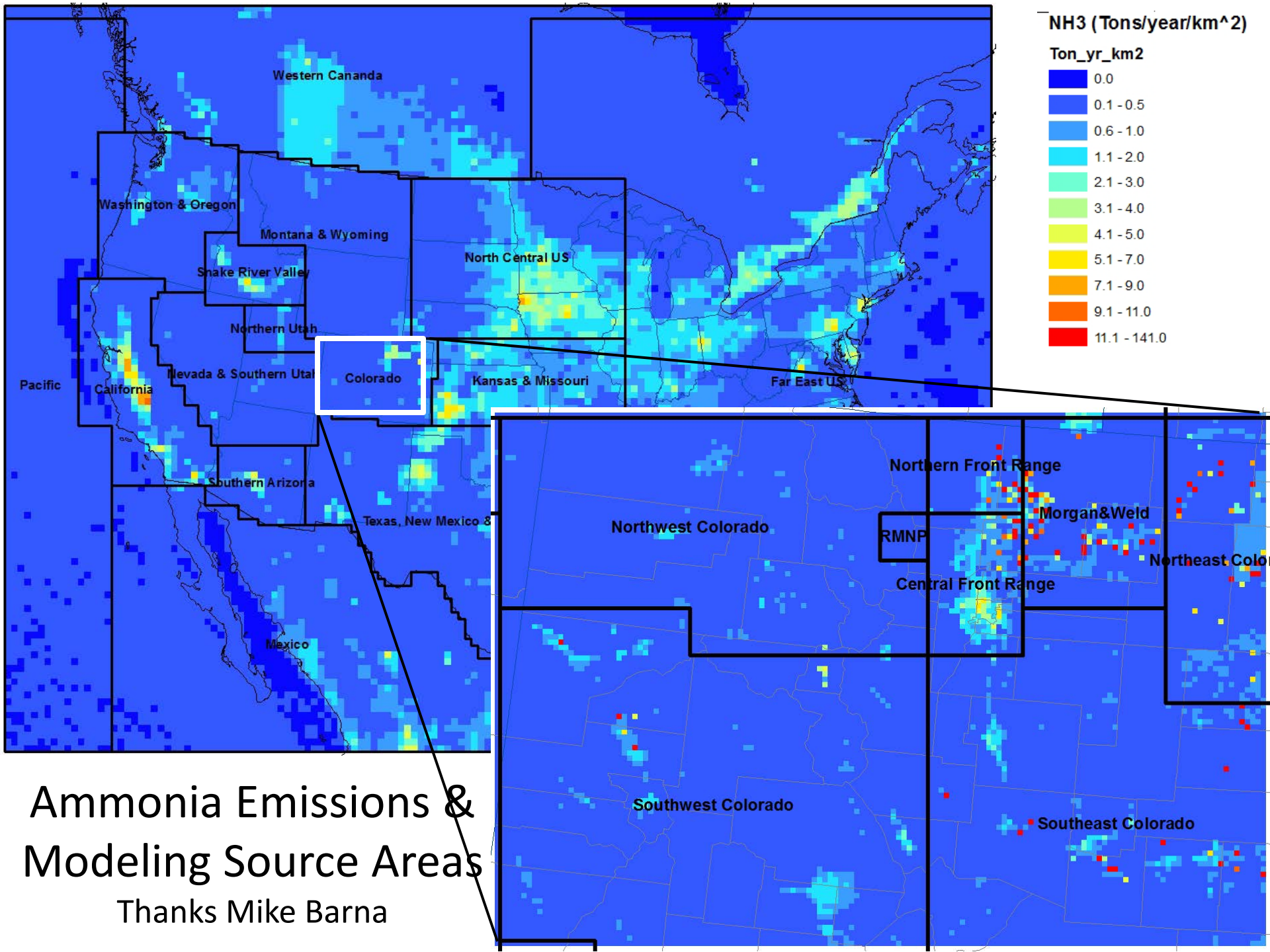
National Park Service

Air Resources Division

Thanks to Roger Claybrooke, University of Illinois, for hourly precipitation data at NADP sites.

National Acid Deposition Program (NADP)
Annual Meeting and Scientific Symposium
Santa Fe, NM, Nov 1-4, 2016

2016 National Park Service CENTENNIAL



Ammonia Emissions & Modeling Source Areas

Thanks Mike Barna

IMPROVE to Beaver Meadows ~ 10 km, Loch Vale to Beaver Meadows ~ 11 km

National Acid Deposition Program/National Trends Network (NADP/NTN) - Two Sites
Rocky Mountain National Park
North Central Colorado

Loch Vale (CO98)

Elevation 3159 m (10,362 ft)

Beaver Meadows (CO19)

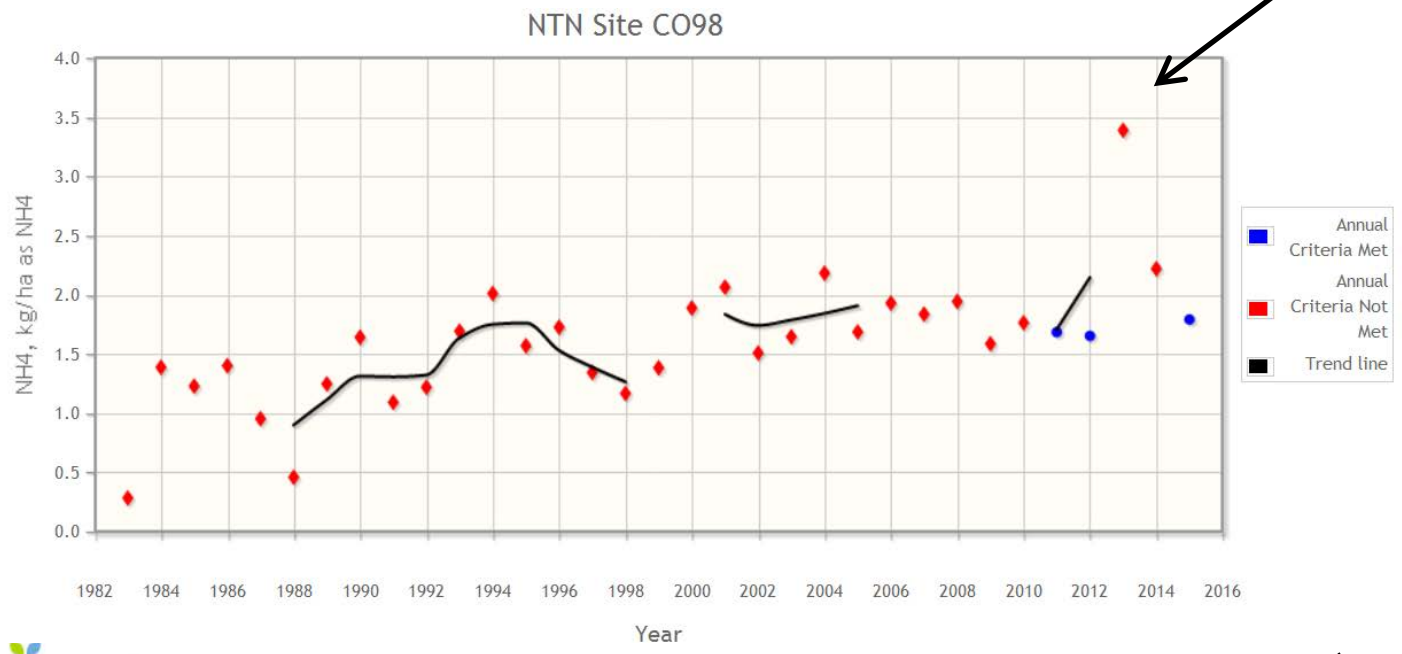
Elevation 2477 m (8125 ft)

Photos from http://nadp.sws.uiuc.edu/data/sites/siteDetails.aspx?net=NTN&id=CO19 (& CO98)

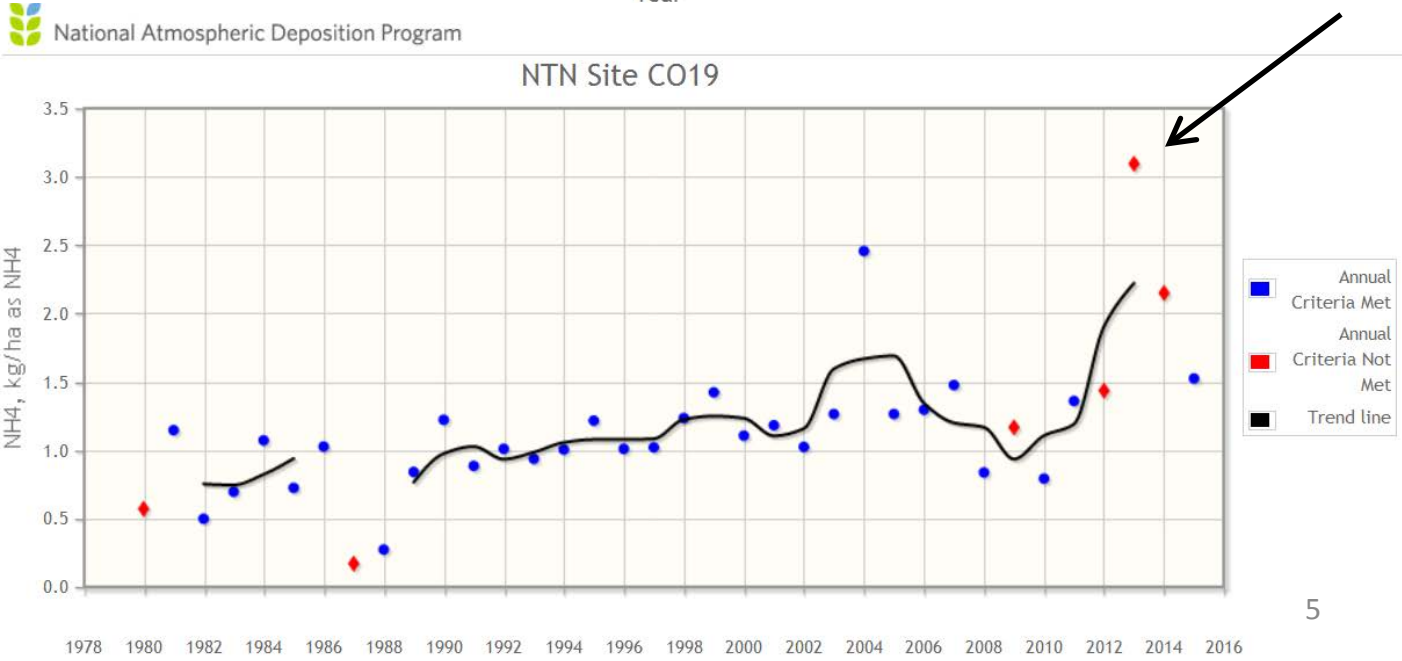
What Happened at Rocky Mountain NP in 2013?

Loch Vale

Ammonium Wet Deposition



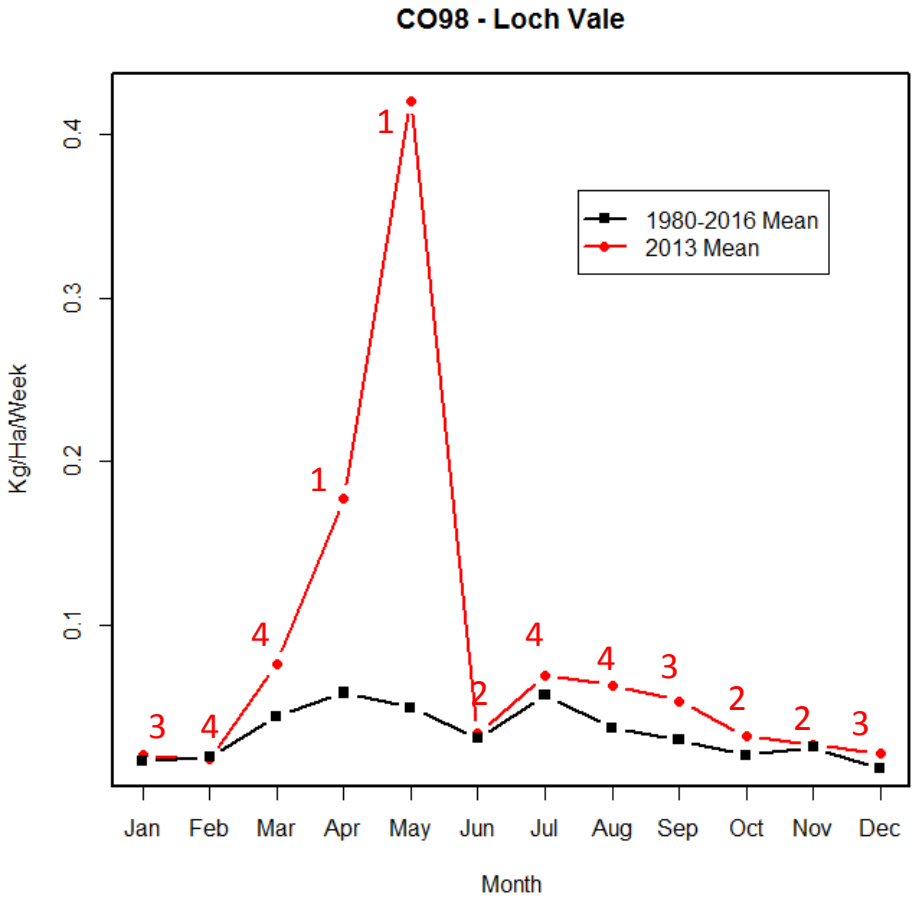
Beaver Meadows

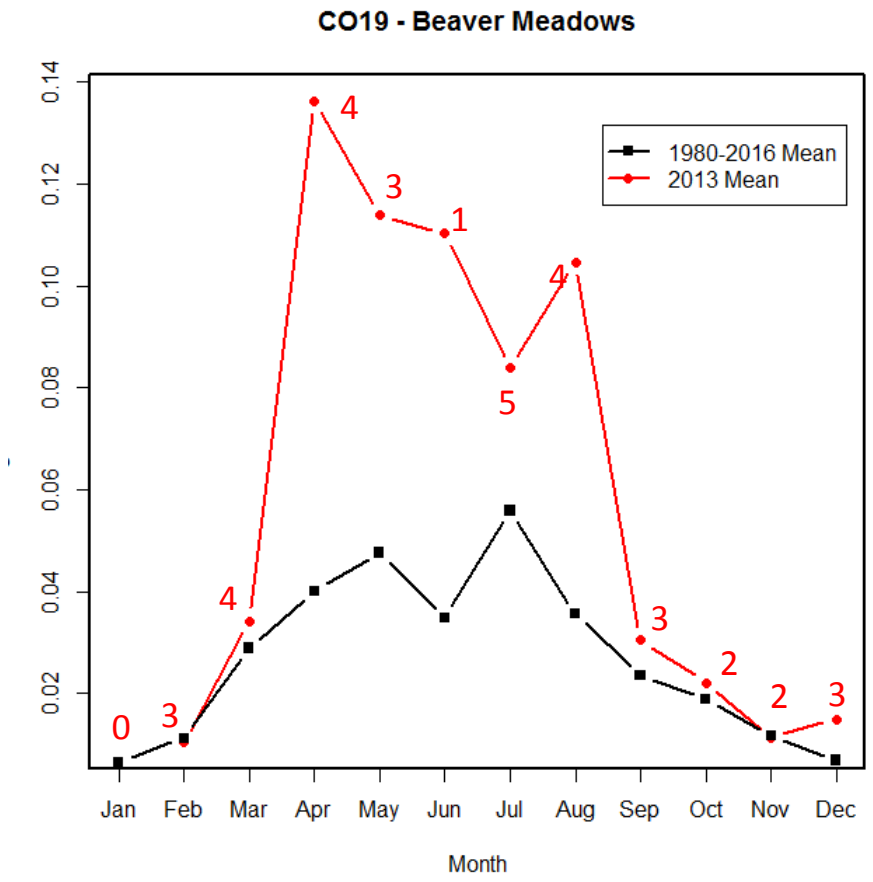


Monthly Mean Wet Ammonium Deposition

2013 (red) vs All Years (black)

Sep-Feb were fairly typical at both sites
Jun, Jul, & Aug also typical at Loch Vale, Mar typical at Beaver Meadows
Concentrate Trajectory Analyses on Apr & May

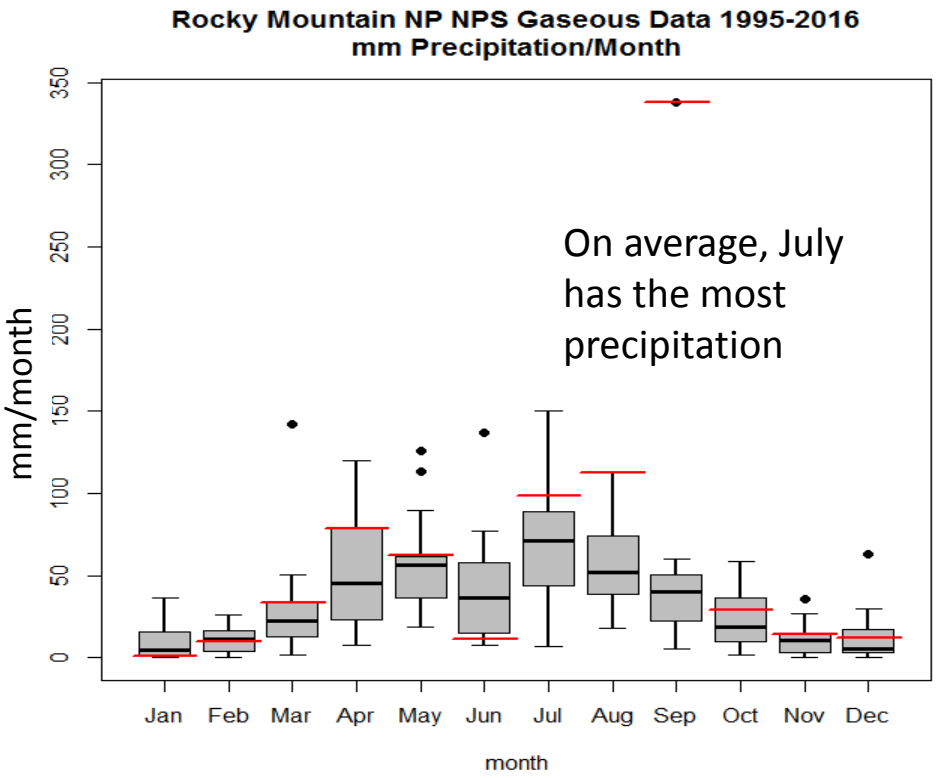


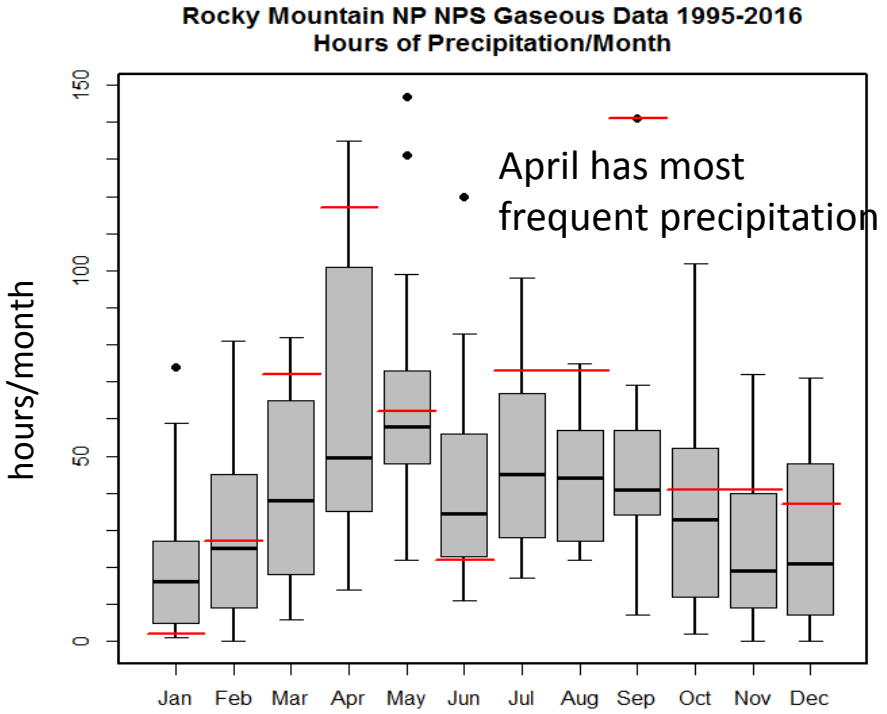


Note: Fewer Observations at Loch Vale During Key Months (Numbers in Red)

What Met Data Exists? (as of Sep 2016)

1. **NADP/NTN at Beaver Meadows (CO19)**
   - 1980-Jan 2016 daily precip, weekly concentrations
   - 2008-Sep 2016 hourly precip
2. **NADP/NTN at Loch Vale (CO98)**
   - 1983-Jan 2016 daily precip, weekly concentrations
   - 2007-Sep 2016 hourly precip
3. **NPS Gaseous Monitoring Meteorology at Longs Peak**
   - 1987-Jul 2016 hourly, Precip 1995-Jul 2016
4. **RAWS Meteorology in Estes Park**
   - 2001-Sep 2016 hourly
5. **12-km Gridded Meteorology for Trajectories (NAM12)**
   - 2008-Sep 2016 hourly
6. **32 km Gridded Meteorology for Trajectories (NARR)**
   - 1979-Jul 2016 hourly
7. **Special Studies, 2005, 2006, 2009, 2014, others**
   - Higher resolution, shorter duration

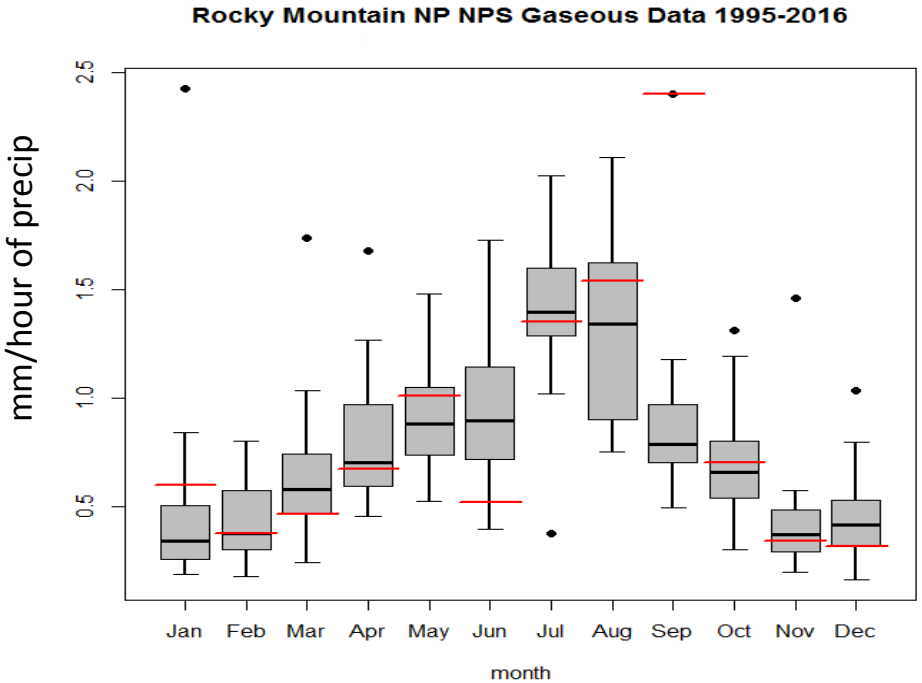




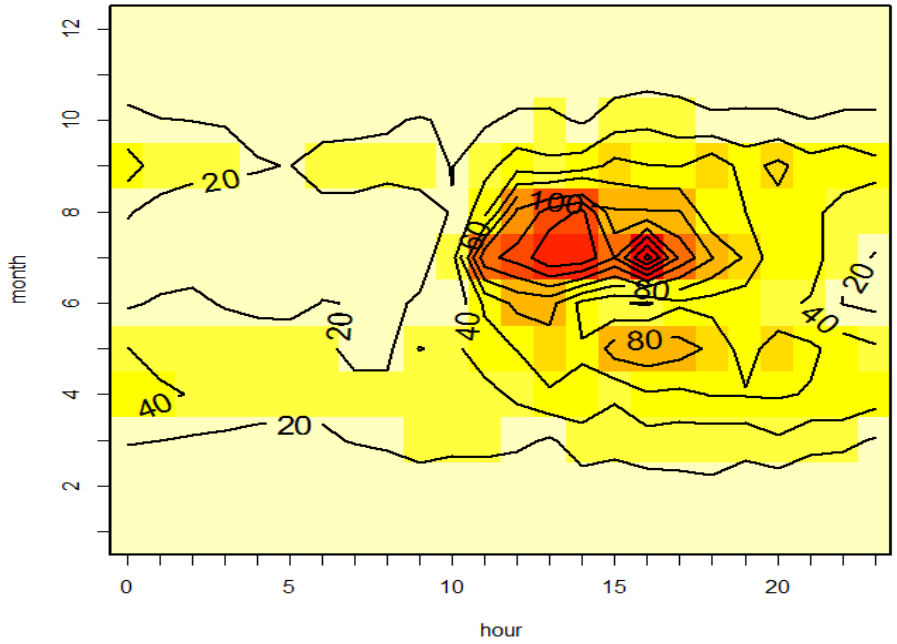
Red Lines are values for 2013

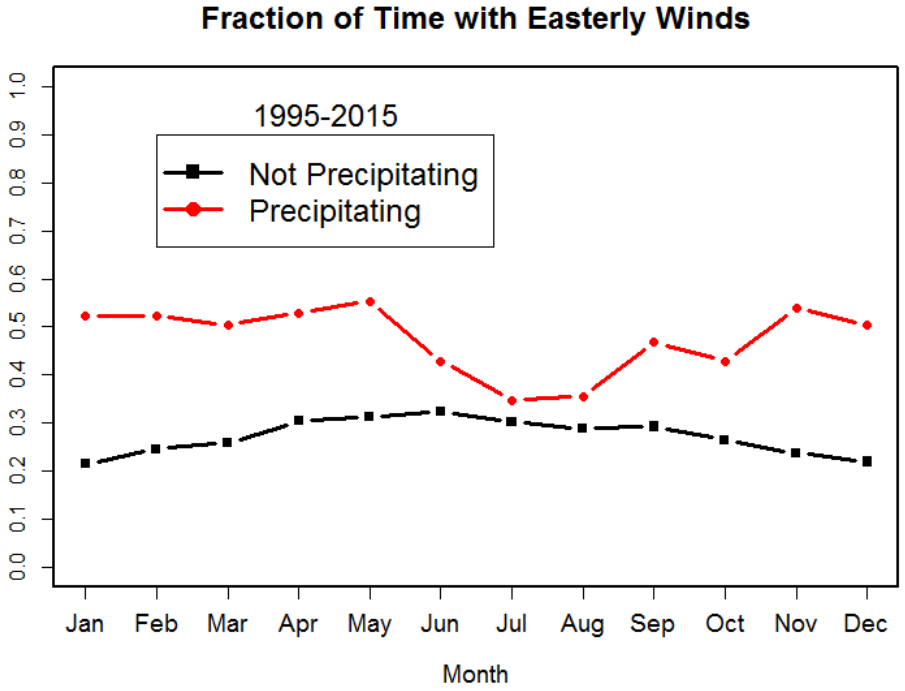
Apr & May 2013 had higher than usual frequency and amount of precipitation.

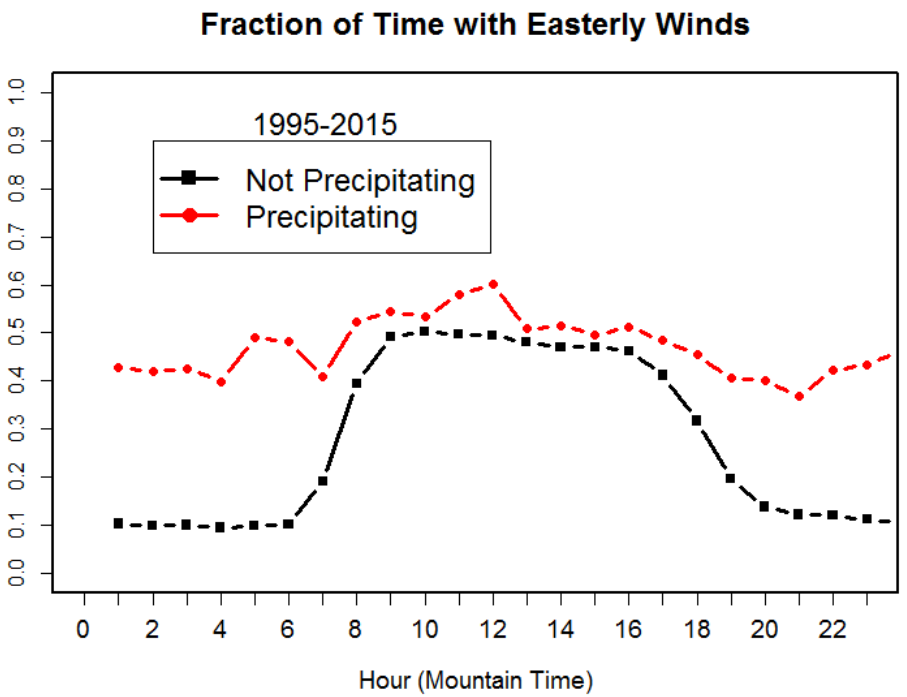
Precipitation per hour was lower than average in Apr, higher in May.



Precipitation by hour of day and month 1995-2015





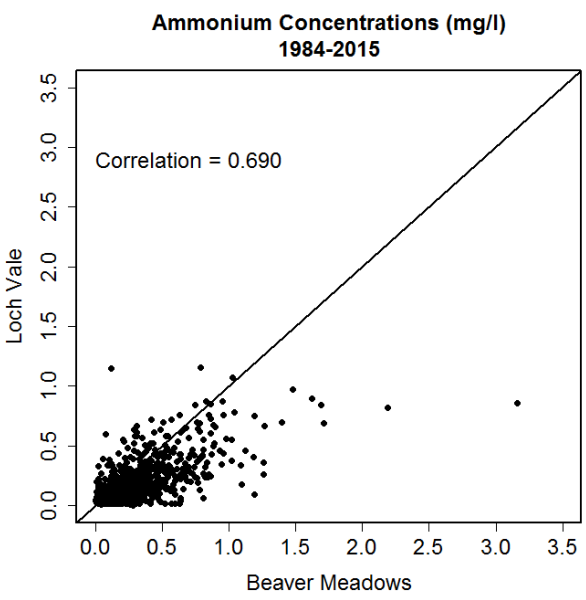


Comparing Beaver Meadows (CO19) and Loch Vale (CO98)

(Why Compare? – Beaver Meadows has more observations,
Loch Vale has an extra year of hourly precip data)

Ammonium concentrations, deposition & precipitation are highly correlated between the two sites.

- CO98 (Loch Vale) has more and more frequent precipitation… and is missing precipitation at some key times.
- Mean weekly Concentrations are higher at Beaver Meadows (0.29 vs 0.19 mg/l)
- Mean deposition is slightly higher at Loch Vale (0.035 vs 0.029 Kg/Ha/Week)



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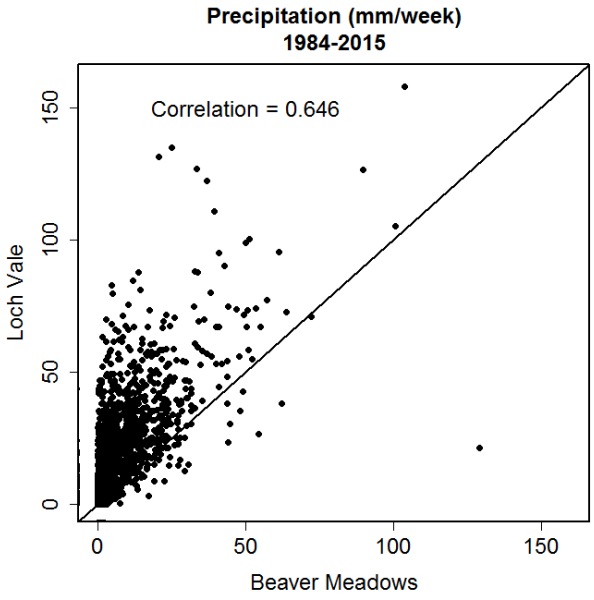

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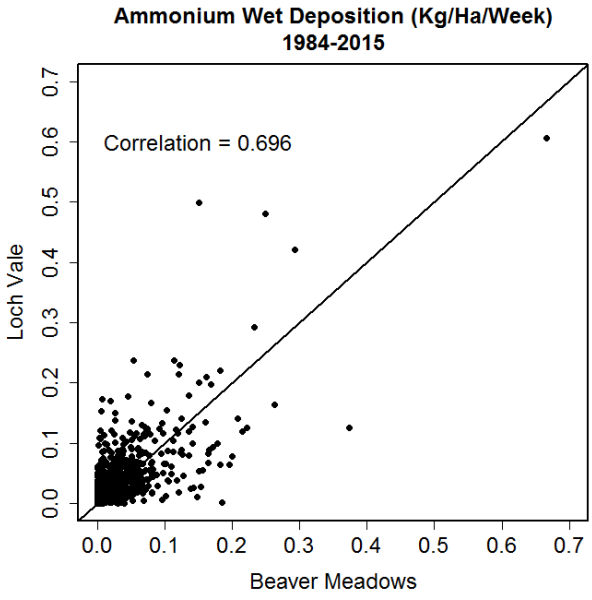
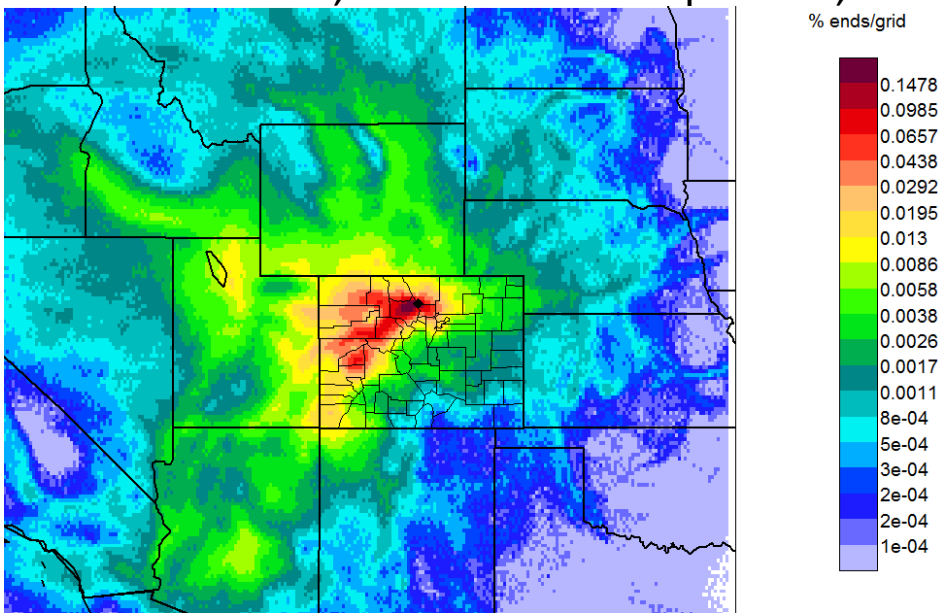


1984-2015

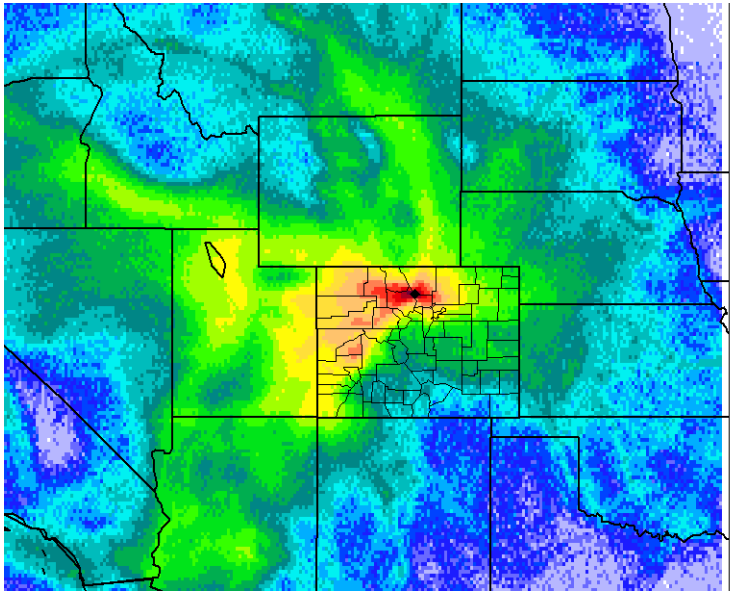
Transport Patterns: All Hours With Data, Hours With Precipitation, Hours Without Precipitation

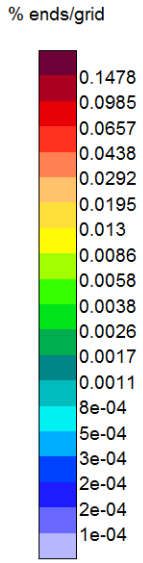
Hourly Precip
Loch Vale
April & May
2008-2016



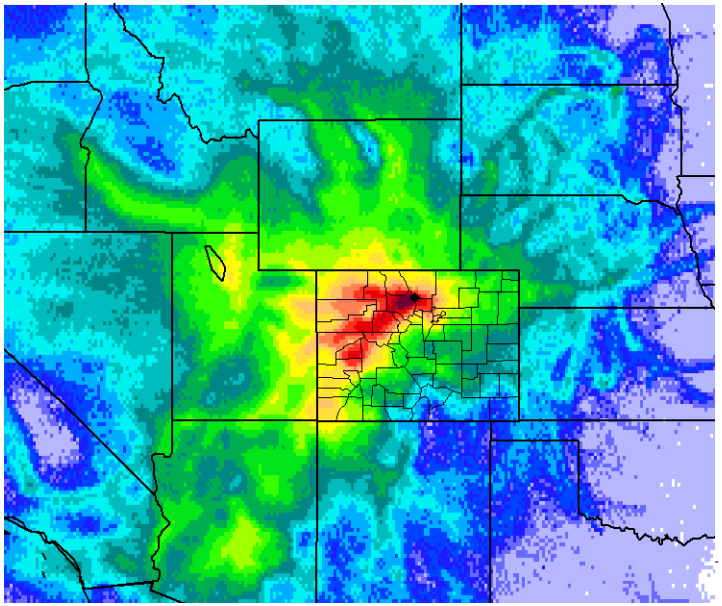
All Hours with Precipitation Data
12,387 Hours

Hours With Precipitation
(20% of Hours)

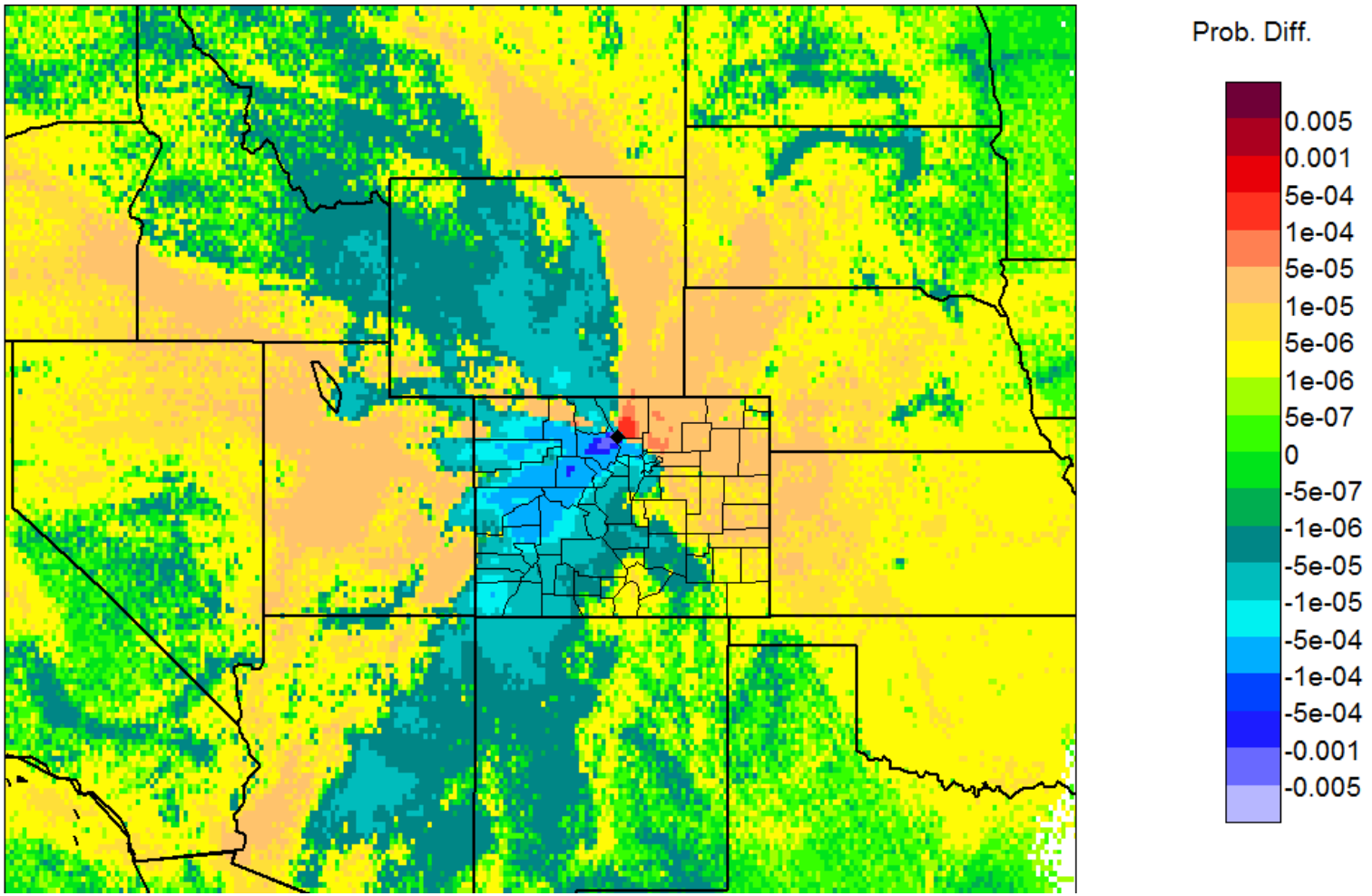




Hours With No Precipitation
(80% of Hours)



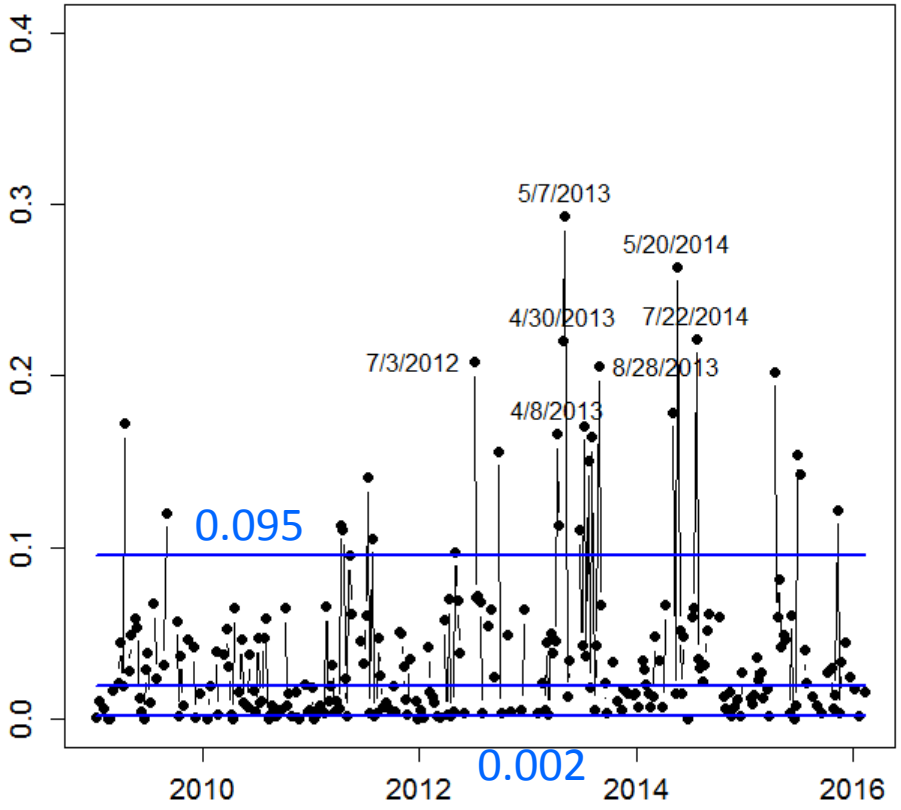
To make the differences easier to visualize, look at the differences between the transport patterns. This is the probability of transport during all hours subtracted from the probability of transport during hours with precipitation .



When there is precipitation at Loch Vale there is more likely to be transport from the east (red) than during average conditions. (Apr & May 2008-2016)

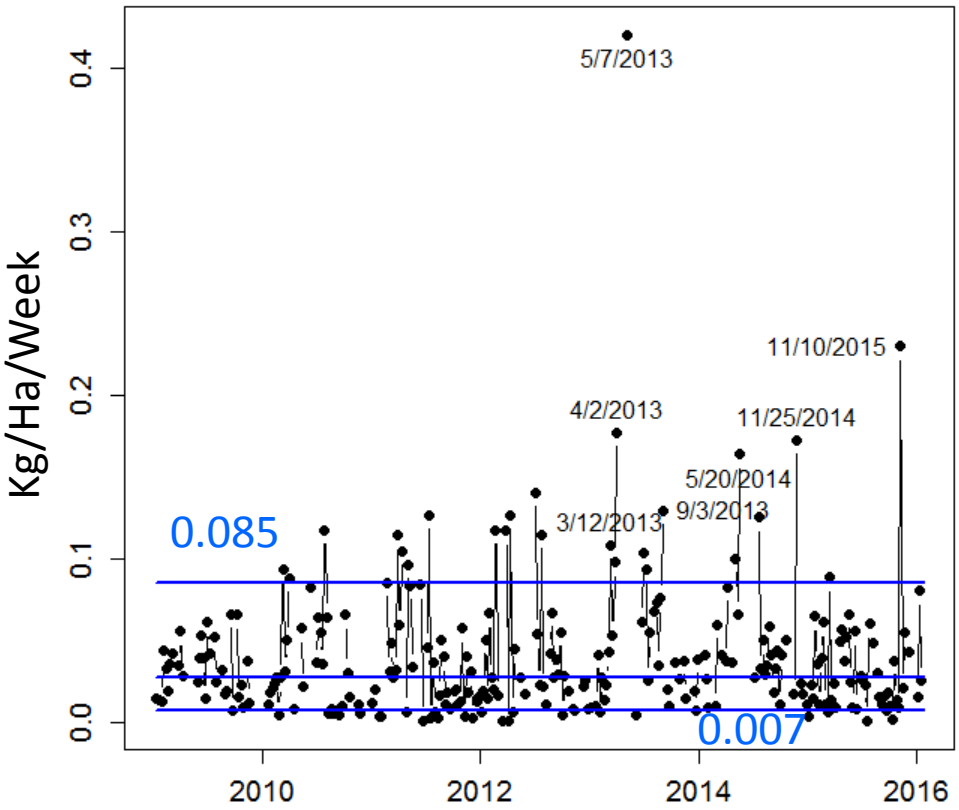
Traditional Back Trajectory Analyses Applied to NADP Data
Choice of "High" and "Low" Weeks for Trajectory Analyses

Beaver Meadows (CO19)
Weekly Ammonium Wet Deposition



9/1/2008 – 2/1/2016

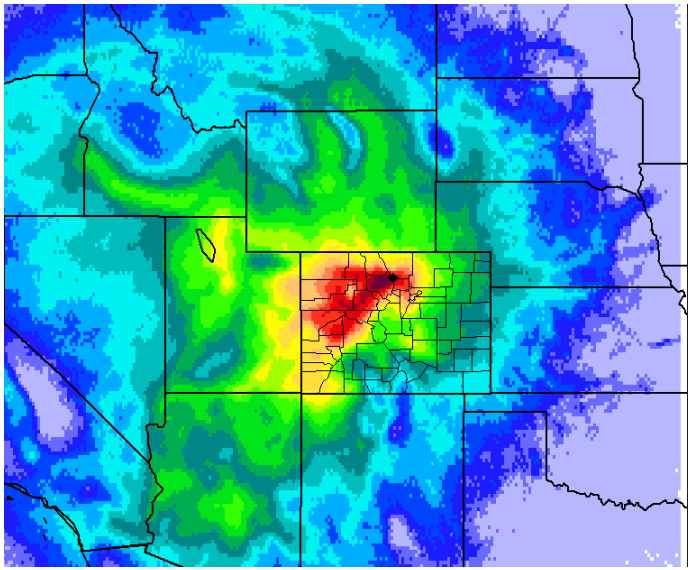
Loch Vale (CO98)
Weekly Ammonium Wet Deposition

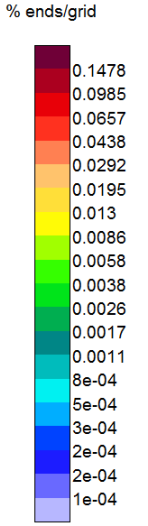


1/1/2008 – 2/9/2016

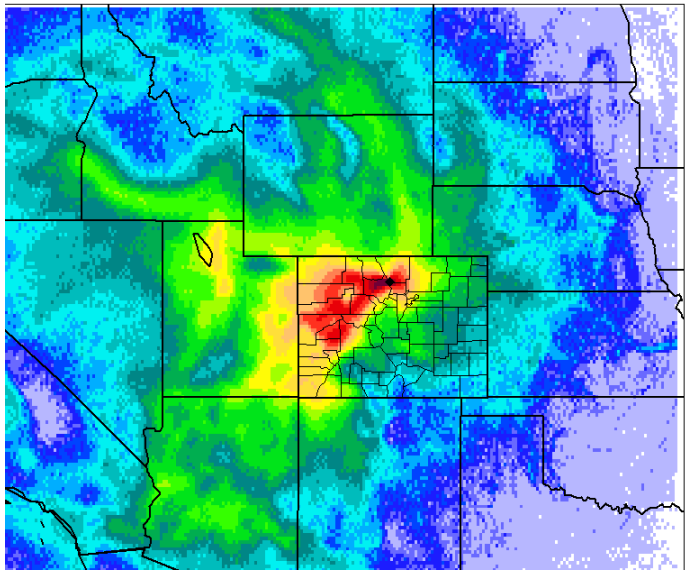
These are weekly values, so will also look only at hours with precipitation.
Dates include all times with both hourly precipitation and weekly concentrations/deposition

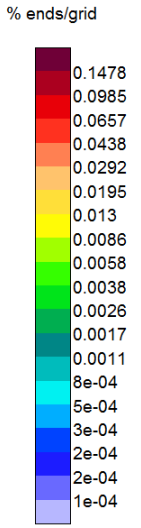
Overall Transport – All Hours





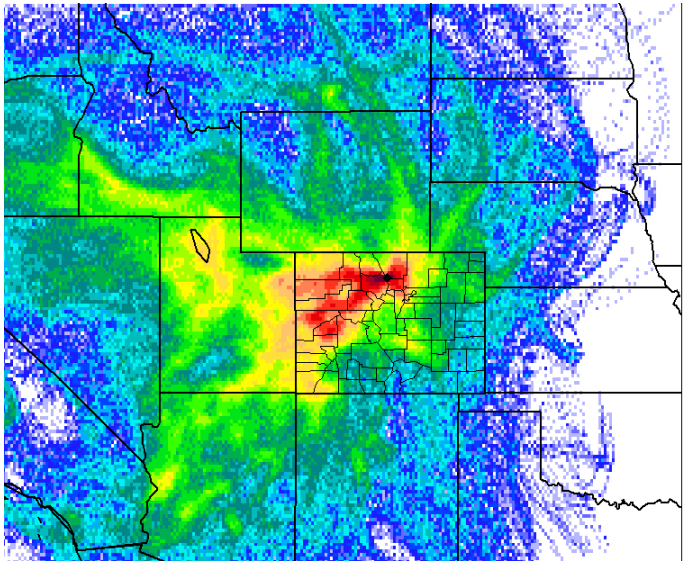
Overall Transport, Precipitation > 0

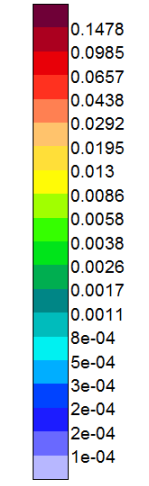




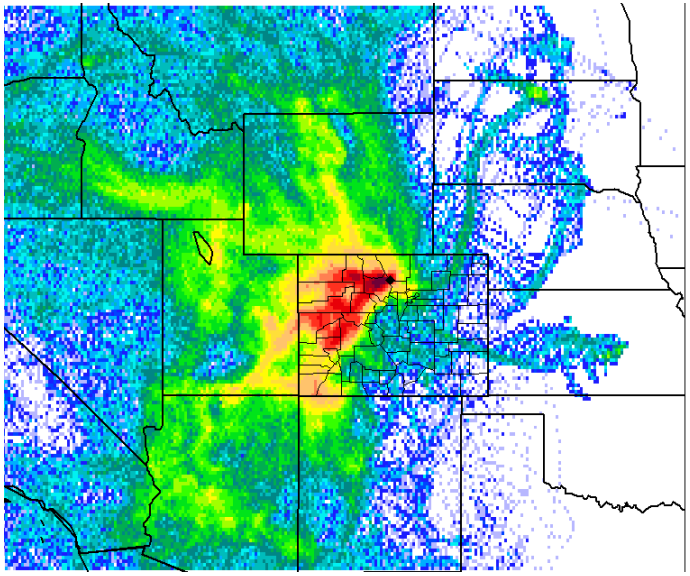
3-Day Trajectories Loch Vale 1/2008-1/2016, All Months of the Year

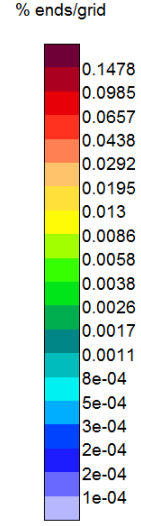
High NH_4 Dep Transport, Precip > 0





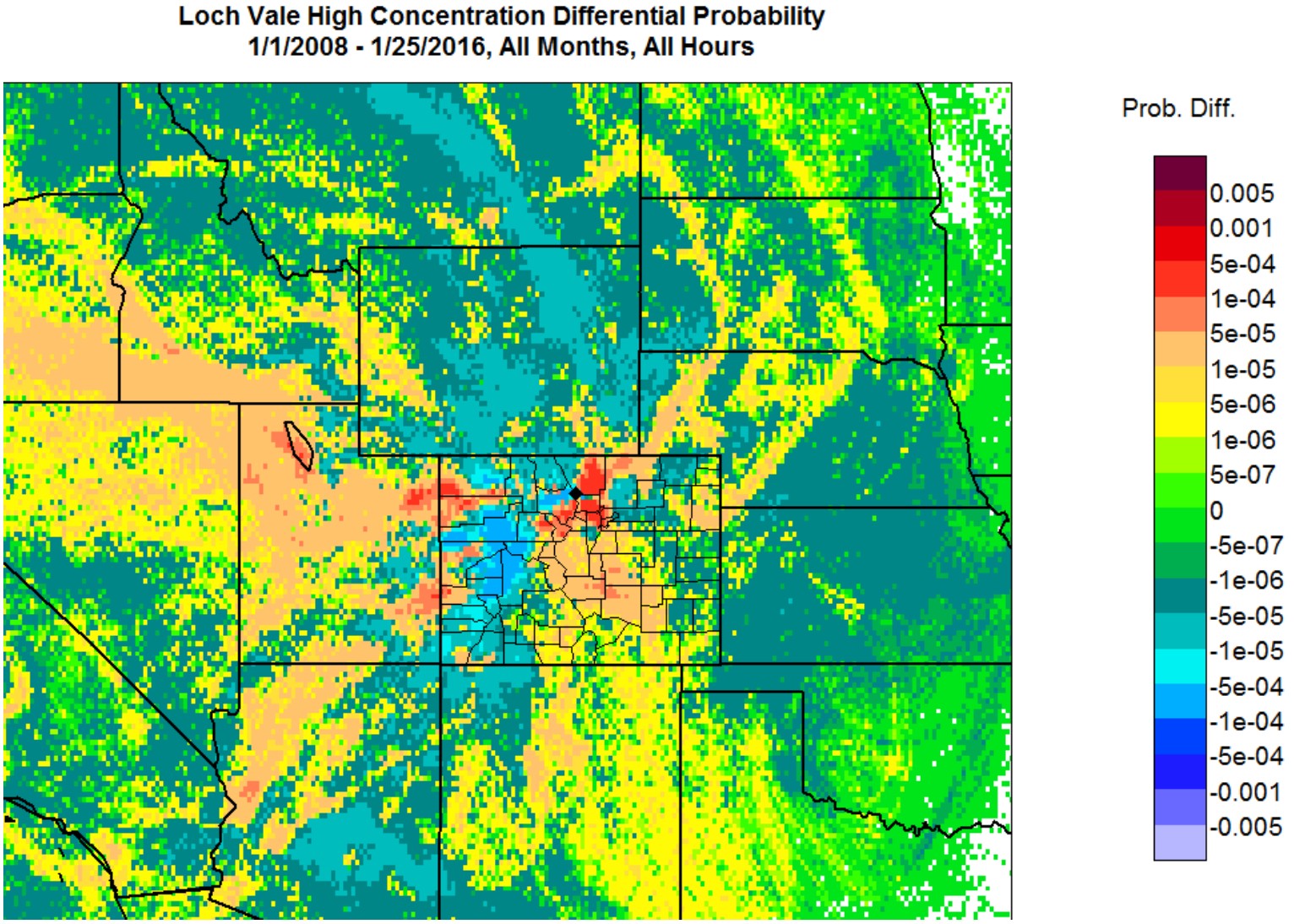
Low NH_4 Dep Transport, Precip > 0





Transport Differences: Hours with Precipitation

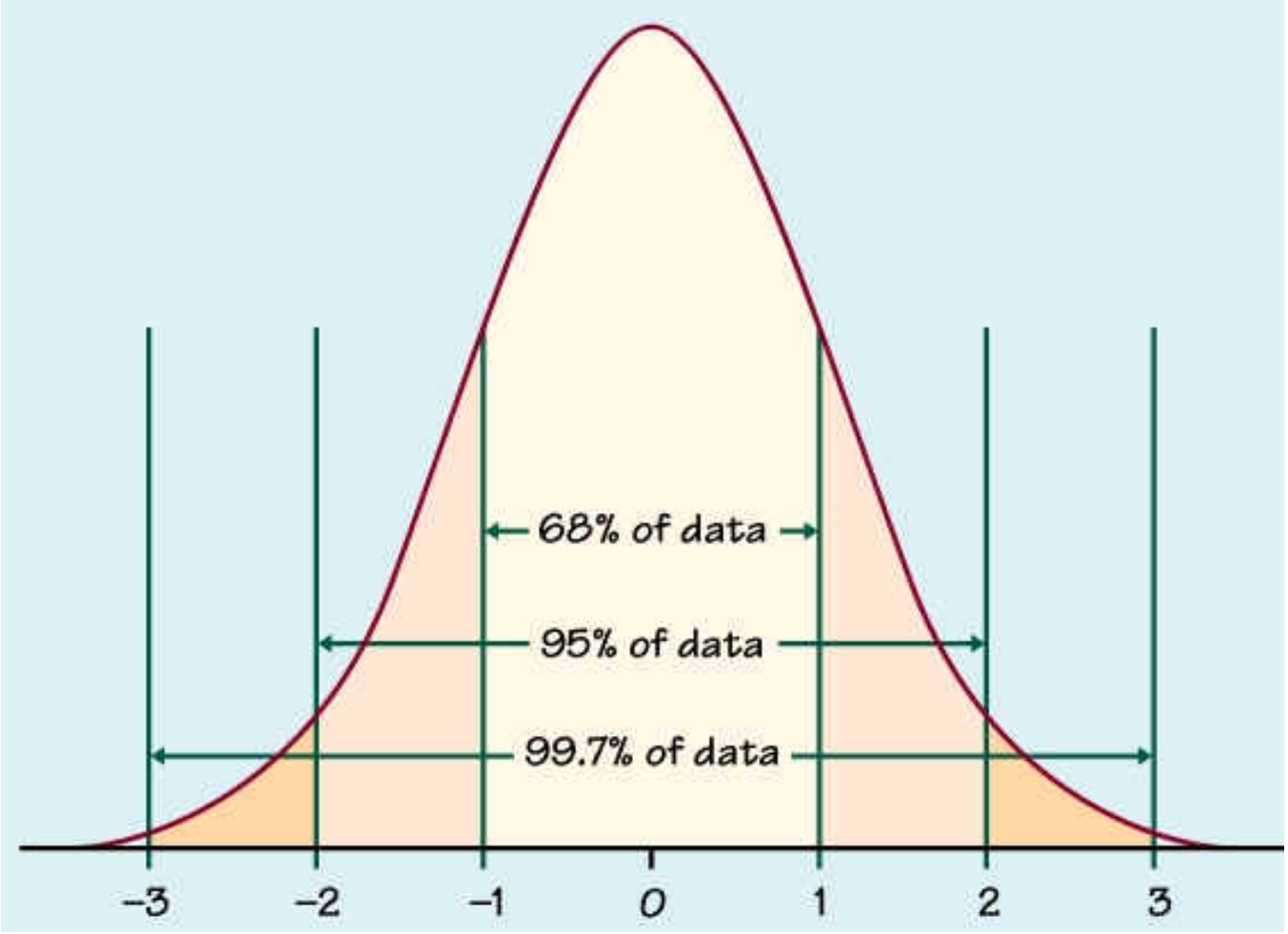
(High NH_4 Dep Transport - Average Transport)



New Trajectory Analyses… How unusual are the differences?

Z Score = Number of Standard Deviations from the Mean

Z = (X – Mean) / (Standard Deviation)

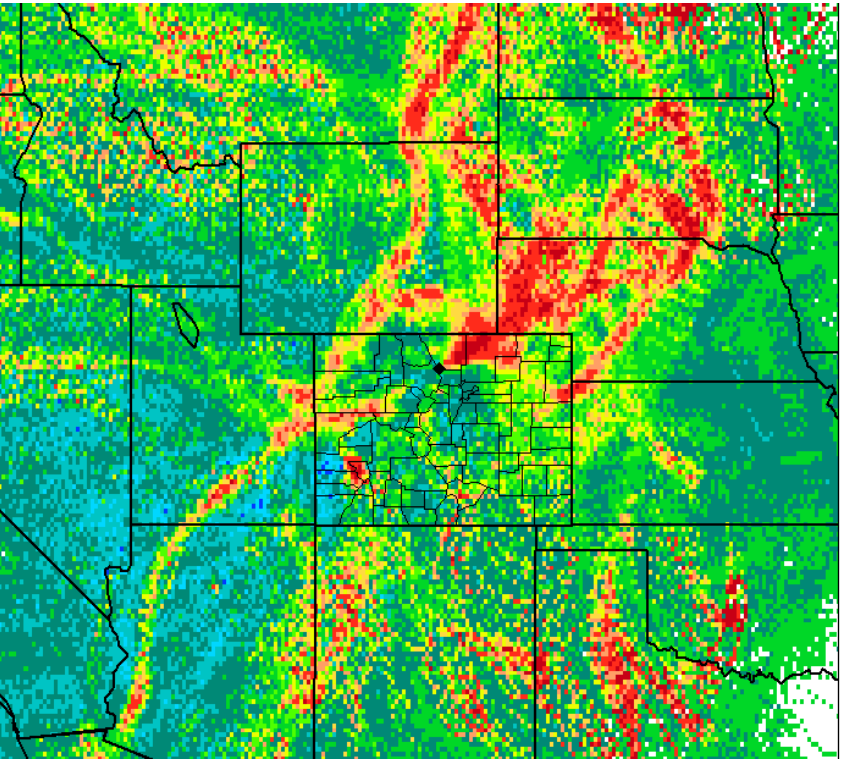


Transport Z Scores

NAM12 Met Data, April & May, 2008 - 2016 (n=9)

Loch Vale, 3 Day Trajectories, Only Hours With Precipitation

2013 – High Wet Deposition

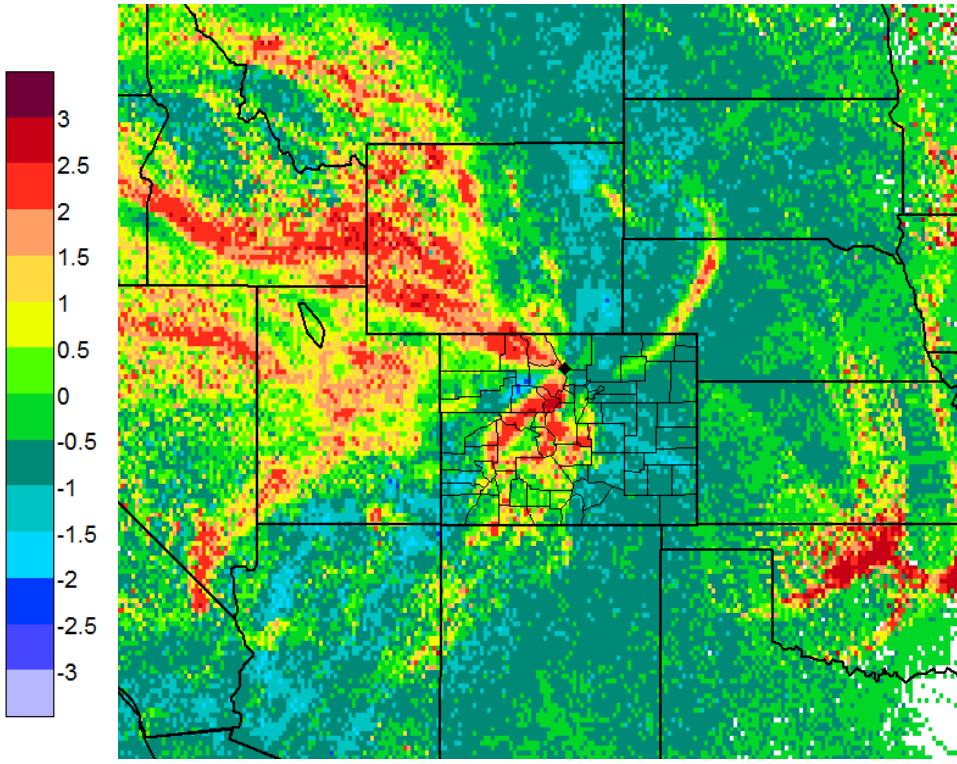


Ammonium Deposition (Kg/Ha/Week)

Mean = 0.30 Loch Vale, 0.13 Beaver Meadows

Max = 0.42 Loch Vale, 0.29 Beaver Meadows

2008 – Low Wet Deposition



Ammonium Deposition (Kg/Ha/Week)

Mean = 0.04 Loch Vale, 0.08 Beaver Meadows

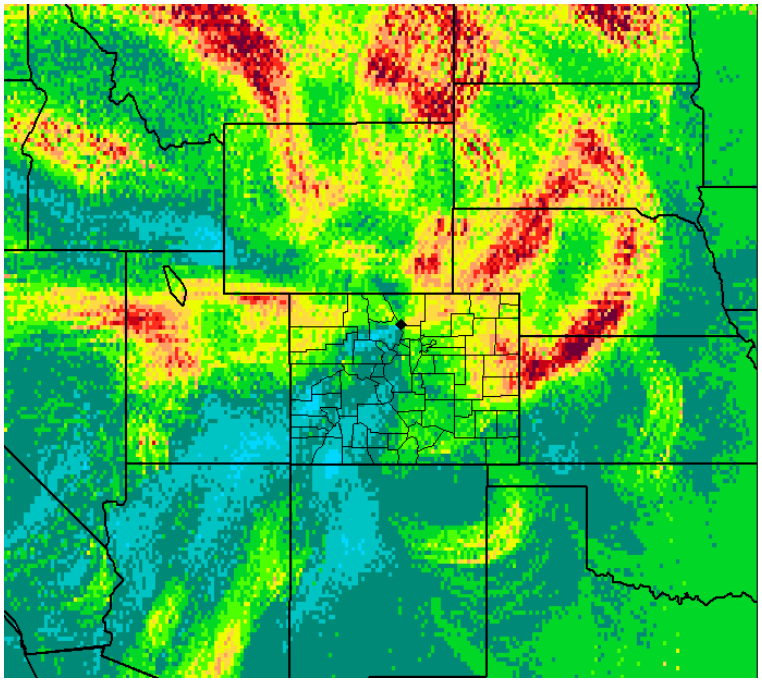
Max = 0.12 Loch Vale, 0.21 Beaver Meadows

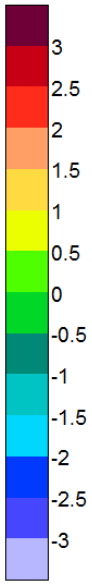
Transport Z Scores

32 Km NARR Met Data, April & May, 1980 - 2016 (n=37)

Loch Vale, 3 Day Trajectories, All Hours

2013 – High Wet Deposition





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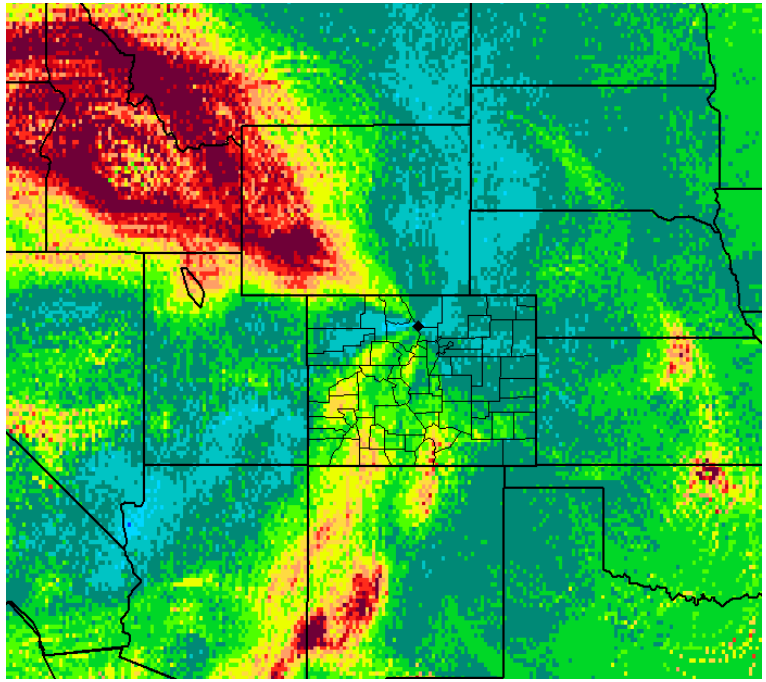
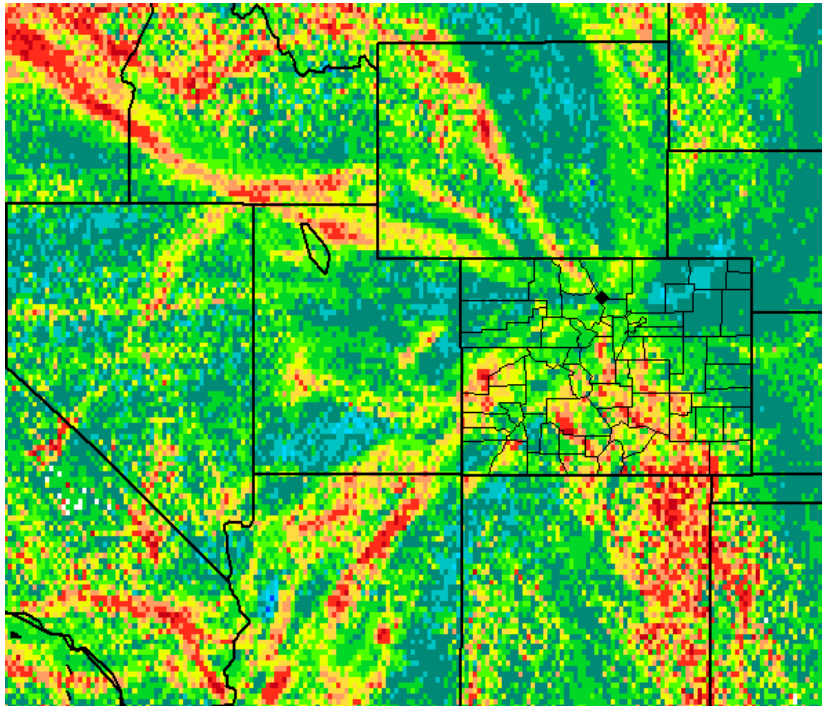


Ammonium Deposition (Kg/Ha/Week)
Mean = 0.04 Loch Vale, 0.08 Beaver Meadows
Max = 0.12 Loch Vale, 0.21 Beaver Meadows

Transport Z Scores (More Confusing Results)

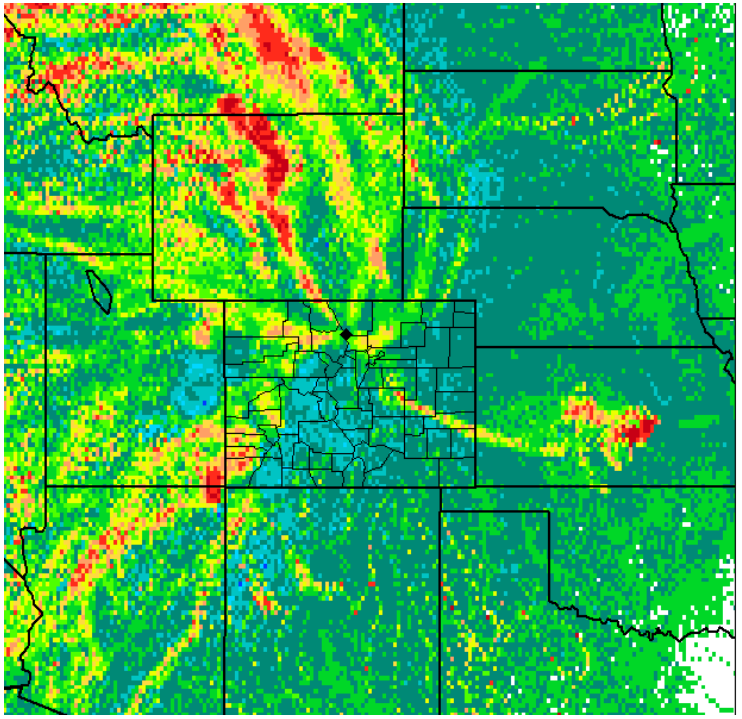
April & May, 2008 - 2016 (n=9), Loch Vale, 3 Day Trajectories, Only Hours With Precipitation

2014 (High Wet Deposition Year)
Yet Few Easterlies – Other Sources? N Utah & Snake River Valley, S. Front Range?



Ammonium Deposition (Kg/Ha/Week)
Mean = 0.08 Loch Vale, 0.10 Beaver Meadows
Max = 0.16 Loch Vale, 0.26 Beaver Meadows

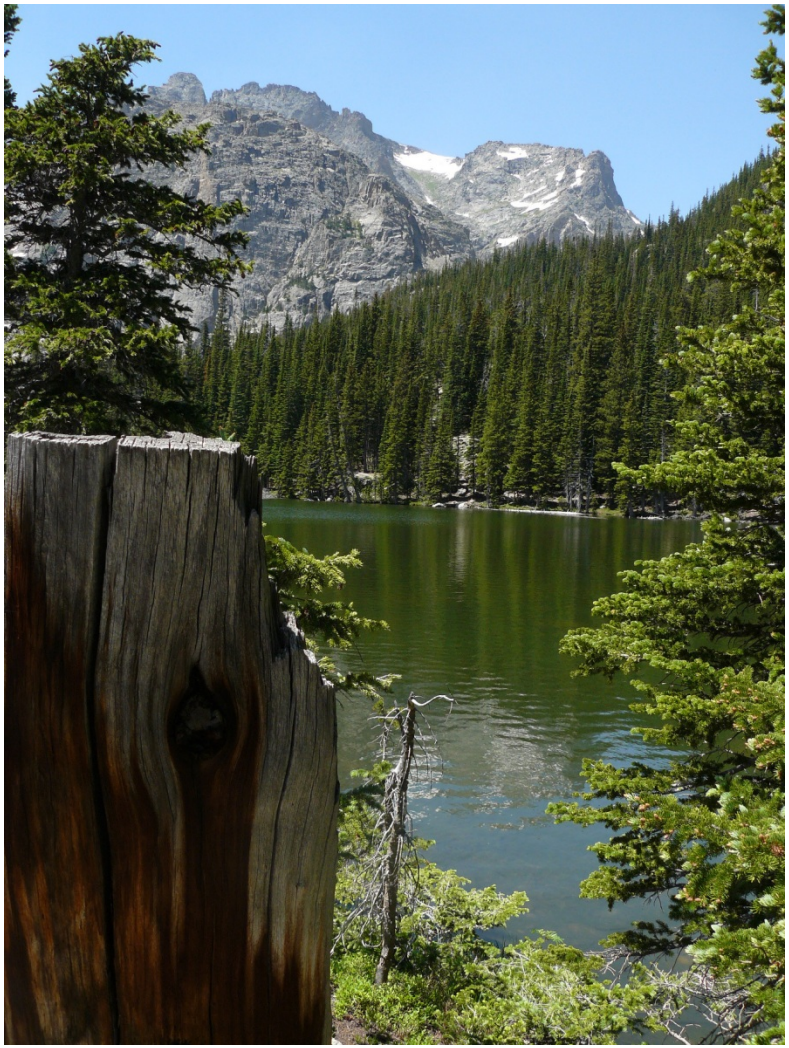
2012 (Low Wet Deposition Year)
Yet with Easterlies - Other Factors? , deposition before reaching park?



Ammonium Deposition (Kg/Ha/Week)
Mean = 0.04 Loch Vale, 0.04 Beaver Meadows
Max = 0.13 Loch Vale, 0.10 Beaver Meadows

To Do List

1. Map Z Score to P-Value and Student's T to better understand significance.
2. Repeat analysis for Nitrate & possibly Sulfate
3. If correlated, use modeled precipitation from Hysplit to fill in hourly precipitation data when measured does not exist.
4. If above doesn't work – possibly use precip days and limit hours to afternoon.
5. Does it work at other sites?
6. Examine higher elevation trajectories (cloud movement).



The Loch, Rocky Mountain National Park, CO, 2008

Summary

1. Unusually high ammonium wet deposition at RMNP in April & May 2013. Why?
2. Climatologically, April and July have the greatest precipitation at RMNP. April more likely to have synoptic scale storms . July more likely to have convective storms.
3. When precipitation occurs, there is more likely to be transport from the east. Evident in both 10-m tower data at Longs Peak and back trajectory analyses.
4. Ammonia emissions are higher to the east.
5. About 6% at of hours at Longs Peak, 7% at Beaver Meadows and 16% at Loch Vale have precipitation. Precipitation most likely during 10 am to 5 pm.
6. Both traditional back trajectory residence time analyses and new Z score analyses for April & May show 2013 had unusually frequent transport from eastern Colorado.
7. Results for some other years are less simple and need further study.
8. Analyses could be done for other species, sites, elevations.

Ouzel Falls , RMNP, Colorado, 1994