Trends in Reactive Nitrogen at Rocky Mountain National Park by Transport Direction

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Loch Vale (CO98)
Rocky Mountain National Park, CO
Elevation 3159 m (10,362 ft)

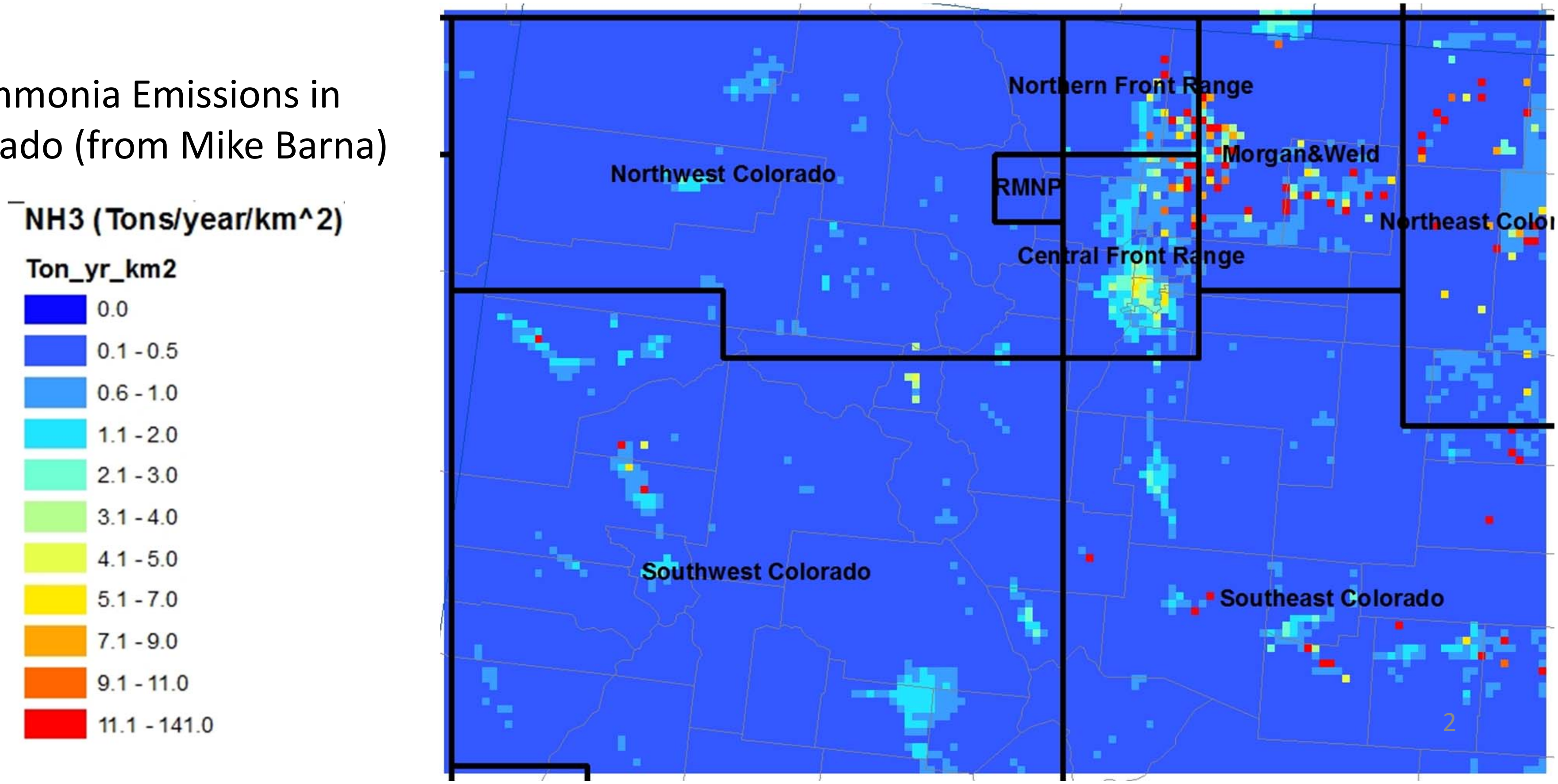
National Acid Deposition Program (NADP) Scientific Symposium & Fall Meeting
Albany, New York, Nov 5-9, 2018
Last Update 7 Nov 2018

Photo http://nadp.sws.uiuc.edu/data/sites/siteDetails.aspx?net=NTN&id=CO98

Why Explore Directional Trends?

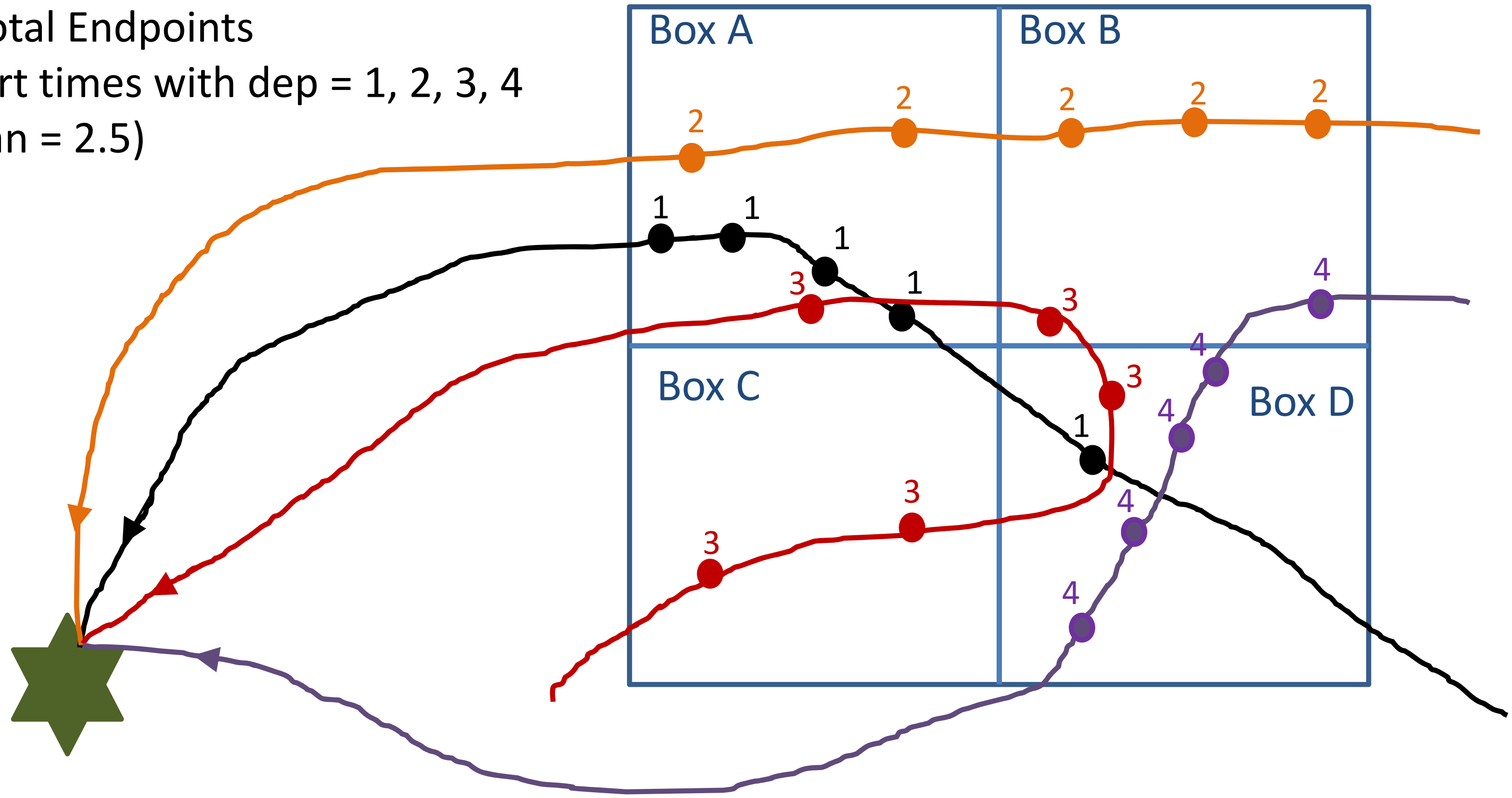
- Emissions are greater to the East of the park.
- There is more frequent transport from the West.
- Large precipitation amounts are often associated with transport from the east, especially in the spring
- Ag producers in Eastern CO have been participating in a voluntary early warning system. Impacts?
- Are trends due to meteorology or emissions changes?

Ammonia Emissions in Colorado (from Mike Barna)



Two Trajectory Analyses – Mean Deposition & Overall Residence Time

Example:
20 Total Endpoints
4 start times with dep = 1, 2, 3, 4
(mean = 2.5)



Mean Box A = (1*4 + 2*2 + 3*1)/7 = 1.57	ORT Box A =7/20 = 0.35
Mean Box B = (2*3 + 3*1 + 4*1)/5 = 2.60	ORT Box B = 5/20 = 0.25
Mean Box C = (3*2)/2 = 3.00	ORT Box C = 2/20 = 0.10
Mean Box D= (1*1 + 3*1 + 4*4)/6 = 3.33	ORT Box D = 6/20 = 0.30

Mean (Box A,B,C,D) = (1.57*7 + 2.6*5 + 3.0*2 + 3.33 * 6)/20 = 50/20 = 2.5

Input Data

Back Trajectories

- Hysplit Model ver 3, ensemble mode - start point is wiggled in horizontal & vertical, 27 start points/start hour
- Start heights at 10 m (near ground) and 1000 m (closer to cloud height)
- Traced for 1, 2, and 3 days back in time. Dropped 1st 3 endpoints.
- Input – North American Regional Reanalysis (NARR) 32 km grid spacing

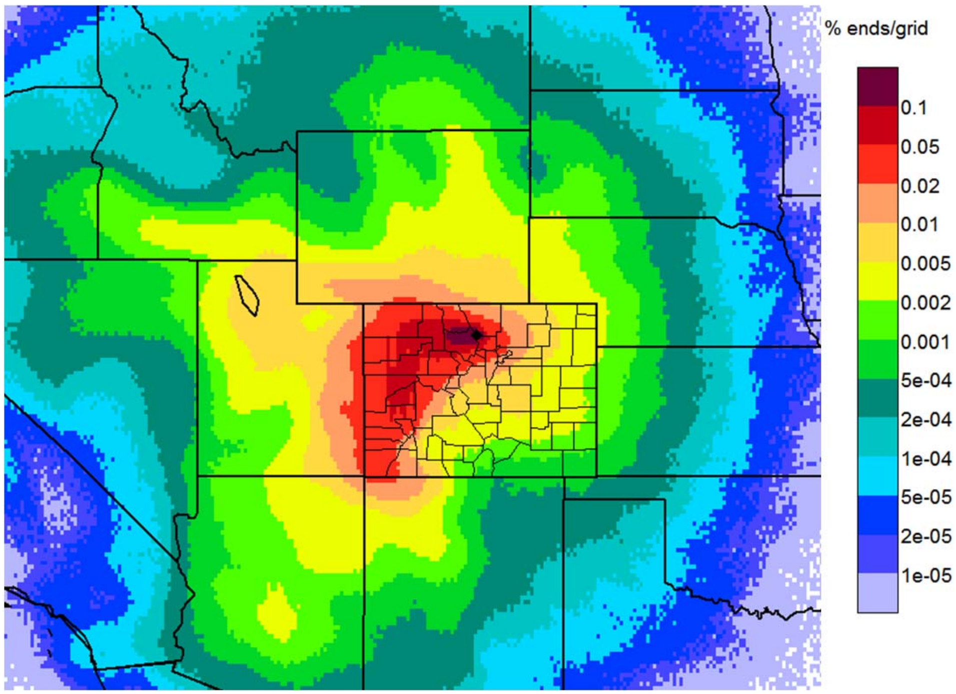
1 day trajectories: 24 starts/day * 27 ensembles/start * 24 hours traced = 15,552

NADP Data

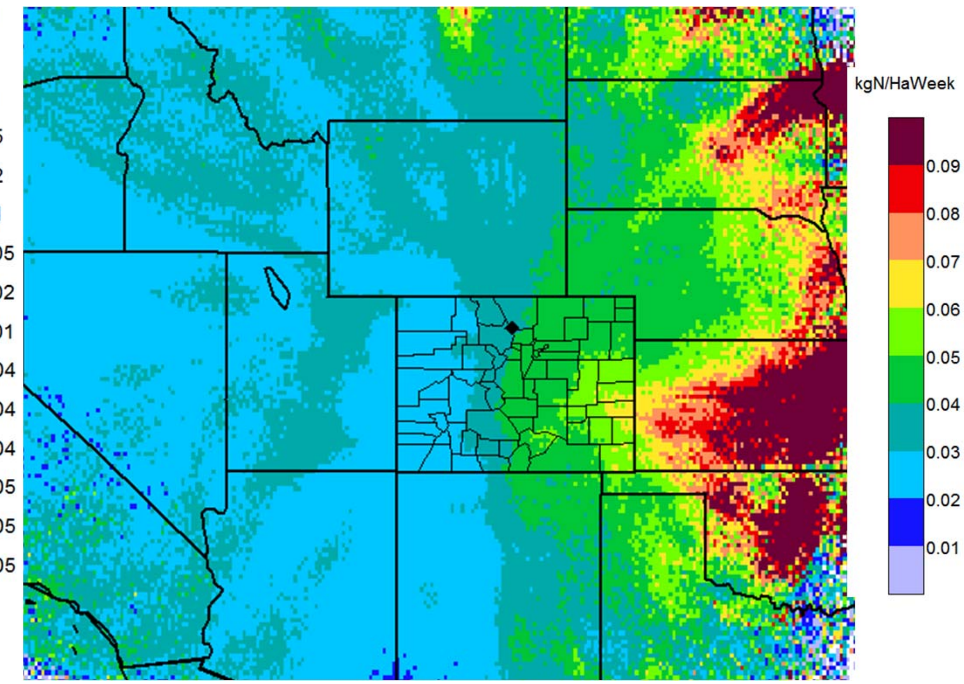
- NADP Valid Weekly concentrations – No attempt to fill in missing.
- Calculated deposition in units of kgN/Ha/week using NADP recommended weekly precipitation value.
- Daily precipitation from NADP web site – Days with missing or 0 precipitation were eliminated (about half the days).

<u>Examples</u>: Loch Vale (CO98) 1984-2017, 2-Day duration, 10 m start, Days with valid weekly NADP obs and Daily Precip > 0

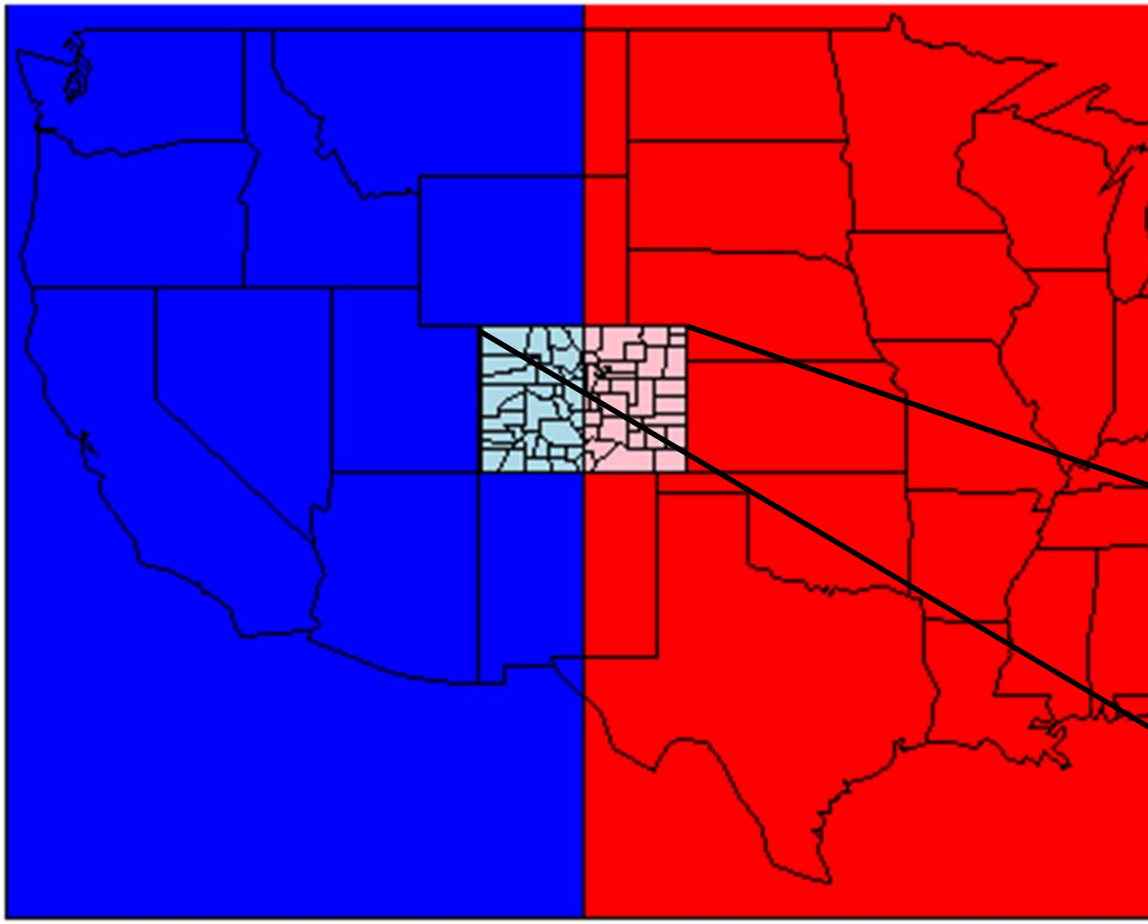
Overall Residence Time
(Where did air come from?)



Mean Ammonium Deposition
(What was deposition when it arrived?)

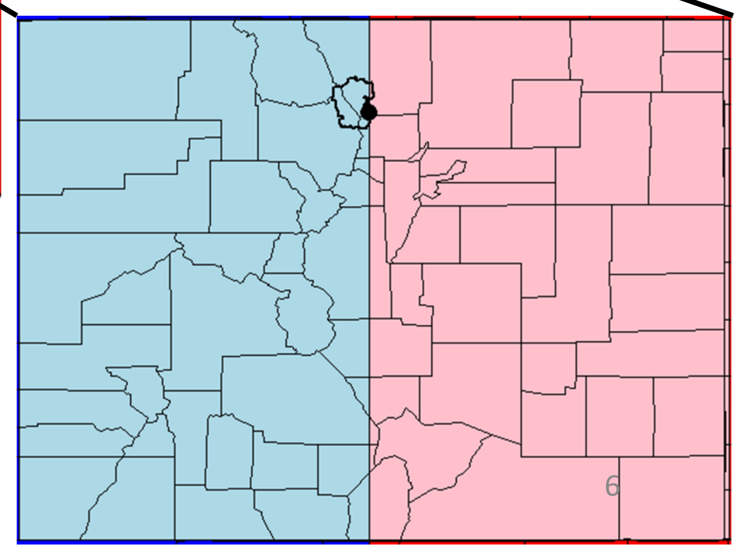


Four Upwind Regions

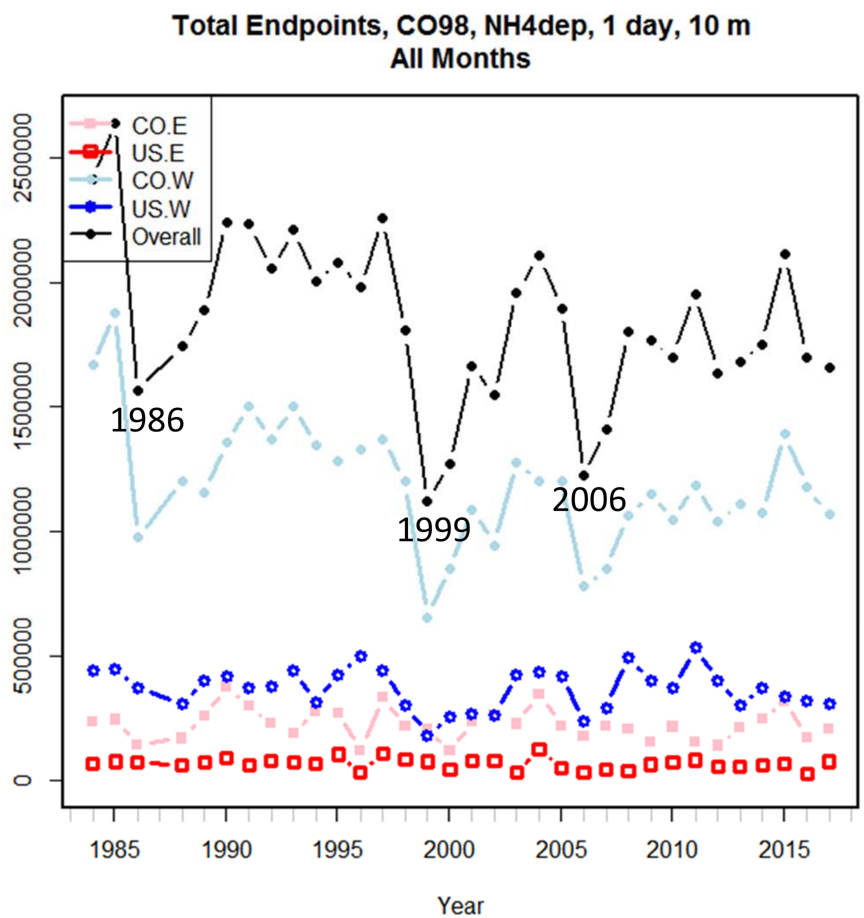


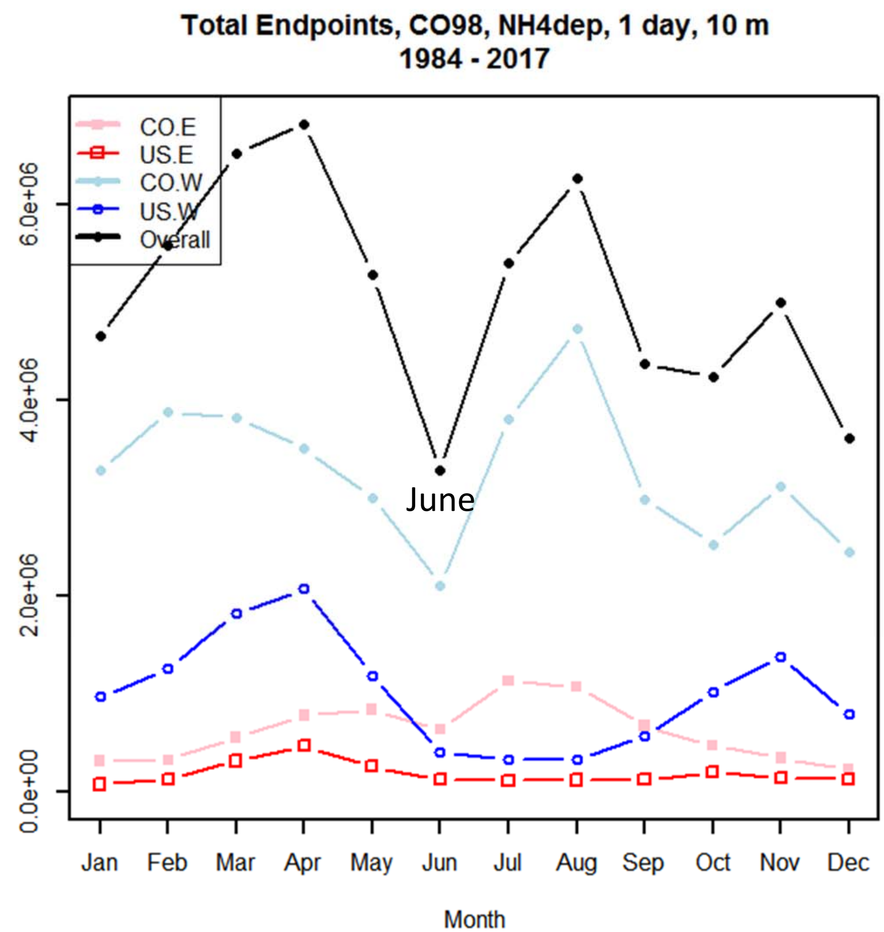
Eastern U.S. (red) and
Western U.S. (blue)

Western Colorado (light blue) and
Eastern Colorado (light red)



Total Endpoints (Overall Residence Time)
Depends on Number of Valid Weekly Sample and Days of Precipitation

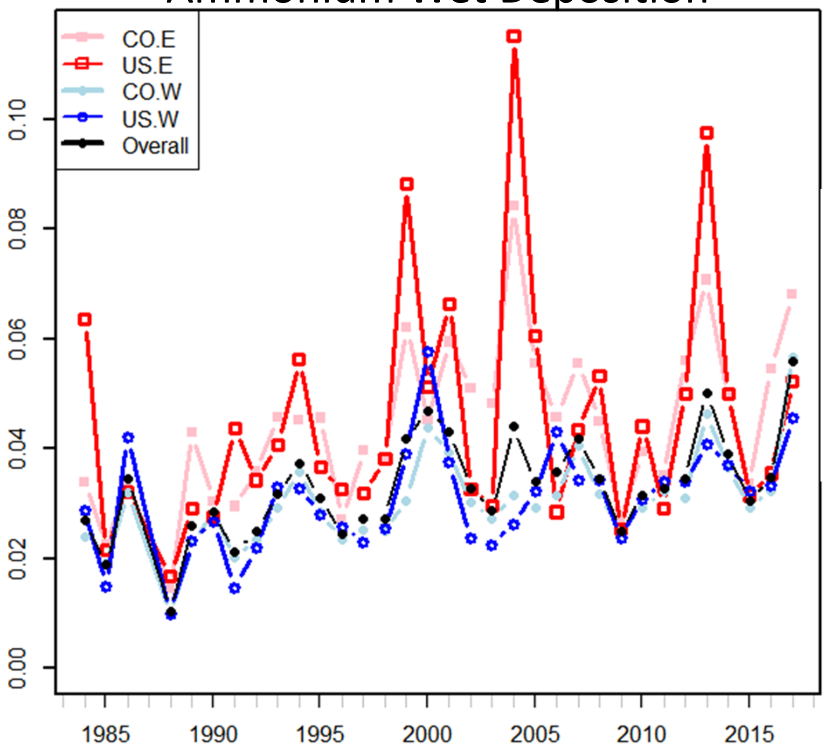




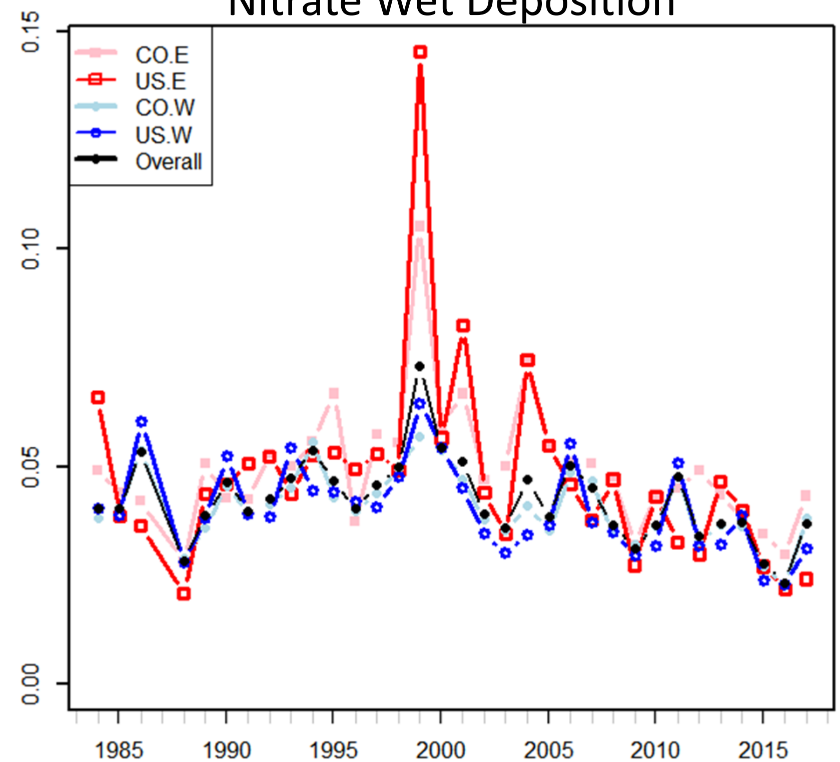
Annual Means by Transport Region – 1 day, 10 m, All Months, 1984-2017

Kg N/Ha Week

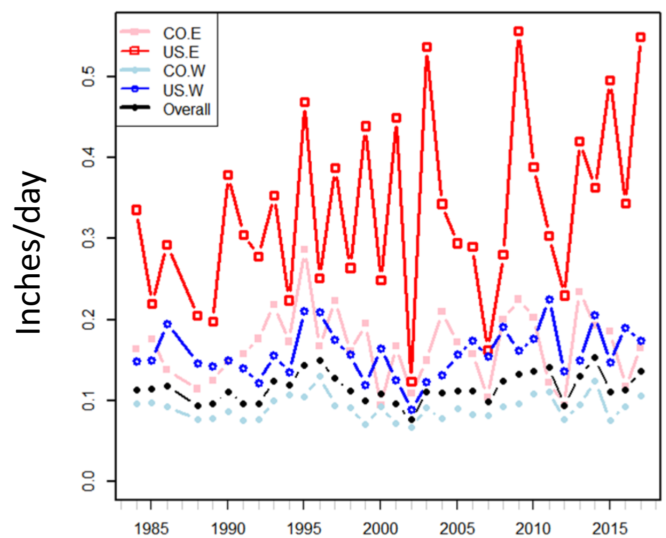
Ammonium Wet Deposition



Nitrate Wet Deposition

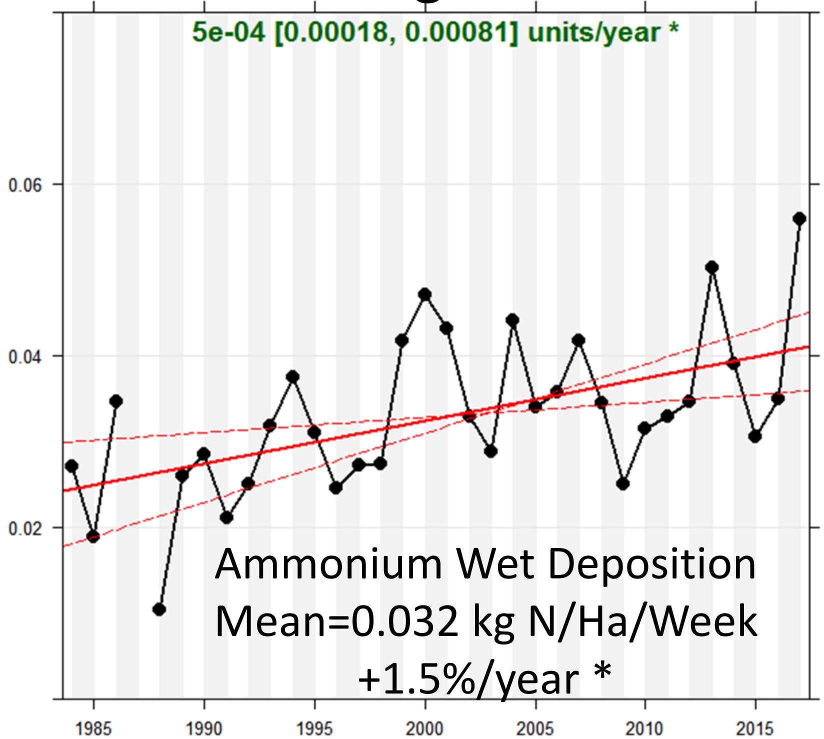


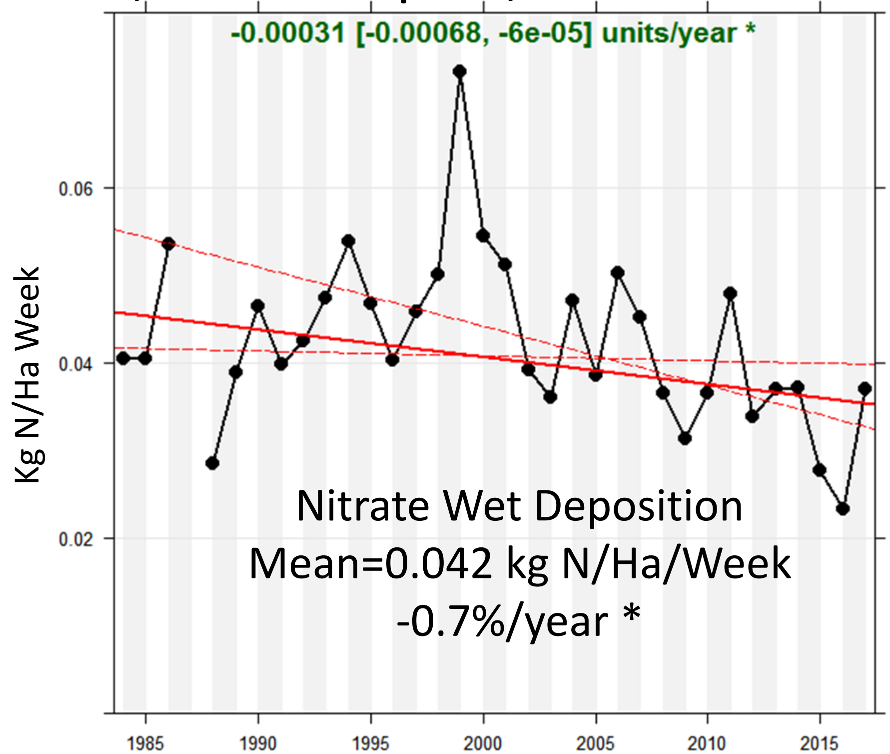
Precipitation



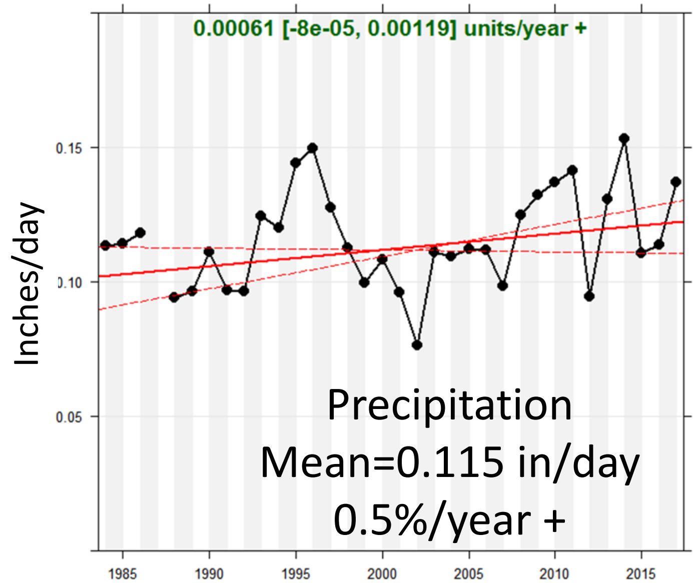
Why the zig zags?
Need to explore.

Theil Regressions – All Months, All Transport, 1984-2017



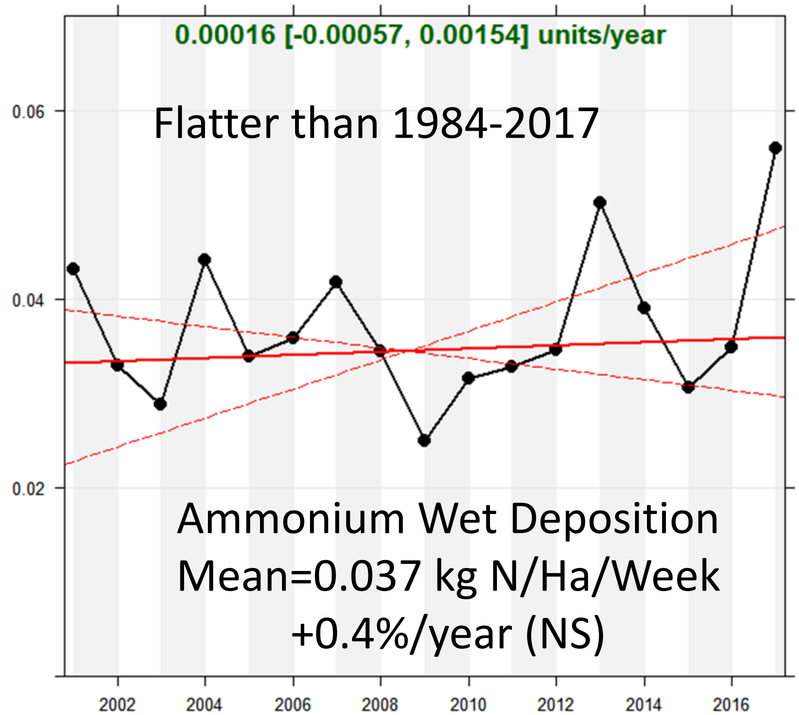


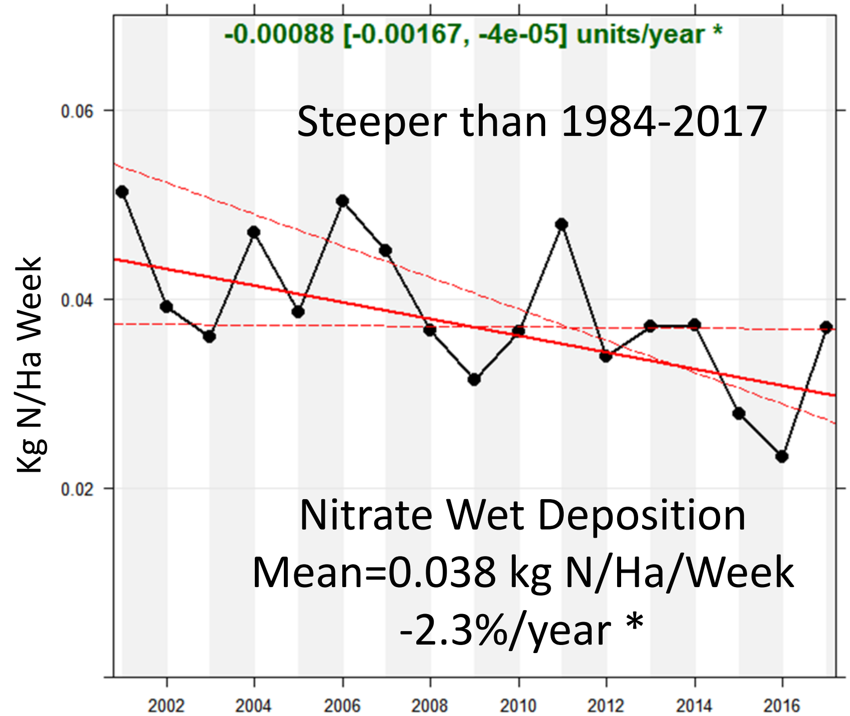
All Years – Big Picture
NOT official NADP trends



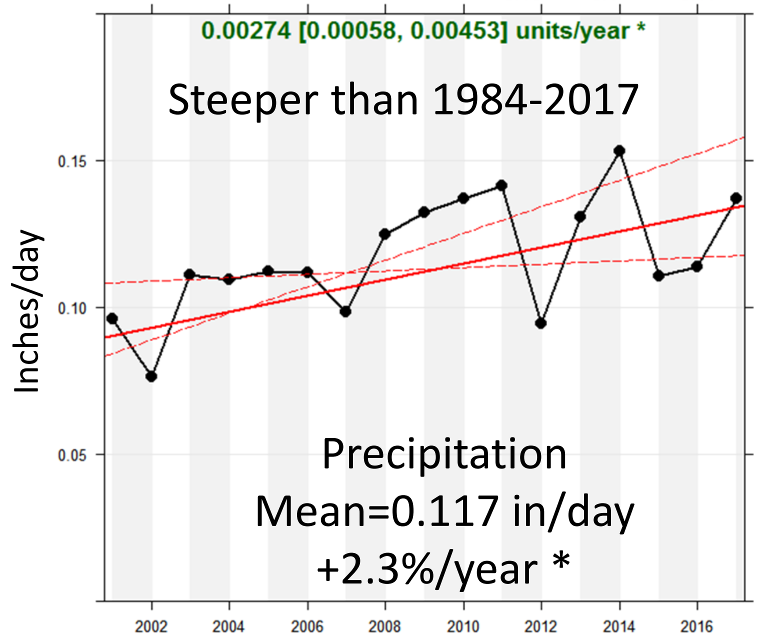
Probability slope = 0:
$p < 0.001$ = ***
$p < 0.01$ = **
$p < 0.05$ = *
$p < 0.1$ = +
$P > 0.1$ = (NS)

Theil Regressions – All Months, All Transport, 2001-2017





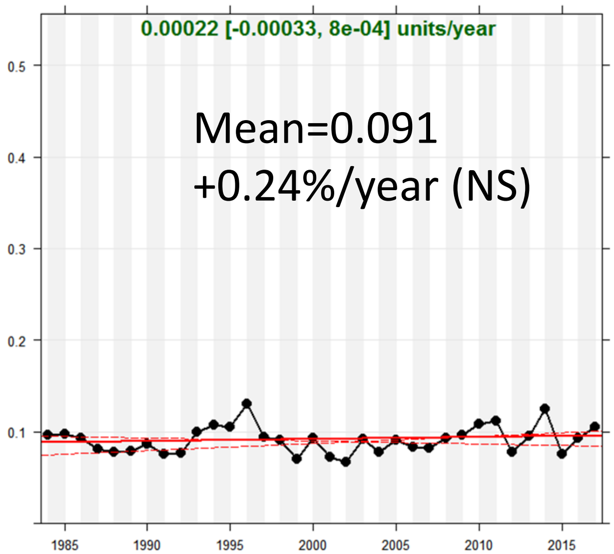
Recent Years



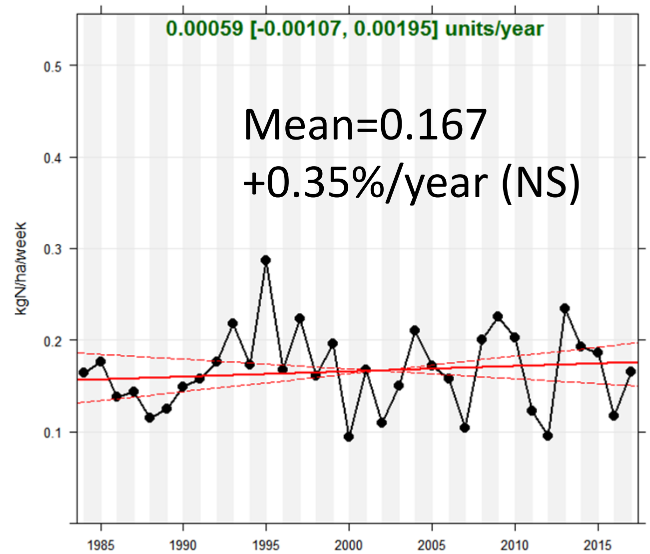
Probability slope = 0:
p < 0.001 = ***
p < 0.01 = **
p < 0.05 = *
p < 0.1 = +
P > 0.1 = (NS)

Theil – Precipitation Annual, By Area, 1 day, 10m, 1984-2017

Colorado West



Colorado East

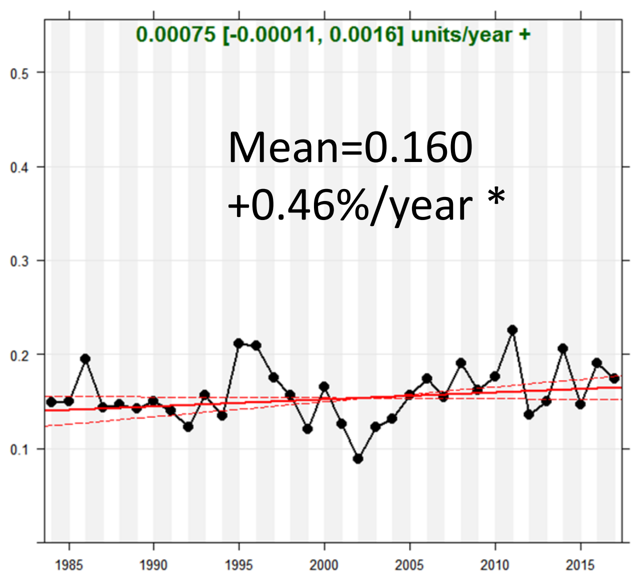


Overall Mean = 0.115 Inches/day

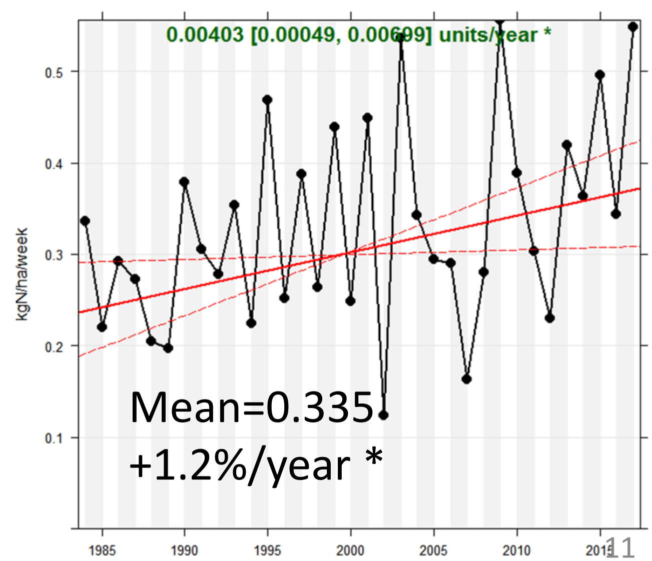
Prob. Slope = 0:
p < 0.001 = ***
p < 0.01 = **
p < 0.05 = *
p < 0.1 = +
P > 0.1 = (NS)

All Years – Big Picture

U.S. West

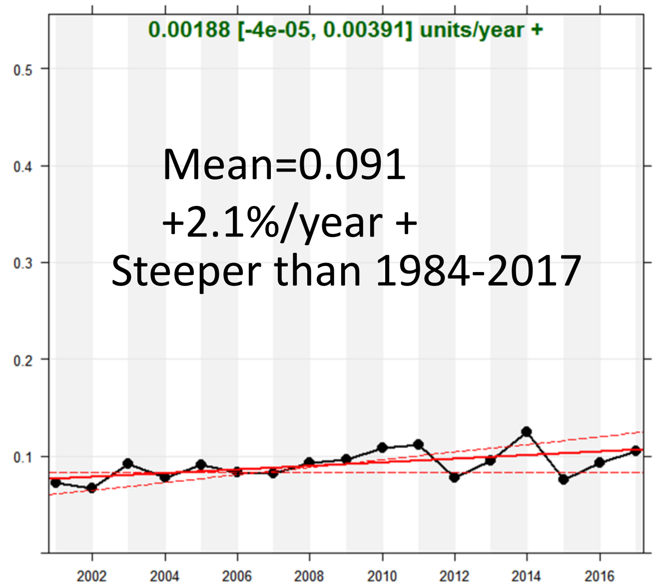


U.S. East

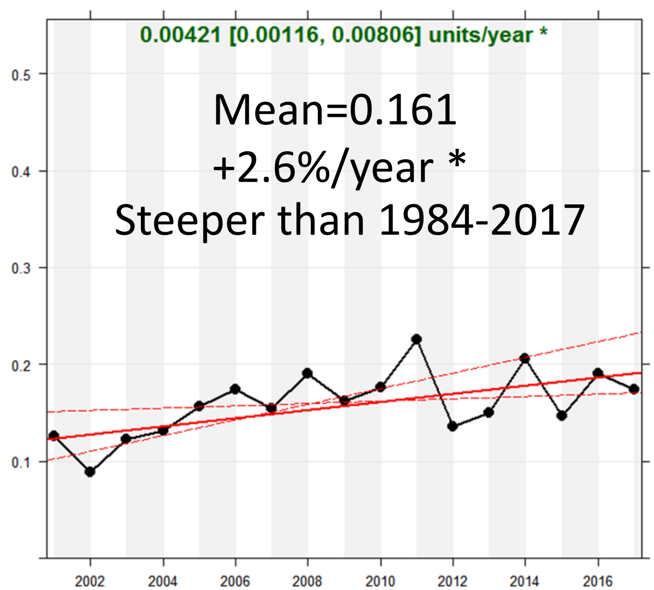


Theil – Precipitation Annual, By Area, 1 day, 10m, 2001-2017

Colorado West



U.S. West

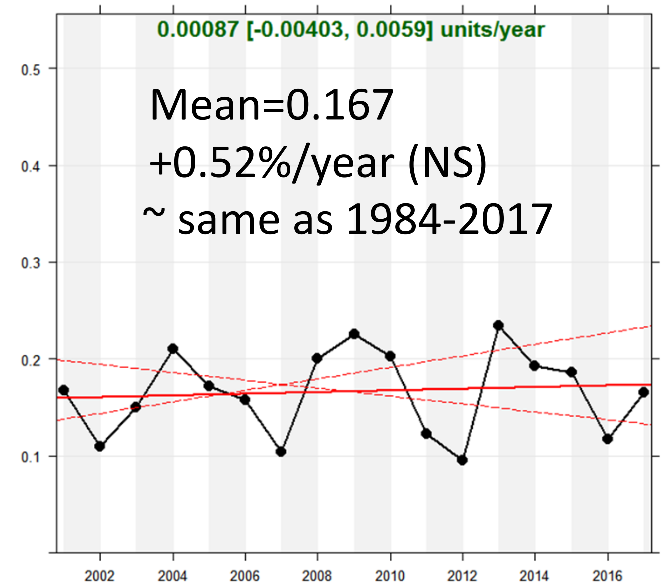


Overall Mean=
0.117 inches/day

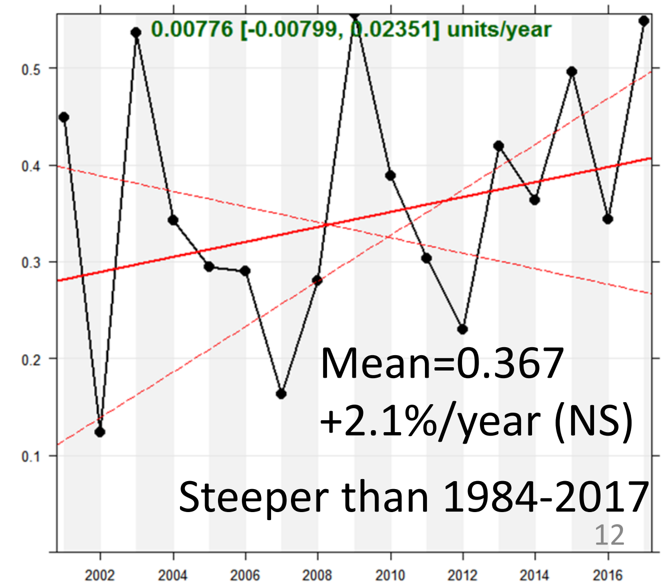
Prob. Slope = 0:
p < 0.001 = ***
p < 0.01 = **
p < 0.05 = *
p < 0.1 = +
P > 0.1 = (NS)

Recent Years

Colorado East

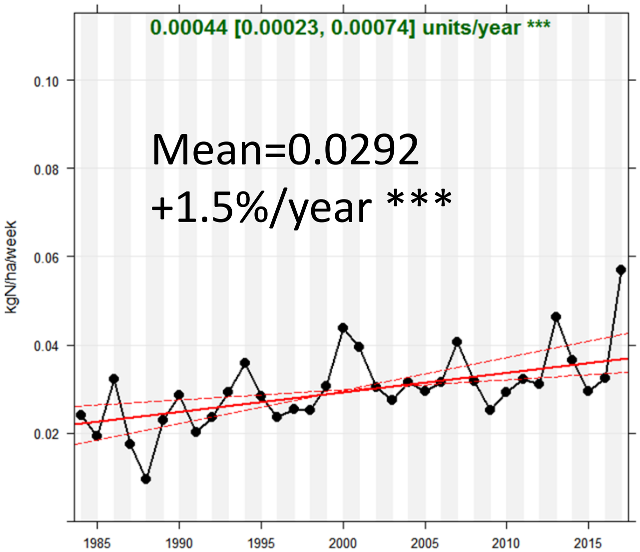


U.S. East



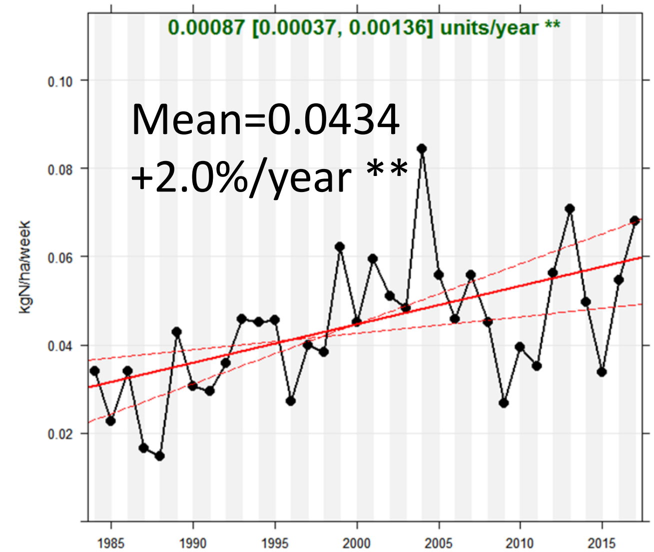
Theil – NH_4 Wet Deposition Annual, By Area, 1 day, 10m, 1984-2017

Colorado West



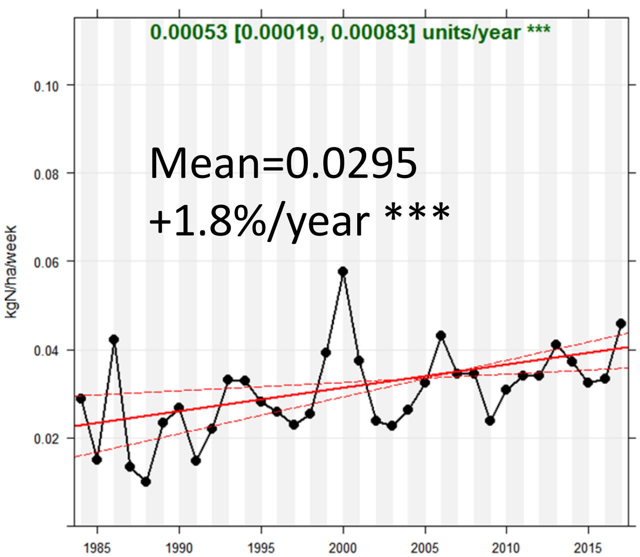
Overall Mean=
0.032 kg N/Ha/Week

Colorado East



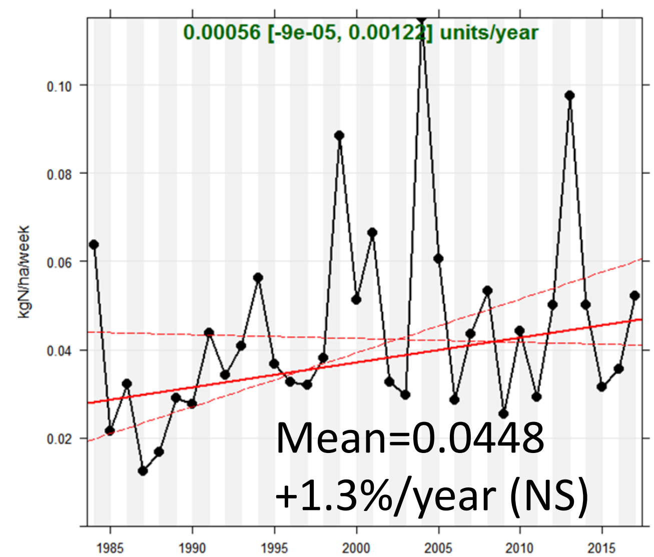
Prob. Slope = 0:
p < 0.001 = ***
p < 0.01 = **
p < 0.05 = *
p < 0.1 = +
P > 0.1 = (NS)

U.S. West



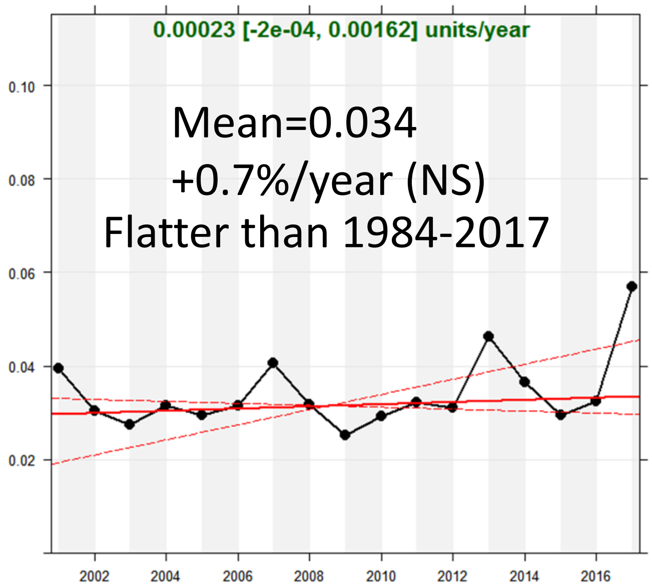
All Years

U.S. East

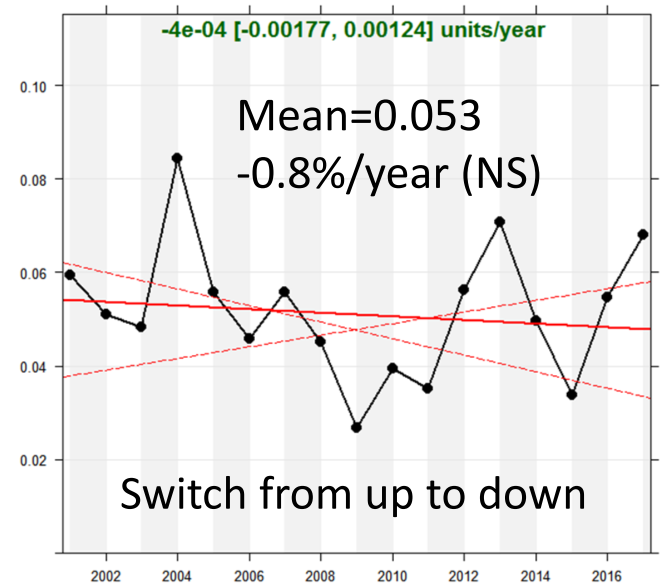


Theil – NH_4 Wet Deposition Annual, By Area, 1 day, 10m, 2001-2017

Colorado West



Colorado East

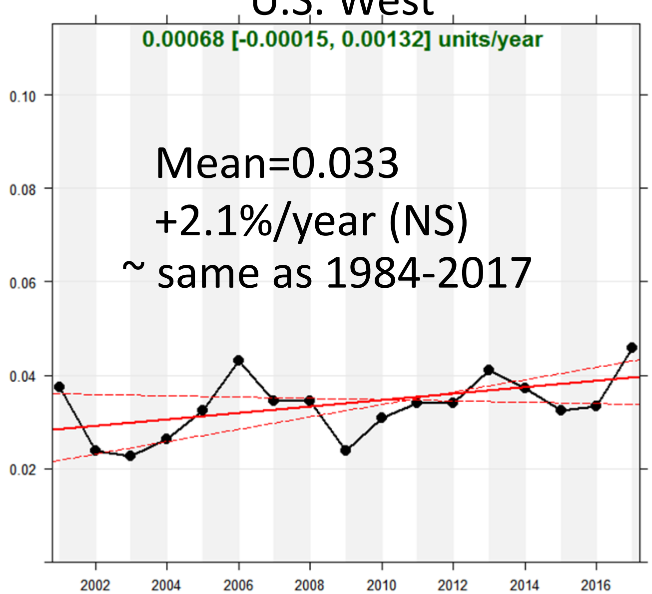


Overall Mean=
0.037 kg N/Ha/Week

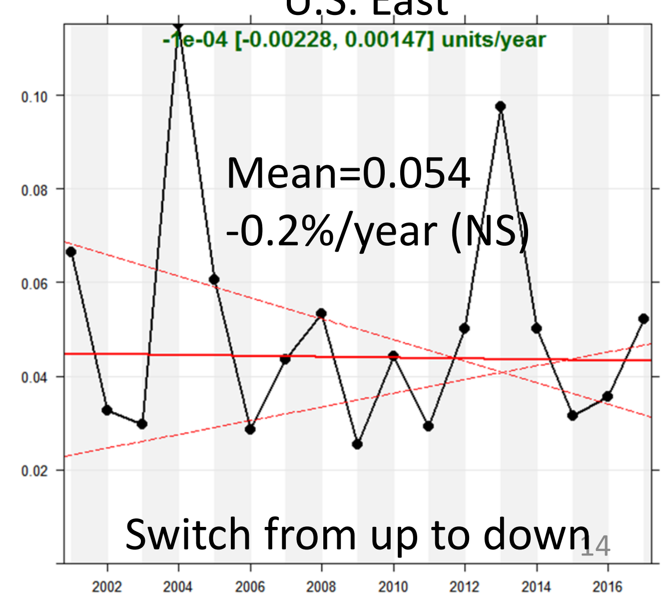
Prob. Slope = 0:
$p < 0.001$ = ***
$p < 0.01$ = **
$p < 0.05$ = *
$p < 0.1$ = +
$P > 0.1$ = (NS)

Recent Years

U.S. West

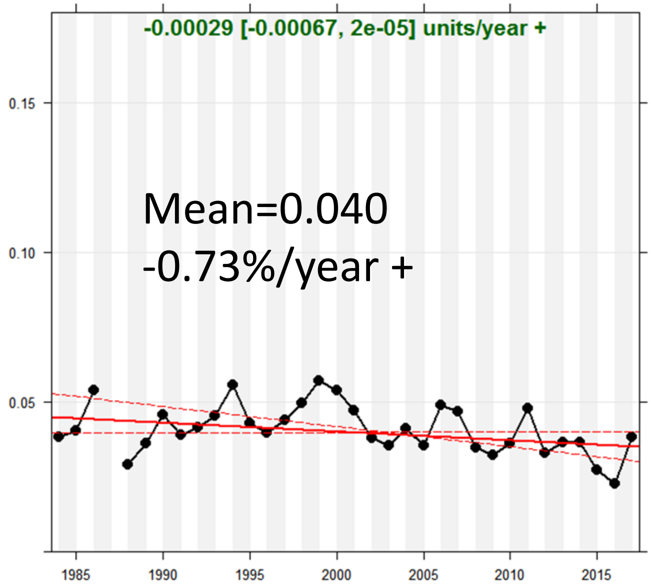


U.S. East

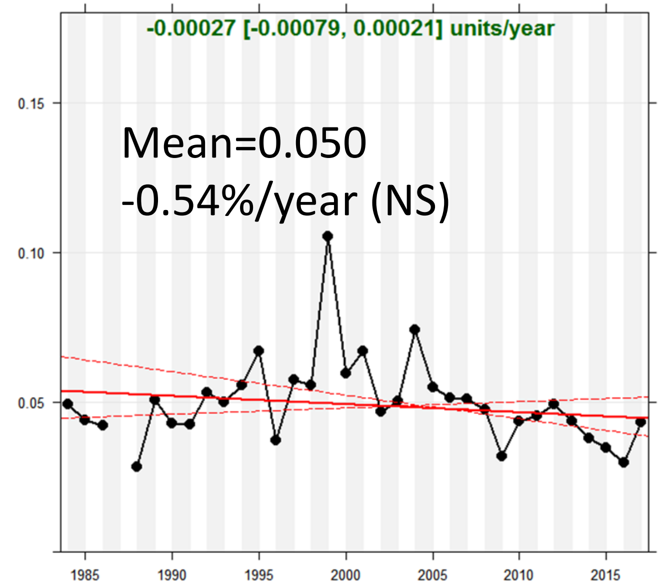


Theil – NO_3 Wet Deposition Annual, By Area, 1 day, 10m, 1984-2017

Colorado West



Colorado East

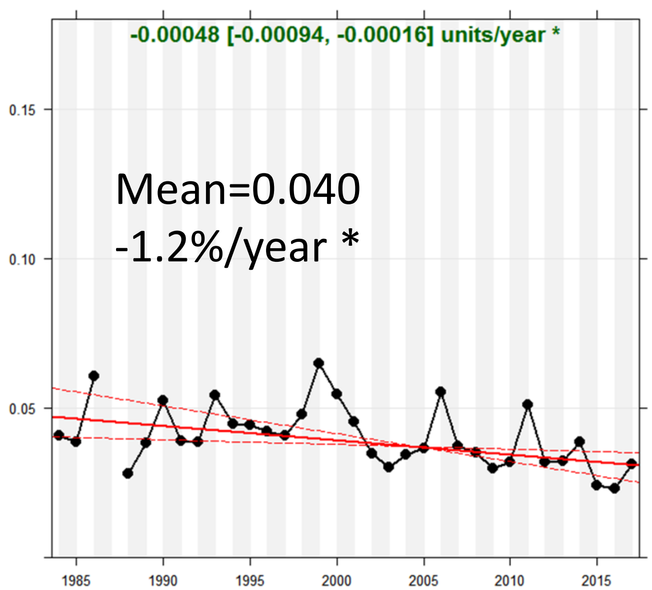


Overall Mean=
0.042 kg N/Ha/Week

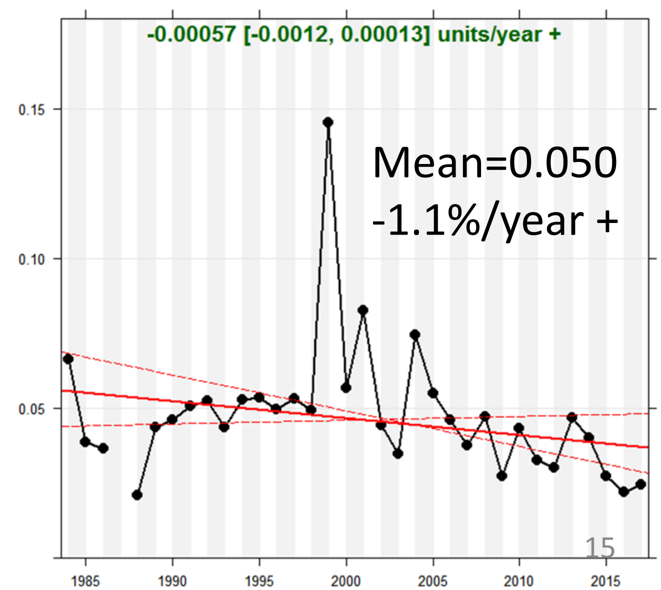
Prob. Slope = 0:
p < 0.001 = ***
p < 0.01 = **
p < 0.05 = *
p < 0.1 = +
P > 0.1 = (NS)

All Years – Big Picture

U.S. West

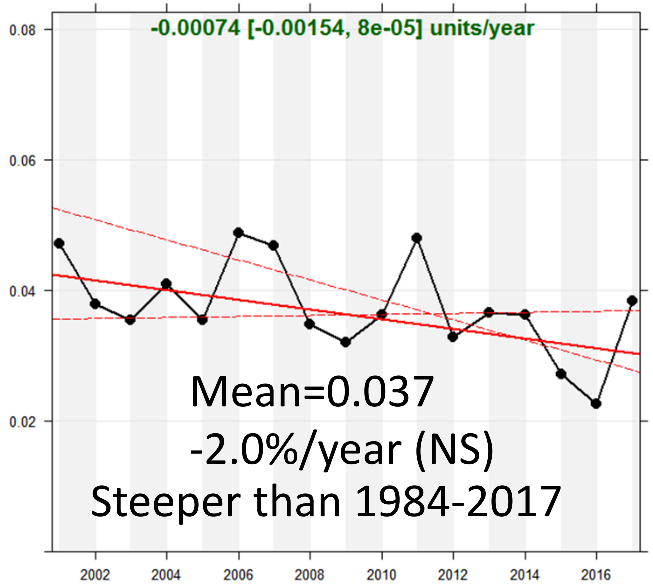


U.S. East



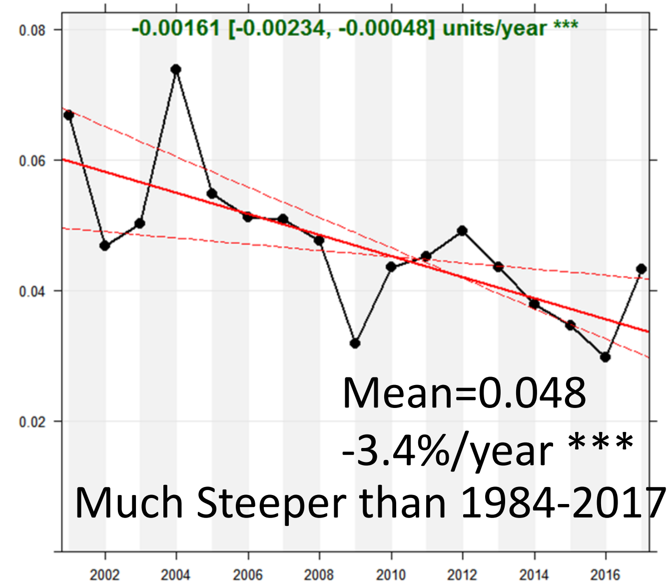
Theil – NO_3 Wet Deposition Annual, By Area, 1 day, 10m, 2001-2017

Colorado West



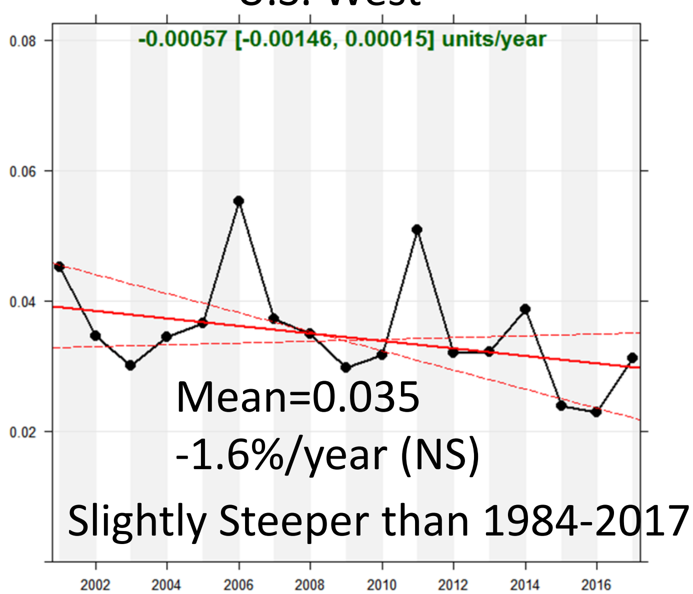
Overall Mean=
0.038 kg N/Ha/Week

Colorado East



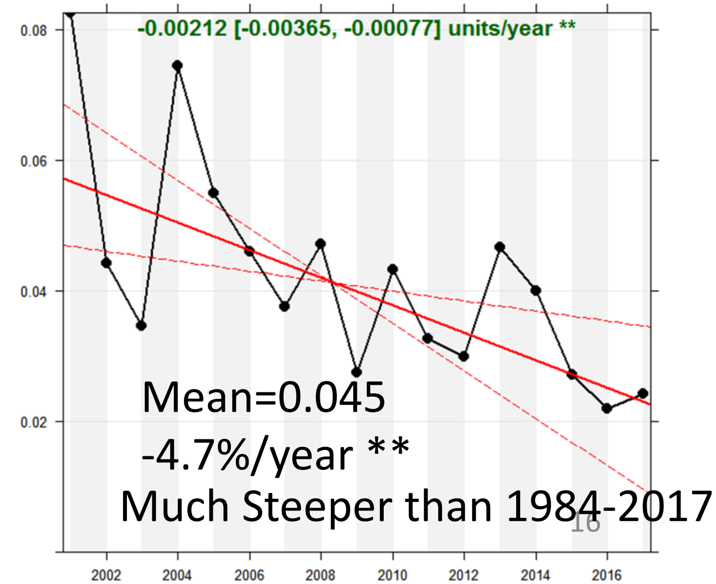
Prob. Slope = 0:
p < 0.001 = ***
p < 0.01 = **
p < 0.05 = *
p < 0.1 = +
P > 0.1 = (NS)

U.S. West



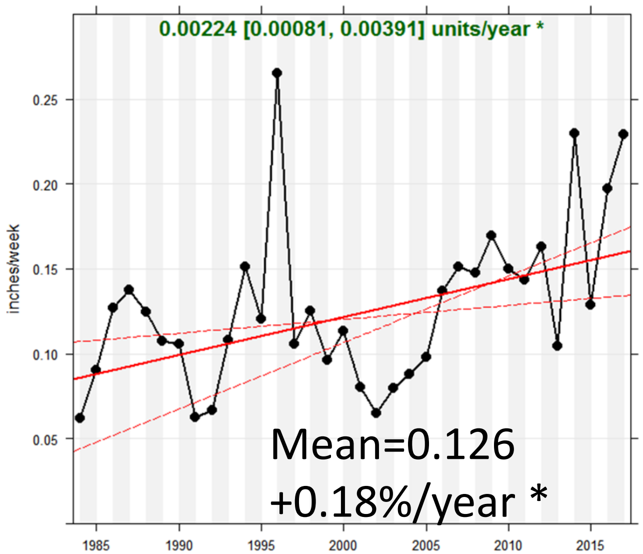
Recent Years

U.S. East

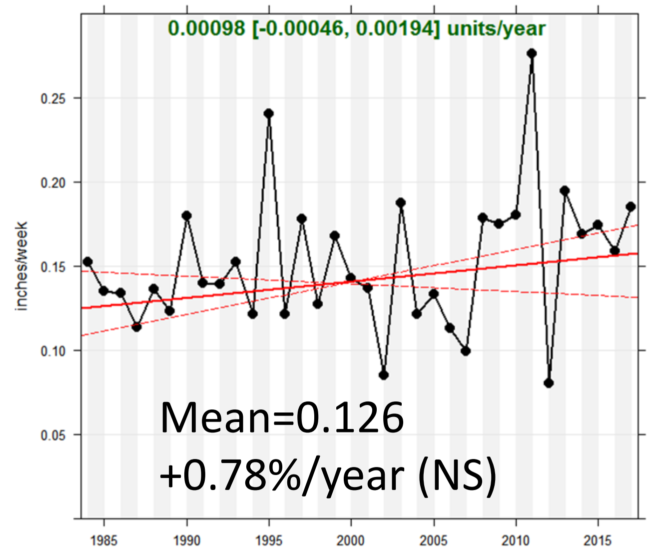


Theil Regressions – Precipitation By Season, All Transport, 1984-2017

Winter



Spring

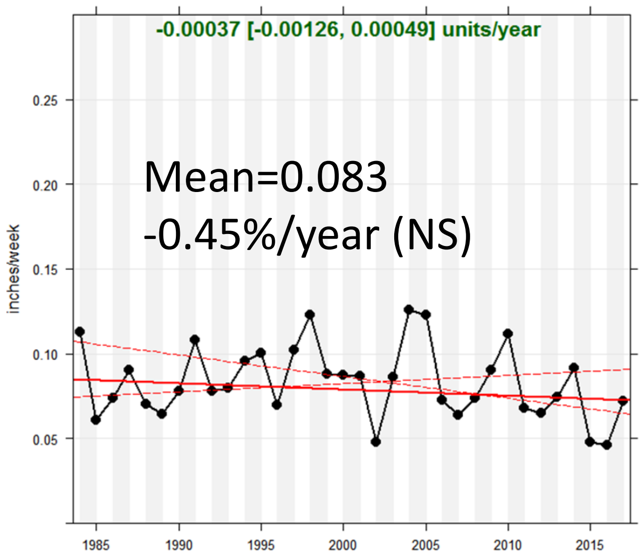


Mean=0.115 in/day

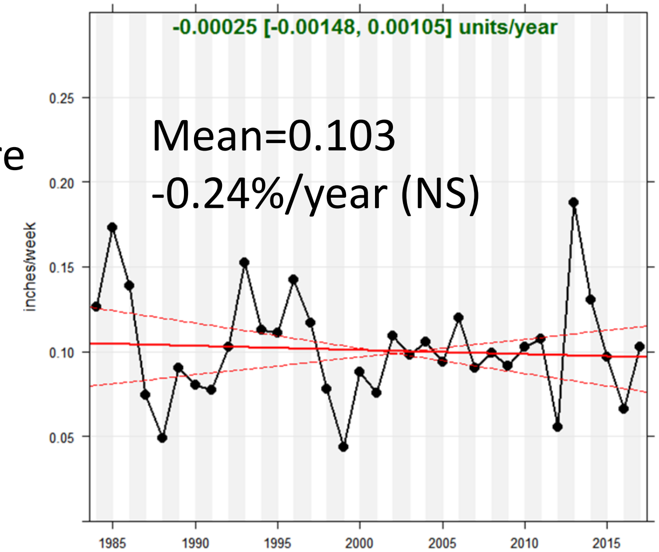
Prob. Slope = 0:
p < 0.001 = ***
p < 0.01 = **
p < 0.05 = *
p < 0.1 = +
P > 0.1 = (NS)

All Years – Big Picture

Summer

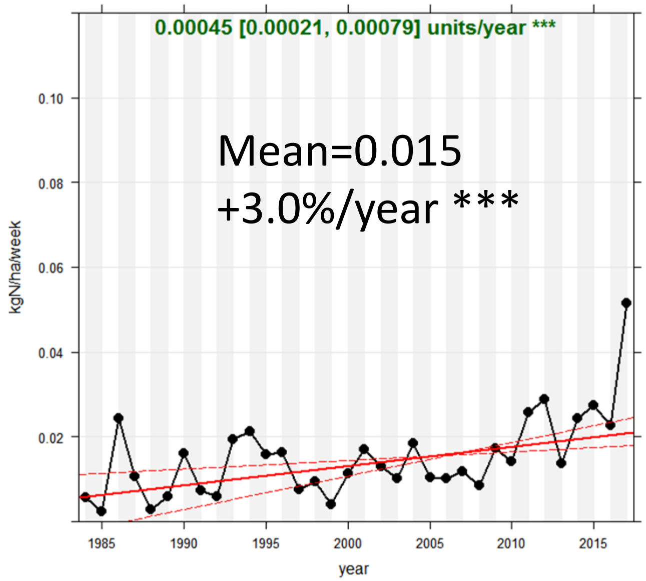


Fall

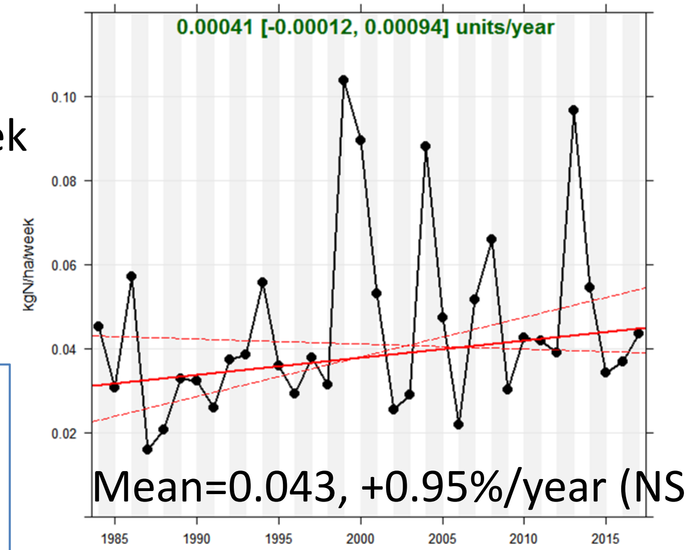


Theil Regressions – NH_4 Wet Deposition By Season, All Transport, 1984-2017

Winter



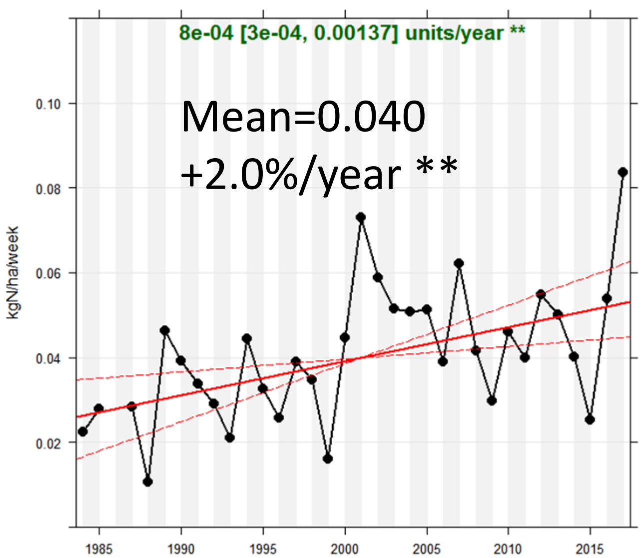
Spring



Overall Mean=
0.032 kg N/Ha/Week

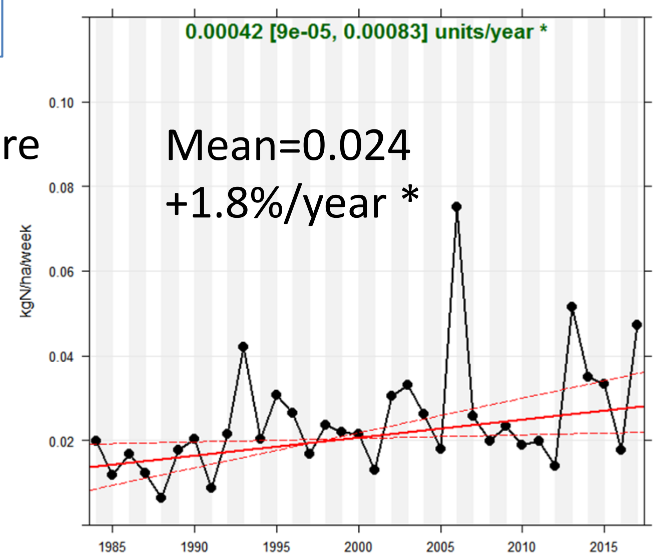
Prob. Slope = 0:
$p < 0.001$ = ***
$p < 0.01$ = **
$p < 0.05$ = *
$p < 0.1$ = +
$P > 0.1$ = (NS)

Summer



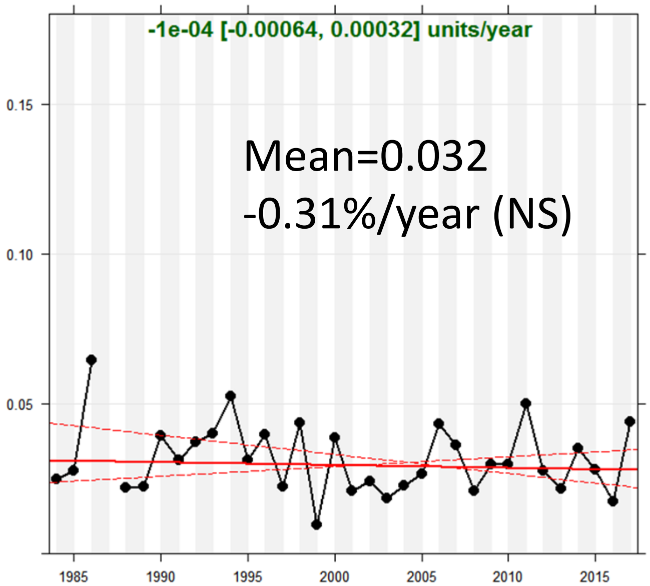
All Years – Big Picture

Fall



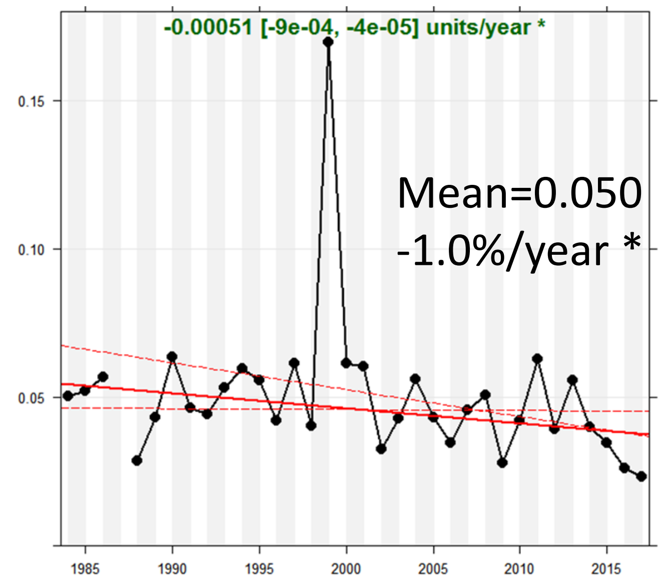
Theil Regressions – NO_3 Wet Deposition By Season, All Transport, 1984-2017

Winter



Overall Mean=
0.042 kg N/Ha/Week

Spring



Prob. Slope = 0:
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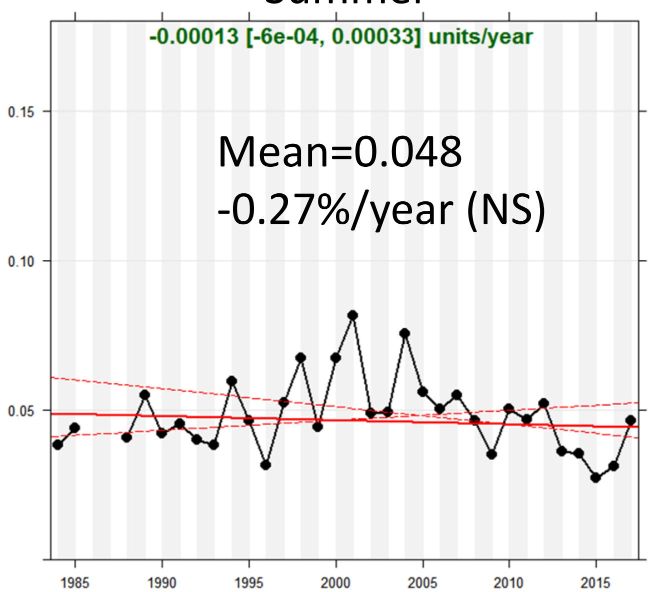
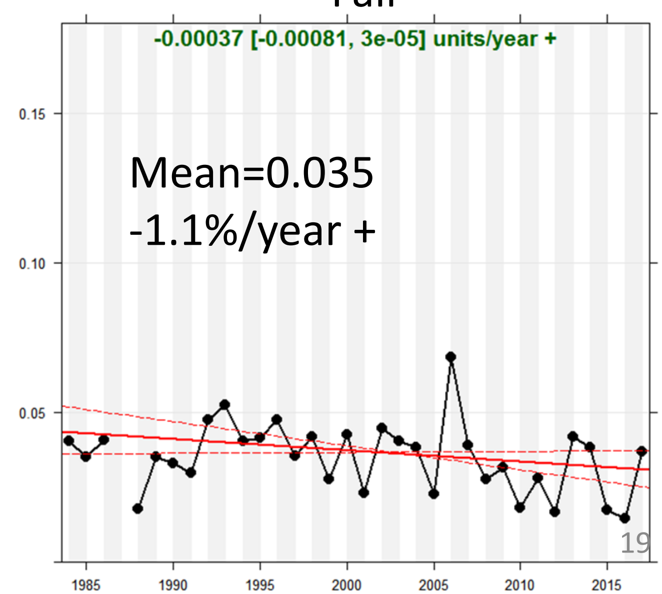
$p < 0.01$ = **
$p < 0.05$ = *
$p < 0.1$ = +
$P > 0.1$ = (NS)

Summer



All Years – Big Picture

Fall



Summary

General

- Results are preliminary, vary by start/stop years.
- Fraction of transport from (E/W) and (in/out) CO depends on trajectory start height, season, trajectory length. No long term trend in transport direction. Height & length have little impact on mean slopes (trust me).
- More Westerly winds than Easterly. But precipitation & N wet deposition higher with easterly winds.
- Significant long term annual upward trends in precipitation & NH_4 , downward in NO_3. Same directions in later years, but NH_4 not significant. Precipitation & NO_3 steeper slopes.

By Regions

- Precipitation up from all directions, all & later years. Not highly significant.
- NH_4 up from all areas for long term. Very significant except E.US . Up from west, down from east in later years. All later years insignificant.
- NO_3 long term down from all directions. Larger slopes with transport from outside CO. Later years down faster from all areas, higher significance & bigger slopes for east.

By Seasons

- Precipitation up winter & spring, down summer & fall. Low significance.
- NH_4 is greater spring & summer, up all seasons, most significance in winter, least in spring.
- NO_3 down all seasons, 3xgreater slopes and more significance spring & fall.
- Transport from E. CO peaks in summer, W. CO winter & summer. Influence from outside Colorado peaks spring and fall (higher wind speeds).

To Do List

- Try multiyear smoothers on data.
- Fill in data for missing weeks (NADP and/or Schichtel method).
- Do trends only for later years (2008 & later) that have hourly precipitation data and higher resolution gridded meteorology for trajectories.
- Use method on total nitrogen, and sulfate deposition.
- Compare to CO19 (Beaver Meadows) and other sites.
- Could use different source areas – East /West only or smaller areas
- Could apply Trajectory Mass Balance Model (TrMB) to get source apportionment estimates.
- Explore joint trends by season & transport.
- Questions: Is zig zag in precipitation real? Why so few obs in June?

Questions?