From Emission to Deposition

Flows of Nitrogen Along the Front Range

AgriLIFE RESEARCH
Texas A&M System

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NATIONAL ATMOSPHERIC DEPOSITION PROGRAM
A Cooperative Research Support Program of the
State Agricultural Experiment Stations (NRSP-3)
Federal and State Agencies
and Non-Governmental Research Organizations

0:55:00 to Cover All This Stuff

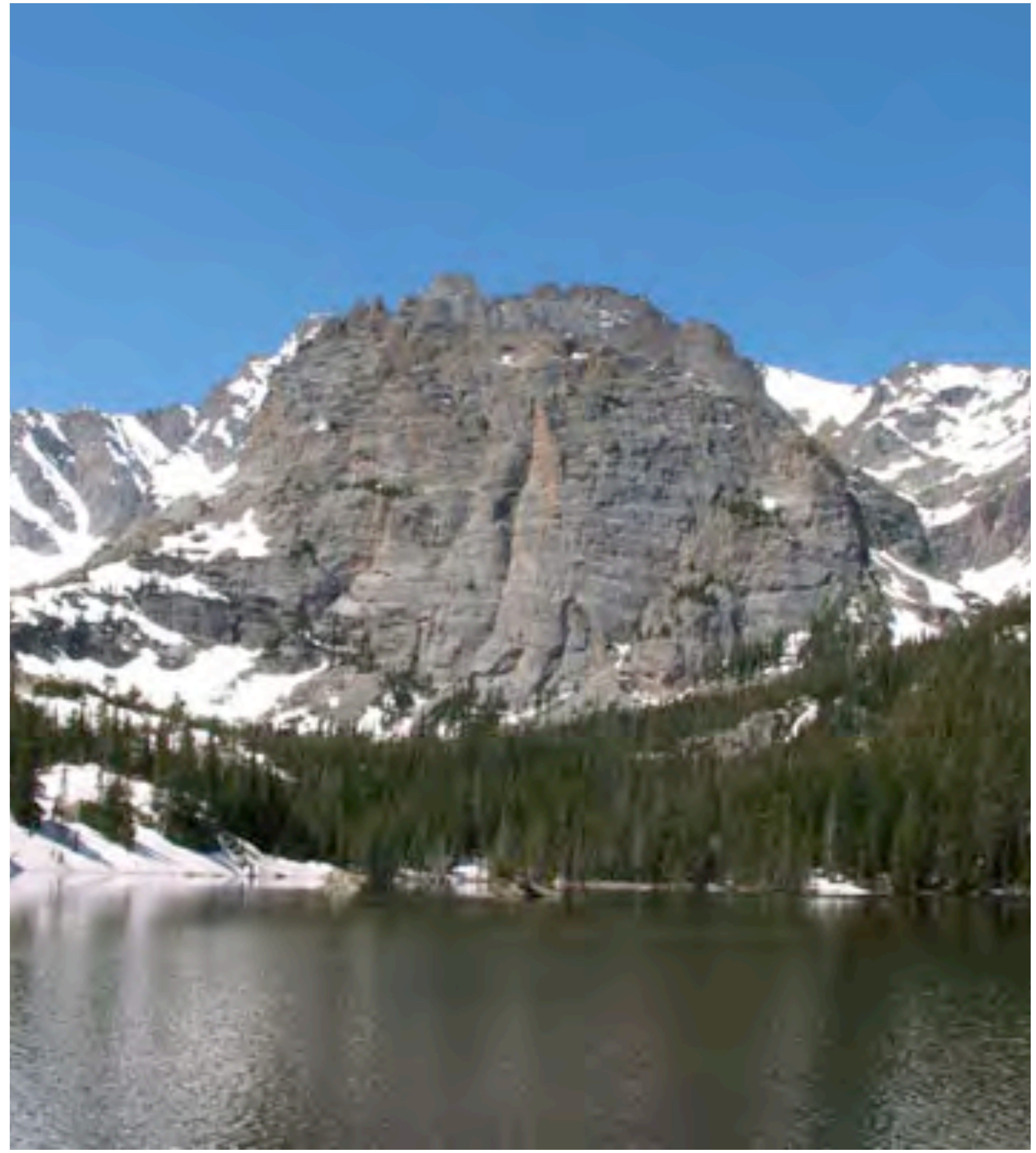
- 0:01:00 - Overview, definitions, and acronyms
- 0:05:00 - Air movement near RMNP
- 0:15:00 - Sources of N along the Front Range
- 0:20:00 - Atmospheric deposition of N in RMNP
- 0:35:00 - Ecological effects of N enrichment in RMNP
- 0:45:00 - The RMNP "glidepath" - an outsider's view
- 0:52:00 - Questions and responses

A Few Acronyms

- RNS - reactive nitrogen species (biggies: NH_x, NO_x)
- TIN - total inorganic nitrogen (TIN = NH_4-N+ NO_3-N)
- NADP - National Atmospheric Deposition Program
- CASTNET - Clean Air Status and Trends Network
- RMNP(I) - Rocky Mountain National Park (Initiative)
- RoMANS - Rocky Mountain Atmospheric Nitrogen and Sulfur study

The Basic Idea

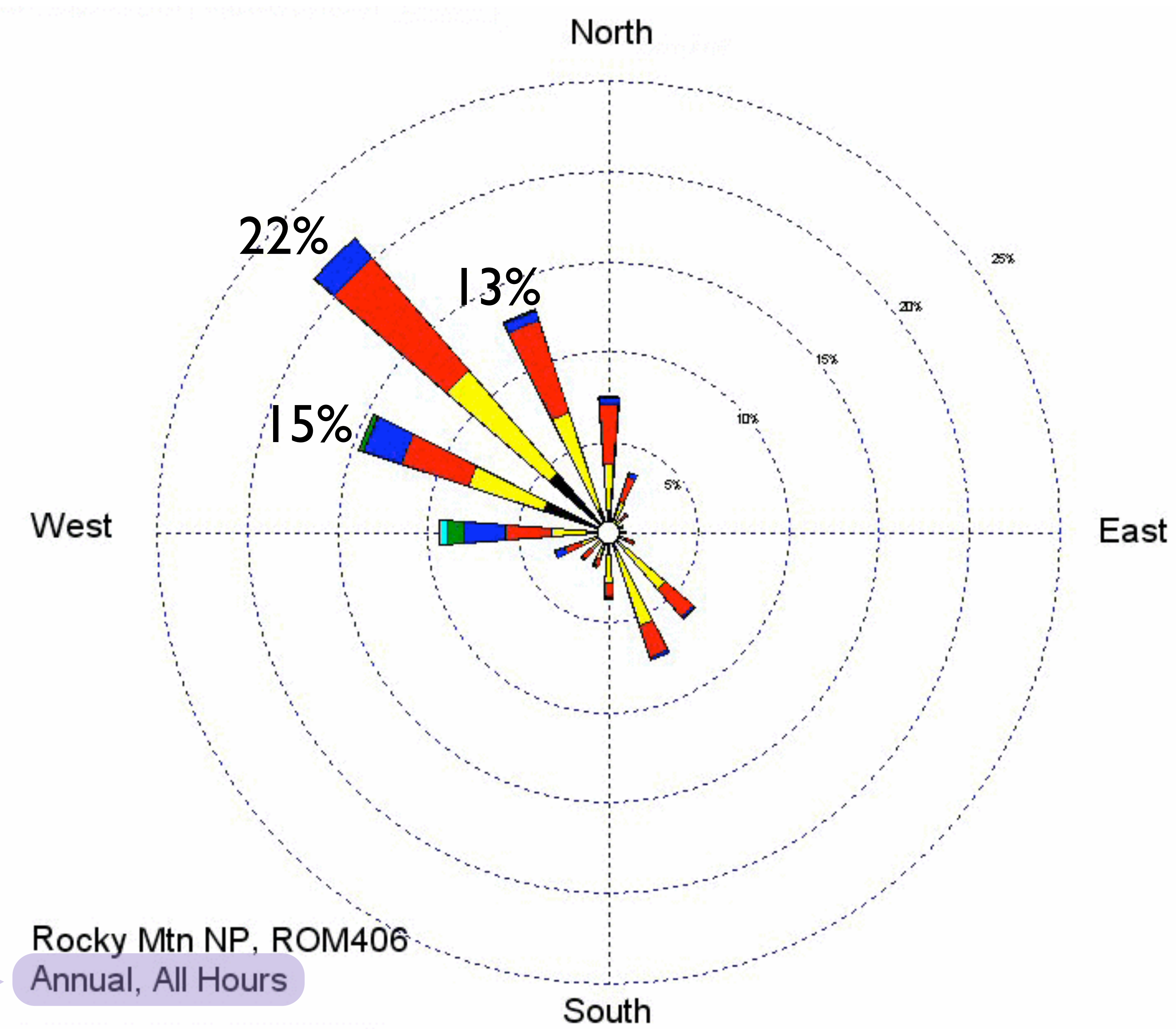
- Pristine RMNP ecosystems evolved with low nutrient inputs
- These ecosystems now exhibit signs of ecological shifts
- The shifts are consistent with nutrient enrichment (primarily N)
- Wet deposition of N appears to have increased in the Park over the past couple of decades
- Hypothesis: Increased wet deposition of N is responsible for irreversible shifts in high alpine ecosystems
- Corollary: Reducing wet deposition of N would head off those ecological shifts



Air Movement Near RMNP

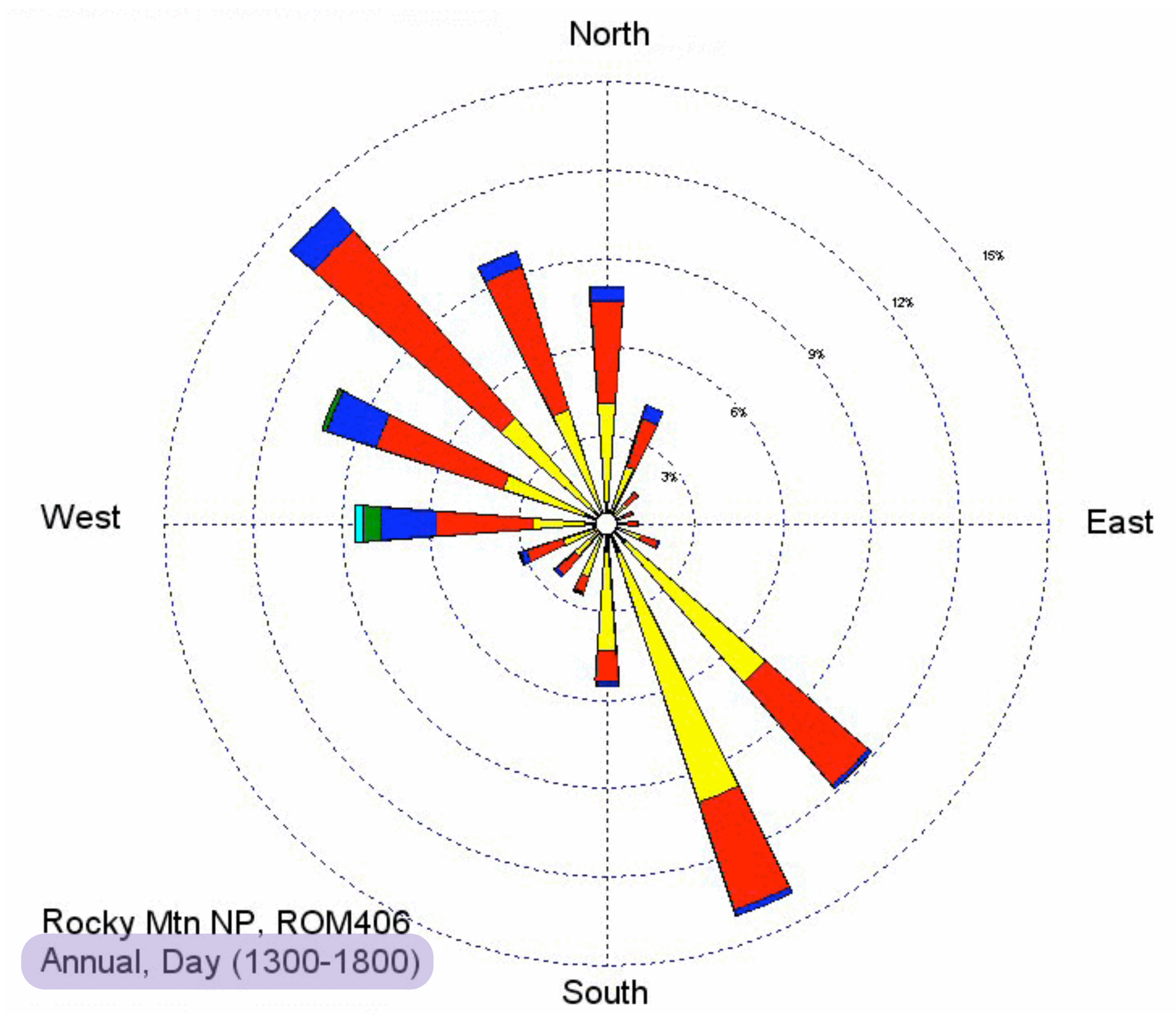
What is a Wind Rose?

- Does not necessarily represent the motion of the airmass as a whole
- Shows wind frequency X speed X direction
- Prevailing (~60%) winds at RMNP have a westerly (downslope) component
- Data may be disaggregated to show seasonality or diurnality



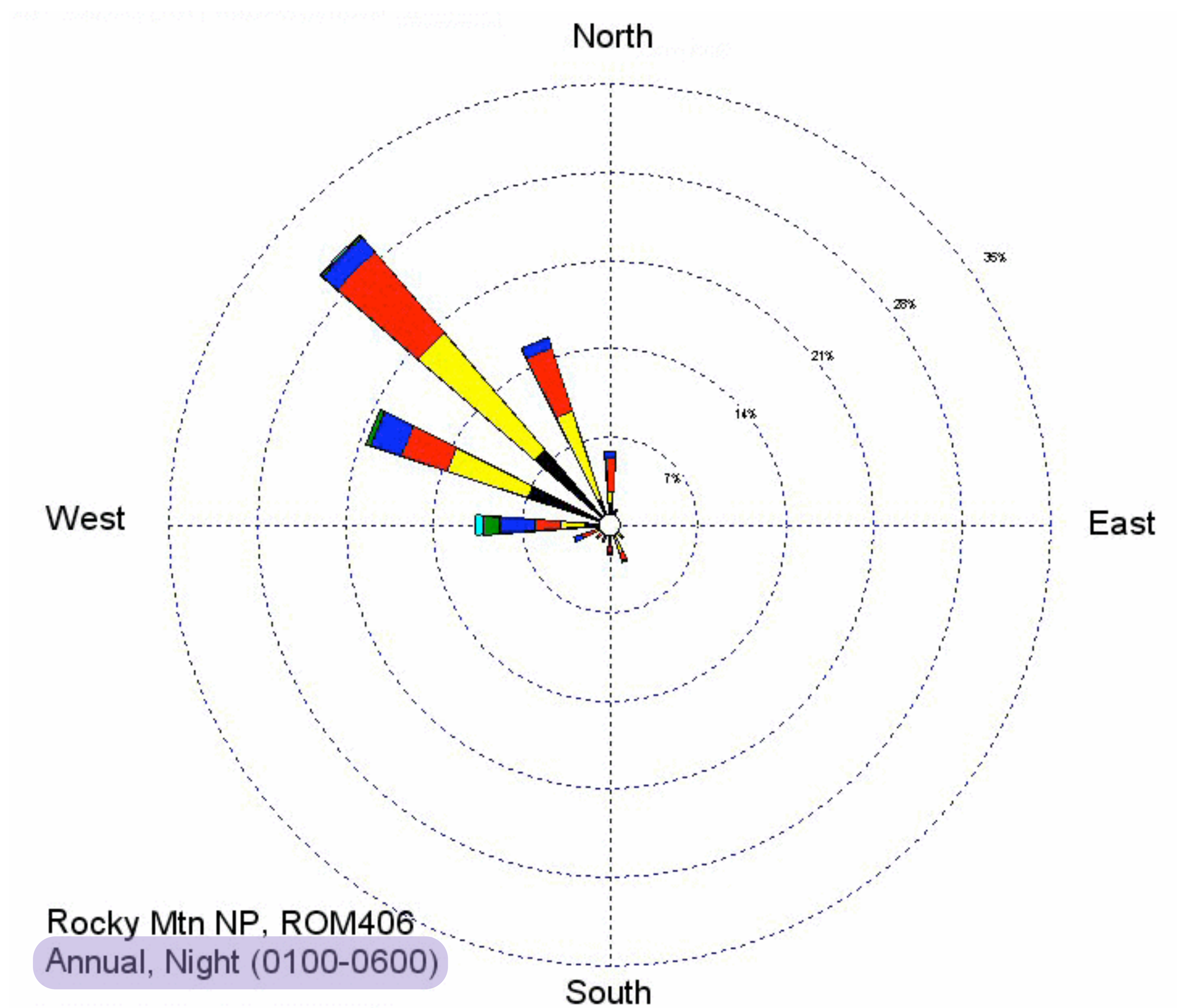
RMNP Wind Rose - Daytime

- Prevailing (~50%) tends to be moderate to strong, downslope (W-N) winds
- Significant component (~25%) is dominated by relatively light, upslope (SSE-SE) winds



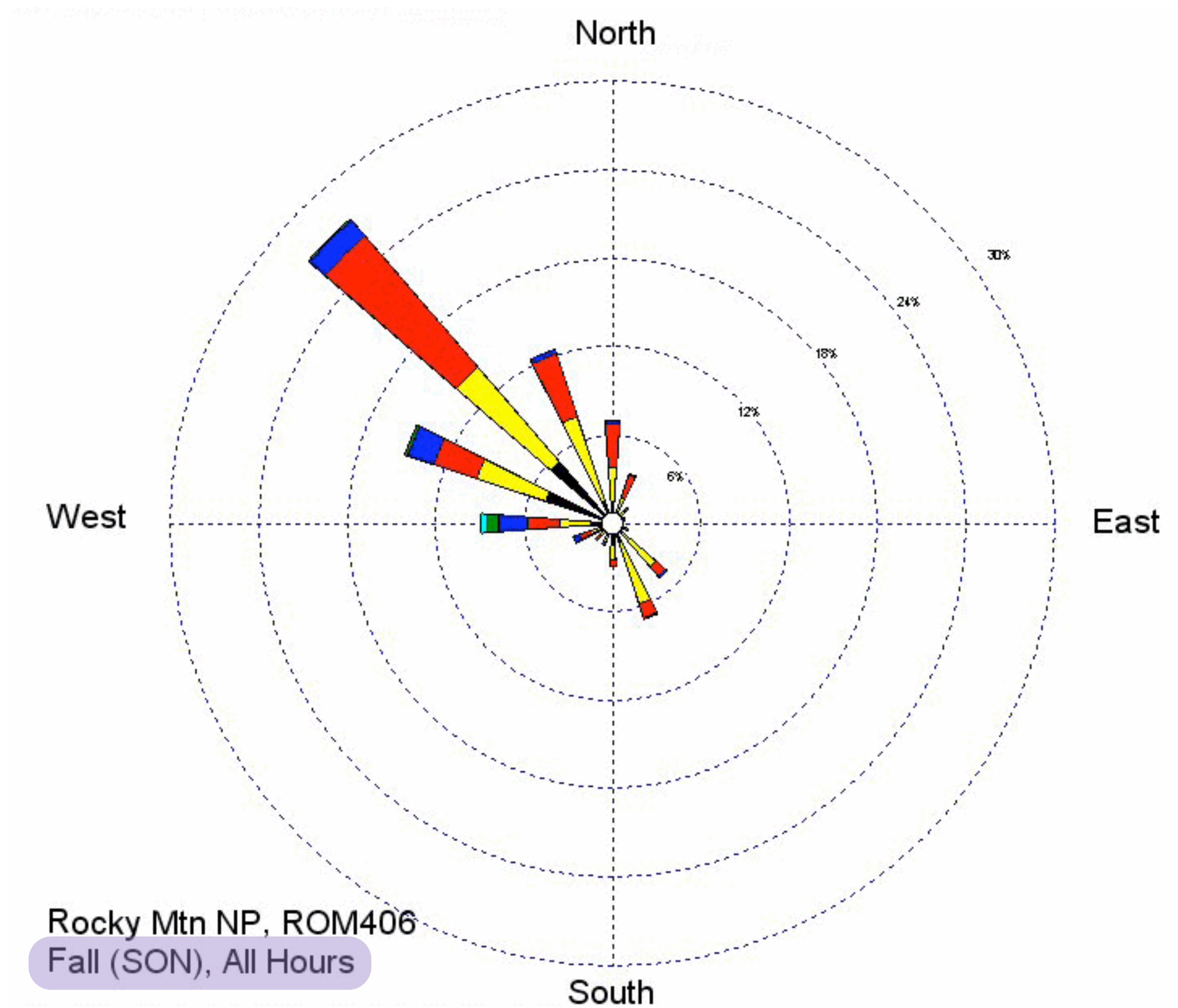
RMNP Wind Rose - Nighttime

- Downslope (sinking, warming) winds present ~70%
- Almost no upslope (E) component at night



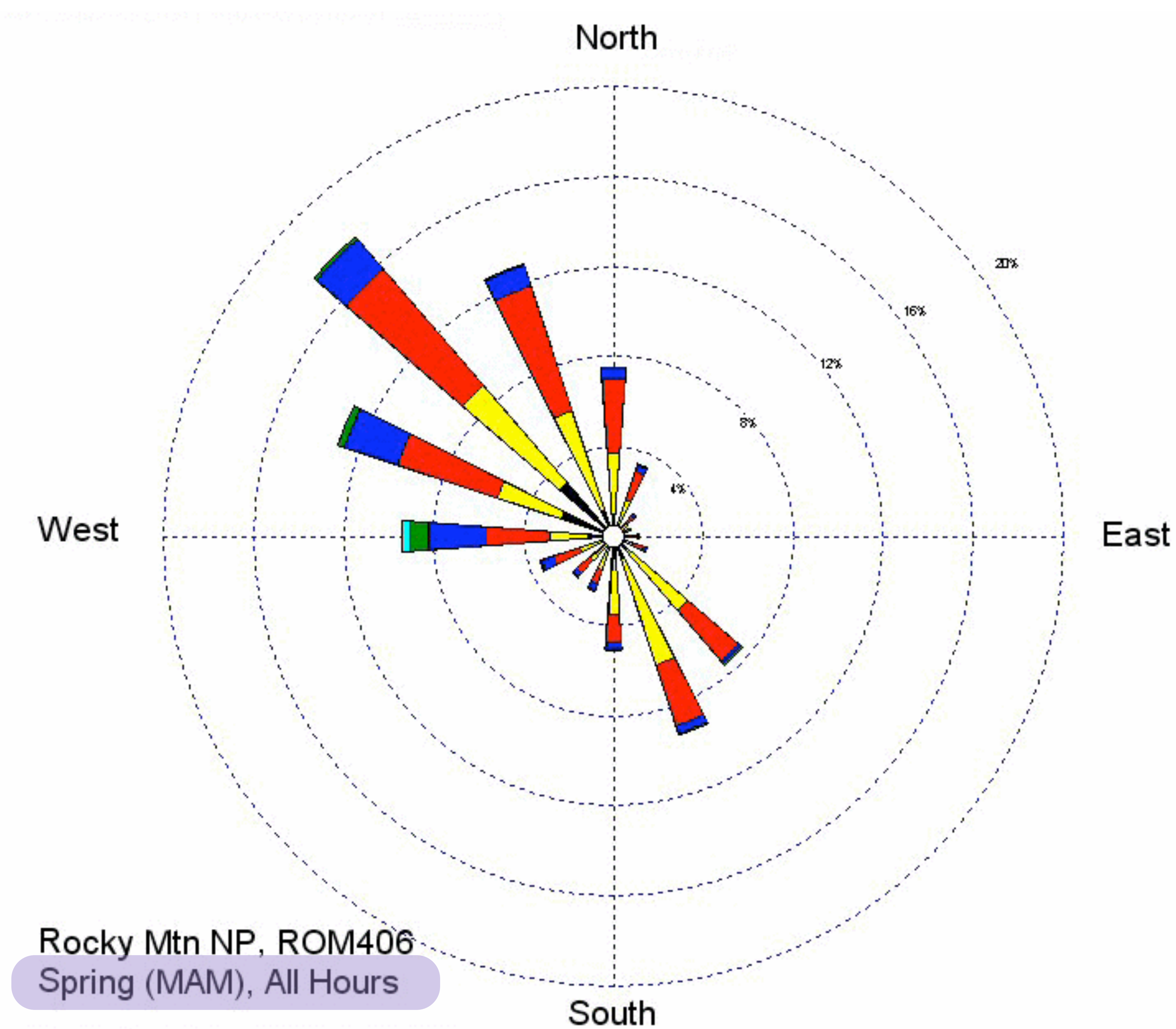
RMNP Wind Rose - Fall

- Chinooks predominate and can be very strong



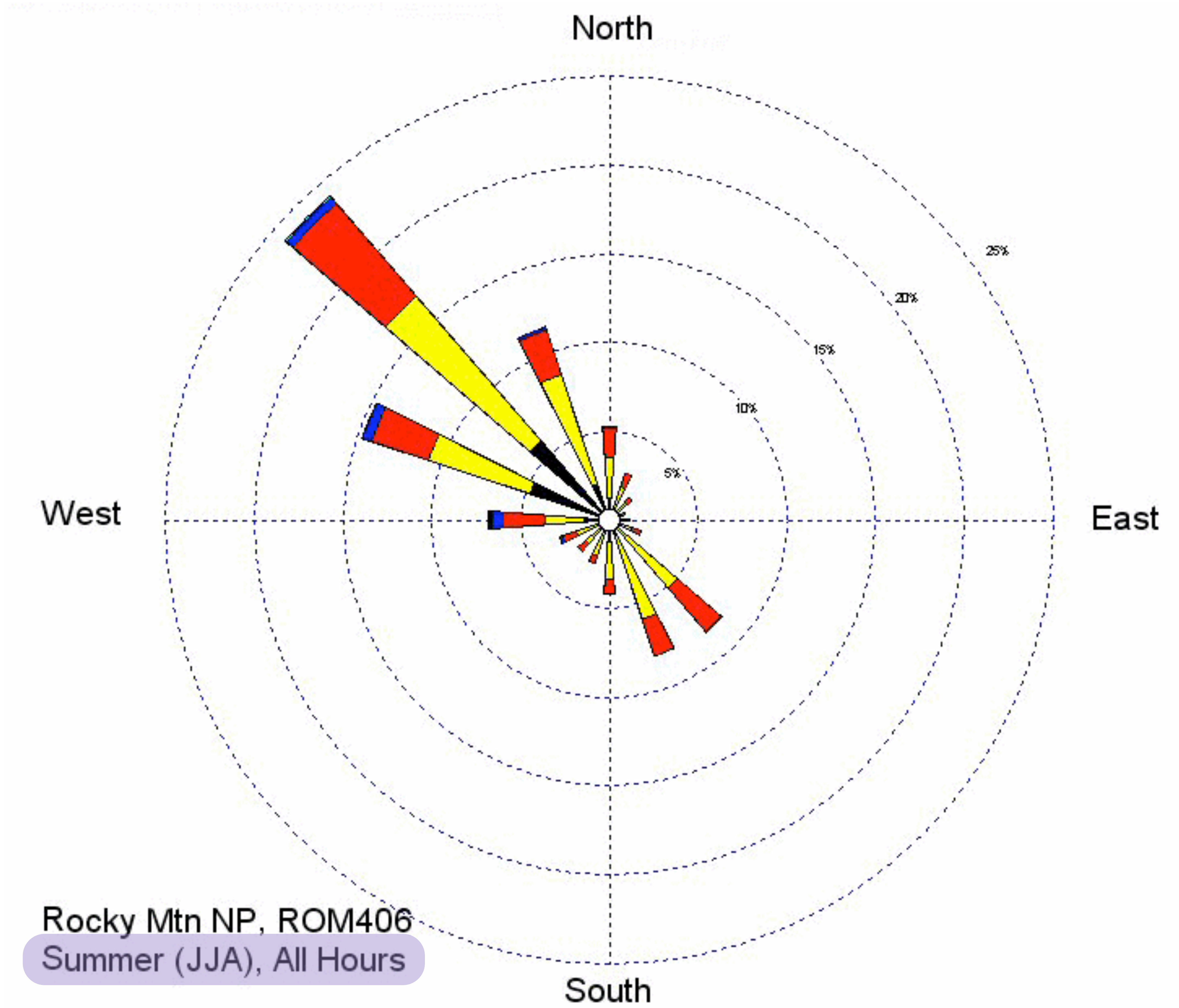
RMNP Wind Rose - Spring

- Strong downslope component
- Significant upslope, moderate speeds



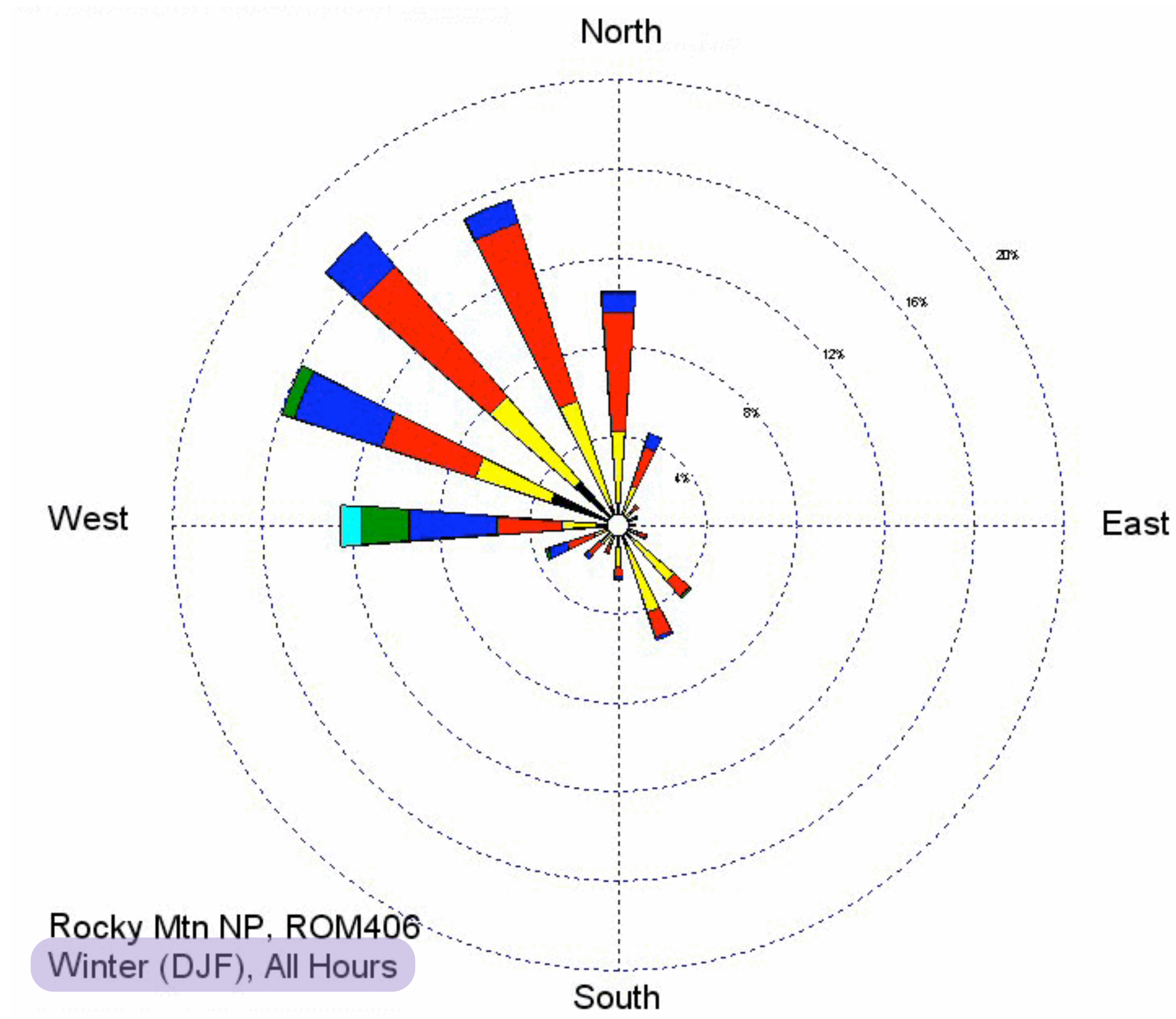
RMNP Wind Rose - Summer

- Downslope component predominates, but wind speeds are not as great
- Upslope winds are light

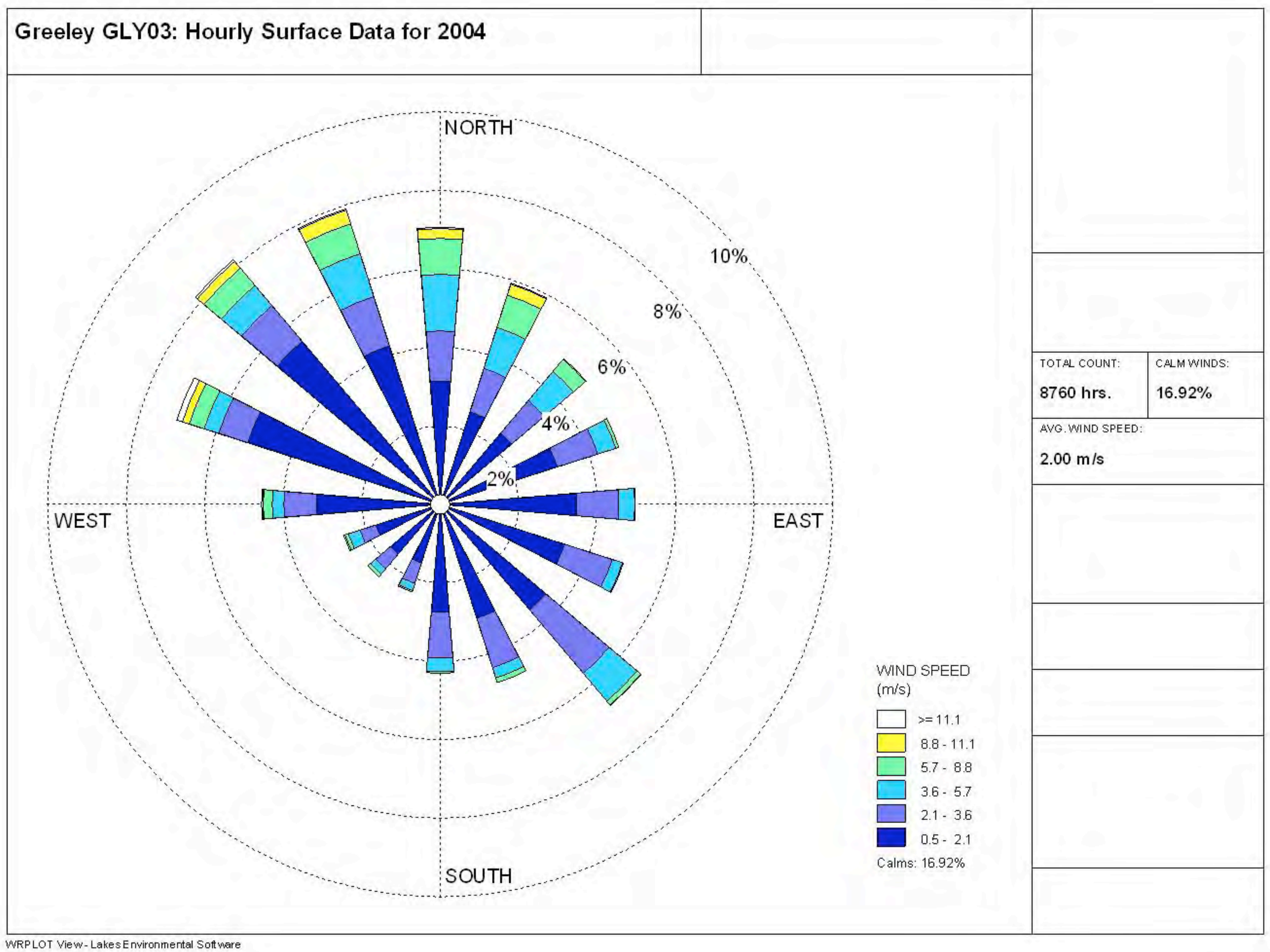


RMNP Wind Rose - Winter

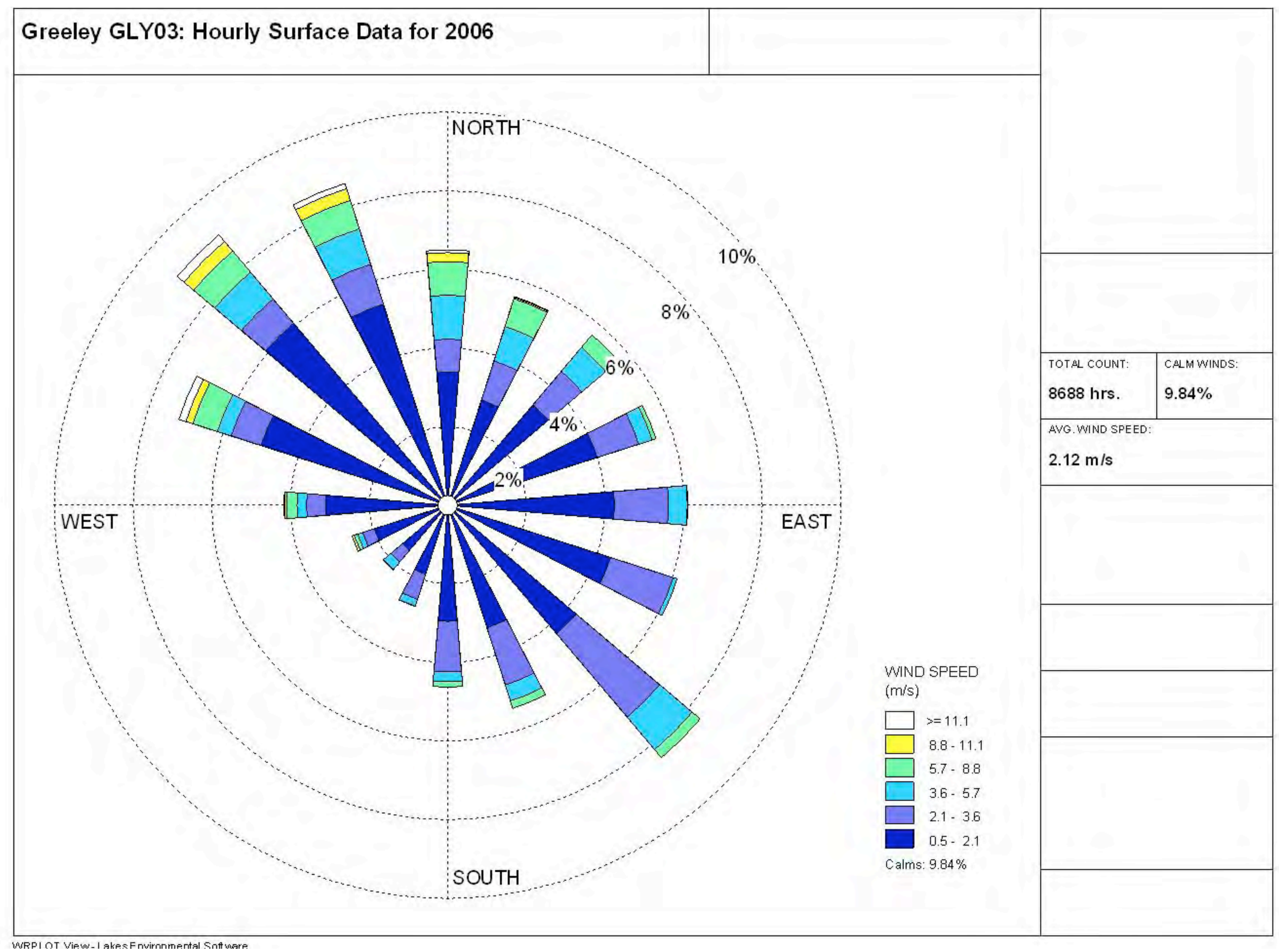
- Chinooks dominant



Greeley Wind Roses

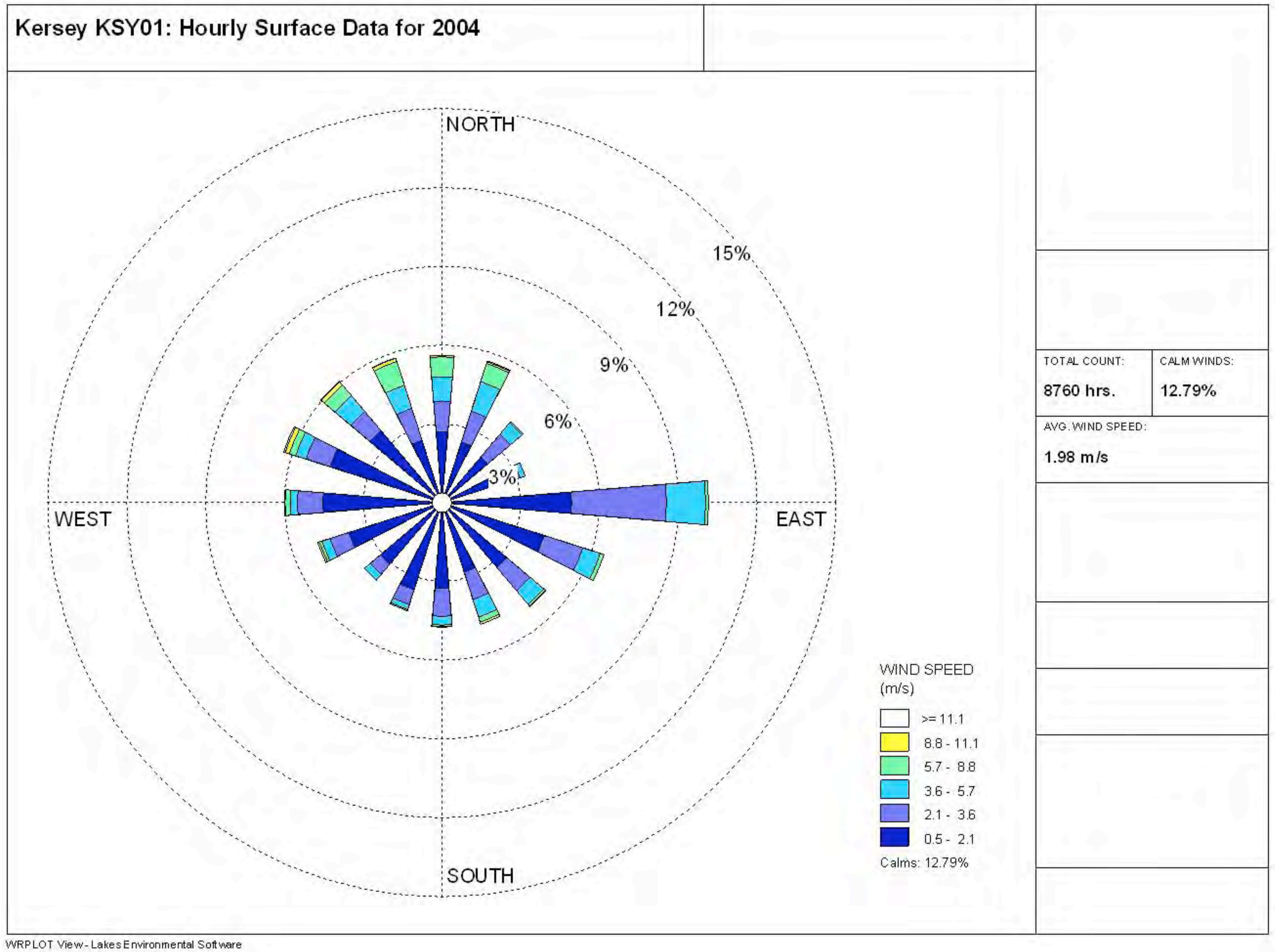


2004

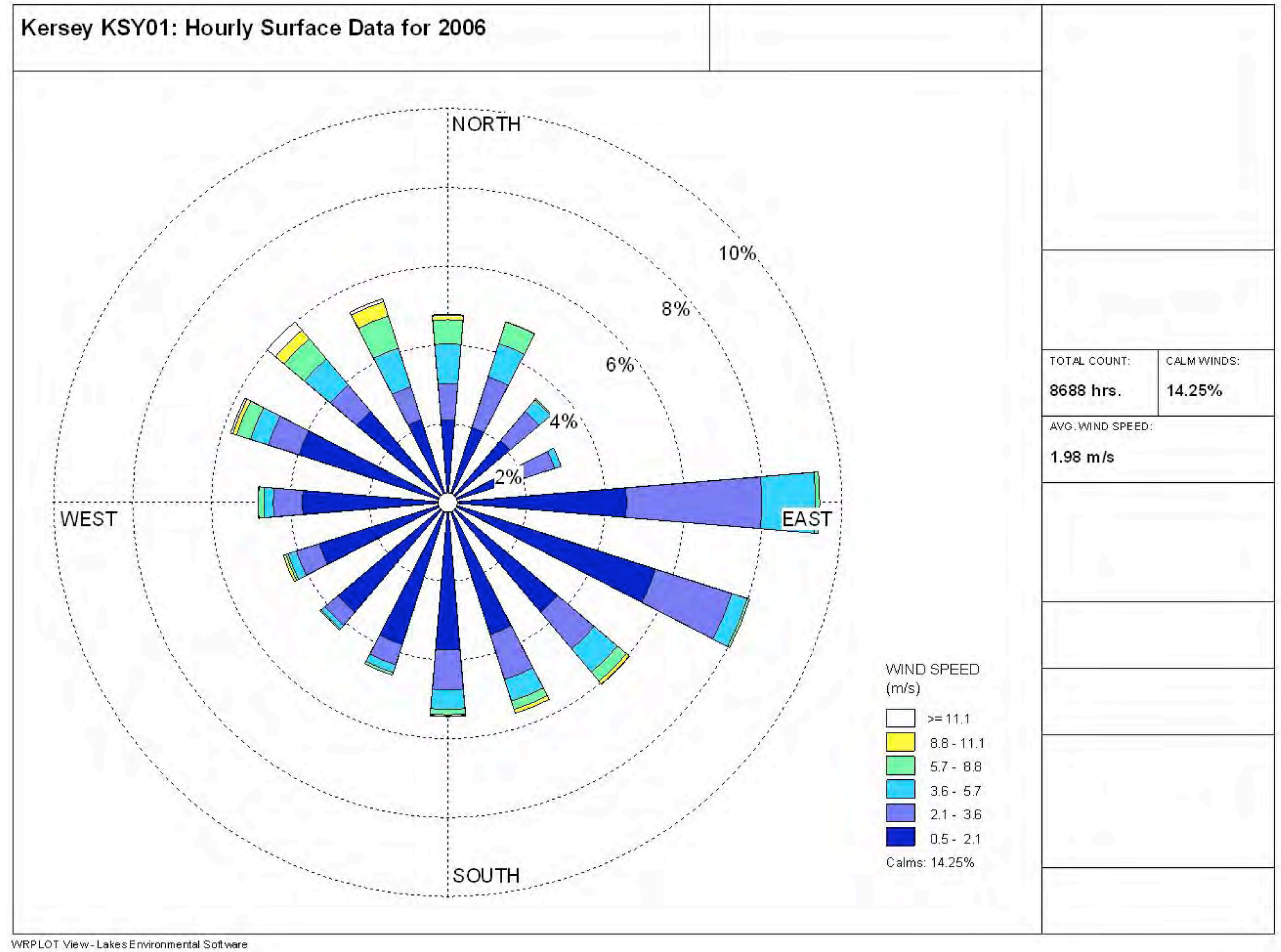


2006

Kersey Wind Roses



2004



2006

So What?

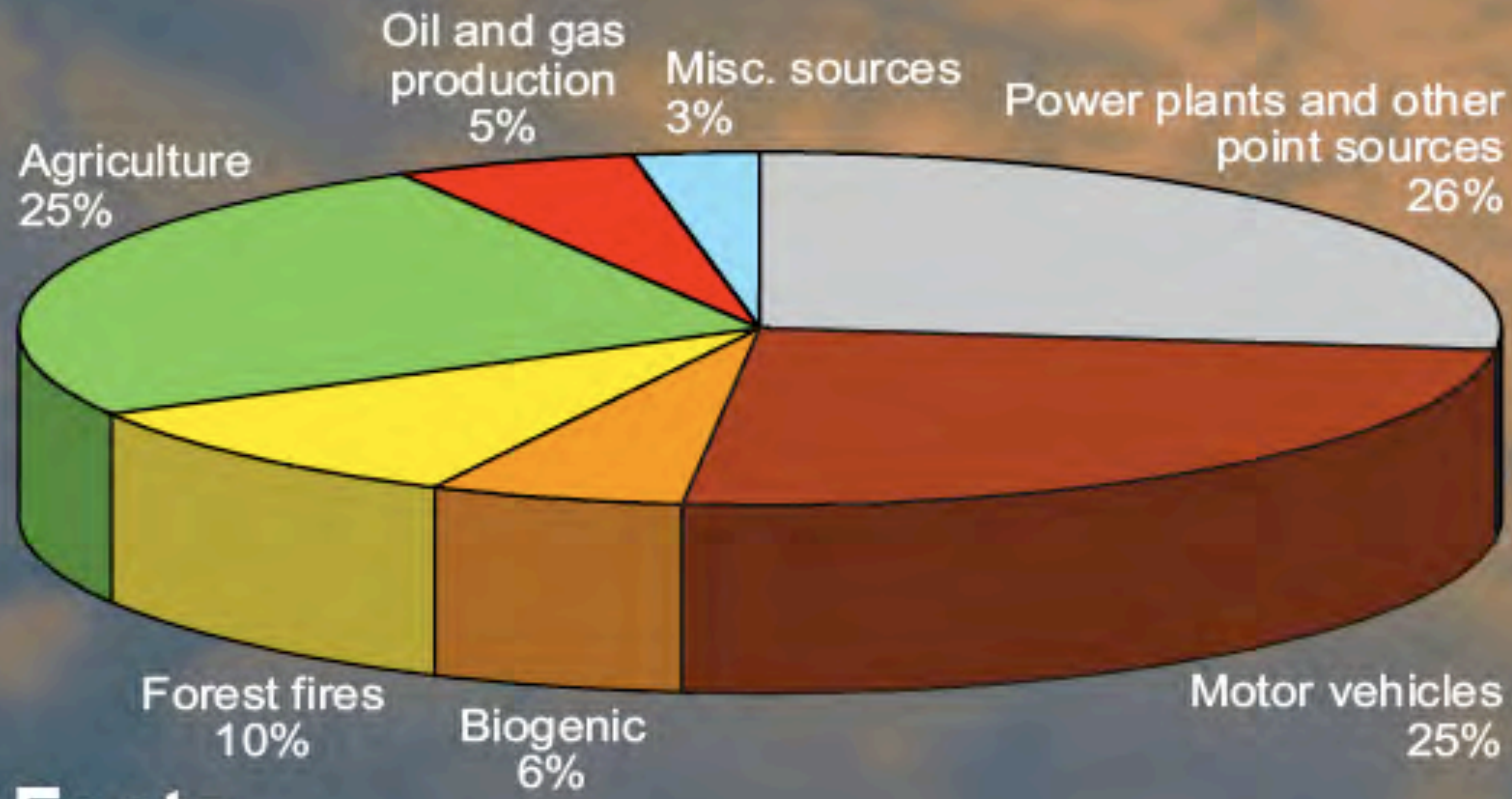
- Air masses over RMNP generally come from the W and NW, depending on the season; BUT
- Air masses *that generate significant precipitation* tend to come from the E and SE
- Wind direction in RMNP does not necessarily point directly back at the source of the air mass!

Sources of N Along the Front Range

Sources

Nitrogen compounds (e.g., NO_X, ammonia) and sulfur compounds are emitted into the atmosphere from a variety of air pollution sources, including automobiles, power plants, industry, agriculture, and fires. Colorado's Front Range is an area of rapid population growth, escalating urbanization, oil and gas development, and agricultural production. Increases in these activities result in corresponding increases in nitrogen deposition in mountain ecosystems.

Nitrogen Emissions in Colorado



Facts

- 2/3 of the state's population lives along the Front Range.
- Ammonium nitrate is a common crop fertilizer and results in emissions of ammonia.
- Some chemical transport models suggest that 25-30% of nitrate and 45-50% of sulfate is associated with emissions from within Colorado.

Source: Rocky Mountain Atmospheric Nitrogen and Sulfur (RoMANS) Brochure

What Happens to Emitted NH_3?

- Atmospheric residence time of NH_3 gas is fairly short (<7 days) due to its high reactivity with surfaces, with water, and with acid gases
- NH_3 sources tend to be at ground level (i. e., not stack emissions)
- Dry deposition of gaseous NH_3 dominates near sources
- Wet deposition of particle-phase NH_4^+ dominates away from sources

Source: Asman et al. (1998)

Watson et al. (1996)

- Northern Front Range Air Quality Study (NFRAQS)
- Seasonality, composition, and distribution of PM along the I-25 and US85 corridors
- Major conclusion: Study area is relatively enriched with respect to NH_3 as compared to SO_x and NO_x
- Would changes in NH_3 concentration give rise to changes in secondary fine particles (sulfates and nitrates)?

More NFRAQS Conclusions

- Virtually all of the sulfate and nitrate in the NFR can be accounted for as secondary ammonium salts ($PM_{2.5}$)
- If NH_3 levels were reduced by 50%...
  - ...most of the available HNO_3 would be neutralized
  - ...particle NO_3 would be reduced by only 15%
- Beyond 50% reduction in NH_3, particle NO_3 would decrease proportionately with NH_3

Atmospheric Deposition in RMNP

Two Kinds of Deposition

- WET deposition - rainfall, snowfall, fog
  - Gases and particles dissolve into liquid phase to form solution
  - Solution deposits on surfaces (canopies, vegetation, soils, surface water) as fog, dew or precipitation
- DRY deposition - gases and particles impact or settle onto surfaces without assistance from condensing water

Anatomy of an NADP Site

Deposition (kg/ha/yr) = Precipitation (mm/wk) * Concentration (mg/l) * 0.52

Rain Gauge

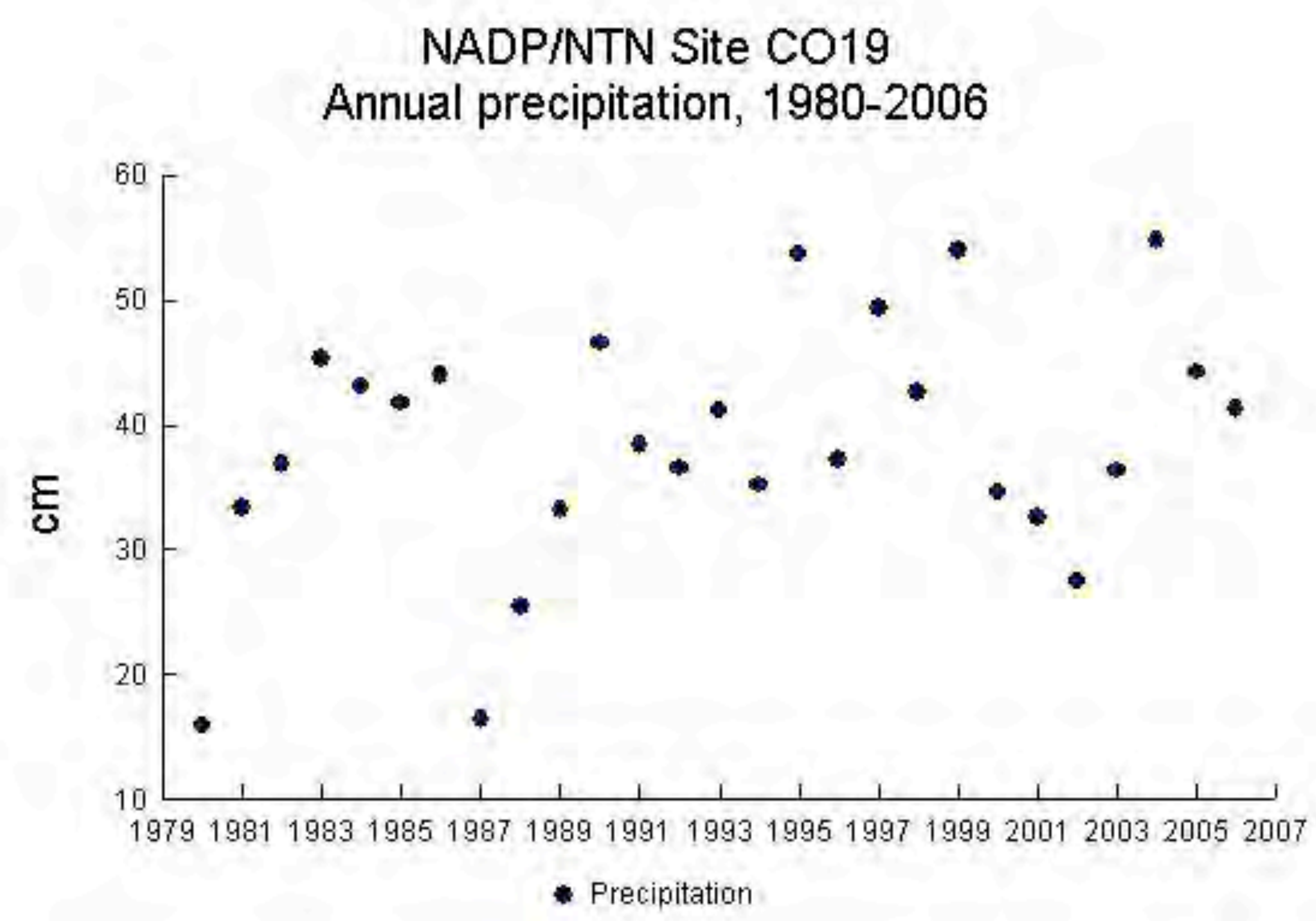
Rainfall Sampler

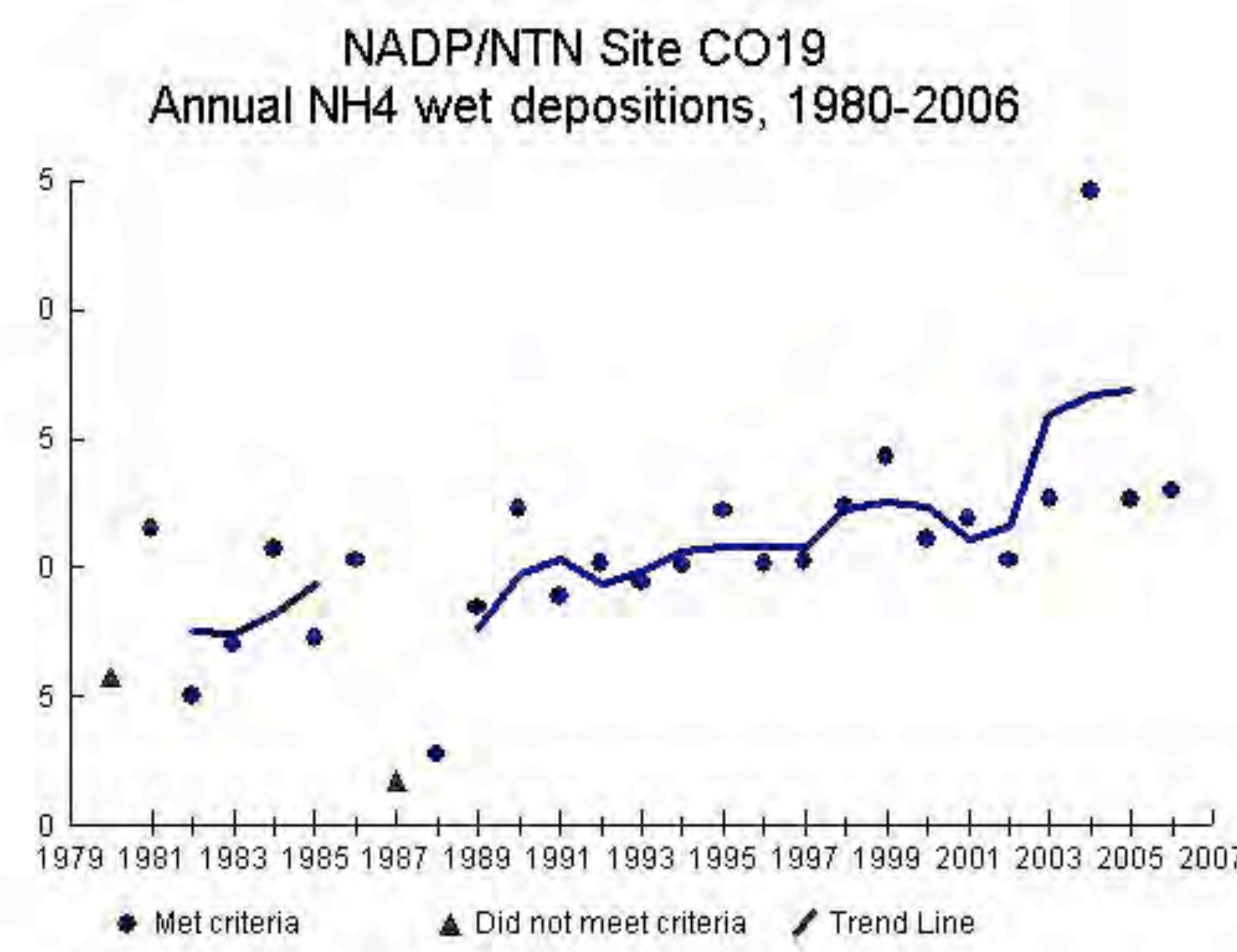
NADP Sites in Rocky Mountain National Park

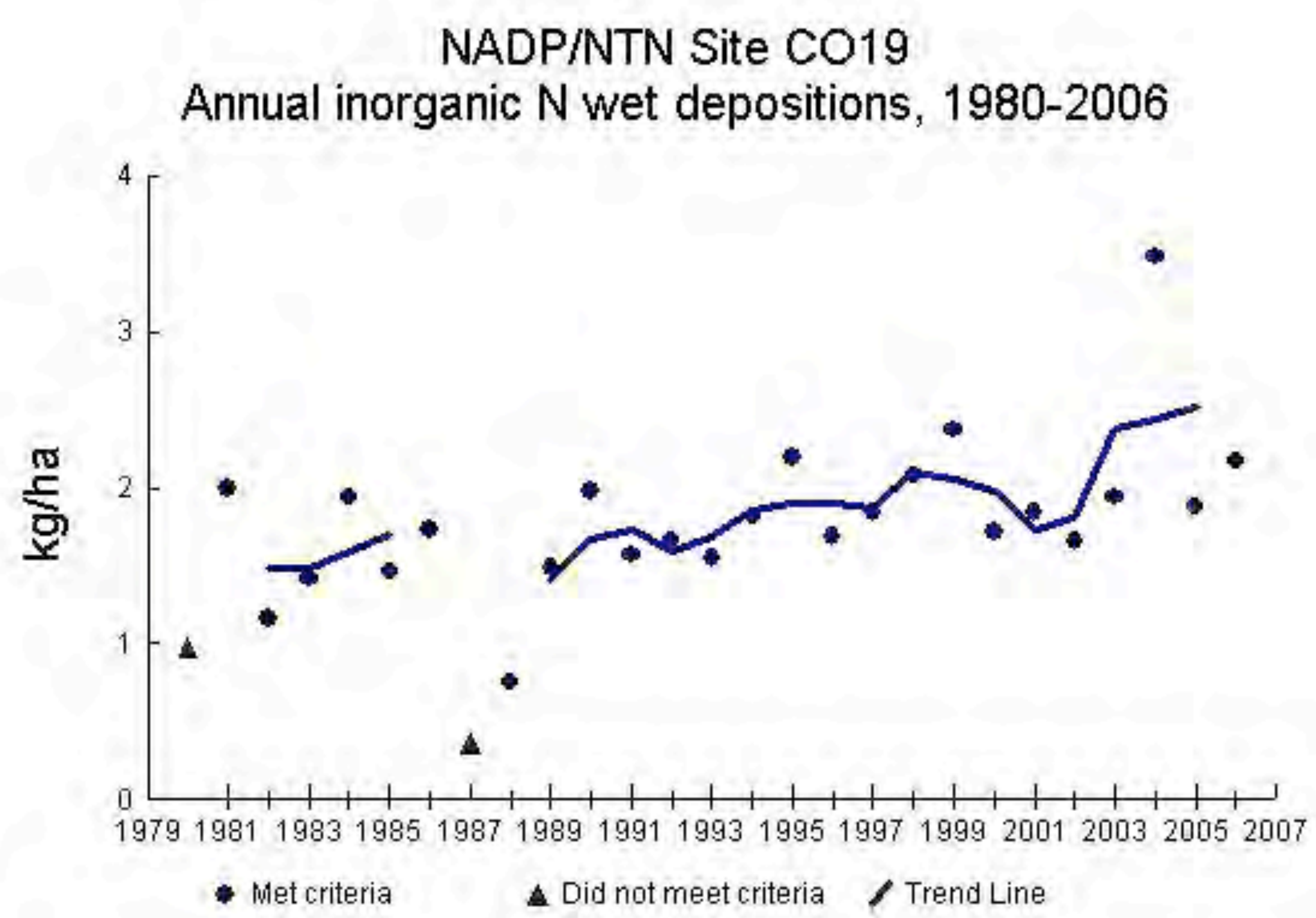
NADP Site CO98 “Loch Vale”

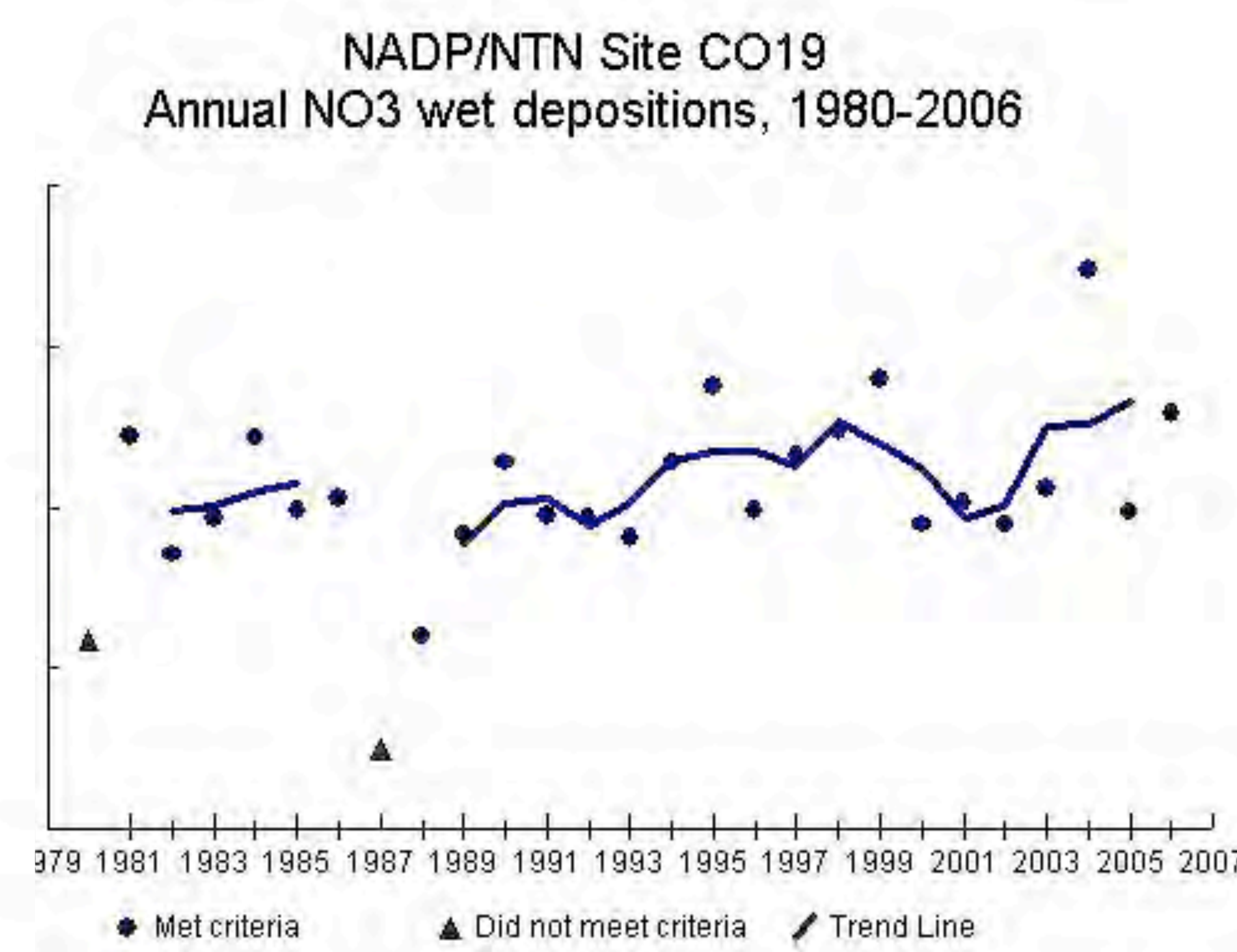
NADP Site CO19 “Beaver Meadows”

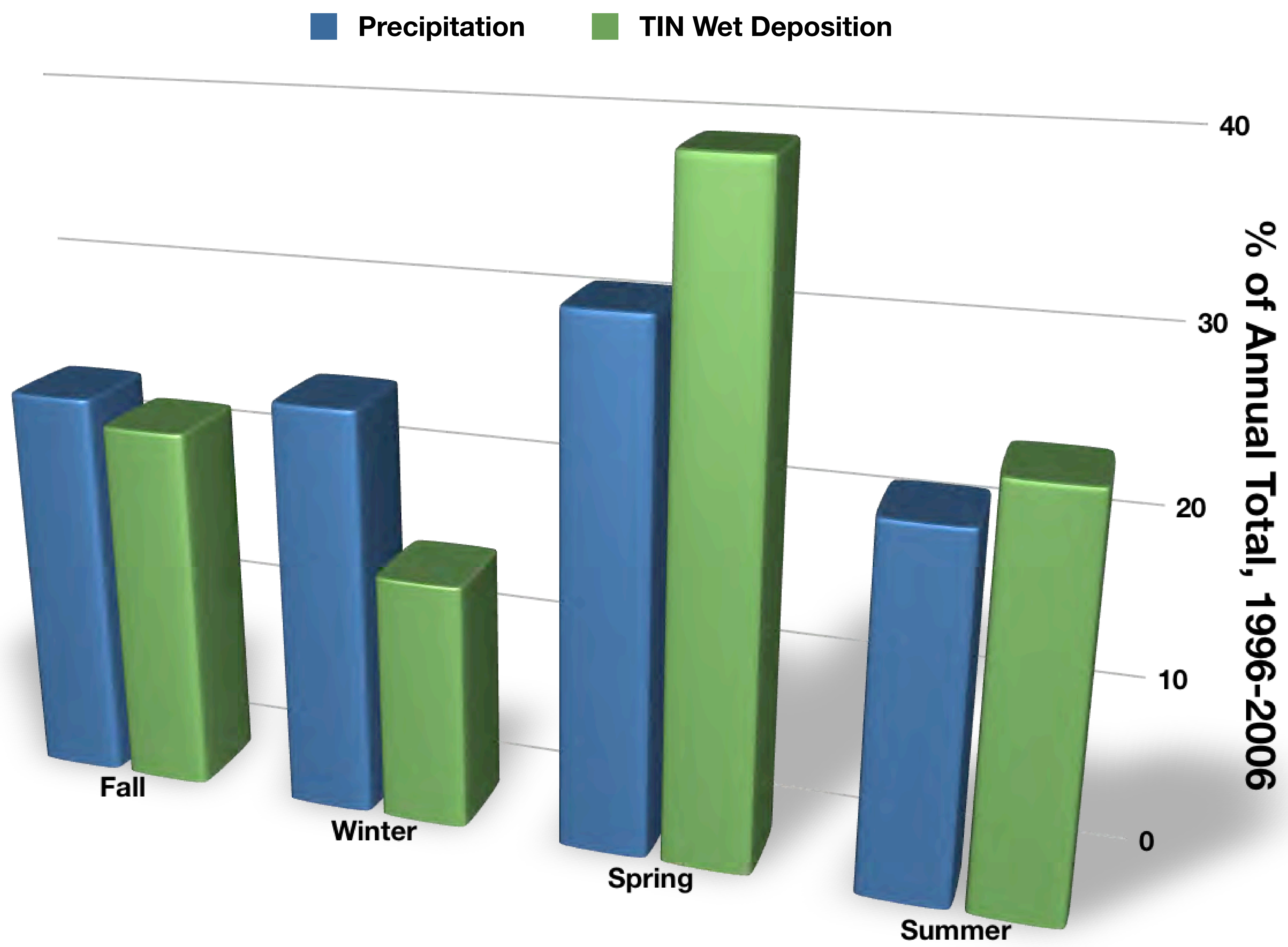
Deposition and Precipitation, CO19



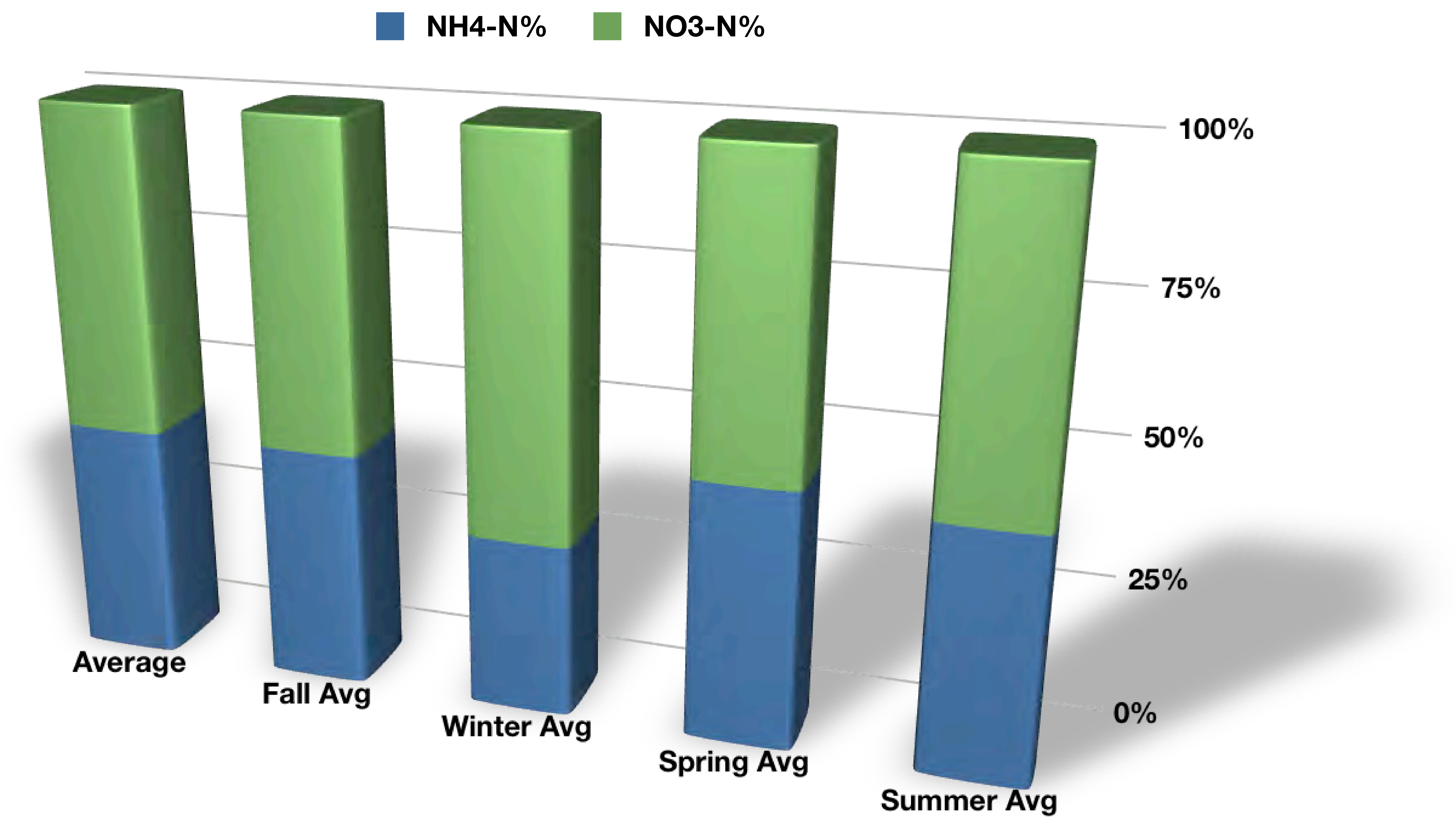






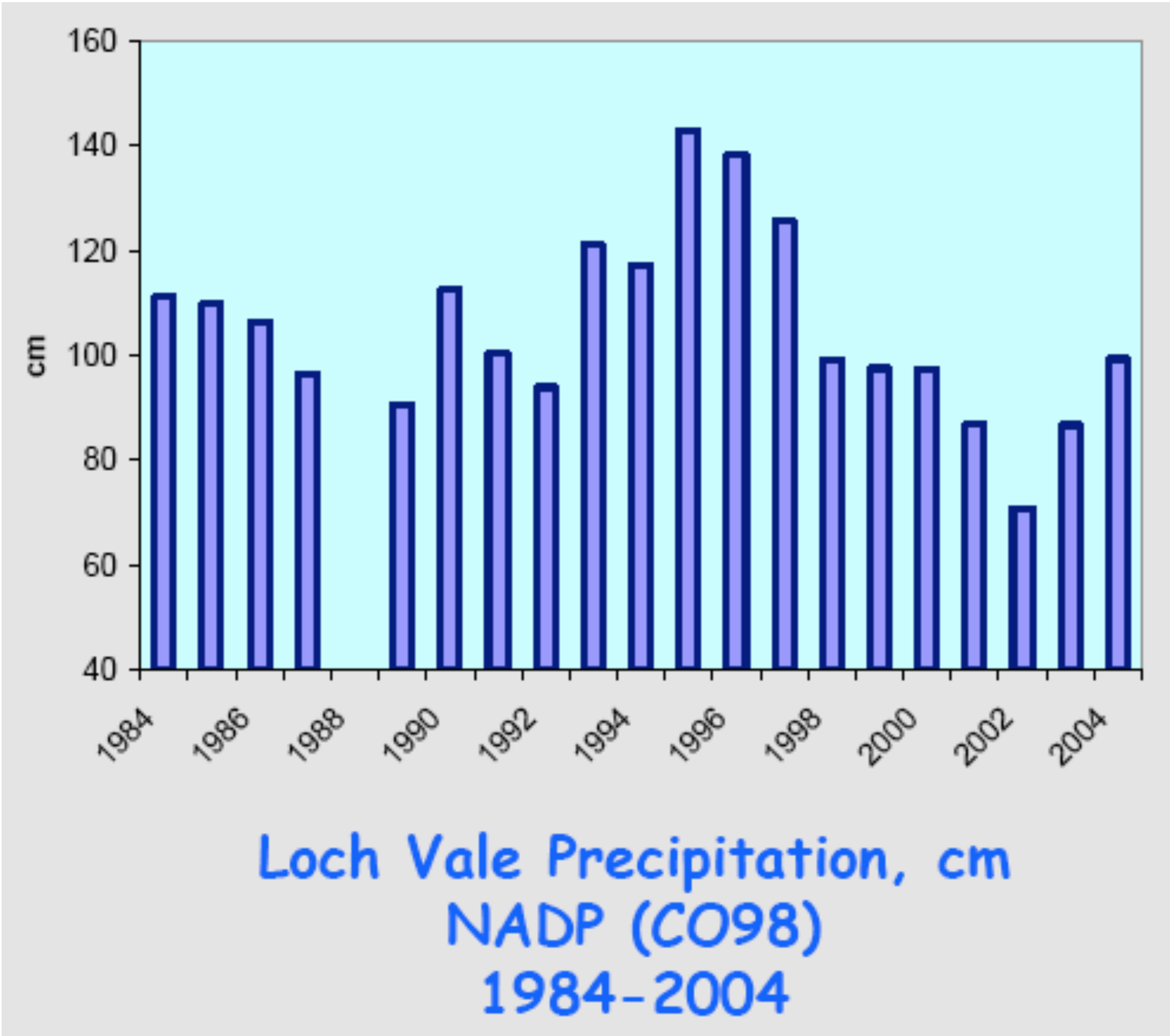


Seasonality of Wet Deposition and Precipitation, Loch Vale

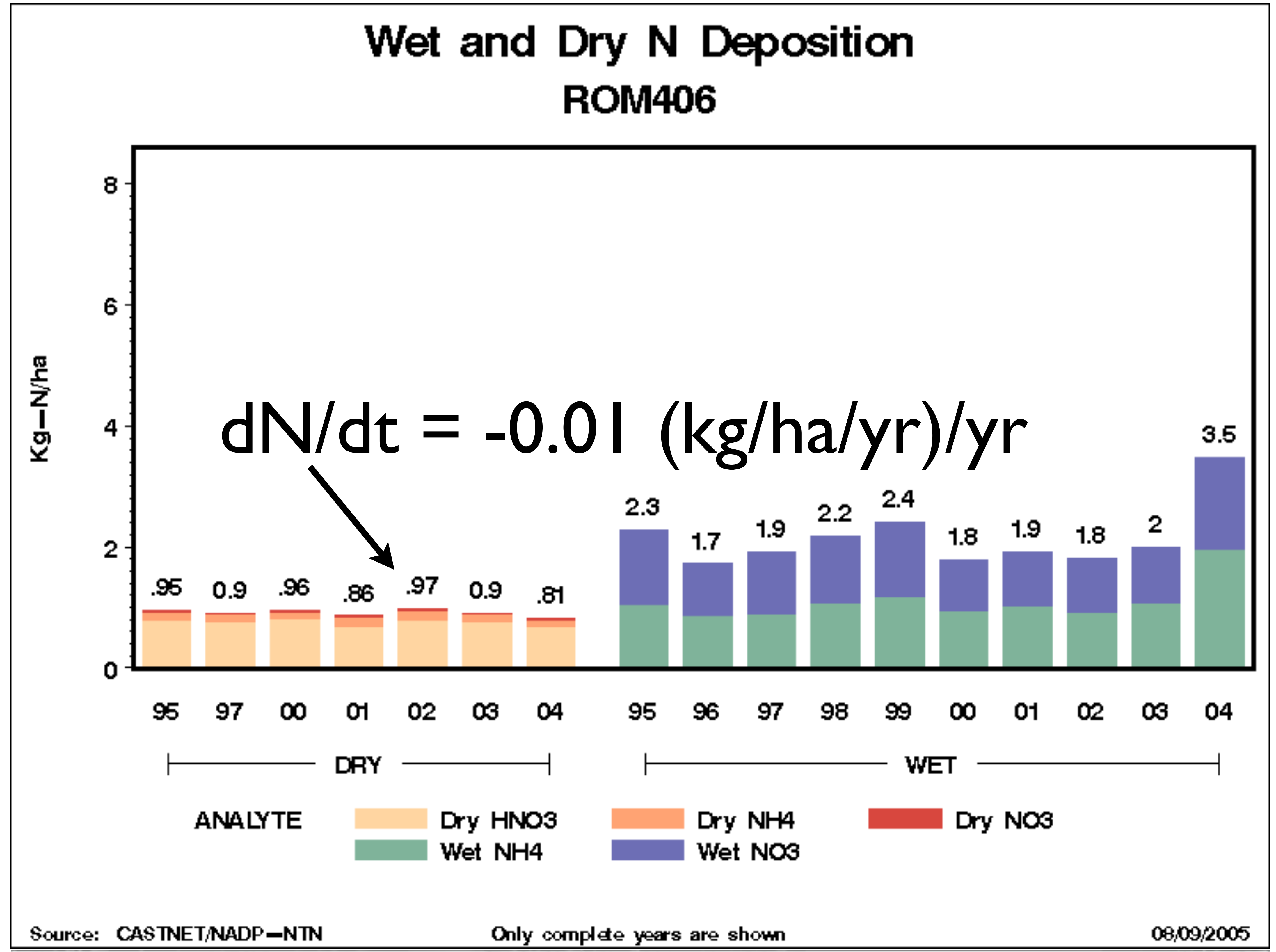


Seasonal Proportion of NO_3-N and NH_4-N in Wet Deposition
Loch Vale, 1996-2006

"An analysis of 1995 through 1998 CASTNET data shows no trend in dry nitrogen or sulfur deposition at the park." (RMNP, 2008)



Baron et al. (2005)



So Who's Responsible?

- This is a question known as "source apportionment"
- Source apportionment requires modeling:
  - Assumptions
  - Discretized domains (grid sizes >4 km)
  - Accepted algorithms
  - Tracers within the source domains
  - GIGO - results can be no more accurate than the input data

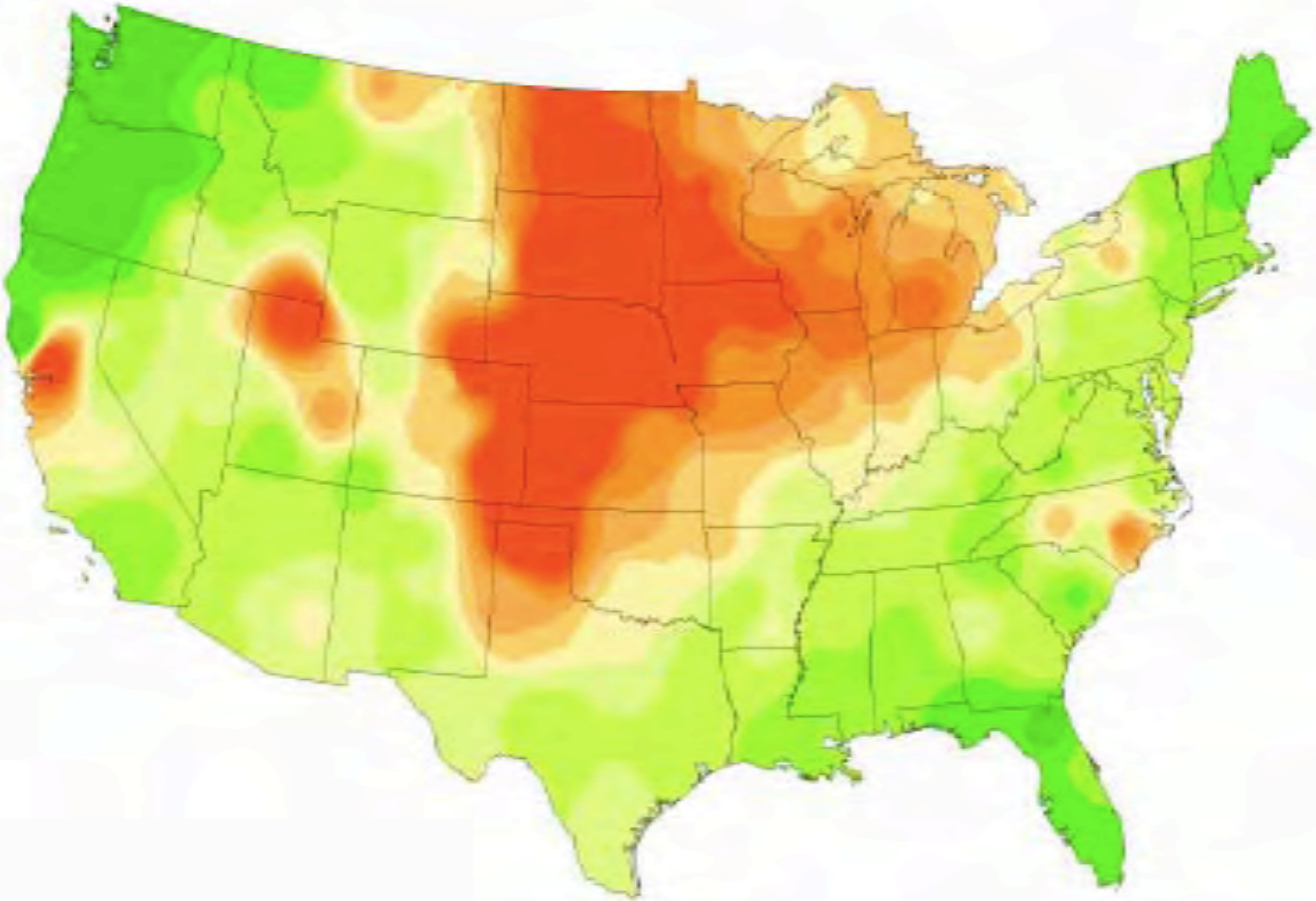
RoMANS:

A Source-Apportionment Study

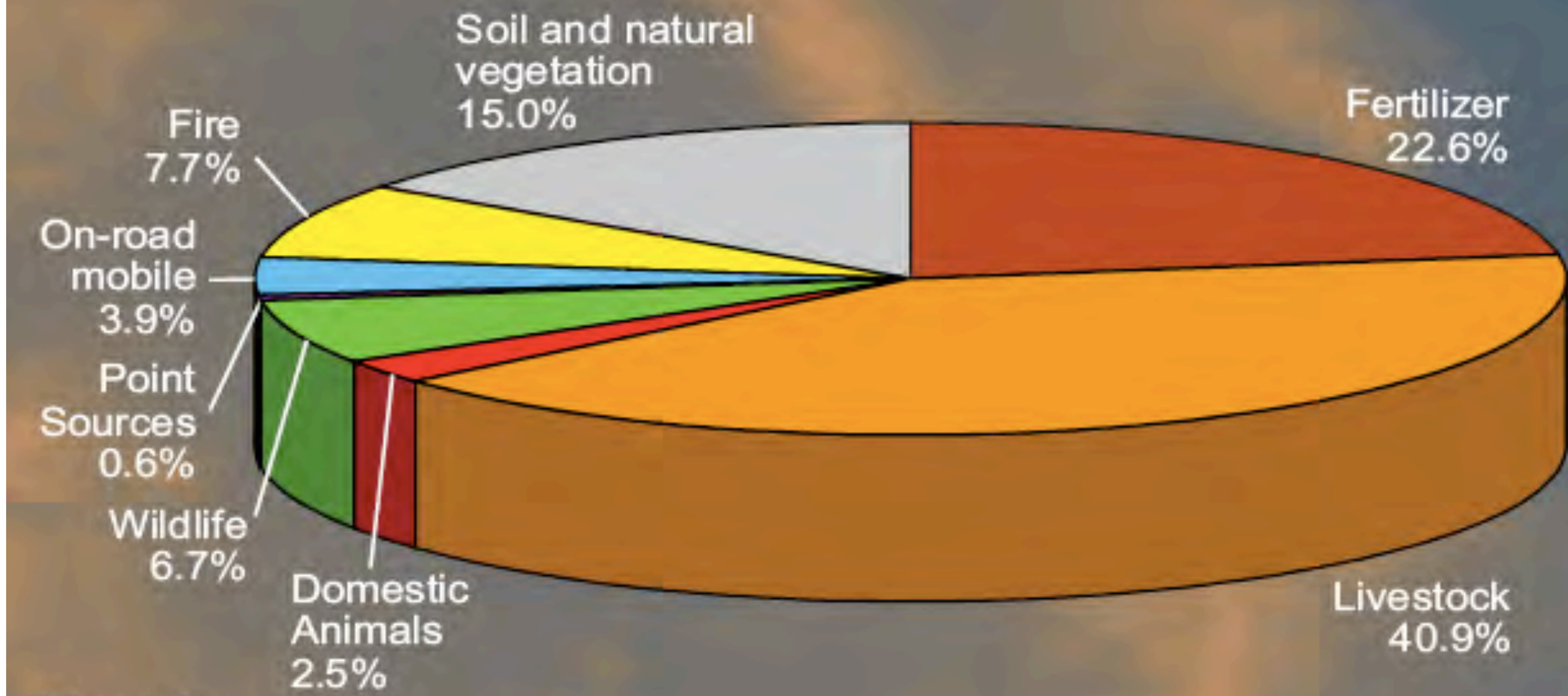
- Two models required
  - MM5 (wind fields, precipitation)
  - CAMx (chemical transport)
- Tracer sources inside and outside of CO
- Interim finding: 33% of NH_3 and 50% of NO_x affecting RMNP are from CO sources

Source: Barna et al. (2007)

NH_4^+ ion concentrations, 2004



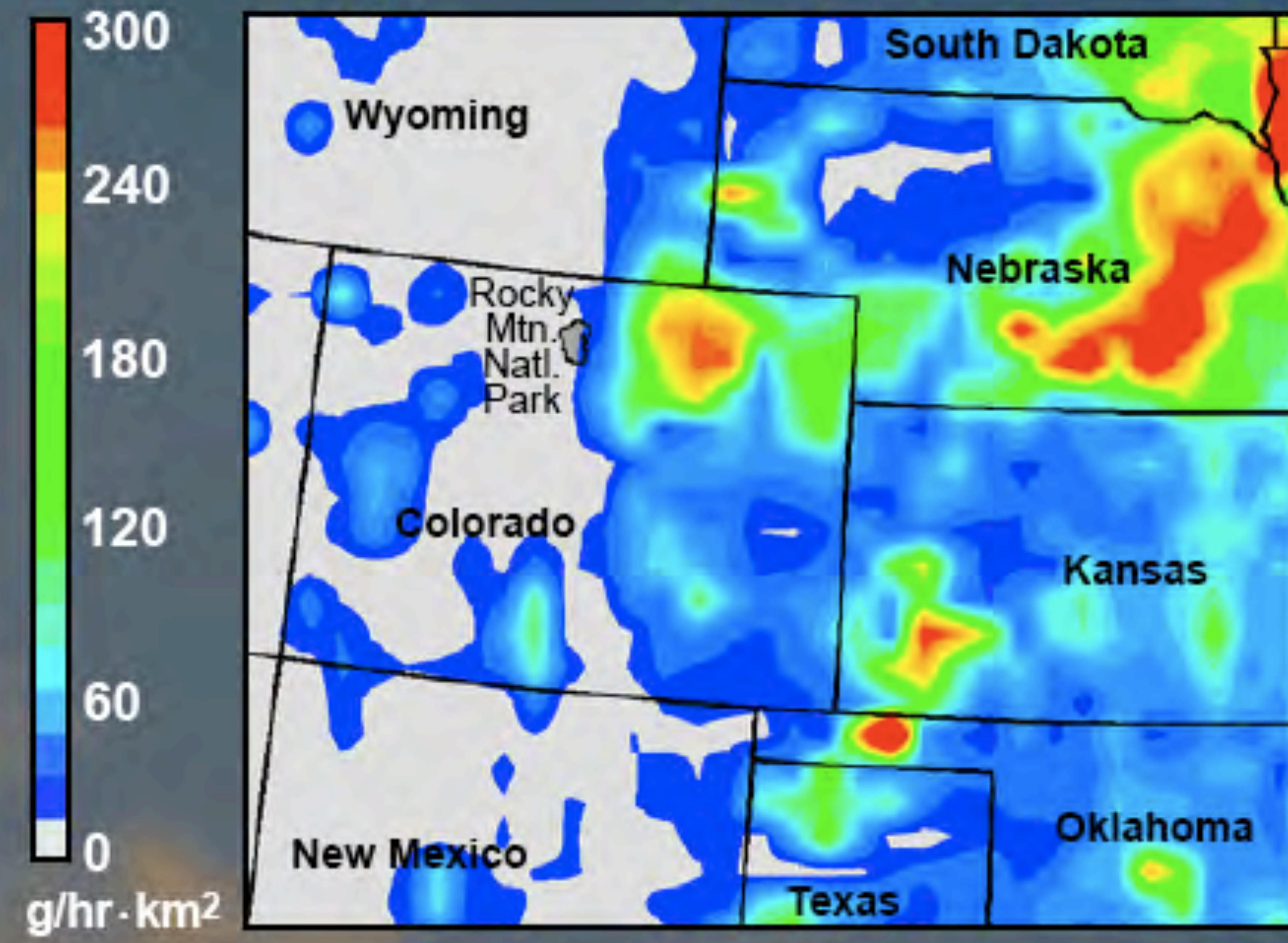
Ammonia Emissions in Colorado



Facts

- Northeastern Colorado is a highly productive agricultural region.
- Colorado ranks 4th in the United States for confined-fed cattle, sheep, and lamb production.
- Colorado ranks 11th in the United States for pig production.

Regional Ammonia Emissions



Typical summertime ammonia emissions, primarily from agricultural sources, in the region surrounding Rocky Mountain National Park

Source: Rocky Mountain Atmospheric Nitrogen and Sulfur (RoMANS) Brochure

Wet Deposition Can Increase If:

- Precipitation increases*; OR
- Emissions of compounds or precursors increase within the source footprint *; OR
- Frequency of upslope conditions increases*; OR
- Any two or more of the above coincide*

*All other influences remaining equal

Ecological Effects of N Deposition in RMNP

Ecological Effects of Alpine N Enrichment

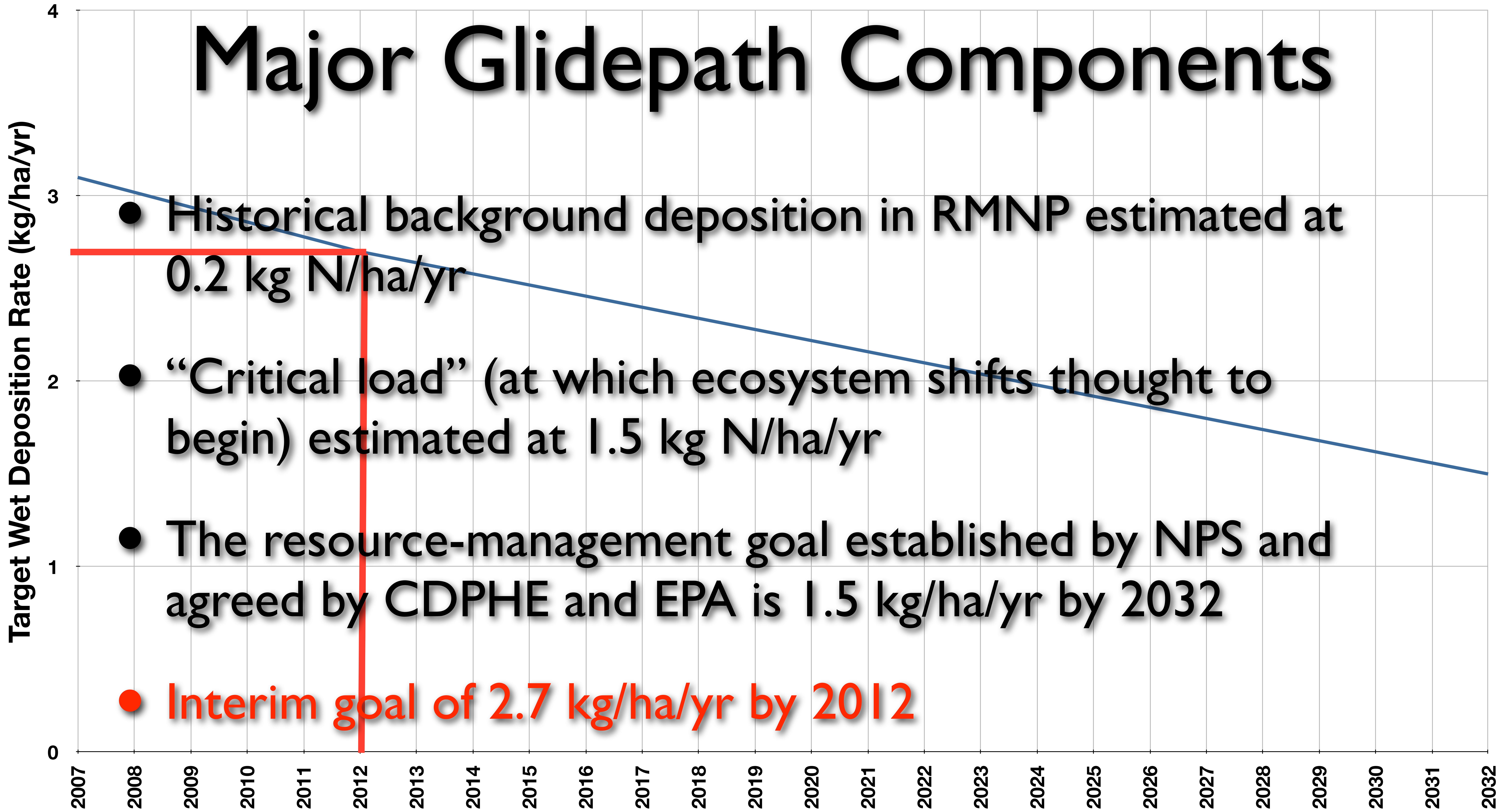
- Water quality: increased N concentrations in streams and lakes
  - Eutrophication
  - Change in microbial flora (diatoms)
- Vegetation: From wildflowers to grasses and sedges
- Soil acidification as NH_4 oxidized to NO_3

Source: Baron et al. (2005)

The RMNP “Glidepath”

Major Glidepath Components

- Historical background deposition in RMNP estimated at 0.2 kg N/ha/yr
- “Critical load” (at which ecosystem shifts thought to begin) estimated at 1.5 kg N/ha/yr
- The resource-management goal established by NPS and agreed by CDPHE and EPA is 1.5 kg/ha/yr by 2032
- Interim goal of 2.7 kg/ha/yr by 2012



Wet Deposition Can Increase If:

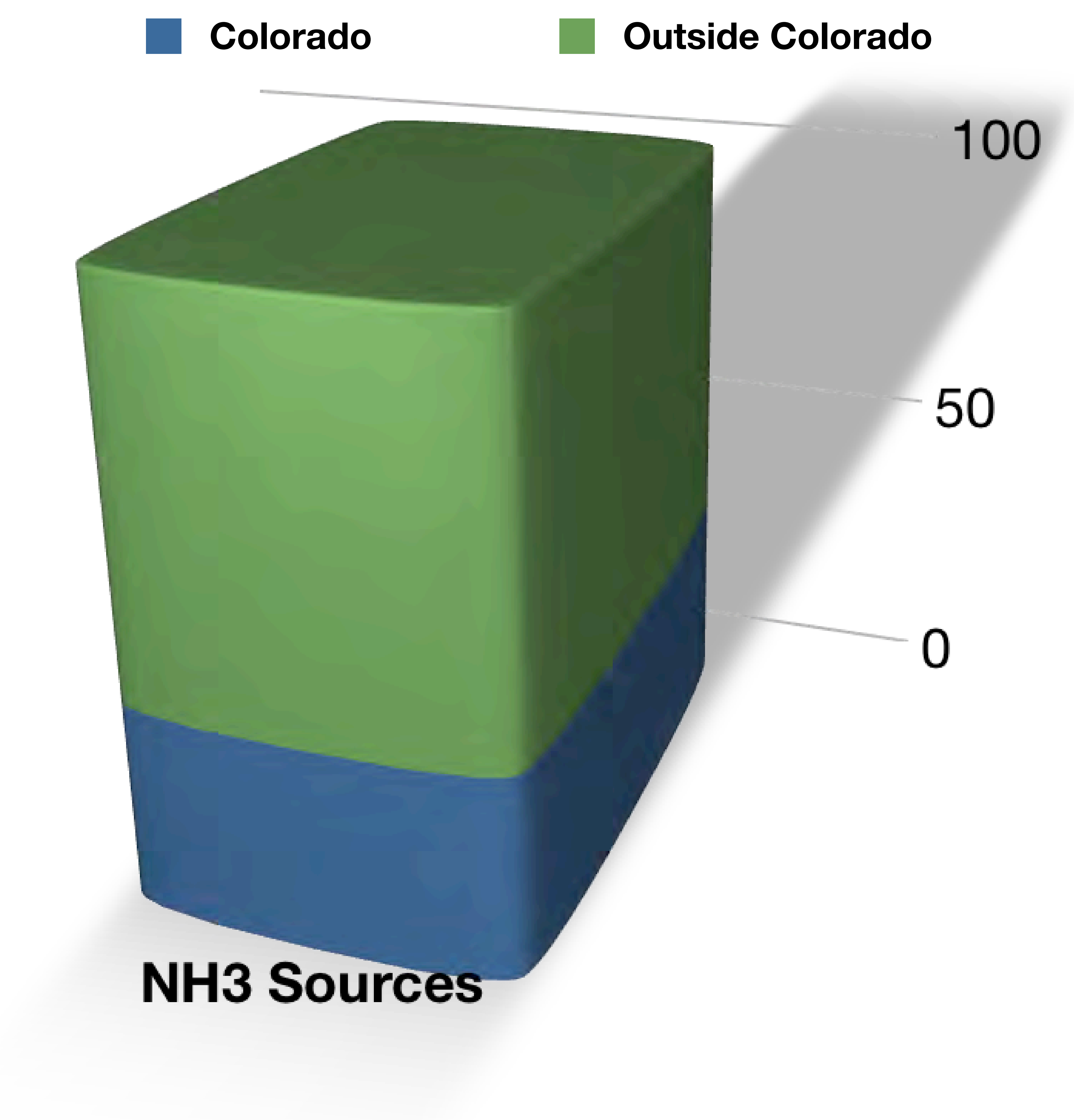
- Precipitation increases*; OR
- Emissions of compounds or precursors increase within the source footprint *; OR
- Frequency of upslope conditions increases*; OR
- Any two or more of the above coincide*

These are the areas where mitigation strategies focus

*All other influences remaining equal

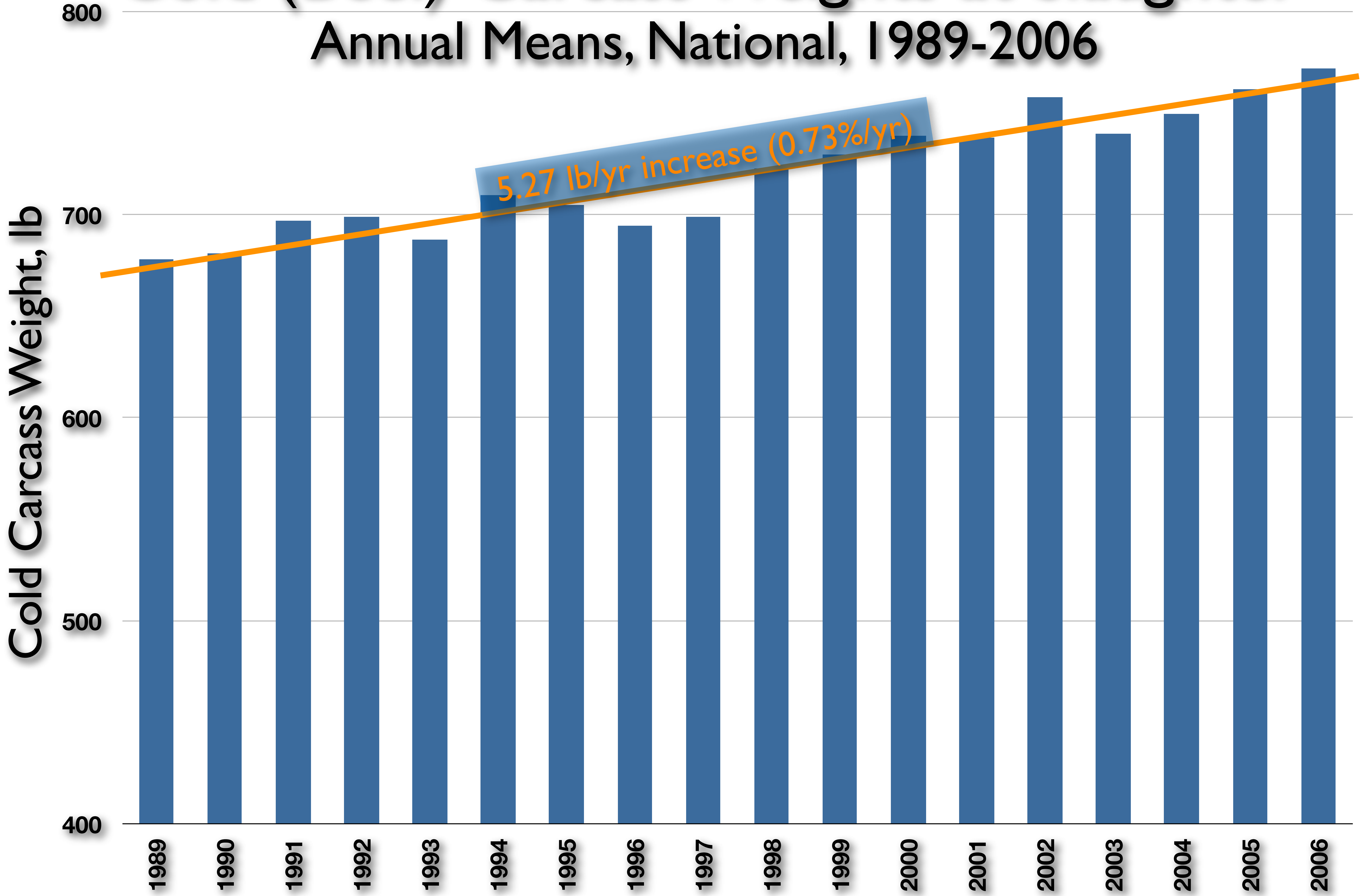
Think About That

- Two thirds (65%) of the NH_3 under consideration originates outside CO?



Cold (Beef) Carcass Weights at Slaughter

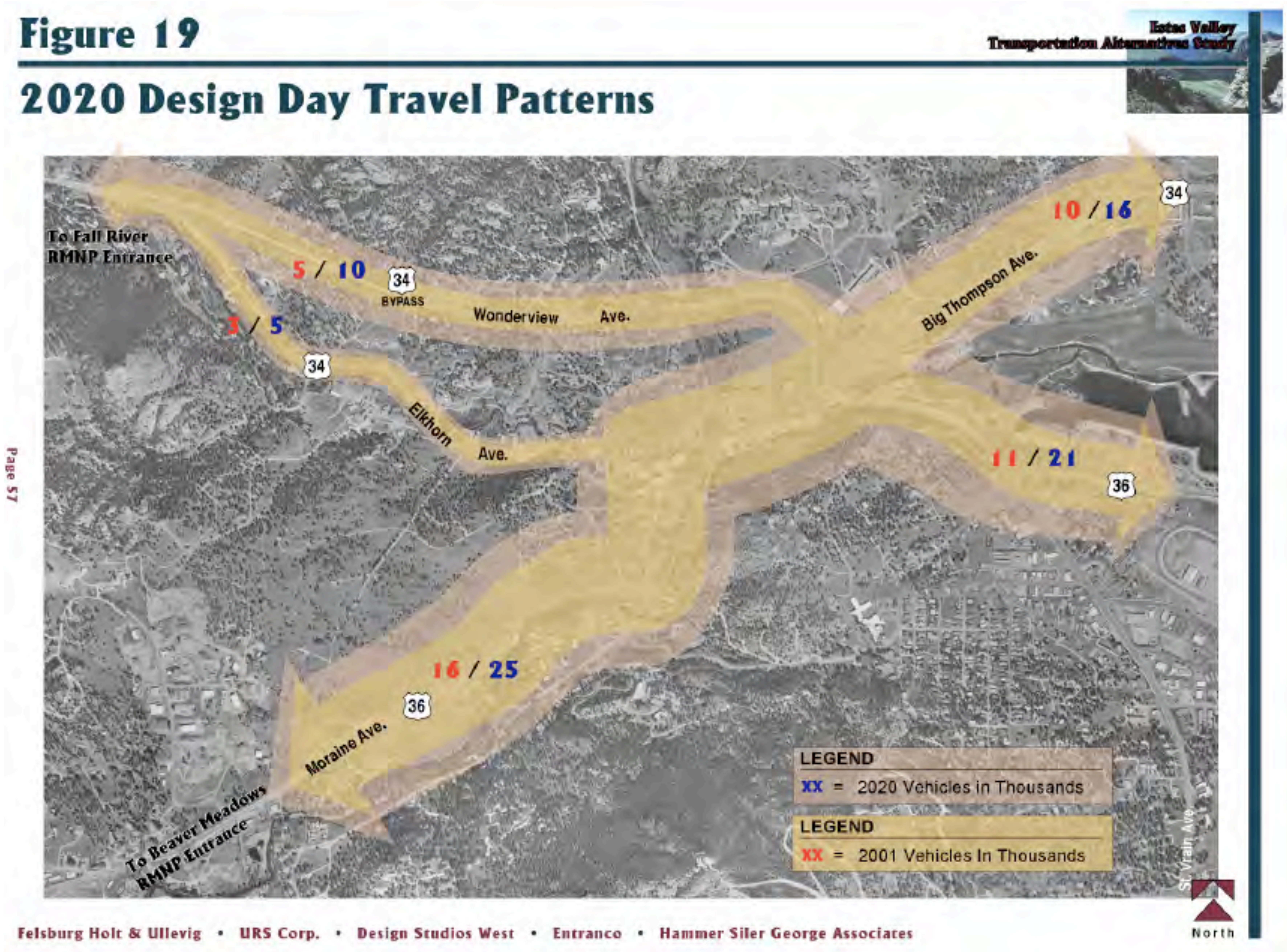
Annual Means, National, 1989-2006



Source: CattleFax

Estes Valley Traffic <u>Projection:</u>

>50% increase over 20 years



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