Understanding Relationships Between Changes in Ambient Ozone and Precursor Concentrations and Changes in VOC and NOx Emissions from 1990 to 2004 in Central California

Phase I Findings and Proposed Phase II Approach
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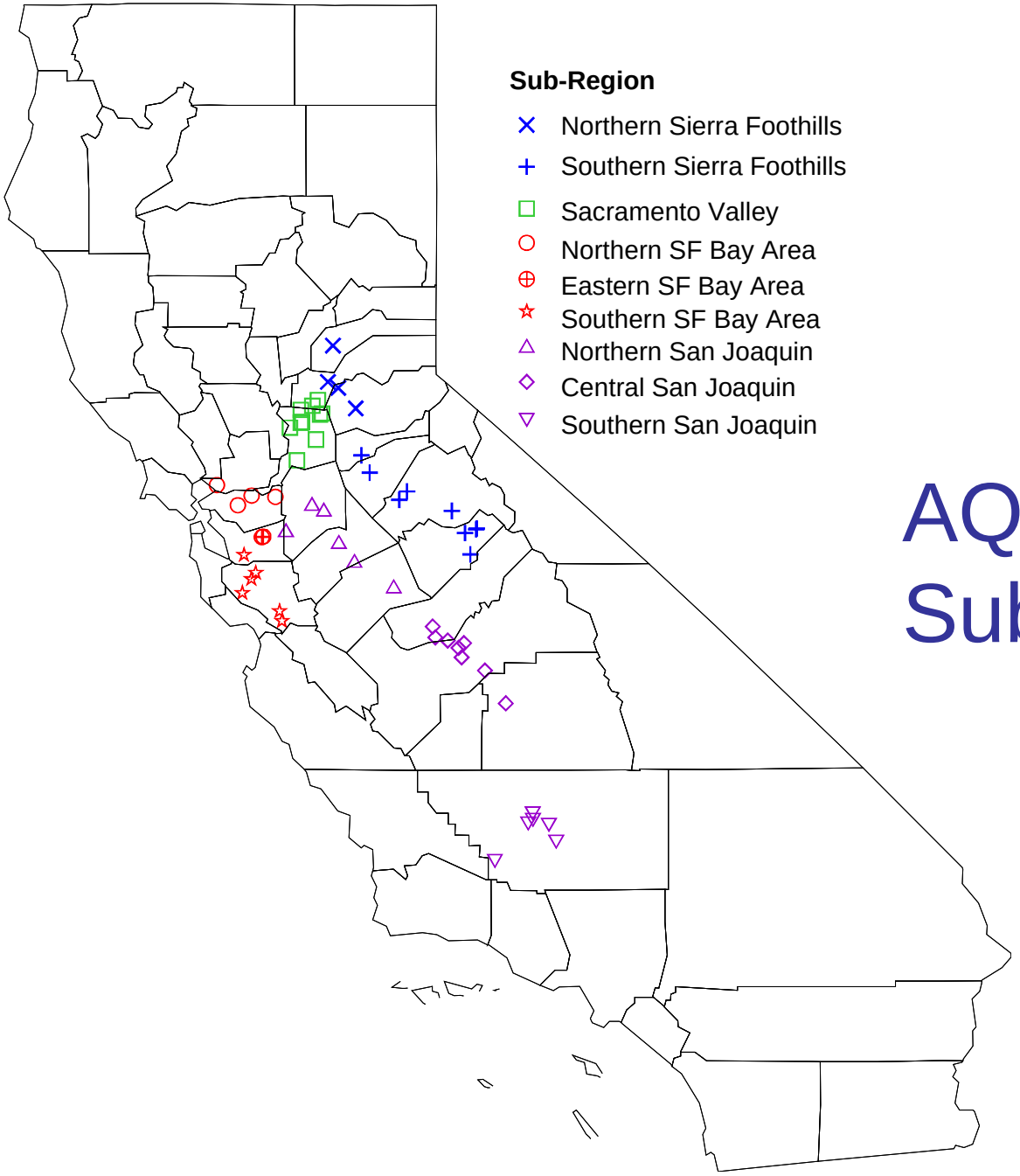
Today's Topics

I. Project overview
II. Trend analysis summary
III. Trends in ozone precursors
IV. Trends in precursors compared with county-level emissions
V. Spatial variations of ozone precursors
    => Questions
VI. Ozone trends
VII. Meteorological classification
VIII. Do met classes shed light on ozone trends?
    => Questions
IX. Phase II analyses and schedule

I. Project Overview

- Phase I
  - Develop databases and methods
  - Characterize ozone and precursor trends by site, subregion – compare precursor trends to county-level emission trends – characterize ozone trends by meteorological class
  - Evaluate prospects for success in Phase II
- Phase II
  - Grid emissions and relate ambient primary-pollutant trends to zone-of-influence emission trends
  - Relate ozone trends to ambient and emission trends of precursors, and to meteorological conditions
  - Submit final report

II. Trends Summary



AQ Sites and Subregions

AQ Metrics – Annual Averages

- Ozone
  - Annual 4th-highest daily 8-hour max, each site
  - Annual mean of top-60 peak 8-hour days, each site (the top-60 days are determined for each subregion)
- CO and NOx
  - Annual means from top-60 days, each site
  - Morning (start hours 5 am – 10 am)
  - Time of peak 8-hour ozone maxima (“mid-day”)
- NMOC
  - Annual means from all days, by site
  - Early morning - 5 am PST (most complete sampling)

1990 – 2004 AQ Trends Summary Results

- No trends significantly upward*
- NOx sig* down at 22 of 28 sites**
- CO sig* down at 21 of 25 sites**
- NMOC sig* down at 5 of 7 sites***
- Ozone sig* down at 7 of 42 sites**
- Annual mean top-60 ozone trends similar to trends in annual 4th-highest 8-hour max

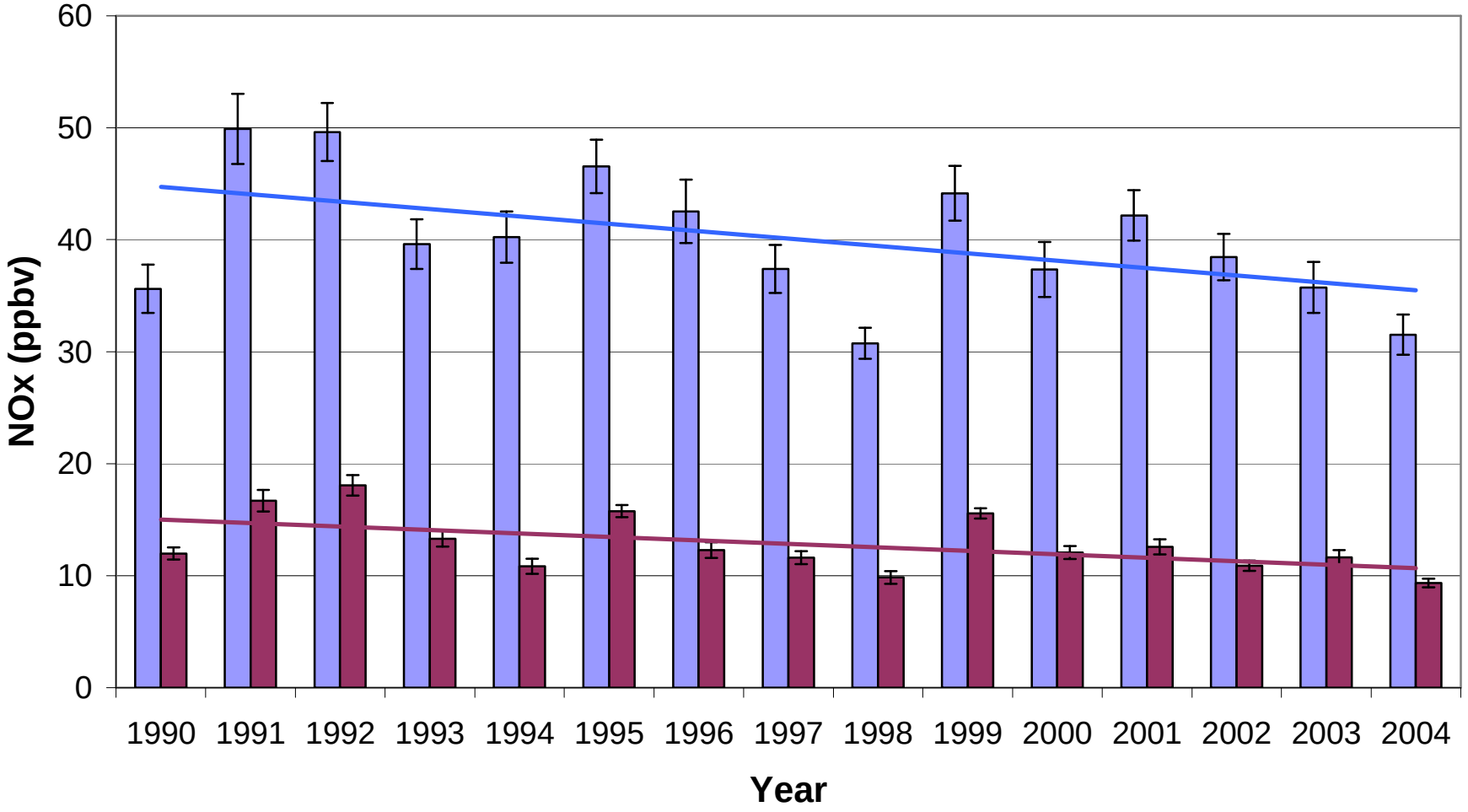
* $p < 0.05$

** At least 10 years data. One or both metrics.

*** 7 - 10 years data

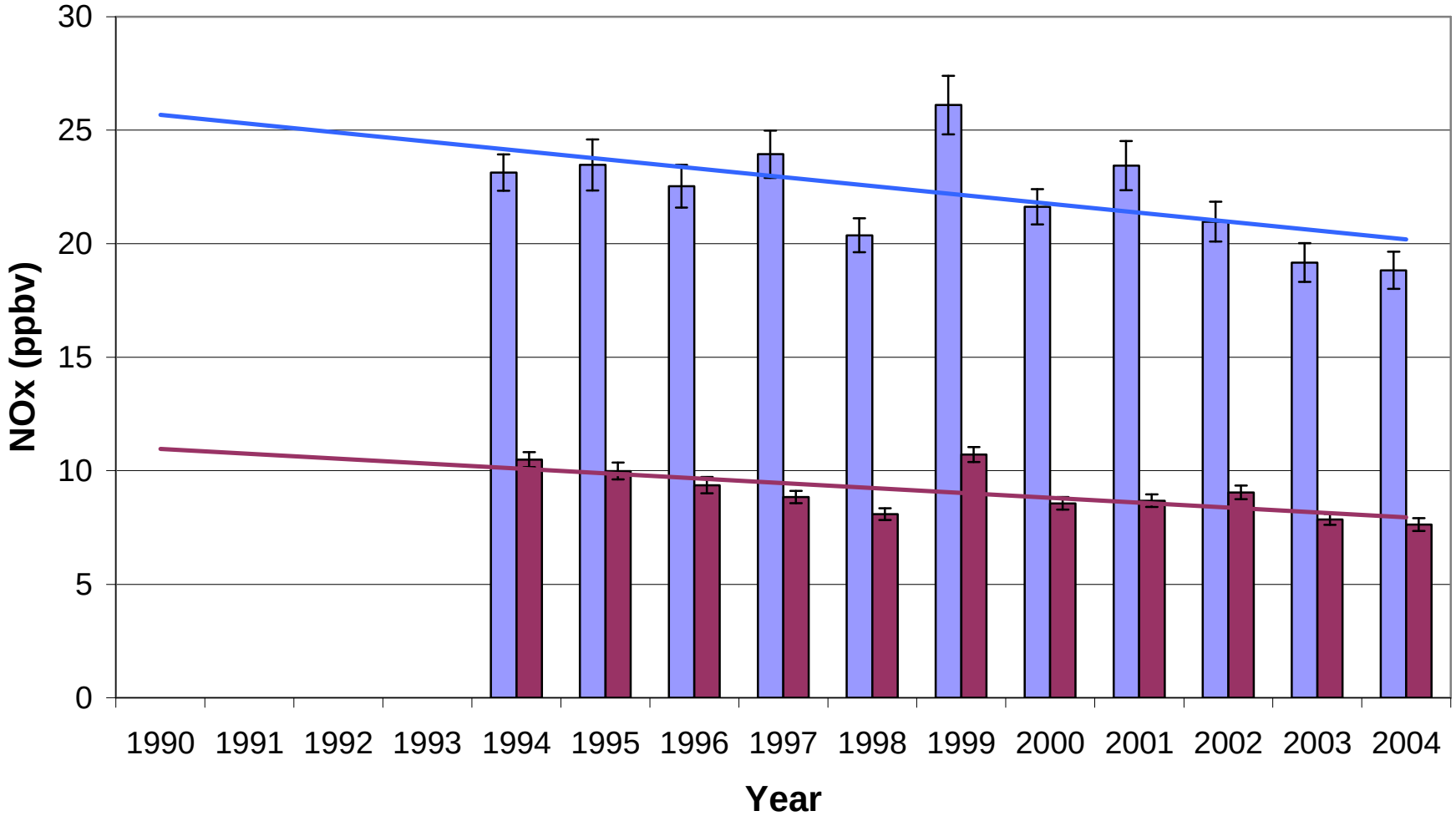
III. Trends in Ozone Precursors

Fresno First Street - Mean Morning (5 am - 11 am) and Mid-day (Time of 8-hour O_3 Max) NOx on Top 60 Subregional Days

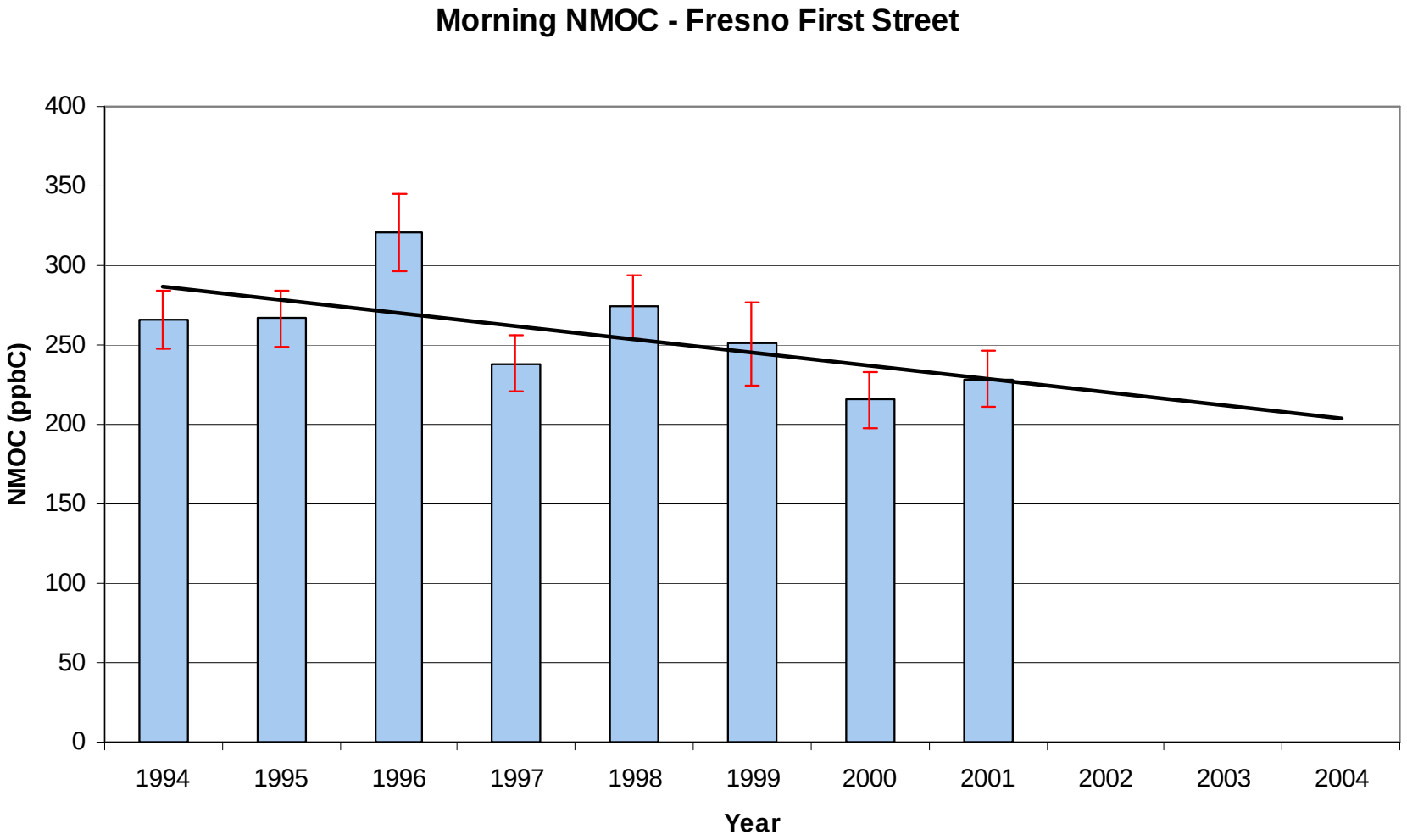


Morning NOx decline: 0.66 ppbv/year (~10 ppbv over period)
Mid-day NOx decline: 0.31 ppbv/year (~5 ppbv over period)

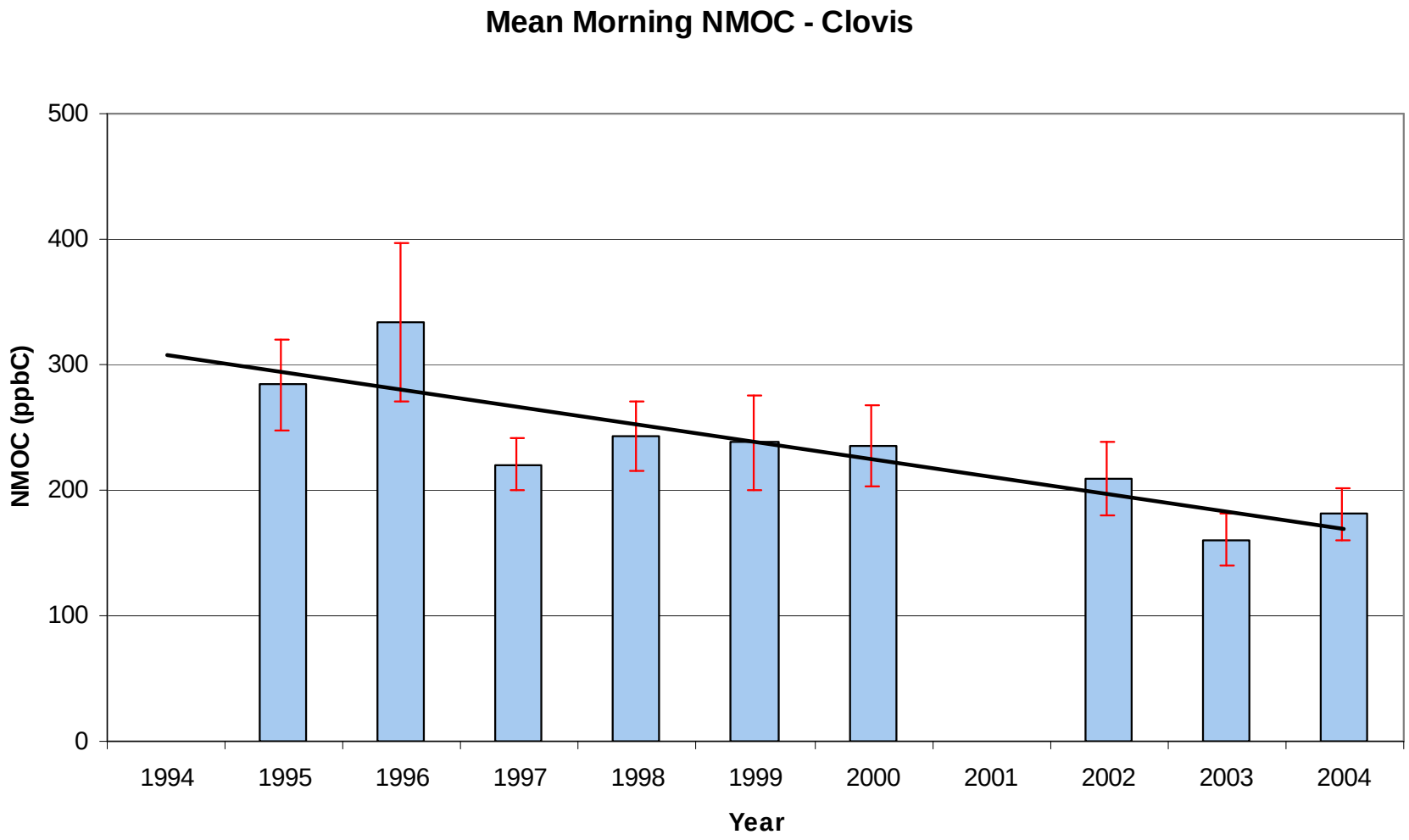
Parlier - Mean NOx on Top 60 Subregional High-Ozone Days
Morning (5 am - 11 am) and Mid-day (Time of 8-hour Ozone Max)



Morning NOx decline: 0.39 ppbv/year (~4 ppbv over period)
Mid-day NOx decline: 0.21 ppbv/year (~2 ppbv over period)

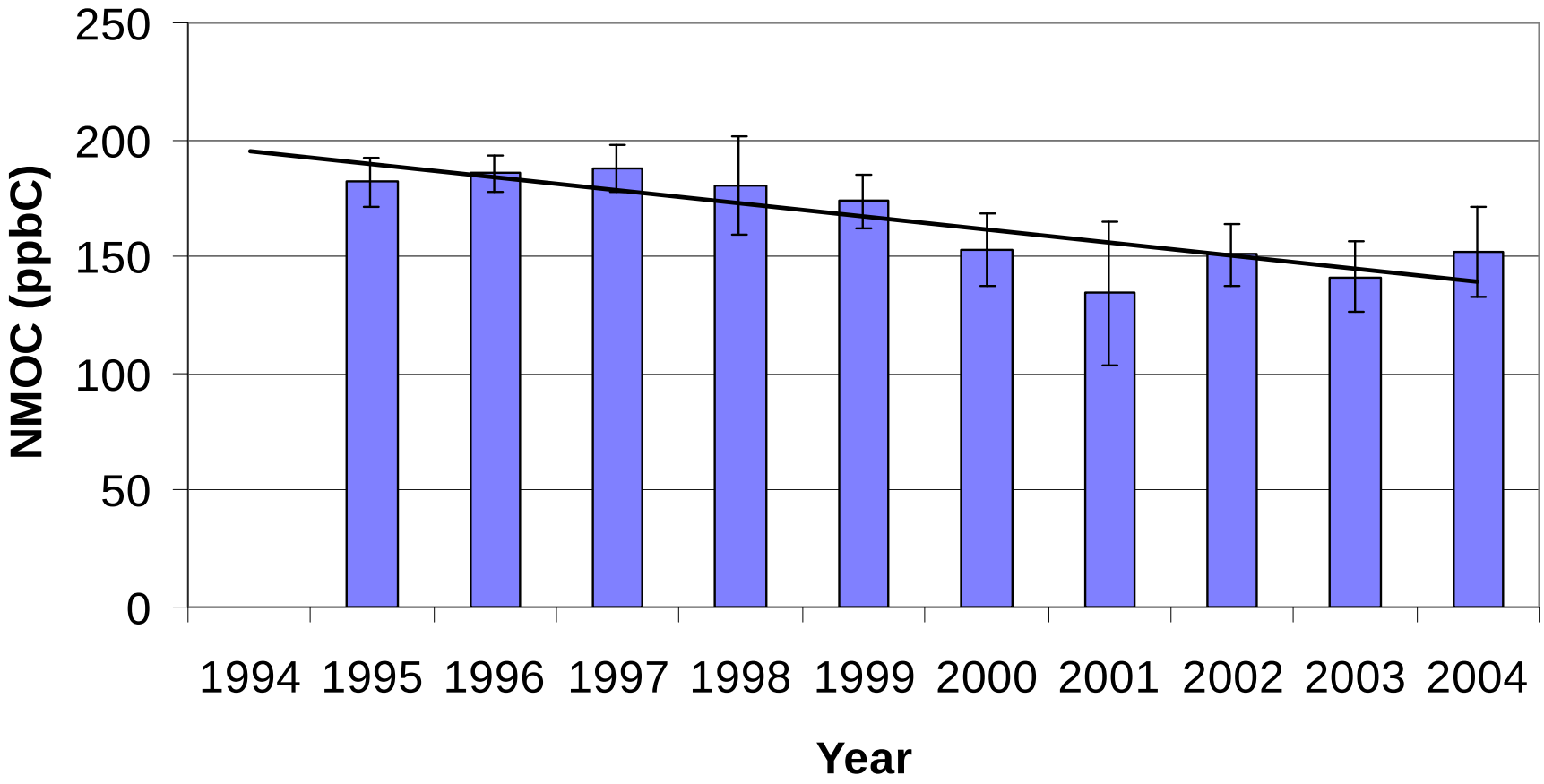


Morning NMOC decline: 8.2 ppbC/year (~66 ppbv over period)



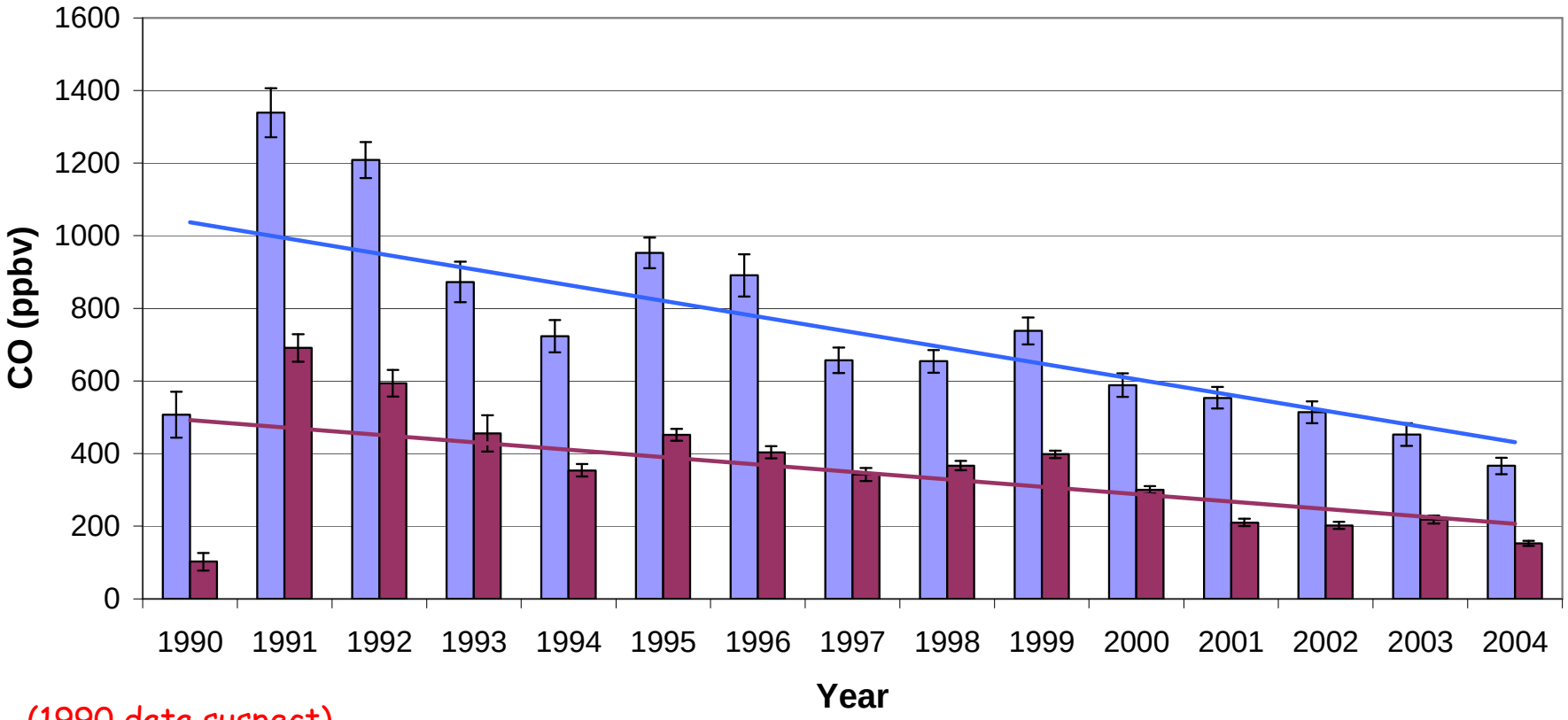
Morning NMOC decline: 11.5 ppbC/year (~115 ppbv over period)

Mean Morning NMOC Parlier



Morning NMOC decline: 5.1 ppbC/year (~51 ppbv over period)

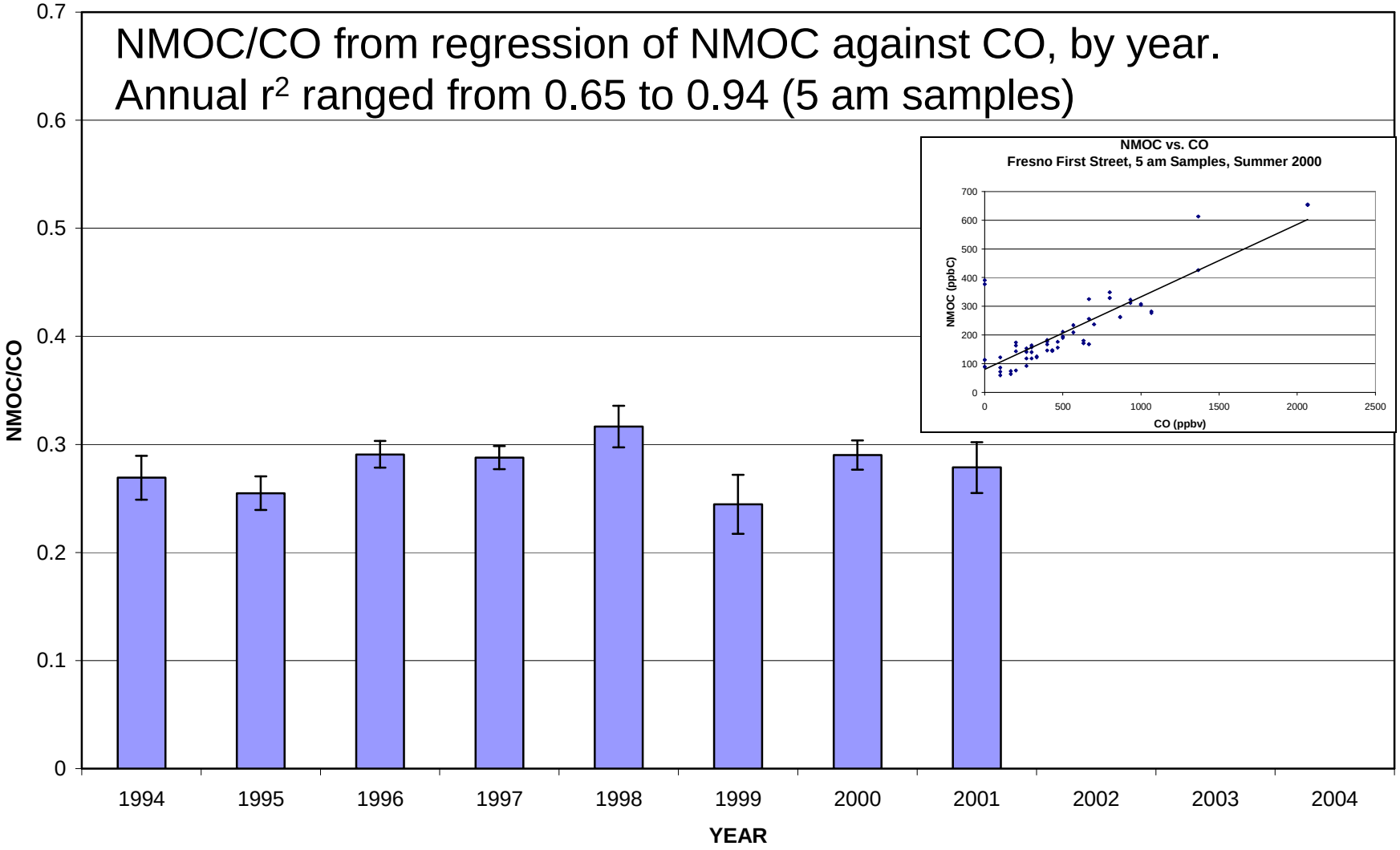
Fresno First Street - Mean CO on Top 60 Subregional High-Ozone Days
Morning (5 am - 11 am) and Mid-day (Time of 8-hour Ozone Max)



(1990 data suspect)

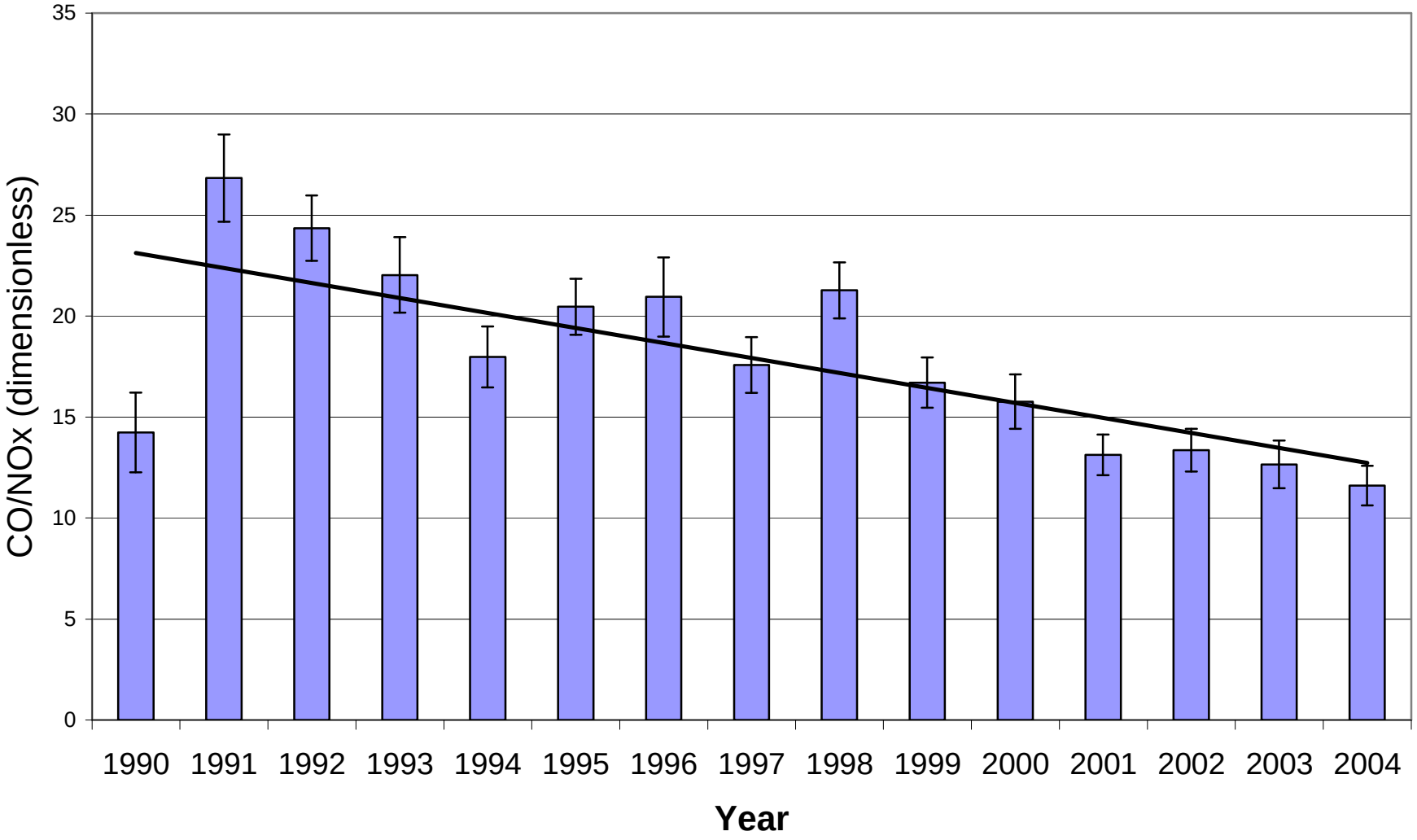
Morning CO decline: 43 ppbv/year (~650 ppbv over period)
Mid-day CO decline: 20 ppbv/year (~300 ppbv over period)

FRESNO



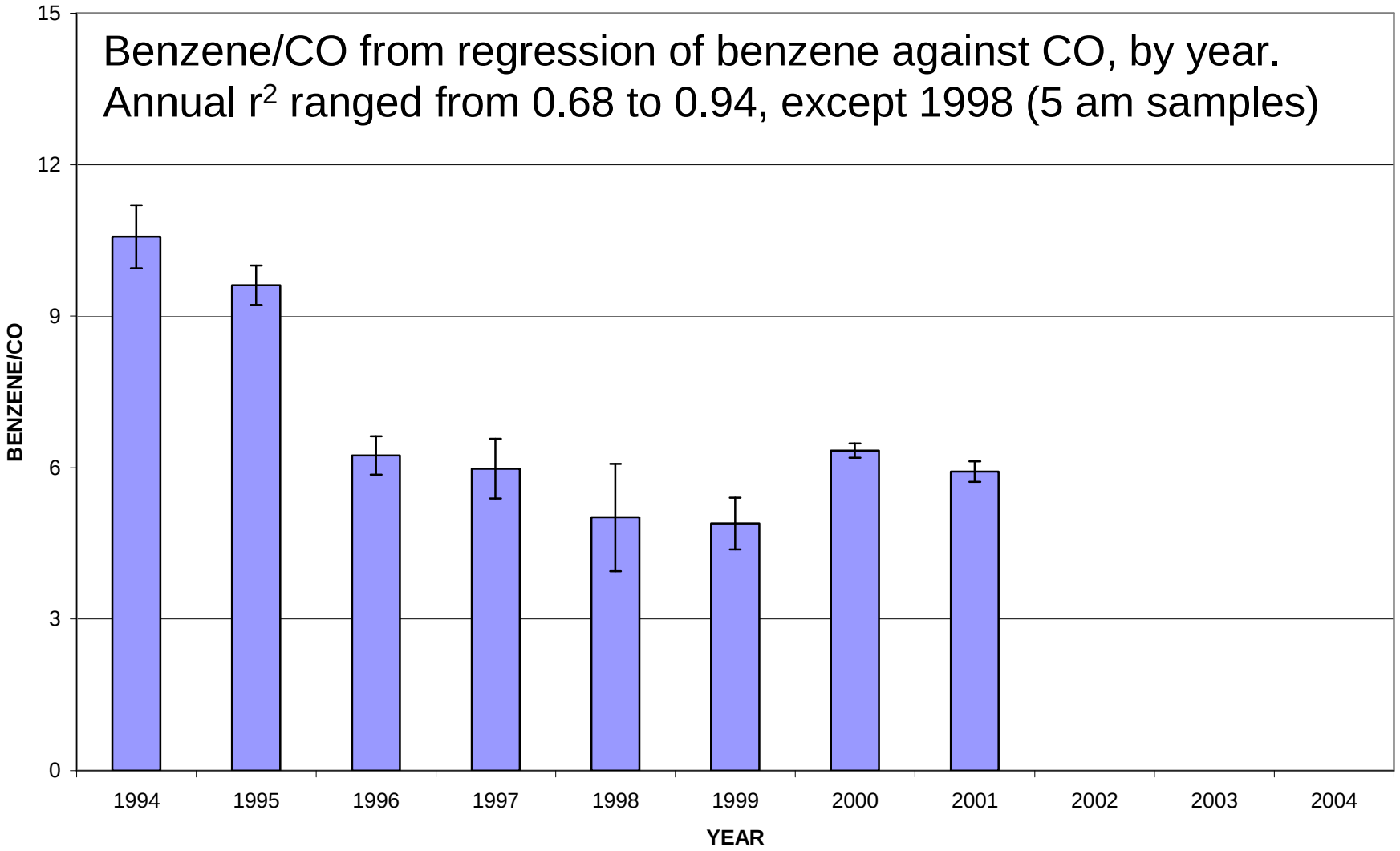
Similar results for Bakersfield and Sacramento Del Paso:
~0.3 ppbC NMOC per ppbv CO (some years differed)

Fresno First Street Morning CO/NOx



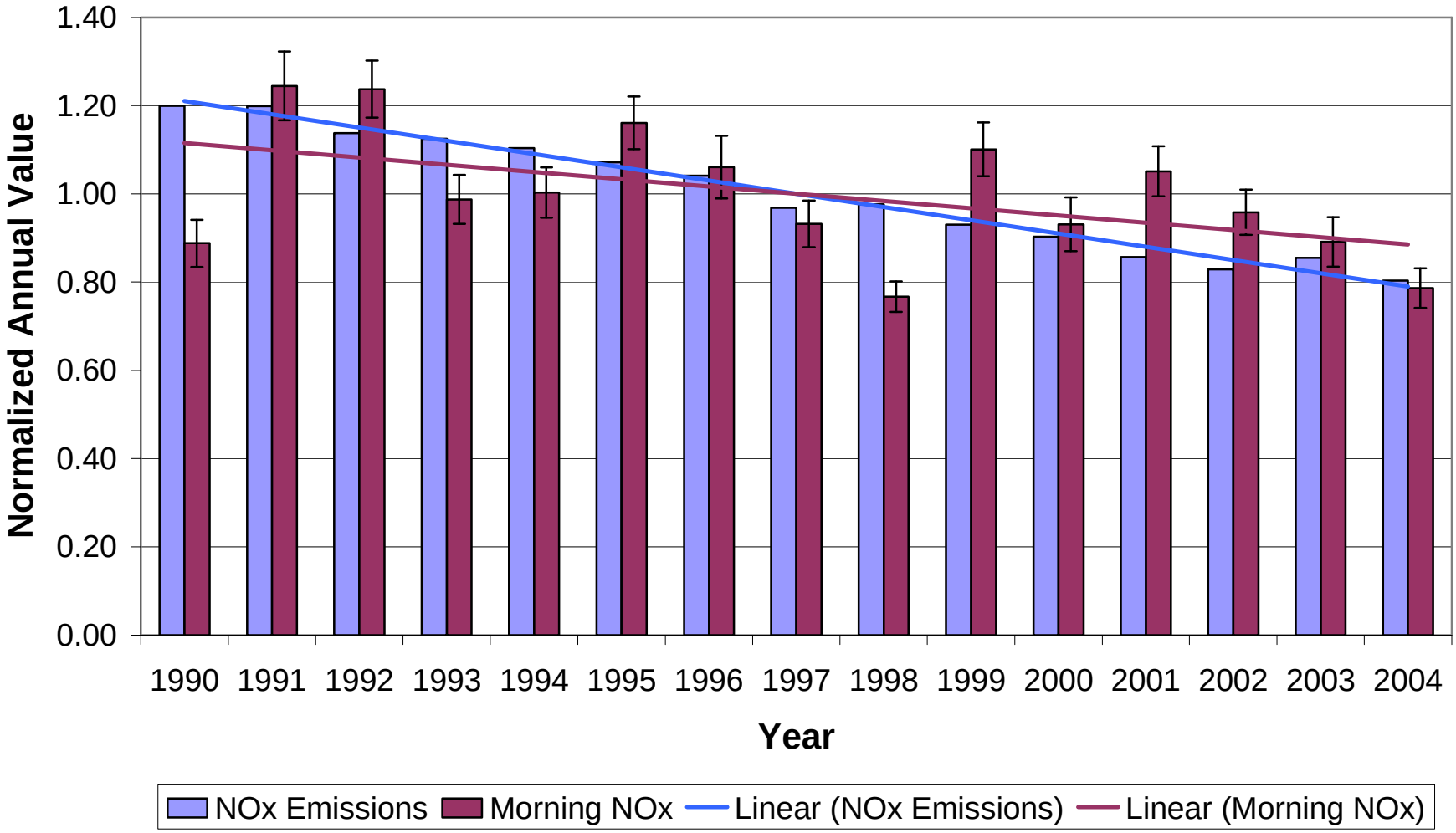
CO/NOx declines ➔ so does NMOC/NOx

FRESNO


Benzene/CO from regression of benzene against CO, by year.
Annual r2 ranged from 0.68 to 0.94, except 1998 (5 am samples)
BENZENE/CO
15
12
9
6
3
0
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004
YEAR

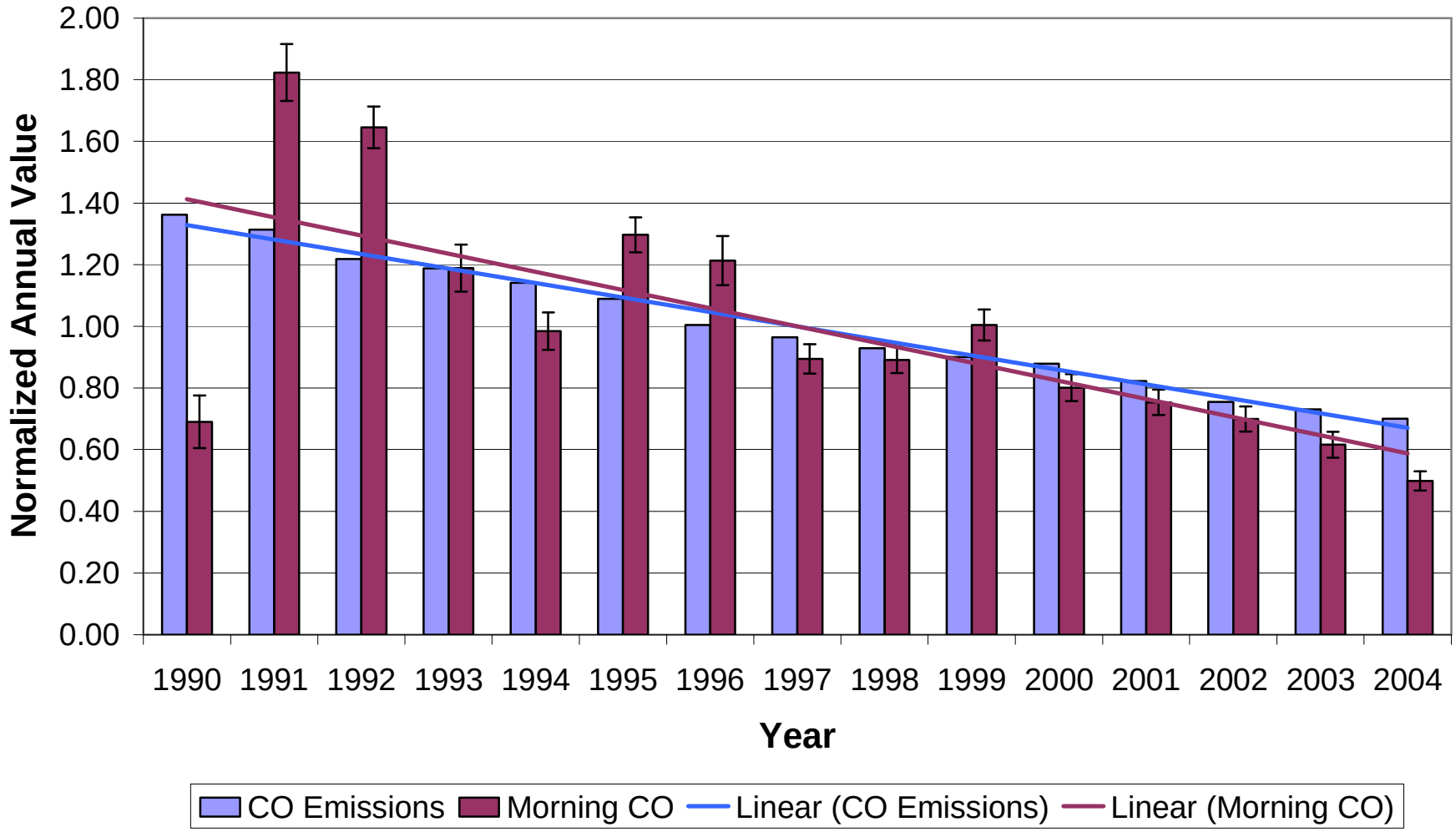
IV. Comparison of AQ Trends to County-Level Emission Trends

Fresno County NOx Emissions Compared With Morning NOx Concentrations at Fresno First Street



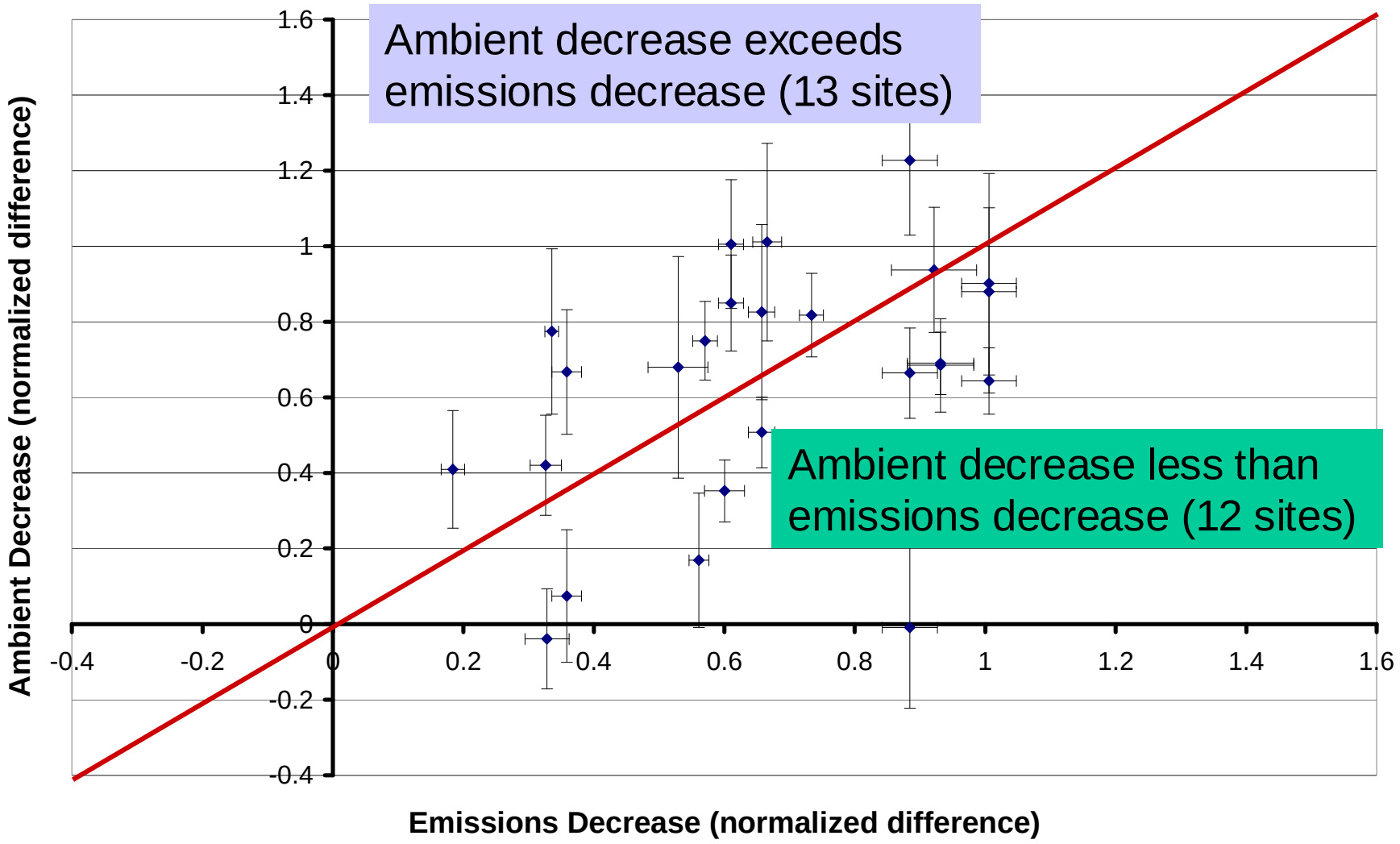
Emission trend (Δ 0.40) exceeds ambient trend (Δ 0.20)

Fresno County CO Emissions Compared With Morning CO Concentrations at Fresno First Street

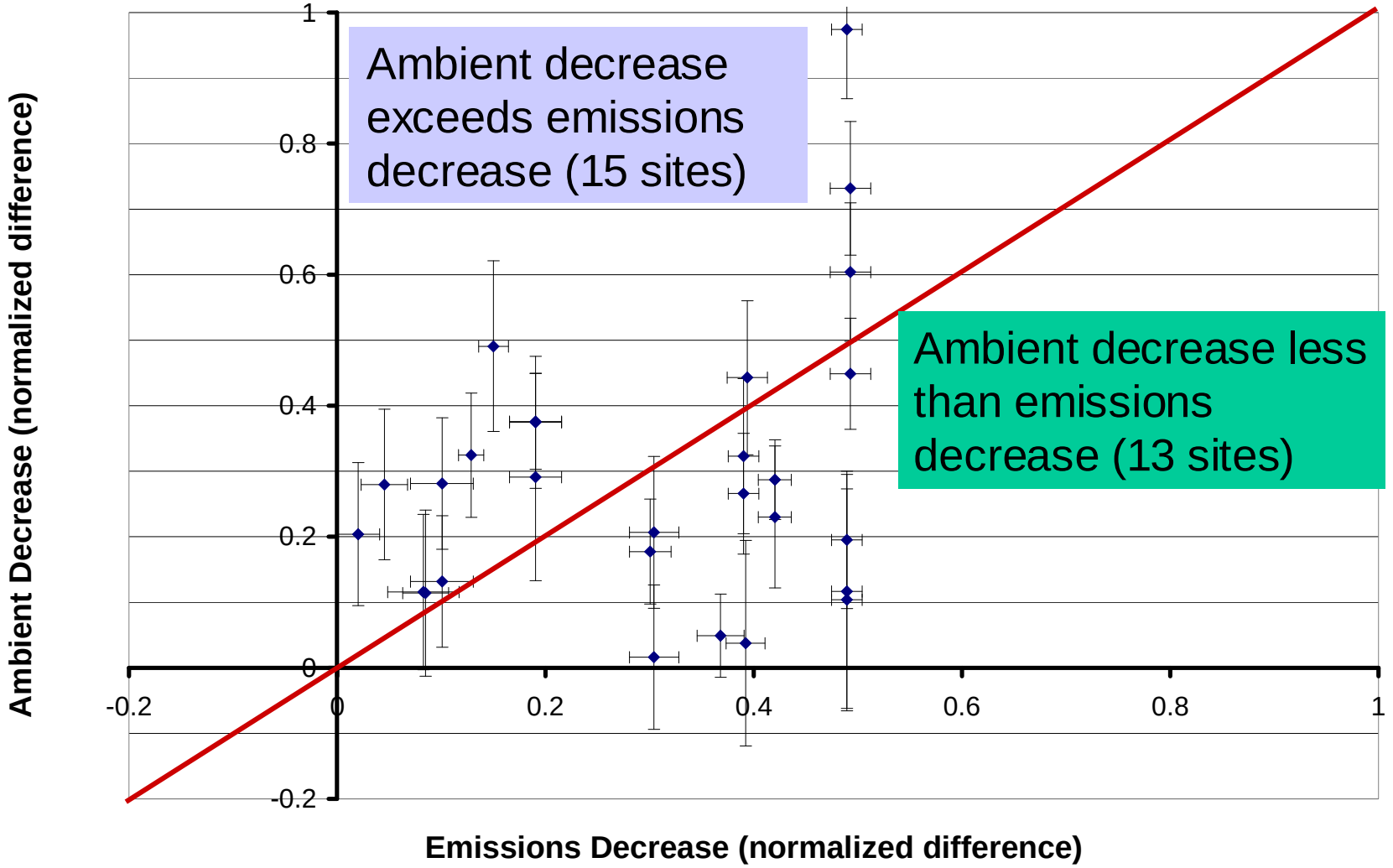


Ambient trend (Δ 0.80) exceeds emission trend (Δ 0.60)

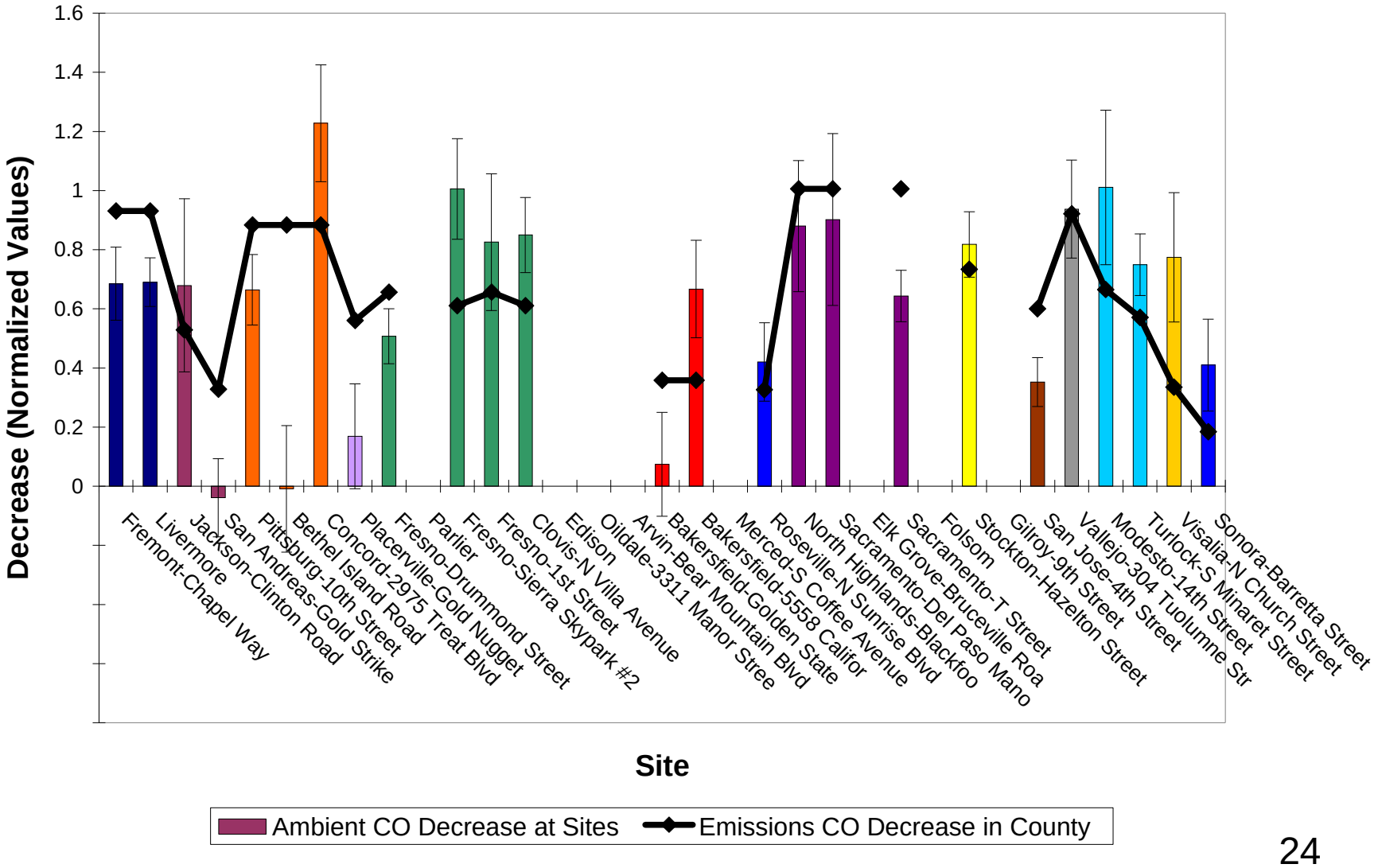
Ambient vs. Emissions Decrease for CO



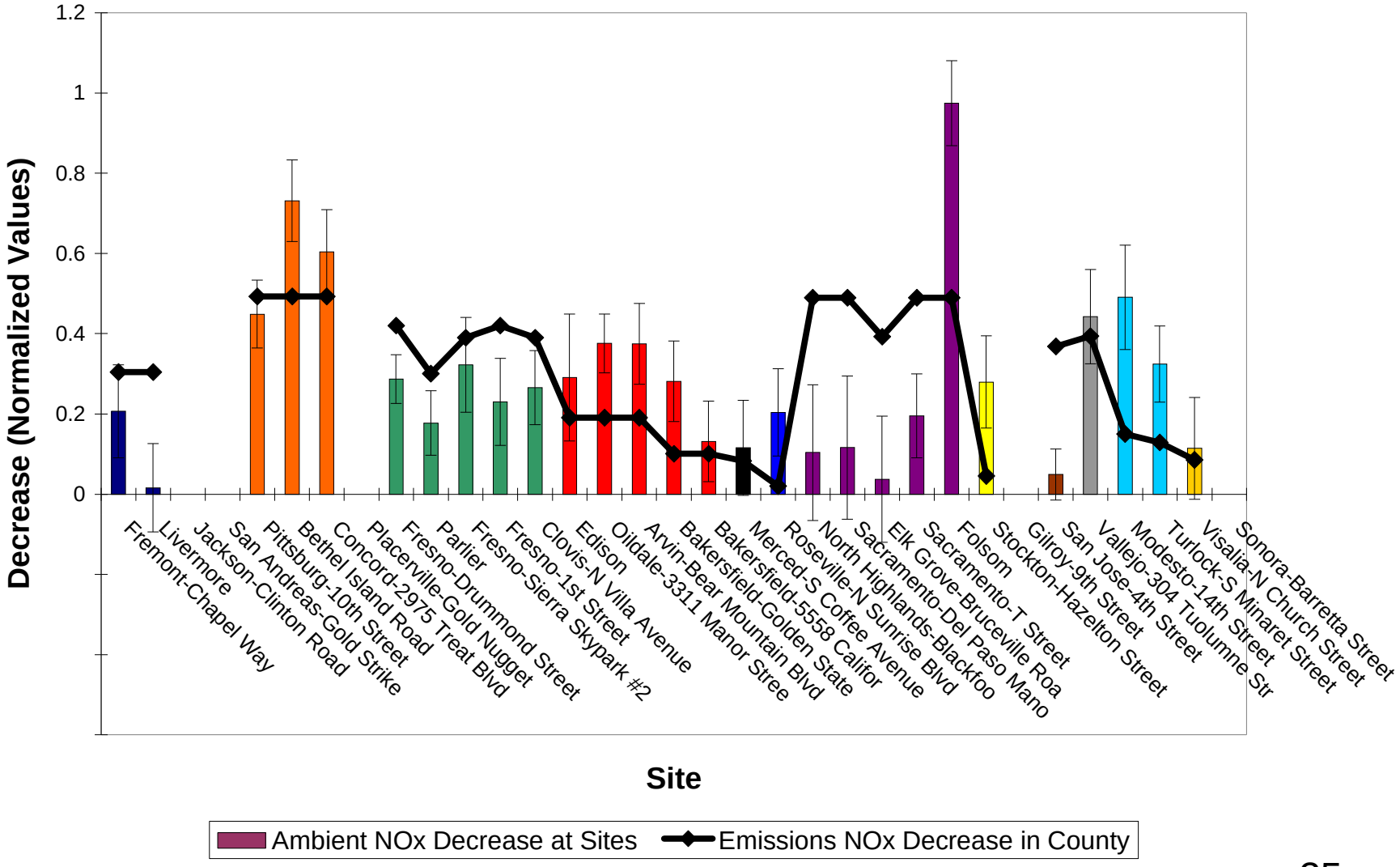
Ambient vs. Emissions Decrease for NOx



Ambient and Emissions Decreases for CO



Ambient and Emissions Decreases for NOx

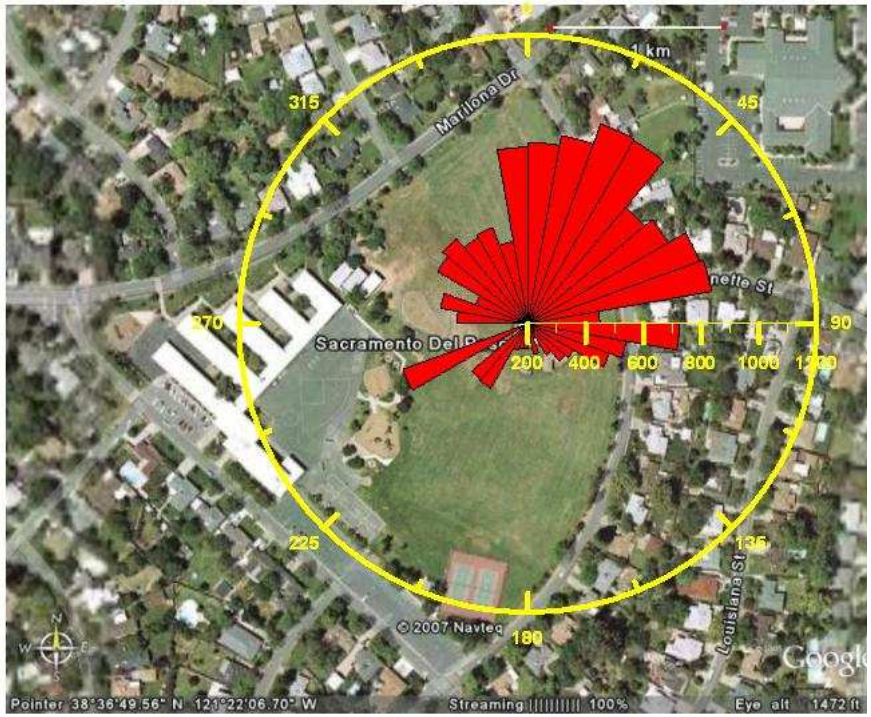


What Did We Learn?

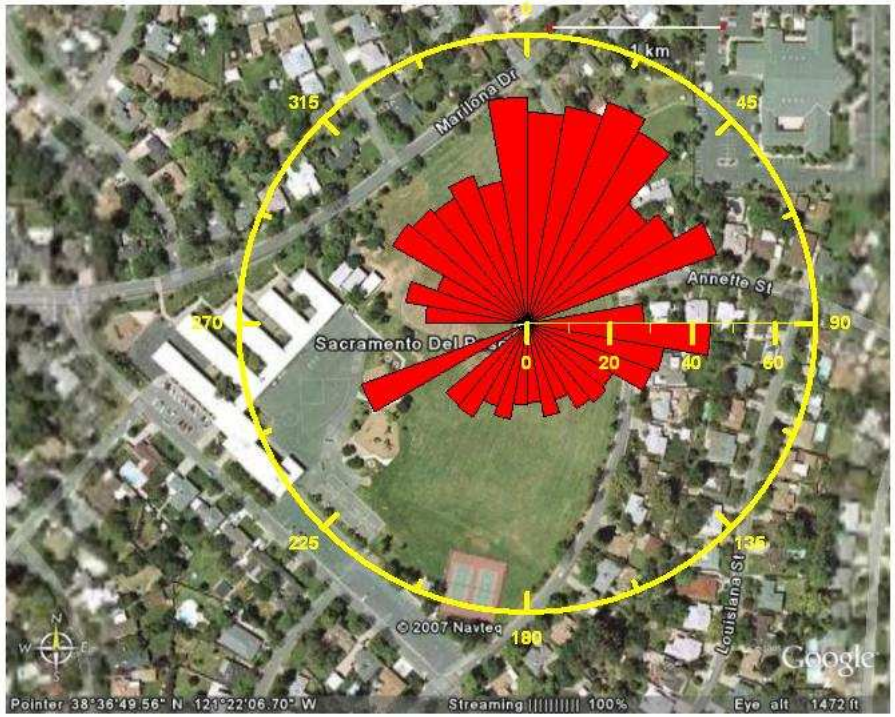
- On average, ambient precursor decreases are comparable to county-level emissions decreases
- There is a possibility that emission decreases are overestimated or underestimated for some counties
- Confirmation requires comparison of site trends to spatially-resolved emission trends (Phase II)

V. Spatial Variations of Ozone Precursors

Sacramento Del Paso Mean Morning Concentrations



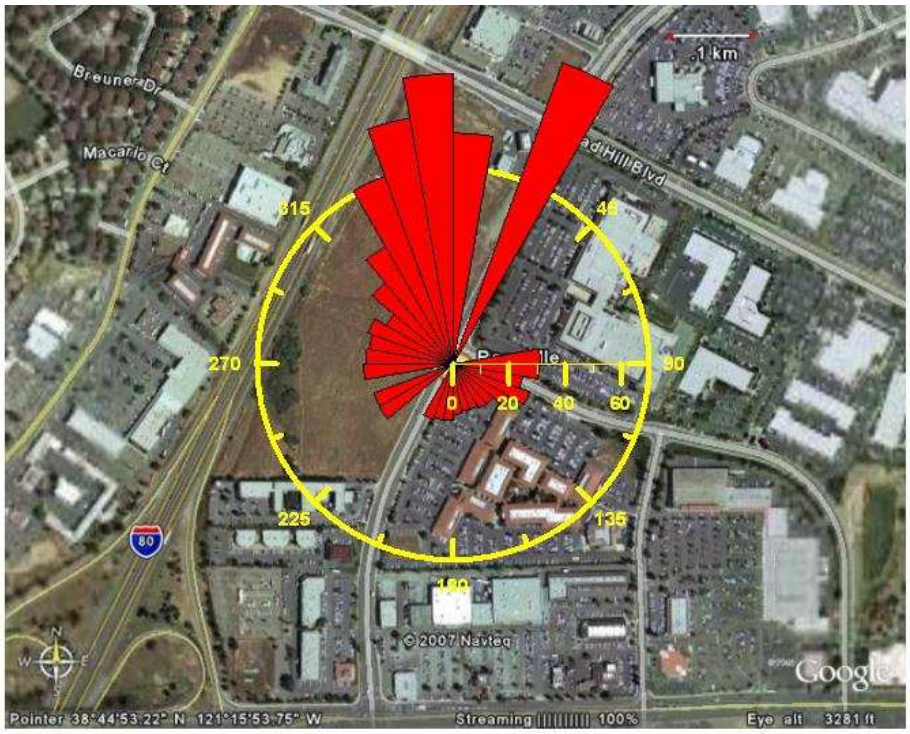
CO



NOx

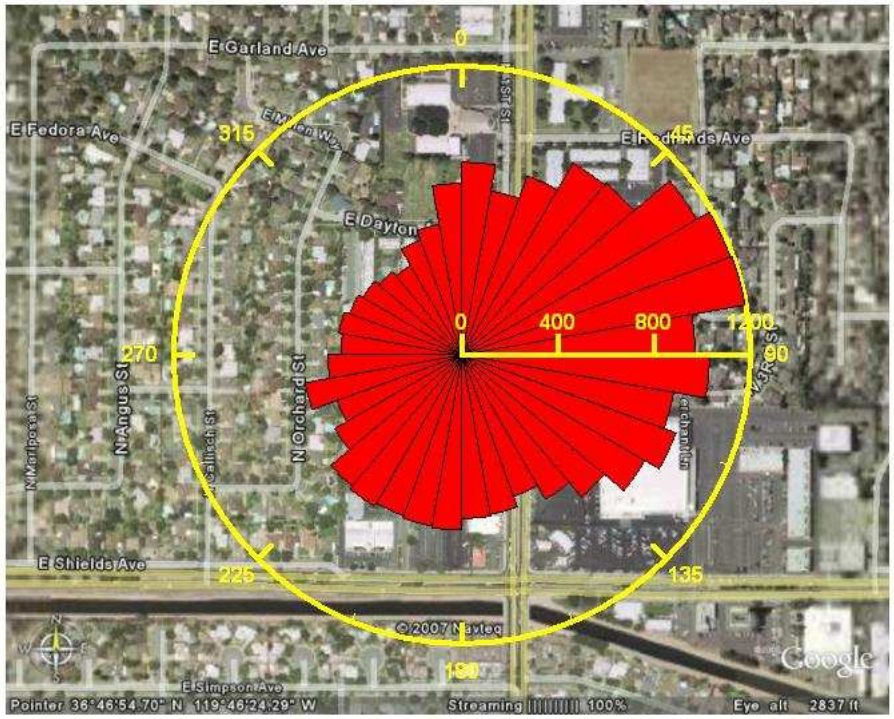
Roseville Mean Morning Concentrations

CO

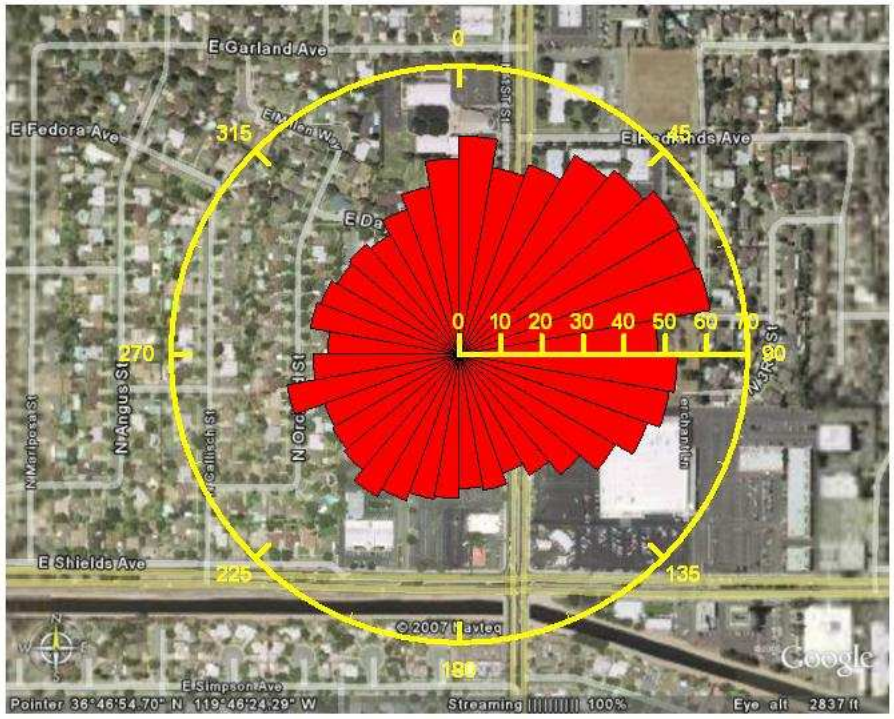


NOx

Fresno 1st St Mean Morning Concentrations

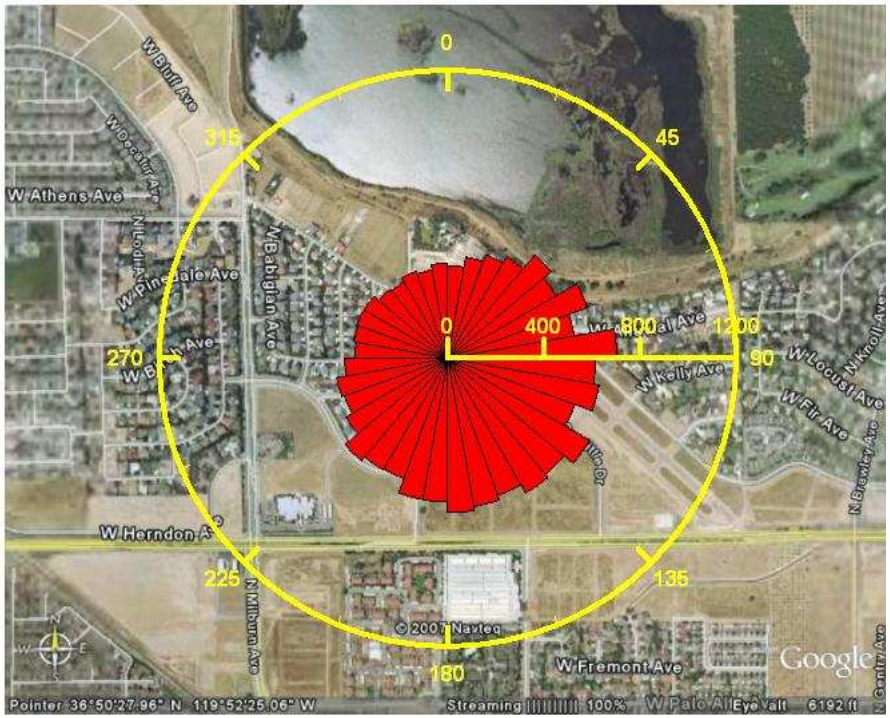


CO

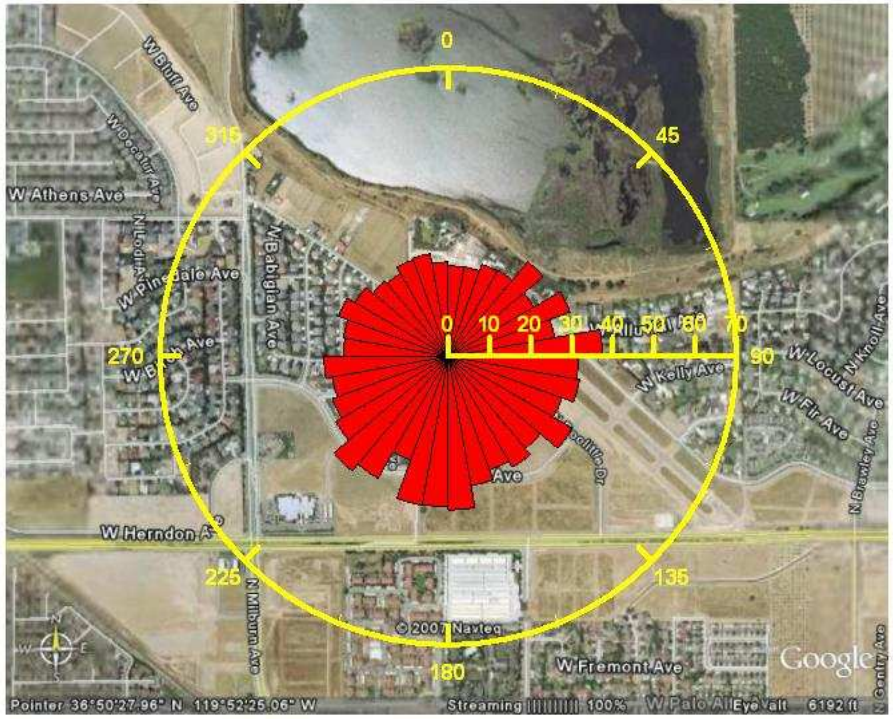


NOx

Fresno Sierra Skypark Mean Morning Concentrations



CO



NOx

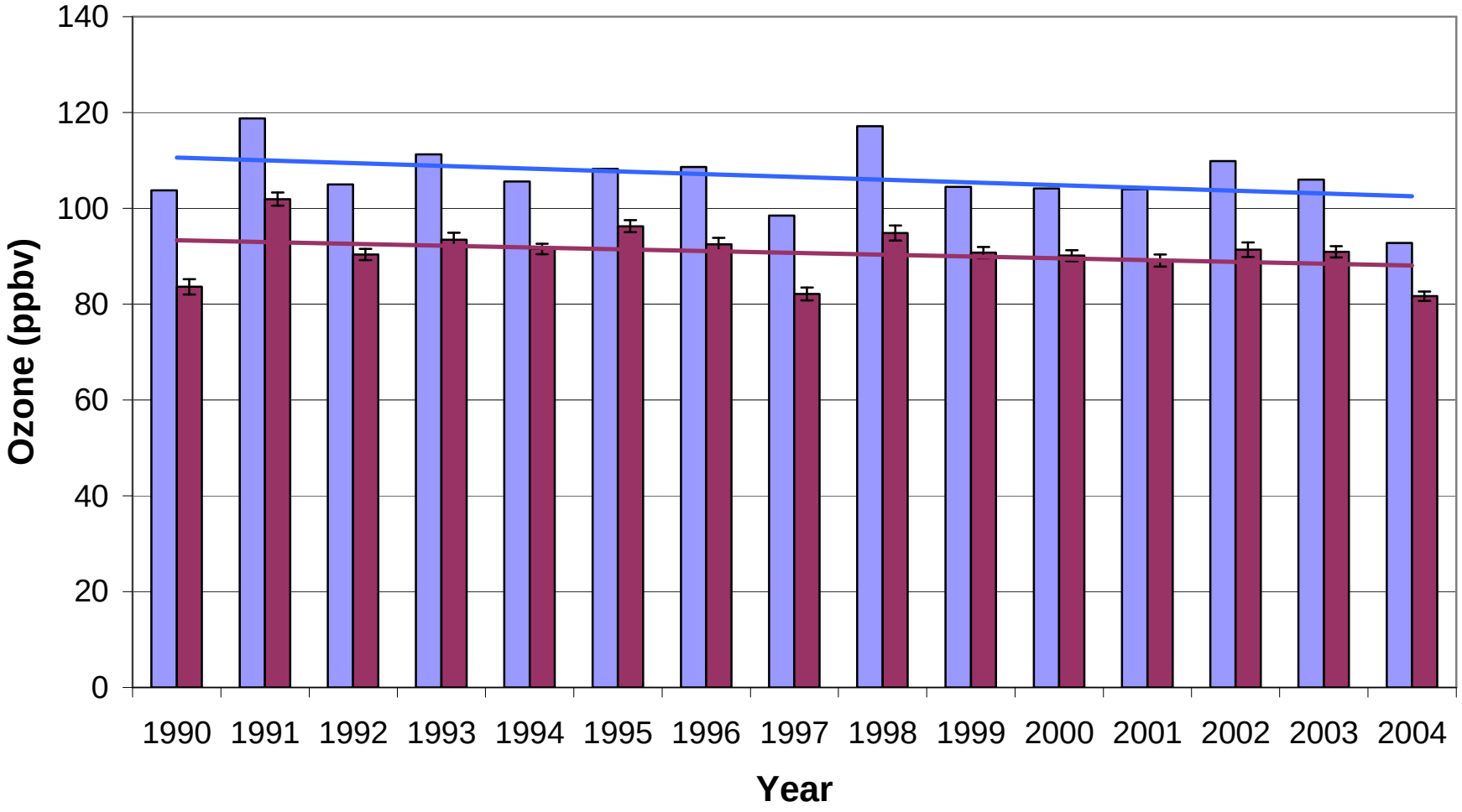
Phase II AQ vs. Emissions

- Directional variations of primary species AQ concentrations imply significant local influences
- Comparison of site primary species AQ trends to emission inventory trends can be improved by using gridded inventories
- The Phase II comparisons will permit more robust conclusions about the differences between site and emission trends – eliminate the mismatch between spatial scales (replace county-level emissions with emissions from local zones of influence)
- Potential limitation is accuracy of gridding

Questions and Comments on Primary Species Phase I Findings and Phase II Objectives

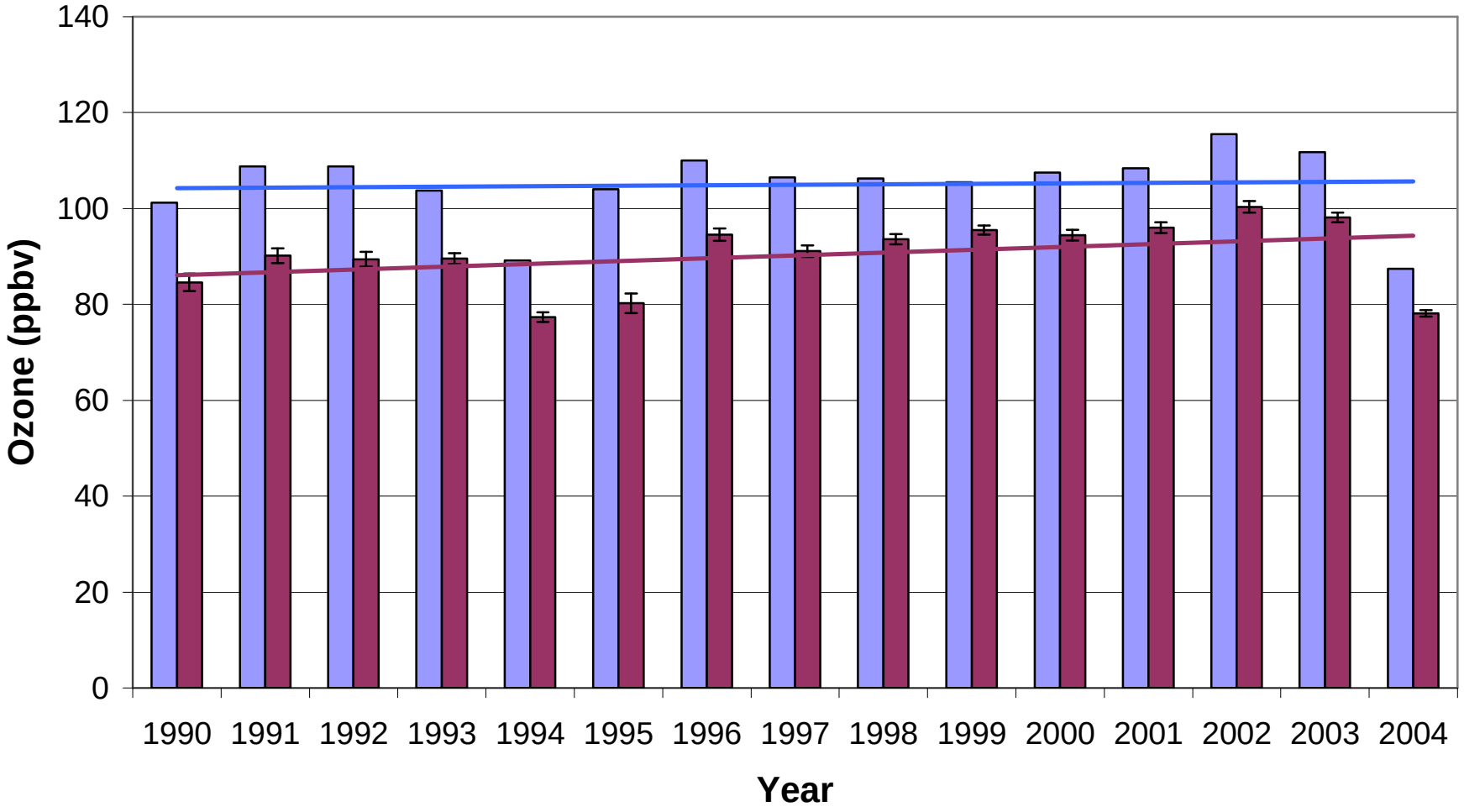
VI. What Are the Ozone Trends?

Fresno First Street -- Annual 4th-Highest 8-Hour Ozone and Mean of Top 60 Subregional Days

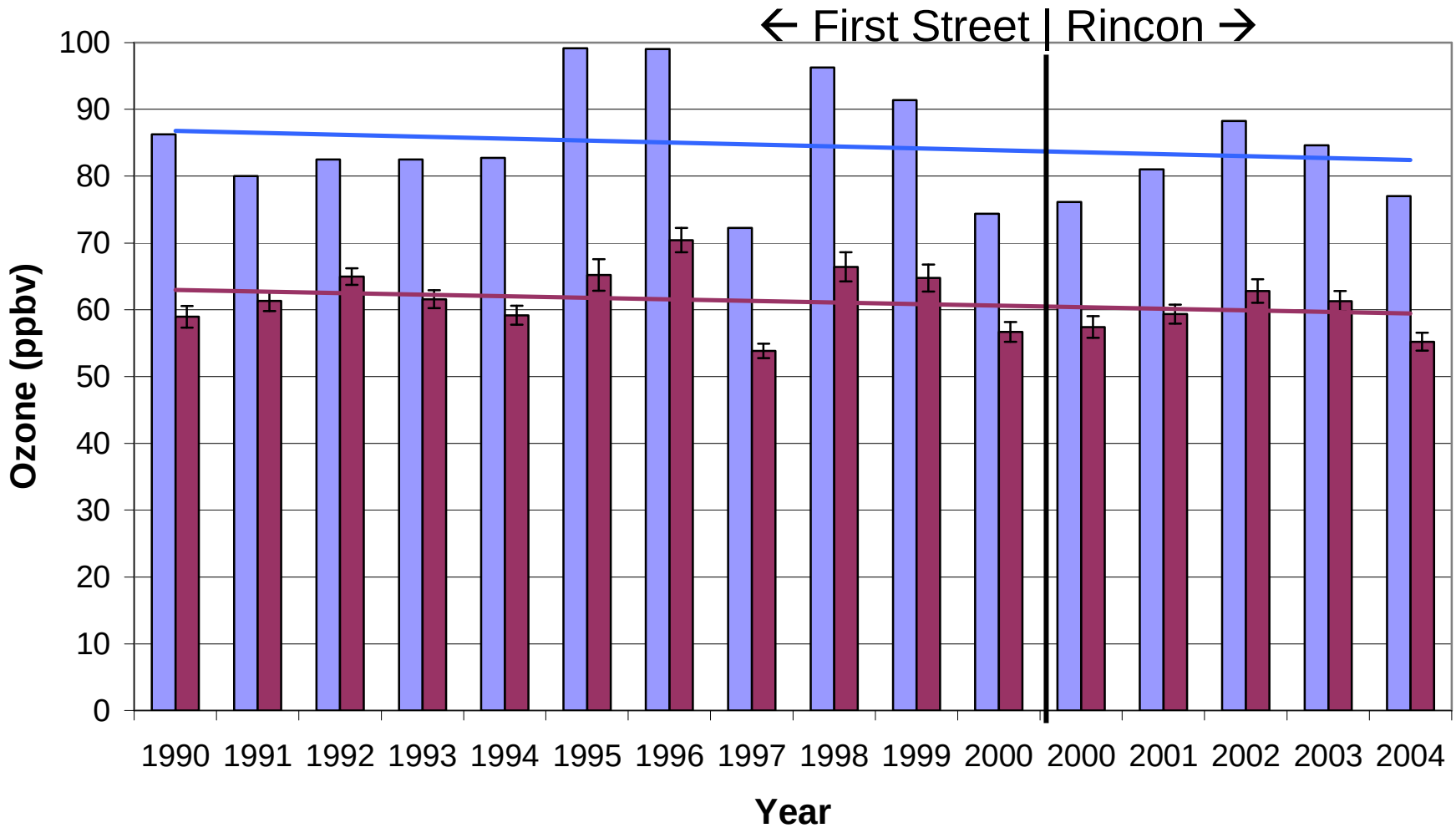


Annual 4th max decline: 0.58 ppbv/year (~9 ppbv over period)
Mean Top 60 decline: 0.38 ppbv/year (~6 ppbv over period)

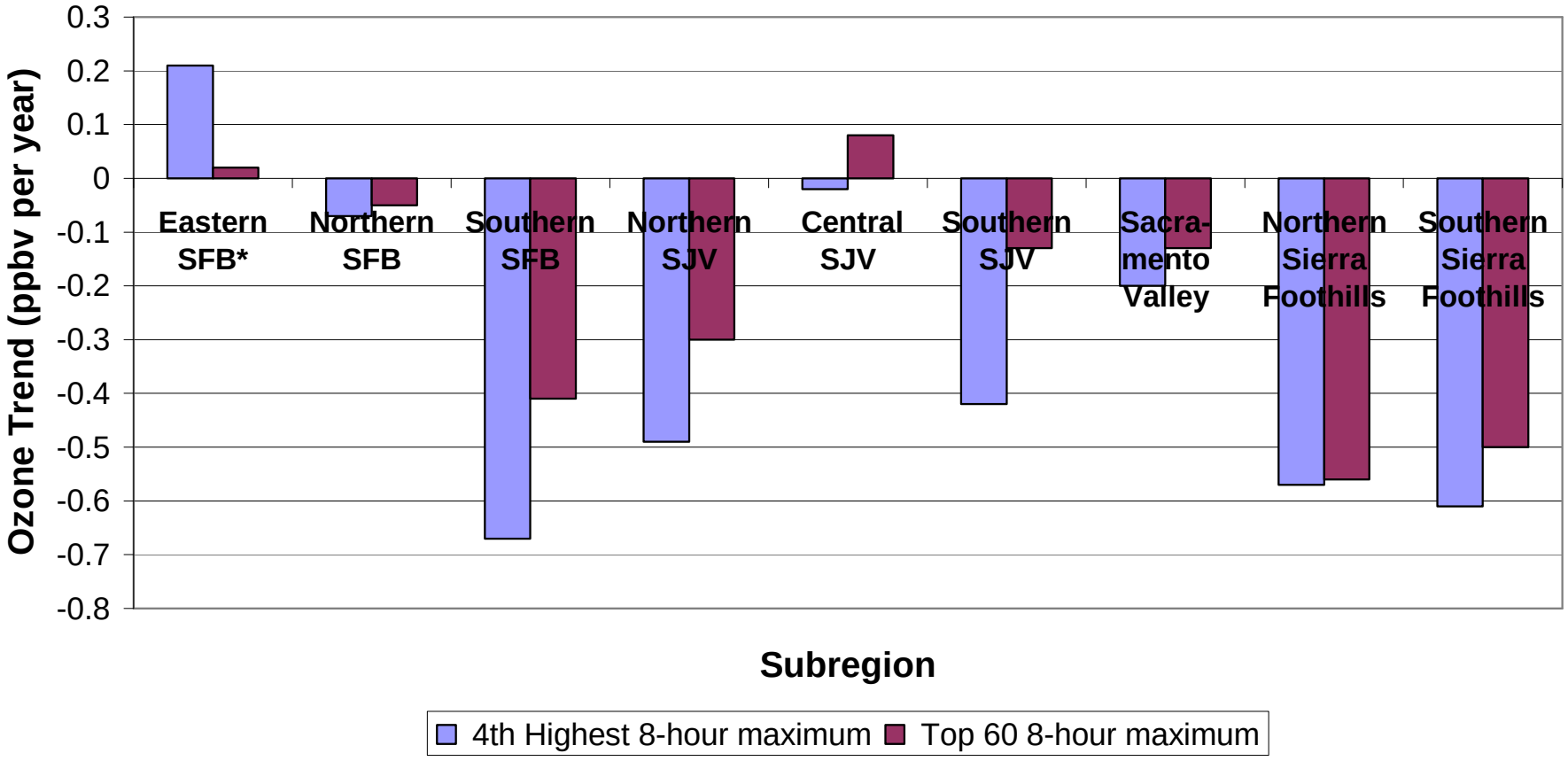
Parlier -- Annual 4th-Highest 8-Hour Ozone and Mean of Top 60 Subregional Days



Livermore Annual 4th-Highest 8-Hour Ozone and Mean of Top 60 Subregional Days



Ozone Trends in Subregions - Medians of Site Trends



* Livermore 1st St only

VII. Meteorological Classification

Why Examine Meteorological Data?

Meteorological information may permit more complete reconciliation of ambient ozone trends with precursor and emissions trends.

Phase I. Uses meteorological information to split days into groups with different meteorological characteristics. Initial evidence indicates that ozone trends vary by site, subregion, met type.

Phase II. More detailed analyses.

Met Classification*:

1. Principal component analysis (PCA) of regional-scale met variables
2. K-means clustering of PCs

* ~~Trend adjustment~~
  Forecasting
  ~~Interbasin transport~~

PCA applied to all days of all years from 1990 to 2004 (n = 5480** days)
Clustering applied to all ozone-season days (n = 2790 days)

** 5441 with pressure gradient data; 4202 with 850 mb data

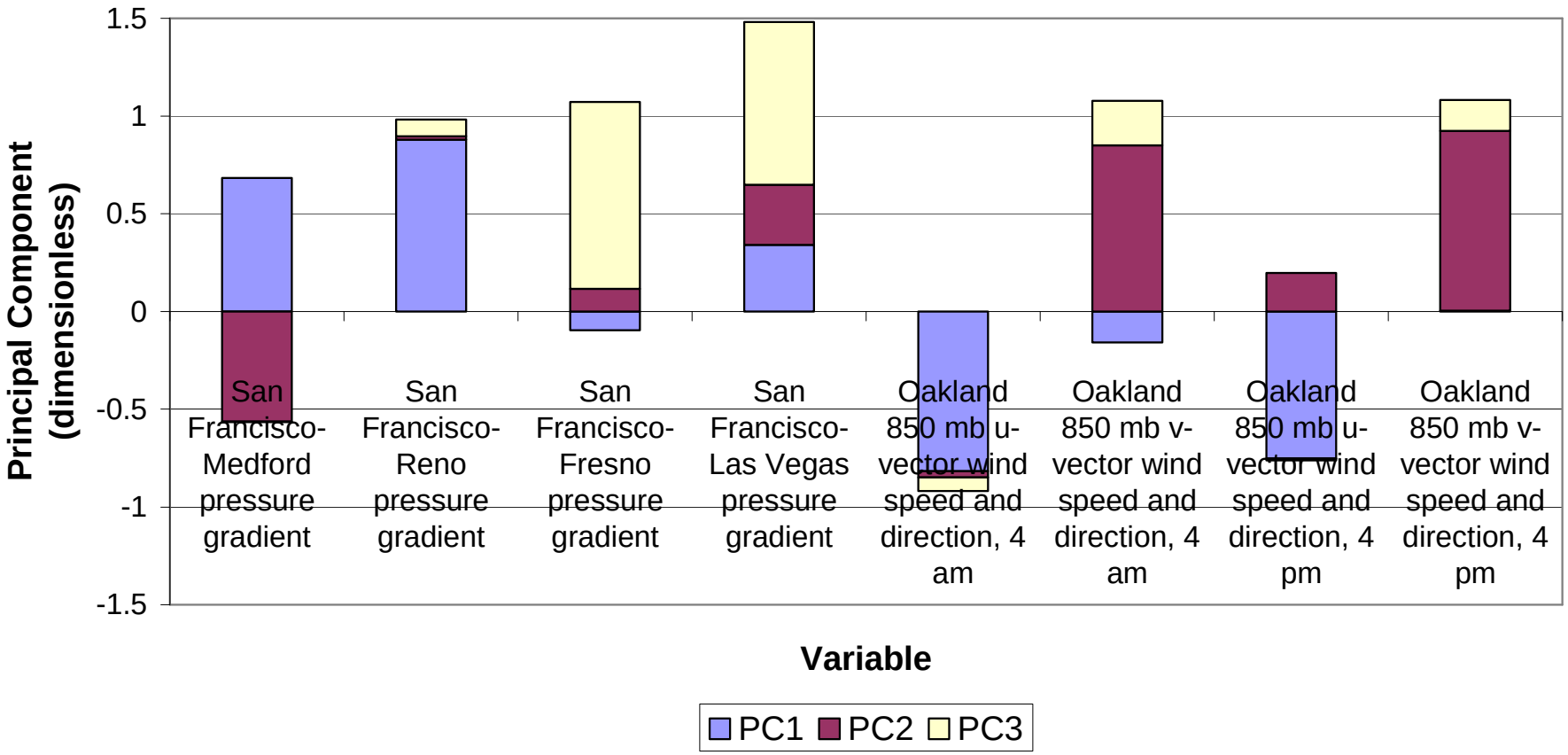
PCA of Regional-Scale Variables

San Francisco-to-Medford sea-level pressure gradient, daily average
San Francisco-to-Reno sea-level pressure gradient, daily average
San Francisco-to-Fresno sea-level pressure gradient, daily average
San Francisco-to-Las Vegas sea-level pressure gradient, daily average

Oakland 850 mb vector component (u) wind speed and direction at 4 am
Oakland 850 mb vector component (v) wind speed and direction at 4 am
Oakland 850 mb vector component (u) wind speed and direction at 4 pm
Oakland 850 mb vector component (v) wind speed and direction at 4 pm

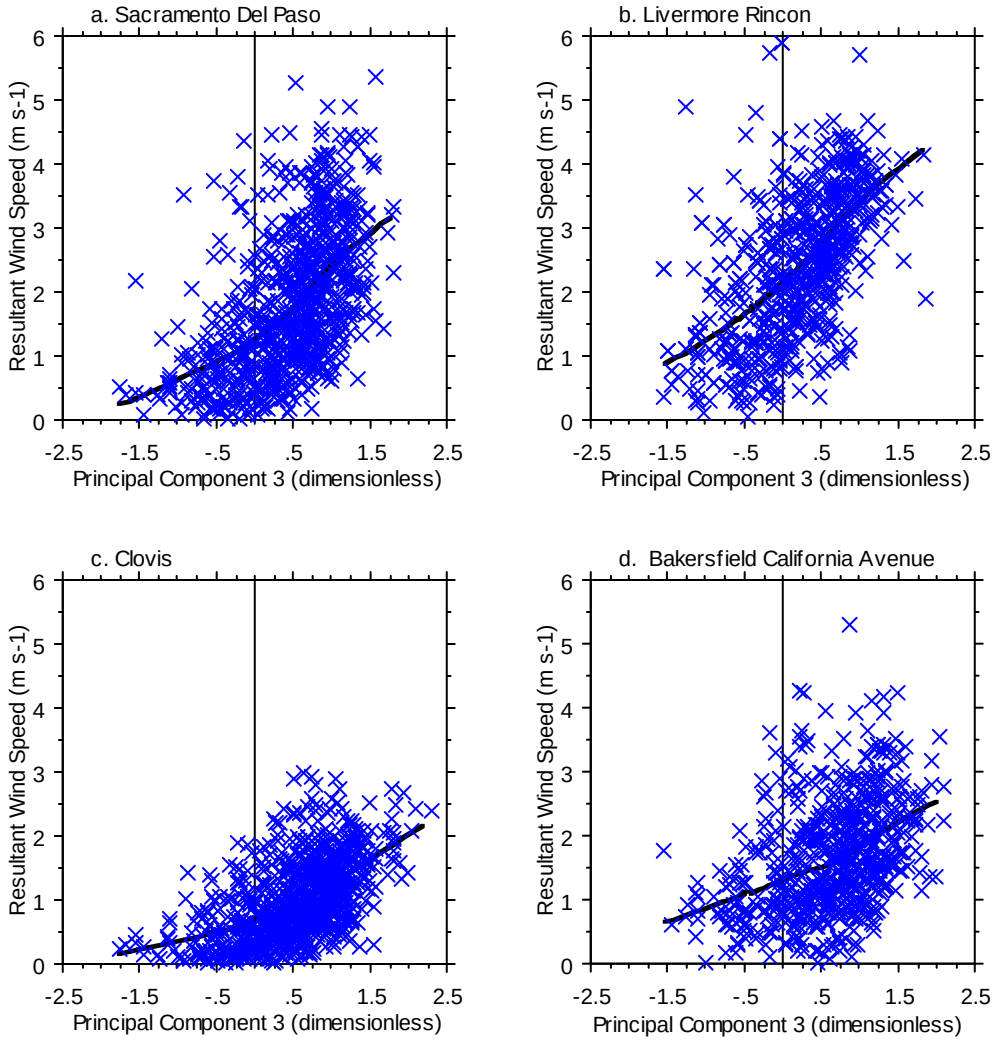
Oakland 850 mb temperature and height at 4 am
Oakland 850 mb temperature and height at 4 pm

PCA - Regional Scale Meteorological Variables



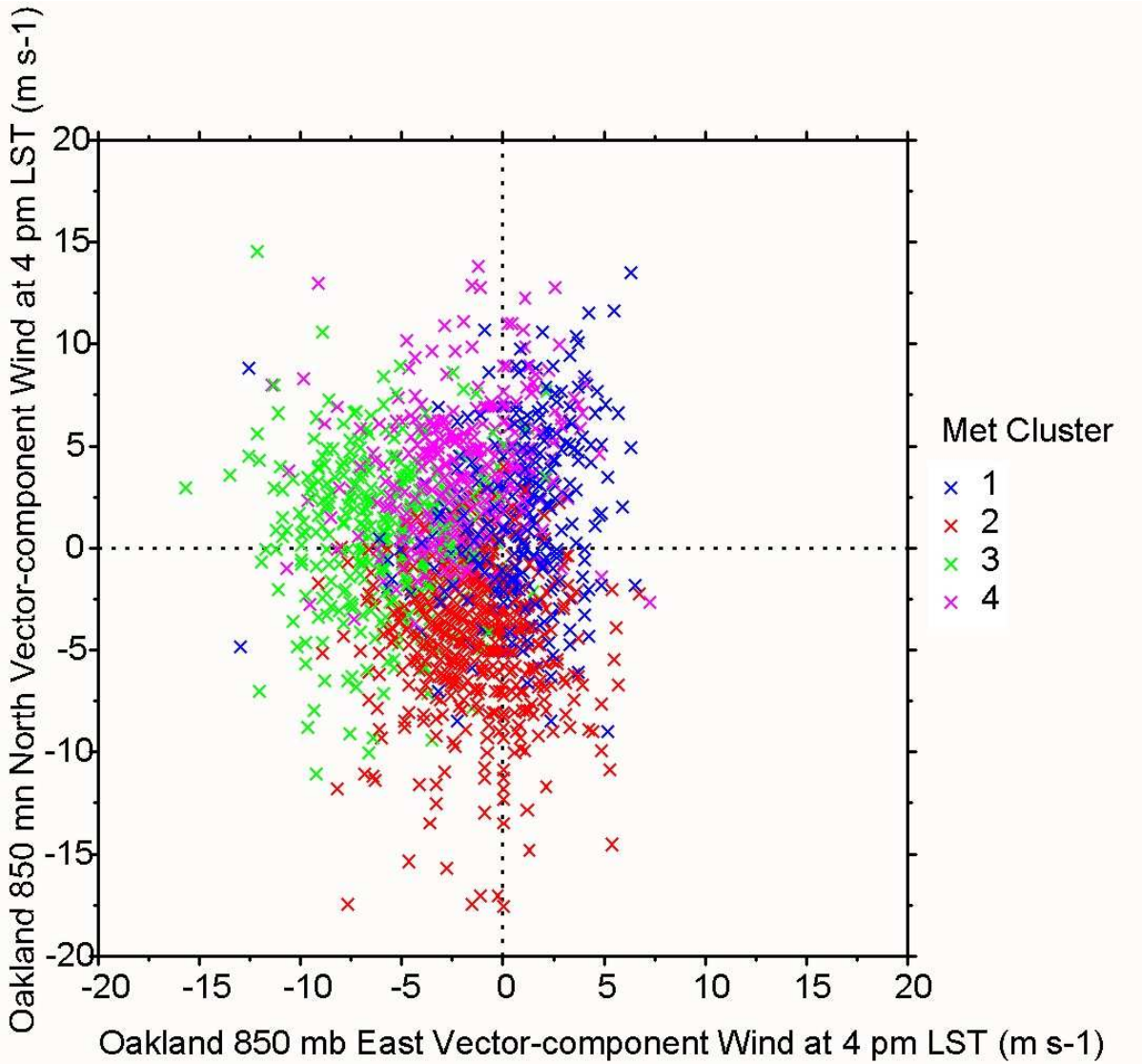
Three PCs explain 80% of variance of eight variables

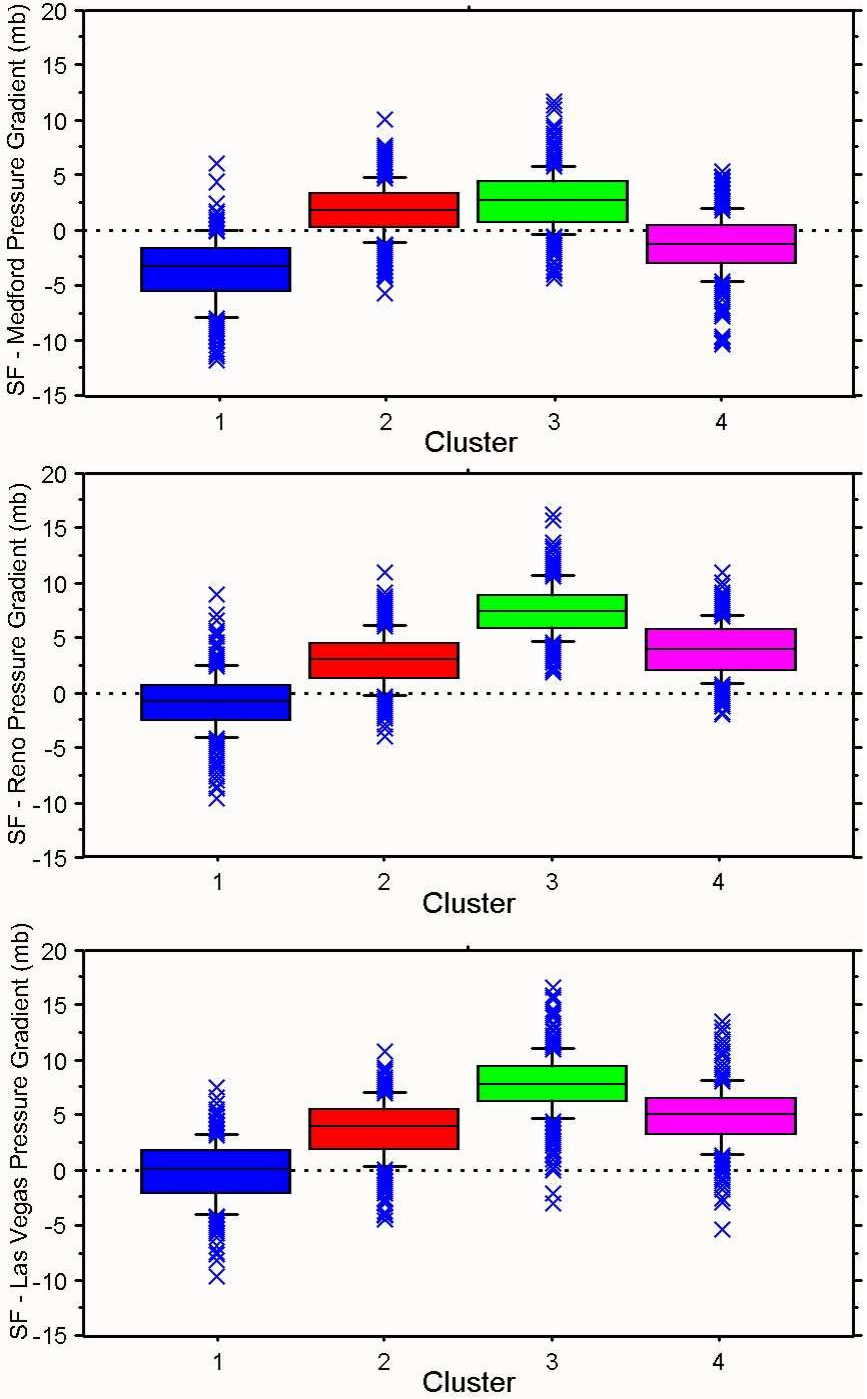
PC1 is westerly wind – PC2 is northerly wind – what is PC3?



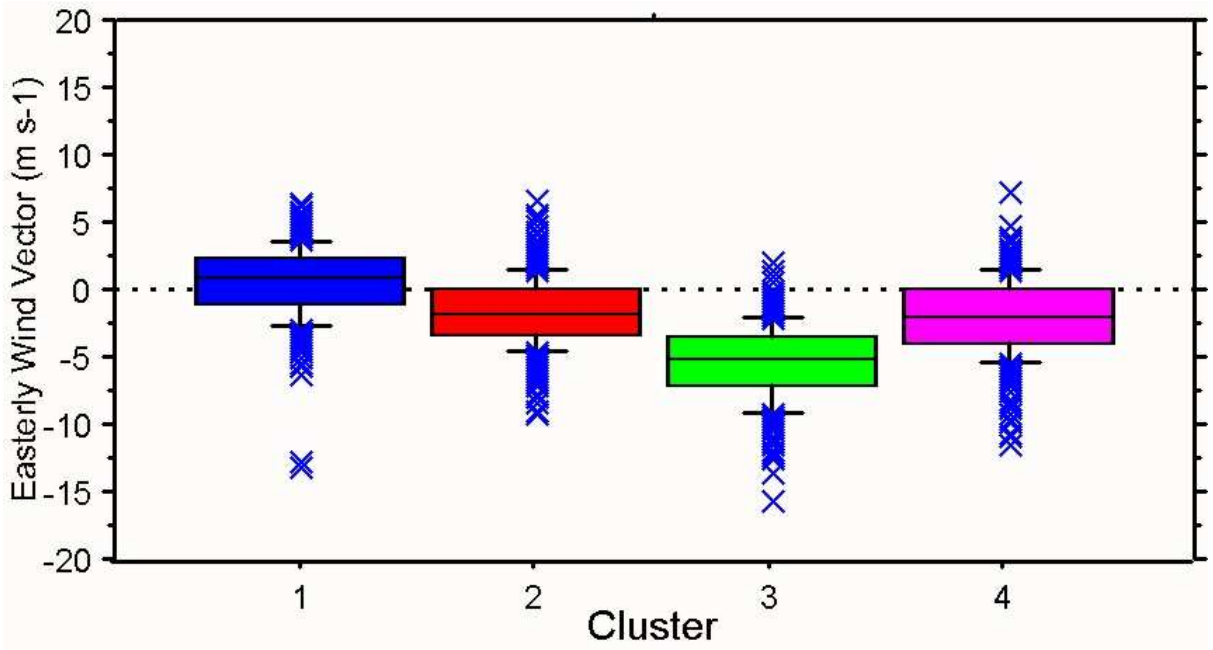
PC3 correlates with surface wind speeds – interpret as ventilation

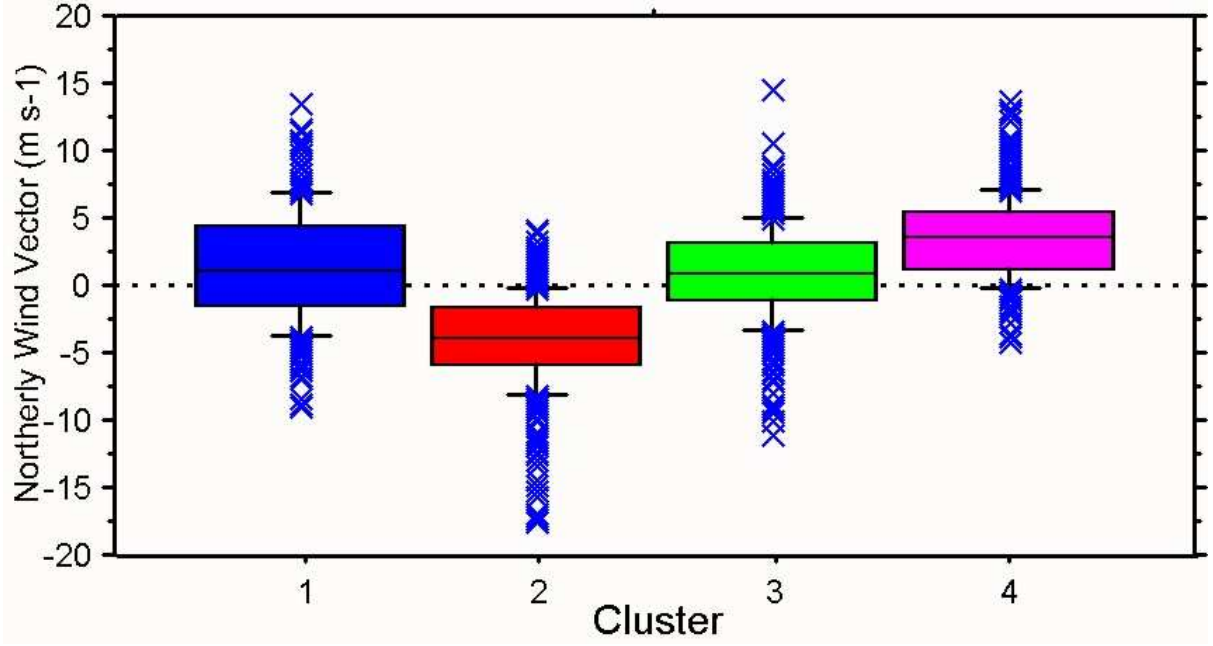
Split days into four groups using K-means clustering



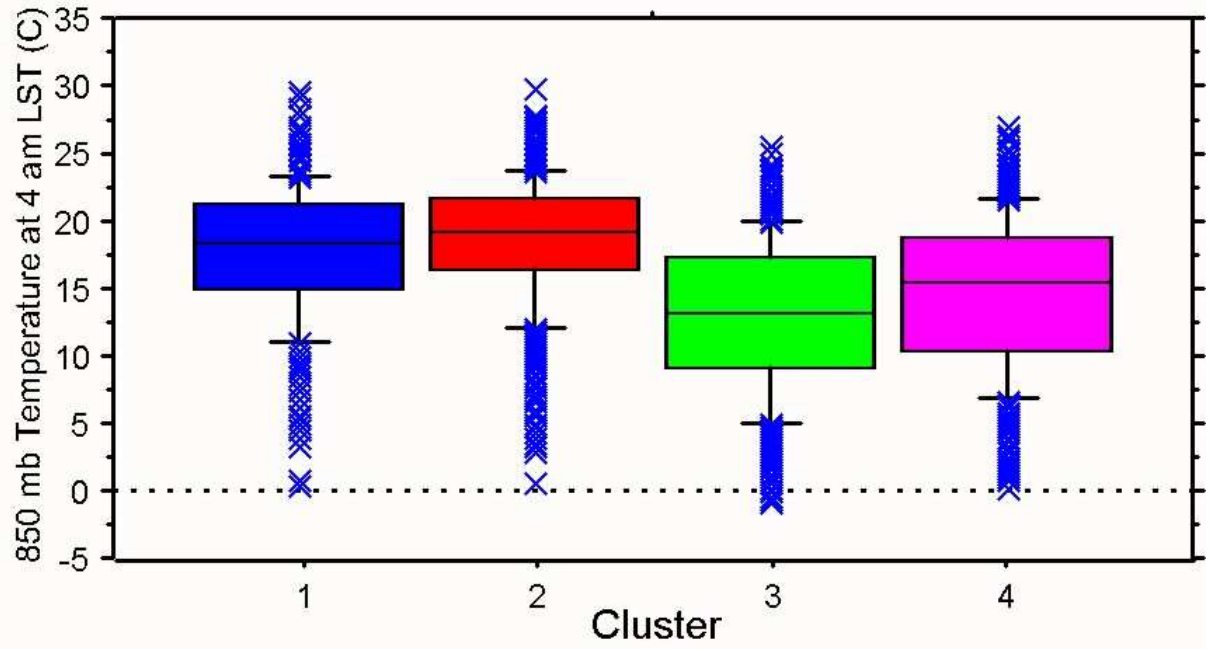


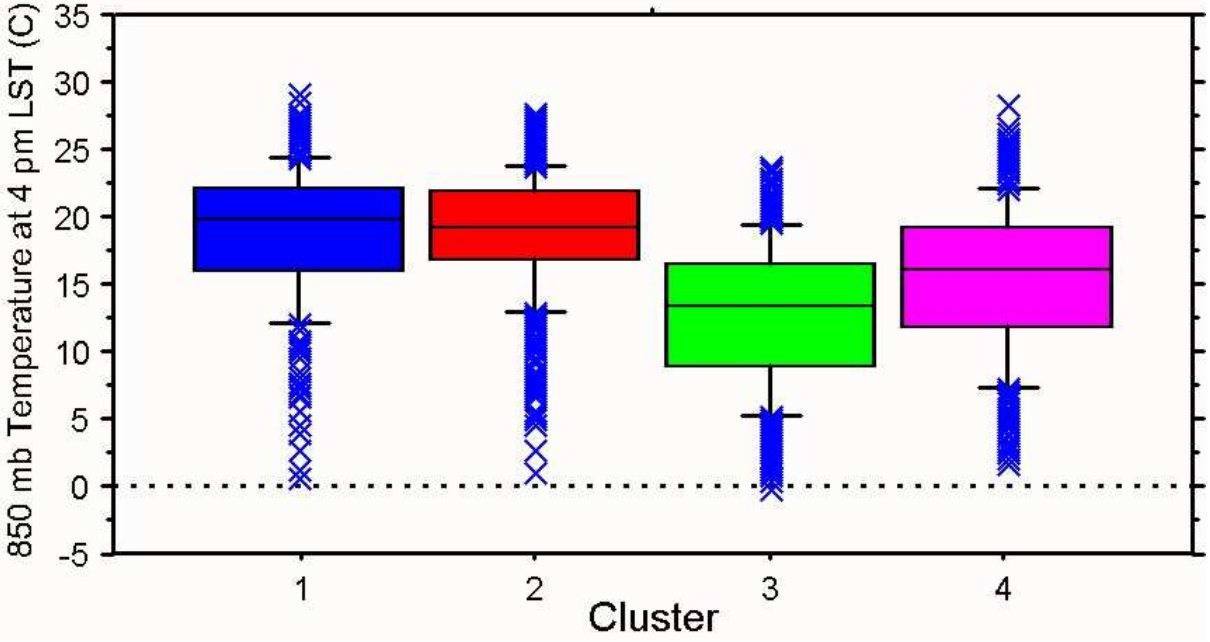
Clusters separate days into groups with different pressure gradients



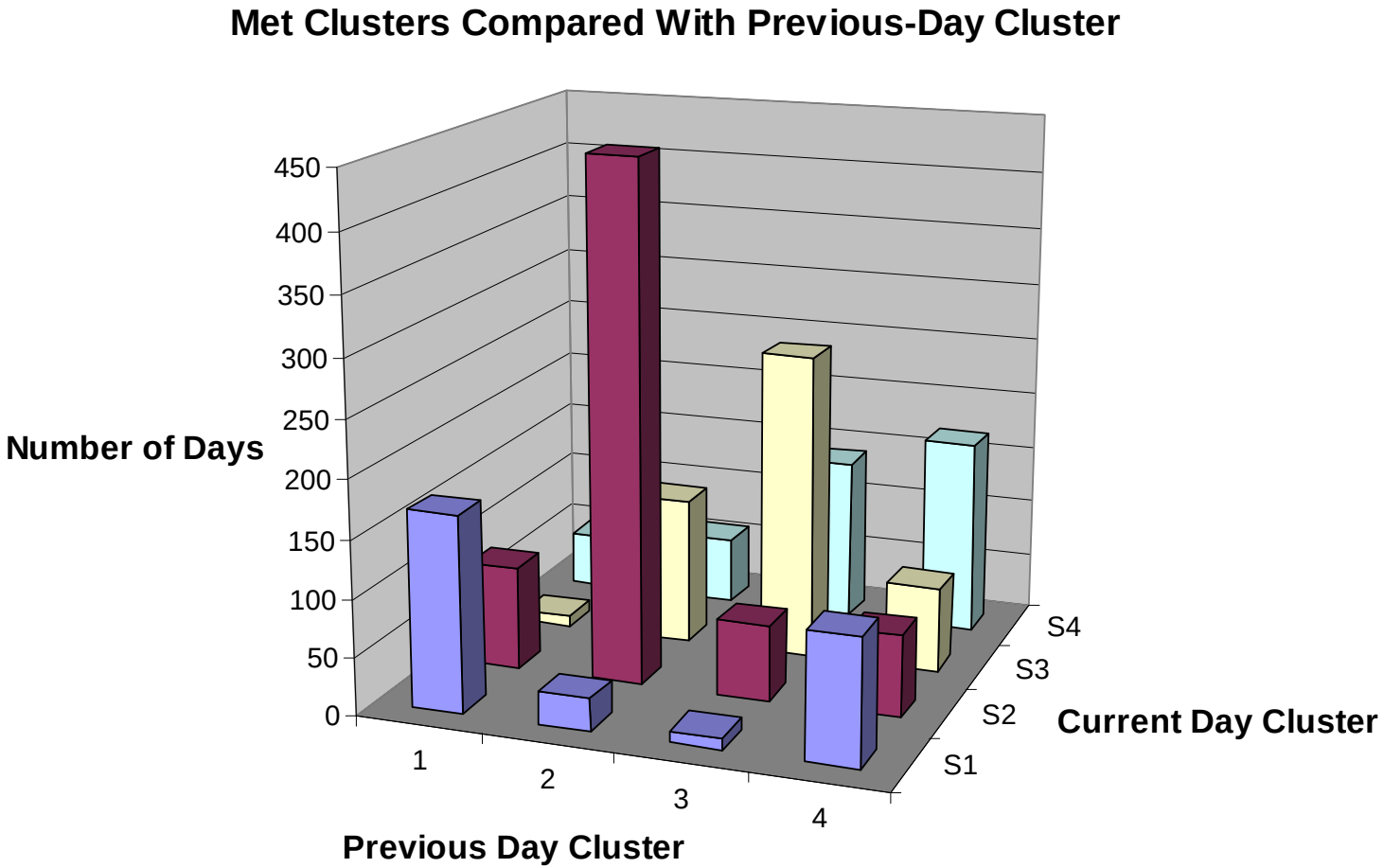


Clusters separate days into groups with different 850 mb wind directions



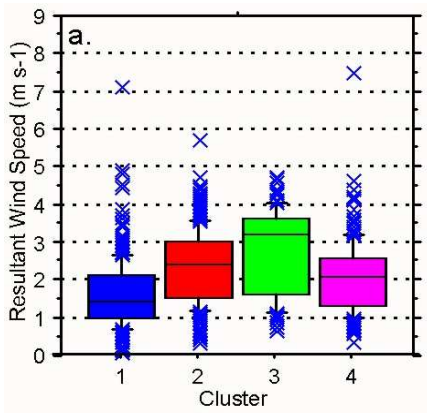


Clusters separate days into groups with different 850 mb T

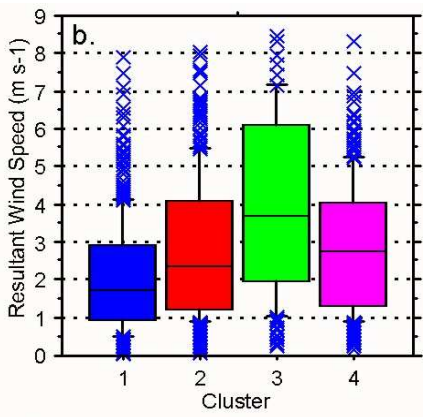


Clusters exhibit persistence and preferred transitions (especially 4-to-1, 2-to-3, and 3-to-4)

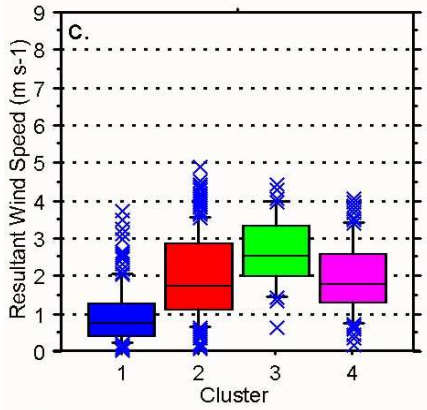
SBA



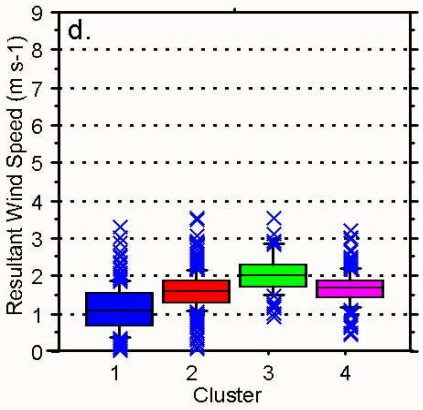
NBA & EBA



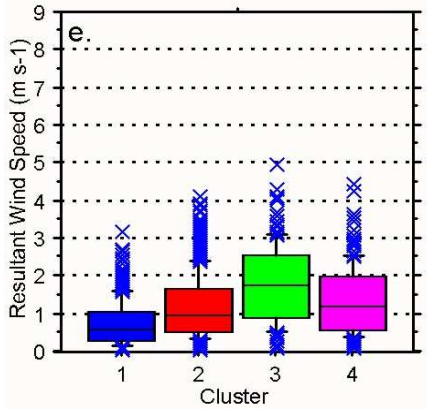
SAC



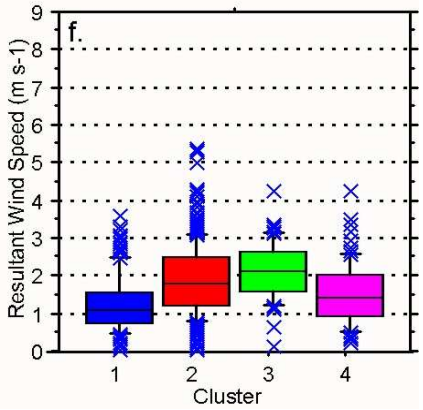
NSJV



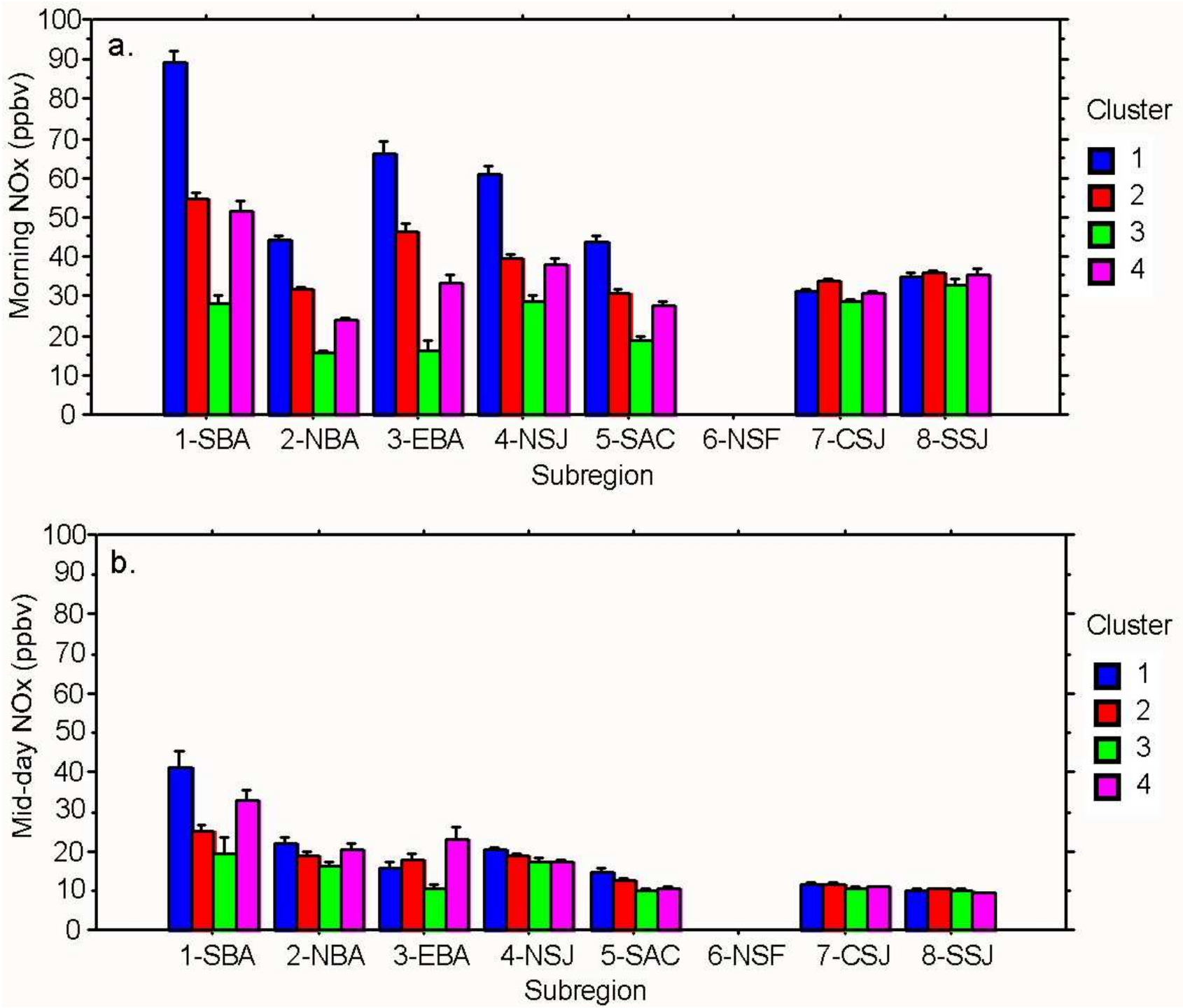
CSJV



SSJV



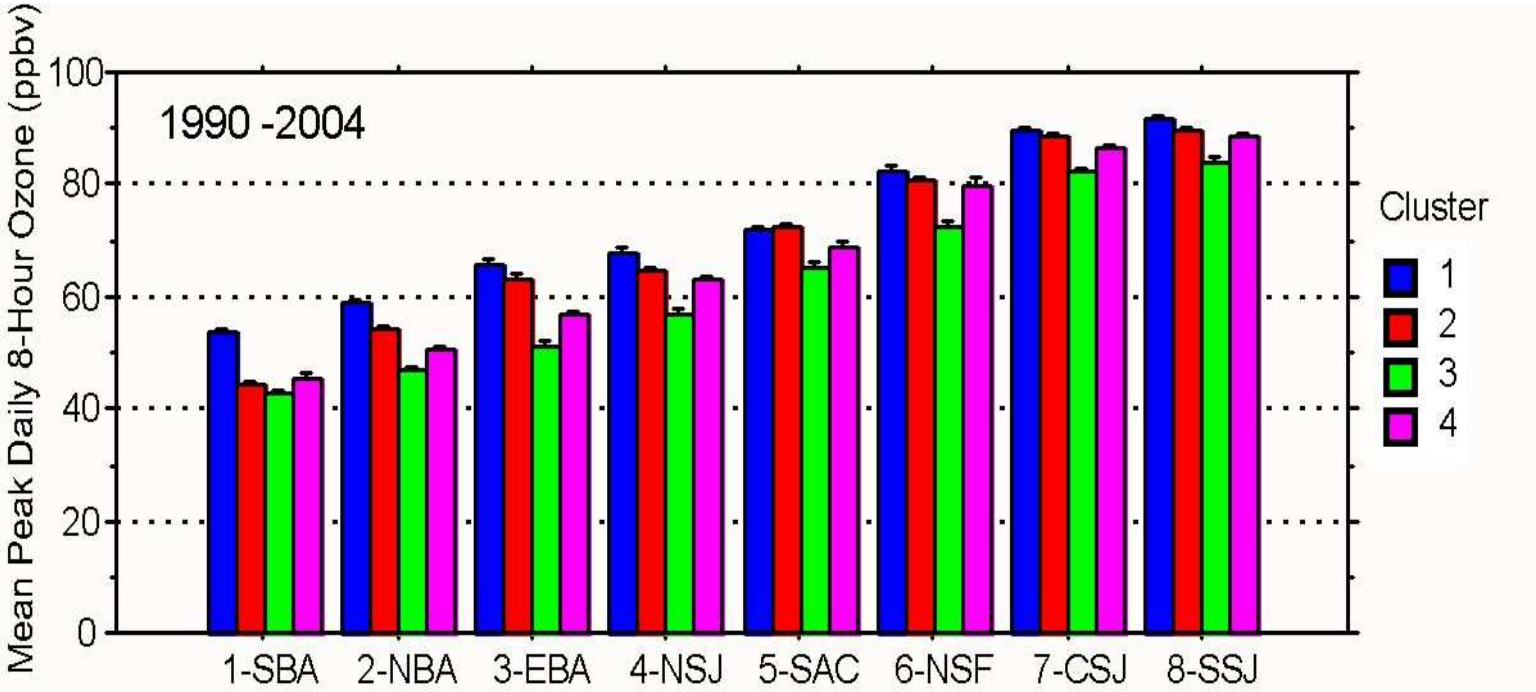
Daily-average surface wind speeds, all sites


a.
Morning NOx (ppbv)
100
90
80
70
60
50
40
30
20
10
0
1-SBA
2-NBA
3-EBA
4-NSJ
5-SAC
6-NSF
7-CSJ
8-SSJ
Subregion
Cluster
1
2
3
4
b.
Mid-day NOx (ppbv)
100
90
80
70
60
50
40
30
20
10
0
1-SBA
2-NBA
3-EBA
4-NSJ
5-SAC
6-NSF
7-CSJ
8-SSJ
Subregion
Cluster
1
2
3
4

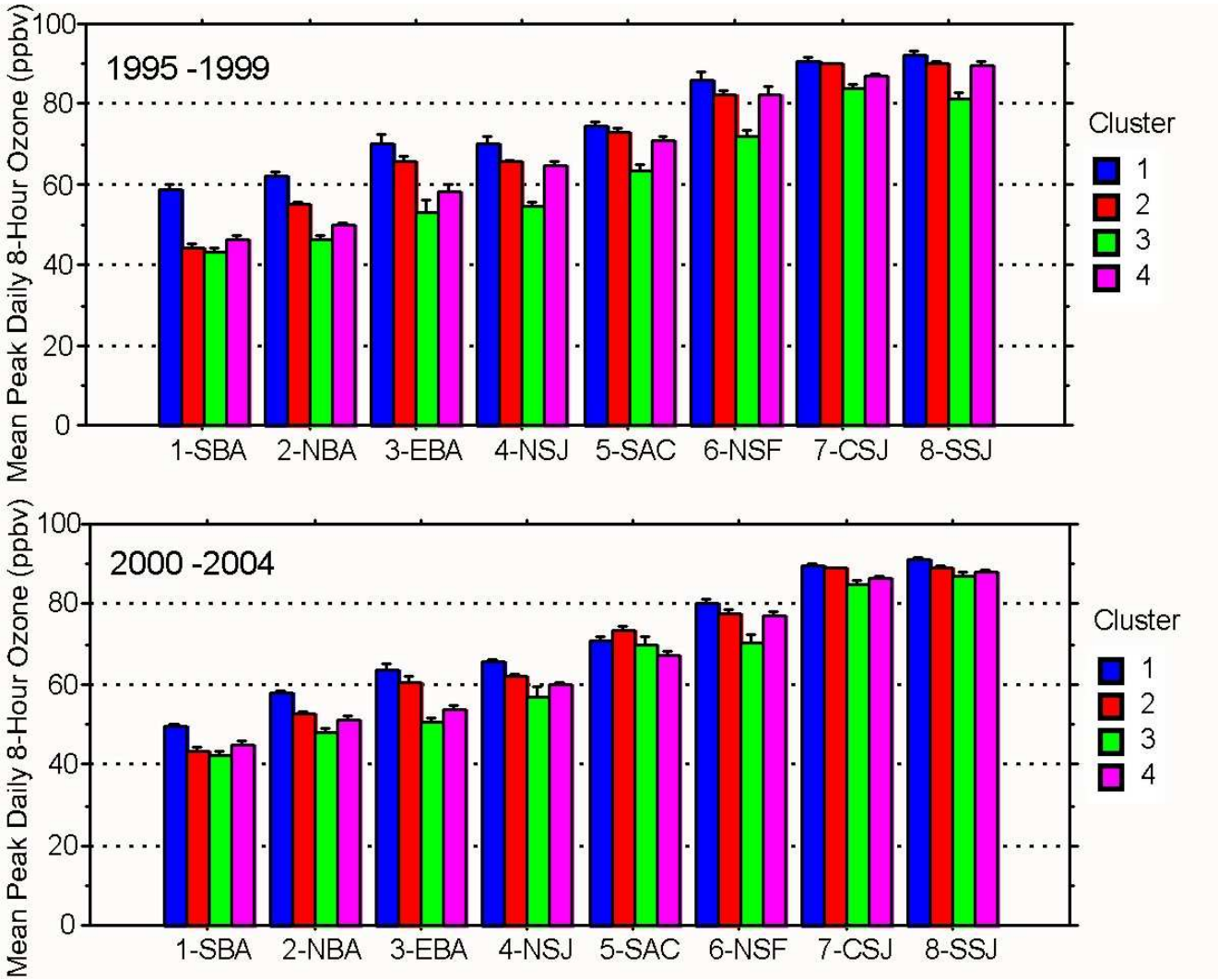
What Can We Learn From Met Clusters?

- Splitting days into groups having similar meteorological conditions is useful for reducing meteorological “noise”
- Potentially may reveal differences in response of ozone to precursor changes under different source-receptor conditions or different degrees of photochemical activity and “aging”

VIII. Do Met Classes Shed Light on Ozone Trends?

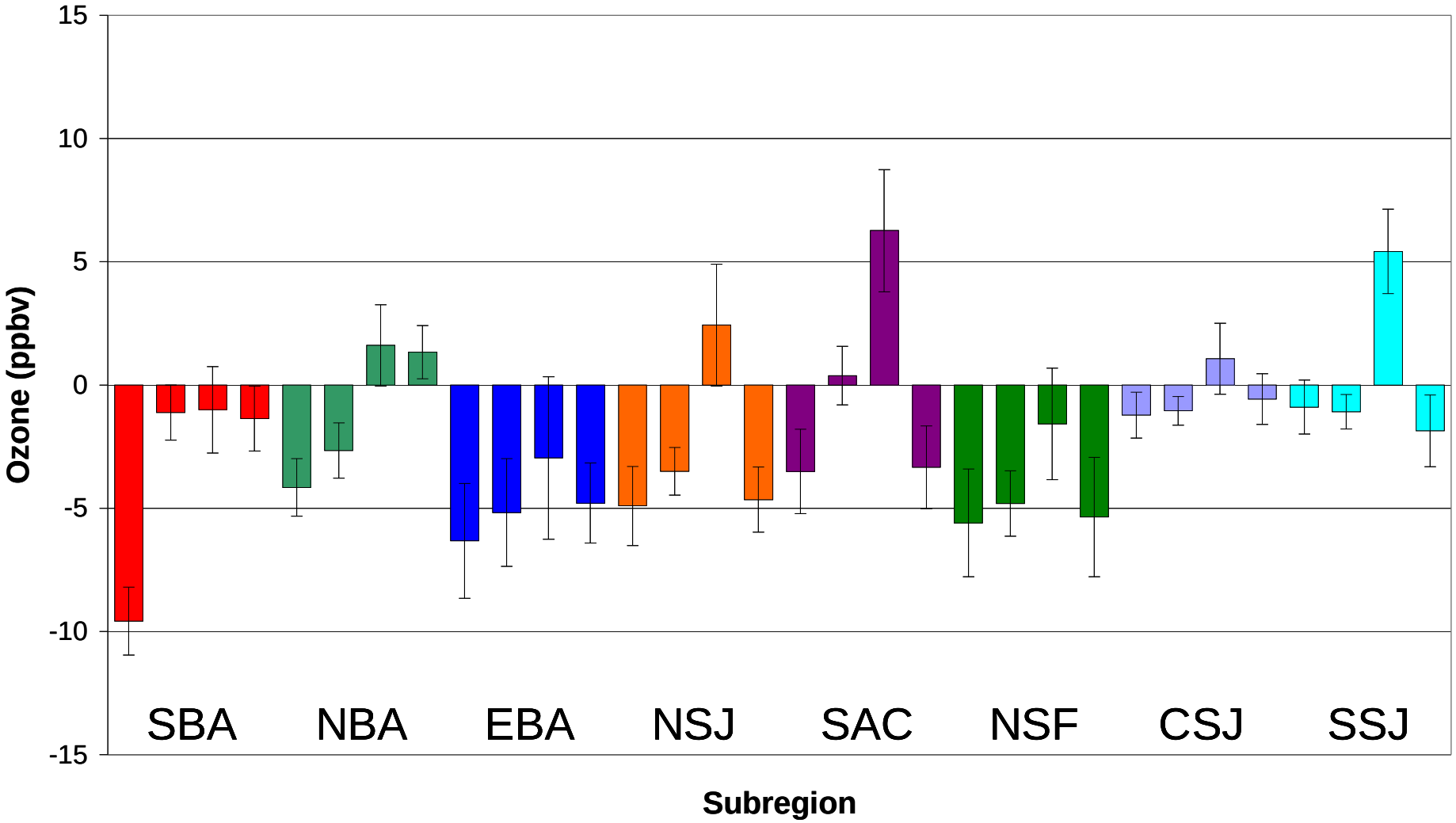


Mean peak 8-hour ozone concentrations varied among sites, subregions, and met types – these days are all top-60 peak 8-hour days

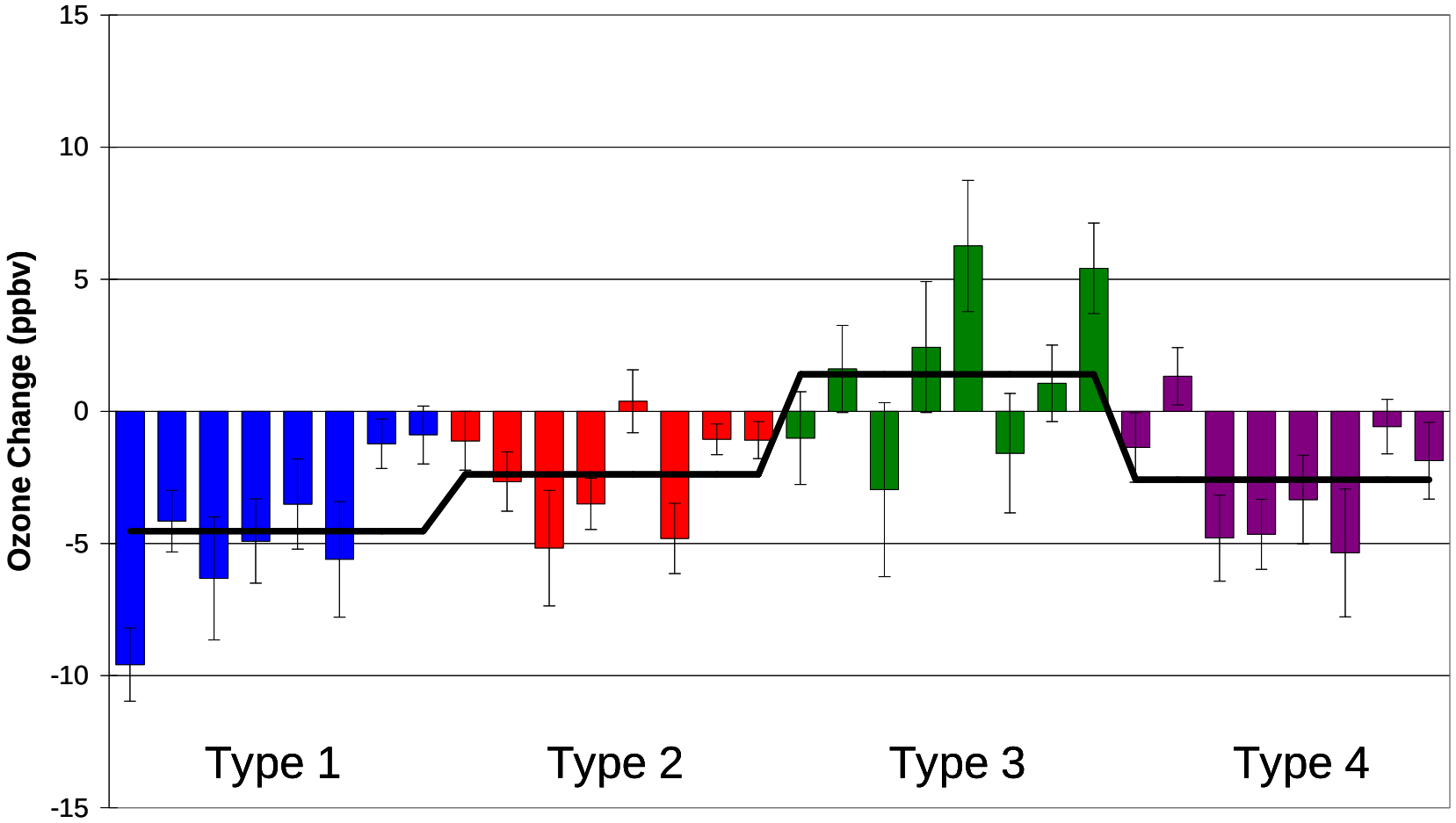


The change in mean peak 8-hour ozone concentrations from 1995-1999 to 2000-2004 varied among sites, subregions, and met types

Change in Mean Peak Daily 8-Hour Ozone, 1995-99 to 2000-04
(by Meteorological Class and Subregion)

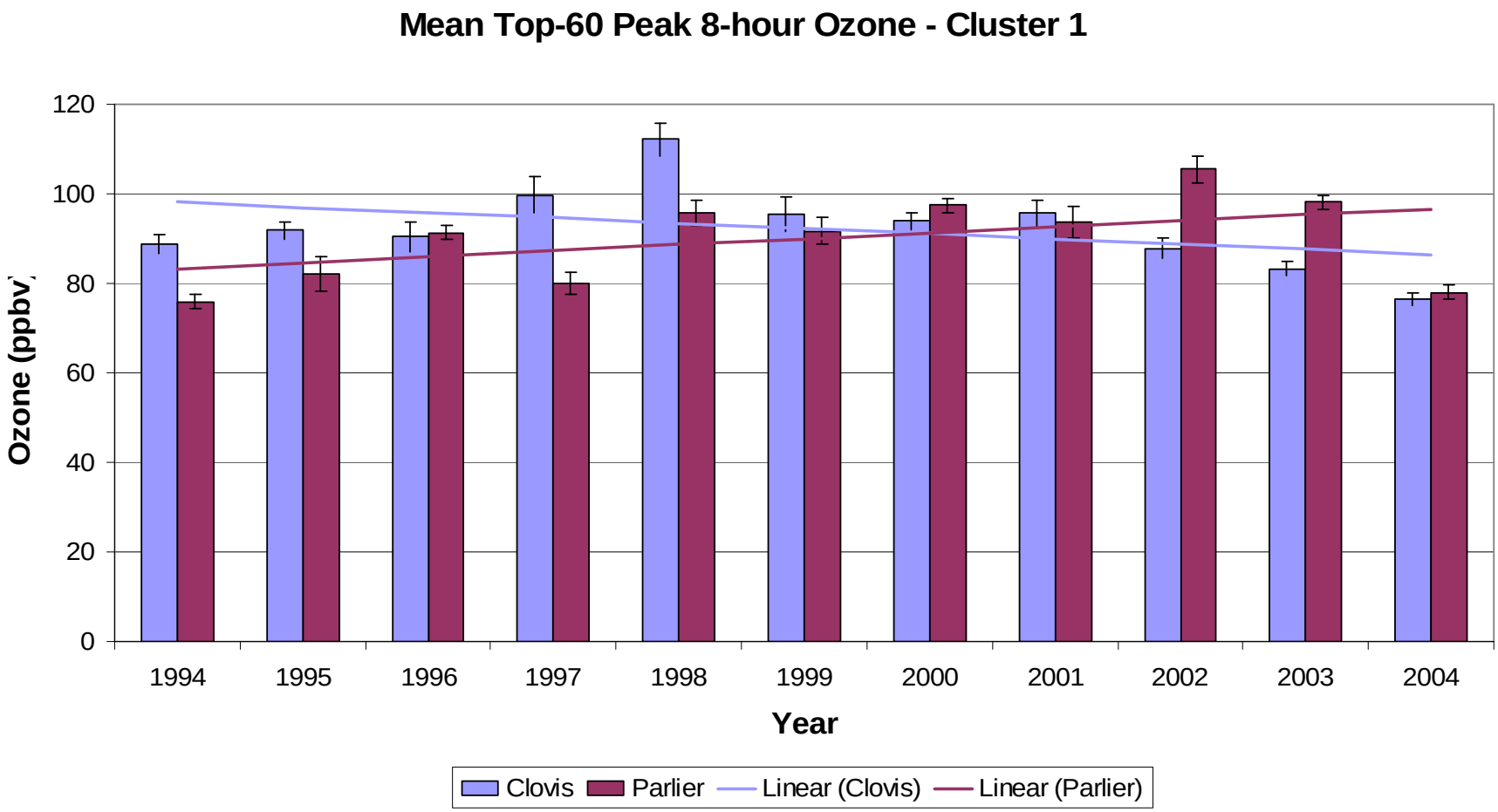


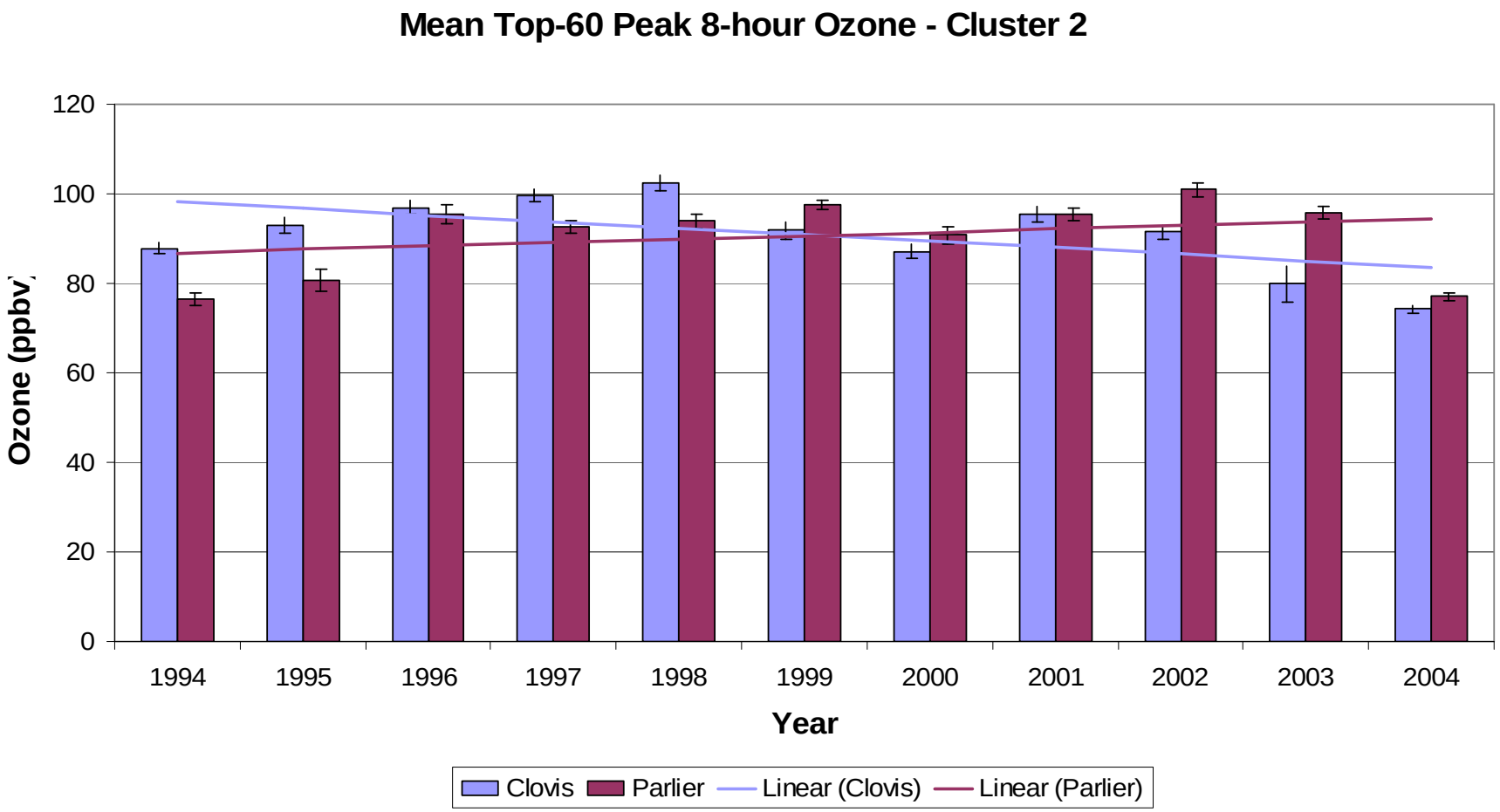
Change in Mean Peak Daily 8-Hour Ozone, 1995-99 to 2000-04
(by Meteorological Class and Subregion)

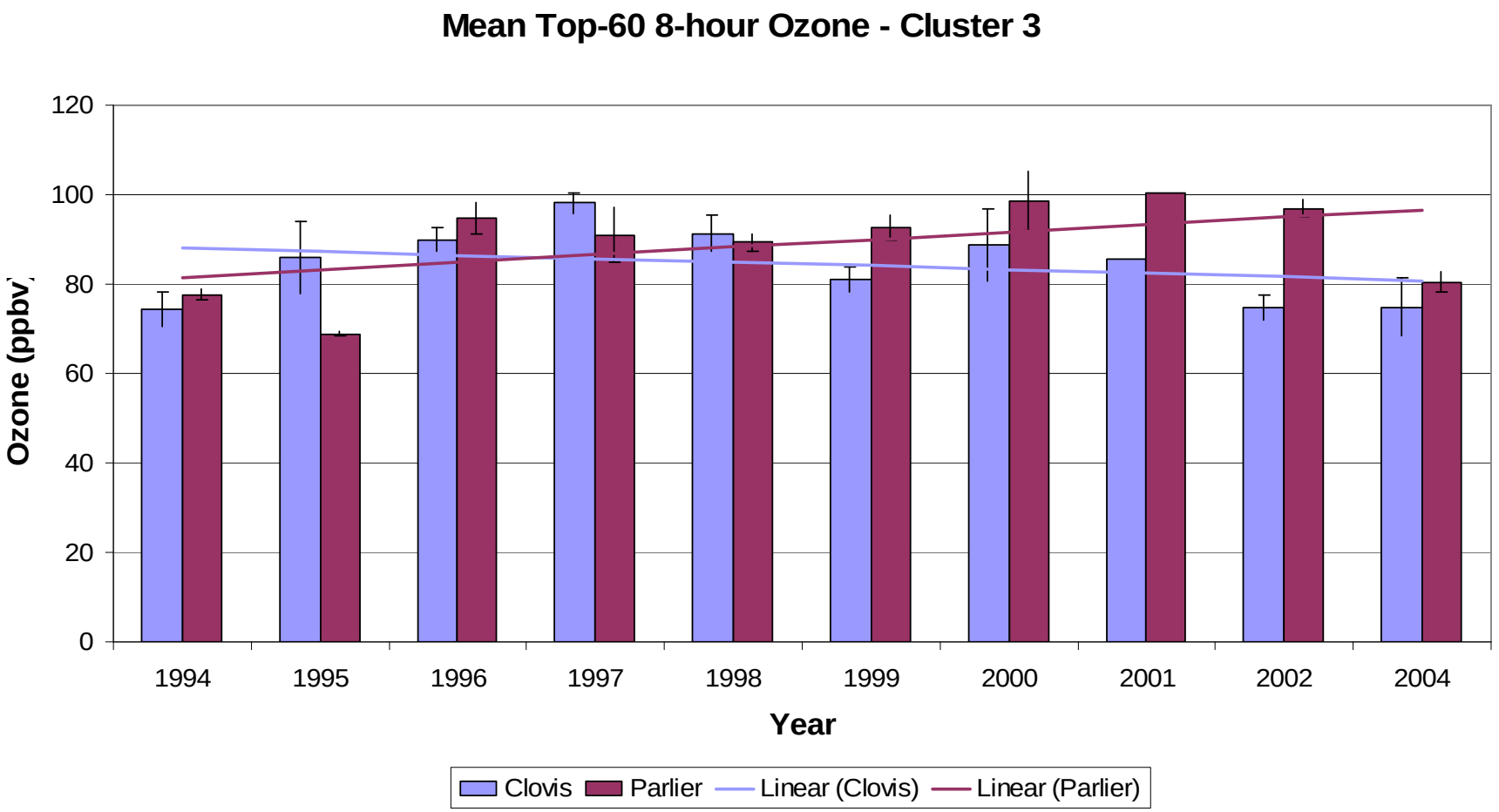


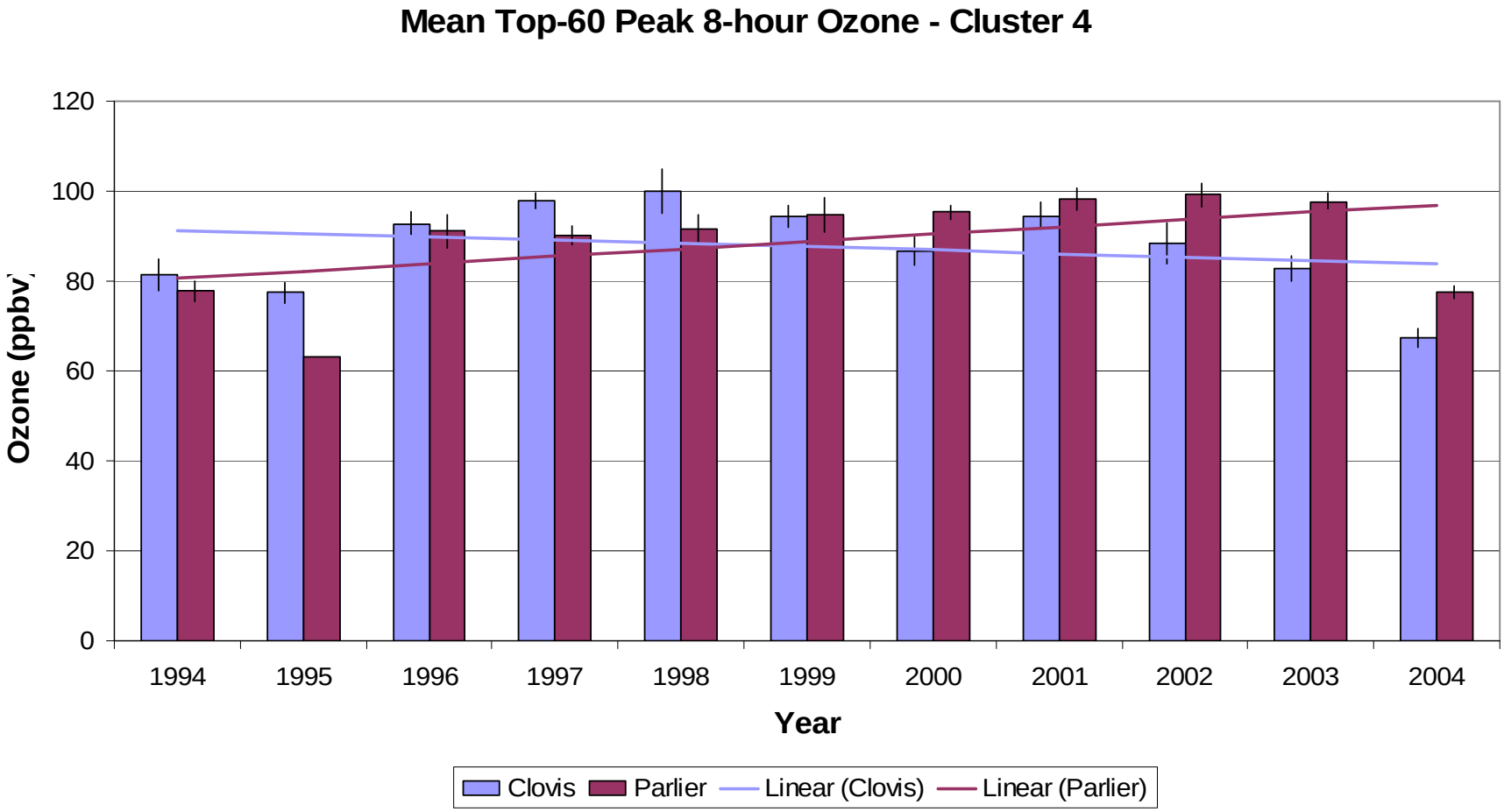
(Order is SBA, NBA, EBA, NSJ, SAC, NSF, CSJ, SSJ)

For all met classes, top-60 mean peak 8-hour ozone is down at Clovis but up at Parlier … the differences in ozone trends at Clovis and Parlier do not appear to be due to changes in meteorology or in the frequencies of occurrence of different meteorological types


Mean Top-60 Peak 8-hour Ozone - Cluster 1
Ozone (ppbv)
120
100
80
60
40
20
0
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004
Year
Clovis
Parlier
Linear (Clovis)
Linear (Parlier)


Mean Top-60 Peak 8-hour Ozone - Cluster 2
Ozone (ppbv)
120
100
80
60
40
20
0
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004
Year
Clovis
Parlier
Linear (Clovis)
Linear (Parlier)


Mean Top-60 8-hour Ozone - Cluster 3
Ozone (ppbv)
120
100
80
60
40
20
0
1994
1995
1996
1997
1998
1999
2000
2001
2002
2004
Year
Clovis
Parlier
Linear (Clovis)
Linear (Parlier)


Mean Top-60 Peak 8-hour Ozone - Cluster 4
Ozone (ppbv)
120
100
80
60
40
20
0
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004
Year
Clovis
Parlier
Linear (Clovis)
Linear (Parlier)

Next Steps – Phase II Ozone Analyses

- Phase I analyses demonstrate variations of ozone and of ozone trends but do not explain them
- Site-to-site variations and directional variations of mean concentrations imply significant local ozone formation
- Need to analyze ozone formation rates
- Potential limitation is signal-to-noise

Questions and Comments on Ozone Phase I Findings and Phase II Objectives

Phase II

- Phase II schedule – complete by December 2007 with final report and draft manuscript
- Why would Phase II be useful?
  - Identify zones of emission influence - more accurate comparison of sites' AQ trends with "zone-of-influence" emission trends
  - Better understanding of ozone trends at sites within each subregion and the relation of ozone to precursor trends, differentiated by met class and subclass

Task 5

- Generate gridded inventories from county-level inventories and historical surrogate files
- Develop monitor-specific “zone-of-influence” emission trends using 3x3 to 7x7 arrays of grid cells around each long-term monitor

Task 6

- Compare “zone-of-influence” emission trends to ambient primary-pollutant trends. Identify consistencies and discrepancies. Evaluate evidence for inaccuracies in emission estimates.
- Subdivide met classes. Determine peak ozone changes by site, met class and subclass, and (if warranted) month and day of week. Relate ozone changes to precursor trends and meteorology.

Reporting

- Task 7: Prepare final report and draft manuscript
- Task 8: Provide data, documentation, and software
- Task 9: Present findings at meetings