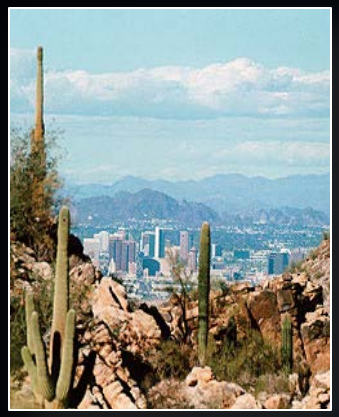
Analysis of Rising Ozone Concentrations in Maricopa County in 2011-2012

MAG Air Quality Technical Advisory Committee
August 22, 2013

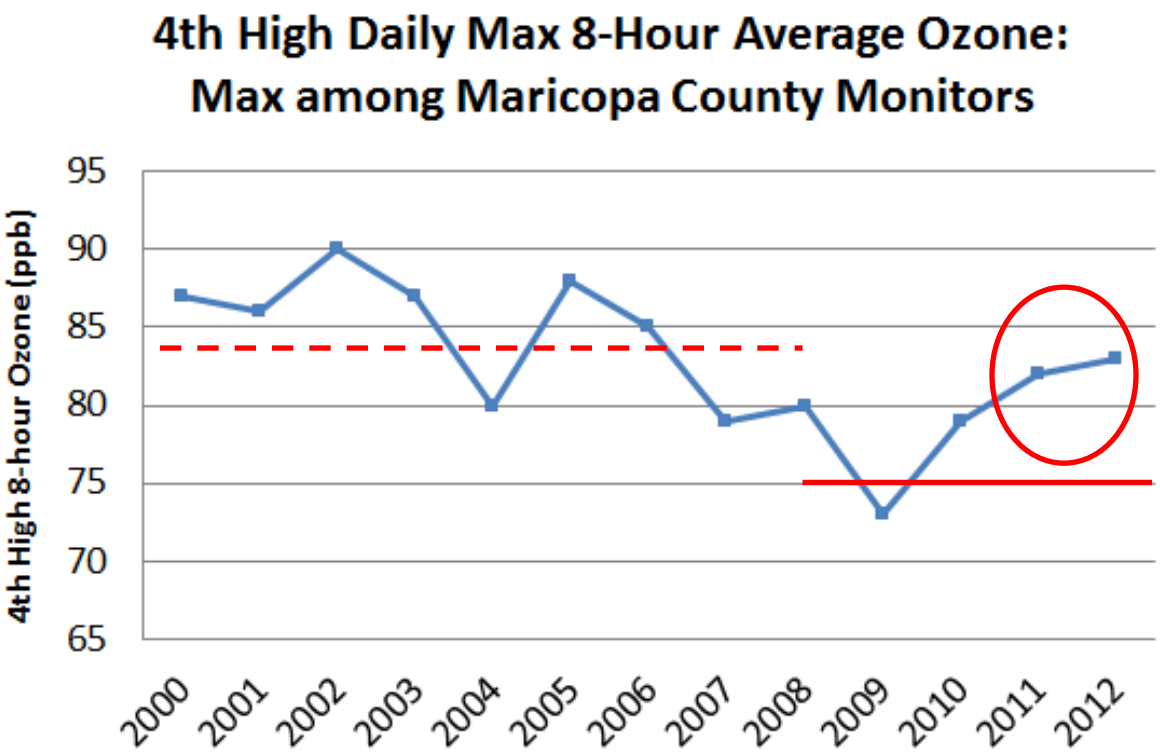
MARICOPA ASSOCIATION of GOVERNMENTS



Analysis of Rising Ozone Concentrations in Maricopa County in 2011-2012

- ENVIRON, MAG Air Quality On-Call Consultant, conducted an analysis of recent ozone trends to identify cause(s) of rising ozone concentrations
- Following slides provided by ENVIRON explain the findings of their analysis

Purpose



- Determine cause(s) of rising ozone concentrations in Maricopa County in 2011-2012
  - Local and Regional Factors
  - Long-range transport

Hypotheses

- Changes in Emissions
  - Summer-time use of 10% ethanol gasoline blend fuel since 2011 and associated production of aldehydes
  - Local/regional anthropogenic emissions
  - Local biogenic emissions
  - Local and regional wildfire activity
- Changes in importance of VOC-limited ozone reactions in the urban core and the role of NOx emissions
- Changes in local and regional meteorological and climatic conditions
  - Temperature, winds, clouds/rainfall, ENSO phase, etc.
- Changes in background ozone concentrations/transport

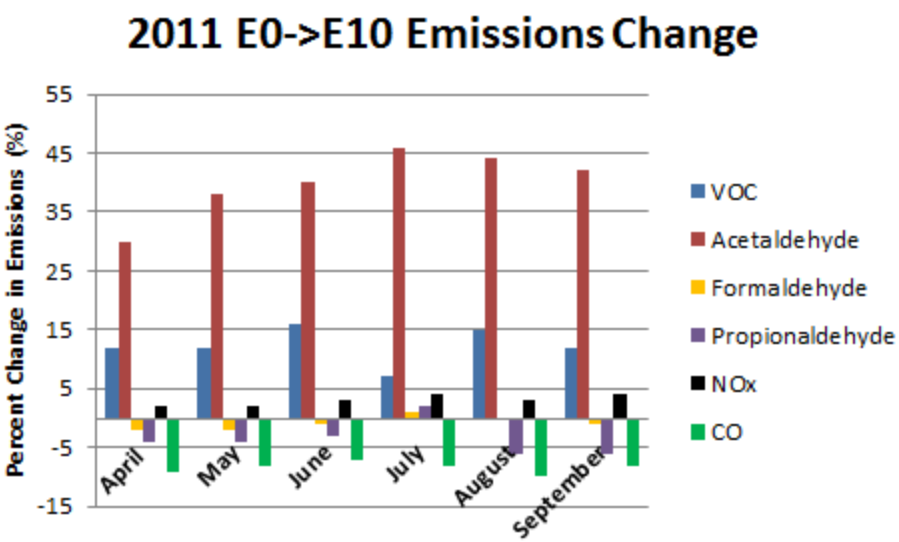
Conclusions

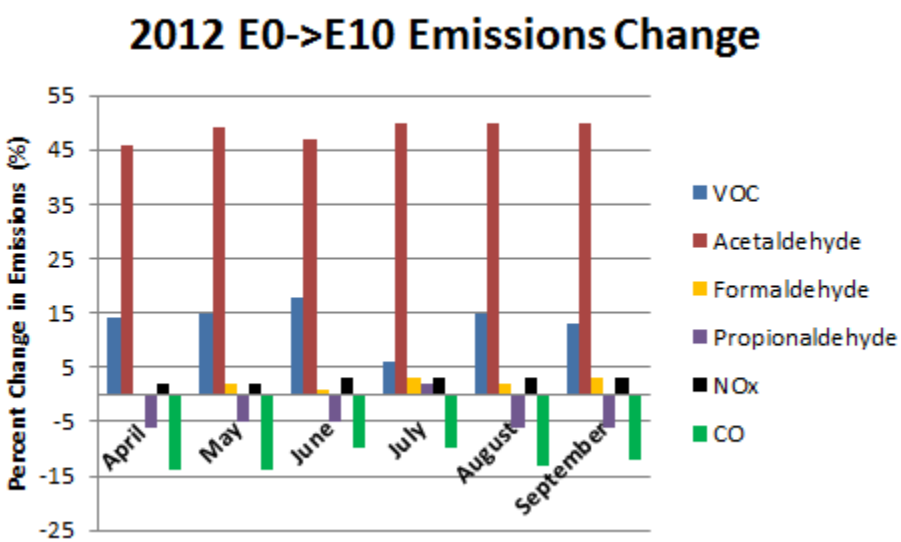
- Maricopa 2008-2012 ozone trend similar to other large metro areas in southwest US
  - Suggests regional-scale factors are important
  - 2008-2012 May-June cloudiness is consistent with ozone trends
- Phoenix data show:
  - Unusually large amount of cloud cover in May-June 2009
  - Small amount of cloud cover in May-June 2011-2012
  - Unusually high temperatures in 2012
- More potential wildfire impacts in 2012
- Local anthropogenic NOx and VOC emissions generally decrease during 2008-2011
  - Vehicle emissions decrease during 2008-2012, but increase after 2010 due to use of E10
- No evidence of changes in transport patterns

Summer Use of 10% Ethanol Gasoline

- Did use of E10 fuel in 2011 and 2012 cause an increase in on-road mobile VOC emissions?
  - Aldehydes of particular interest due to their reactivity
- Run MOVES for Maricopa County for April to September, 2008-2012 with E0 and E10 fuels
  - Calculate change in emissions going from E0 to E10
    - NOx, CO, VOCs and three aldehydes: form-, acet-, propion-)
  - MOVES input data provided by MAG, specific to month and year in Maricopa County
  - Ambient temperature and humidity for MOVES from Phoenix Sky Harbor International Airport

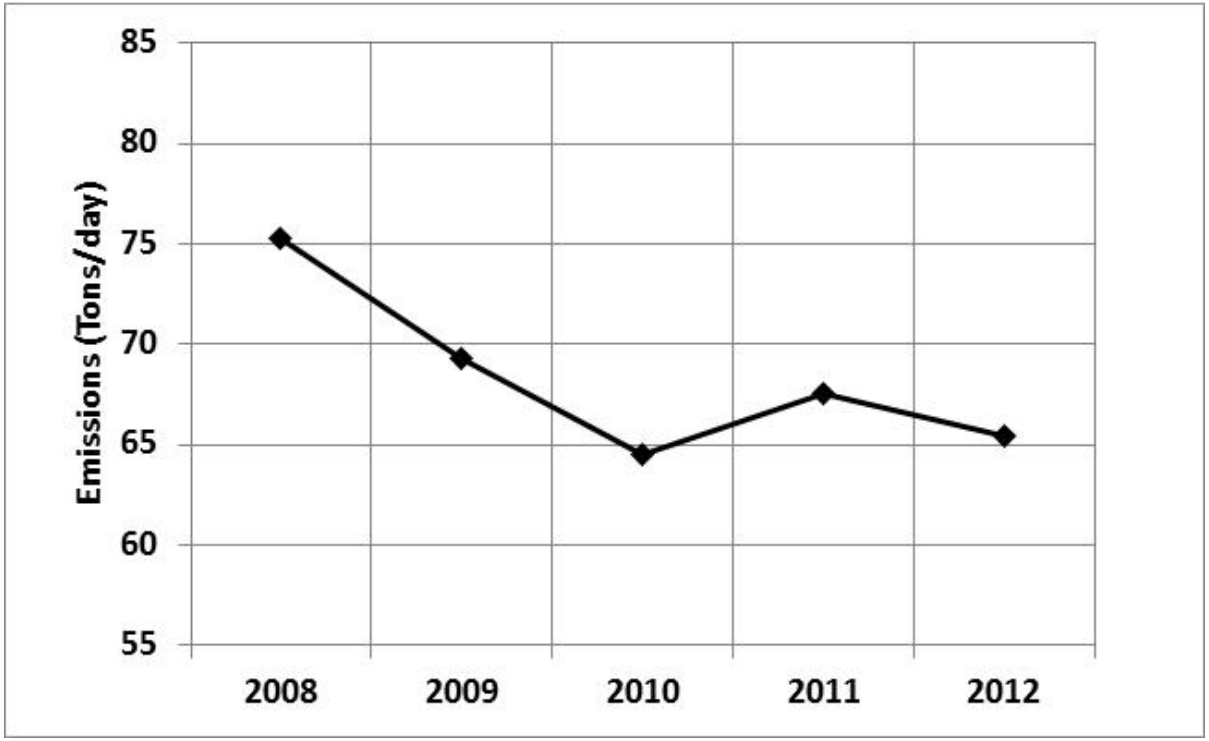
Effect on Emissions of Going from E0 to E10 Gasoline in 2011 and 2012





- VOC, NOx emissions increase, CO decreases
- Acetaldehyde has largest percent increase, but makes up ~1% of total VOC emissions
- Formaldehyde, propionaldehyde changes depend on month/year
  - Formaldehyde is ~2% of VOC emissions
  - Propionaldehyde is 0.1% of VOC emissions

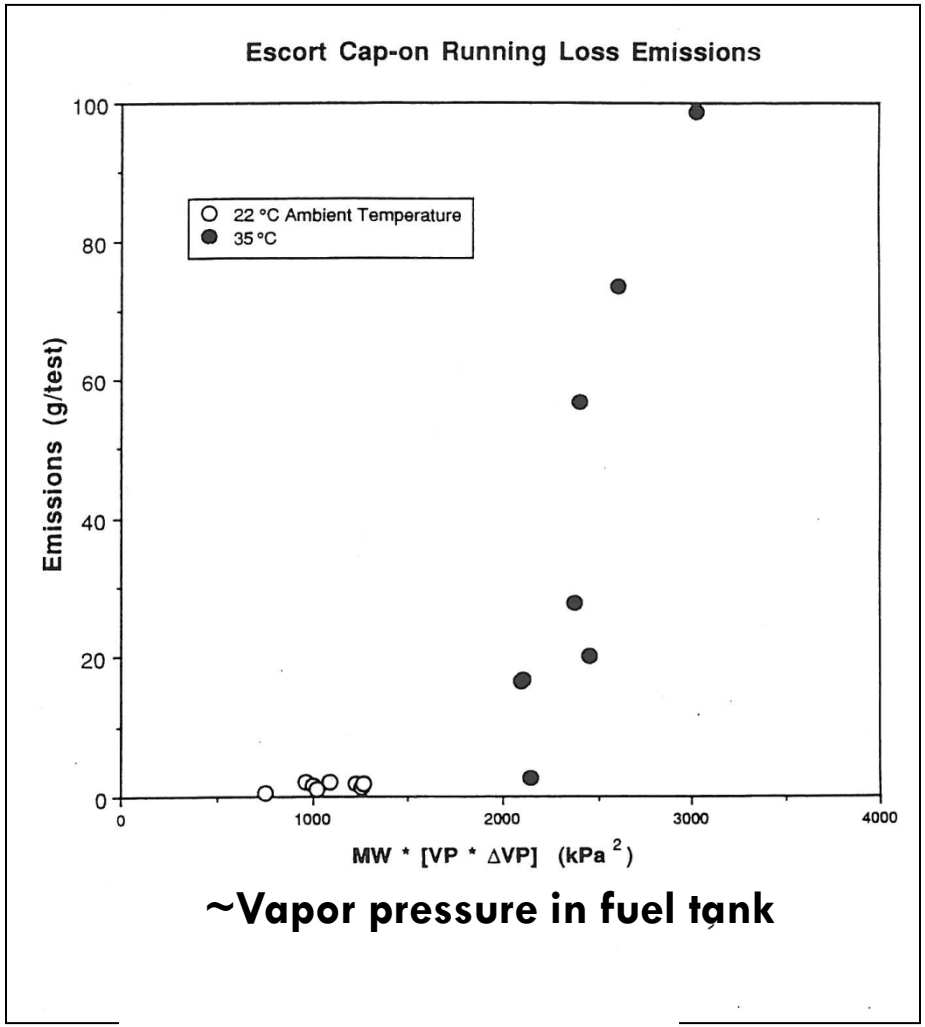
Total Ozone Season VOC Trends: 2008-2012



- Overall 2008-2012 downward trend for VOC is due to fleet turnover (same is true for CO, NOx trends)
- VOC emissions increase in 2011 due to fuel change

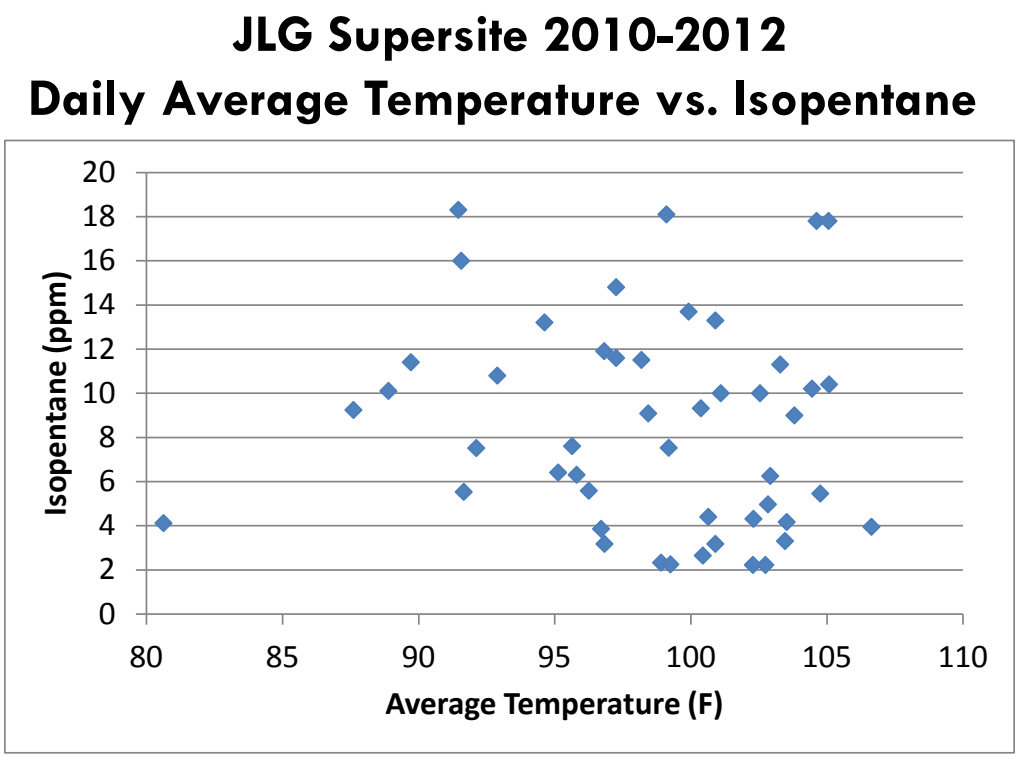
Evaporative Emissions

- Evaporative emissions can exhibit a catastrophic increase at high T
  - Vapor pressure determined by fuel volatility and temperature
- Does this phenomenon occur at the high summer temperatures in Maricopa?

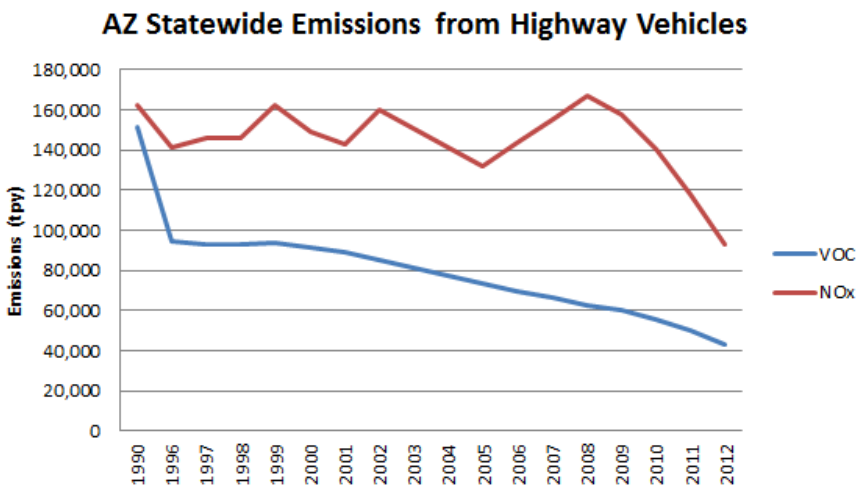


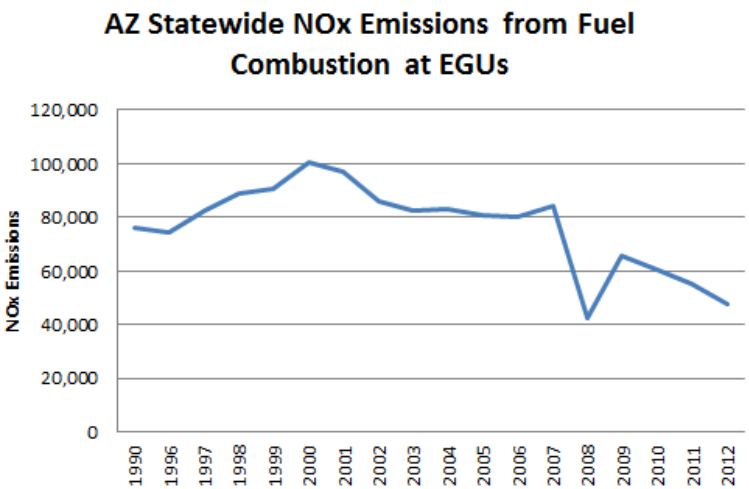
Evidence of Evaporative Emissions

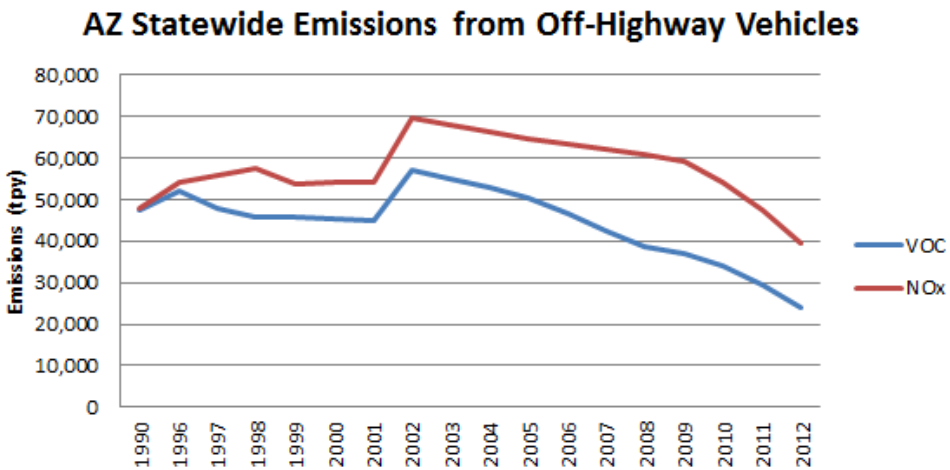
- Isopentane is a marker for evaporative emissions
  - Found in evaporative emissions from low RVP gasoline (butane is largely removed to attain 7 RVP)
- Lack of correlation between isopentane and temperature
- No evidence of fuel volatility affecting VOC ambient levels
- Canister sampling with 24 hour duration
  - 6-9 am sampling would be useful for evaluating on-road mobile emissions

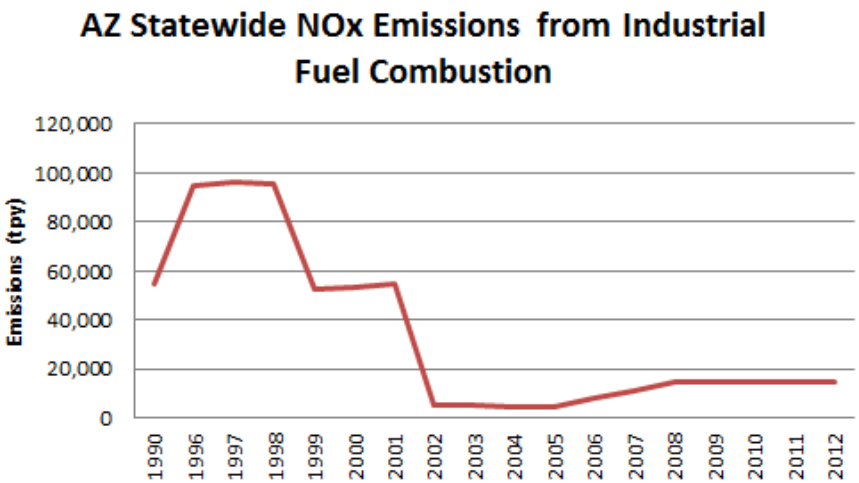


Regional Emissions Trends



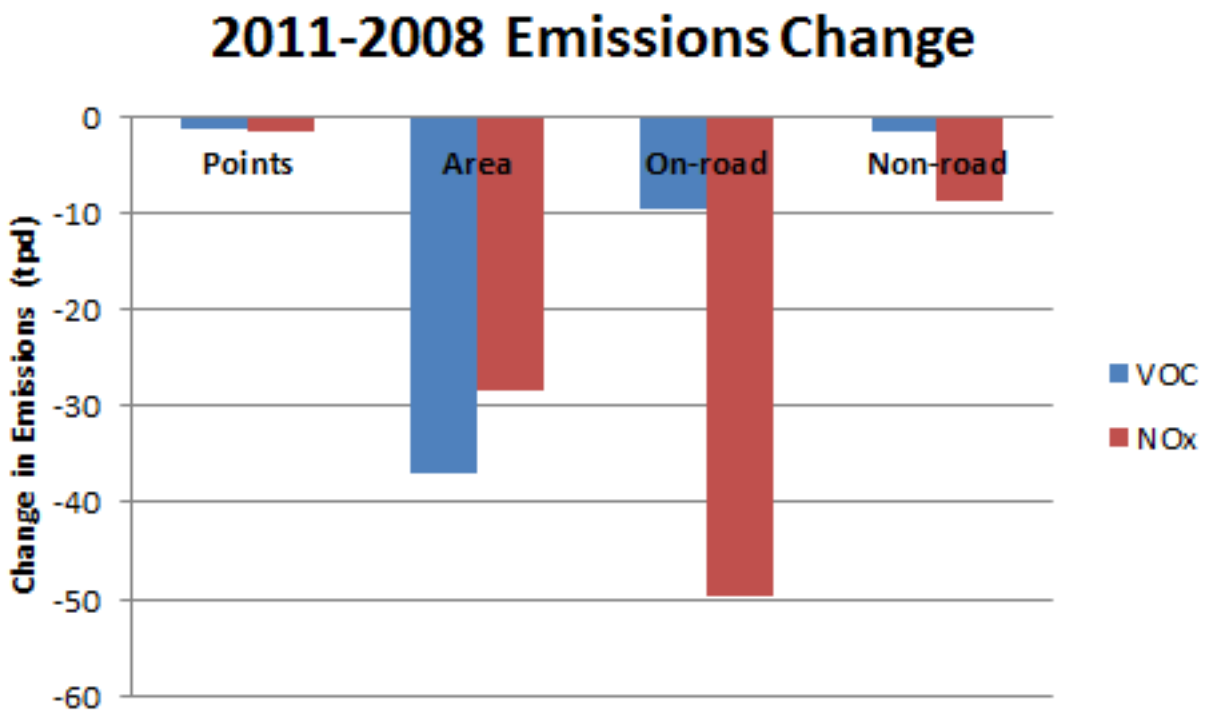






- Data from US EPA's National Emissions Trends Report; potential year-to-year methodology changes
- Largest anthropogenic source categories shown
- No evidence of increasing anthropogenic emissions during 2011-12 relative to previous years

Maricopa Non-Attainment Area Ozone Season Day Anthropogenic Emissions Trends



- 2008 and 2011 anthropogenic emission inventories supplied by MAG for all categories except on-road mobile
  - On-road mobile emissions calculated by ENVIRON using MOVES 2010a
- Anthropogenic emissions of NOx and VOC decreased overall in 2011 relative to 2008

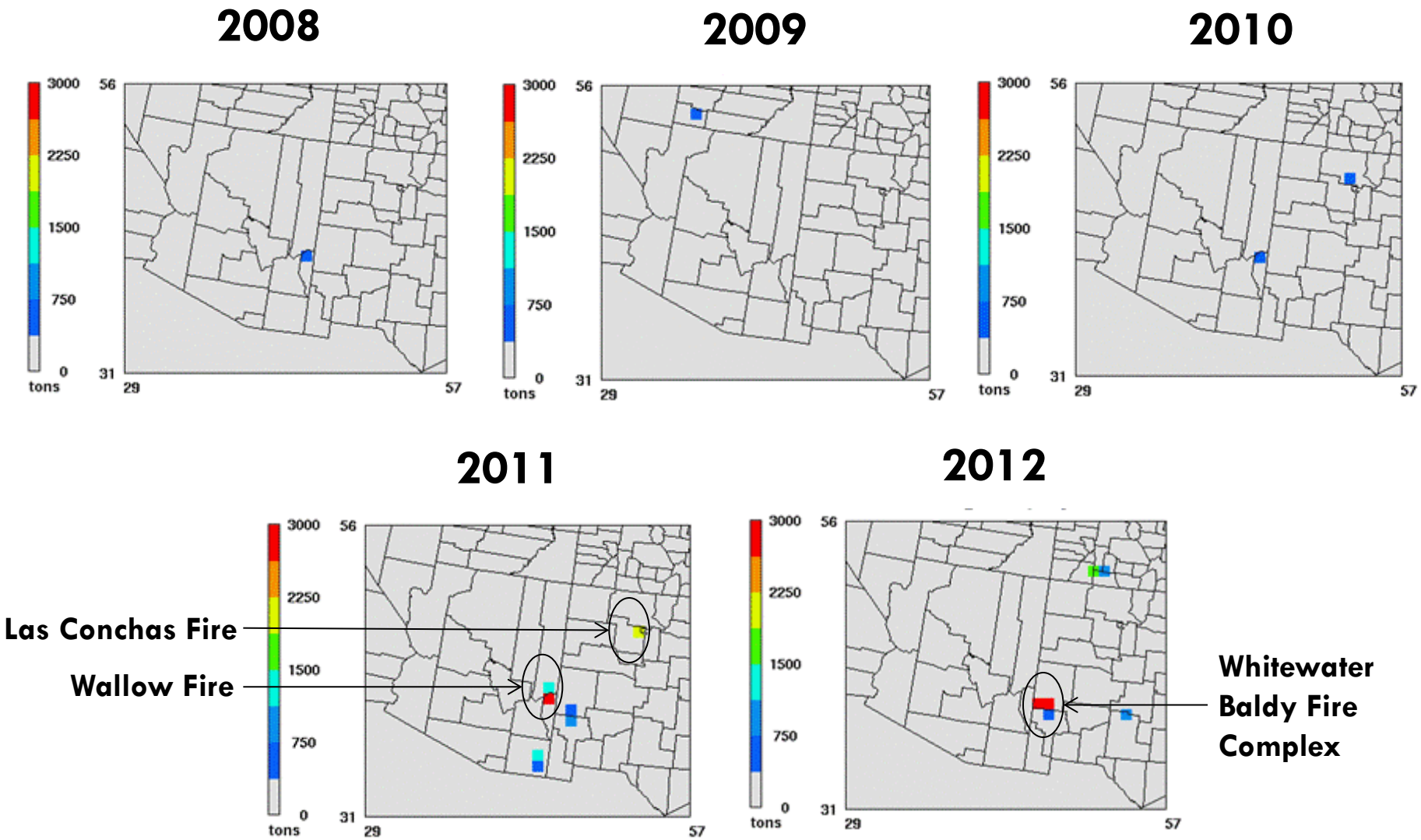
MAG Biogenic Emissions

- MAG's biogenic emissions modeling indicates that 2009 was the peak emissions year during the period 2008-2012
- Variations in local biogenic emissions not consistent with 2008-2012 ozone trends
- Uncertainty in the biogenic modeling (e.g. land use inputs) means it is not possible to rule out biogenic emissions altogether as a possible contributor to higher ozone concentrations in 2011-2012

FINN Fire Data

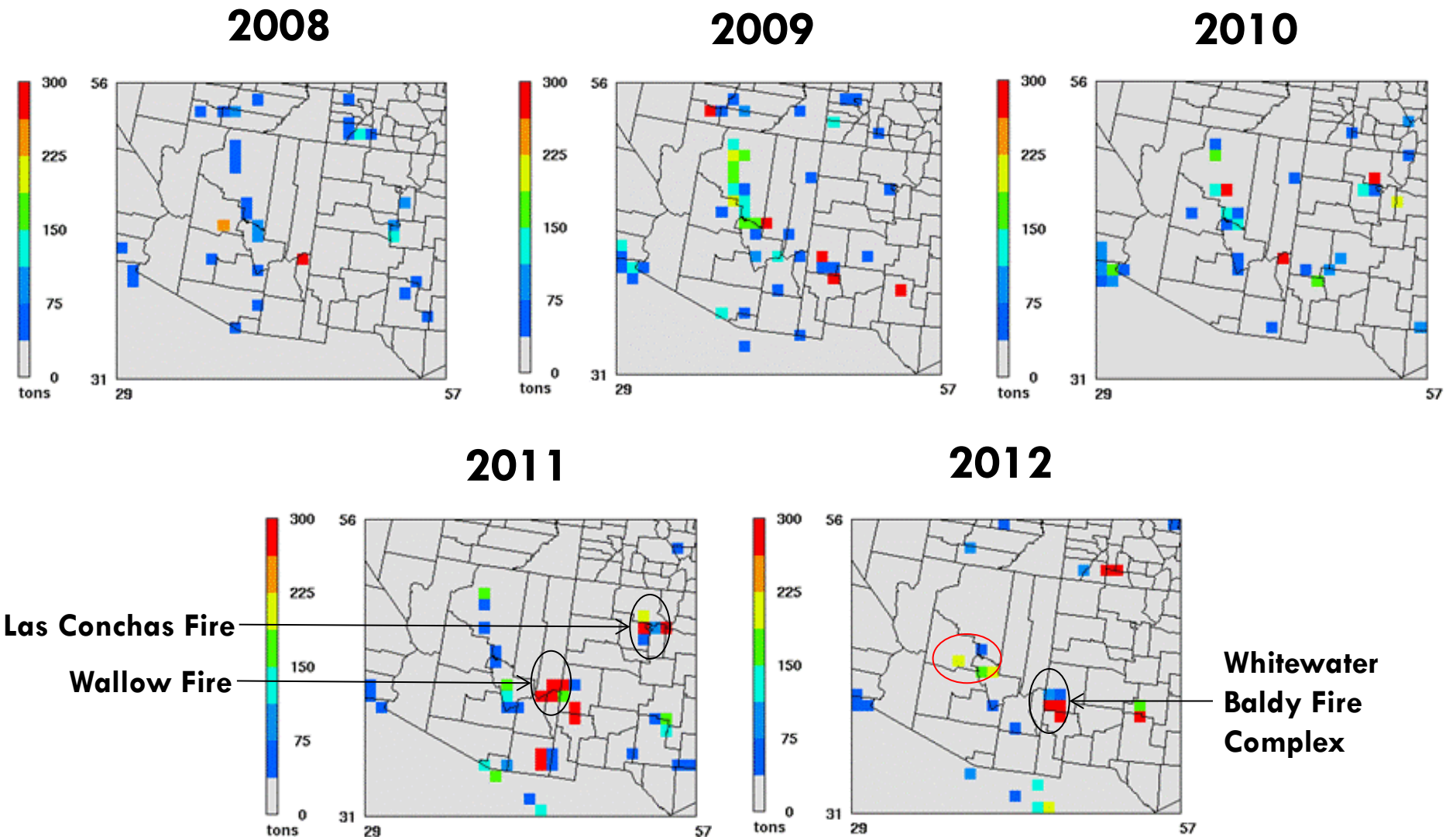
- Fire emissions from NCAR
- Satellite fire detections (MODIS); 1 km^2 resolution
- April-September total NOx fire emissions across the western US for each of the 5 years from 2008-2012 (36km resolution).
  - September, 2012 fire emissions are not available yet, so 2012 only includes 5 of the 6 months
- 2010 had the lowest fire emissions in the western half of the US; 2009 was the second lowest

NOx Emissions from Large Fires in AZ and Vicinity



- 2011 and 2012 had large wildfires east of Maricopa

Changed Scale to Show Emissions from Smaller Fires

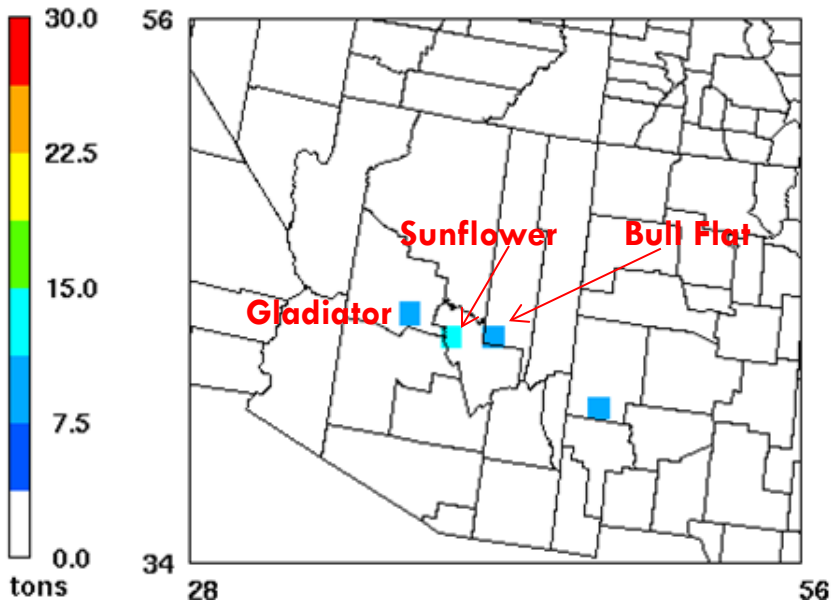


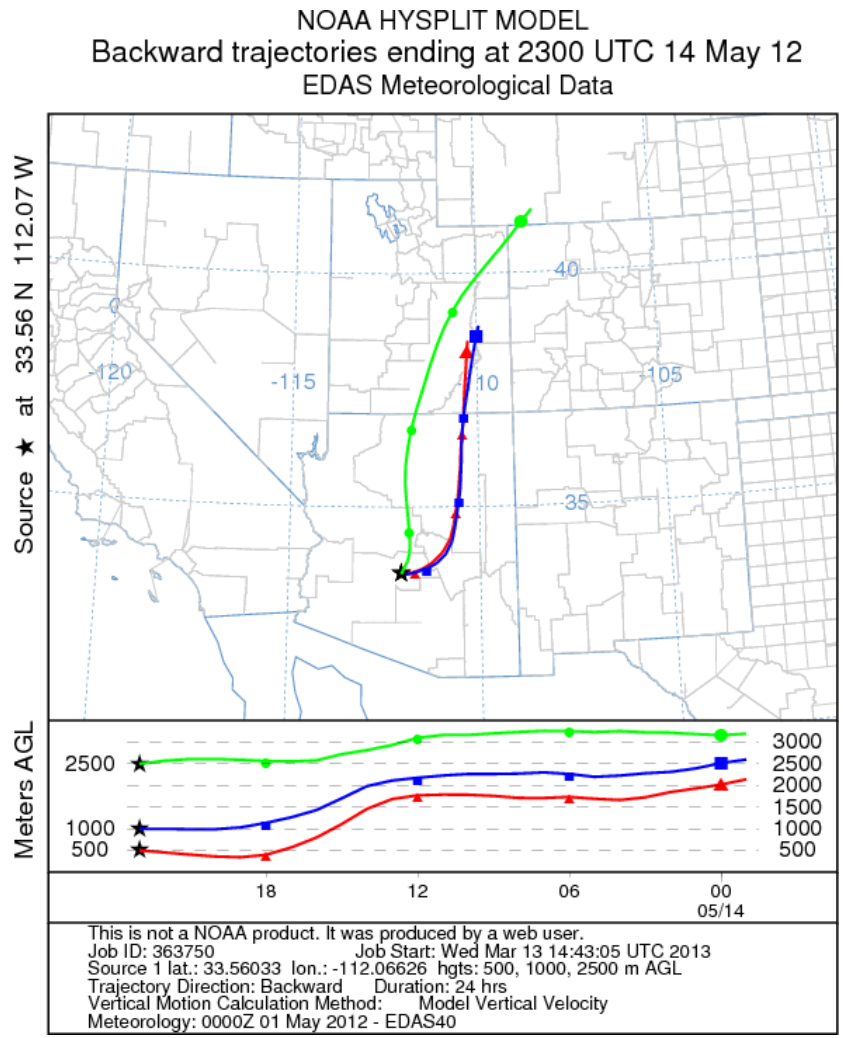
Fires on High Ozone Days: 2008-2012

- Reviewed all days that had a Maricopa monitor with daily max 8-hour ozone > 75 ppb, 2008-2012
- For each high ozone day, prepared HYSPLIT back trajectories from time of highest 1-hour ozone for exceeding monitors
- Evaluated whether back trajectories cross vicinity of FINN wildfire NOx emissions on high ozone day or previous day
- Determined whether wildfire impact could have contributed to high ozone
  - How does number of days with wildfire impacts vary by year?

Example: May 14, 2012

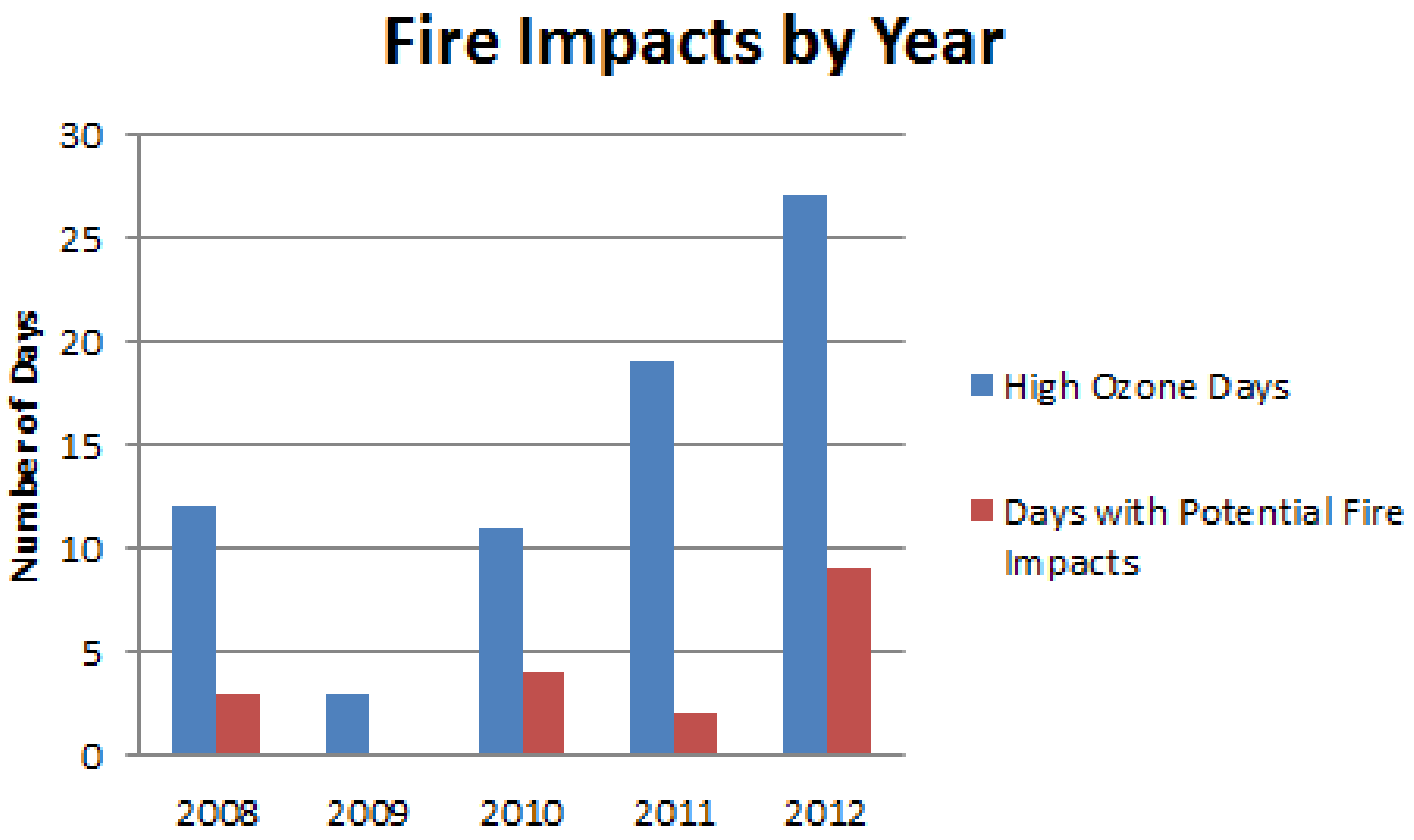
FINN NOx Emissions





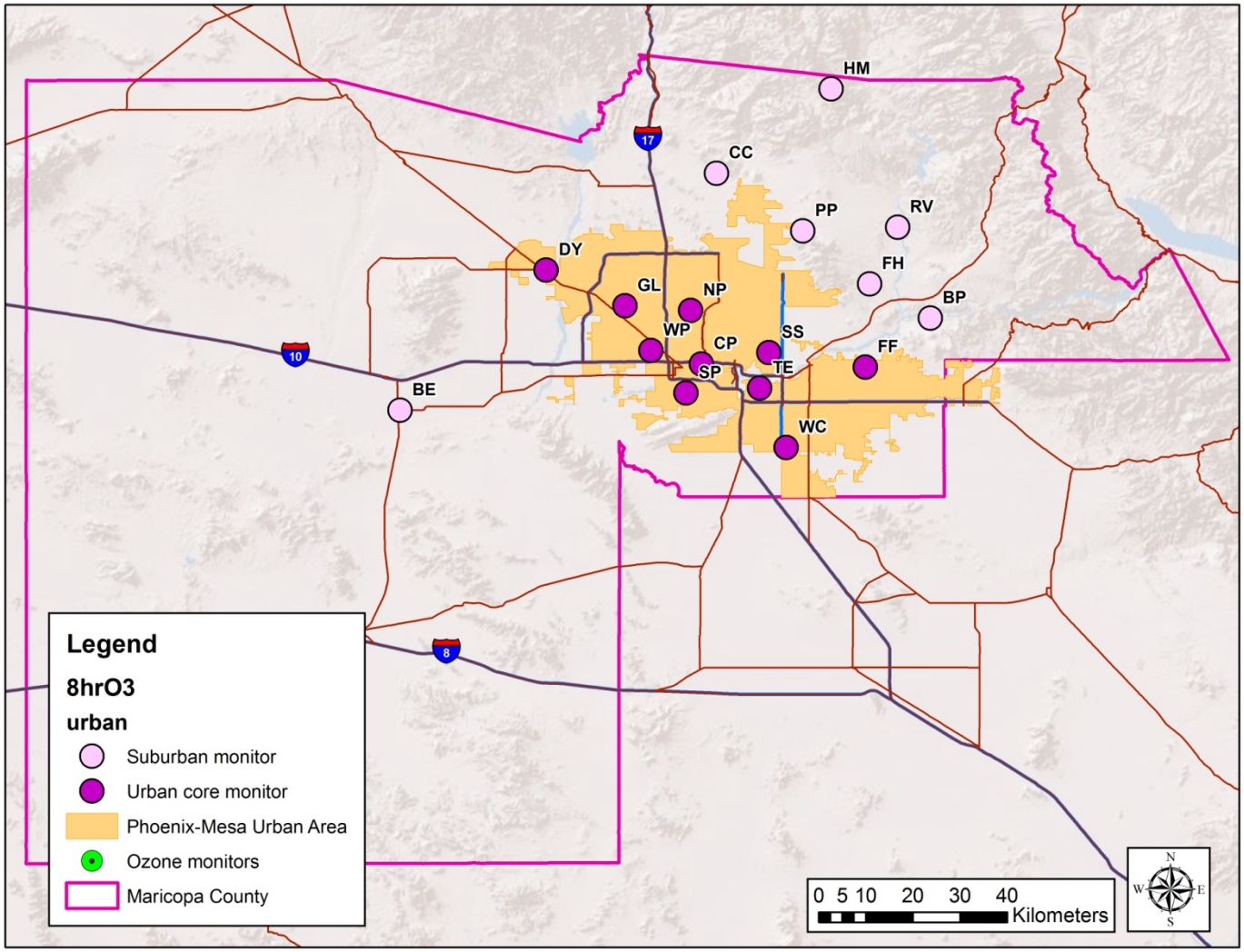
- Back trajectory is for North Phoenix monitor at time of peak 1-hour ozone
- Possible fire impact
- News reports indicate health watches for air pollution issued by Maricopa AQD

Fire Impacts Summary

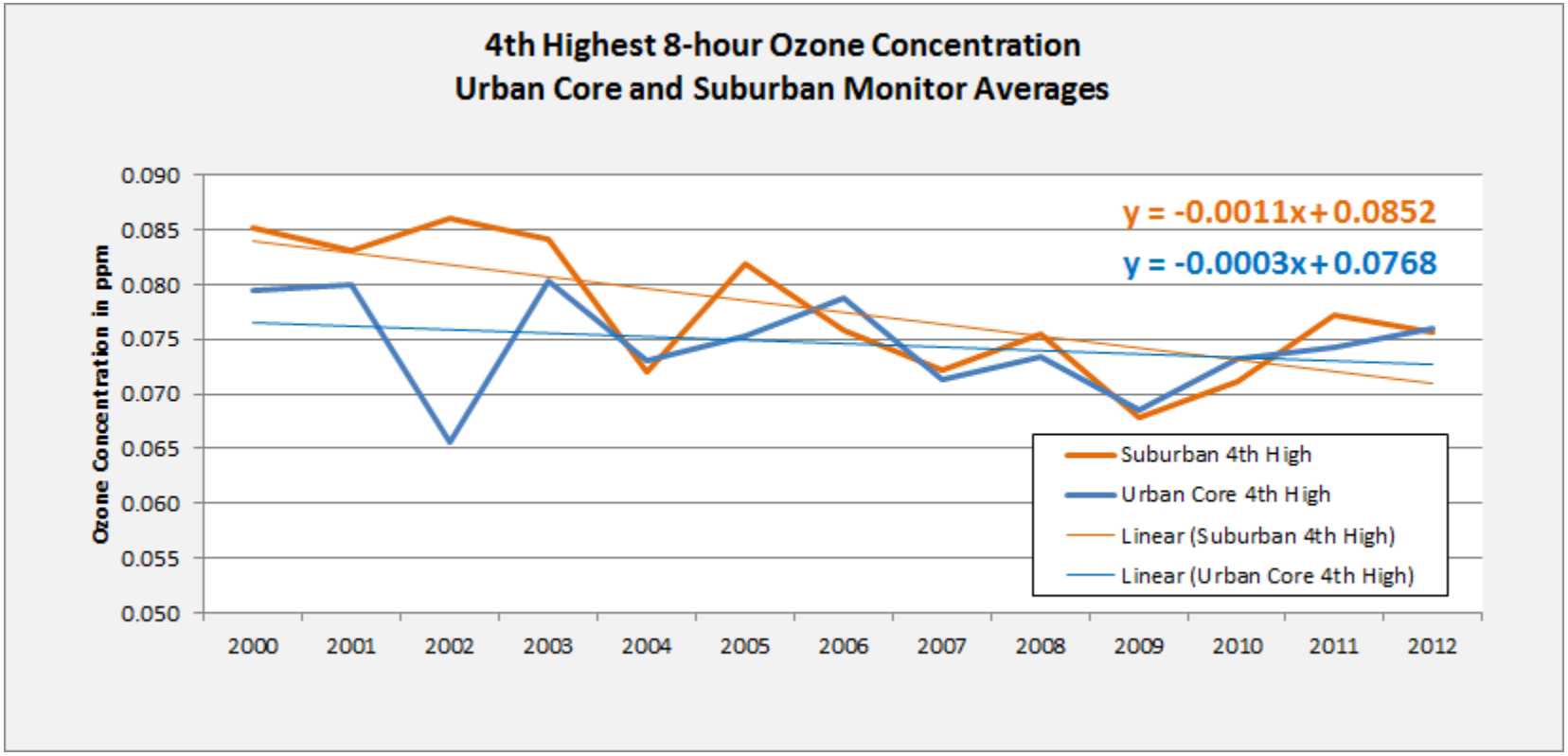


- 2012 has largest number of potential fire impacts during 2008-2012
- 2011 has a relatively low number of fire impact days

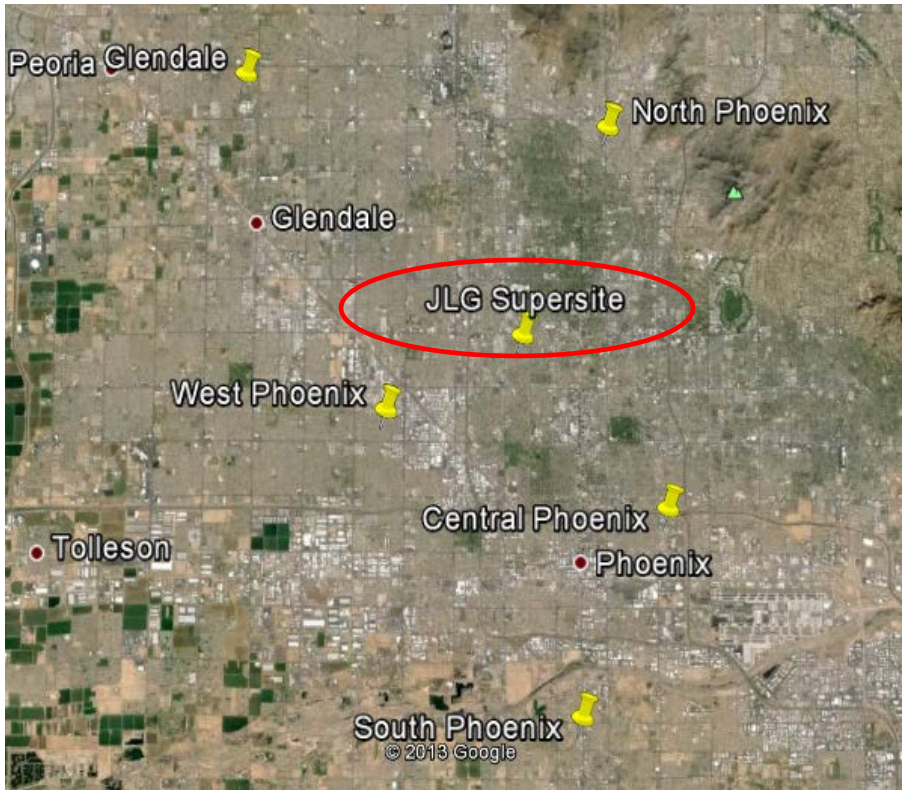
Maricopa Urban Core and Suburban Ozone Monitors



Ozone Trends in Urban and Suburban Monitors
4th Highest Value

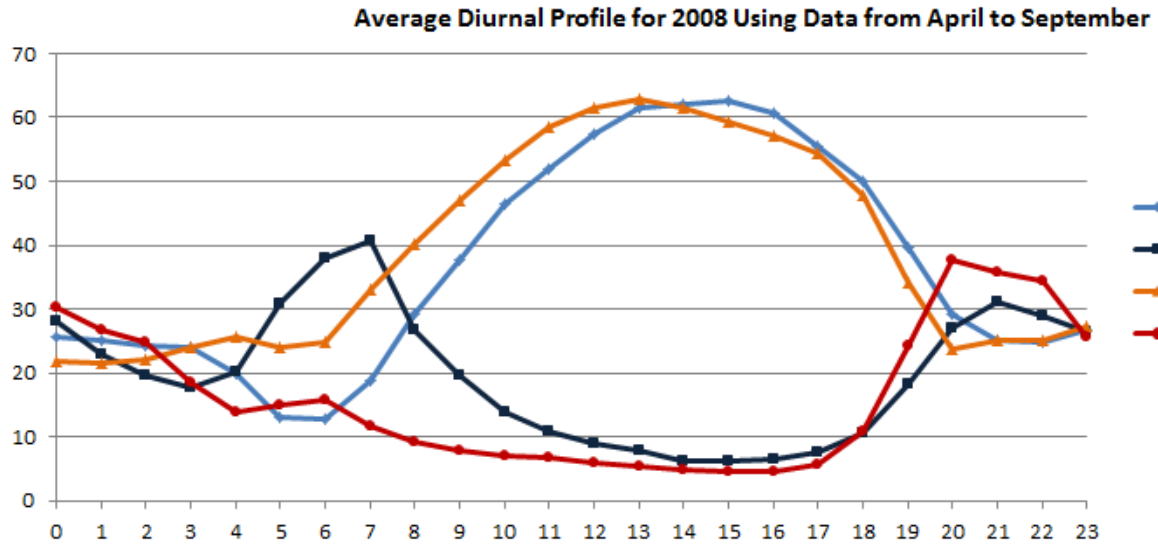


Weekday/Weekend Analysis

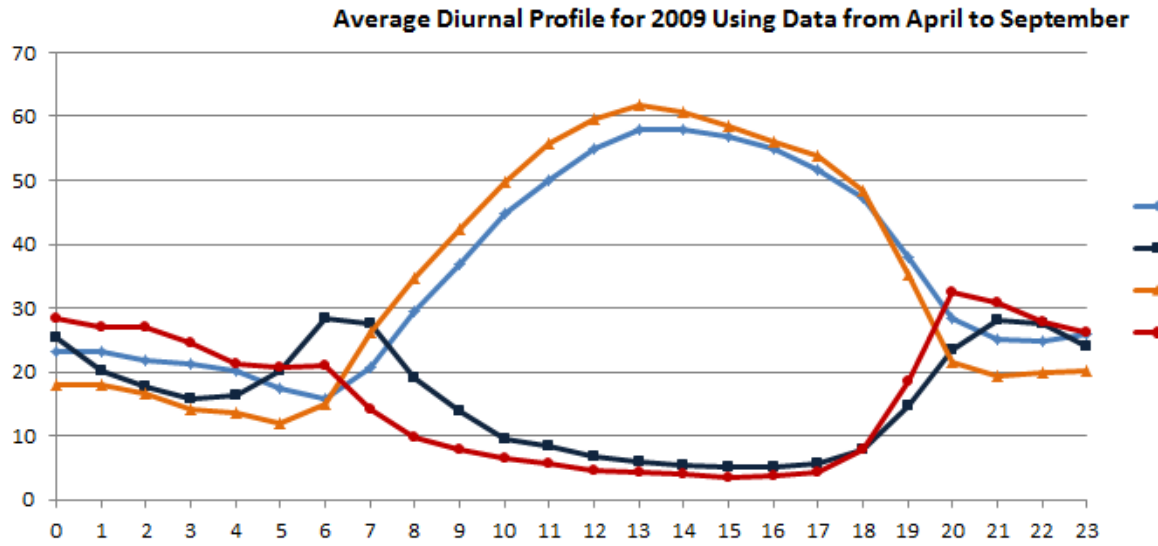


- Is ozone formation NOx-limited or VOC-limited?
- JLG Supersite NOx, ozone data
- April-September, 2008-2011
  - Sunday: weekend
  - Wednesday: weekday

Weekday/Weekend Analysis

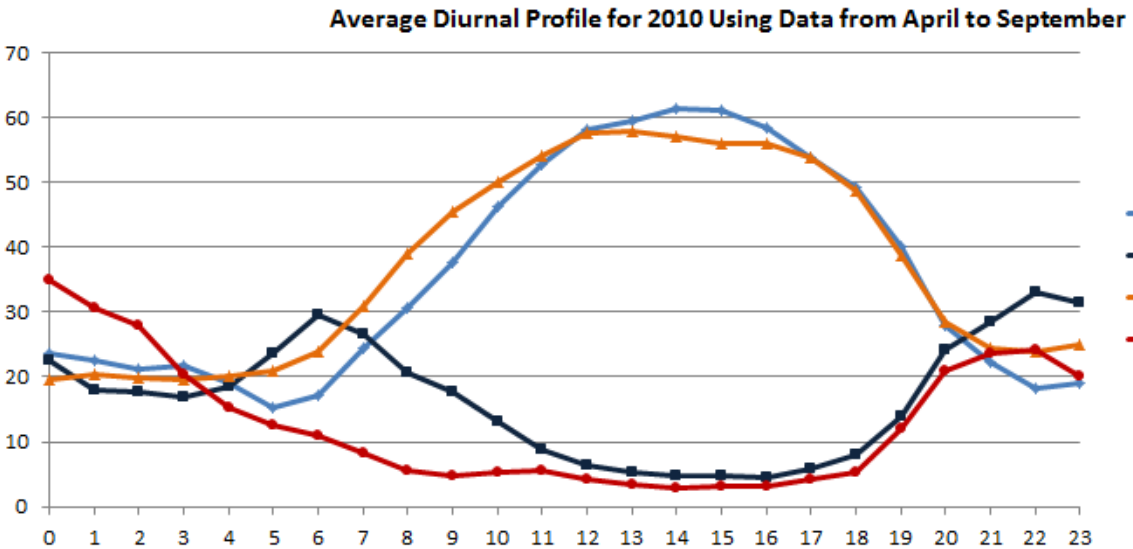


	Number of points in average
Wednesday Ozone (ppb)	26
Wednesday NOx (ppb)	23
Sunday Ozone (ppb)	25
Sunday NOx (ppb)	23

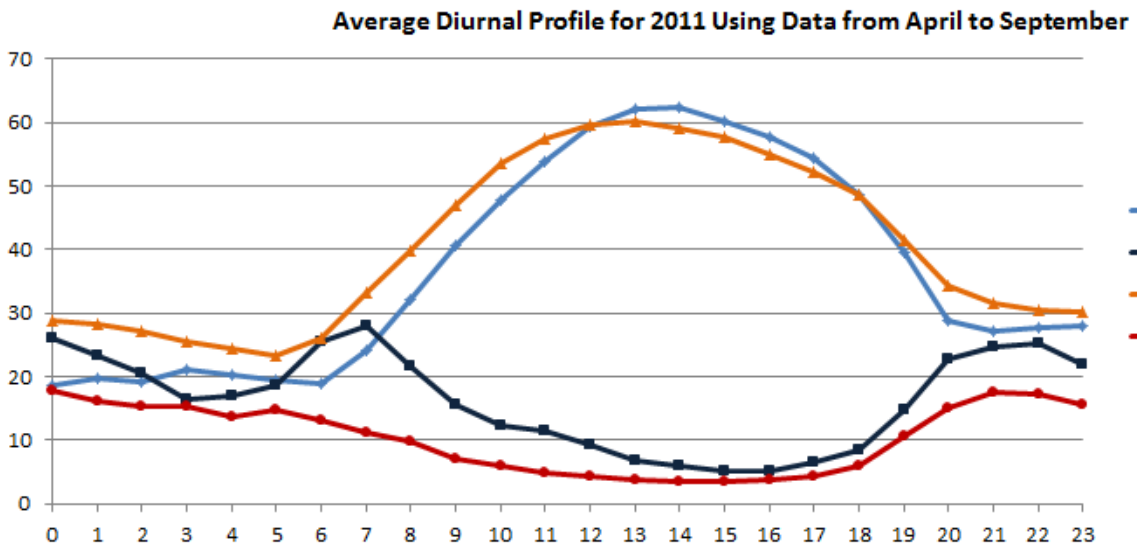


	Number of points in average
Wednesday Ozone (ppb)	27
Wednesday NOx (ppb)	25
Sunday Ozone (ppb)	26
Sunday NOx (ppb)	23

Weekday/Weekend Analysis



	Number of points in average
Wednesday Ozone (ppb)	25
Wednesday NOx (ppb)	17
Sunday Ozone (ppb)	26
Sunday NOx (ppb)	16



	Number of points in average
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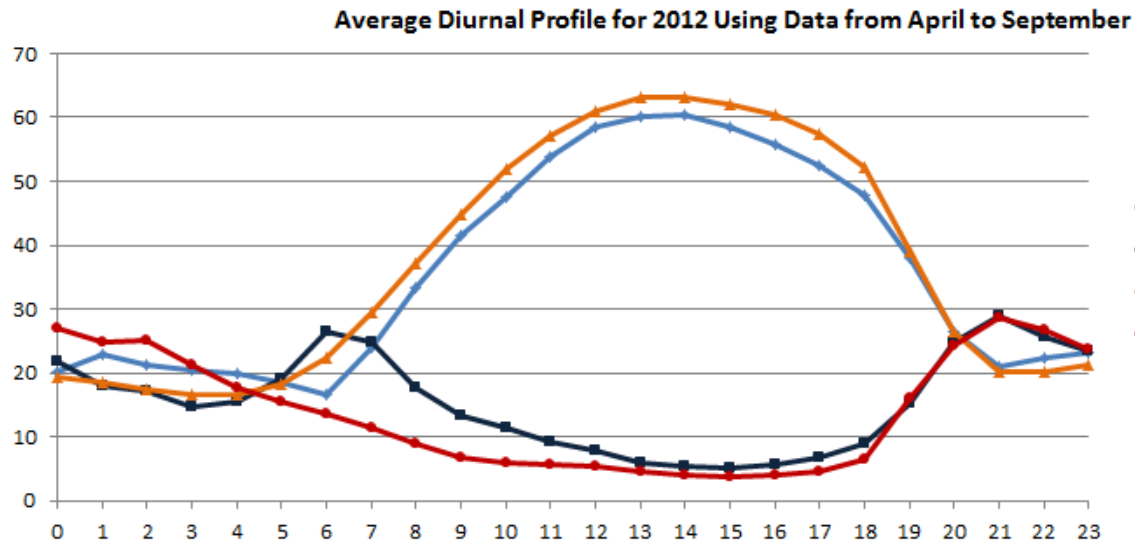
Wednesday NOx (ppb)	26
Sunday Ozone (ppb)	25
Sunday NOx (ppb)	25

Weekday/Weekend Analysis

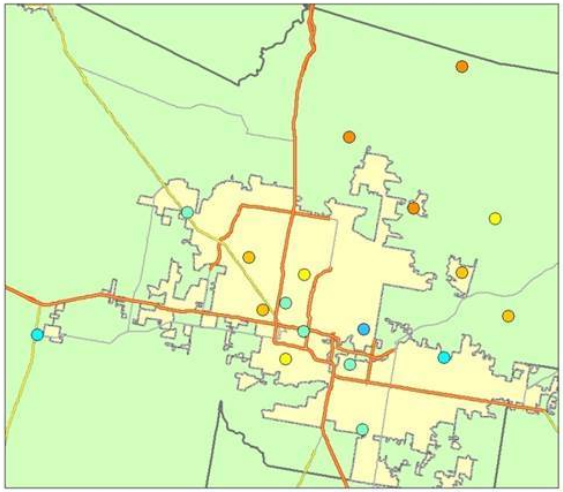


	Number of points in average
Wednesday Ozone (ppb)	23
Wednesday NOx (ppb)	24
Sunday Ozone (ppb)	25
Sunday NOx (ppb)	25

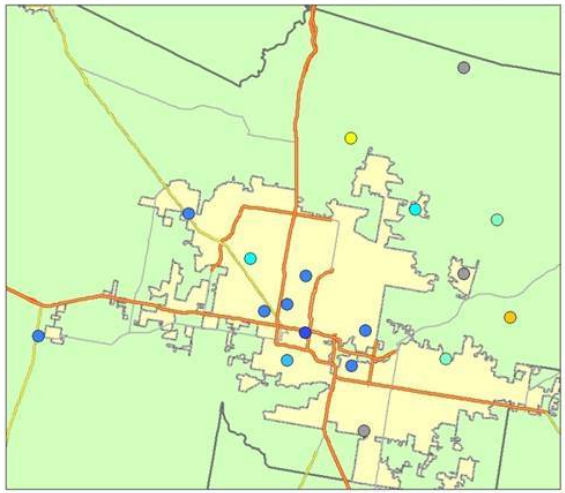
- Large NOx reduction Wed → Sun in all years
- Wed → Sun ozone response at JLG Supersite is inconsistent over years
- Analyze downwind monitors to determine whether ozone response is NOx-limited (or not)

Weekend-Weekday Ozone Peak Difference

2008



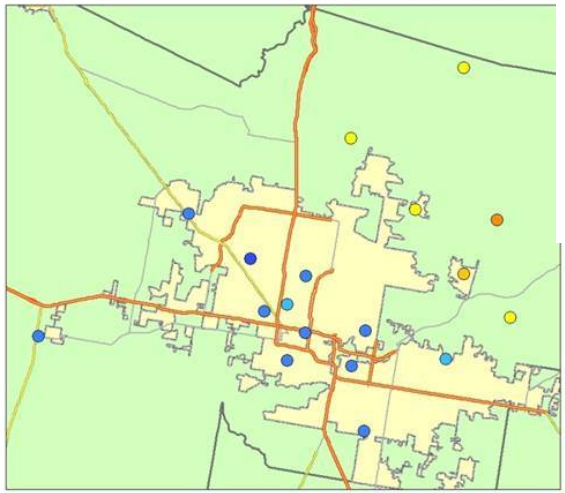
2009

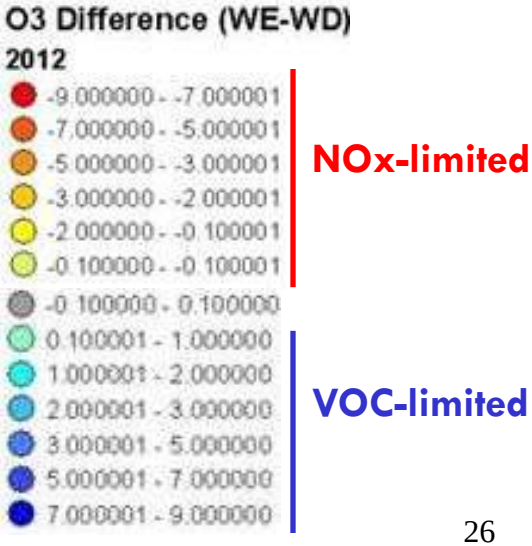


2010

2011

2012





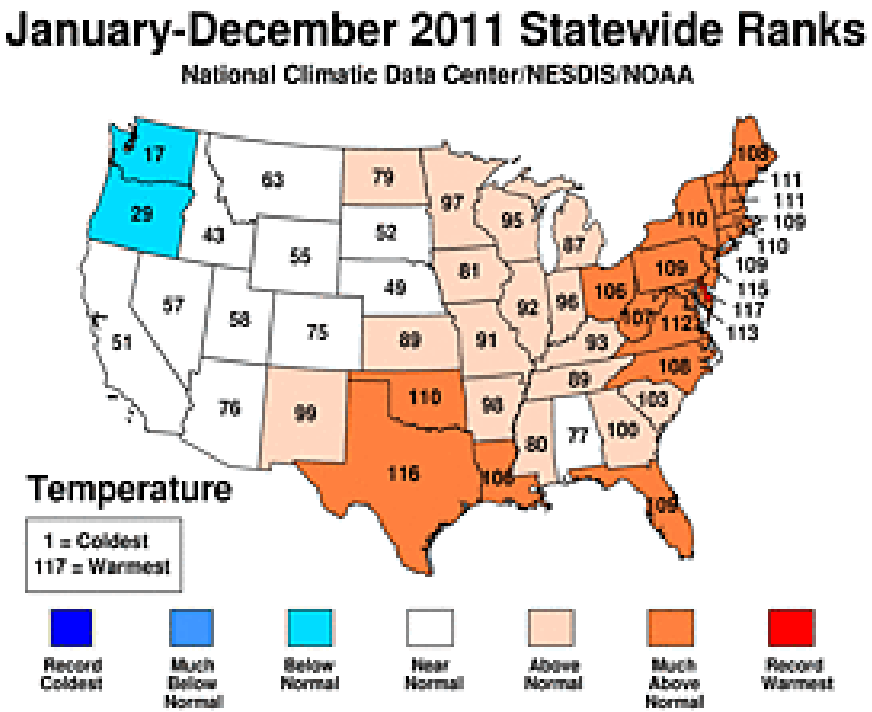
Weekday/Weekend Analysis Results

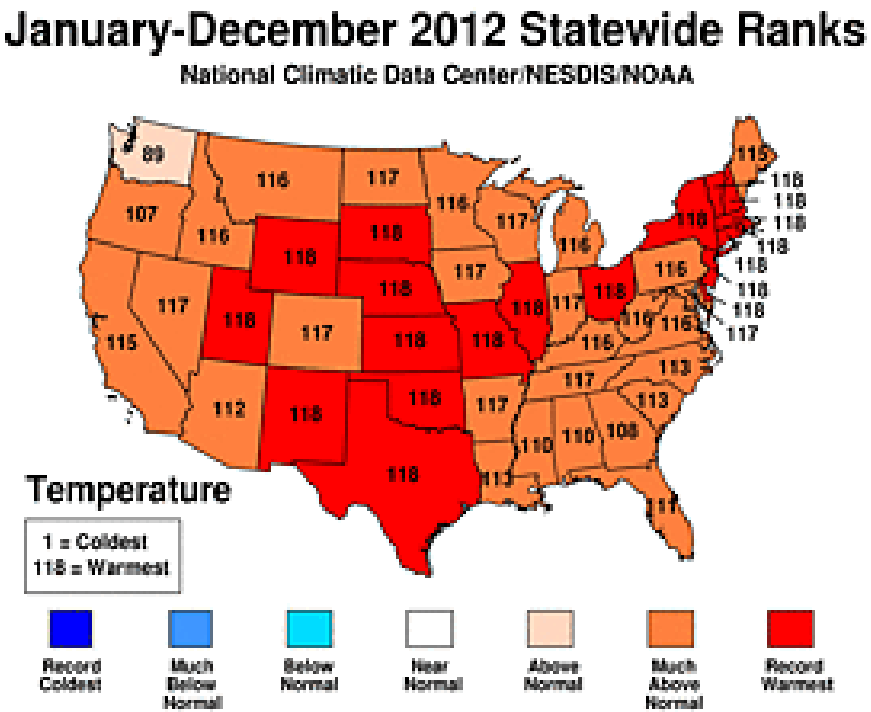
- Suburban sites northeast of urban core are NOx-limited except in 2009
- Buckeye is always VOC-limited
- Urban core sites behave as a bloc except in 2008
  - Urban core sites vary together between being VOC- and NOx-limited
- In 2011, urban core sites are NOx-limited, while Non-Attainment Area EI suggests NA is VOC-limited (VOC/NOx emission ratio = 6.2)

Meteorological/Climatic Conditions

- Tested many hypotheses for meteorological influences on ozone in Maricopa County from 2002-2012
- Temperature, cloud cover, precipitation, wind speed, wind direction, sea level pressure, stagnant winds, wind reversals, El Nino phase, North American Monsoon strength

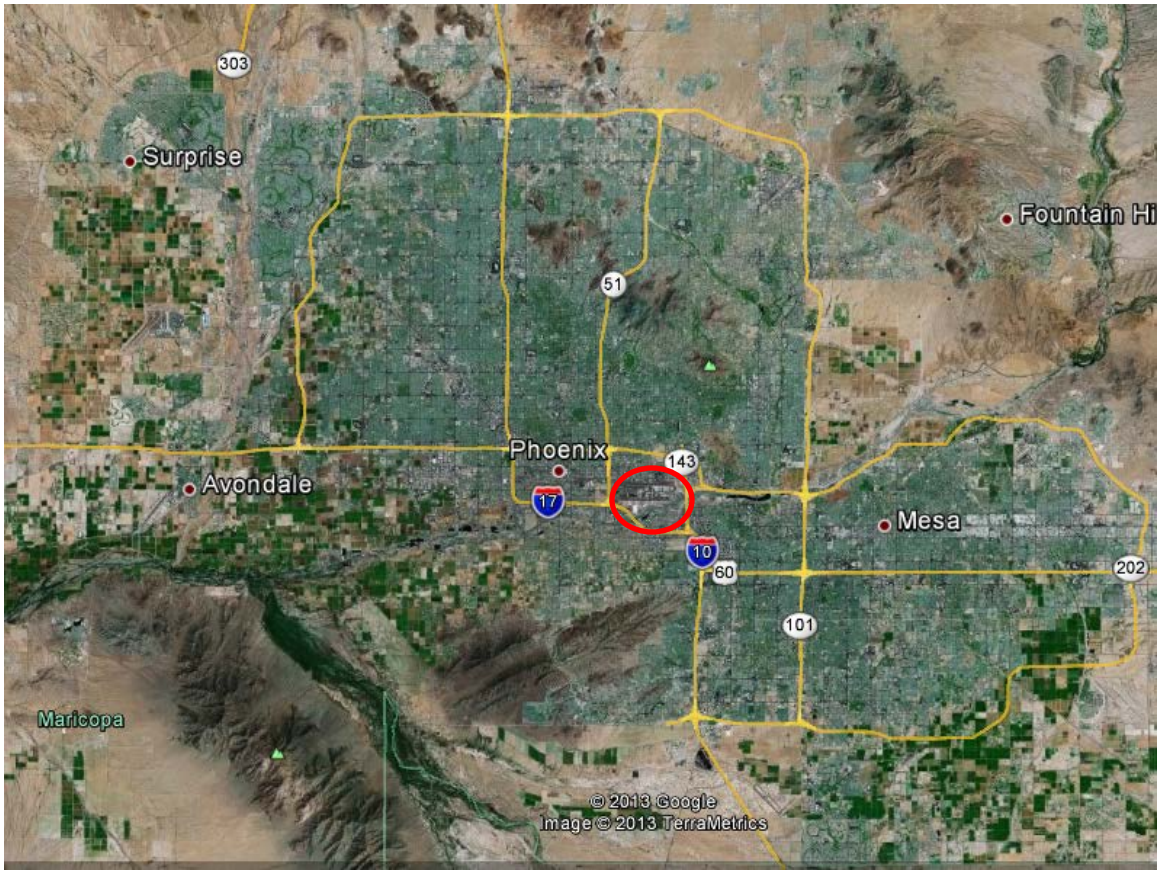
2011-2012 Temperatures in Arizona





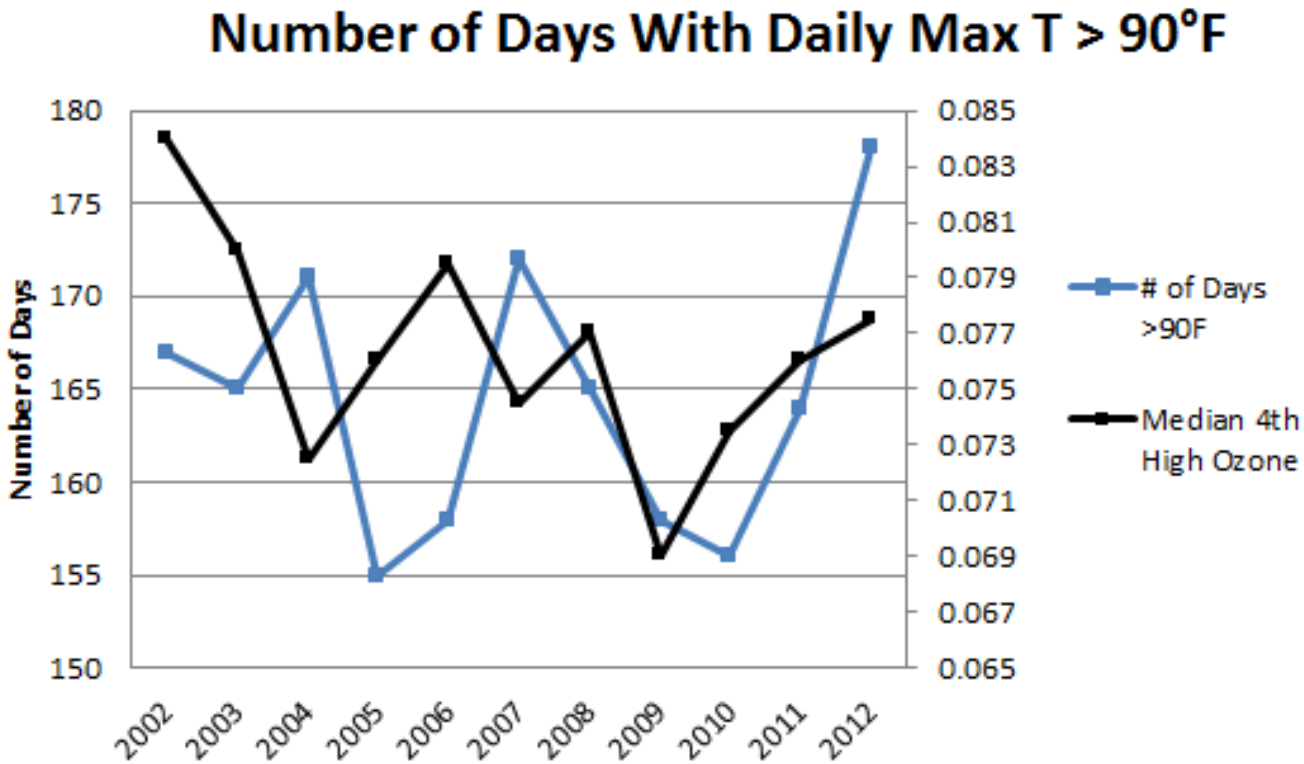
- 2012 was the 112th highest year out of the 118 year record
- 2011 was near normal

Influence of Meteorological Conditions on 2011-2012 Ozone in Maricopa County:



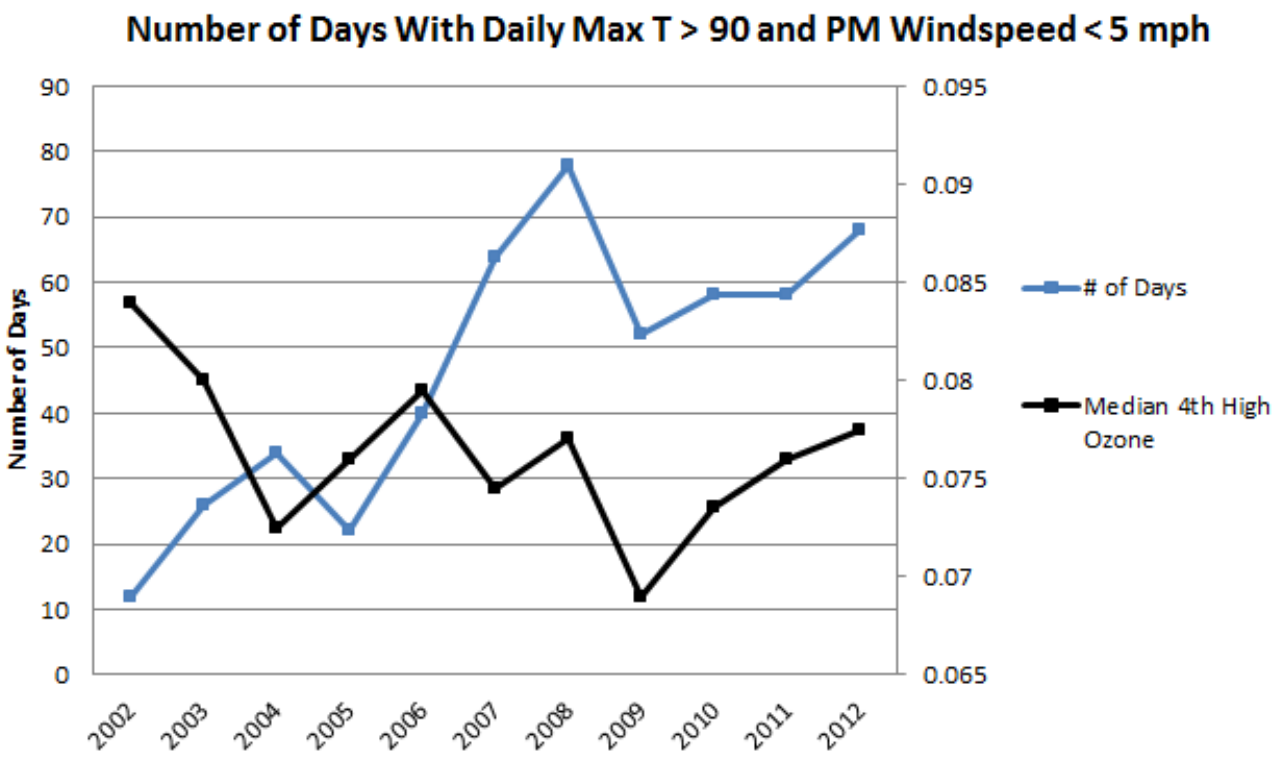
- Data for Phoenix Sky Harbor Airport from ds3505
  - Temperature
  - Wind speed, direction
  - Precipitation
  - Cloud cover

Daily Max Temperatures



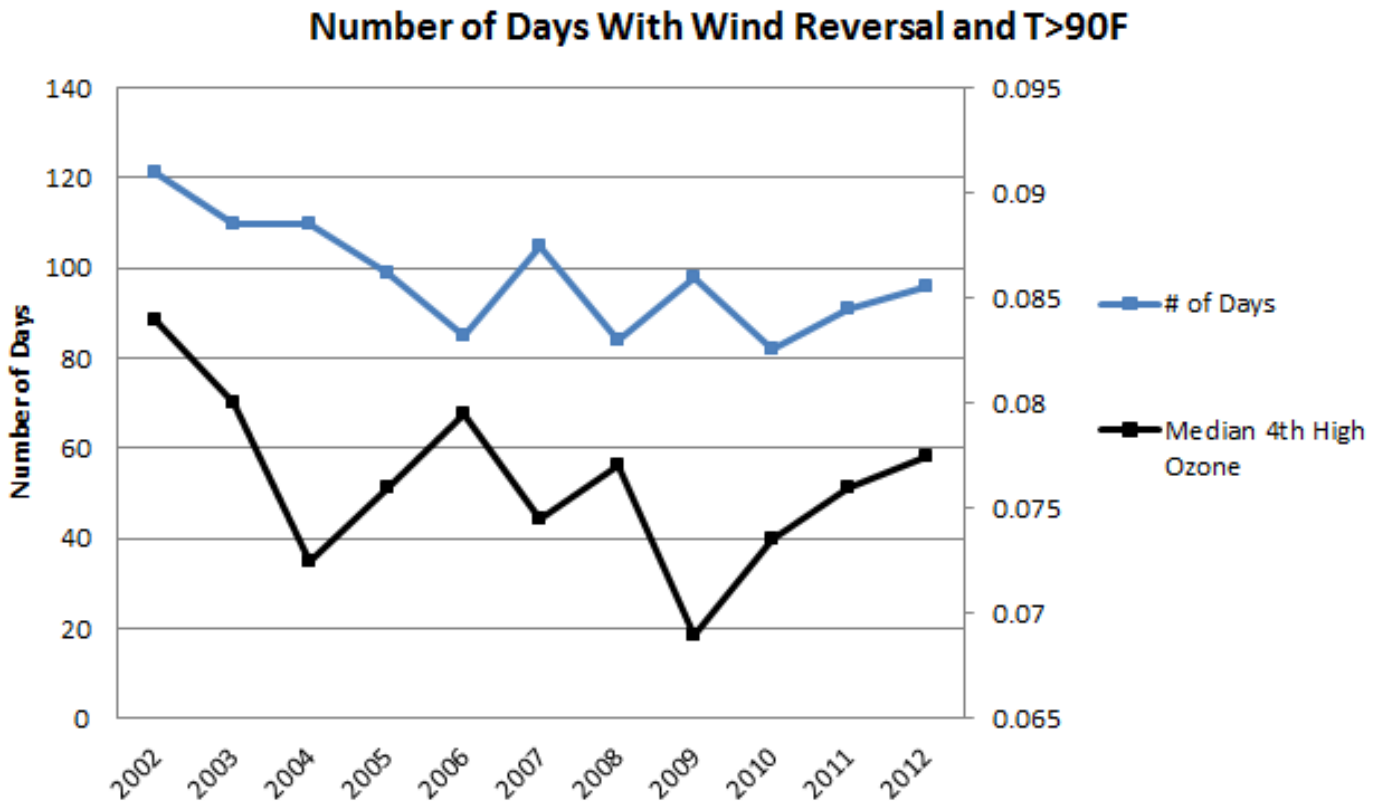
- 2012 had the highest number of days >90°F in the last decade
- 2002-2012 correlation coefficient with Maricopa median 4th high is 0.2

T>90F and Light Afternoon Winds



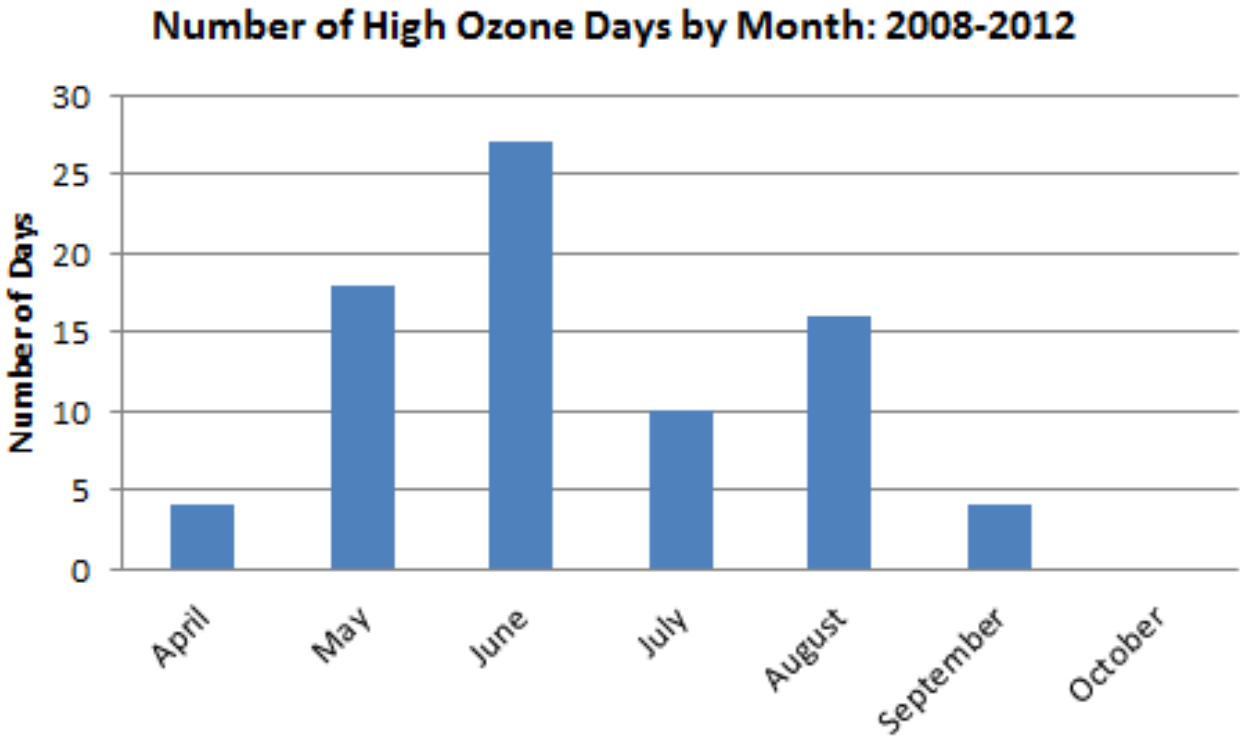
- 2008-2012 correlation coefficient is 0.8
- 2002-2012 correlation coefficient is -0.4

Wind Reversal and T>90°F



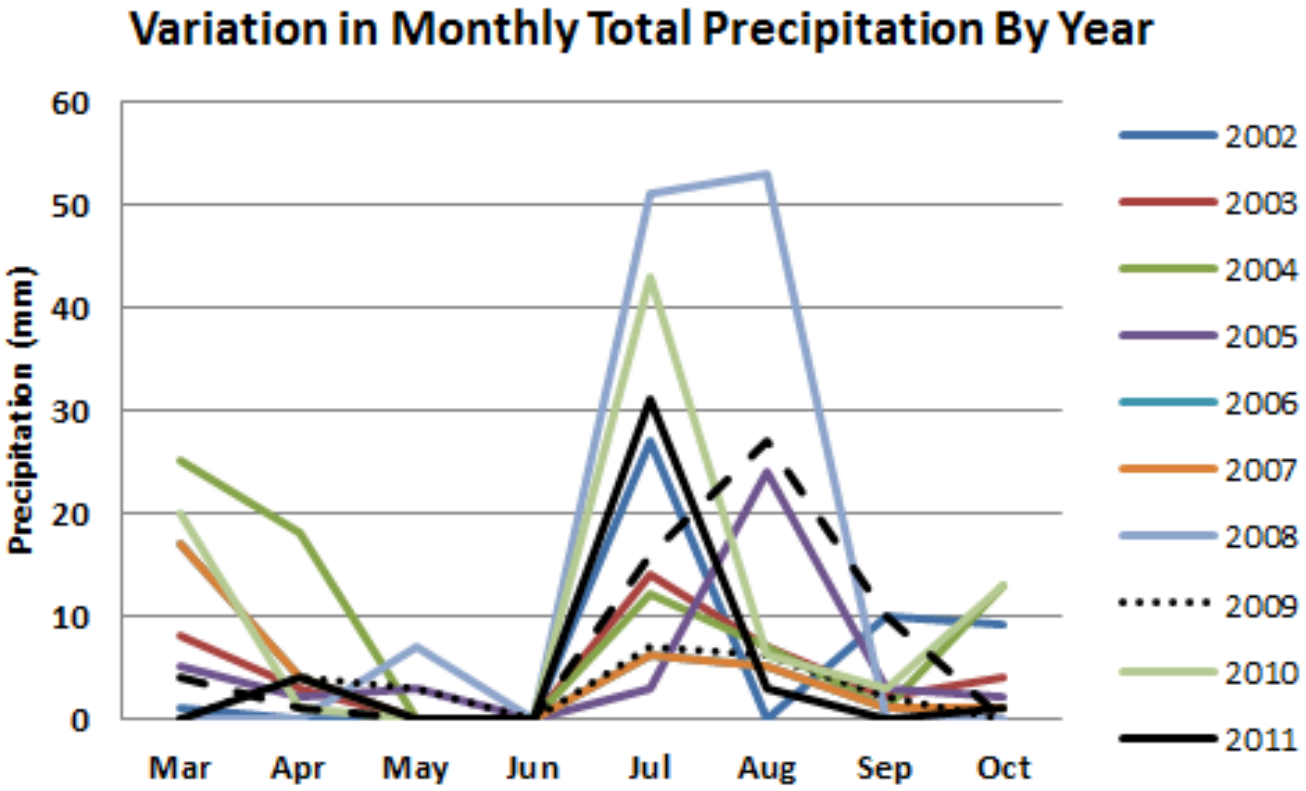
- Wind rose analysis showed winds frequently from east in am, west in pm
- Correlation coefficient is 0.3

Maricopa High Ozone Days by Month



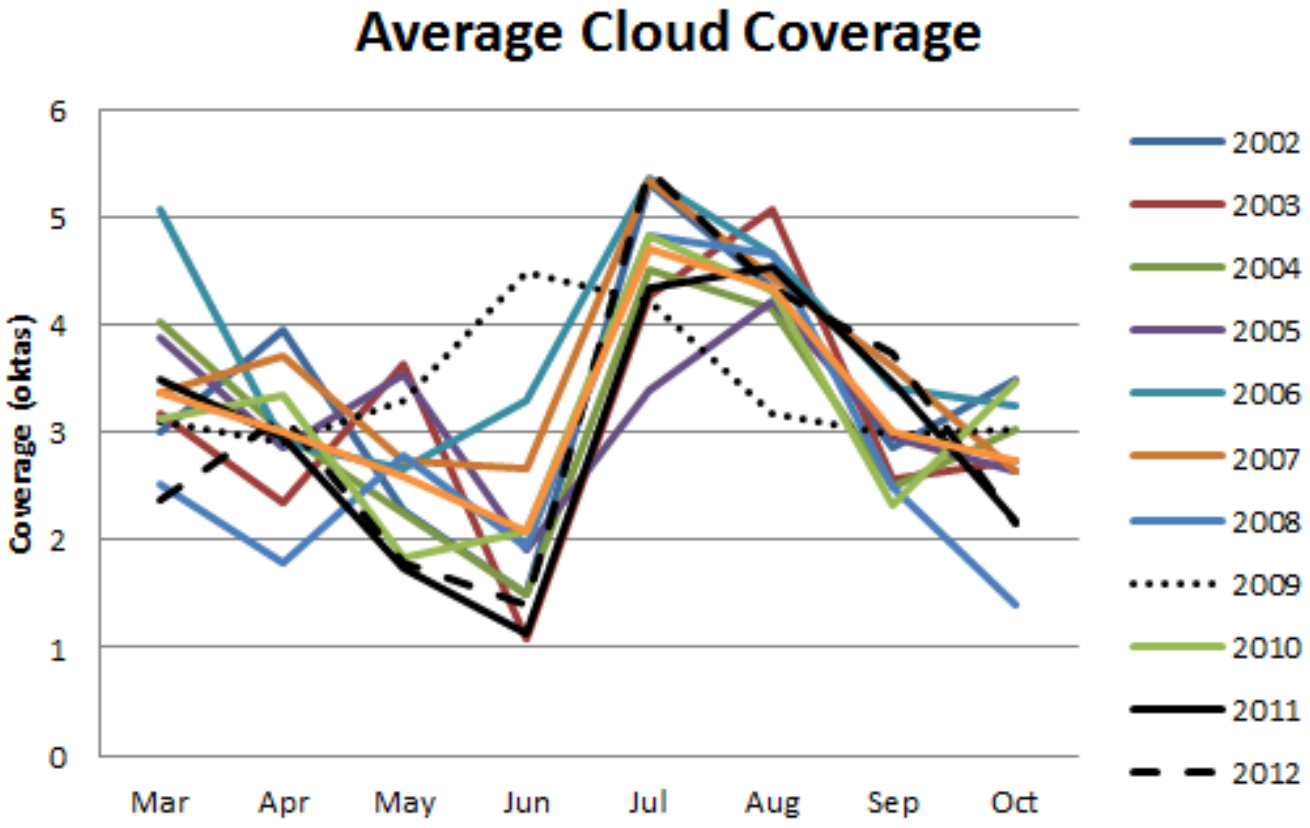
- May, June and August had the most high ozone days
- July has lower number of days due to monsoon onset

Precipitation



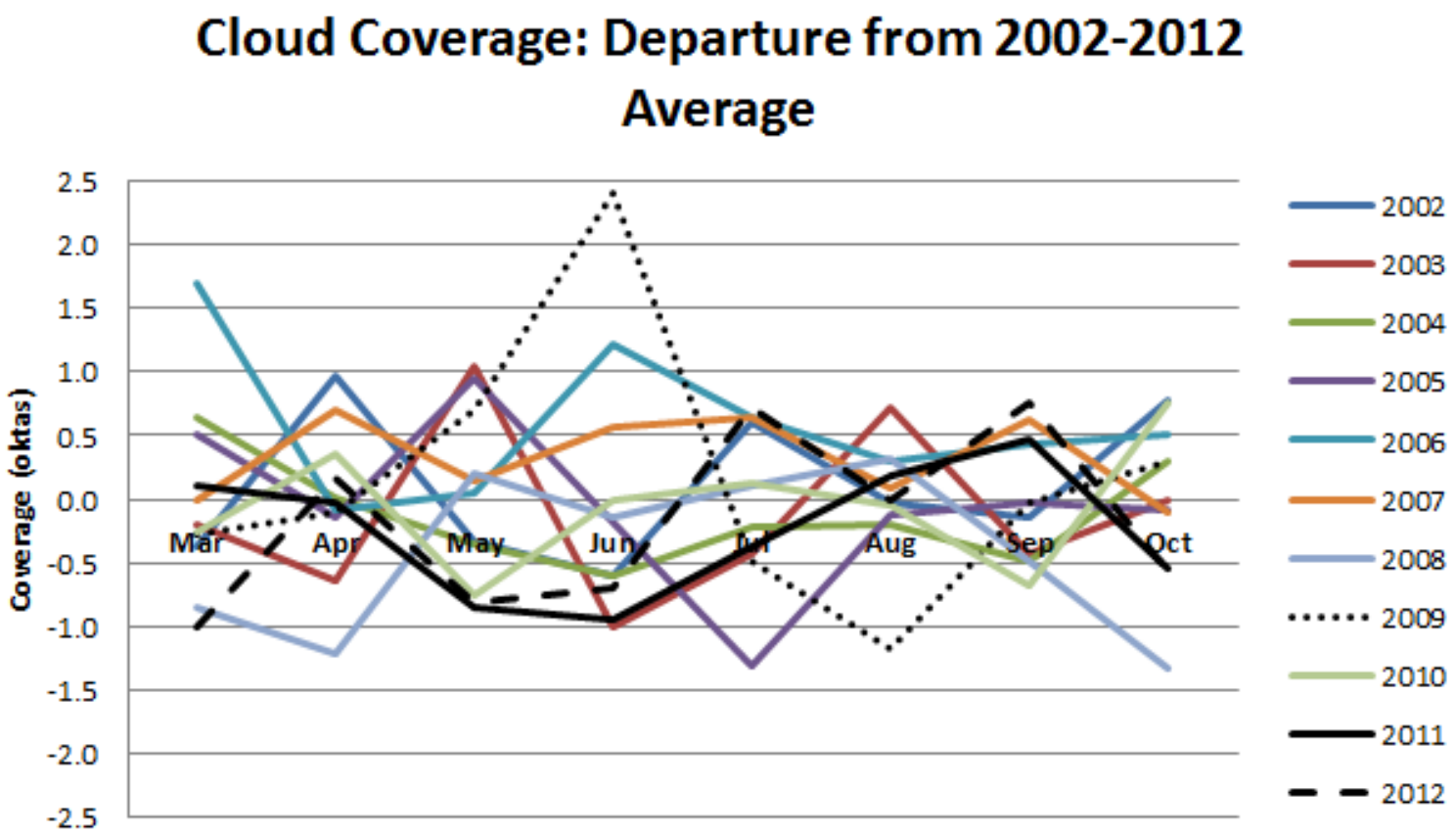
- Influence of North American Monsoon on rainfall distribution by month
- Not especially dry in 2011-2012

Cloud Cover



- Minimum in cloudiness in June, maximum in July-August
- 2011 and 2012 have less than usual cloudiness in May-June (wildfires in June 2011)

Cloud Cover

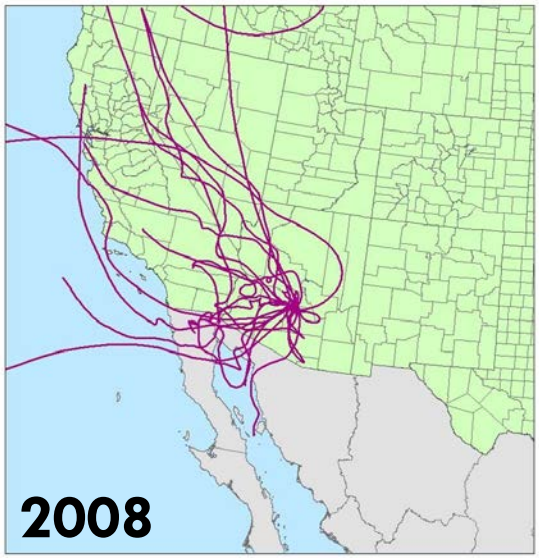


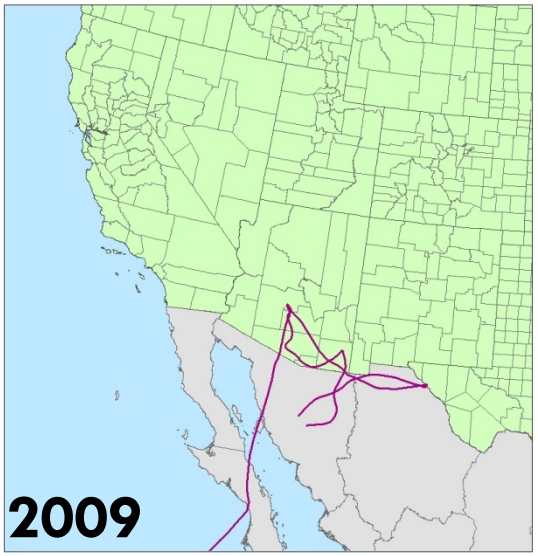
- 2009 was unusually cloudy during June, typically a month with a high frequency of high ozone days

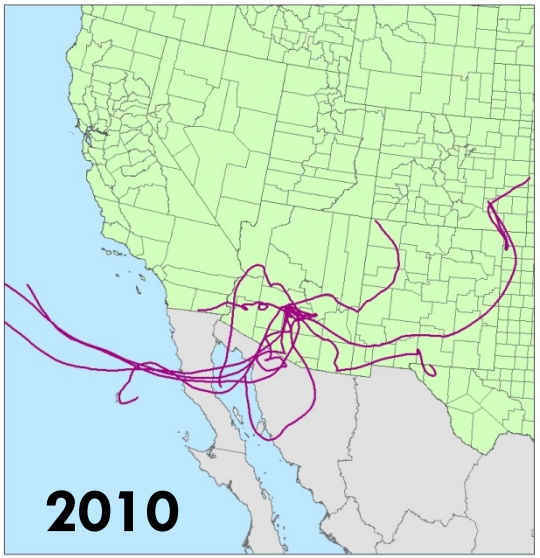
Transport Patterns

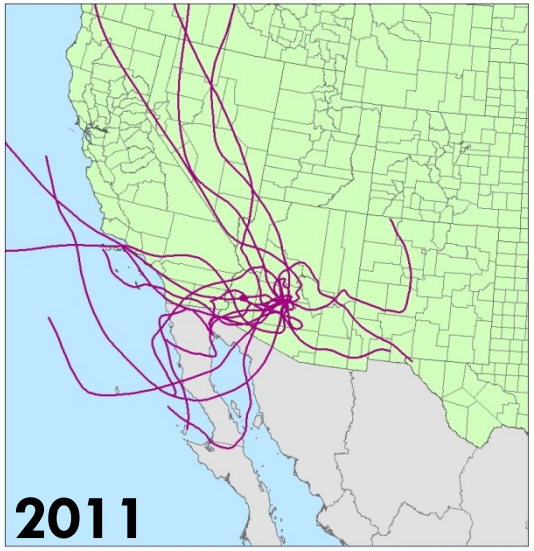
- 3 sets of HYSPLIT back trajectory plots for central Phoenix monitor:
  - All days in each year from 2008-2012 when any Maricopa County monitor had daily max 8-hour ozone:
    - > 75 ppb (High ozone)
    - Between 65 ppb and 75 ppb (moderately high ozone)
    - < 60 ppb (low ozone)
  - 72 hour back trajectory, ending at 1000 m AGL
- Are transport patterns different in 2011 and 2012 than during 2008-2010?

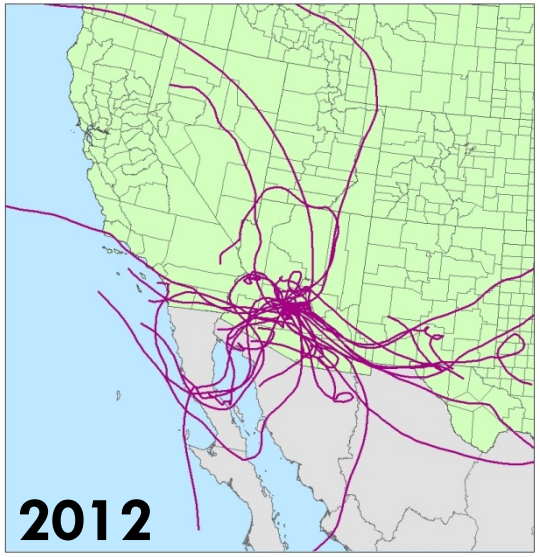
MDA8>75ppb



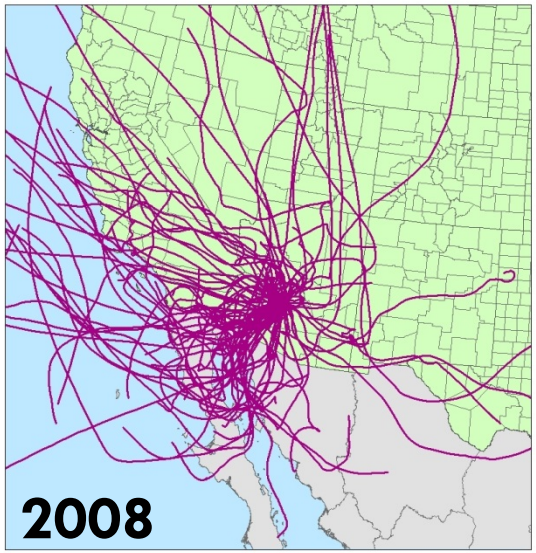


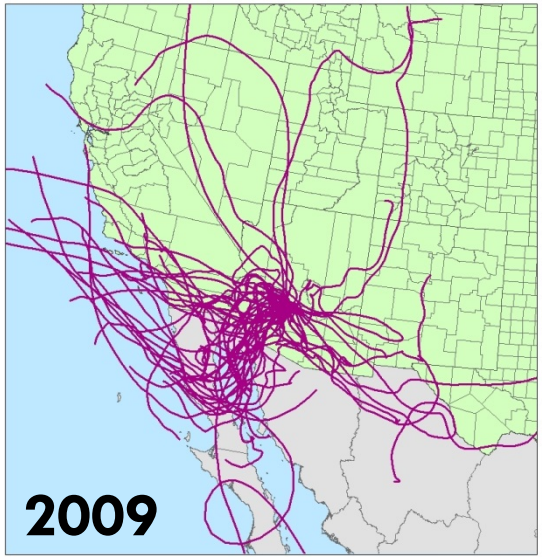


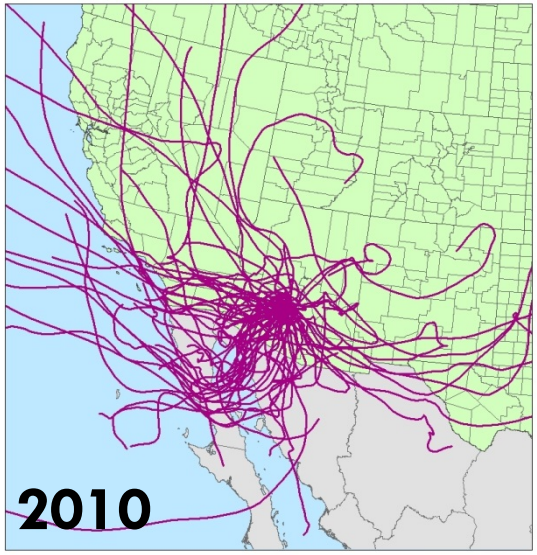


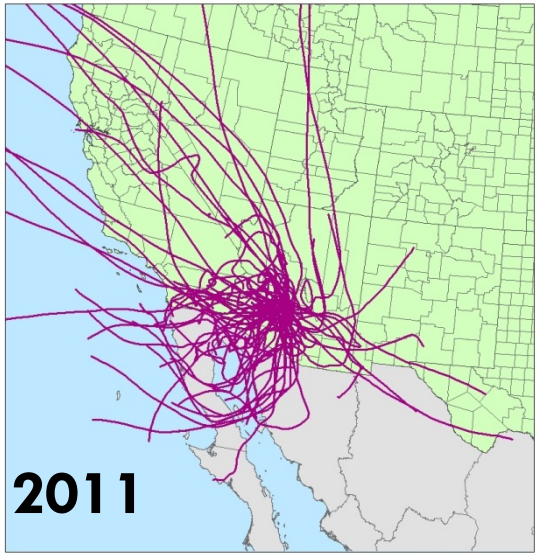


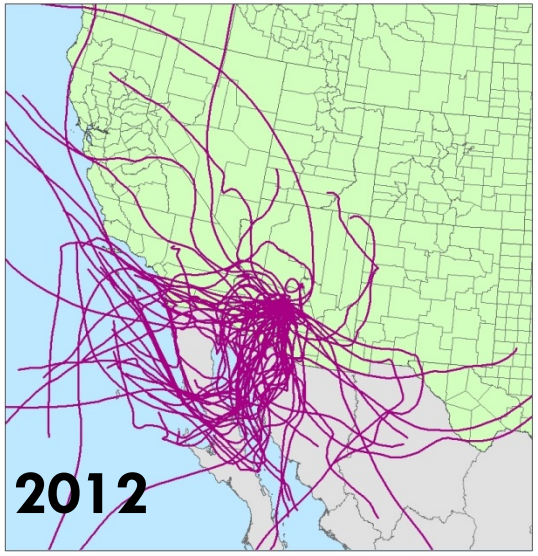
65 ≤ MDA8≤75 ppb



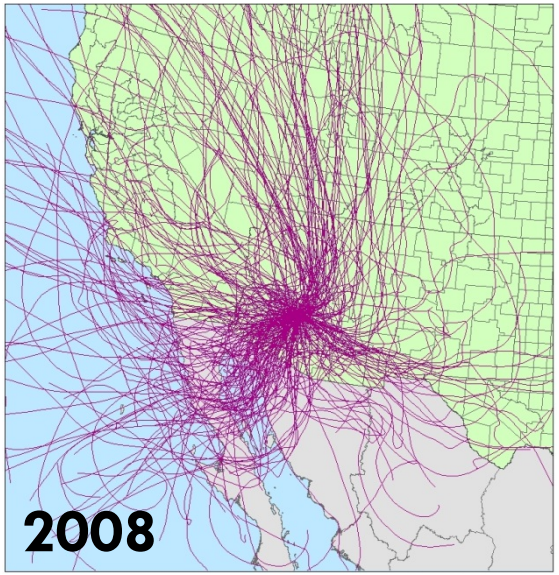


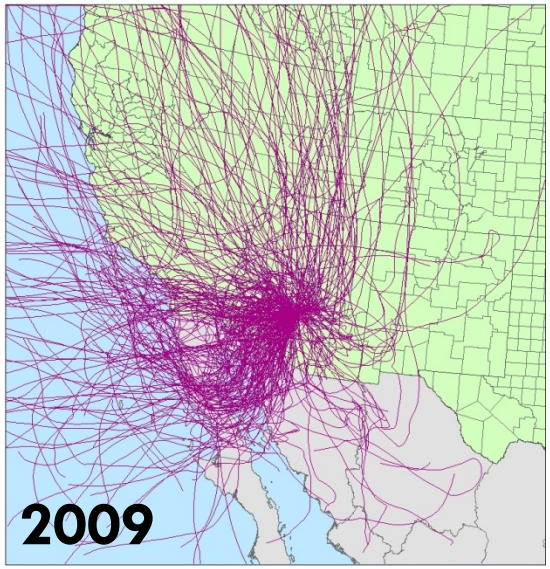


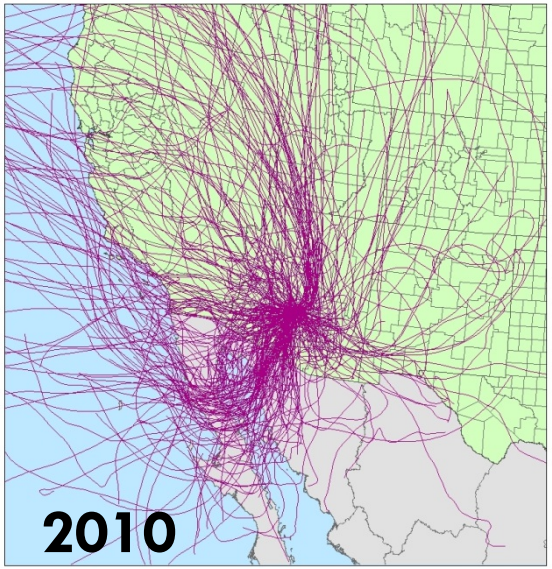


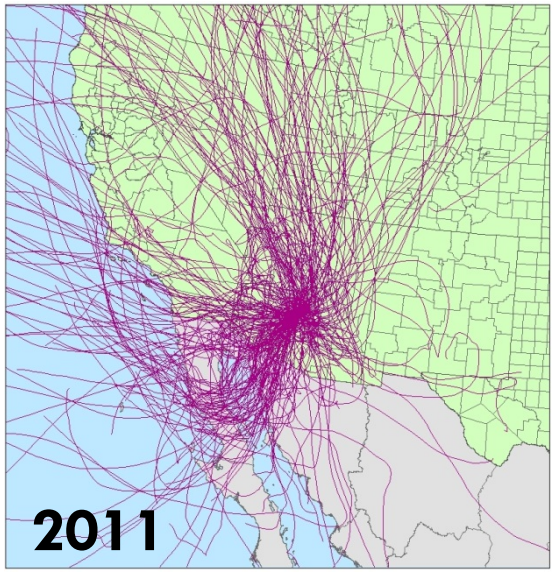


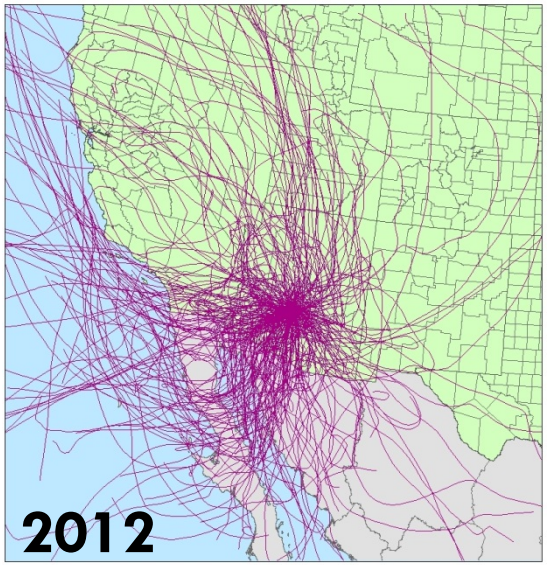
MDA8<60 ppb











HYSPLIT-Conclusions

- Clean days similar to high ozone days, except wind speeds generally higher
- Suggests that it is not transport changes that cause higher ozone in 2011-2012

Background Ozone

- EPA defines North American background (NAB)
  - From all natural sources (biogenic, fires, lightning, STE)
  - From anthropogenic sources outside NA
- Estimated from observations and models (25-50 ppb)
  - Both suggest events >50 ppb in western US
    - Fires, Asian plumes, spring STE events
    - Higher altitudes (>2 km) exposed to mid-tropospheric air
  - Variable by year, season, elevation, latitude/longitude
    - Driven by upper-level transport patterns and local natural sources
  - Evidence that ozone entering west coast is increasing 3-5 ppb/decade

Measured Spring Ozone Trend

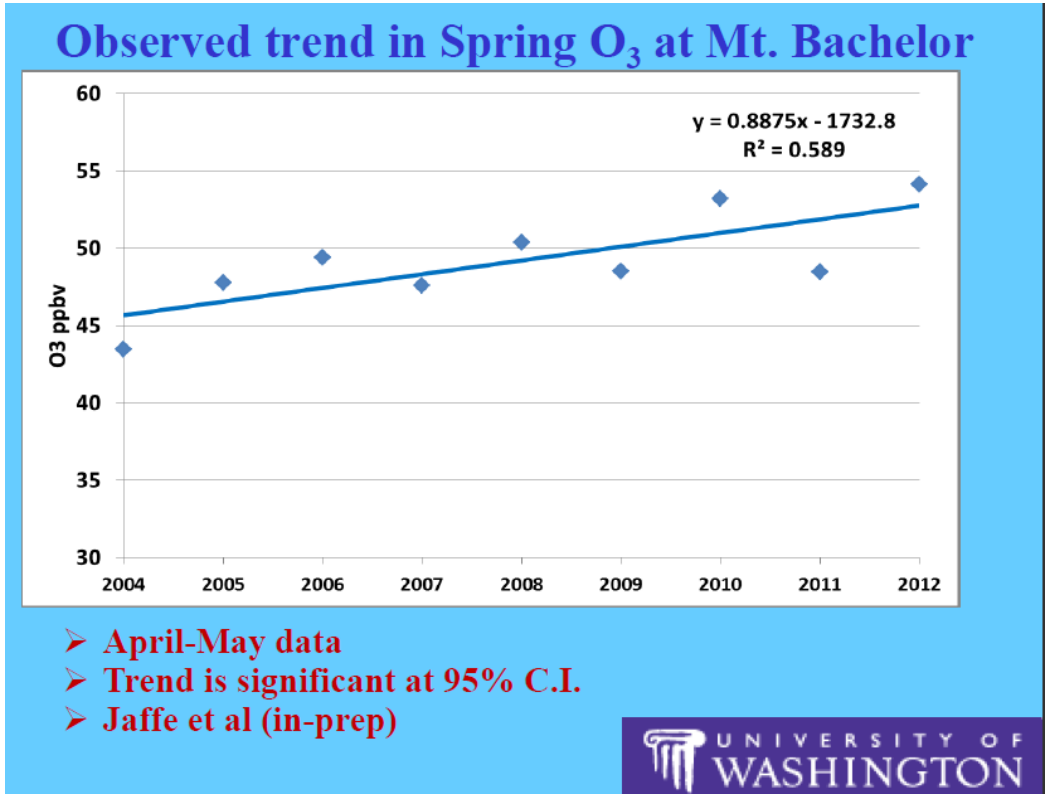


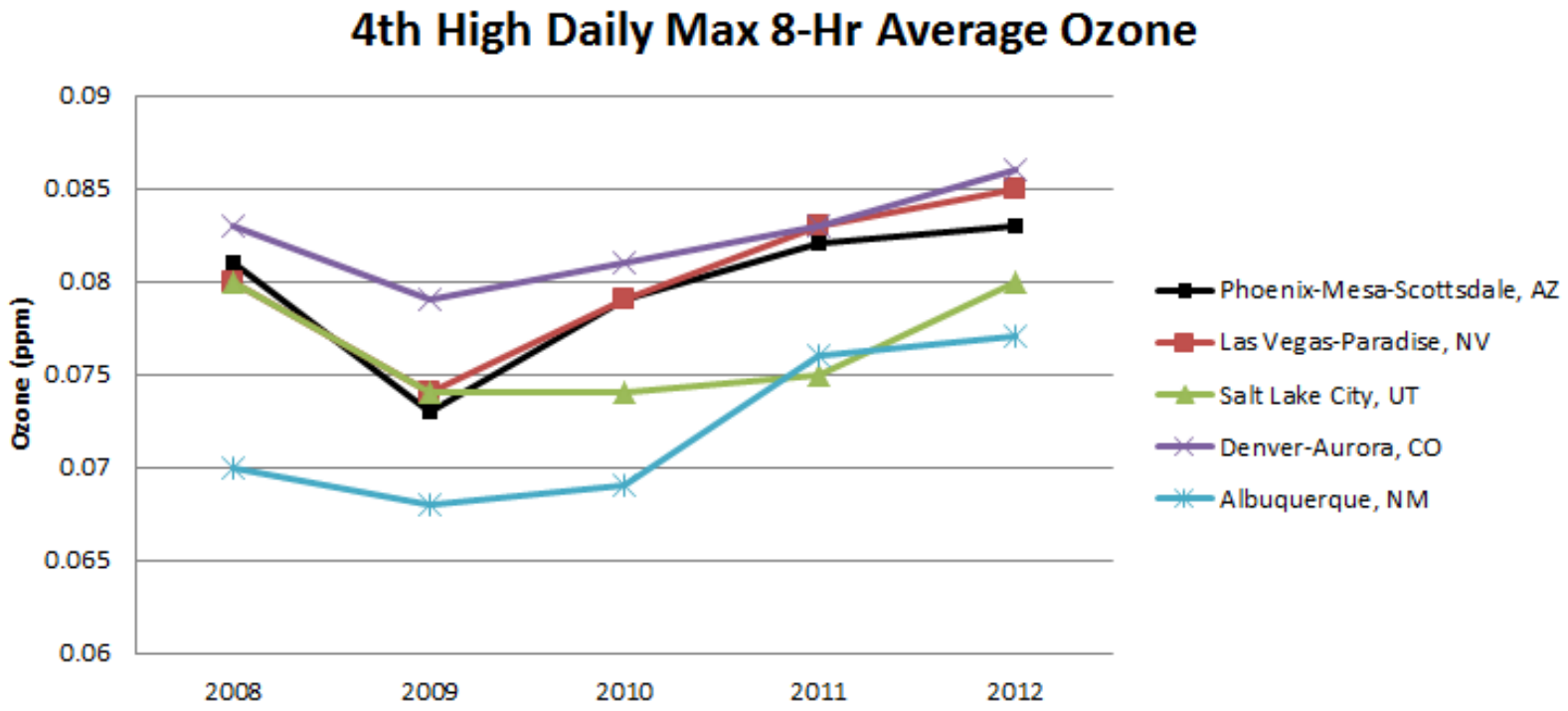
Figure from "The challenge of tropospheric ozone in the W. US" by Dan Jaffe, WESTAR/UNR Conference on Western Ozone Transport October 10, 2012

- Mt. Bachelor, 2004-2012: 0.89 ppbv/year
- Aircraft and sondes, 1995-2008: 0.63 ppbv/year (Cooper et al 2010).

Background Ozone in Phoenix

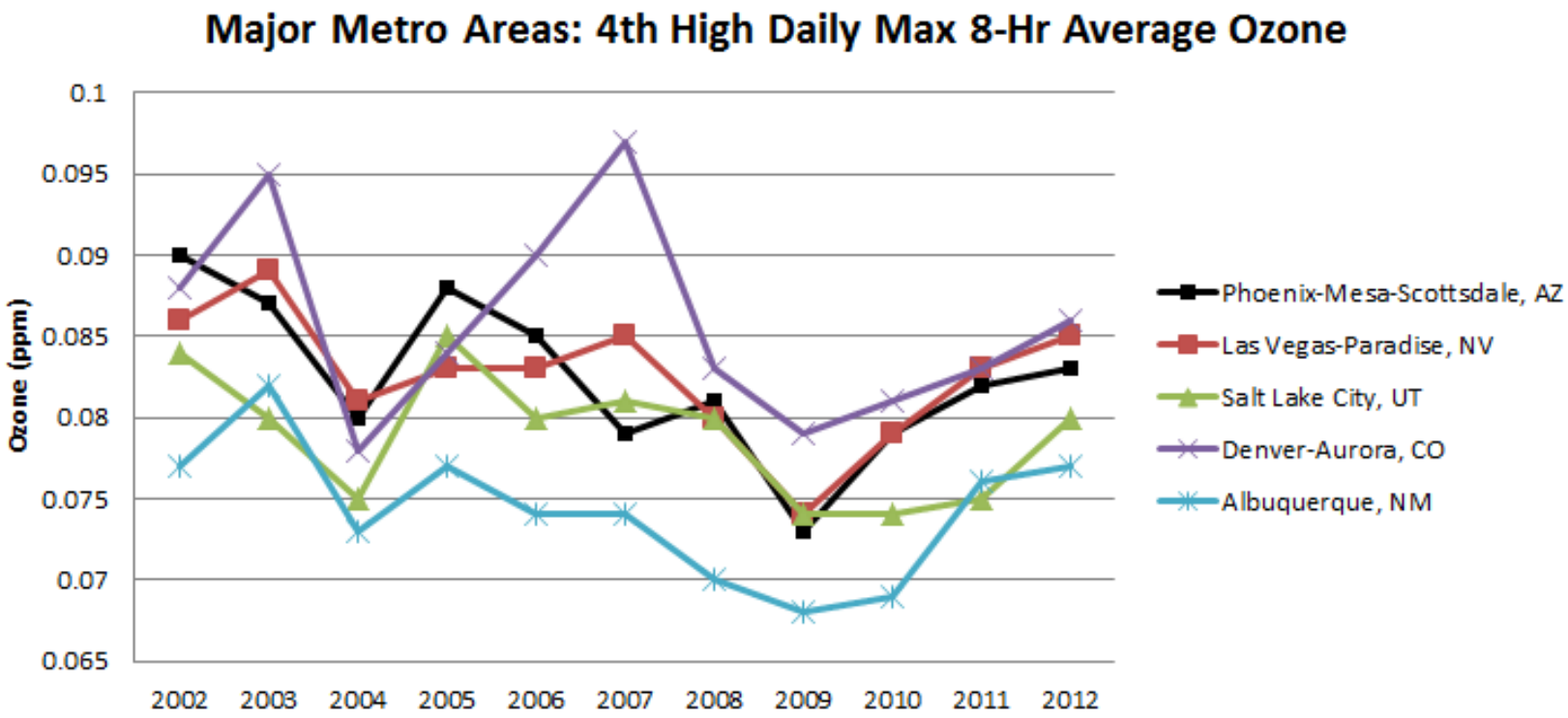
- Springtime STE influence
  - Strongest influence at high altitude/latitude sites
    - Little readily available information on STE activity over western US
    - Phoenix at relatively low altitude/latitude
    - AZDEQ forecasters suspect STE can play a role in spring ozone in Phoenix
- Summertime fire influence
  - Better evidence for recent Phoenix ozone increases
- Measurement and modeling studies are spatially/ temporally spotty
  - No routine/consistent data available to assess 2008-2012 background trends in Phoenix

2008-2012 Ozone Trends in Large Metro Areas in the Western U.S.



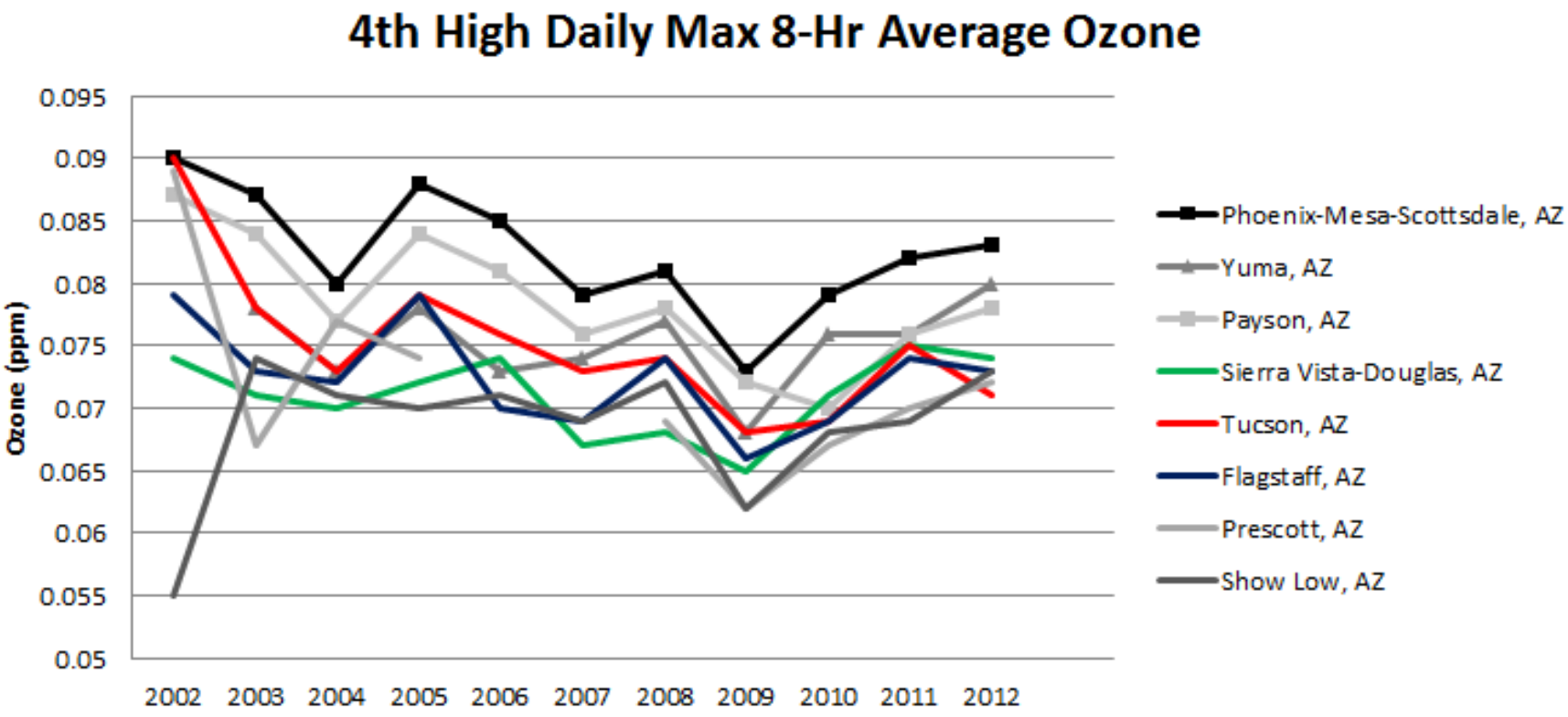
- All of these large metro areas have similar trend to Maricopa
  - Reduction in 2009 ozone relative to 2008
  - Increasing trend from 2009 to 2012

2002-2012 Ozone Trends in Large Metro Areas in the Western U.S.



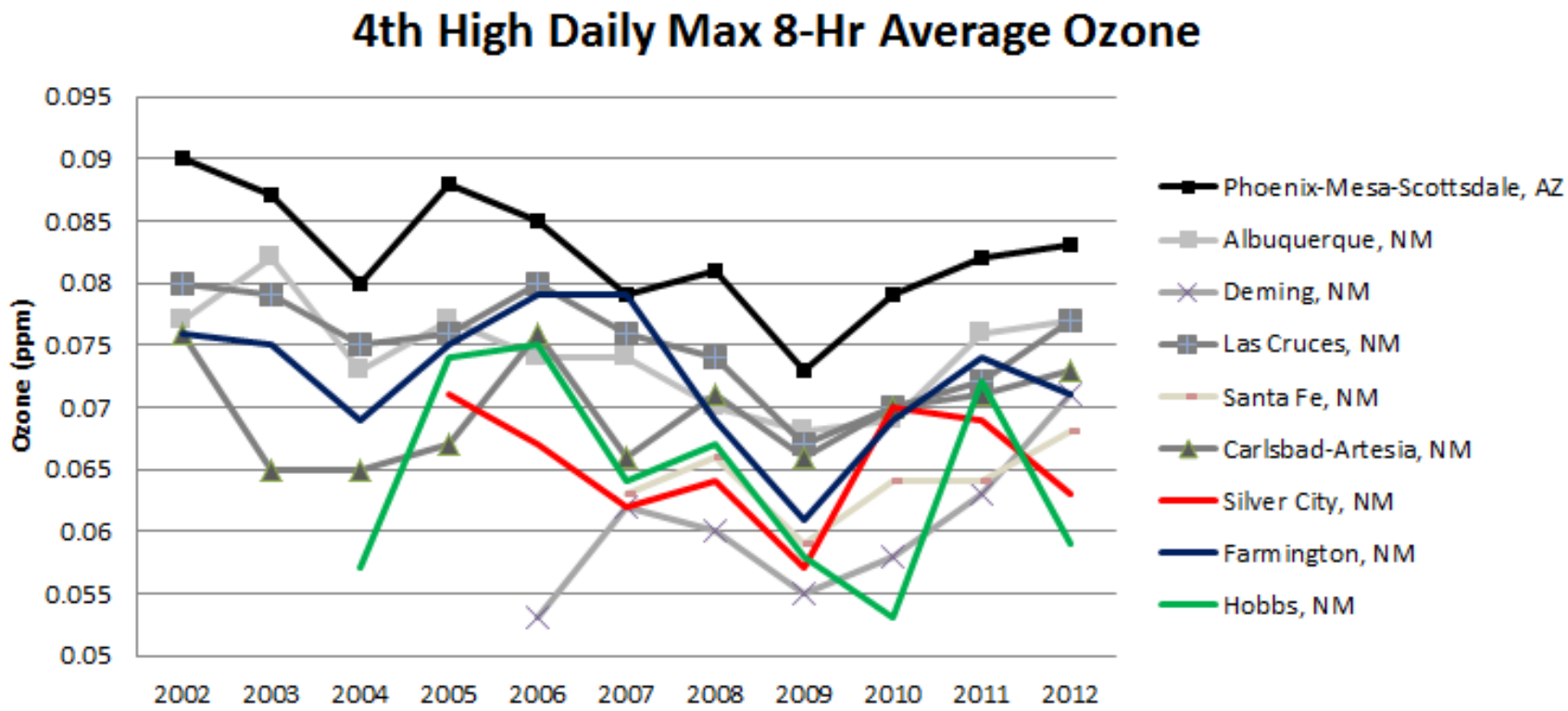
- All sites have relatively low ozone in 2004, 2009
- All sites have increasing trend 2010-2012
- Trends differ among monitors during 2005-2008

2002-2012 Ozone Trends: Arizona



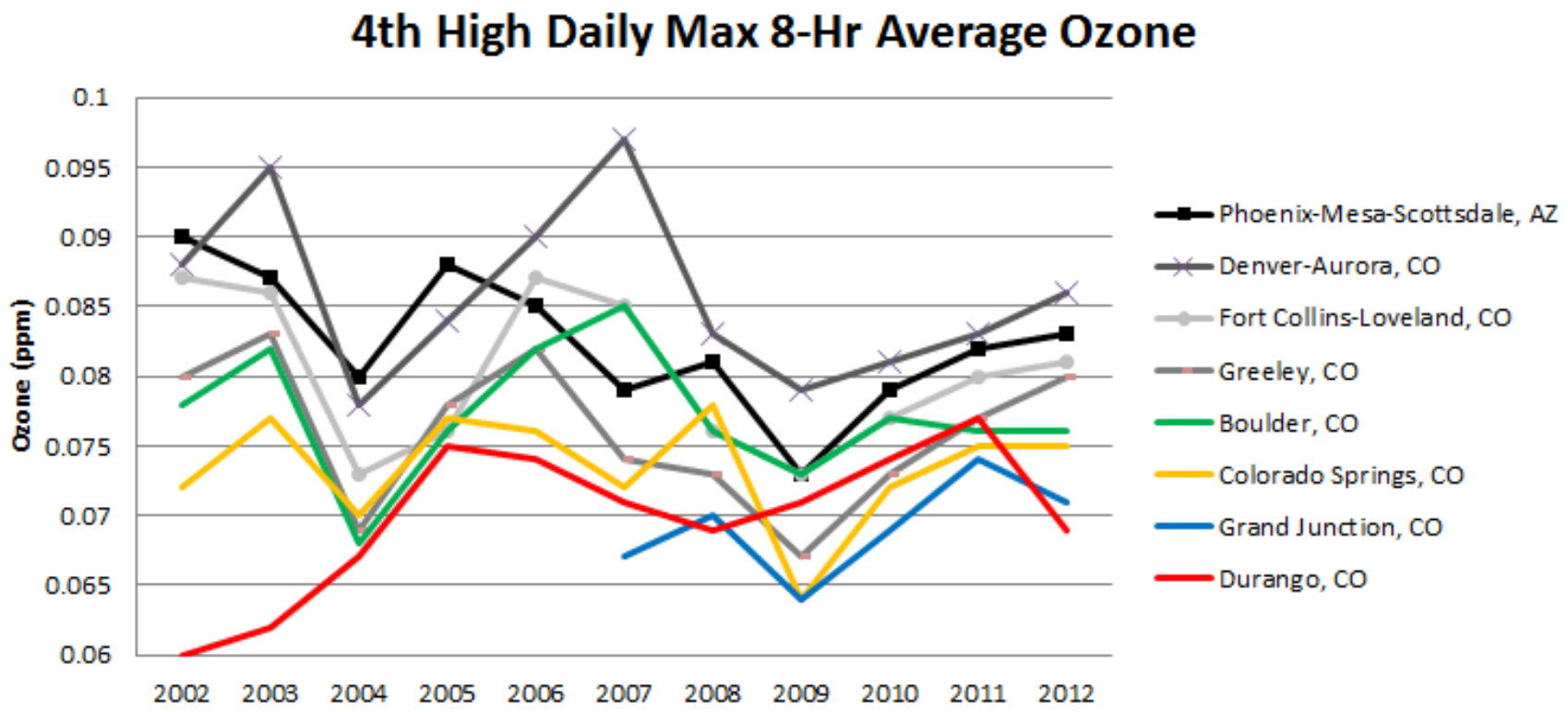
- Trends similar after 2007 for most monitors
  - Show Low and Prescott diverge from others in 2002-3

2002-2012 Ozone Trends: New Mexico



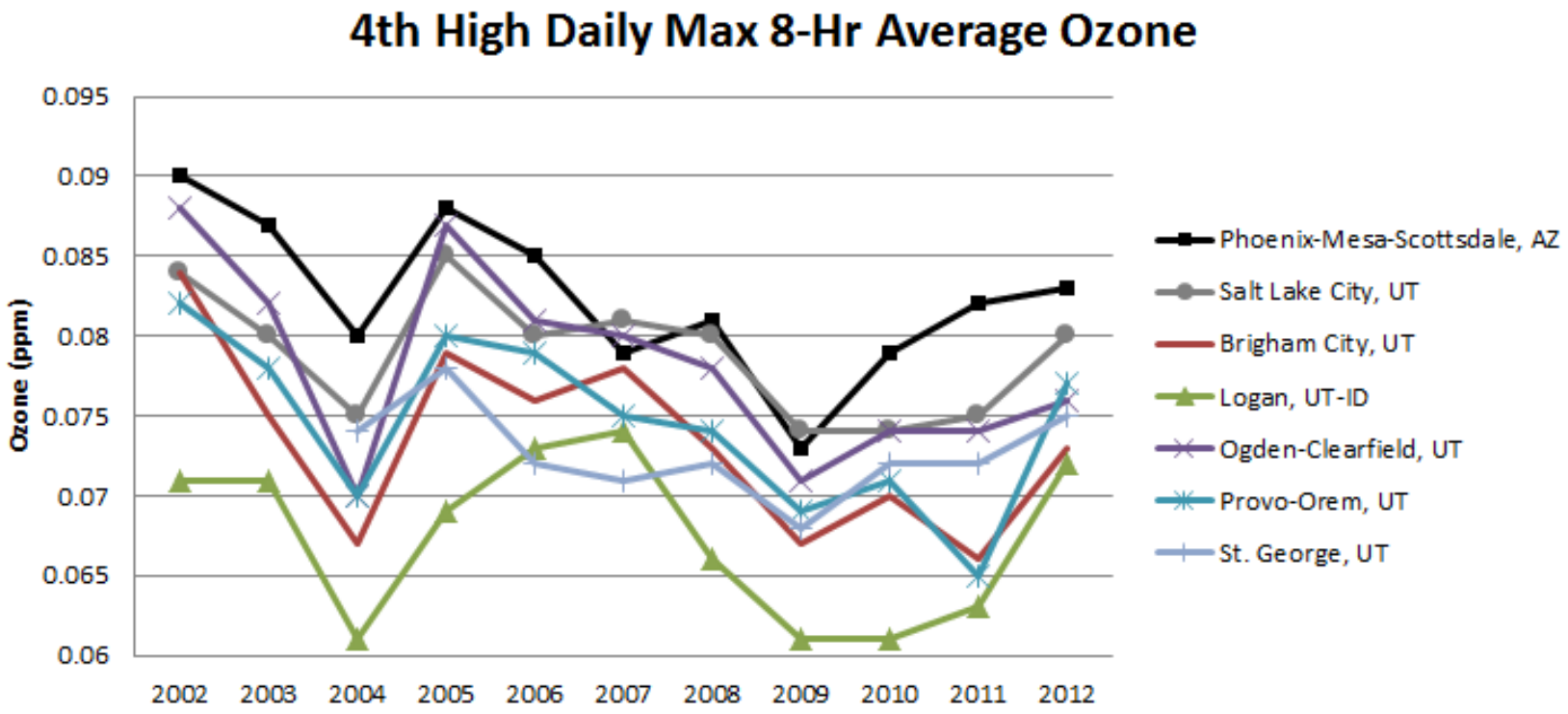
- Silver City and Hobbs look different from the rest

2002-2012 Ozone Trends: Colorado



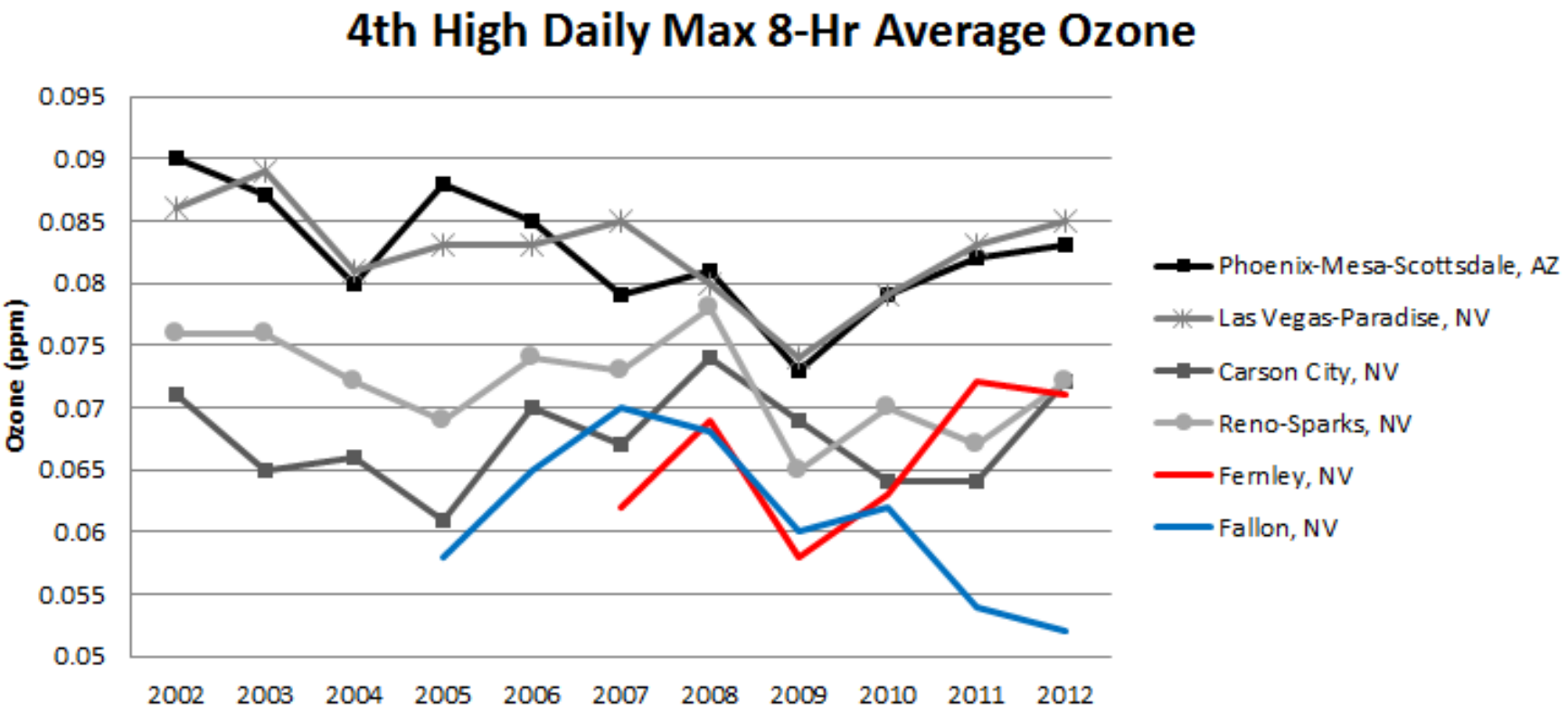
- Except for Durango, all show decrease in ozone in 2004 and 2009
- Some stations show decline in ozone in 2012

2002-2012 Ozone Trends: Utah



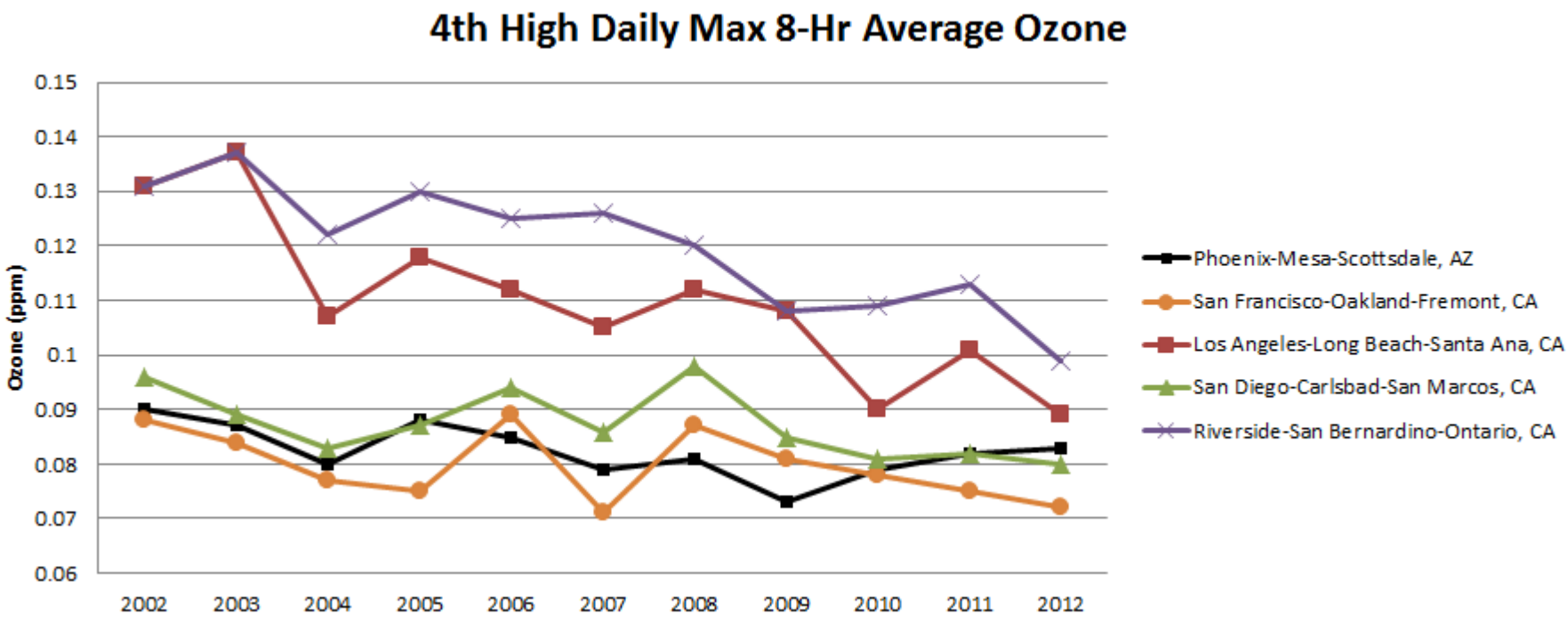
- Minima in 2004 and 2009 for all sites
- All show increase in 2012 relative to 2011

2002-2012 Ozone Trends: Nevada



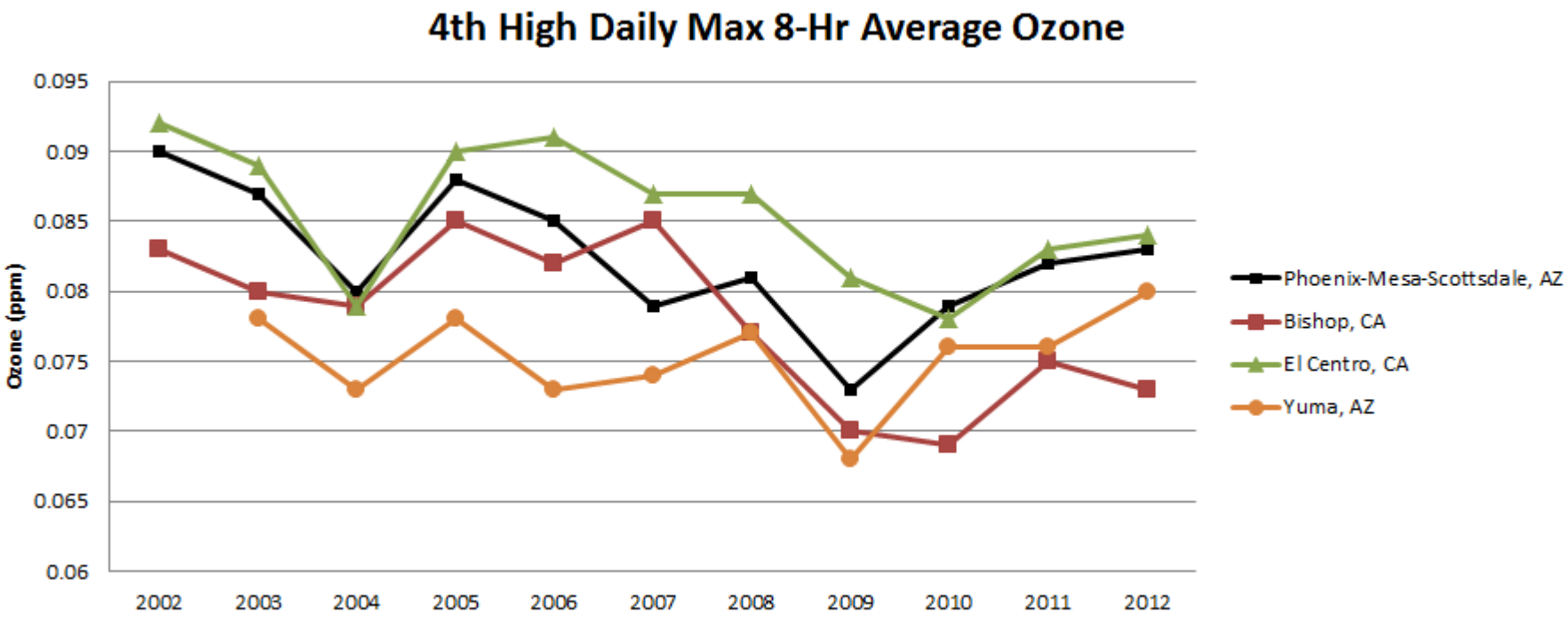
- All sites show decrease in ozone from 2008 to 2009

2002-2012 Ozone Trends: Large Coastal Metro Areas of California



- All areas show drop in ozone in 2004 and 2009
- 2003-2009 behavior similar to Phoenix for SoCal sites

2002-2012 Ozone Trends: Eastern CA Sites and Yuma, AZ



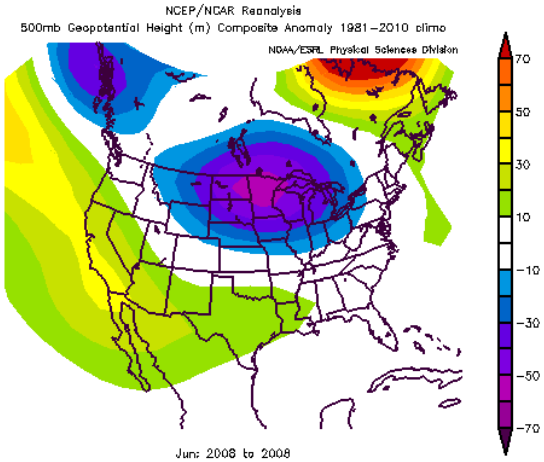
- Overall rising trend during 2009-2012 for all sites
- El Centro and Yuma are near one another

Regional Ozone Trends: Summary

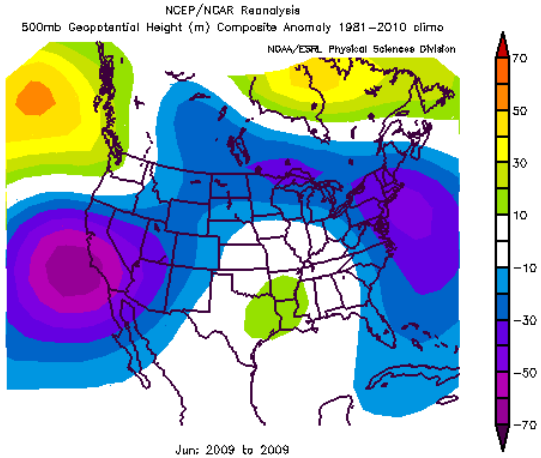
- For some periods (2003-2005 and 2008-2012) ozone has similar trends at many stations throughout the southwestern U.S.
  - Variability in ozone at CA monitors in large coastal metro areas has different pattern than sites east of the Sierras
- Can we find regional meteorological factor(s) that could make conditions conducive to ozone formation across the southwestern U.S.?
  - Example: regional high pressure anomaly during high ozone years that would tend to cause sunny skies, hot temps, light winds
- NCDC Climate Summaries, NCEP Reanalysis

June 500 mb height anomaly

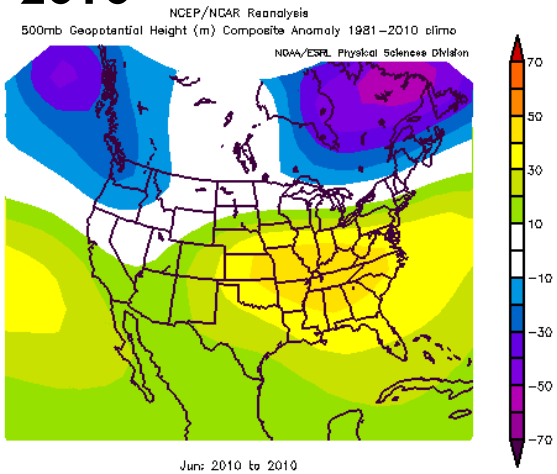
2008



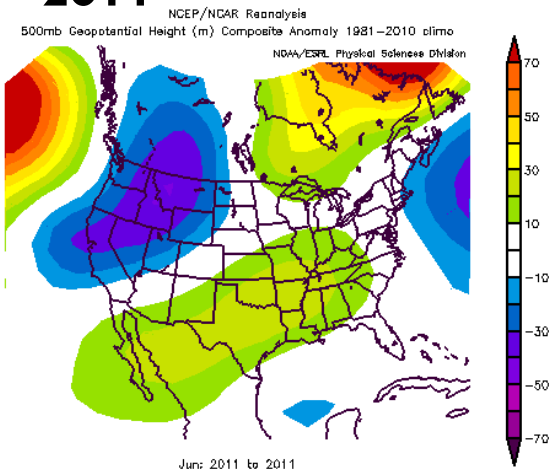
2009



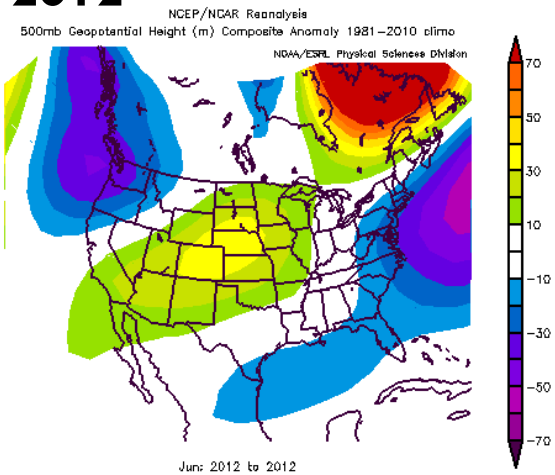
2010



2011



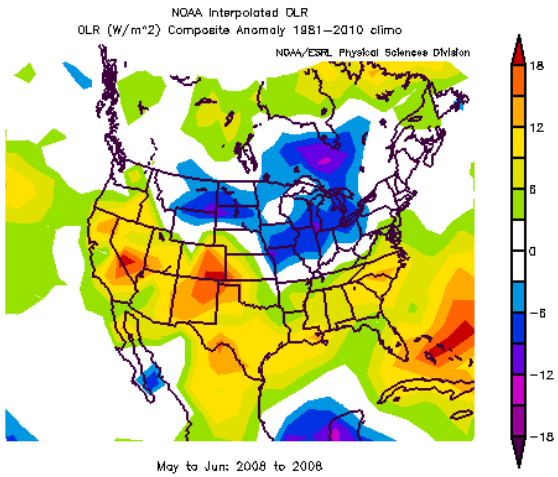
2012



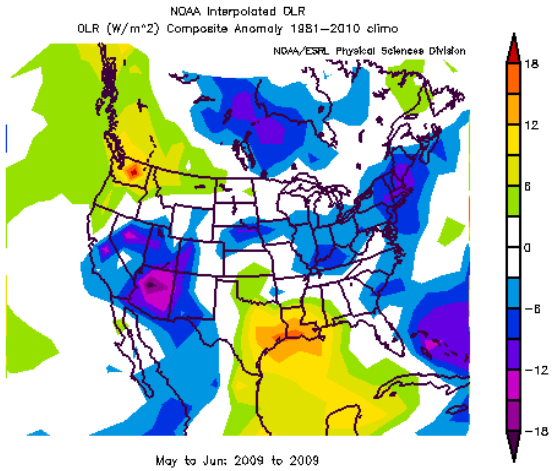
- Seasonal average does not show a pattern consistent with the variation in ozone in southwest
- Seasonal average includes effects of monsoon, which makes detecting anomaly signals in many fields difficult (compare July OLR anomalies to May-June)

May-June OLR Anomaly

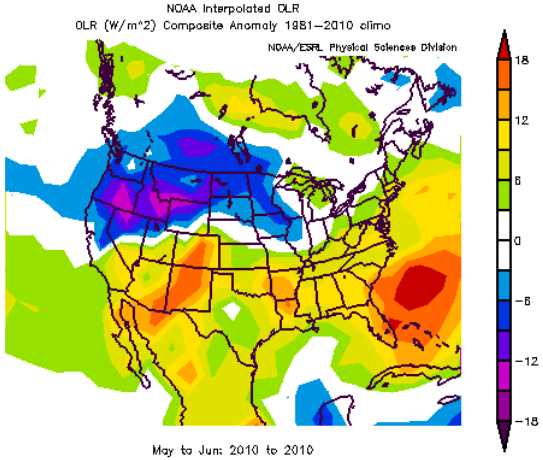
2008 (high MC ozone)

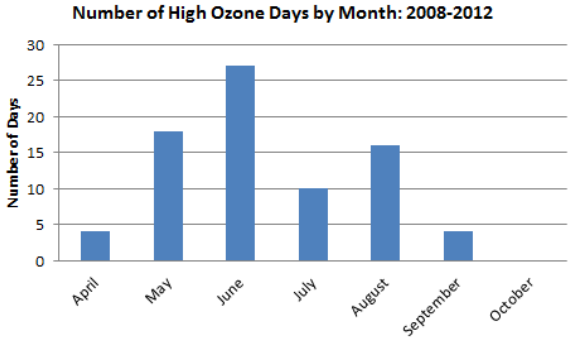


2009 (low MC ozone)

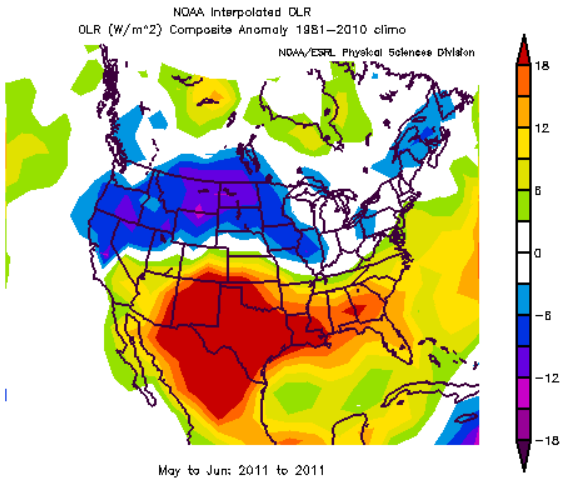


2010 (+MC Ozone)

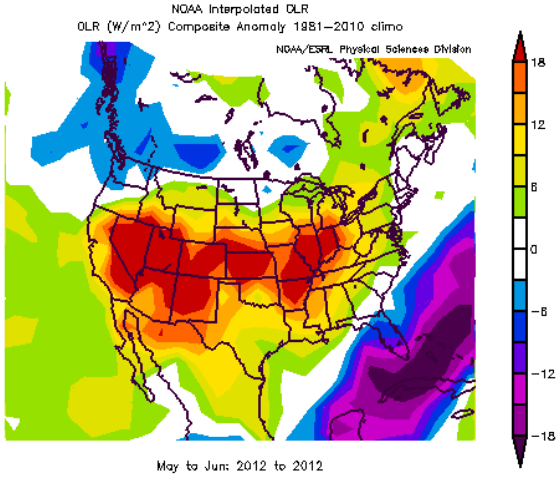




2011 (+MC ozone)



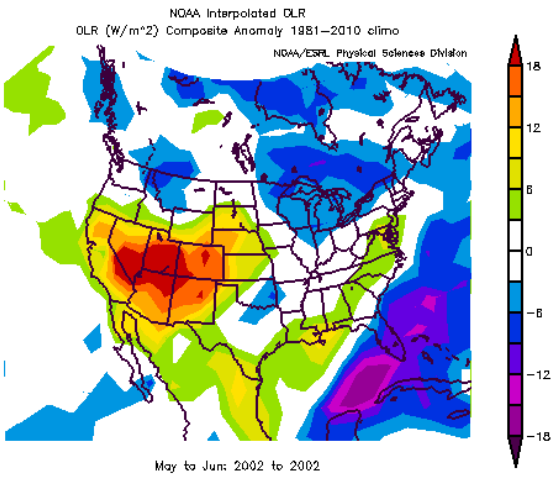
2012 (high MC ozone)



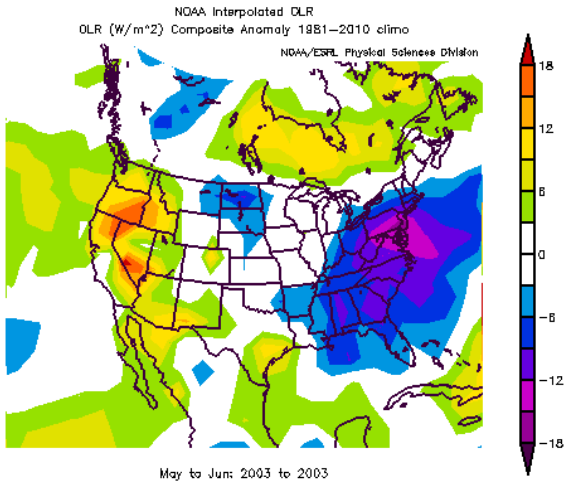
- Phoenix airport showed enhanced cloudiness in May-June 2009, little cloud cover in 2011-2012

May-June OLR Anomaly

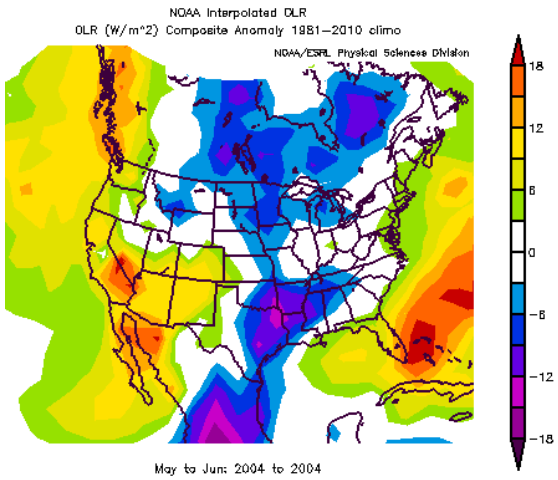
2002 (high MC ozone)



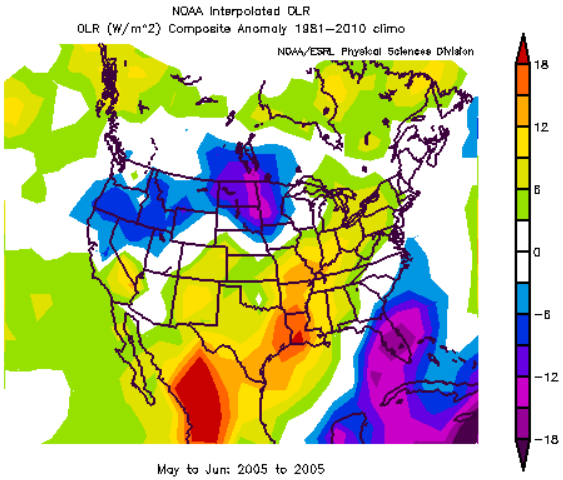
2003 (high MC ozone)



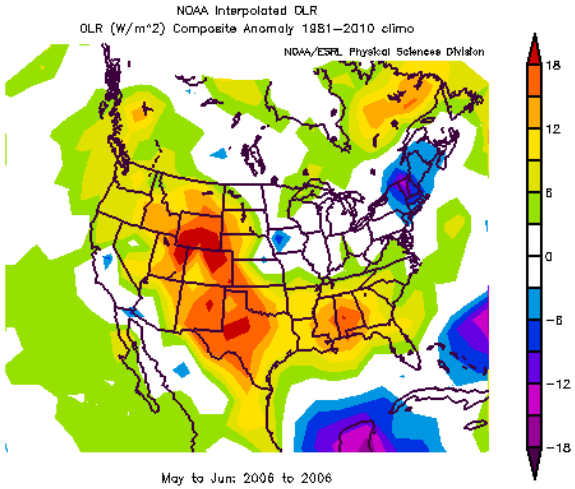
2004 (low MC Ozone)



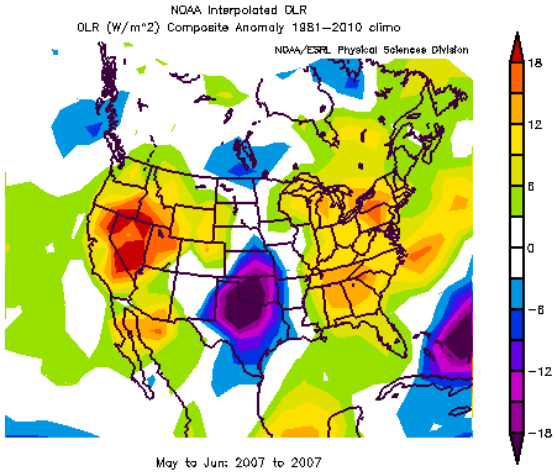
2005 (high MC ozone)



2006 (- MC ozone)



2007 (- MC ozone)



- NOAA interpolated satellite OLR-not influenced by model

Large-Scale Meteorological Analysis: Conclusions

- Taking averages of met fields over the ozone season can be problematic because of monsoon effects that appear in July-August
- OLR anomaly shows variations consistent with ozone trends in AZ and surrounding states from 2008-2012
  - Consistent with variations in cloudiness at KPHX
- Difficult to see such variations in other meteorological fields examined here
- Possible that in some years (2008-2012), large scale met factors such as cloudiness are important in creating conditions conducive to ozone formation, but in other years, local factors dominate

Conclusions

- Maricopa 2008-2012 ozone trend similar to other large metro areas in southwest US
  - Suggests regional-scale factors are important
  - 2008-2012 May-June cloudiness is consistent with ozone trends
- Phoenix data show:
  - Unusually large amount of cloud cover in May-June 2009
  - Small amount of cloud cover in May-June 2011-2012
  - Unusually high temperatures in 2012
- More potential wildfire impacts in 2012
- Local anthropogenic NOx and VOC emissions generally decrease during 2008-2011
  - Vehicle emissions decrease during 2008-2012, but increase after 2010 due to use of E10
- No evidence of changes in transport patterns

Avenues for Further Work

- ADEQ analysis of Phoenix high ozone days shows:
  - In spring, surface high pressure over the Four Corners region causes easterly flow over the Phoenix area that “locks” ozone in the Valley
  - High ozone at urban core monitors occurs when easterly morning winds persist until afternoon, delaying onset of westerly upslope winds
  - Phoenix ozone often increases following convective storms or ahead of 500 mb trough that migrates westward from Southern California
  - STE may play a role in early season ozone events
- Could review recent high ozone days and use archived meteorological data to form composite picture of each type of event
  - How does annual frequency and intensity of each type of event change over time?
  - Evaluate correlation with Maricopa ozone
- Evaluate meteorological data for sites other than KPHX
  - Recommended by MAG

Recommendations

- Shorter duration canister sampling at JLG Supersite during 6-9 am period would help to:
  - Determine ambient VOC/NOx ratio
  - Isolate on-road mobile evaporative emissions changes
  - If lab can analyze ethanol, could examine E10 effects
- Role of possible biogenic hot spot near the North Phoenix monitor
  - MEGAN urban LAI is set to a regional average for the areas where MODIS does not provide LAI; analysis of LAI will not answer this question

MARICOPA ASSOCIATION of GOVERNMENTS

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