O_3 Welfare Effects and the W126 Metric

Presentation for the Joint Fall Meeting of the OTC and MANE-VU

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Dr. Bryan Hubbell
EPA/OAQPS

Ozone NAAQS Recent History

March 27, 2008: EPA revises primary and secondary ozone standards from 84 ppb to 75 ppb (8-hour average).

- In 2013, the D.C. Circuit remanded the secondary standard to the Agency for reconsideration because the Agency did not determine what level of protection was requisite to protect the public welfare.

January 19, 2010: EPA proposes to reconsider the 2008 ozone standard.

- Change primary standard to within range of 60 to 70 ppb.
- Change secondary standard to cumulative seasonal standard within range of 7 to 15 ppm-hours.

September 2, 2011: President asks EPA to withdraw its January 2010 proposal and focus on upcoming 5 year review.

June 19, 2013: Coalition of public health and environmental groups, including Sierra Club and ALA, file lawsuit in federal court asking court to set deadline for action on overdue ozone standards.

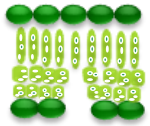
April 29, 2014: U.S. District Court in San Francisco orders EPA to issue new ozone standards (proposal by Dec.1, 2014, final by Oct.1, 2015).

NAAQS Statutory Requirements: Secondary Standards

- ***Secondary (welfare-based) standards:*** "…specify a level of air quality the attainment and maintenance of which" in the "judgment of the Administrator" is "requisite to protect the public welfare from any known or anticipated adverse effects" (CAA §109)
  - Welfare effects include . . . "effects on soils, water, crops, vegetation, man-made materials, animals, wildlife, weather, visibility and climate . . ." (Clean Air Act §302)
- Determining what is adverse to the public welfare requires policy judgments about the societal impact of adverse effects to crops, vegetation, etc.
- In setting secondary standards:
  - EPA is required to engage in "reasoned decision making" to translate scientific uncertainty into standards
  - In so doing, EPA may not consider cost in setting standards. Rather, cost is considered in developing control strategies to meet the standards

O_3 Effects on Sensitive Plants, Associated Ecosystems and Services

O_3 exposure



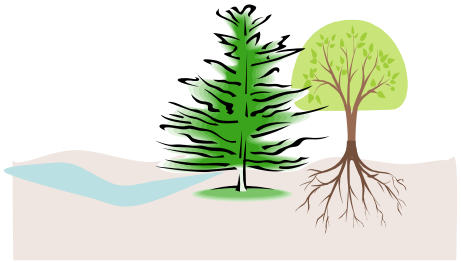
O_3 uptake & physiology (Fig 9-2)
- Antioxidant metabolism up-regulated
- Decreased photosynthesis
- Decreased stomatal conductance or sluggish stomatal response

Effects on leaves
- Visible leaf injury
- Altered leaf production
- Altered leaf chemical composition

Plant growth (Fig 9.8)
- Decreased biomass accumulation
- Altered reproduction
- Altered carbon allocation
- Altered crop quality

Belowground processes (Fig 9.8)
- Altered litter production and decomposition
- Altered soil carbon and nutrient cycling
- Altered soil fauna and microbial communities

Differential O_3 sensitivity



Affected ecosystem services
- Decreased productivity
- Decreased C sequestration
- Altered water cycling (Fig 9-7)
- Altered community composition (i.e., plant, insect & microbe)

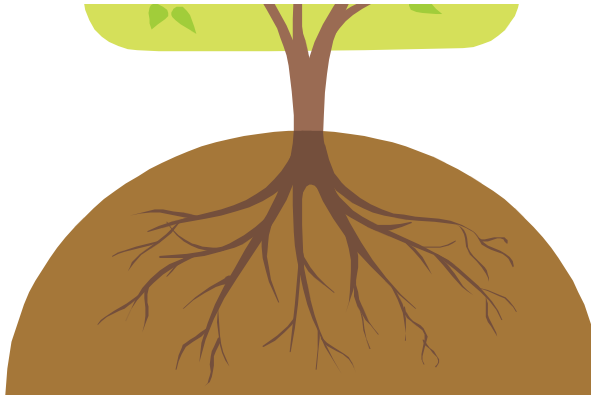
O_3 Effects on Sensitive Plants

Reduced above ground growth/ productivity

Visible leaf injury

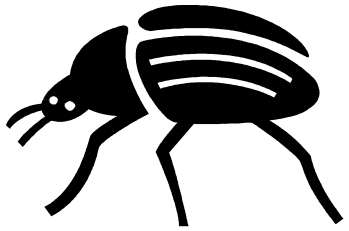
Reduced reproduction/ yields

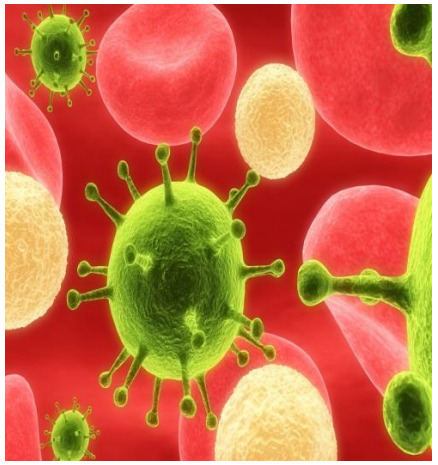
Reduced below ground root growth/storage



O_3 Effects on Sensitive Plants (2)

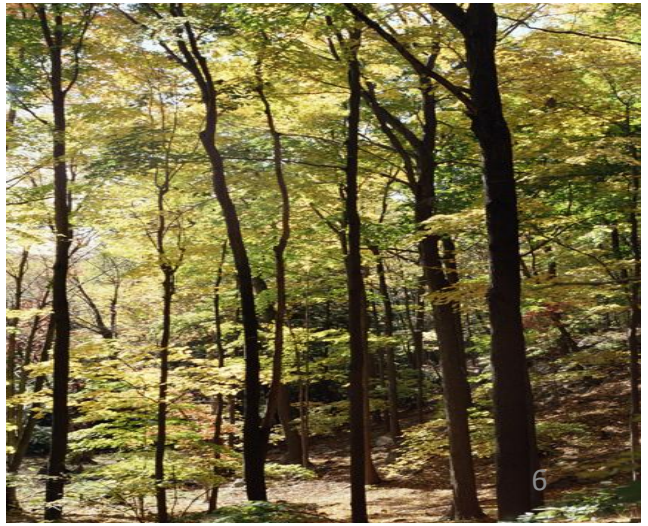
Reduced resistance to insects/disease





Reduced resistance to harsh weather

Alteration of competitive interactions



O_3 Impacts on Associated Ecosystems and Services

- Decreases air pollution removal in urban areas
- Decreases CO_2 sequestration/climate regulation
- Decreases crop and timber yields
- Damages aesthetics in valued natural areas
- Alters biogeochemical and hydrologic cycles
- Potential impacts to insect outbreaks, fire regimes
- Potential impacts on community composition

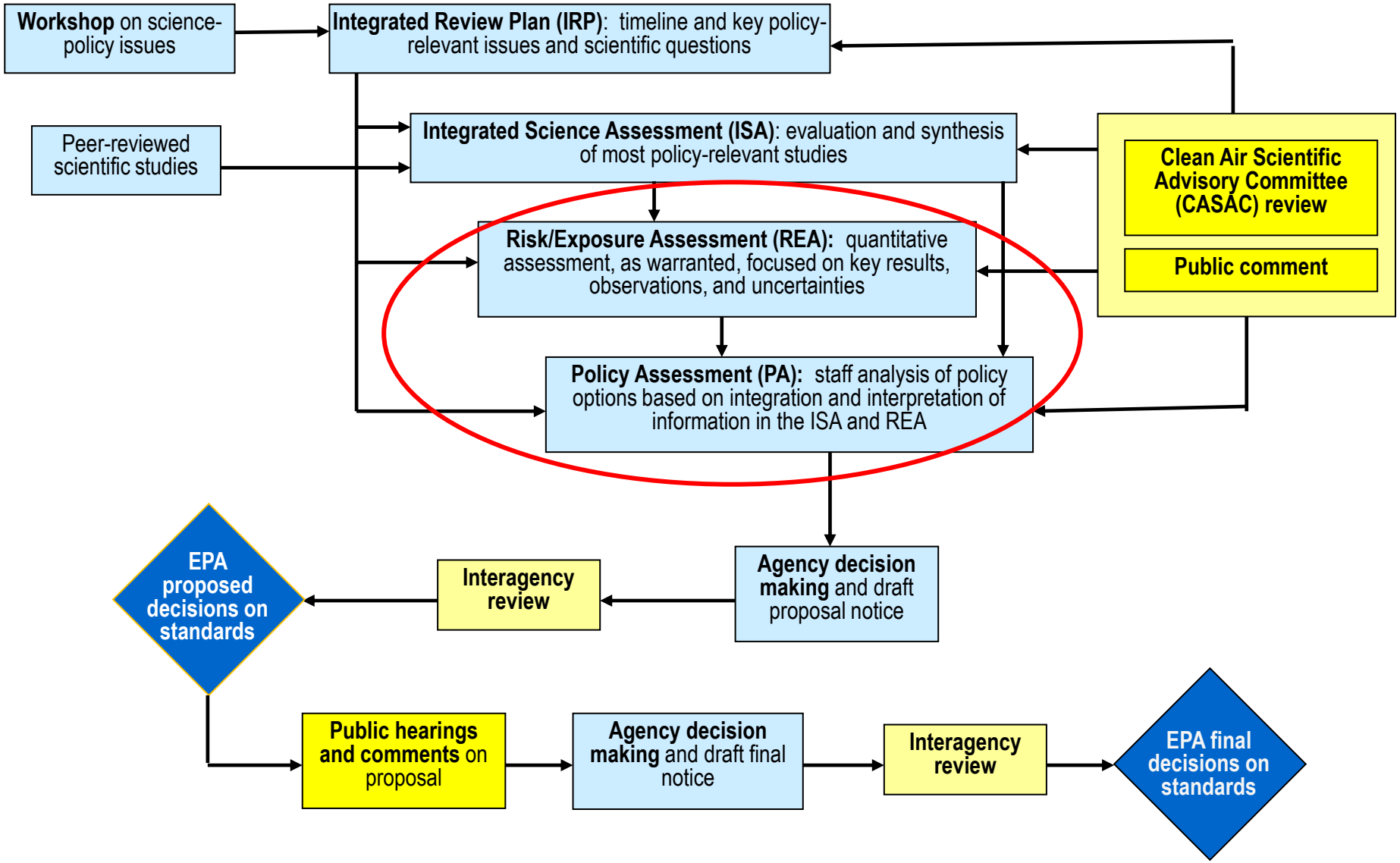
Scientific Information on O_3 Effects on Vegetation

- Plant response to O_3 depends on both the cumulative nature of exposures over the growing season and levels of exposure
- Over 50 years of research, beginning with discovery of oxidant injury to grape leaves (Richards, et al., 1958)
- Studies show that effects on sensitive tree species (e.g., loss of vigor and competitive advantage, increased susceptibility to disease) could have adverse implications for ecosystems (e.g., water availability in watersheds, carbon sequestration, changes in biodiversity)
- Measures of vegetation and ecosystem effects
  - *Tree Biomass Loss*: Annual losses could be significant due to compounding over lifetime of a tree
  - *Reduced Crop Yield*: Agricultural systems are heavily managed and adverse impacts from other factors (e.g., weather, insects, disease) can be orders of magnitude greater than from O_3 exposure
  - *Foliar Injury*: Indicator of potentially more significant ecosystem-wide effects
- Informs judgement of what is "requisite to protect the public welfare," considering "intended use" and "location" (e.g. Class I areas) and various dimensions (spatial, temporal, and social) across which public welfare benefits can accrue

Why the focus on a W126 metric?

- Plant response to O_3 depends on both the cumulative nature of exposures over the growing season and levels of exposure
  - The 1996 AQCD and subsequent reviews have continued to reach these same conclusions based on the most recent research.
- The 2008 review and the current review both considered the appropriateness of different forms.
  - Other forms considered included those analyzed in various studies, including SUM06, AOT06, and W95.
  - It was determined that the W126 was the more appropriate form, particularly based on the scientific understanding that there is not an exposure threshold that is applicable across studied plant species.
- Since 1996, CASAC has consistently supported the use of a cumulative form and in both 2008 and the current review, preferred the W126 index.

NAAQS Review Process



Welfare Risk and Exposure Assessment

- WREA provides broad analysis of impacts on forests and crops – the Policy Assessment emphasized the impact on forest species in national parks and wilderness areas (Class I Areas)
- WREA evaluated 12 tree species with well characterized concentration-response functions relating cumulative ozone exposure to losses in tree biomass – results were extrapolated to other species for the analysis of forestry market impacts
- Also looked at foliar injury, especially in national parks, and air pollution removal by trees in urban areas

Air Quality Analysis for the Welfare Risk and Exposure Assessment

- Air quality adjusted to estimate ozone concentrations that meet current standard (75 ppb) and potential alternative W126 standards, with 3-year average form (15, 11 and 7 ppm-hrs)
  - Used air quality model results to adjust ozone monitor values
  - Used monitor data from 2006-2008
  - Monitors were grouped into 9 regions
  - Highest monitor in each region dictated the NOx reductions required to meet each standard level
- After adjusting air quality to meet the current 75 ppb standard we found that most places had modeled W126 values at or below 15 ppm-hrs. This reflected domain wide reductions in NOx which resulted in region wide reductions in W126.

WREA Assessment of Exceedances of CASAC Recommended Benchmarks for Biomass Loss in Tree Species

Percent of assessed geographic area above benchmark RBL values

RBL Benchmark	Existing Standard	15 ppm-hrs	11 ppm-hrs	7 ppm-hrs
1%	21%	19%	15%	12%
2%	12%	11%	9%	8%

Number of Class I areas (out of 119 with data) above benchmark RBL values

RBL Benchmark	Existing Standard	15 ppm-hrs	11 ppm-hrs	7 ppm-hrs
1%	31	25	10	5
2%	12	7	3	3

Basics of Market Analysis

- Agricultural and forestry market dynamics can lead to either increases or decreases in overall societal welfare
- Increased yields will result in lower prices (holding the demand curve for crops constant)
- Depending on the responsiveness of quantity demanded to prices, the increase in quantity demanded might not be enough to offset the reduction in prices
  - Consumers will always gain from the lower prices
  - Producers will see reduced profits if the increase in quantity demanded does not offset the price reduction
  - If the loss to producers exceeds the gains to consumers then net welfare will go down

WREA Assessment of Effects of Biomass Loss on Agricultural and Commercial Forestry Economic Sectors

Service	Base Value for Existing Standard	Change from Existing Standard (annualized 2010-2040)		
		15 ppm-hr	**11 ppm-hr**	**7 ppm-hr**
Timber welfare	$814 billion	$-24 million	$-28 million	$26 million
Agricultural welfare	$2.6 trillion	$-0.2 million	$21 million	$231 million
Carbon sequestration	93,427 $MMtCO_2e$	1 $MMtCO_2e$	21 $MMtCO_2e$	53 $MMtCO_2e$

The largest air quality and welfare benefits occurred when moving from recent ozone conditions to just meeting the current 8-hour standard of 75 ppb

Summary of CASAC Advice

- **Adequacy:** “the current secondary standard is not adequate to protect against current and anticipated welfare effects of ozone on vegetation”

- **Form**: Strong evidence that cumulative exposures drive plant response, therefore secondary standard should be in terms of a cumulative, seasonal form (i.e., W126 - 8 am to 8 pm sum and maximum 3-month sum)

- **Level**: Recommends that the level be within the range of 7 to 15 ppm-hrs (annual)

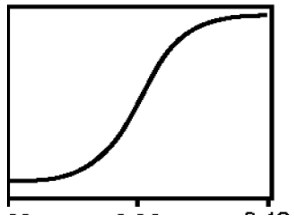
- **Averaging period**: CASAC “does not recommend” a 3-year averaging period but if using 3-year average, level should be set lower to not allow annual level to exceed in any one year

Key Features of the W126 Metric

- Daily period – 12 hour daylight period (8:00 am to 8:00 pm)

- Seasonal period – Consecutive 3 month period with max exposure

- Weighting function – W126 weighs higher exposures more

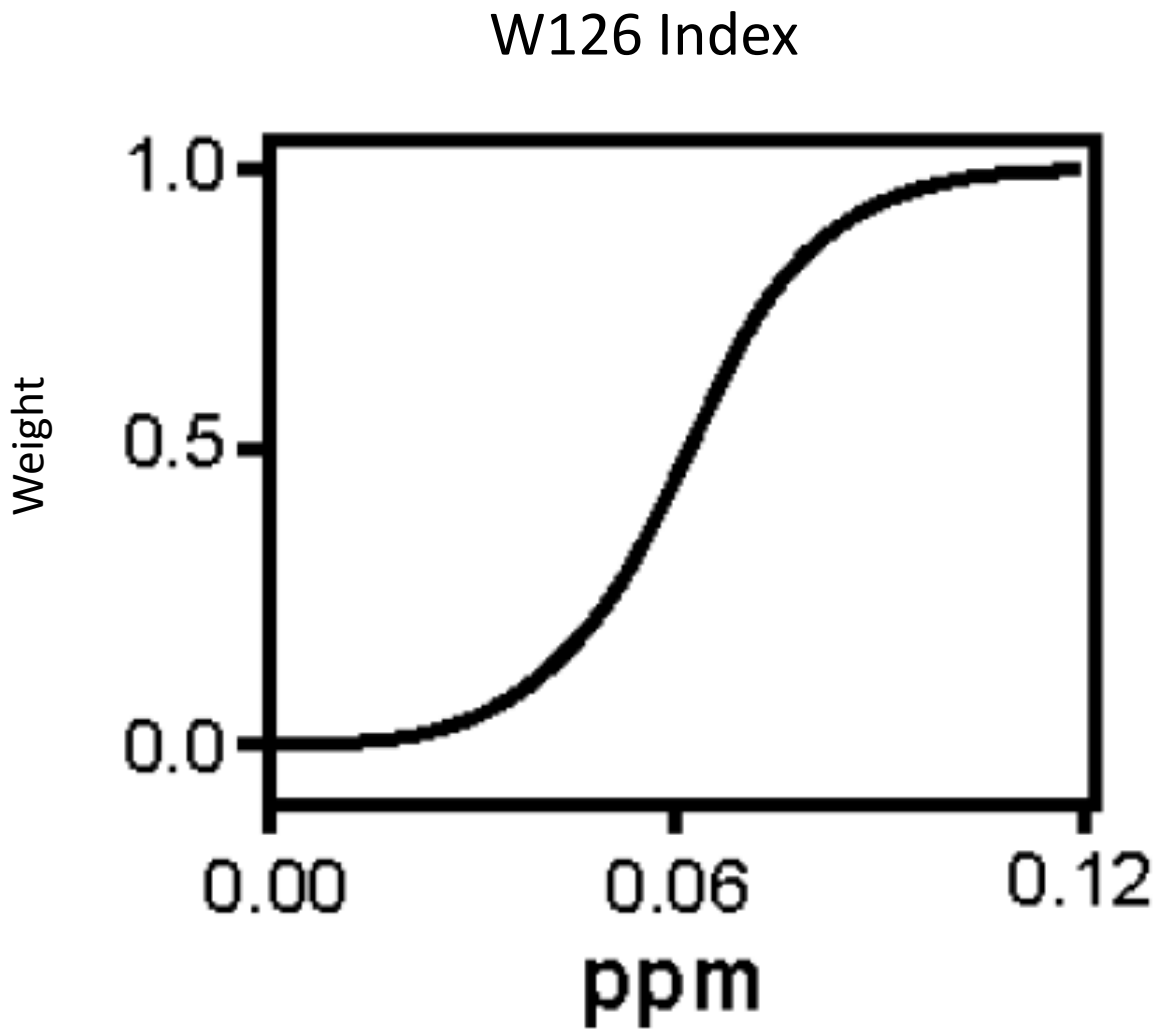


- Both annual and 3-year average forms

The W126 Metric

$$D.I. = \sum_{i=8am}^{7pm} O_{3i}\left(\frac{1}{1+\left(4403\ e^{-126O_{3i}}\right)}\right)$$

http://www.epa.gov/ttn/analysis/w126.htm



Example: W126 Metric

- Start with hourly values in 12-hour period 8am-8pm
- Transform each hourly value using sigmoidal weighting function and add them together to get the daily value

$$D.I. = \sum_{i=8am}^{7pm} O_{3i}\left(\frac{1}{1+\left(4403\, e^{-126O_{3i}}\right)}\right)$$

AQS Start Hour (Local Standard Time)	1-hour Ozone Concentration (ppm)	Weighted Concentration (ppm)
8:00 AM	0.045	0.002781048
9:00 AM	0.06	0.018218179
10:00 AM	0.075	0.055701197
11:00 AM	0.08	0.067537497
12:00 PM	0.079	0.065326731
1:00 PM	0.082	0.071714507
2:00 PM	0.085	0.077393908
3:00 PM	0.088	0.082447735
4:00 PM	0.083	0.073683225
5:00 PM	0.081	0.069666519
6:00 PM	0.065	0.029260124
7:00 PM	0.056	0.011675533
		0.625406204

→ Daily Value

Example: W126 metric (2)

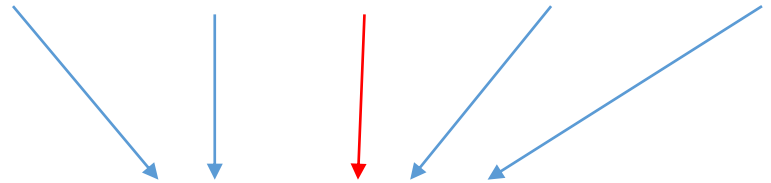
- Add the daily values for each month

	Daily Value
5/1/2007	0.79
5/2/2007	0.657
5/3/2007	0.664
5/4/2007	0.703
5/5/2007	0.698
5/6/2007	0.596
5/7/2007	0.7
5/8/2007	0.822
5/9/2007	0.786
5/10/2007	0.82
5/11/2007	0.867
5/12/2007	0.854
5/13/2007	0.888
5/14/2007	0.841
5/15/2007	0.839
5/16/2007	0.783
5/17/2007	0.78
5/18/2007	0.776
5/19/2007	0.787
5/20/2007	0.751
5/21/2007	0.652
5/22/2007	0.671
5/23/2007	0.673
5/24/2007	0.717
5/25/2007	0.766
5/26/2007	0.789
5/27/2007	0.737
5/28/2007	0.678
5/29/2007	0.662
5/30/2007	0.845
5/31/2007	0.773
	23.365

→ Monthly Value

- Then add the monthly values for each rolling 3 month period over the growing/ozone season and compare the 3 month values to determine the annual maximum 3 month period.

	April	May	June	July	August	September	October
Monthly Value	4.442	9.124	12.983	16.153	13.555	4.364	1.302
3-Month sum (Months Included)			26.549 (A, M, J)	38.260 (M, J, J)	42.691 (J, J, A)	34.072 (J, A, S)	19.221 (A, S, O)



3-month sums – Three month period (J, J, A) has highest 3 month sum

Example: W126 metric (3)

- For a three-year average of the highest 3-month sum from each of the three years:

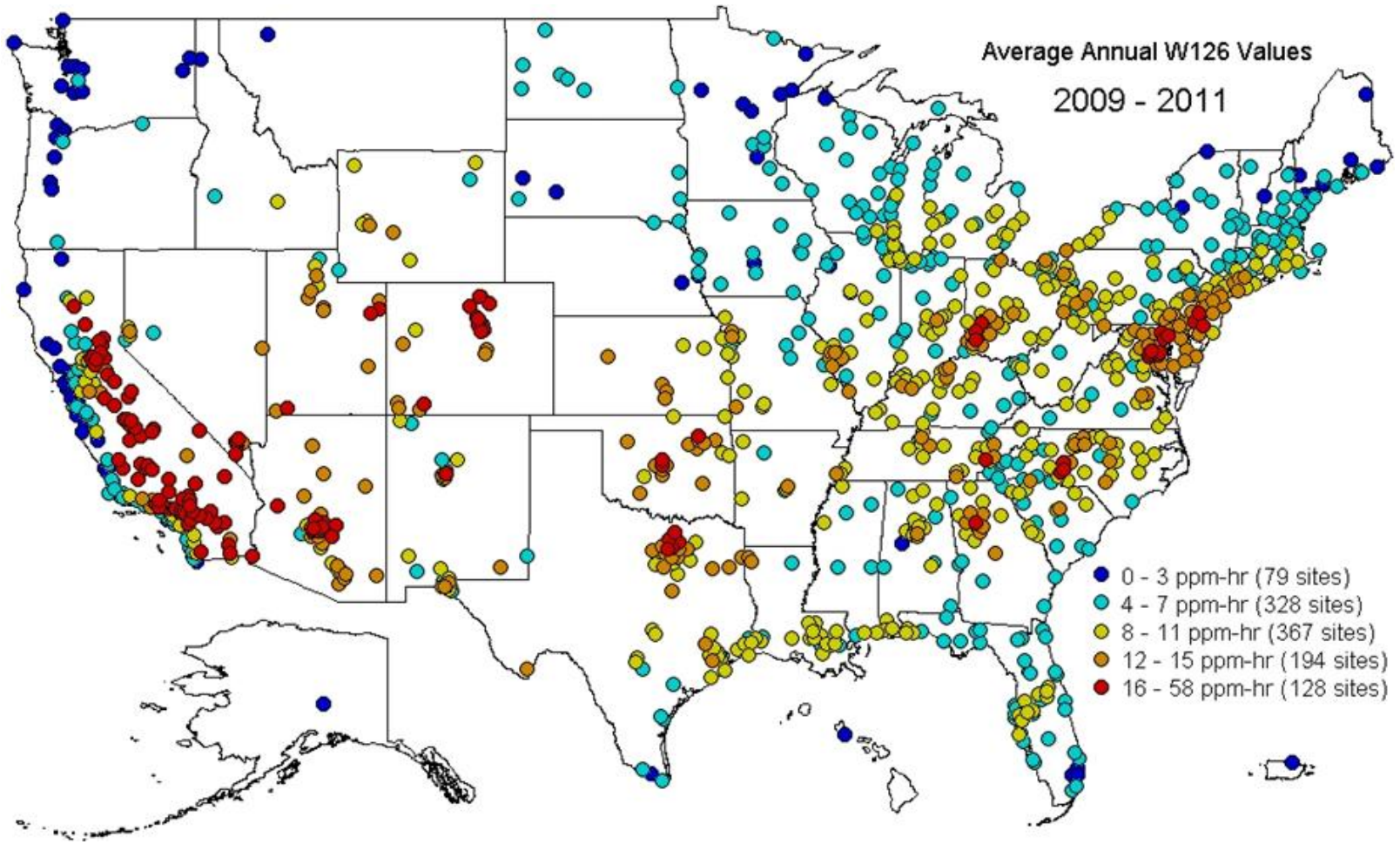
Year 2004	April	May	June	July	August	September	October
Monthly Value	4.442	9.124	12.983	16.153	13.555	4.364	1.302
3-Month sum	na	na	26.549	38.260	**42.691**	34.072	19.221

Year 2005	April	May	June	July	August	September	October
Monthly Value	3.114	7.214	8.214	8.111	7.455	7.331	5.115
3-Month sum	na	na	18.542	23.539	**23.780**	22.897	19.901

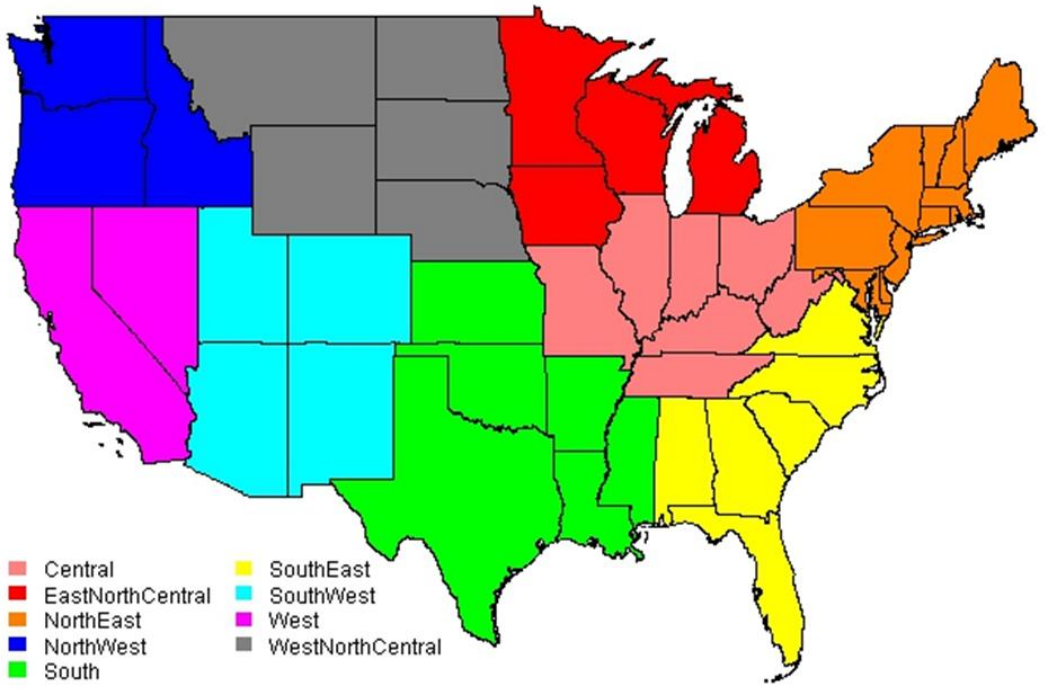
Year 2006	April	May	June	July	August	September	October
Monthly Value	4.574	5.978	6.786	8.214	5.579	4.331	2.115
3-Month sum	na	na	17.338	**20.978**	20.579	18.124	12.025

W126 value = (42.691 + 23.780 + 20.978)/3 = 29.149666… rounds to **29 ppm-hours**

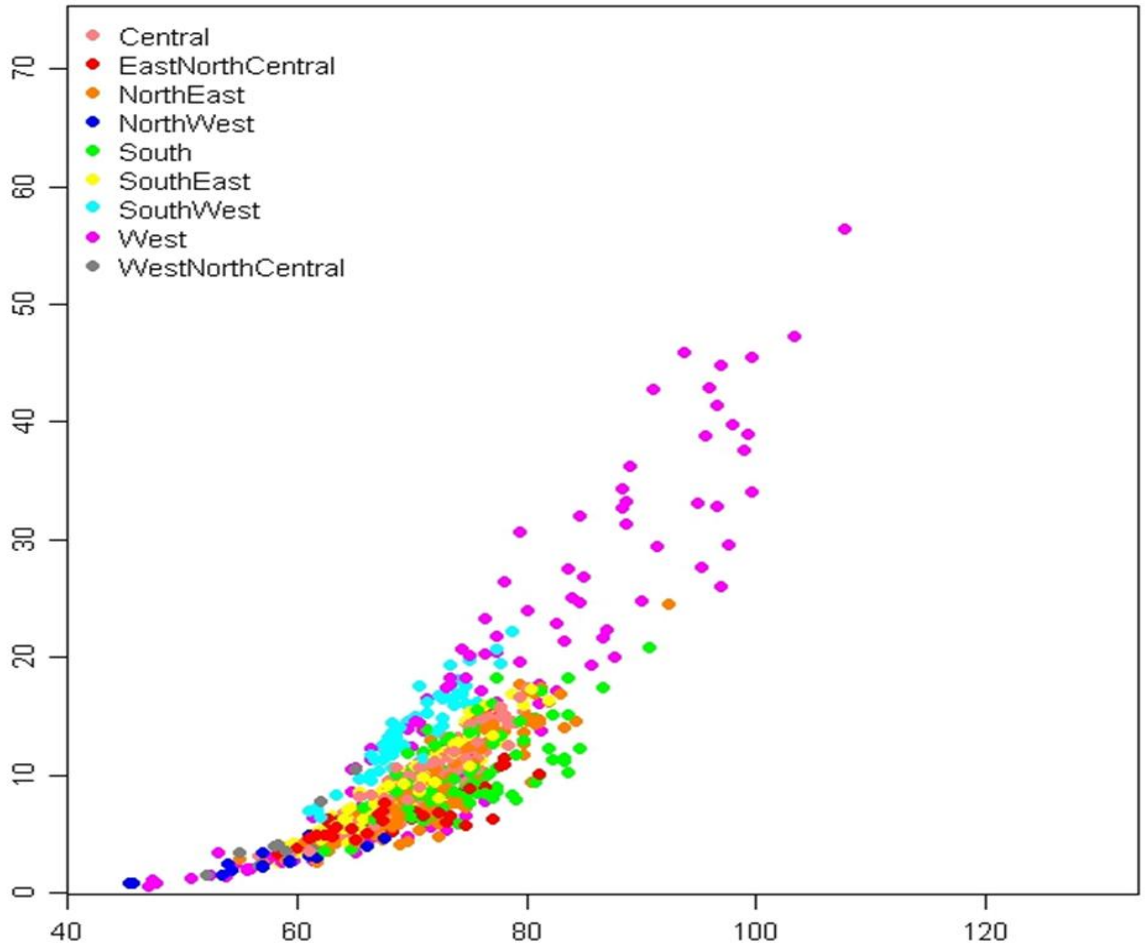
2009-2011: W126 Concentrations (ppm-hrs) at Monitoring Sites (from Policy Assessment)



Regional Comparison of W126 Metric to the Current O_3 Standard (from the Policy Assessment)



Map of the 9 NOAA climate regions (Karl and Koss, 1984)



2009-2011: Design values for the current O_3 standard in ppb (x-axis) versus 3-year average W126 values in ppm-hrs (y-axis)

Questions?

Resources:

Ozone NAAQS review:
http://www.epa.gov/ttn/naaqs/standards/ozone/s_o3_index.html

Ozone W126 Data Resources:
http://www.epa.gov/ttn/analysis/w126.htm