

# Estimation of the Effects of Ship Emissions Using Existing PM<sub>2.5</sub> Particle Compositions

Philip K. Hopke

Center for Air Resources Engineering and Science

Clarkson University

Potsdam, NY 13699-5708

hopkepk@clarkson.edu



# Outline

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- Introduction
  - Ship Emissions
  - Health Effects
- Data Issues
  - Availability
  - Data Issues
- Data Analysis Tools
  - PMF
  - CPF
- Results
- Conclusions



# Acknowledgements

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- The results being presented in this talk is the work of
  - In-Jo Hwang
  - Eugene Kim
  - Jong-Hoon Lee
- Their hard work and dedication to doing good data analyses is what has made it possible to complete this project.



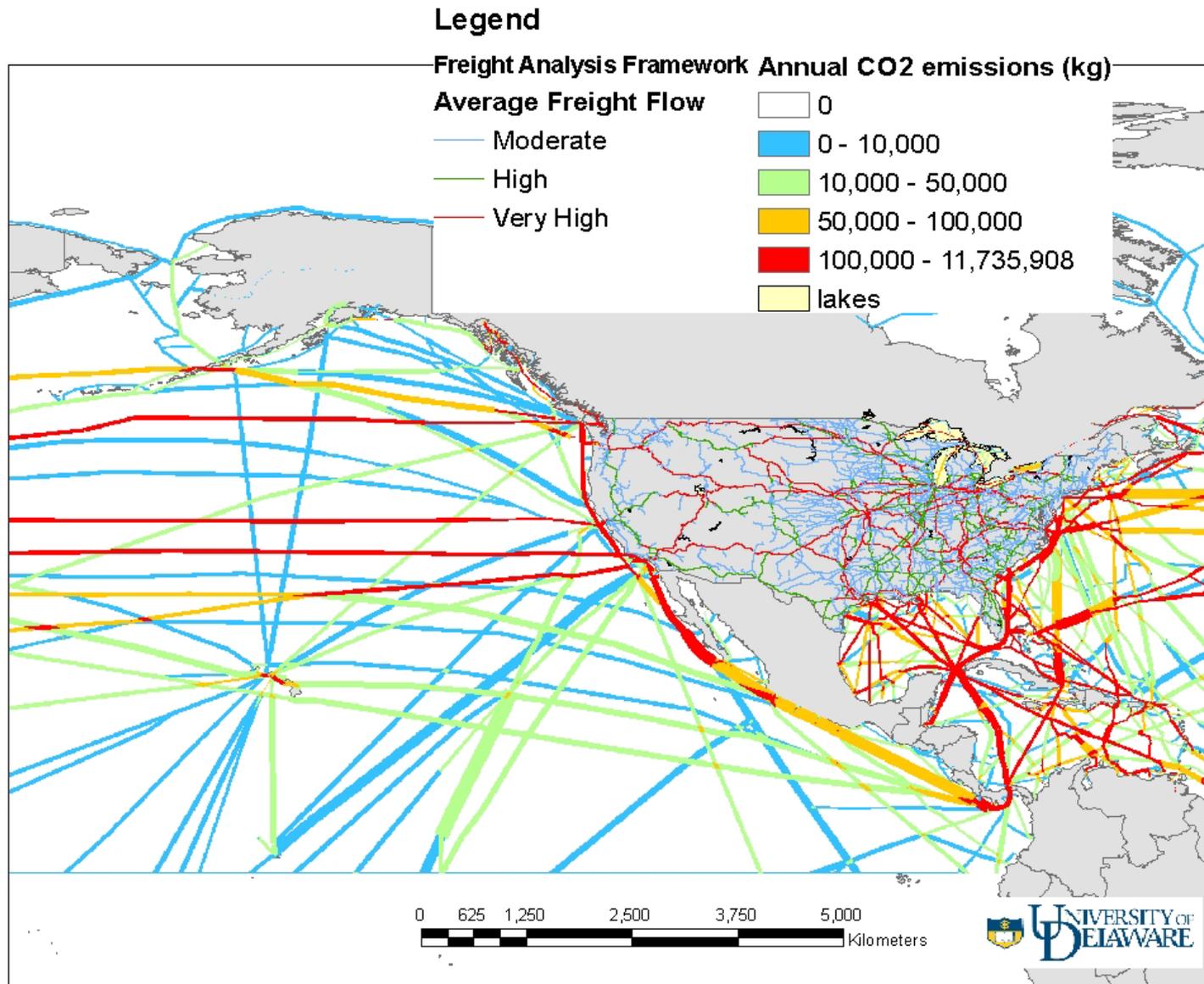
# Ship Emissions

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- With the globalization of manufacturing and movement of natural resources such as crude oil, large transport ships (container ships, supertankers, etc) represent a major flow of goods and materials into and out from major ports.



# Shipping Patterns (Corbett- U DE)



# Ship Emissions

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- It can be seen that there is major ship traffic into
  - Seattle
  - San Francisco
  - Los Angeles/Long Beach
  - San Diego



# Ship Emissions

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- Ship diesels can utilize a wide range of quality fuels and will typically utilize the lowest cost fuels available.
- Thus, they utilize low volatility residual oil, often referred to No. 6 or bunker-C oil.
- These fuels are typically high in sulfur ( $\sim 2\%$ ) and porphyrins that contain Ni and V.





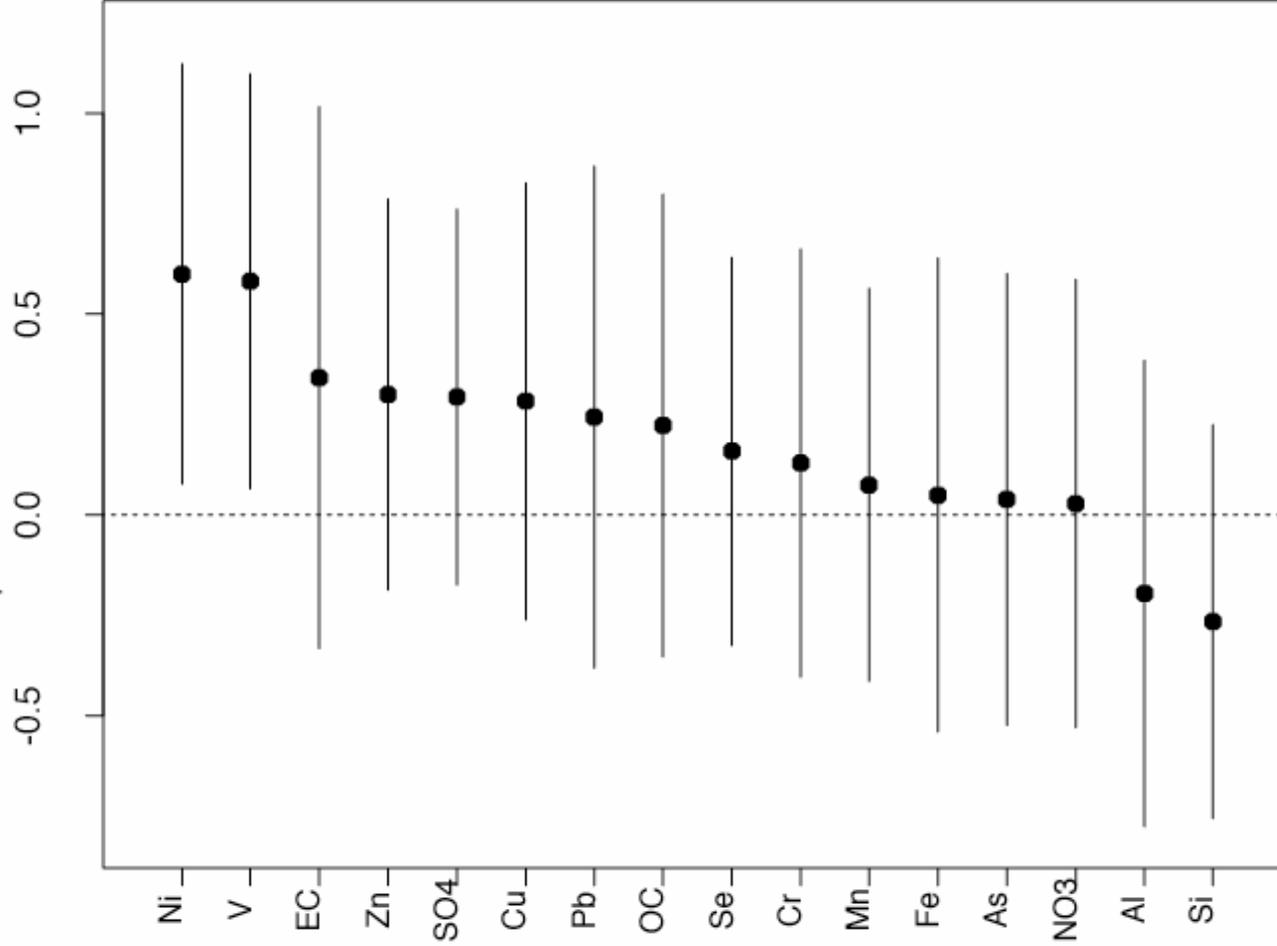
# Health Effects

- Recent unpublished work by Lippmann, Ito and others at NYU have examined the key FPM components from the speciation network and the NMMAPS PM10 daily mortality risk estimates.
- The PM10 mortality risk estimates (expressed as percent excess deaths per  $10 \mu\text{g}/\text{m}^3$  increase in PM10) were then regressed on each of the log of the PM<sub>2.5</sub> components, with weights based on the standard error of the PM<sub>10</sub> risk estimates.



# Health Effects

Difference in mortality risk coefficients per the 5th-to-95th percentile difference in PM components across NMMAP cities.





# Health Effects

- As input to the health effect modeling that is planned for the SECA-related work, it may be worthwhile to contact Profs. Lippmann and/or Ito to get their input on the potential for enhanced effects of Ni on health outcomes.

# Ship Emissions

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- Any combustion source using residual oil will have emissions with similar characteristics, but there have been significant efforts to reduce the use of such fuels to reduce the sulfur emissions along the west coast.
- Thus, to a first approximation, Ni and V can be hypothesized as tracers of ship emissions.



# Ship Emissions

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- The ships generally burn fuel as they enter and leave the ports, but do not generally run their engines while docked for loading and unloading so there are limited emissions during this period. However, there would be significant emissions from support vehicles, trucks and railroad engines, as well as cargo handling systems during the loading/unloading operations.



# Ship Emissions

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- Thus, to estimate the impacts of the ship emissions, it is necessary to be able to separate and apportion the residual oil combustion primary particulate matter as well as estimate the amount of related secondary particles that would arise from the oxidation of the co-emitted SO<sub>2</sub>



# Ship Emissions

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- Our project objectives were to
  - Use existing databases of particle compositions for fine particulate matter ( $PM_{2.5}$ ) and apply positive matrix factorization (PMF) to these data to identify and apportion primary ship emissions
  - Through the examination of the resulting apportioned sources, estimate the contribution of the ship emissions to the secondary  $PM_{2.5}$  measured at these locations.

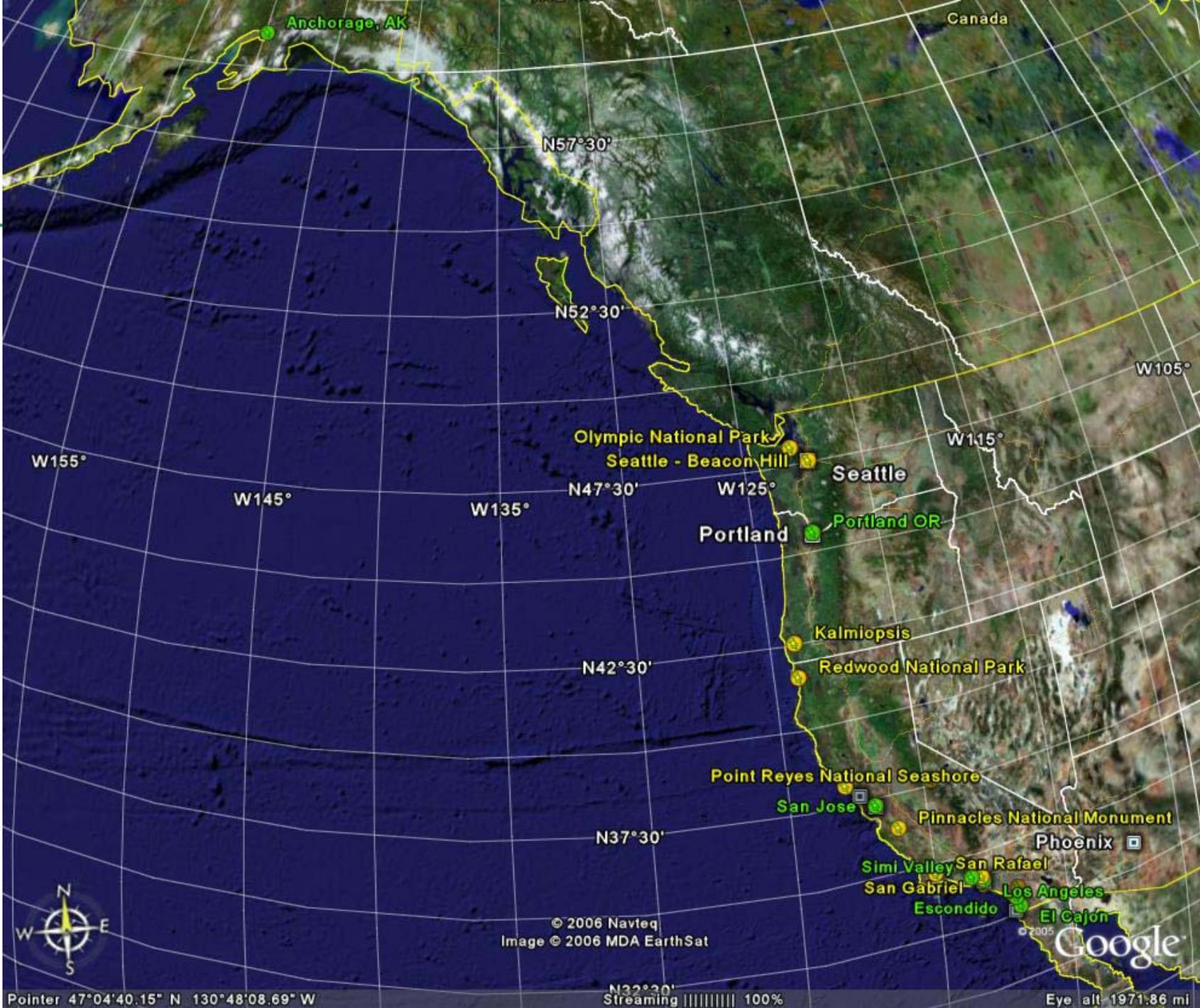


# Data Availability

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- Sampling and Analysis of PM<sub>2.5</sub> samples along the west coast of the United States
  - IMPROVE
  - STN





Anchorage, AK

Canada

N57°30'

N52°30'

W105°

W155°

W145°

W135°

N47°30'

W125°

W115°

Olympic National Park  
Seattle - Beacon Hill

Seattle

Portland

Portland OR

Kalmiopsis

Redwood National Park

N42°30'

Point Reyes National Seashore

San Jose

Pinnacles National Monument

Phoenix

N37°30'

Simi Valley San Rafael

San Gabriel

Los Angeles

Escondido

El Cajon

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Google

Pointer 47°04'40.15" N 130°48'08.69" W

N32°30'  
Streaming 100%

Eye alt 1971.86 mi

# Cities with Multiple Sites

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- Seattle
  - Lake Forrest
  - Olive St
  - Duwamish
  - Beacon Hill
  - Georgetown
- Los Angeles
  - Simi Valley
  - Downtown
  - Rubidoux



# Data Analysis Methods

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- Positive Matrix Factorization
  - Solve the mass balance problem
- Conditional Probability Function
  - Relate the sources to specific wind directions to provide information on likely local sources.





# Mass Balance

The analysis is based on the mass balance equation.

The mass balance can be written to account for all  $m$  chemical species in the  $n$  samples as contributions from  $p$  independent sources

$$x_{ij} = \sum_{k=1}^p g_{ik} f_{kj} + e_{ij}$$

Where  $i = 1, \dots, n$  samples,  $j = 1, \dots, m$  species and  $k = 1, \dots, p$  sources. The  $f$  values are the concentrations of species  $j$  in particles from source  $k$  and the  $g$  values are the mass contributions of source  $k$  to sample  $i$ .



# Mass Balance

- The question is then what is known *a priori* to solve this equation.
- Divide the problem into two classes
  - Source Profiles Known
  - Source Profiles Unknown



# Source Profiles Known

- There has been limited work on chemical characterization of source emissions
- Work is on-going to measure the composition of ship emission and other sources (e.g., railroad diesel)
- Emitted particles change in the atmosphere over relatively short distances and time intervals.



# Source Profiles Unknown

- Thus, we have focused on the development and application of methods that do not require the detailed knowledge of the source profiles.
- Understanding the likely species emitted by various sources is essential to be able to interpret the results of the methods that resolve both the profiles and contributions from the ambient concentration data.



# Receptor Modeling

- SOURCES PROFILES UNKNOWN
  - Factor Analysis
    - Principal Components Analysis
    - Absolute Principal Components Analysis
    - SAFER/UNMIX
    - Positive Matrix Factorization



# Factor Analysis

- Most factor analysis (PCA, APCA, Unmix) use an eigenvector analysis. In an eigenvector analysis, it can be shown [Lawson and Hanson, 1974; Malinowski, 1991] that the equation estimates  $\mathbf{X}$  in the least-squares sense that it gives the lowest possible value for

$$Q = \sum_{i=1}^n \sum_{j=1}^m (e_{ij})^2 = \sum_{i=1}^n \sum_{j=1}^m \left( x_{ij} - \sum_{k=1}^p g_{ik} f_{kj} \right)^2$$



# Factor Analysis

- Thus, most factor analysis use an unrealistic unweighted least-squares fit to the data.

# Positive Matrix Factorization

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- Explicit least-squares approach to solving the factor analysis problem
- Individual data point weights
- Imposition of natural and other constraints, and
- Flexibility to build more complicated models





# Positive Matrix Factorization

- The Objective Function,  $Q$ , is defined by

$$Q = \sum_{i=1}^n \sum_{j=1}^m \left[ \frac{x_{ij} - \sum_{k=1}^p g_{ik} f_{kj}}{\sigma_{ij}} \right]^2$$

where  $\sigma_{ij}$  is an estimate of the uncertainty in  $x_{ij}$

# Conditional Probability Function (CPF)

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- Analyzing source contribution vs wind direction
- Probability that a given factor contribution from a given wind direction will exceed a predetermined threshold criterion (upper 25 % of contribution)

$$CPF_{\Delta\theta} = \frac{m_{\Delta\theta}}{n_{\Delta\theta}}$$

$m_{\Delta\theta}$  : number of occurrence from wind sector  $\Delta\theta$  that are upper 25 % of source contributions

$n_{\Delta\theta}$  : total number of occurrence from the same wind sector

- Sources are likely to be located in the directions that have high CPF values

# Data Issues

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- Data from the IMPROVE and STN networks have some important differences
  - IMPROVE measures a dynamic blank value for OC and subtracts these blanks from the data before reporting it.
  - STN measures static field and laboratory blanks, but these values were not made publicly available and the reported values are NOT blank corrected.





# Data Issues

- Data from the IMPROVE and STN networks have some important differences
  - IMPROVE samples are all measured in the same laboratory for a given species
    - Elements and mass at UC Davis
    - OC/EC at DRI
    - Ions at RTI
  - STN samples have been analyzed for elements in up to 3 laboratories with different error reporting procedures and no errors were reported for the first three years of network operation.



# Data Issues

- PMF requires an estimate of uncertainty in each data value.
- The “uncertainty” needs to include both the measurement error and some measure of the potential variability in the source profile over time.
- We have developed empirical protocols to deal with the data from both networks that permit reasonable results to be obtained from the data.



# Data Issues

- Atmospheric Aerosol Over Alaska: 2. Elemental Composition and Sources, A.V. Polissar, P.K. Hopke, P.A. Paatero, W.C. Malm, and J.F. Sisler, *J. Geophys. Res.* 103: 19,045-19,057 (1998).
- Estimation of Organic Carbon Blank Values and Error Structures of the Speciation Trends Network Data for Source Apportionment, E. Kim, P.K. Hopke, and Y. Qin, *J. Air Waste Manage. Assoc.* 55: 1190 - 1199 (2005).



# Data Issues

- These approaches have now been applied to a large number of data sets by both the Clarkson group and others.
- We have also recently made more detailed comparisons between estimated and actual errors for the STN network data and found that there was relatively little differences in the results and the differences are probably due to the underestimation of the XRF errors reported by one of the STN laboratories.



# Results

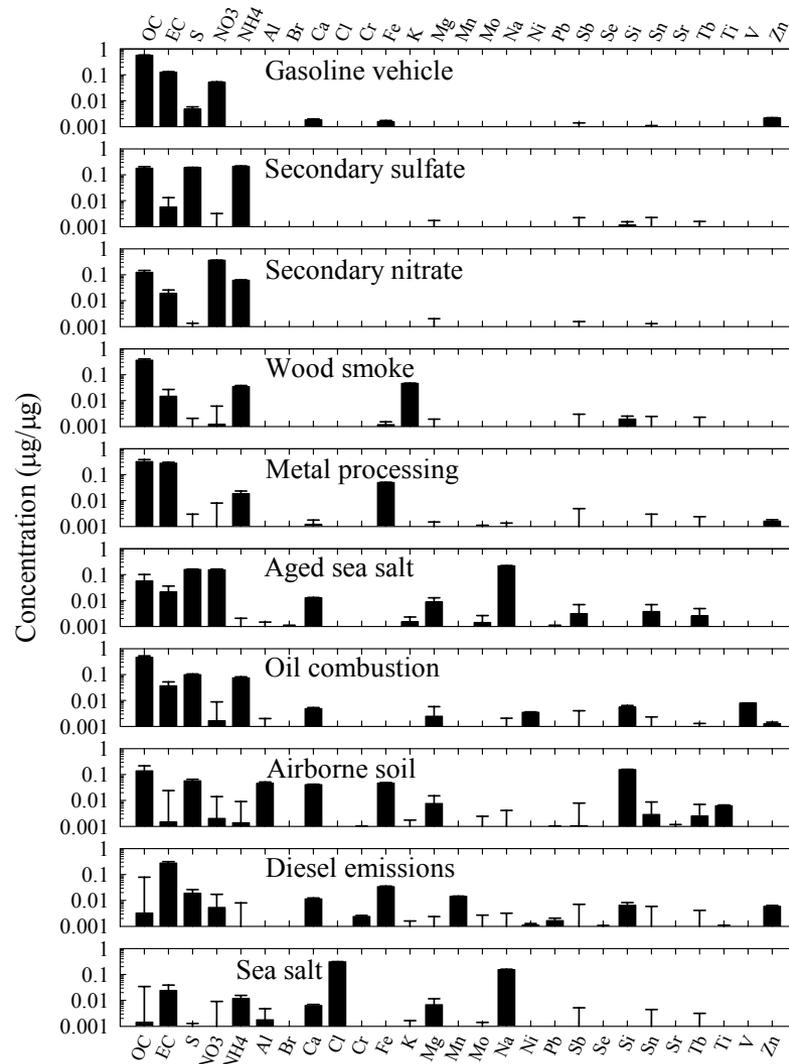
- Residual Oil Profiles could be resolved using the data from:
  - Seattle
    - Beacon Hill
    - Olive St.
    - Duwamish
  - San Diego
    - Escondido
    - El Cajon
  - Point Reyes National Seashore



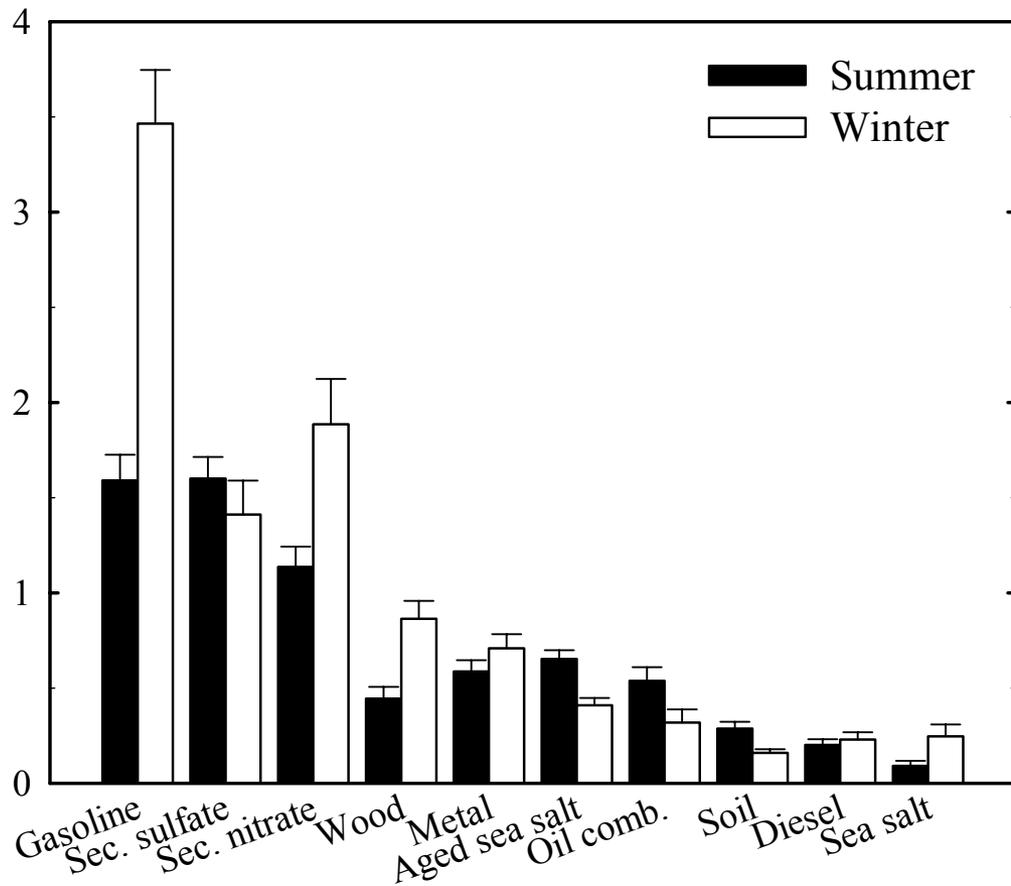
# Results

- Illustrate the results by looking at two sites where the residual oil profile is seen
  - STN (Seattle – Beacon Hill)
  - IMPROVE (Point Reyes National Seashore)
- Site where residual oil is not resolved
  - STN (Rubidoux)
  - Kalmiopsis

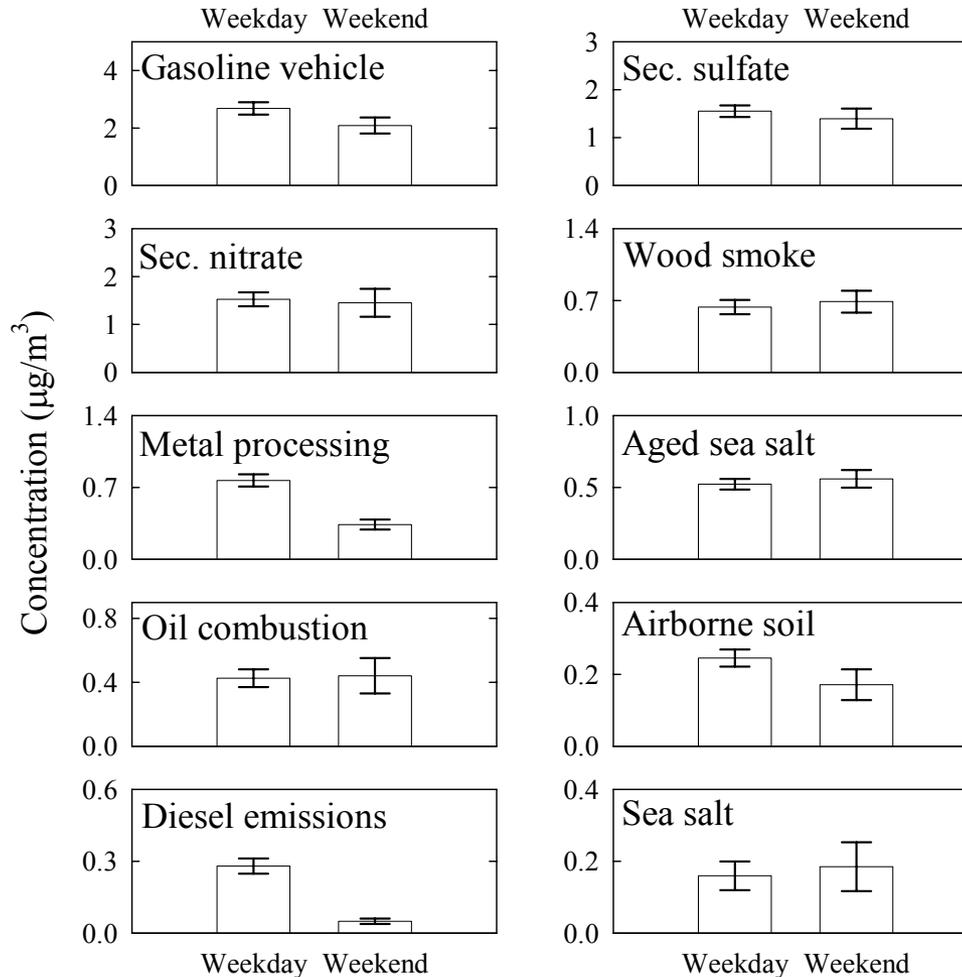
# Results – Beacon Hill



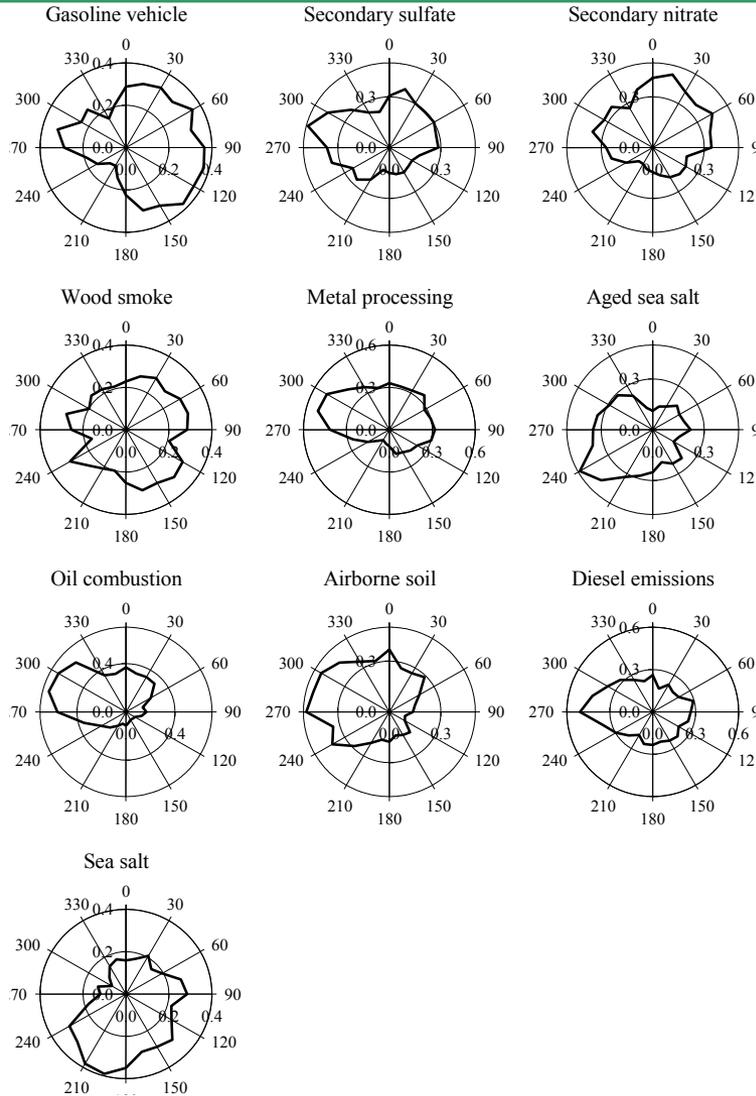
# Results – Beacon Hill



# Results – Beacon Hill



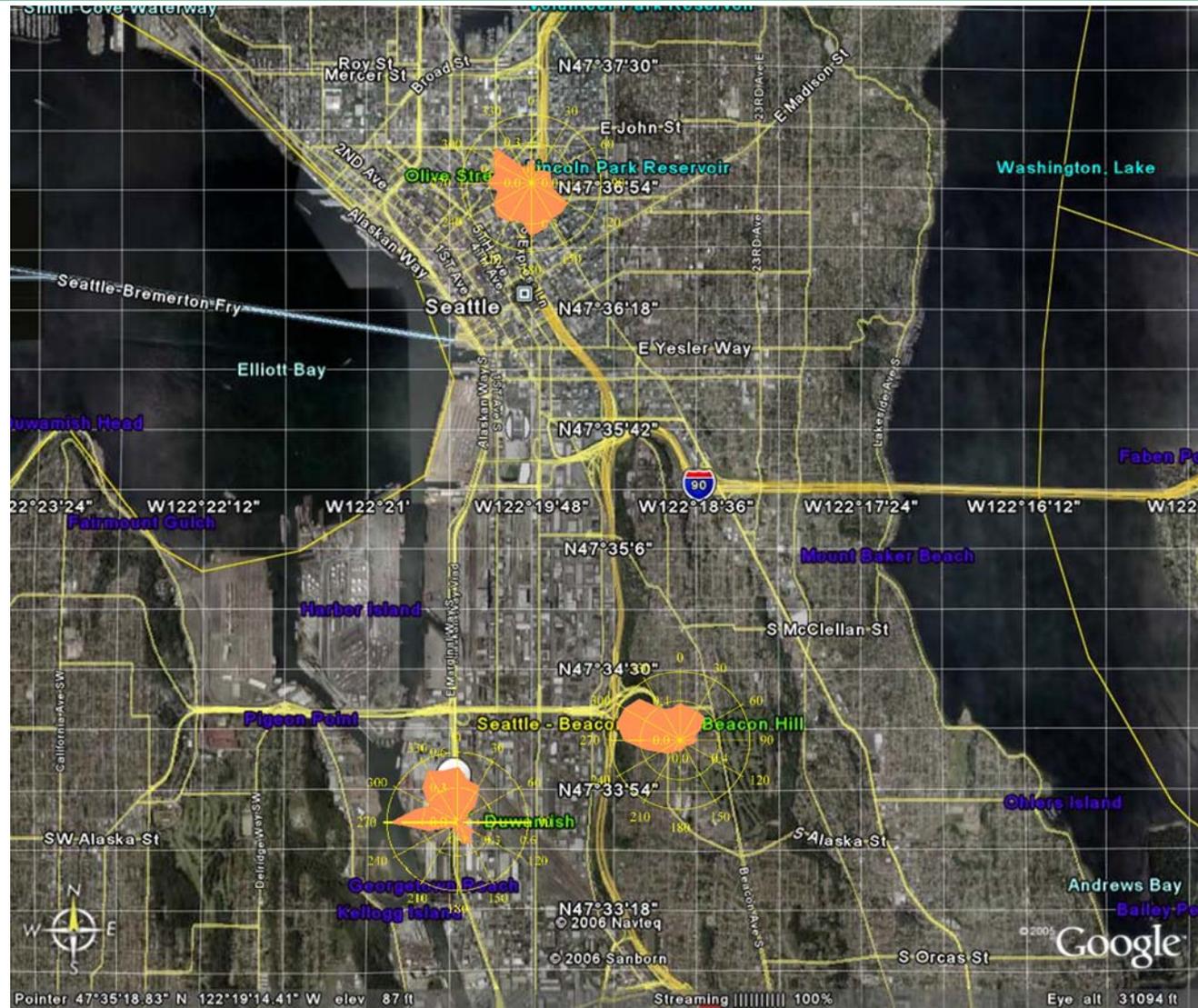
# Results – Beacon Hill



# Results – Beacon Hill

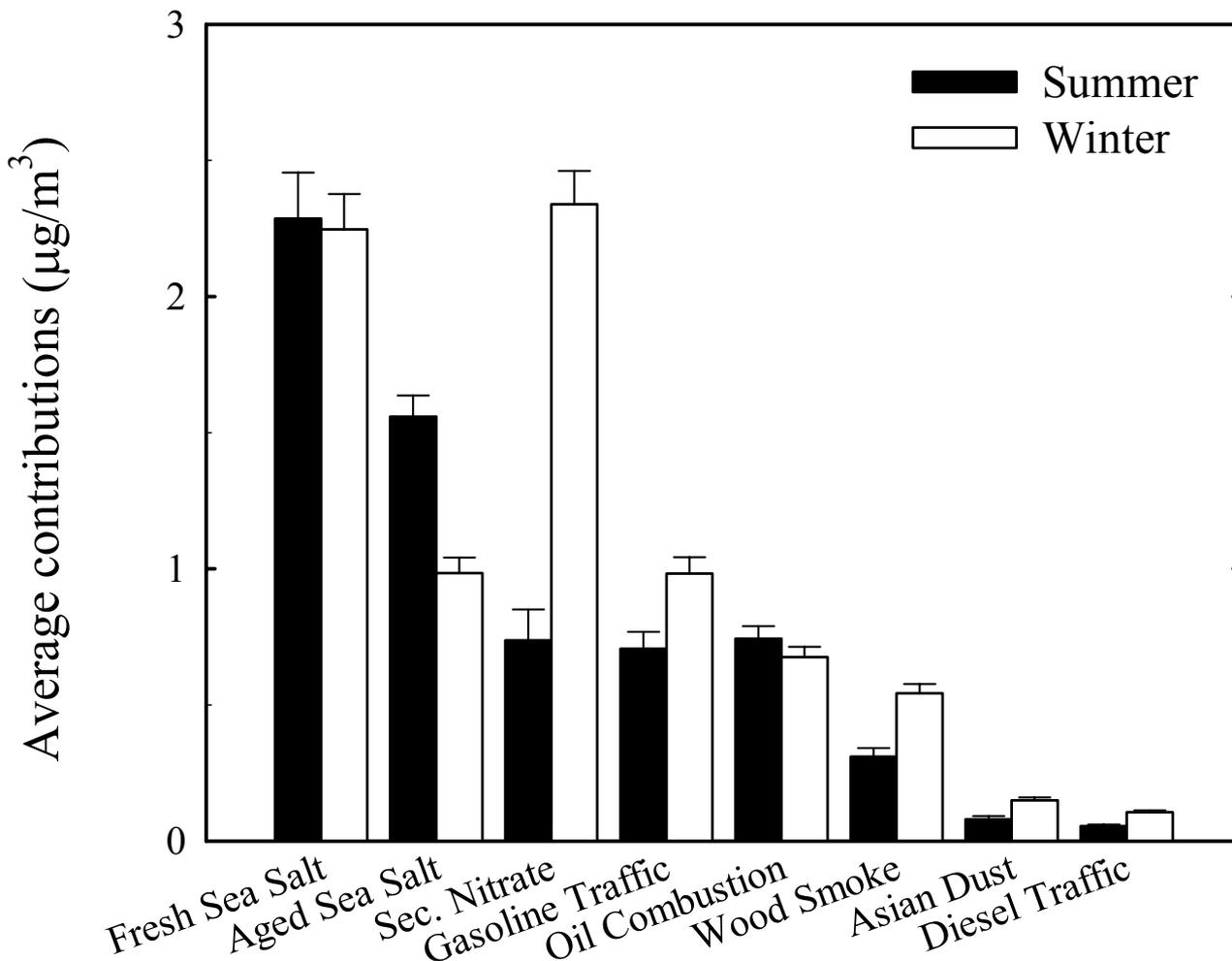


# Results – Seattle CPF for Residual Oil

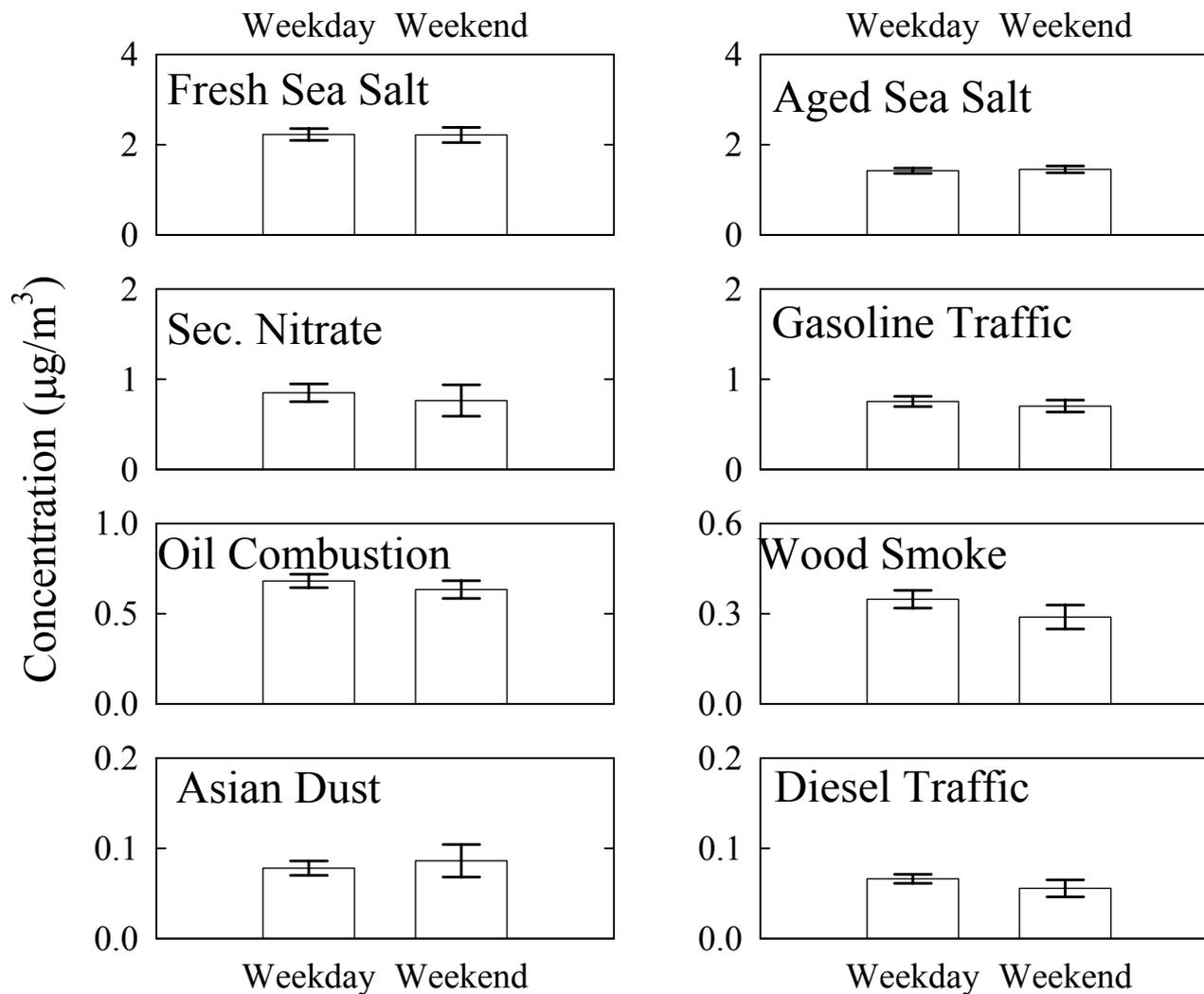




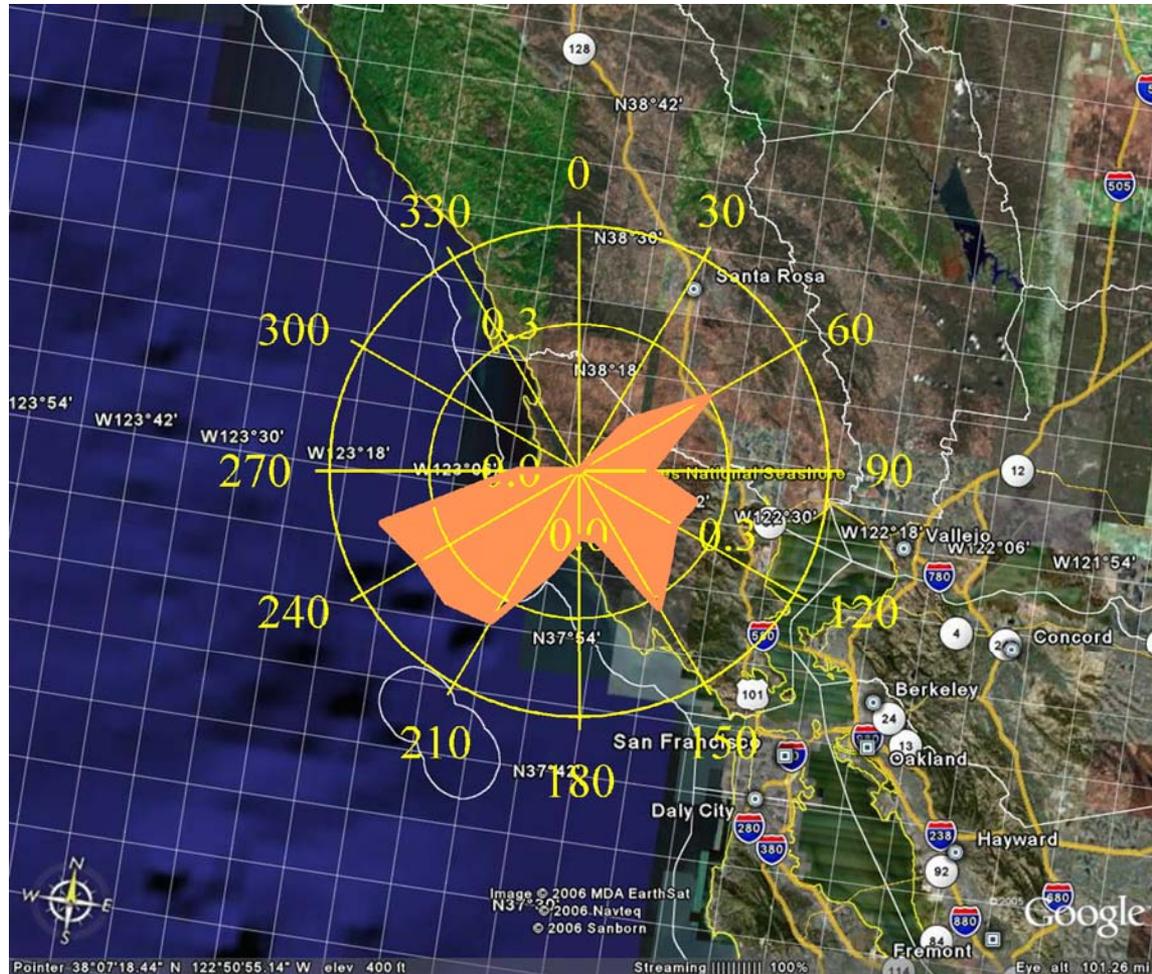
# Results – Point Reyes National Seashore



# Results – Point Reyes National Seashore



# Results – Point Reyes National Seashore



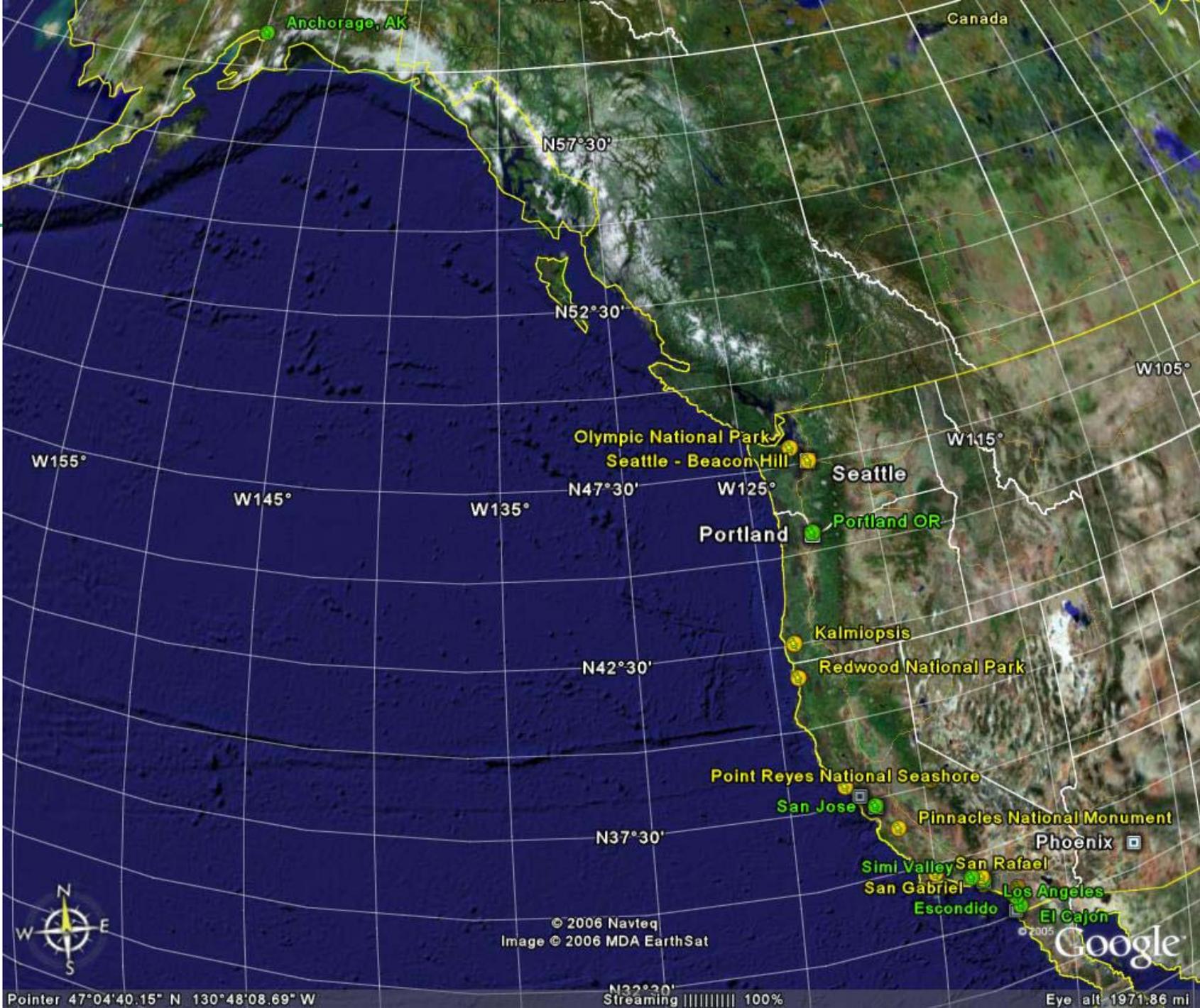




# Results – Rubidoux

- The Ni and V are distributed between the secondary sulfate and aged sea salt profiles.
- Yet there is V and Ni present at Rubidoux and in concentrations approximately 2/3 of those seen at the downtown LA site.
- Results from the past summer at Riverside also see clear evidence of a V/Ni source whose nature is not yet known.





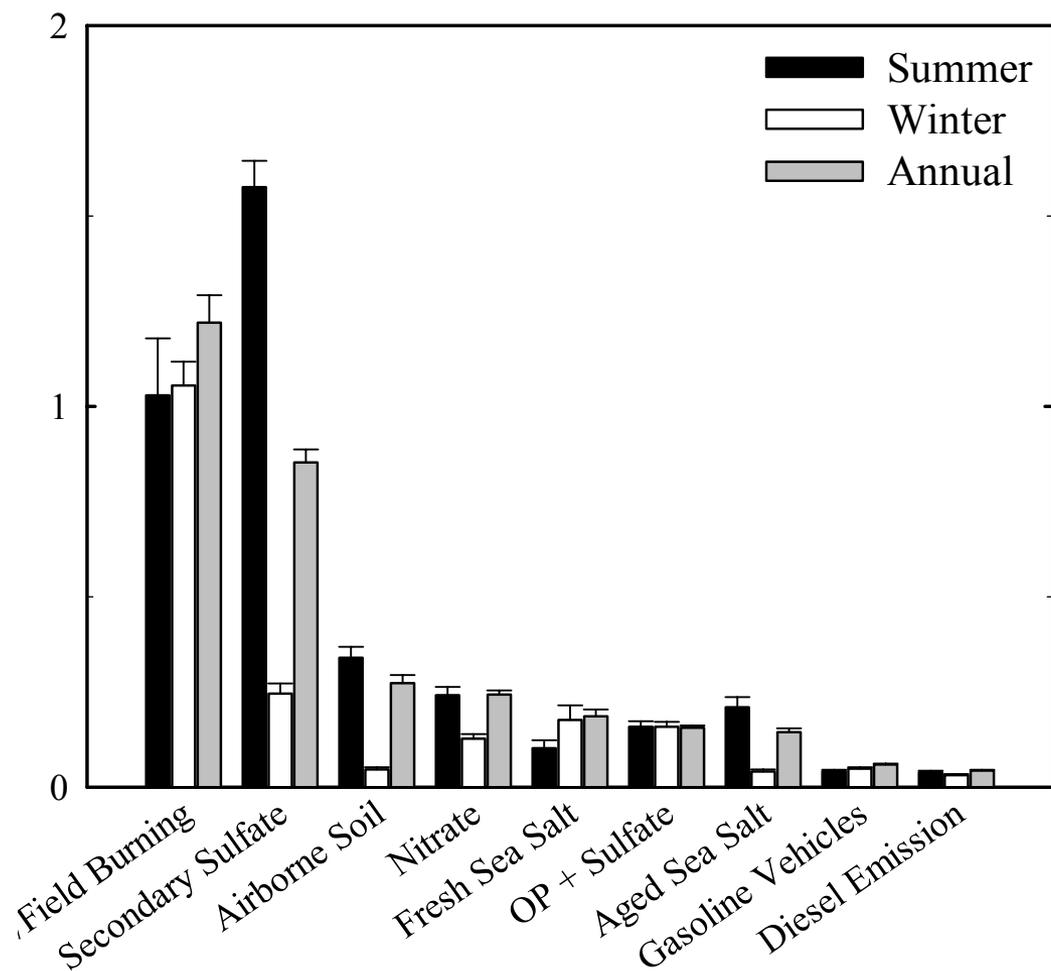


# Results – Kalmiopsis

- The Ni and V are again distributed between the secondary sulfate and aged sea salt profiles.
- Ni and V concentrations are much lower than seen in urban areas.

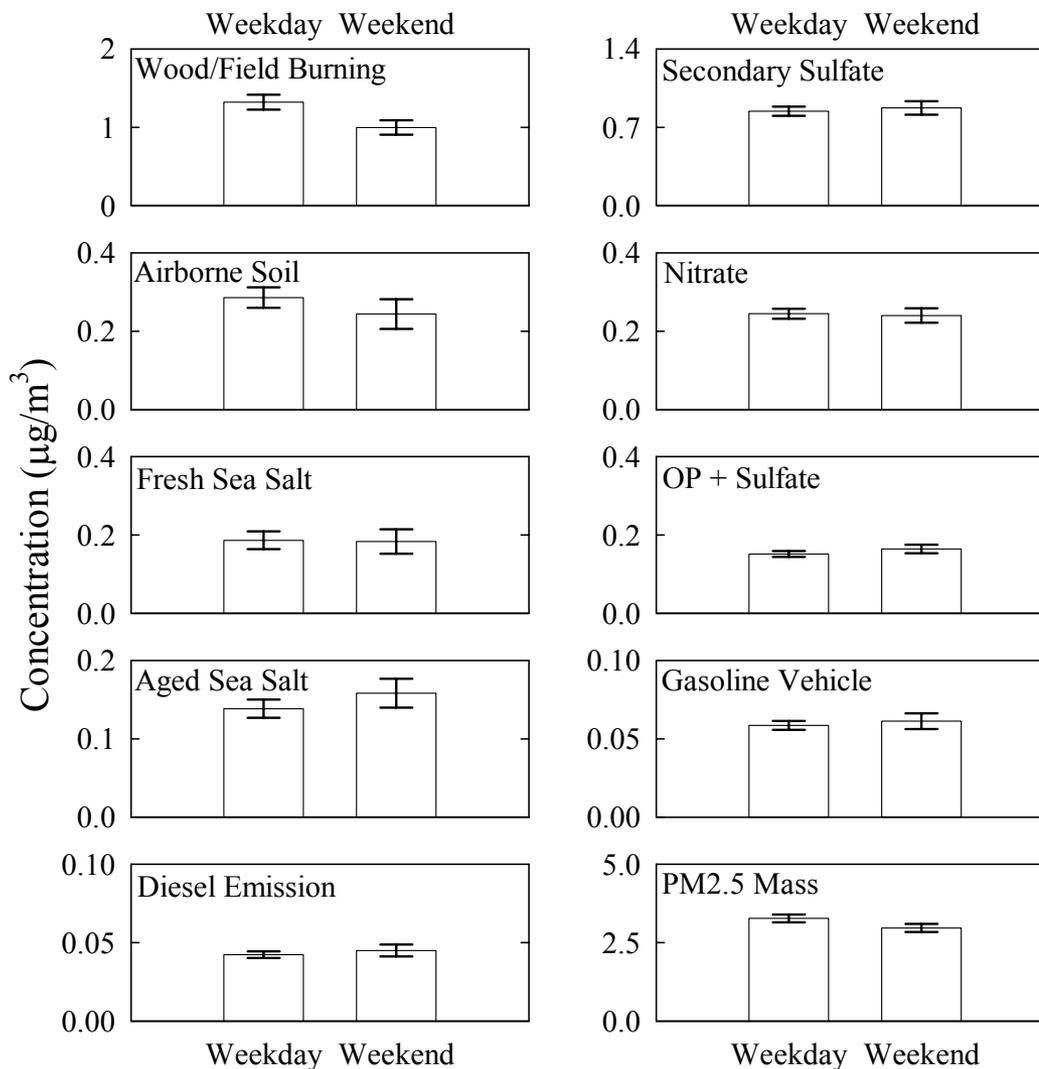


# Results – Kalmiopsis





# Results – Kalmiopsis

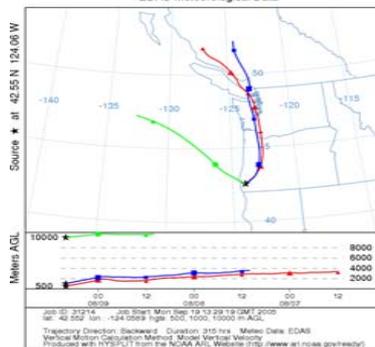




# Biscuit Fire Episode

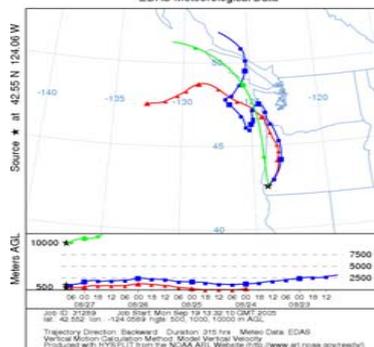
8/9/2002

NOAA HYSPLIT MODEL  
Backward trajectories ending at 08 UTC 09 Aug 02  
EDAS Meteorological Data



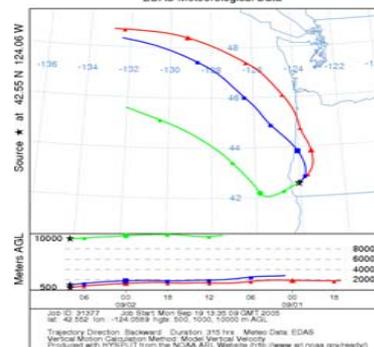
8/27/2002

NOAA HYSPLIT MODEL  
Backward trajectories ending at 08 UTC 27 Aug 02  
EDAS Meteorological Data



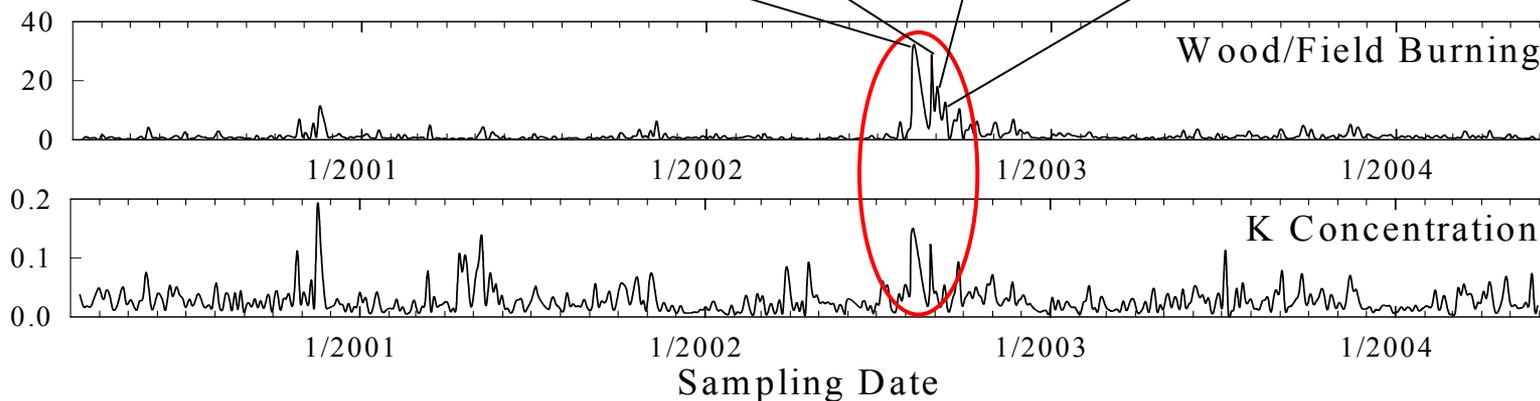
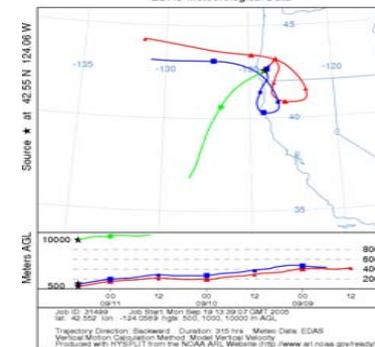
9/2/2002

NOAA HYSPLIT MODEL  
Backward trajectories ending at 08 UTC 02 Sep 02  
EDAS Meteorological Data



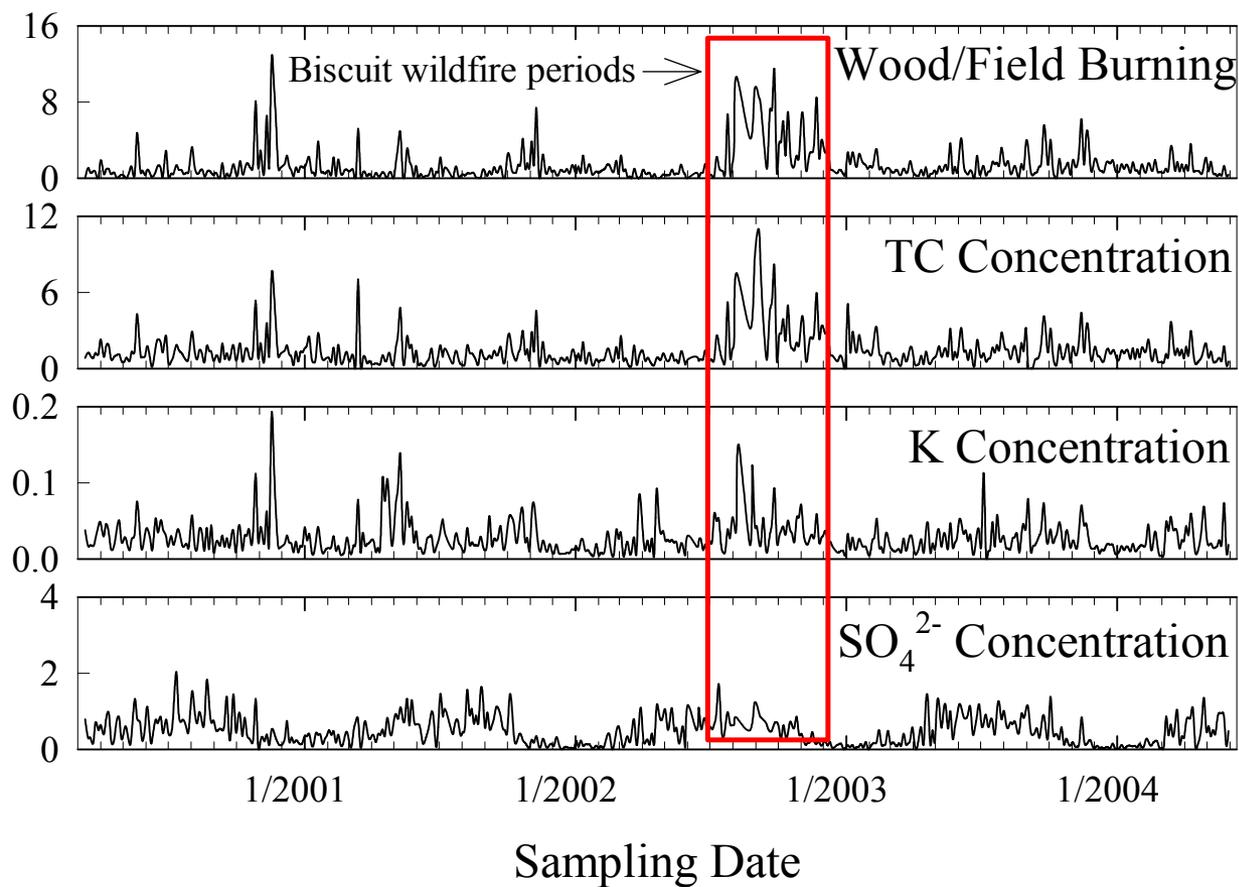
9/11/2002

NOAA HYSPLIT MODEL  
Backward trajectories ending at 08 UTC 11 Sep 02  
EDAS Meteorological Data





# Biscuit Fire Episode



# Impact of Primary Ship Emissions

Site	Type	Mean Residual Oil Contribution ( $\mu\text{g}/\text{m}^3$ )
Seattle		
Olive Street	STN	0.39
Beacon Hill	STN	0.43
Beacon Hill	IMPROVE	0.60
Duwamish	STN	0.43
San Diego		
Escondido	STN	0.57
El Cajon	STN	0.43



# Impact of Primary Ship Emissions

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Site	Type	Mean Residual Oil Contribution ( $\mu\text{g}/\text{m}^3$ )
Aqua Tibia	IMPROVE	0.13
San Rafael	IMPROVE	0.26
Point Reyes National Seashore	IMPROVE	0.66
Olympic National Park	IMPROVE	0.50

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# Impact of Primary Ship Emissions

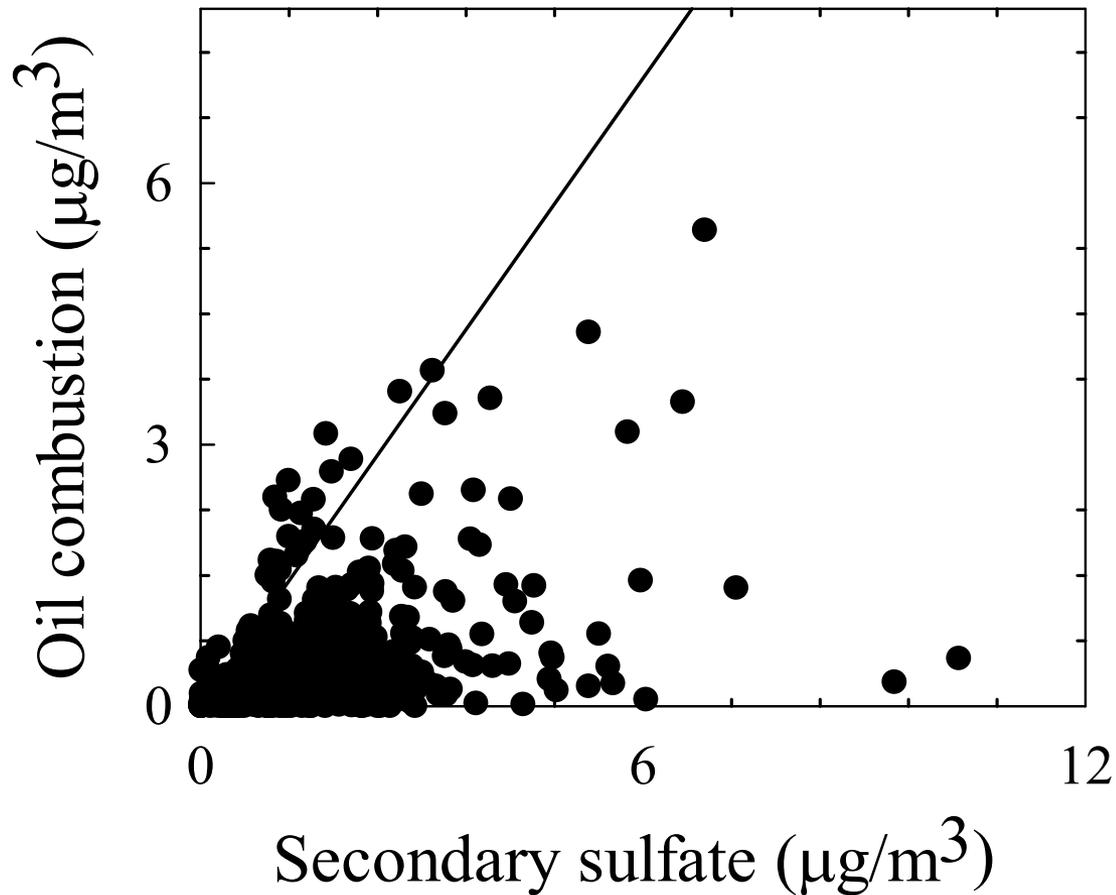
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Ships are also expected to emit  $\text{SO}_2$  as well as the primary V-Ni particles. The  $\text{SO}_2$  will be oxidized into sulfate particles so we might expect to observe a correlation between the residual oil combustion contributions and the amount of secondary sulfate particles. We can look for such correlations by plotting the contributions from one factor against the other.



# Secondary Impacts of Ship Emissions

## Beacon Hill



# Secondary Impacts of Ship Emissions

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The upper edge in this plot is a measure of the maximum amount of oil combustion particles per unit contribution of sulfate. The slope of this line is 1.213 so that there appears to be  $0.82 \mu\text{g}/\text{m}^3$  of sulfate for every  $1 \mu\text{g}/\text{m}^3$  of primary oil combustion particles.

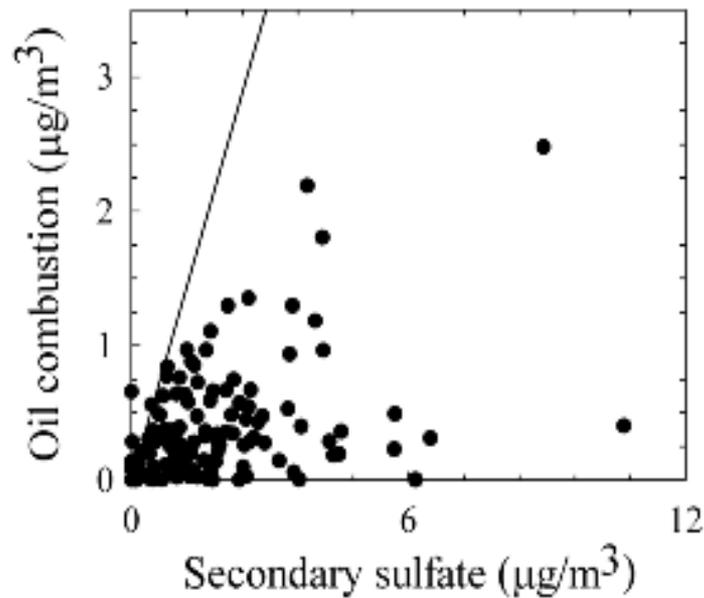
We can look for a similar pattern at other sites.



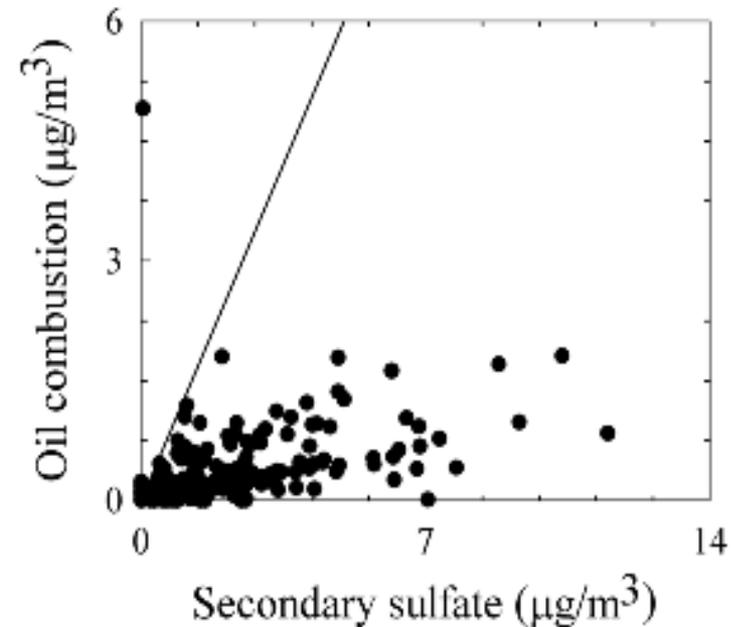
# Secondary Impacts of Ship Emissions

Seattle

Olive Street



Duwamish



# Ship Diesel Contribution in Seattle

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Seattle	Primary	SO <sub>4</sub>	Total
Olive Street	0.39	0.32	0.71
Beacon Hill STN	0.43	0.35	0.78
Beacon Hill IMPROVE	0.60	0.49	1.09
Duwamish	0.43	0.35	0.78

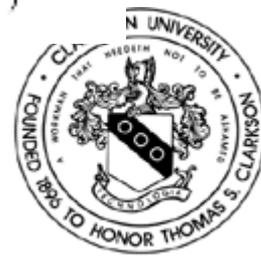
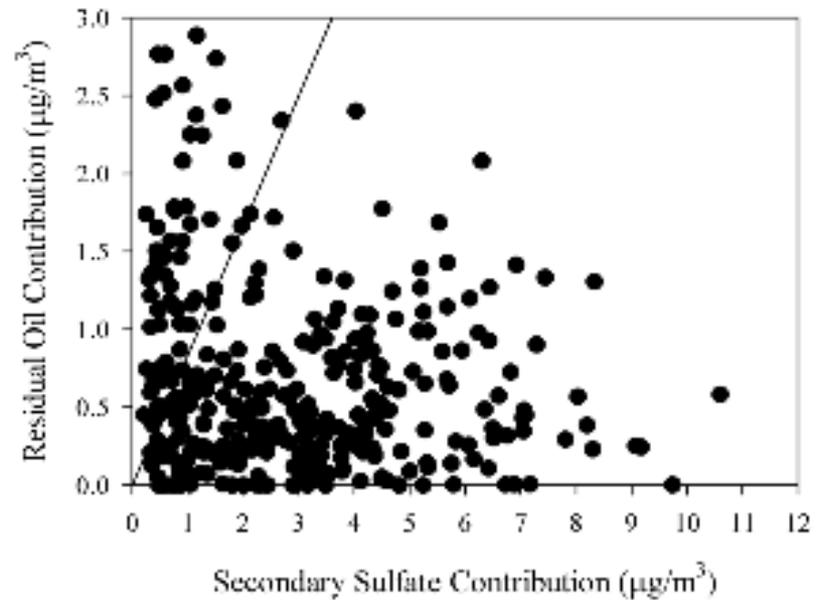
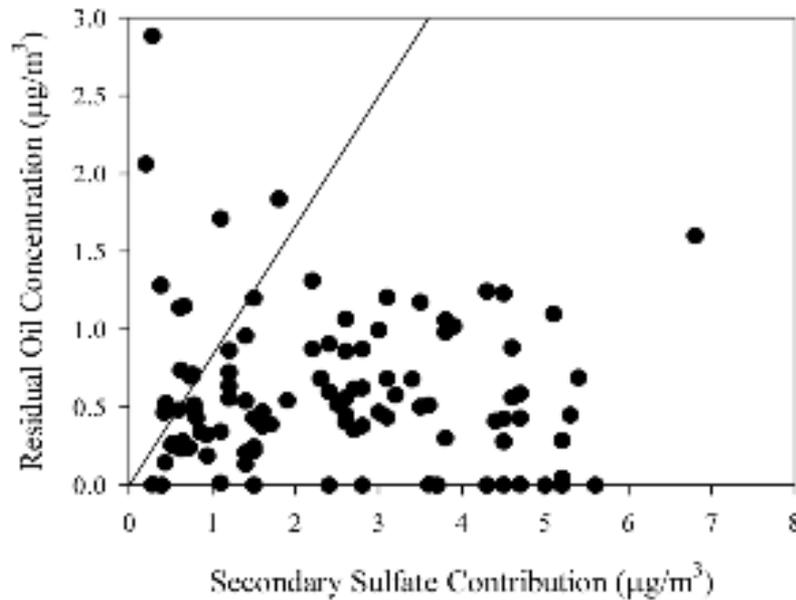
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# Secondary Impacts of Ship Emissions

San Diego

Escondido

El Cajon



# Secondary Impacts of Ship Emissions

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Clearly, there is no obvious relationship between the residual oil factor and secondary sulfate in San Diego. It may be that there is insufficient time to permit significant oxidation of  $\text{SO}_2$  to sulfate.

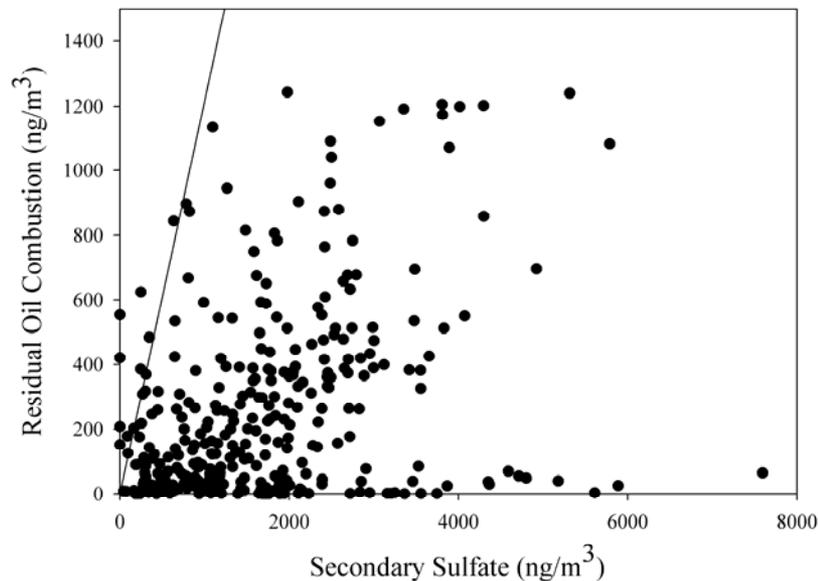
We can also look at the results from IMPROVE Sites like Point Reyes National Seashore and Olympic National Park



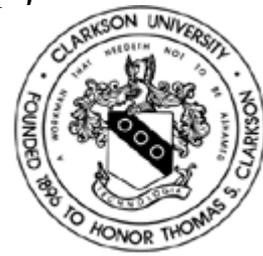
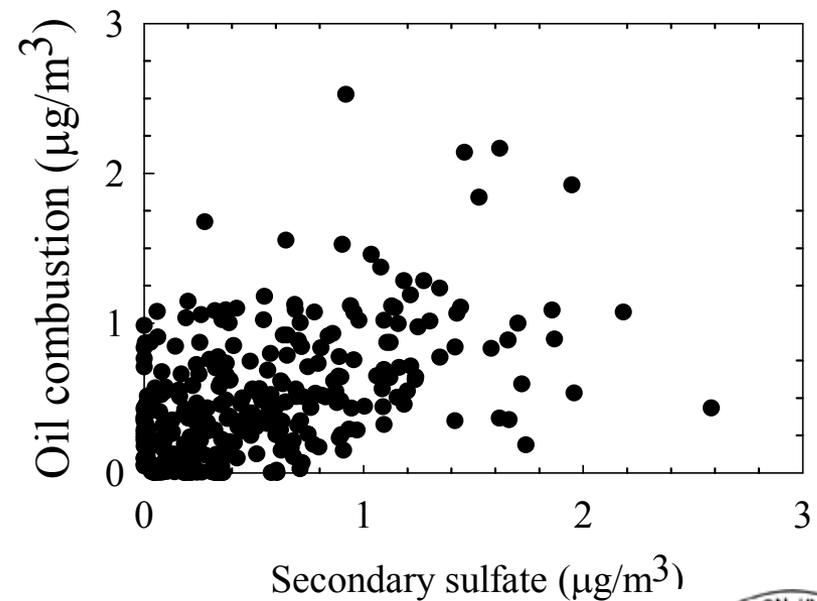
# Secondary Impacts of Ship Emissions

IMPROVE

Point Reyes



Olympic



# Conclusions

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- There appears to be some impact of ship emissions, both primary and secondary. At most sites, these impacts are small. The mean primary emission mass contributions of the order of 0.13 to 0.66  $\mu\text{g}/\text{m}^3$ .
- At some sites, a relationship with the secondary sulfate factor was observed that would roughly double the directly observable contribution of ship emissions to ambient  $\text{PM}_{2.5}$ .



# Conclusions

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- The maximum attributable contribution of ship emissions to any site is approximately 1.2  $\mu\text{g}/\text{m}^3$ . There may be additional secondary sulfate and nitrate arising from their emissions, but they have become disassociated with the primary particulate emissions.



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# QUESTIONS?

