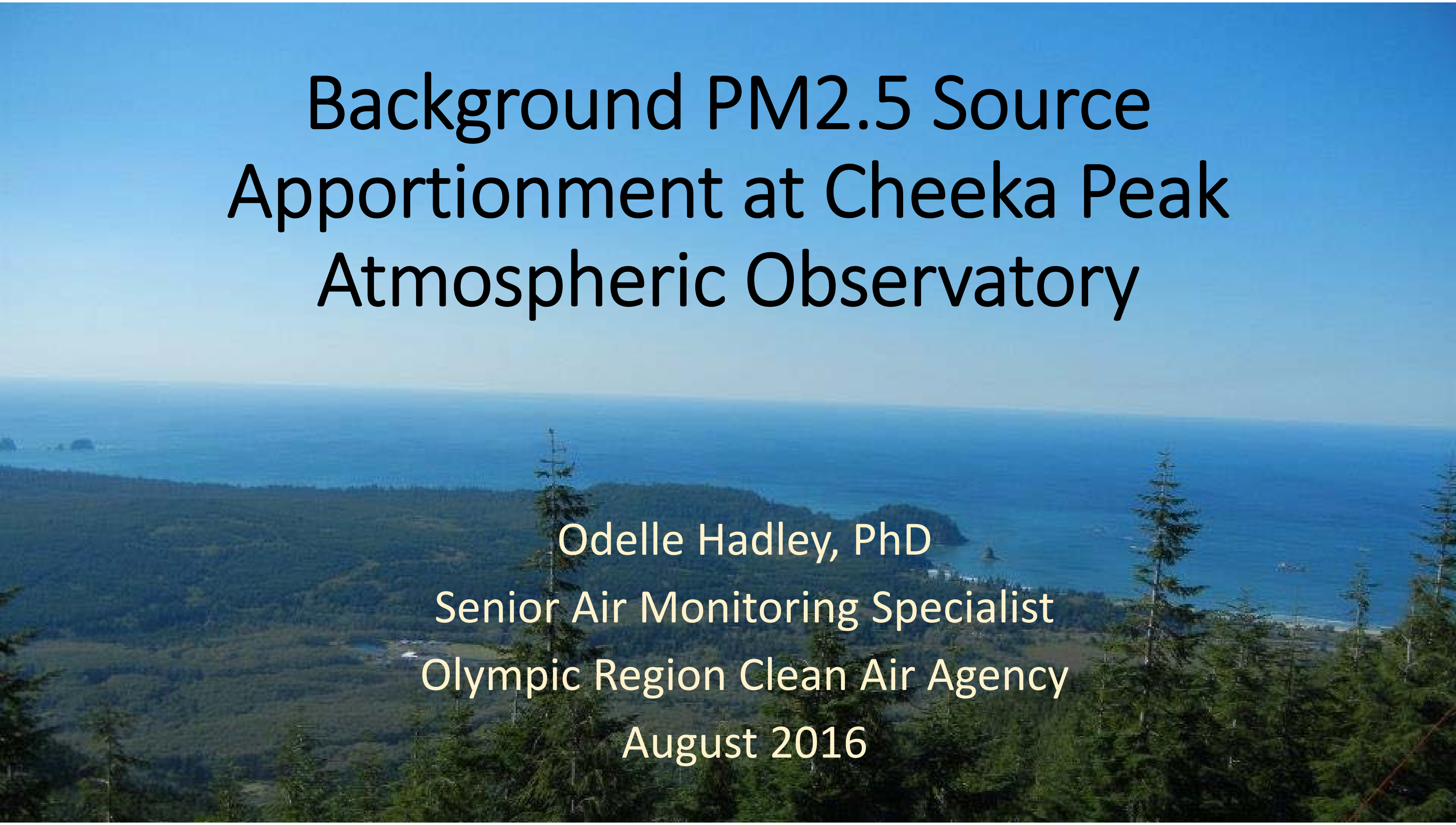

# Background PM2.5 Source Apportionment at Cheeka Peak Atmospheric Observatory

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Senior Air Monitoring Specialist
Olympic Region Clean Air Agency
August 2016

# Cheeka Peak Observatory (CPO)
# Olympic Mountain Range

# Project

- Use positive matrix factorization to determine the primary sources of PM2.5 at a remote west coast air monitoring site between January 2011 and December 2014
- Compare the resulting source factors with collocated trace gases and meteorological measurements
- Look at long term trends and changes in different source contributions to background PM2.5
- Look at seasonal changes in source contribution

# Positive Matrix Factorization (EPA-PMF V5.0)

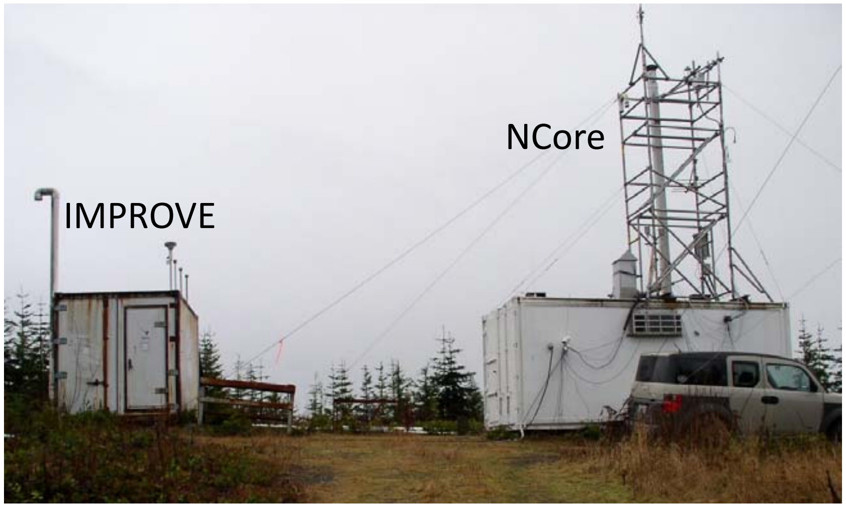
- Receptor based modeling approach
- User determines how many source factors comprise the total aerosol
- Model solves equation 1 iteratively (30 runs) to minimize Q (eqn 2):

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

  - $x_{ij}$ is the input data, where i is the number of days for which a sample was collected and j is the number of chemical species in a sample
  - g is the mass each factor (k) contributes to each sample
  - f is the fraction each chemical species contributes to a source factor
  - $e_{ij}$ is the residual of each species for a given day
- PM2.5 is the "total mass variable"
  - Forces the sum of the source factors to equal the measured PM2.5 input data

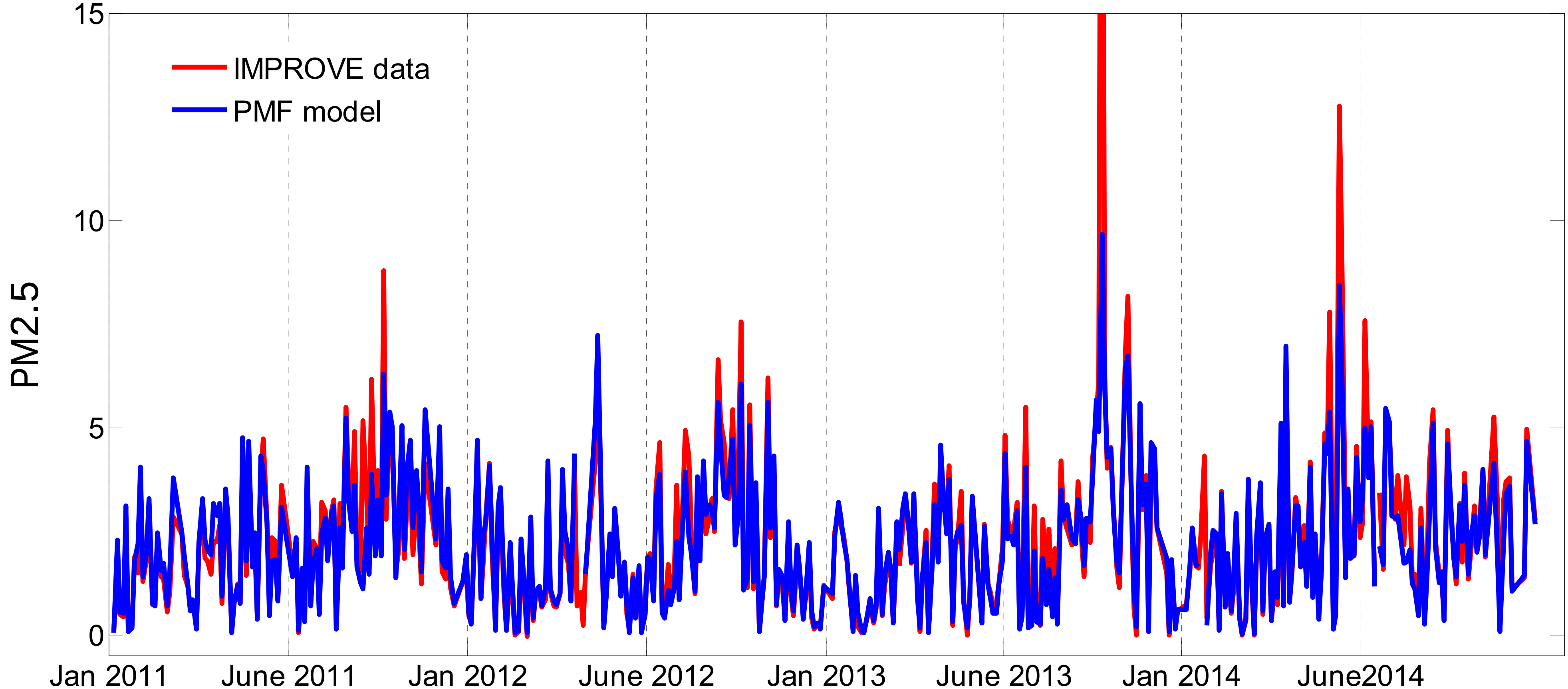
# Data collected at CPO

- IMPROVE data are from PM2.5 filters representing a 24-hour average of chemically speciated particulate collected once every three days
  - 28 chemical species (excluding PM2.5)
  - Was used as input to the PMF model

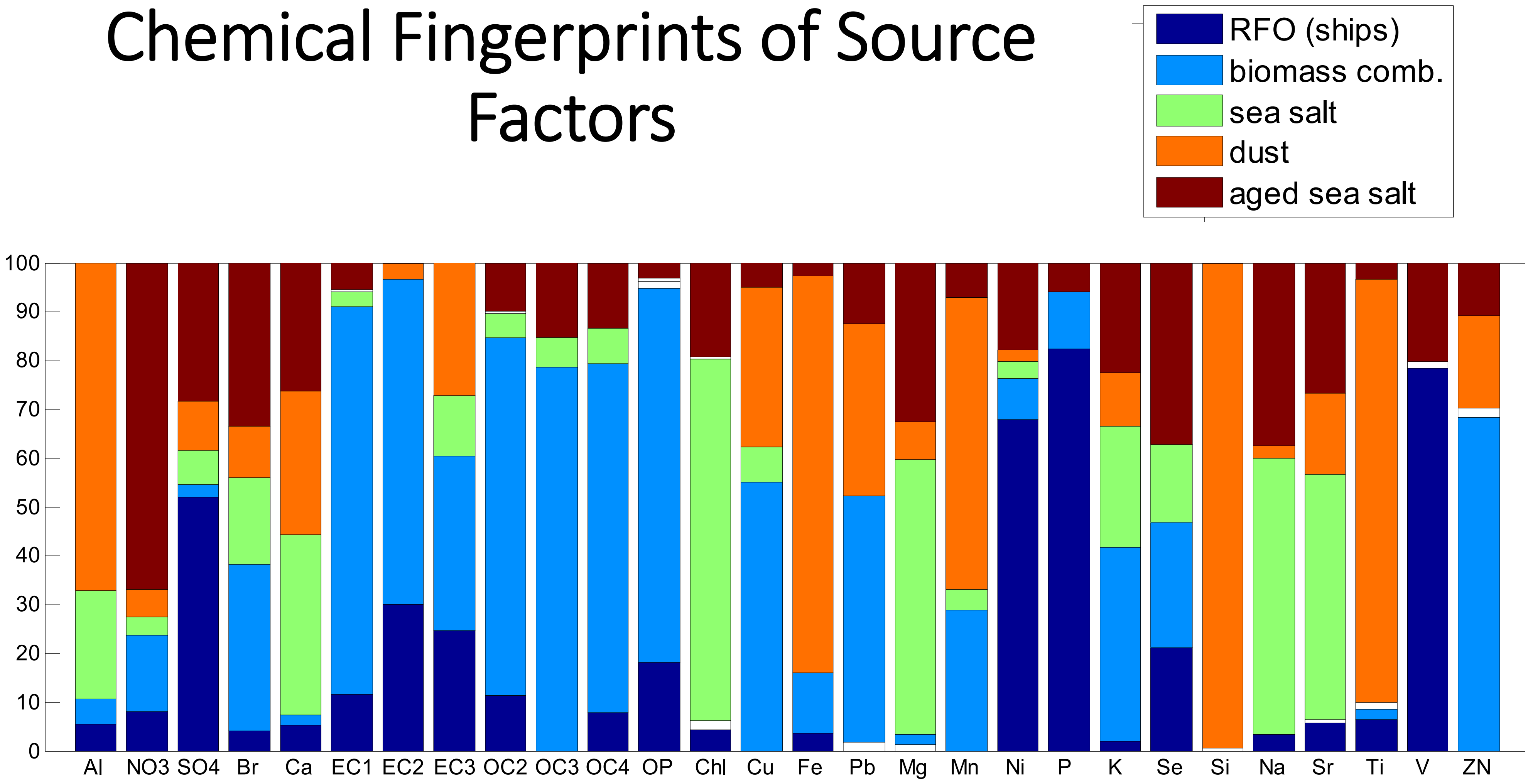



- NCORE data - hourly resolved trace gas, meteorological, and light scatter data
  - **CO**, $SO_2$, **NO/NOy**, & **$O_3$**; nephelometer derived PM2.5; **wind speed and direction**, temperature, pressure, & RH
  - These data helped place PMF model results into context

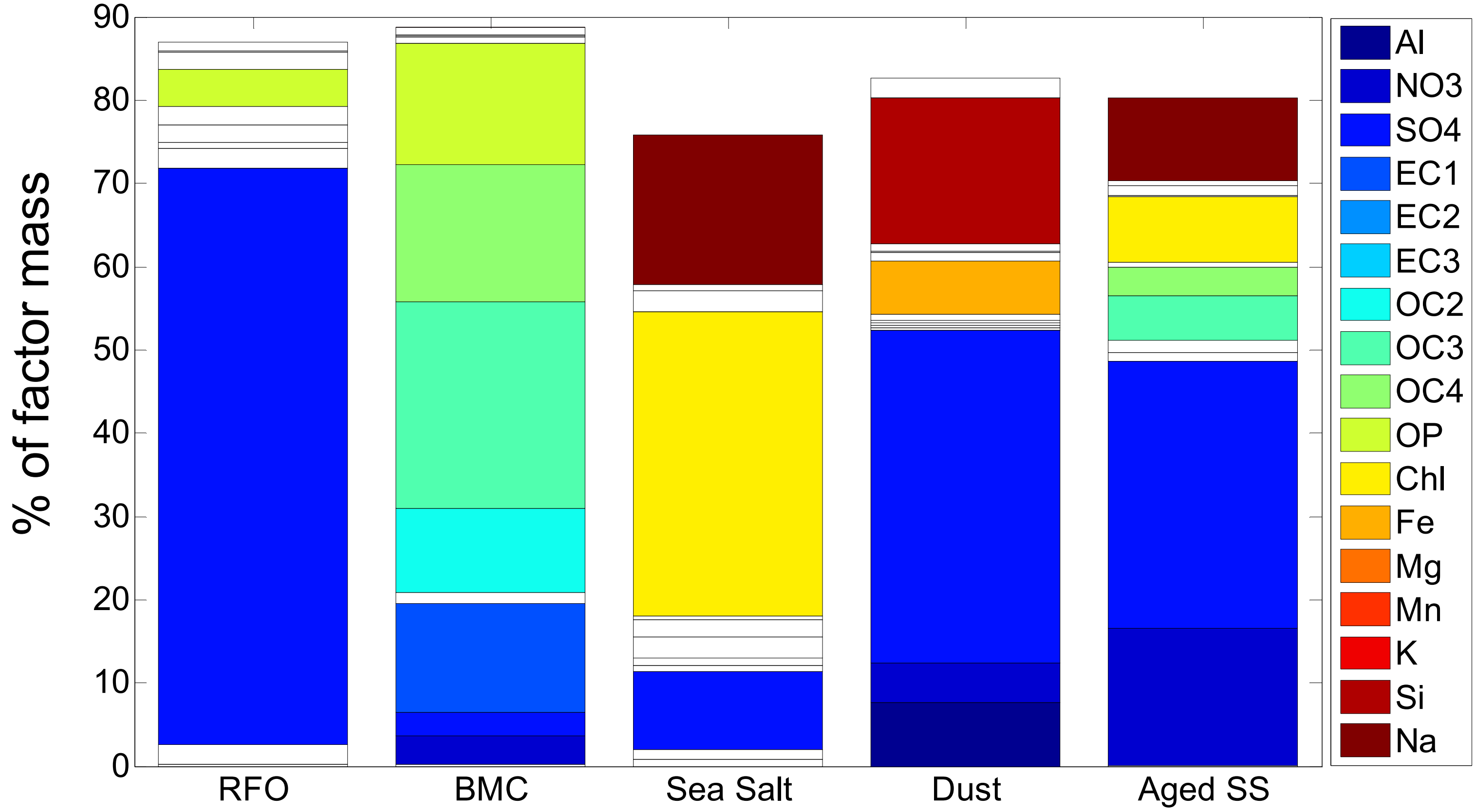
# Measured vs. modeled PM2.5



# Chemical Fingerprints of Source Factors



# Primary components in each source factor



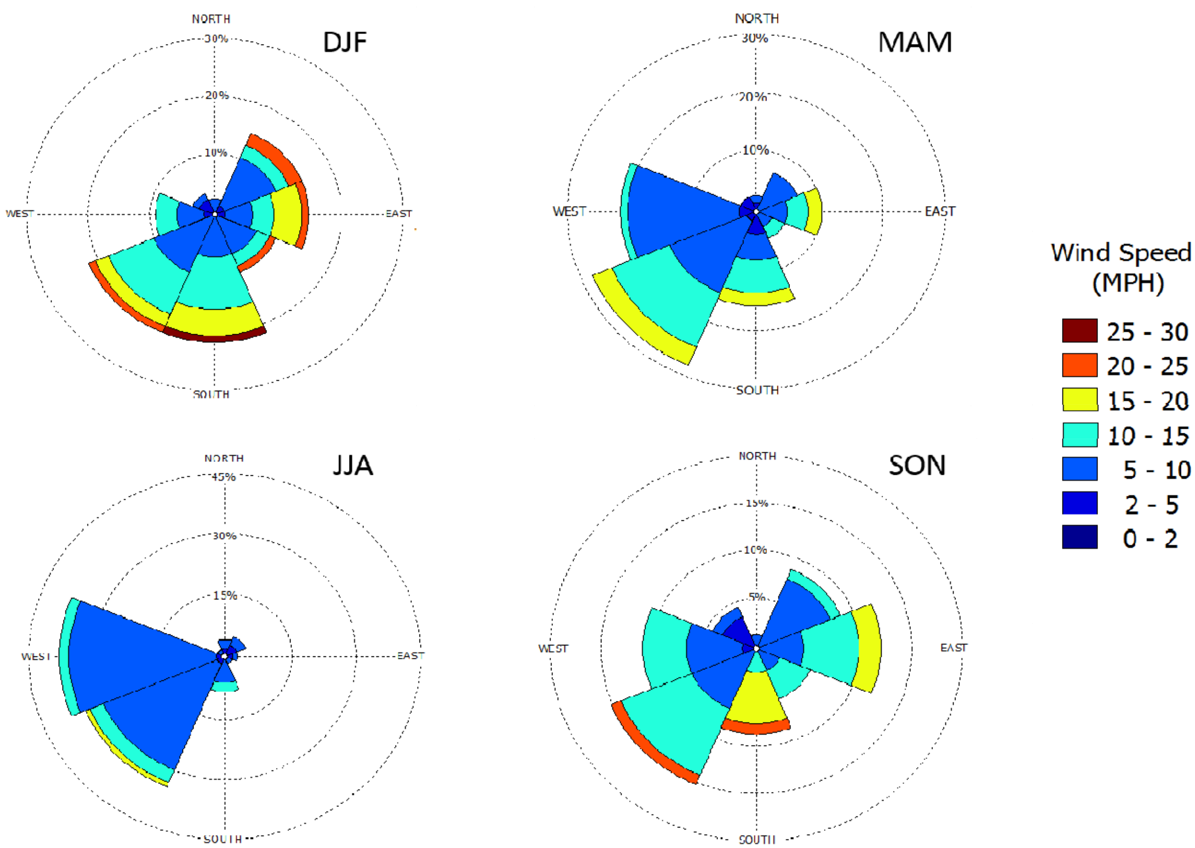
# Error Estimation

- Displacement error estimation
- DISP Diagnostics:
  - Error Code: 0
  - Largest Decrease in Q: -0.105
  - %dQ: -0.000423
  - Swaps by Factor: 0 0 0 0 0 (dQmax = 4, 8, 15, 25)

- Bootstrap error estimation (R=0.7 [0.6]), 100 bootstraps

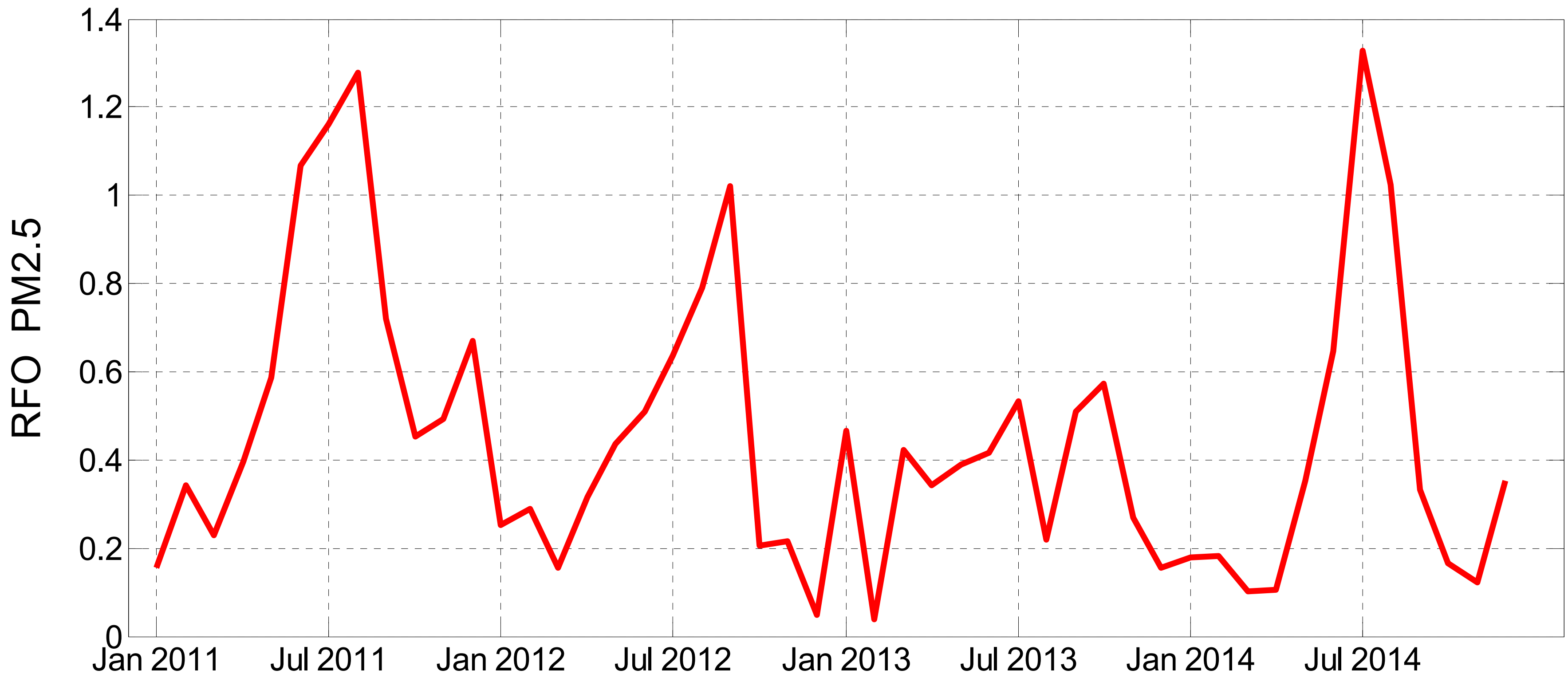
| | RFO_base | BMC_base | SS_base | Dust_Base | Aged_base | unmapped |
|---|---|---|---|---|---|---|
| Boot -RFO | 71 [98] | 8[0] | | | 4 [2] | 17 [0] |
| Boot -BMC | | 100 | | | | |
| Boot -SS | | | 100 | | | |
| Boot -Dust | | | | 100 | | |
| Boot -Aged | | | | | 100 | |

# Seasonal wind rose at Cheeka Peak




- Westerly winds dominate
- Easterly winds are most frequent in winter and fall
- Summer winds are almost exclusively westerly or southwesterly
- Highest wind speeds in winter and fall

# Long term and seasonal trends
# Residual fuel oil (RFO) a.k.a marine vessel emissions



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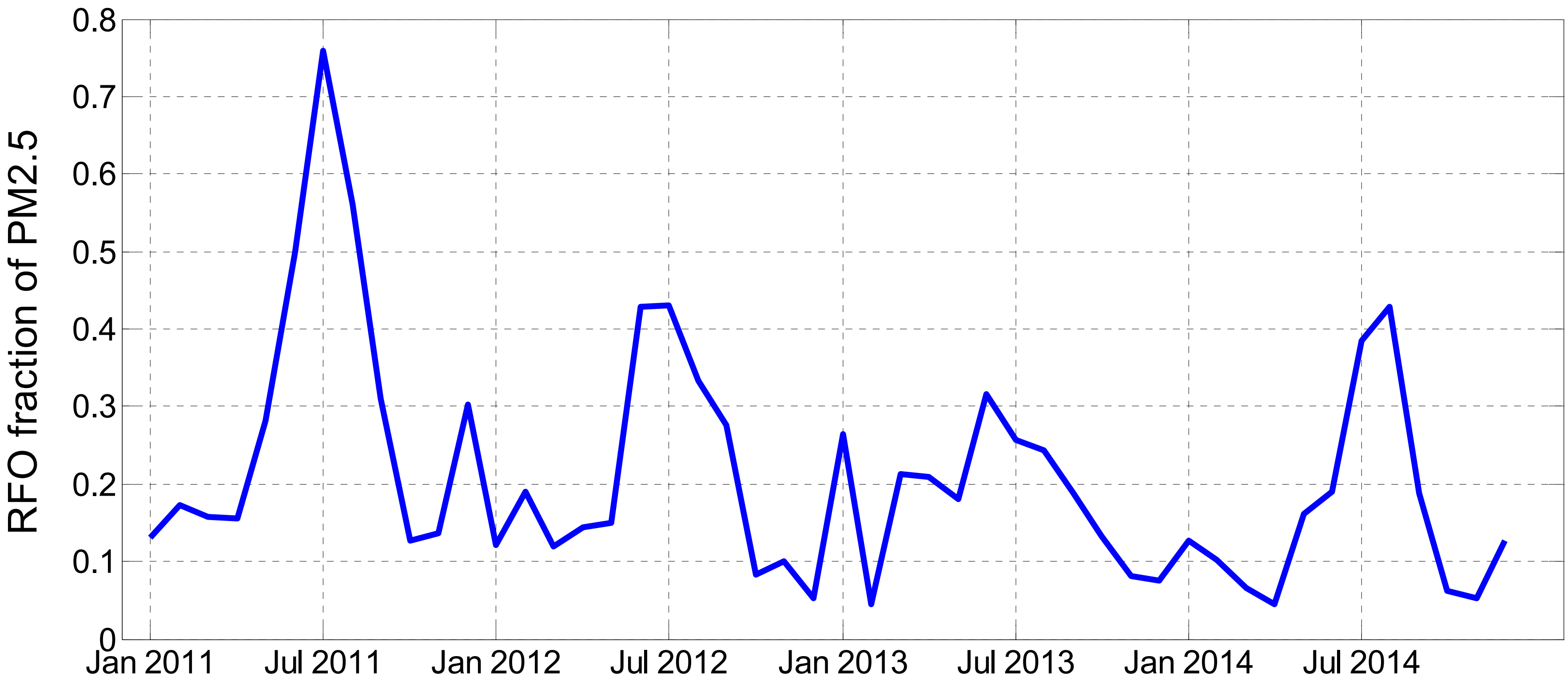
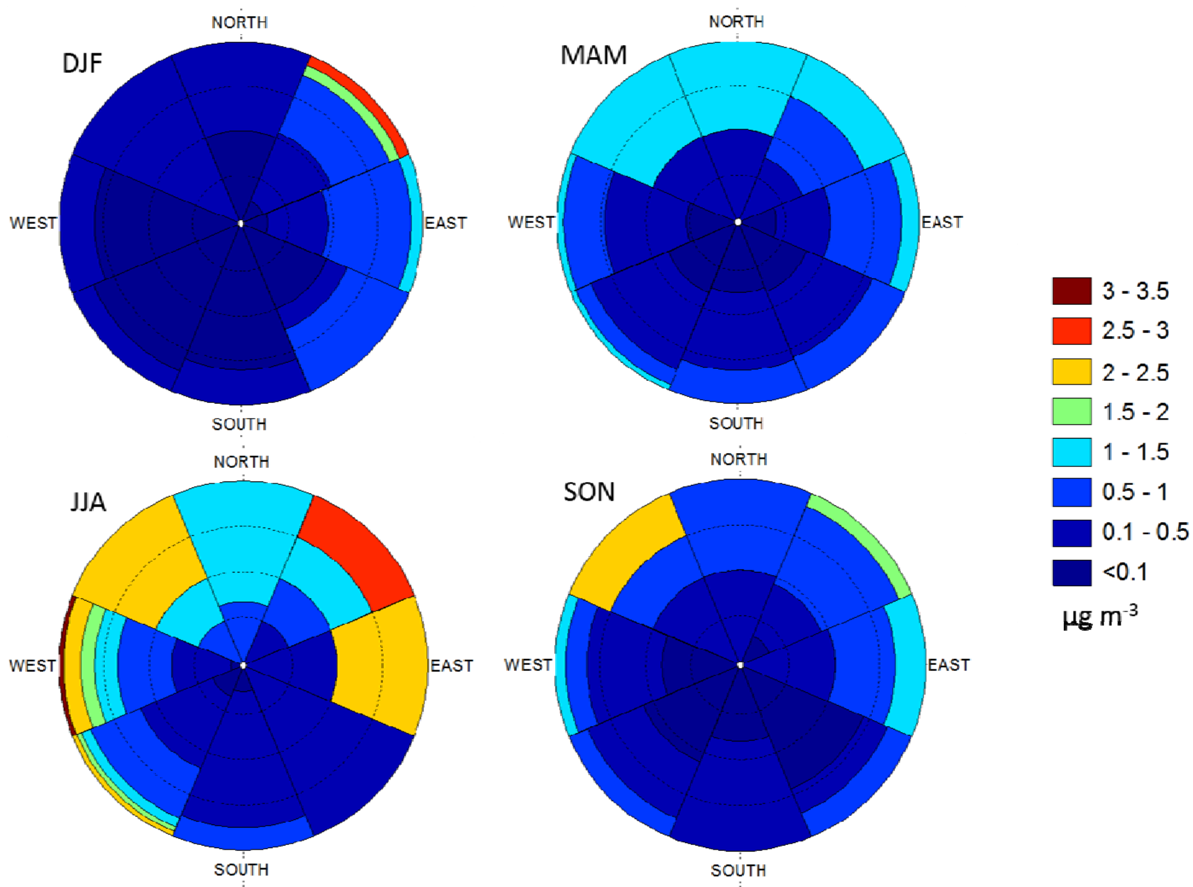
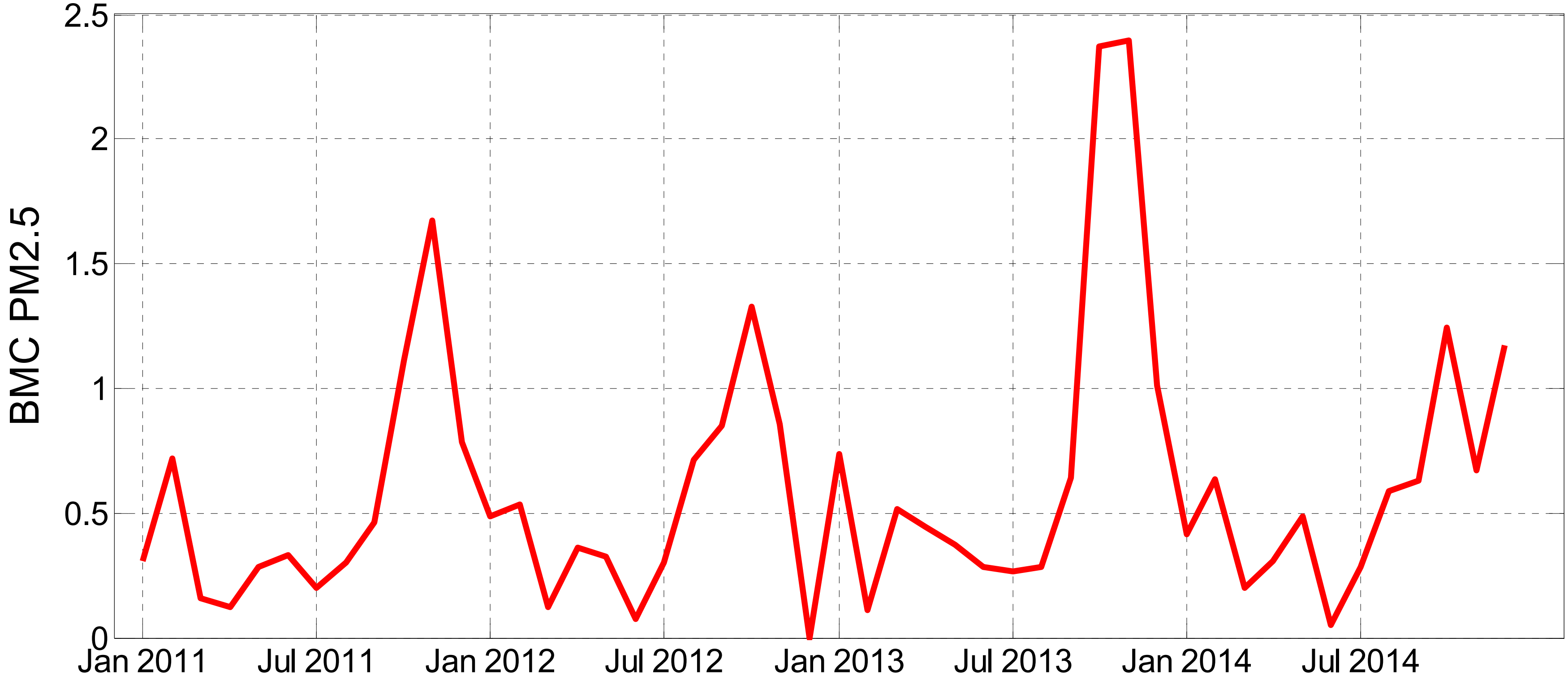


# Seasonal wind direction - RFO

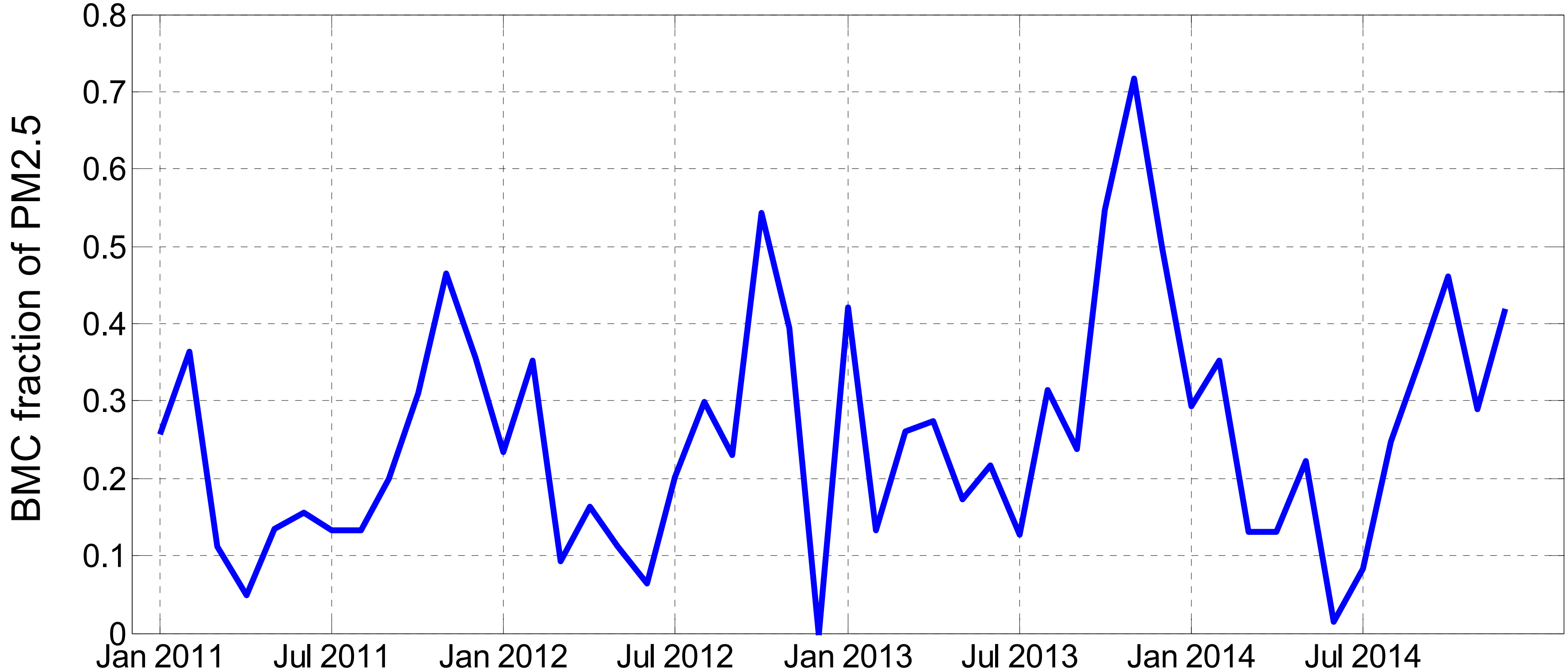



- Normalized frequency distribution with respect to wind direction
- Highest concentrations follow shipping routes:
    - West of CPO
    - North through Strait of Juan de Fuca
    - East and Northeast ports of Tacoma, Seattle, and Vancouver
- Highest concentrations observed in the summer

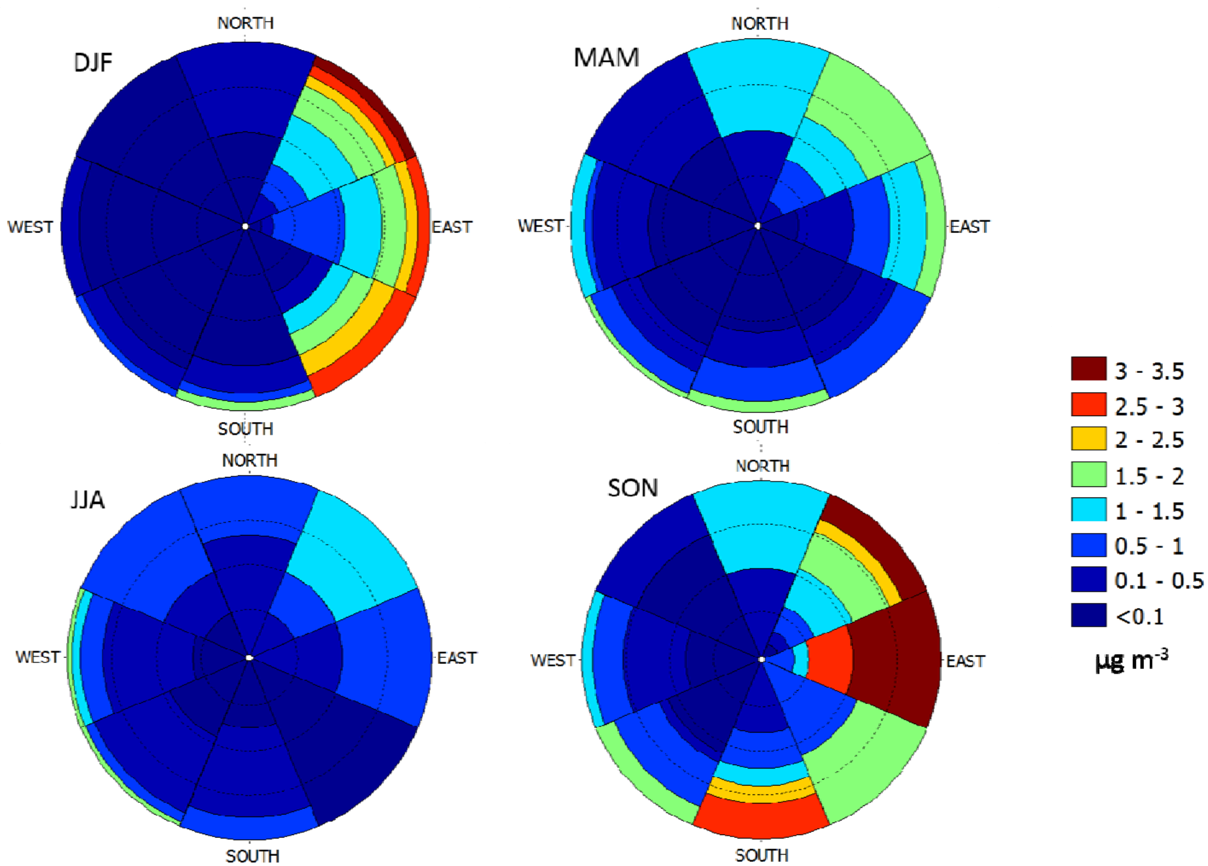
# Long term and seasonal trends biomass combustion (BMC)



# Long term and seasonal trends biomass combustion (BMC)

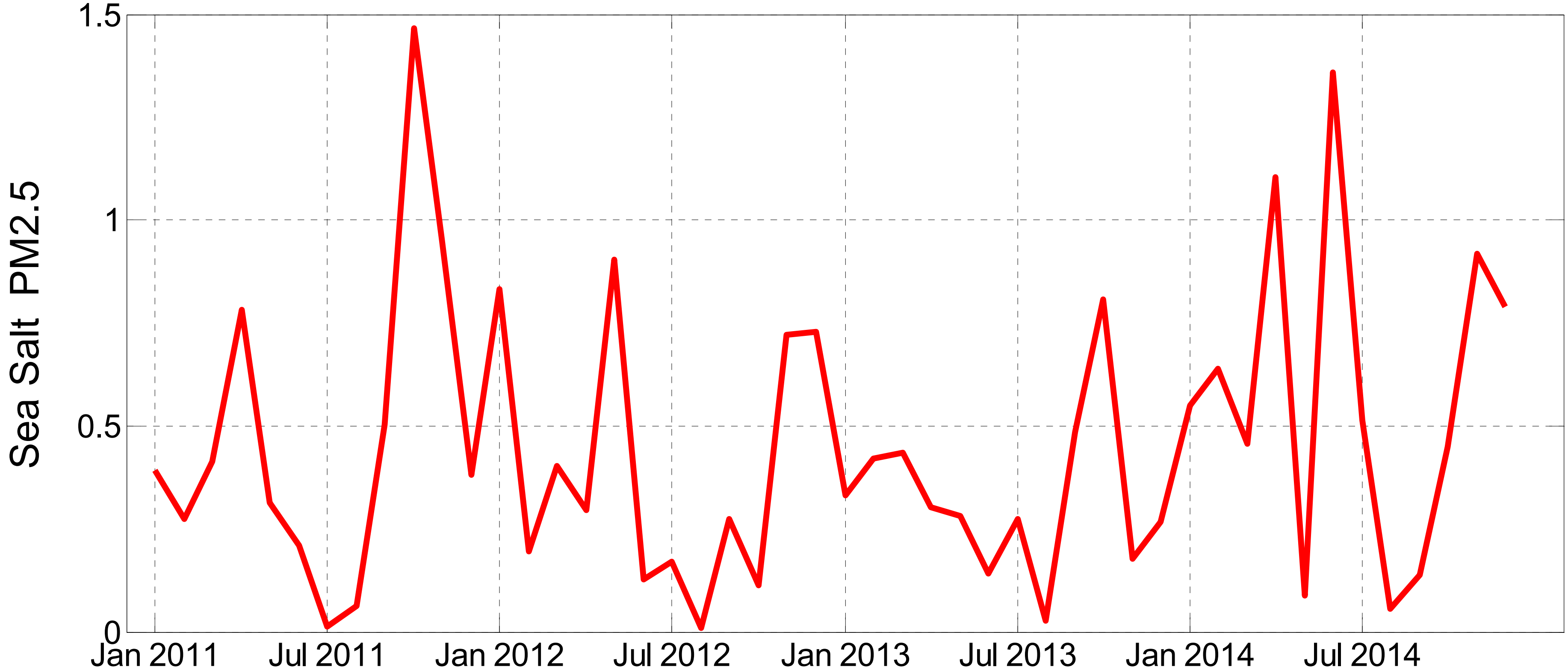


# Seasonal wind direction - BMC




- Highest concentrations are associated with easterly winds:
  - Continental air
- Highest concentrations observed in winter and fall
  - Winter concentrations likely associated with residential burning
  - Fall concentrations with outdoor burning and residential heating

# Long term and seasonal trends – Sea Salt



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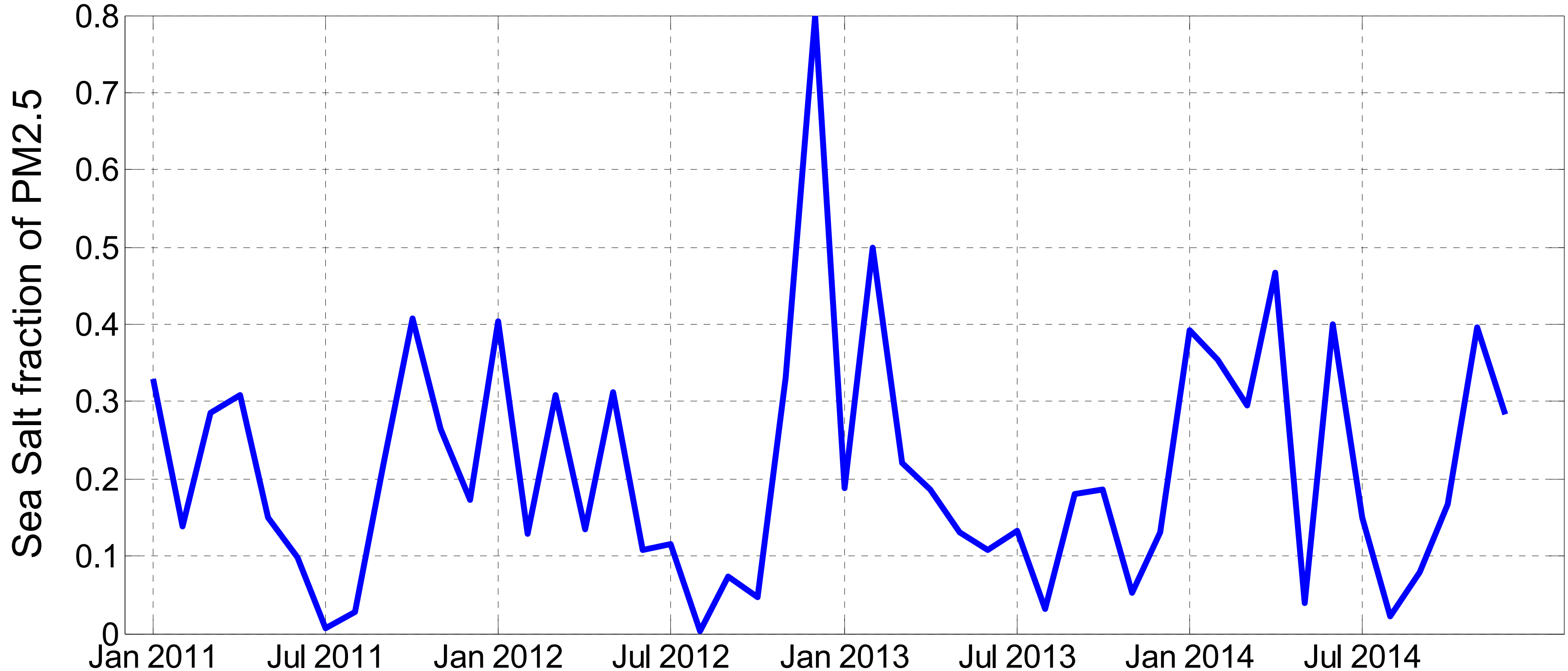
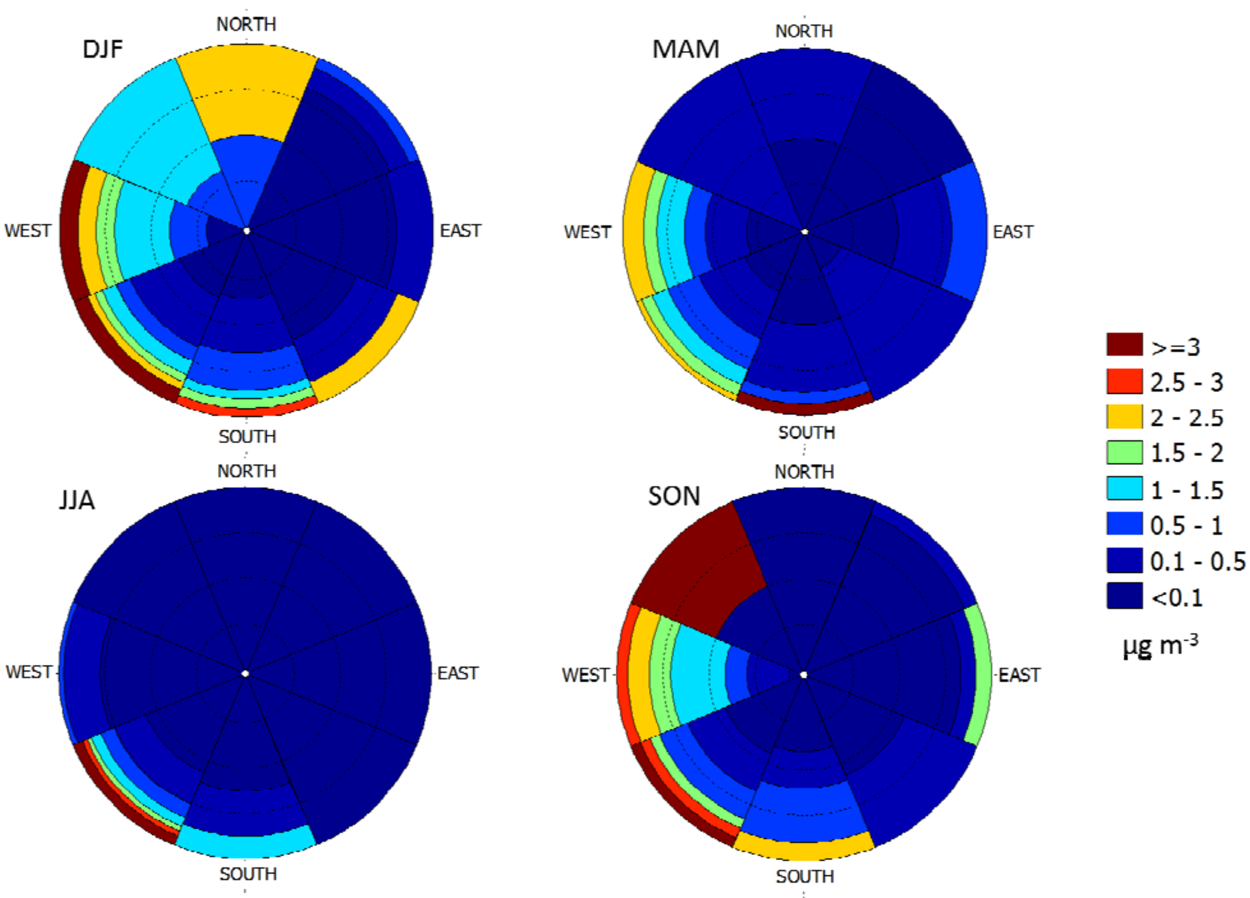
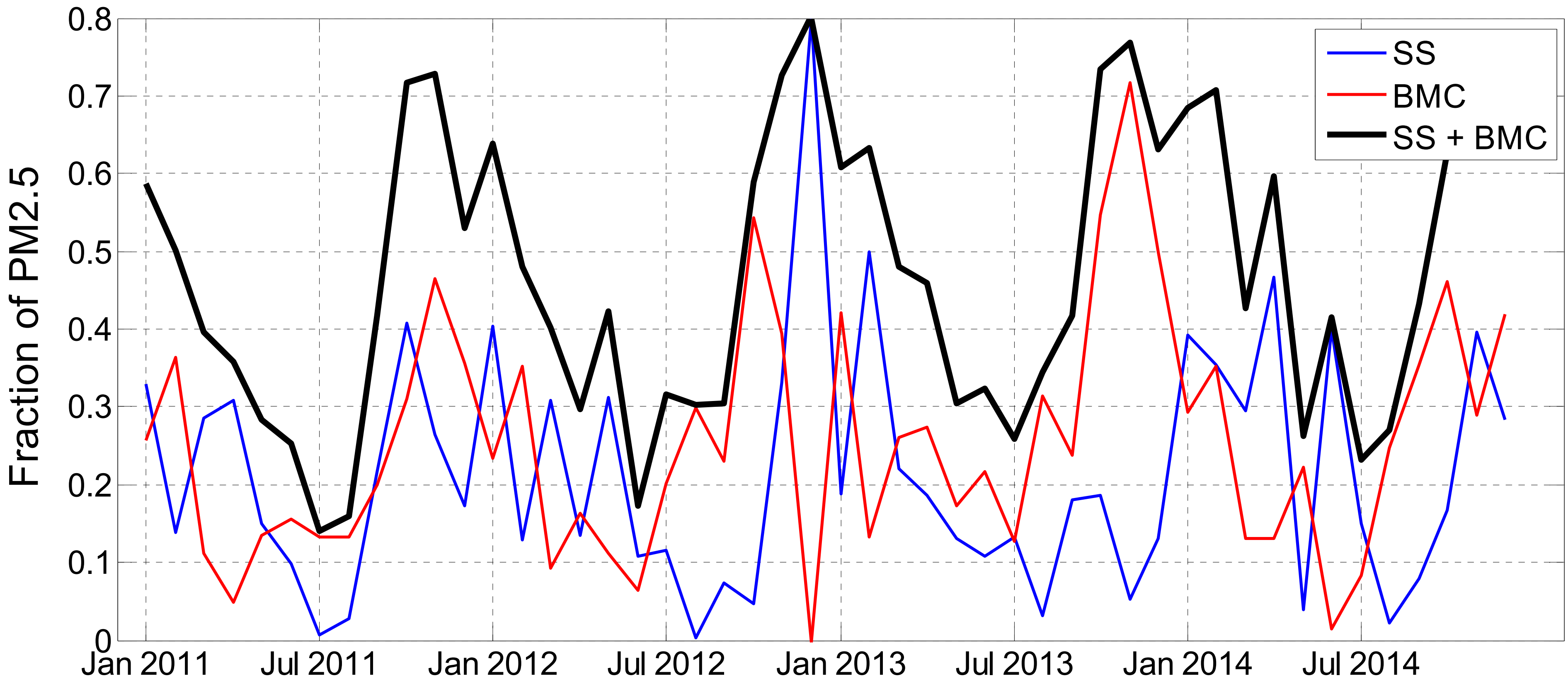


# Seasonal wind direction – Sea Salt

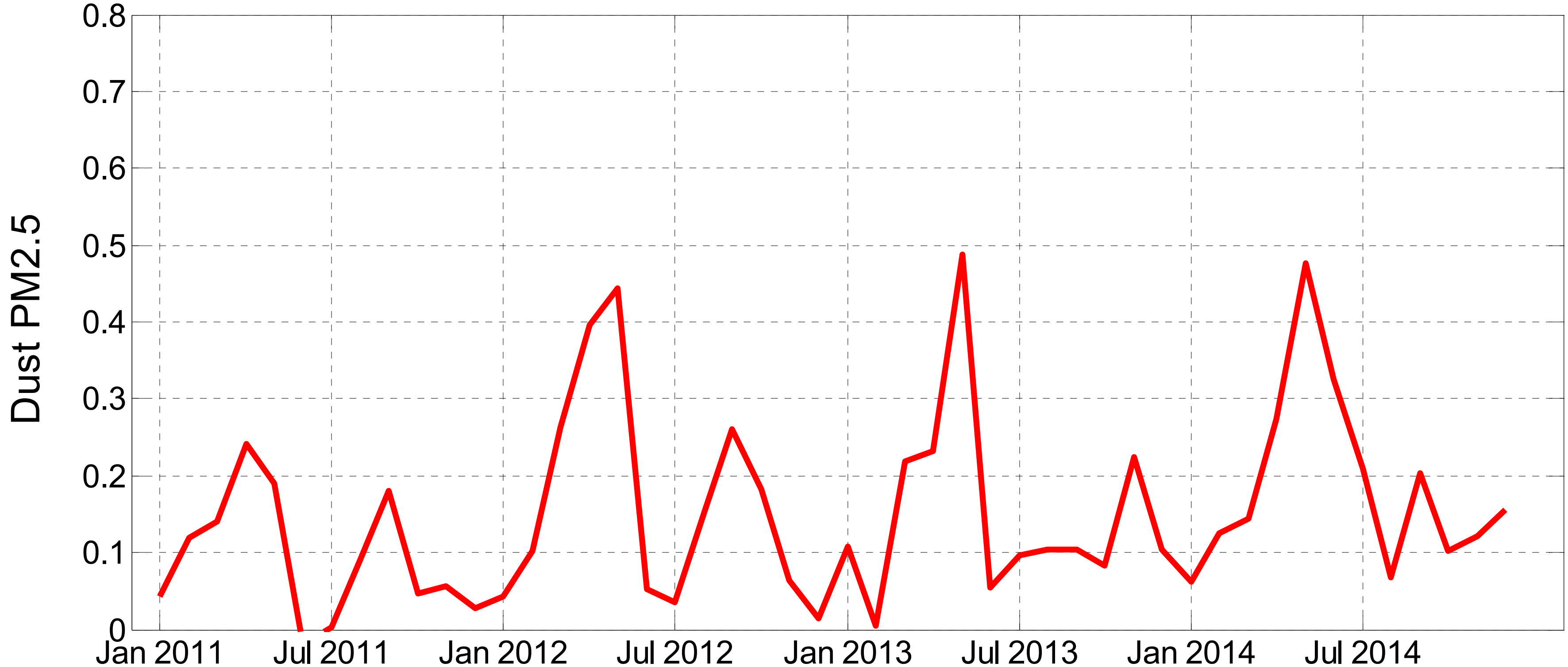



- Highest concentrations are associated with westerly winds:
  - Marine air
- Highest concentrations observed in winter and fall
  - Increase in marine storms (wind speed & wave breaking)

# Sea Salt and BMC are the primary fall/winter pollutants



# Long term and seasonal trends – Dust



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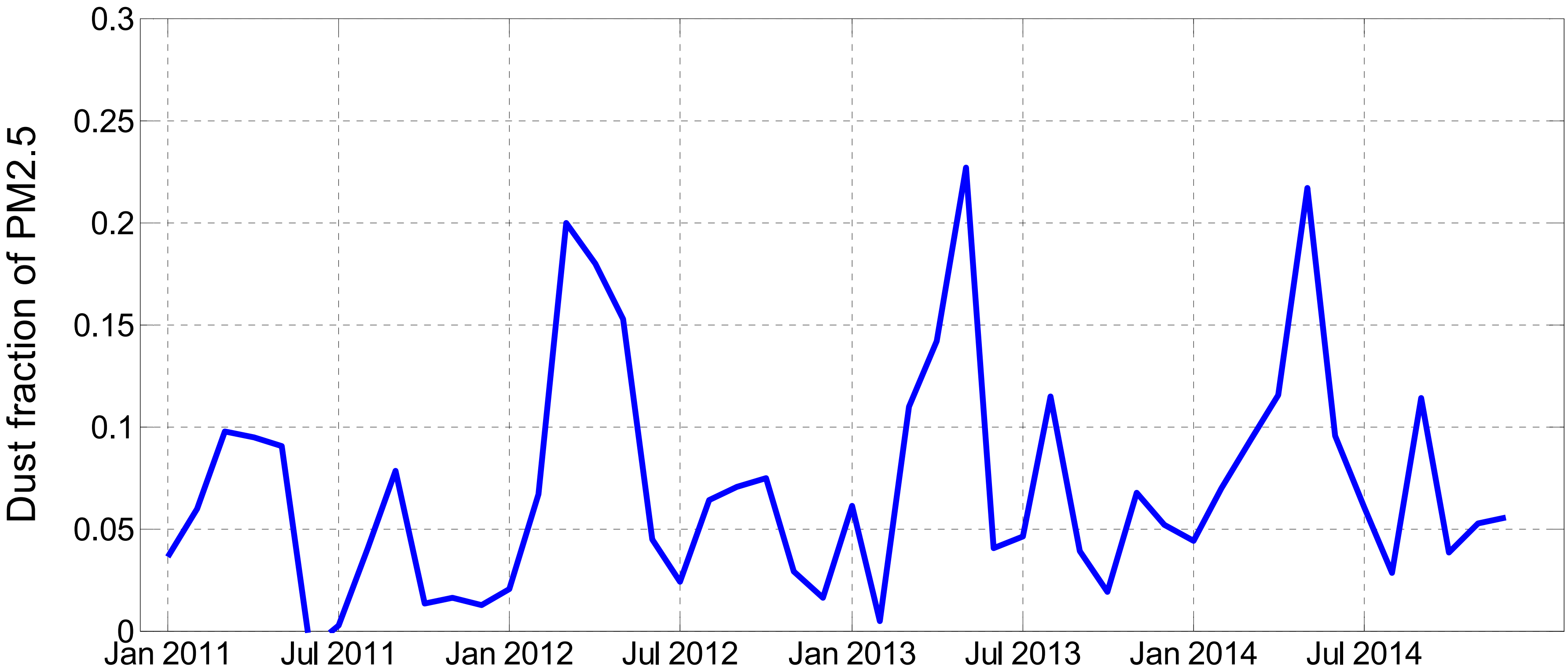
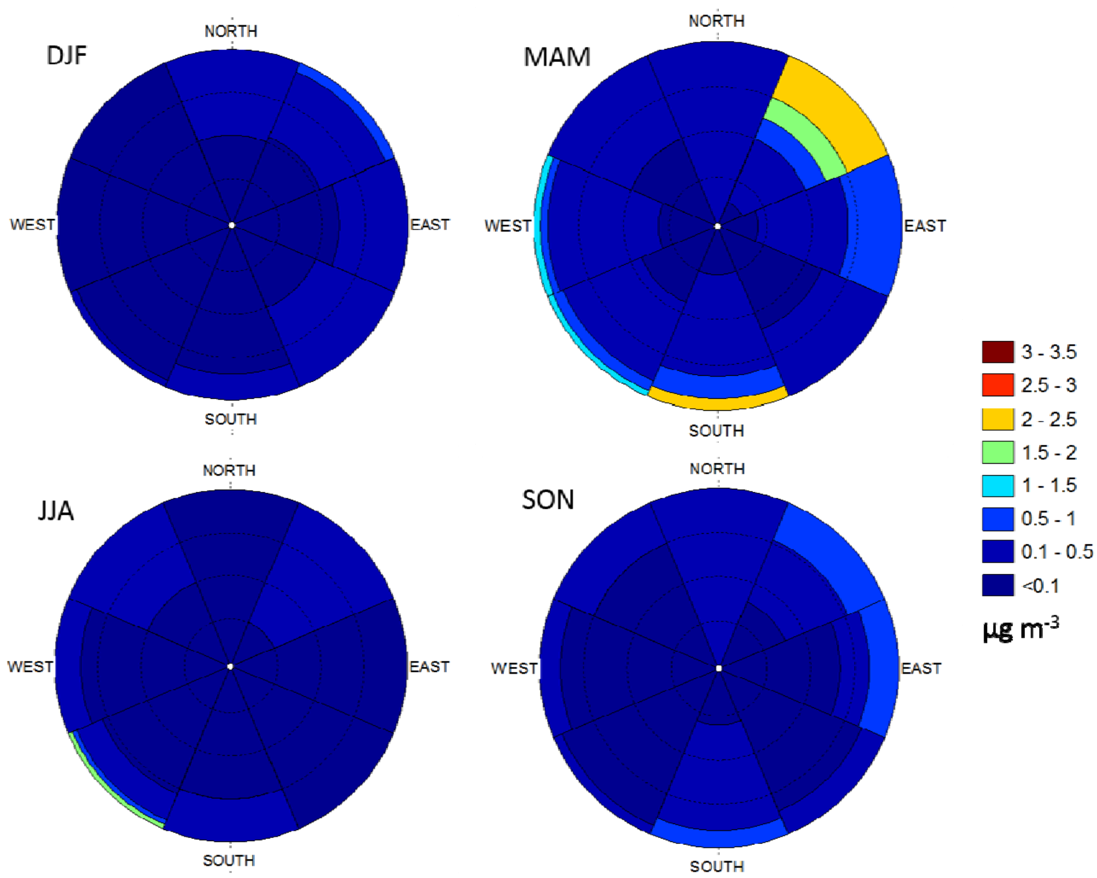
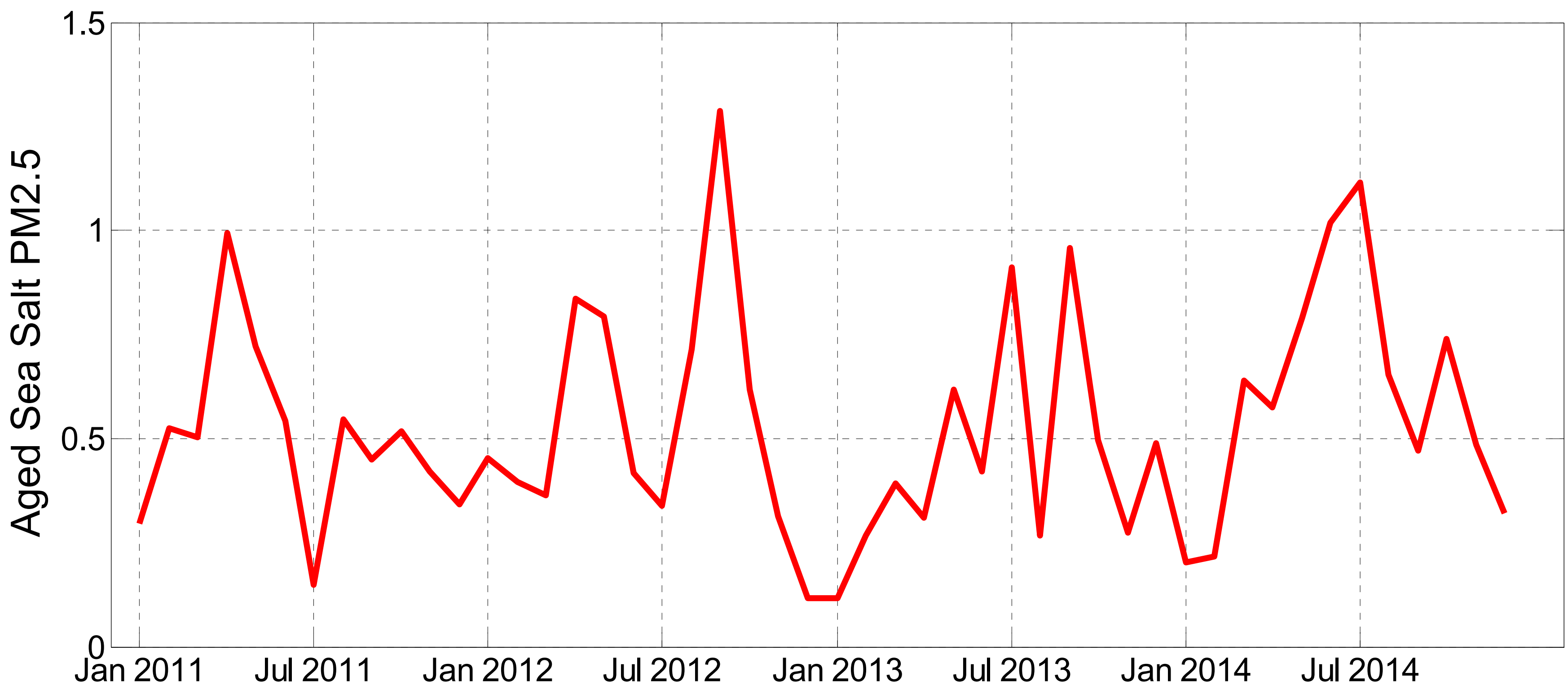


# Seasonal wind direction – Dust




- Highest concentrations are associated with NE winds
- Highest concentrations observed in spring
  - Coincides with spring trans-Pacific transport (TPT) season
  - Surface wind direction is inconsistent with TPT *(Hadley et al 2007)*
  - Fe/Ca exceeds 2 indicating North American source *(VanCuren et al. 2005)*
  - Trajectory analysis is needed

# Long term and seasonal trends – aged Sea Salt



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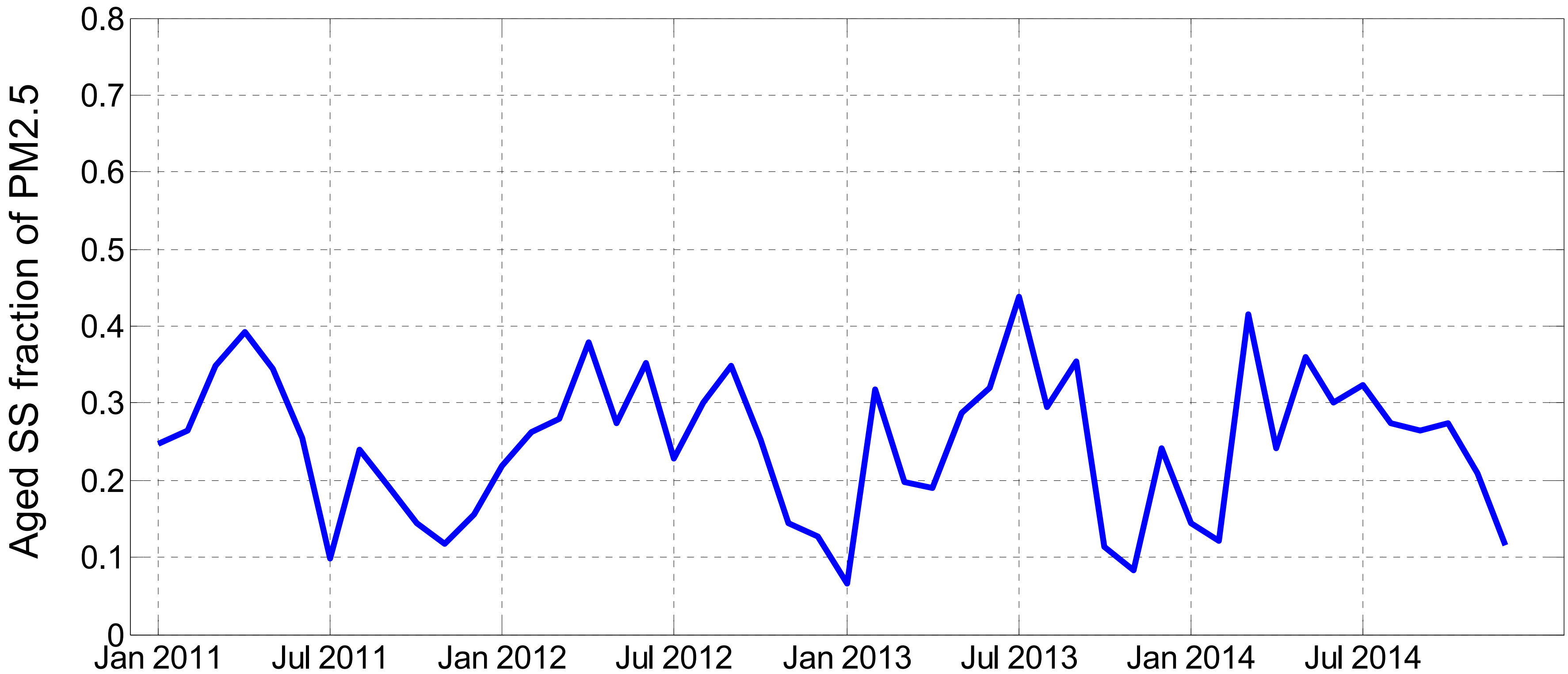
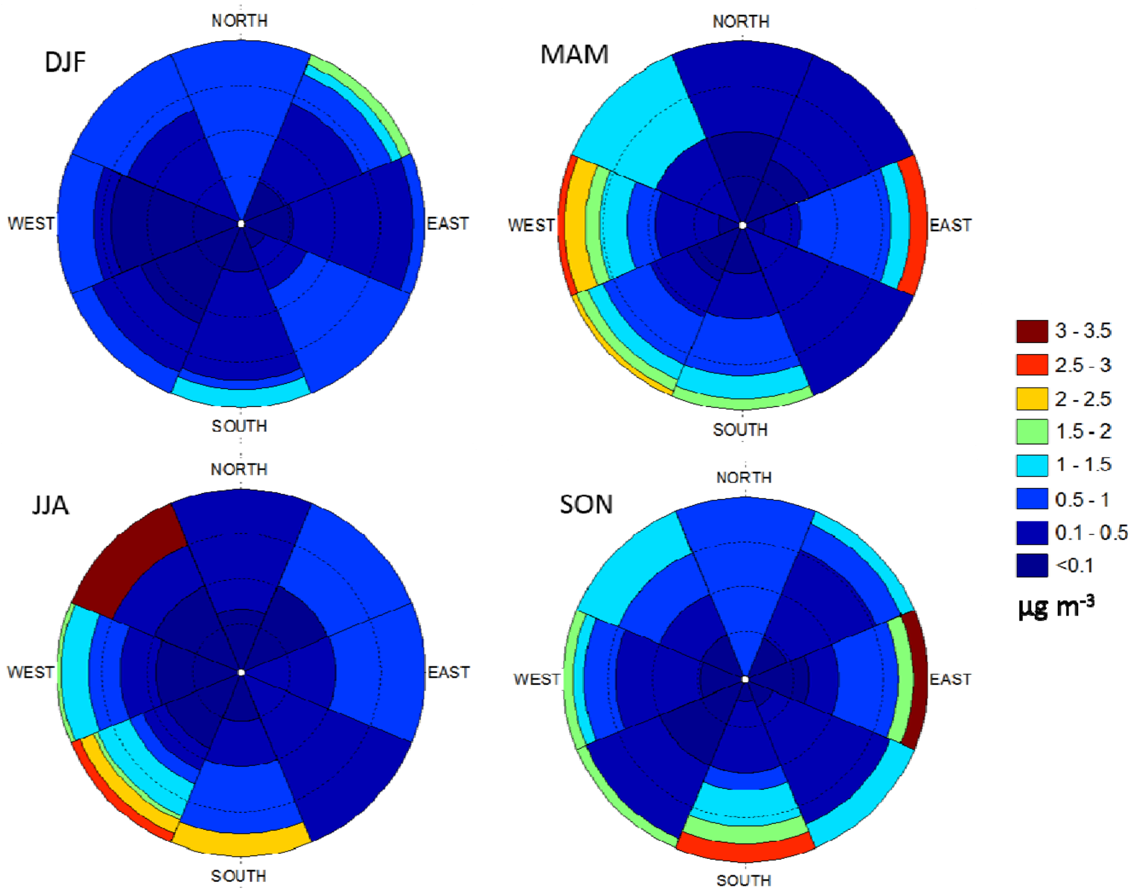
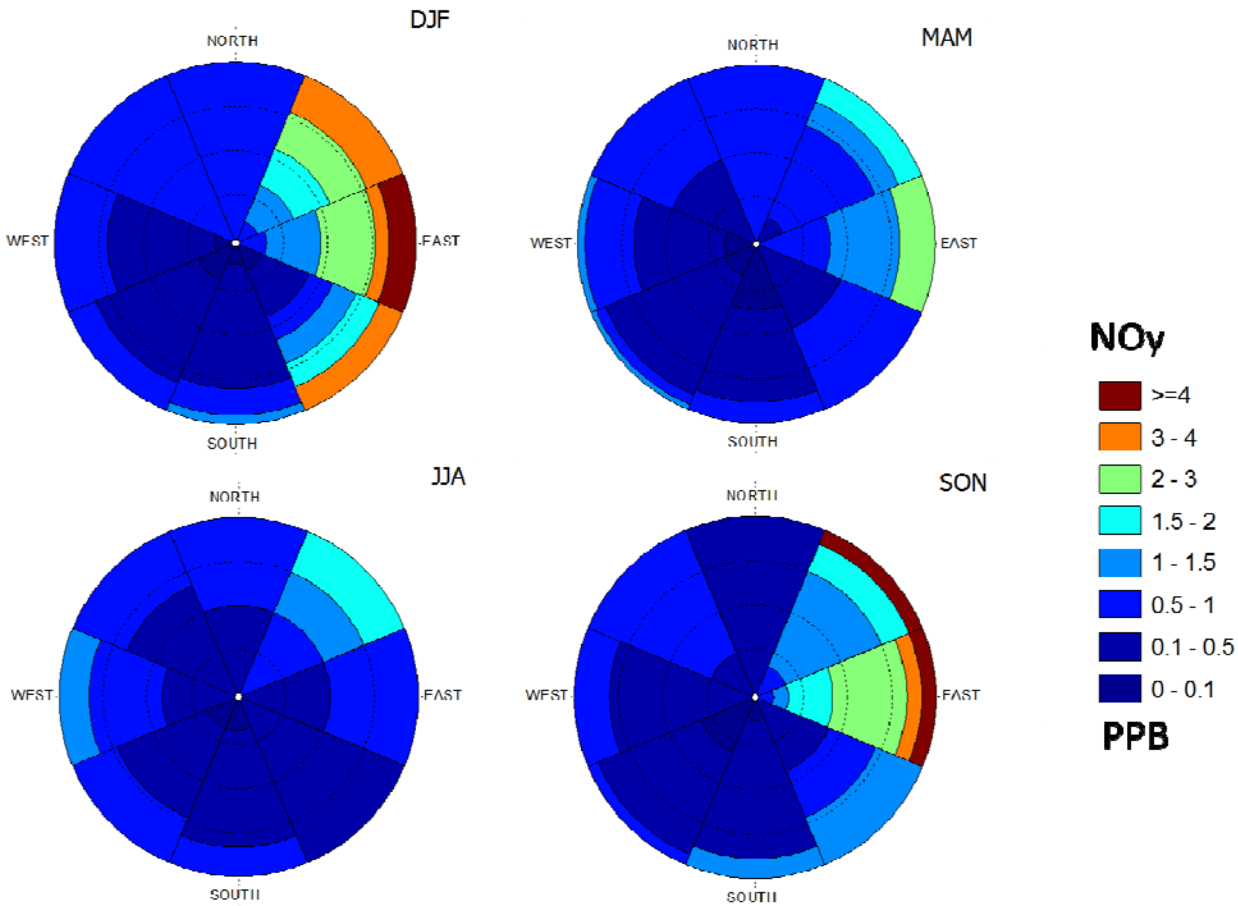


# Seasonal wind direction – aged sea salt



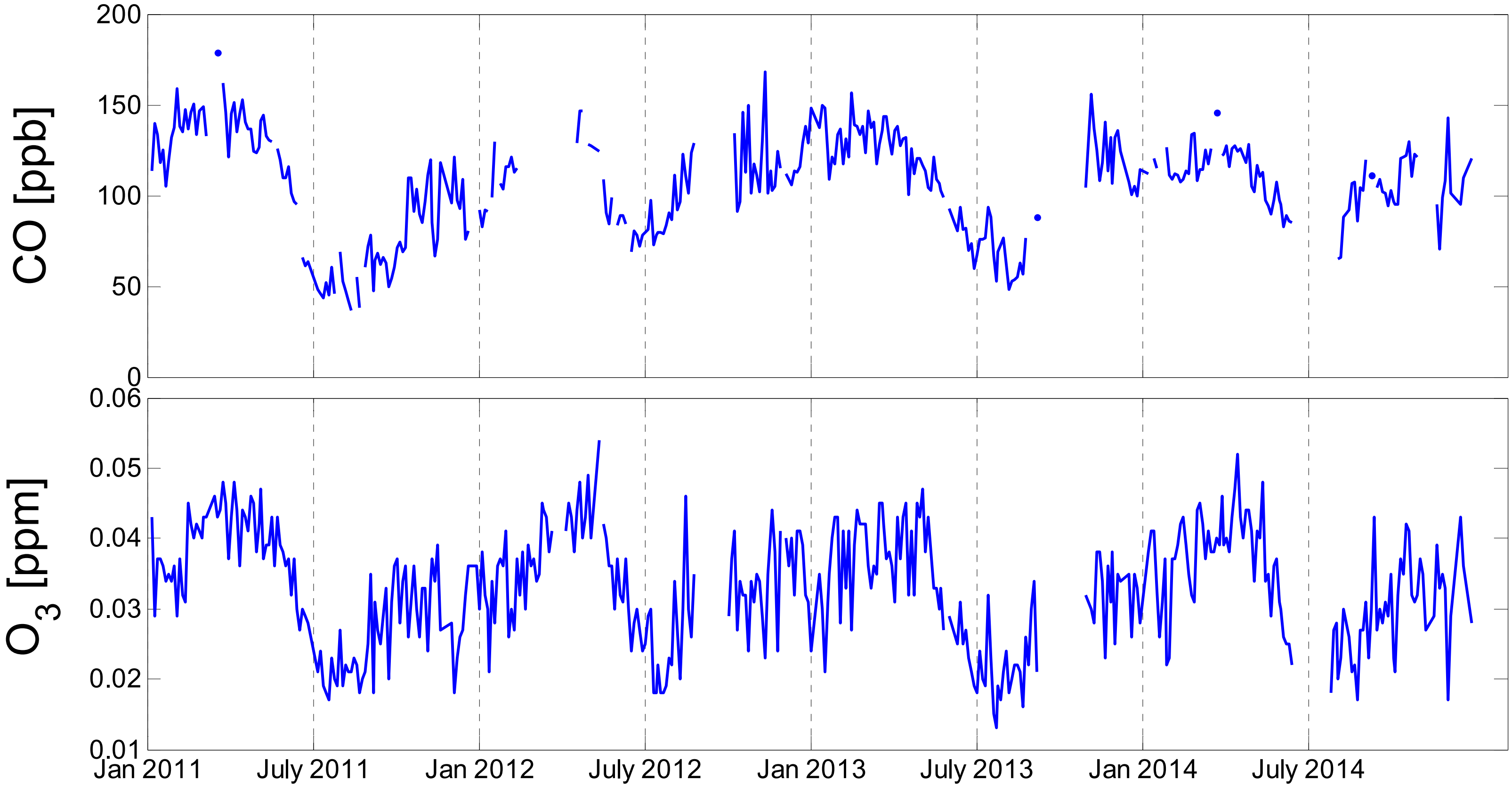

- No clear seasonal correlation
- No clear dependence on wind direction
- The "background" aerosol

# Trace Gases – NO/NOy

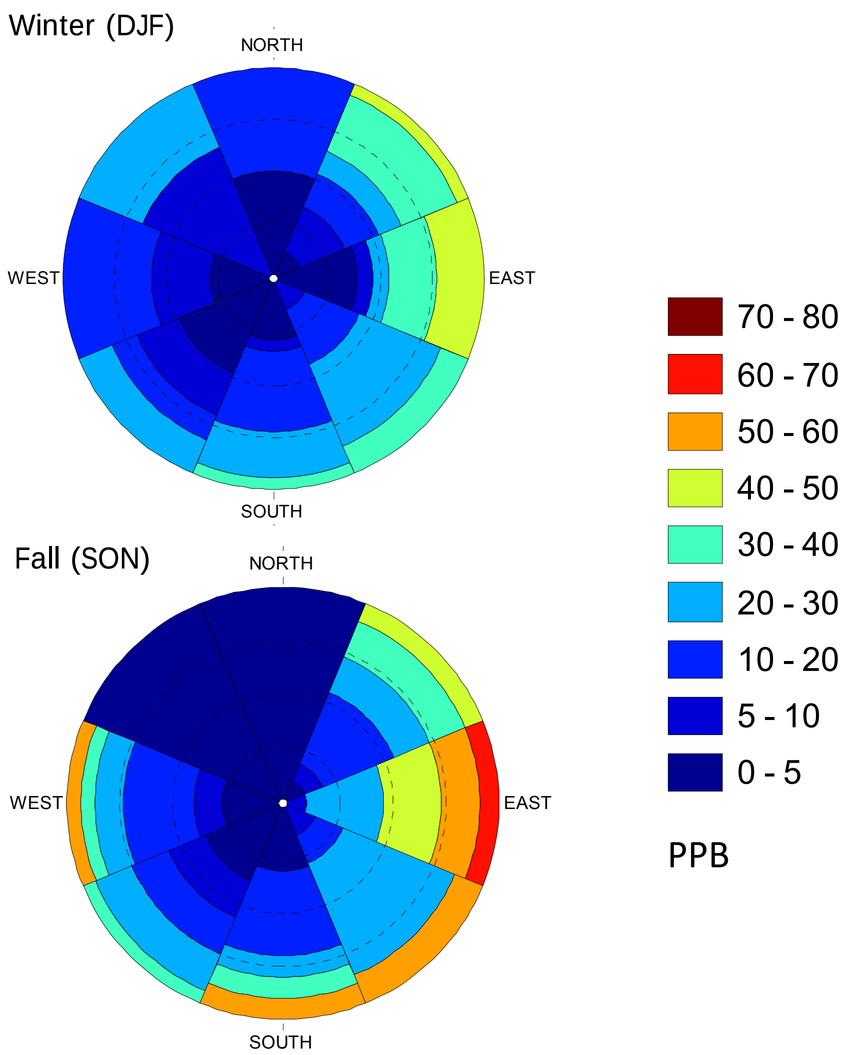



- Similar pattern to BMC source factor
  - Higher concentrations in winter
  - Associated with easterly and northeasterly winds
- Somewhat correlated to BMC ($R^2$ = 0.39)

# Trace Gases – $O_3$ and CO



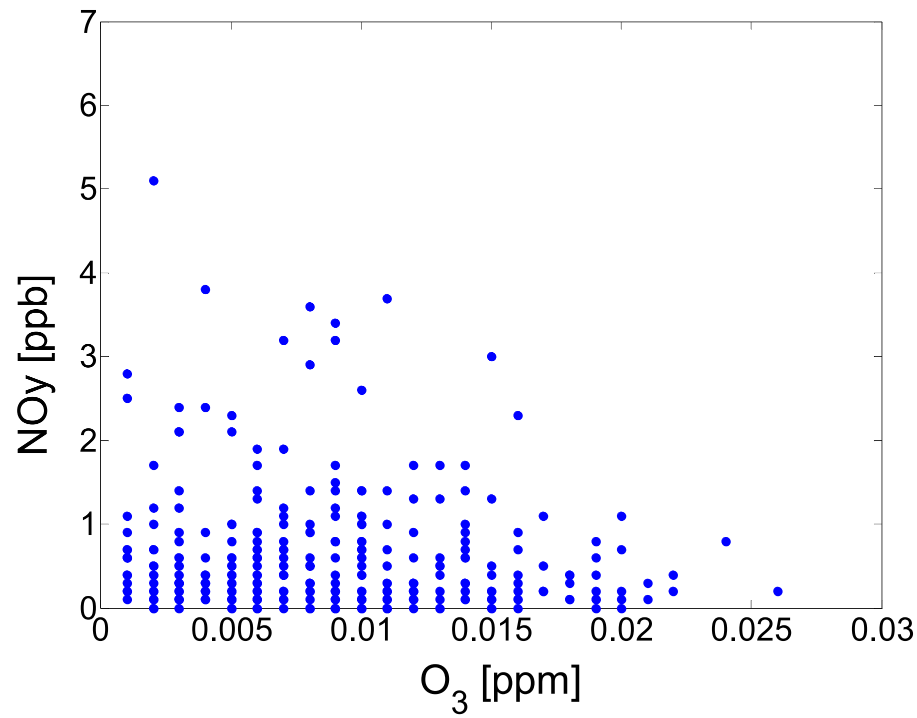
# CO residual




- Subtracted minimum monthly value from CO to remove seasonal signal
  - Refer to this as CO residual
- Winter and fall CO residual is enhanced with easterly winds
- No strong correlation with wind direction in summer or spring
- Highest CO residual values observed in the fall
- Most highly correlated with BMC factor ($R^2 = 0.25$)

# $SO_2$ and $O_3$

- Found no relationship between $SO_2$ and any source factors
- $SO_2$ concentrations are almost always less than 1 PPB
- No relationship between $O_3$ residual and source factors
  - O3 residual is anti-correlated to NOy ($R^2$ = 0.04)



# Summary

- Marine emissions (RFO) are a dominant source of summer PM2.5
  - Source contribution to PM2.5 has decreased since 2011
  - If low sulfur fuel regulations explain decrease, than chemical fingerprint is likely not the same between 2011 and the following years
- Biomass combustion (BMC) and sea salt are the dominant winter and fall contributors to PM2.5
  - Sea salt is primary pollutant when winds are westerly
  - BMC is dominant when winds are easterly
- Dust is a minor contributor with highest concentrations in spring
  - Associated wind direction is northeasterly (not sure of source)
- Aged aerosol (cloud processed) is a mix of sea salt and ship emissions, indicating older, processed marine aerosol

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