# Tracking Marine Vessel $PM_{2.5}$ Emissions – an update


**Robert Kotchenruther Ph.D.**
**EPA Region 10**

**NW-AIRQUEST Meeting**
**June 7, 2013**

# Background

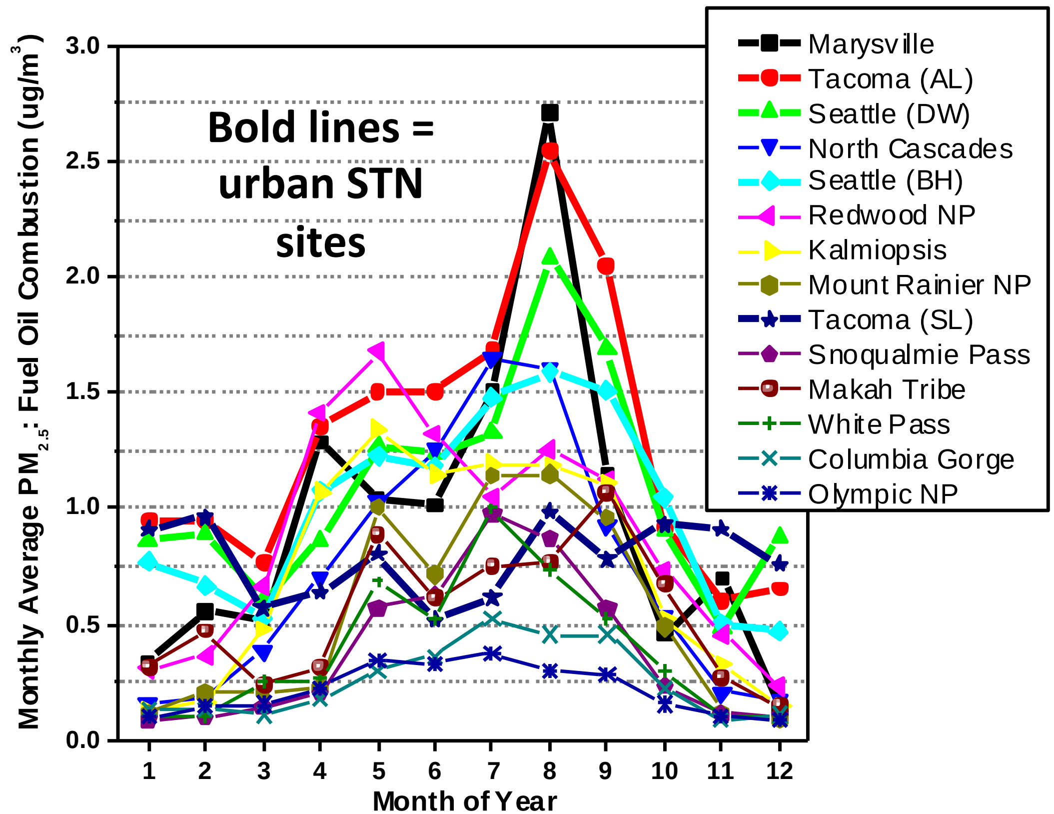

**Marine vessels use fuels that are very high in sulfur content and, until recently , their emissions were generally not subject to controls.**

**However, in 2008 the International Maritime Organization (IMO) agreed to include North America into an Emissions Control Area (ECA)**

- **The ECA became effective August 2012**
- **Emissions from marine vessels must be controlled within 200 nautical miles of coast (mainly through fuel switching).**
  - **2012 - 2015 fuel sulfur content no higher than 10,000 ppm (1%)**
    - outside ECA limit is 35,000 ppm (3.5%) fuel sulfur content
  - **2015 & onwards fuel sulfur content no higher than 1000 ppm (0.1%)**
    - estimated to reduce SOx and PM2.5 emissions by 86% & 74%, respectively
  - **2016 & onwards NOx controls**

# Background

Last year I reported on results of PMF source apportionment modeling and identified 14 urban and rural monitors in the PNW impacted by marine vessels burning residual fuel oil (RFO).


**2007 – 2010 PM2.5 Impacts were:**

Strong seasonal cycle, monthly averages of

~0-1 ug/m3 in winter

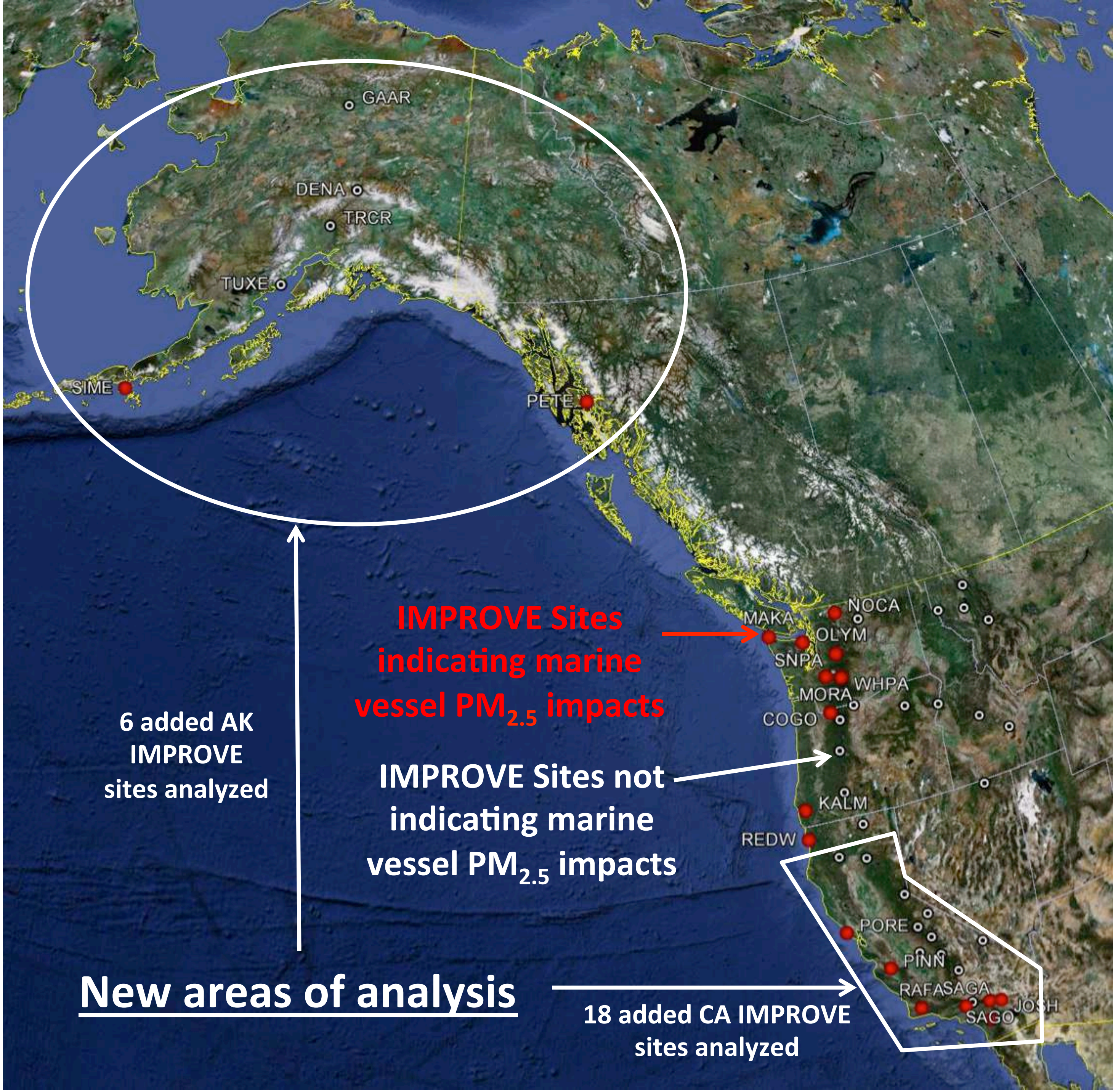
~0.5-2.5 ug/m3 in summer

**Since then, I have expanded the analysis to include:**

- 6 IMPROVE monitors in Alaska
- 18 in California.

Of these, 2 AK and 7 CA sites indicate $PM_{2.5}$ impacts from marine vessels.

**Mass impacts and season patterns were similar to those in the original study**



**Issue: For tracking progress in $PM_{2.5}$ emissions reductions, modeling is time consuming and has a range of assumptions and uncertainties.**


**The remainder of this pretention will explore whether there is an easier/faster way to track emissions changes.**

**In particular, I'll be looking at the usefulness of tracking just the monitored V and Ni data as surrogates for primary emissions from marine vessels.**

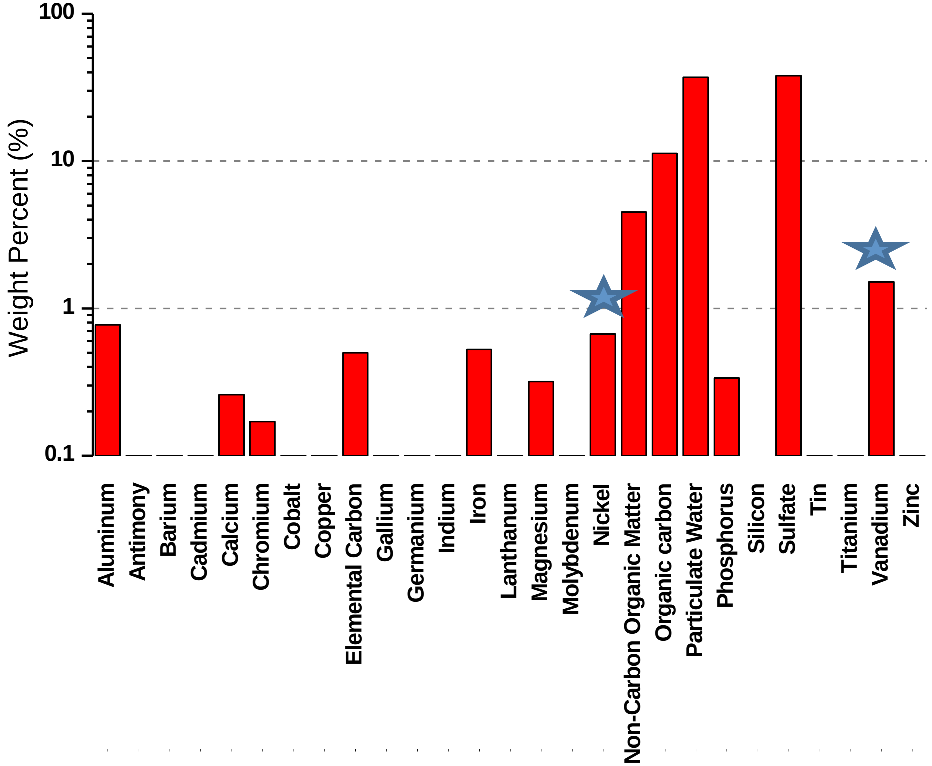
# Why V and Ni?

V and Ni are well known trace metals associated with emissions from residual fuel oil combustion.

$PM_{2.5}$ from residual fuel oil combustion has a very high V and Ni content (~1-2%), so a strong signal.

And marine vessels burning residual fuel oil emit V and Ni in a consistent ratio of ~3:1 V:Ni.

**Marine Diesel Heavy Fuel Oil $PM_{2.5}$ Emissions Profile.**



## Problems with this approach?


Biggest problem is that other sources of V and Ni could be mistakenly attributed to marine vessel emissions.

So success in using V and Ni data as surrogates for primary marine vessel emissions will depend on:

**How many other sources of V and Ni impact monitoring locations?**

**and**

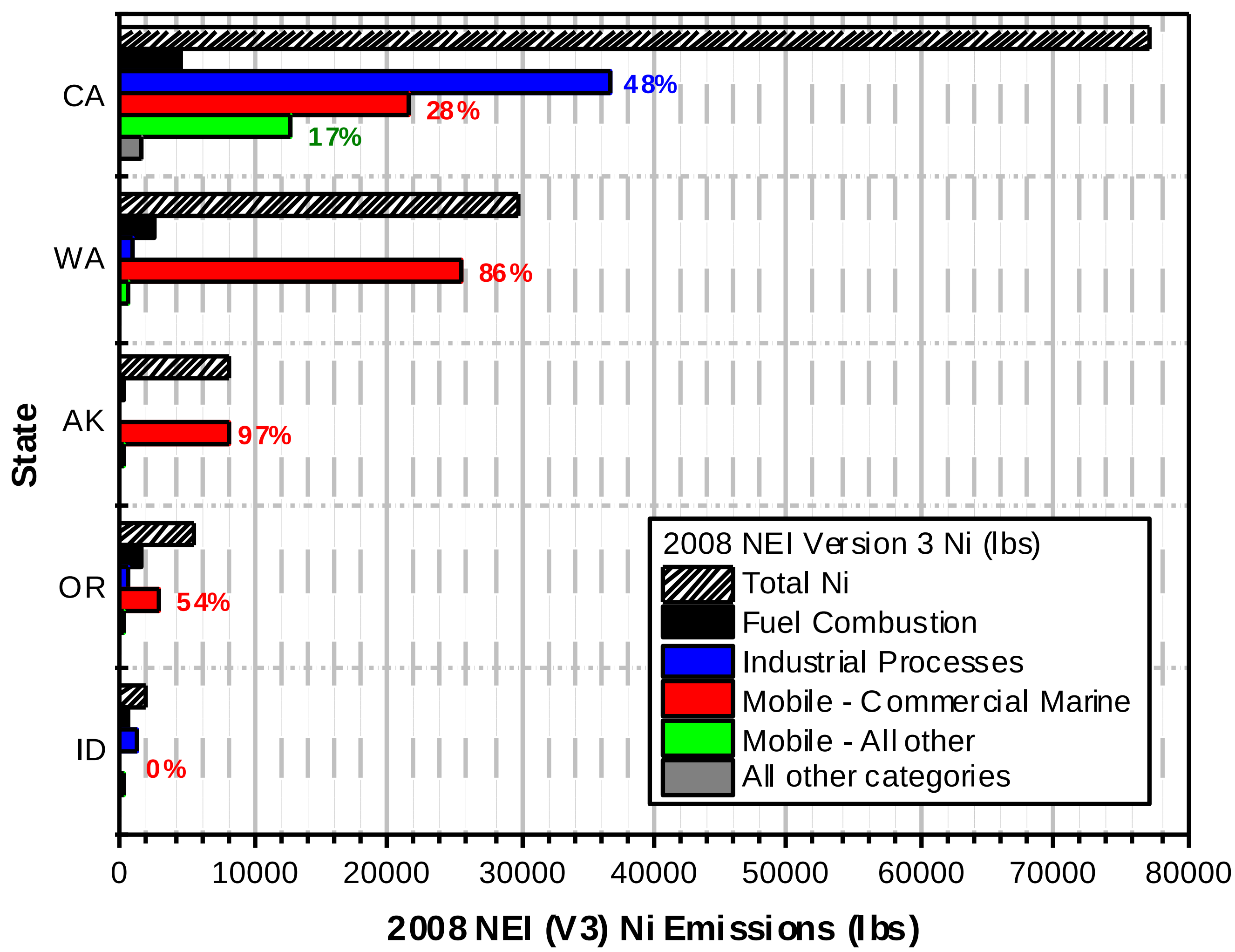
**How rare is a V:Ni ratio ~3:1?**

# Sources of Ni emissions



**Ni is a pollutant tracked by EPA, so we have emissions estimates for that.**

EPA 2008 National Emissions Inventory (NEI)
V





**Note: V data not reported in the NEI.**

**Conclusion:**

**Monitored Ni data could be useful for tracking west coast commercial marine emissions in many areas, but might be troublesome in CA.**

# How rare is a V:Ni ratio of ~ 3:1?

## Data for that is available from the EPA Speciate database

**(the source categories below focusing on industrial and mobile sources active on the US west coast and with reported V and Ni emissions.)**

| **Industrial** | V (%) | Ni (%) | V : Ni ratio | Speciate Profile(s) |
|---|---|---|---|---|
| Oil refinery operations | 0.089 | 0.111 | 0.80 : 1 | 4403, 4407 (ave.) |
| Cement production | 0.016 | 0.024 | 0.66 : 1 | 91127 |
| Chemical manufacturing | 0.007 | 0.025 | 0.28 : 1 | 900022.5 |
| No. 2 fuel oil boiler | 0.001 | 0 | N/A | 127102.5 |
| Municipal Incinerator | 0.001 | 0.029 | 0.03 : 1 | 171082.5 |
| Primary Metal production | 0.102 | 0.174 | 0.58 : 1 | 900072.5 |
| Secondary Metal production | 0.008 | 0.312 | 0.03 : 1 | 900082.5 |

| **Mobile – Commercial Marine** | V (%) | Ni (%) | V : Ni ratio | Speciate Profile(s) |
|---|---|---|---|---|
| Marine Vessel – Heavy Fuel Oil | 1.673 | 0.694 | 2.41 : 1 | 5674, 5676 (ave.) |
| Marine Vessel – Marine Gas Oil | 0.083 | 0.026 | 3.19 : 1 | 5675 |

| **Mobile - other** | V (%) | Ni (%) | V : Ni ratio | Speciate Profile(s) |
|---|---|---|---|---|
| On-road diesel - heavy duty: | 0.0001 | 0.005 | 0.02 : 1 | 5679 |
| On-road gasoline engine : | 0 | 0.02 | N/A | 3224 |
| Diesel locomotive | | | | (no profile) |

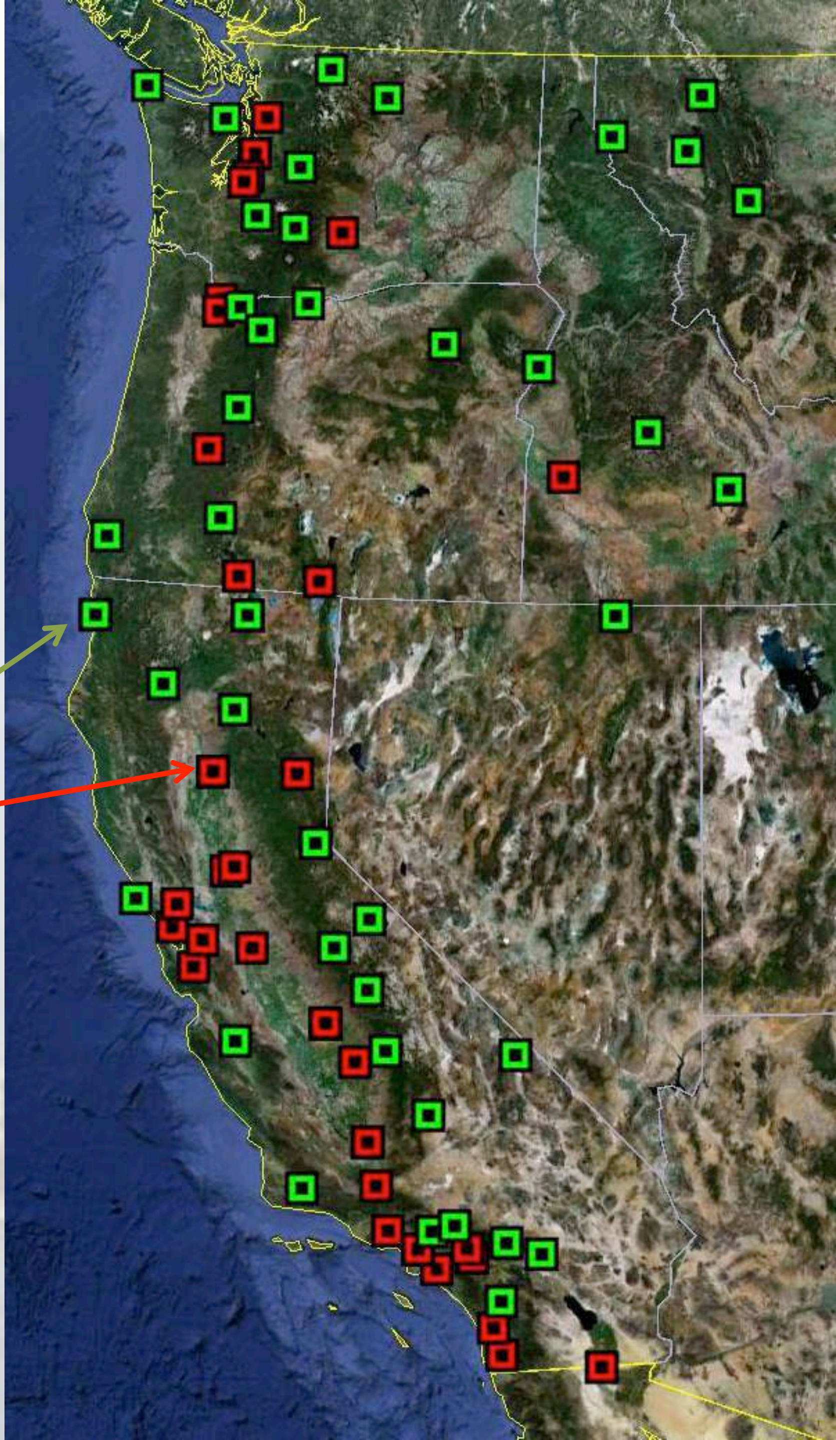
# What are the available sources of ambient data?

Success in using V and Ni data to track marine vessel emissions also depends on the range of sources impacting a monitor.

There are 2 main $PM_{2.5}$ networks that chemically speciate the data.

IMPROVE

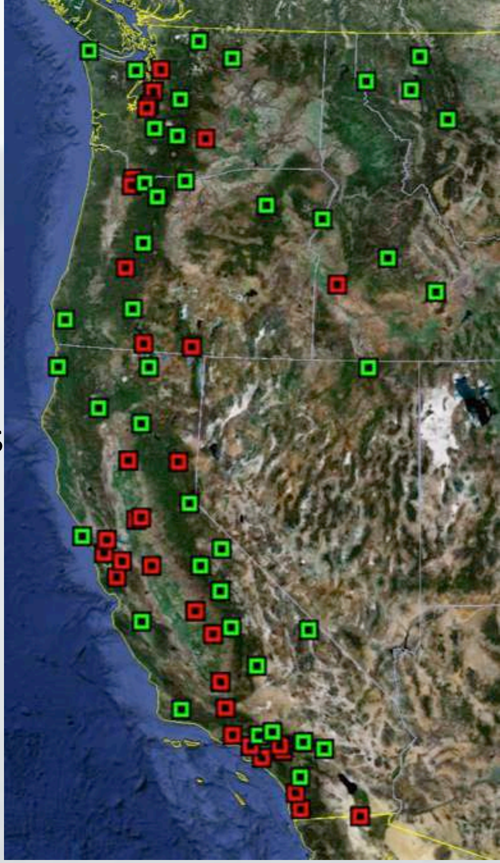
and CSN



The CSN network is an urban network and IMPROVE is a rural/ remote network.

For a range of reasons, IMPROVE is a better network to use for this analysis.

# Why is the IMPROVE network data better for this analysis than CSN?



## Benefits of the IMPROVE network

• ***Fewer potential V and Ni sources nearby - Most IMPROVE sites are in rural/remote locations, so fewer anthropogenic sources.

• ***Can detect V and Ni at much lower concentrations - V and Ni detection limits are much better at IMPROVE sites than at CSN sites (IMPROVE ~ 100x as sensitive as CSN).

• More data per site - IMPROVE sites monitor on a 1-in-3 schedule (many CSN sites monitor at 1-in-6).

## Drawbacks of the IMPROVE network

• Wait time - The time lag to obtain IMPROVE data is much longer than CSN data.

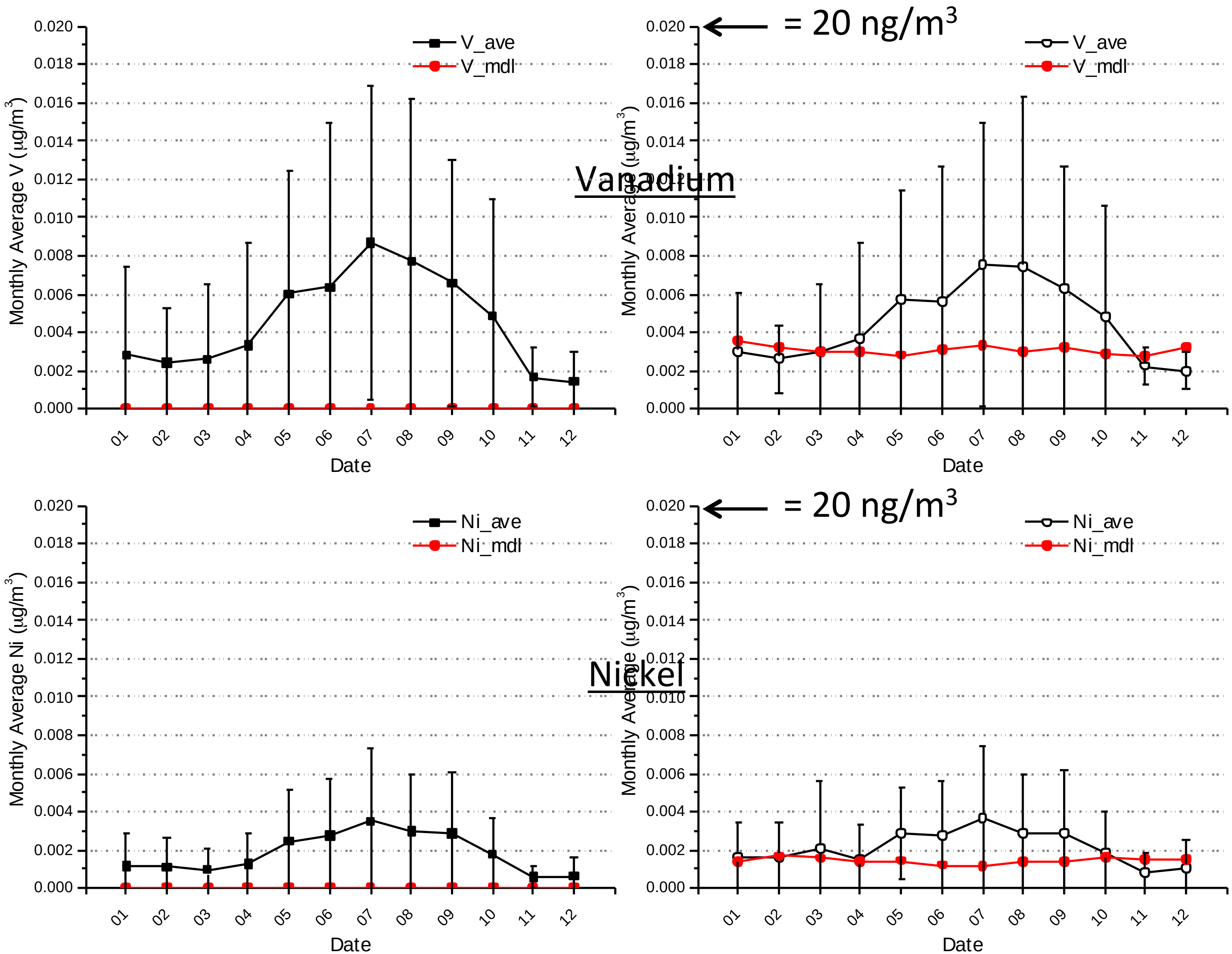
IMPROVE ~ 12-18 months

CSN ~ 3-6 months

**The remainder of this presentation will focus on data from the rural/remote IMPROVE network.**

# IMPROVE vs. CSN Co-located site data Beacon Hill Seattle: V and Ni Data

IMPROVE Data (2007-2011) CSN Data (2007-2011)




**For tracking emissions reductions ....**

V and Ni Data from the CSN network monitor is much closer to the MDL, making observing changes in monthly averages subject to higher uncertainty.

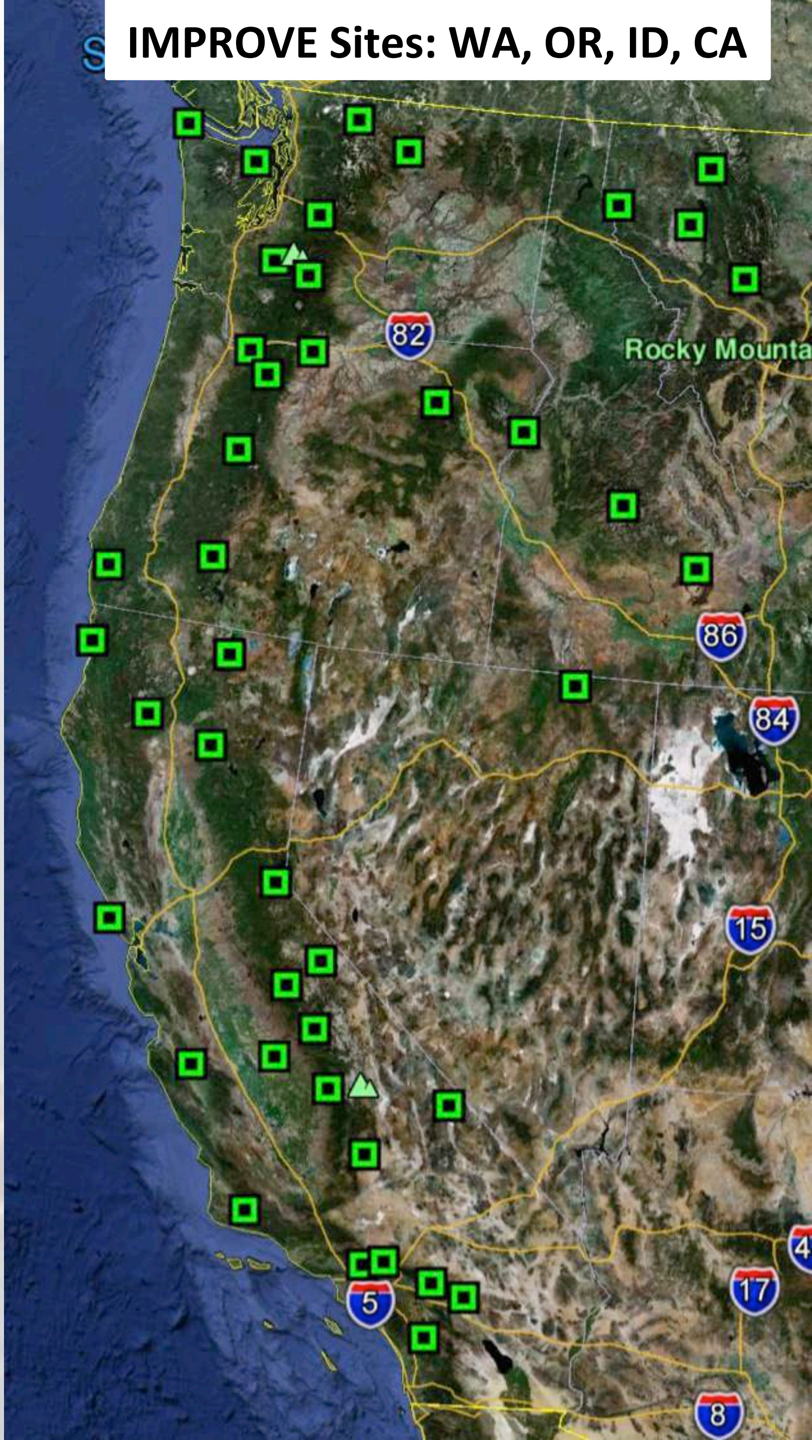
**So summarizing:**

**Successful tracking of primary marine vessel emissions might be possible by:**

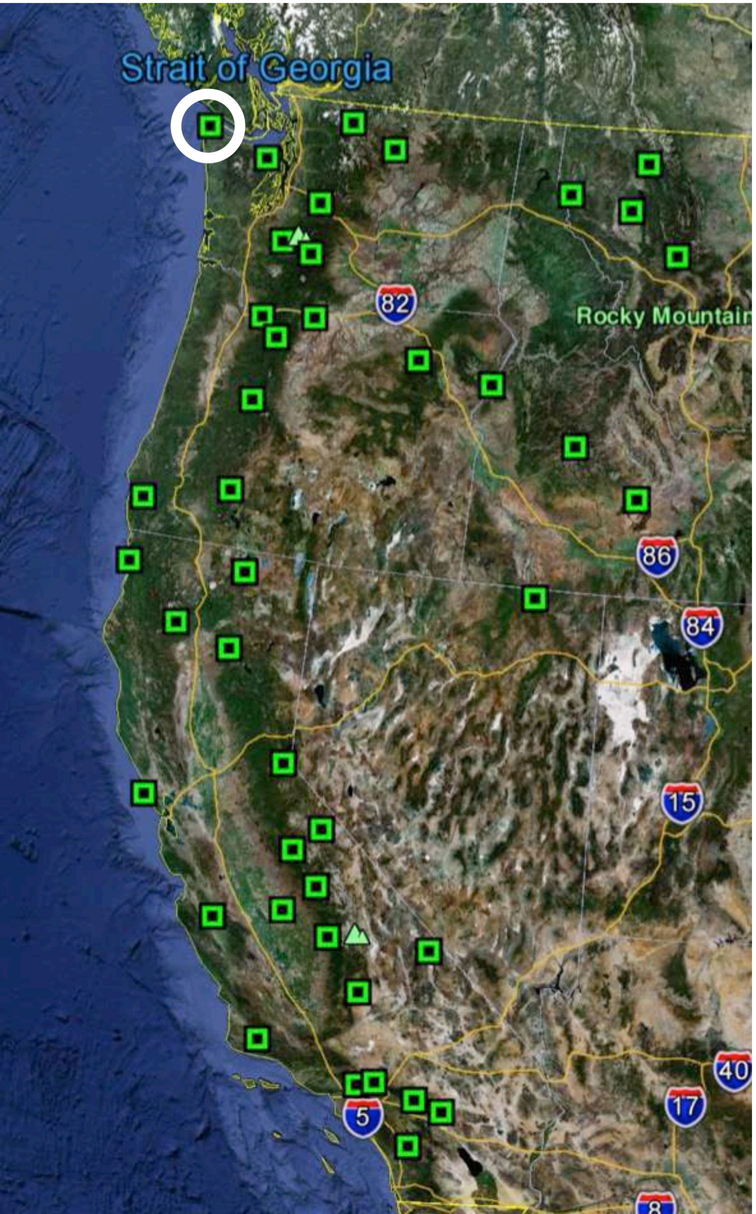
- **Combining an analysis of V and Ni data with an analysis of V:Ni ratio.**
- **Focusing on data from the IMPROVE network.**

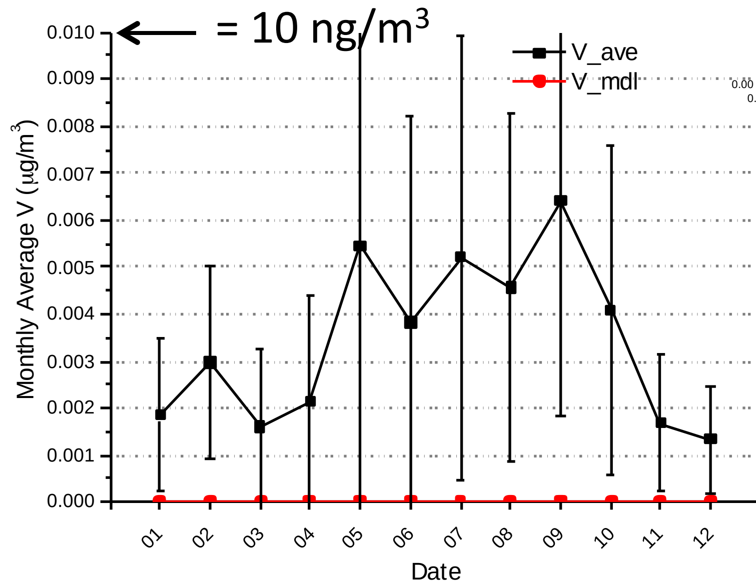
# Exploring V & Ni IMPROVE Data

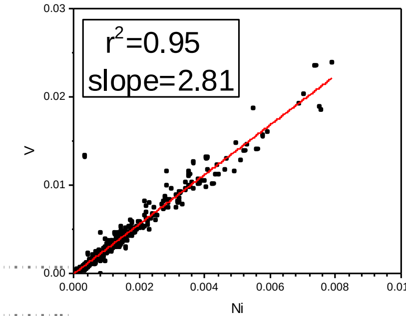
## Example of a progression from coastal to continental sites.



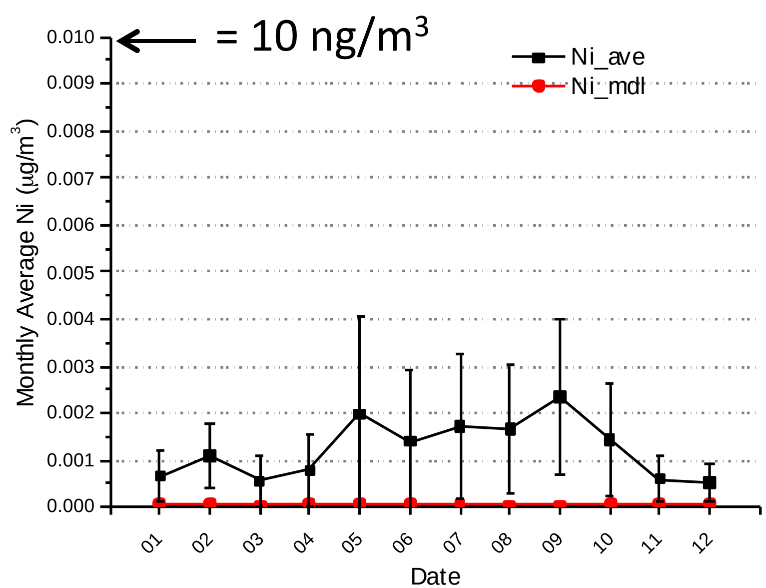
# Makah (2007-2010 data)
# IMPROVE Site V and Ni Data




Note: good correlation between V & Ni at the Makah site

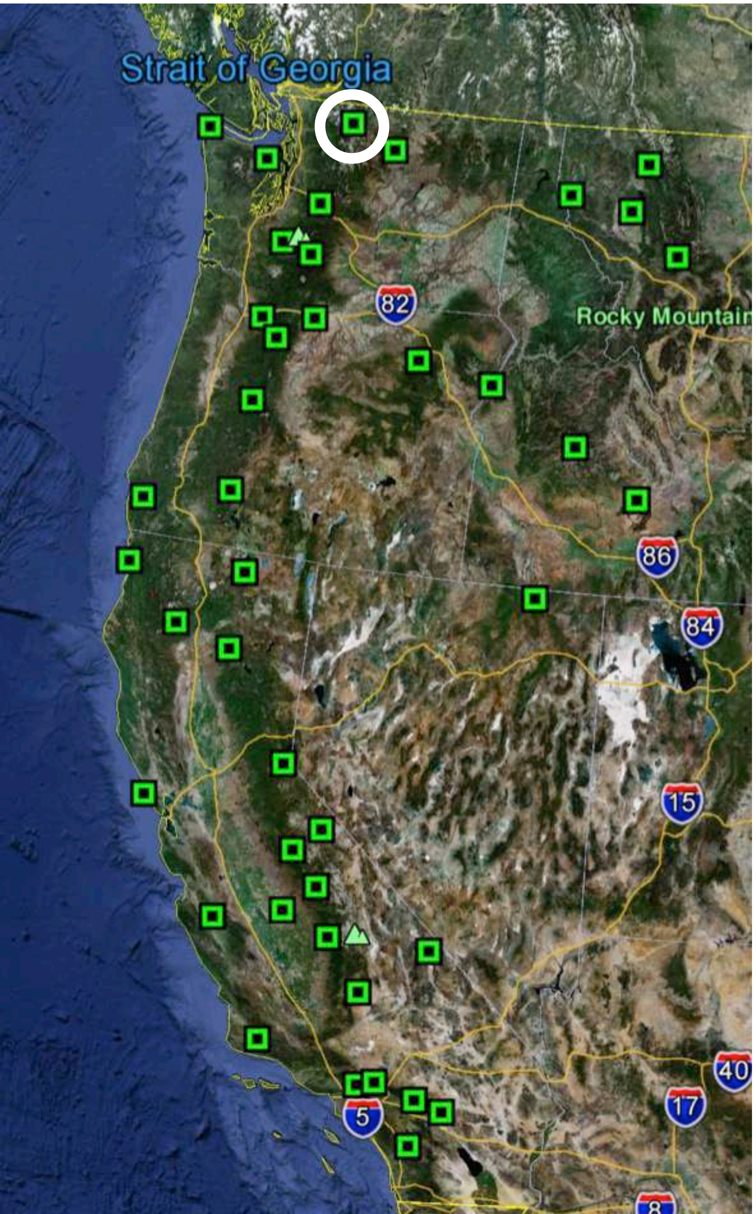


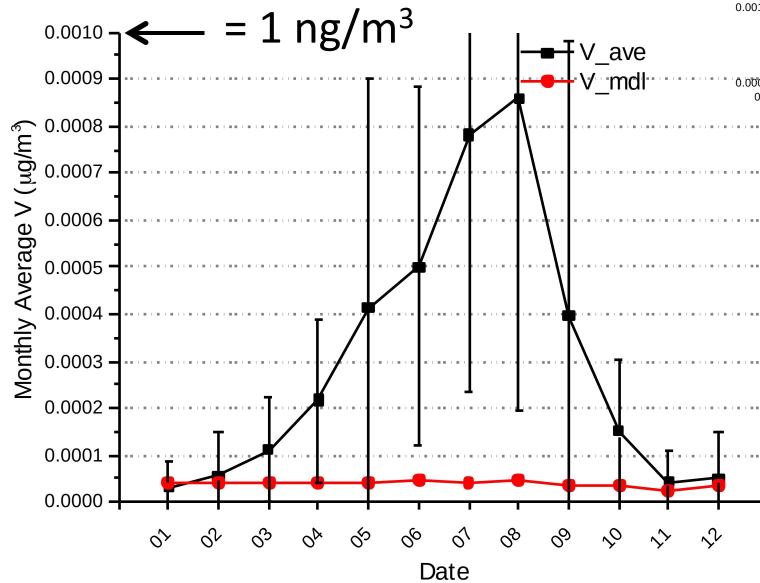

Makah
V : Ni
2.81 : 1

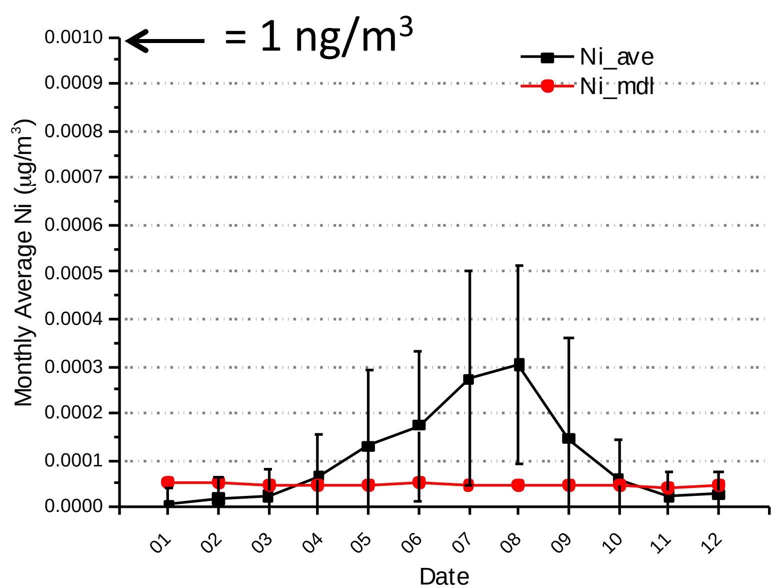
Marine vessels using residual fuel oil
V : Ni
~ 3 : 1

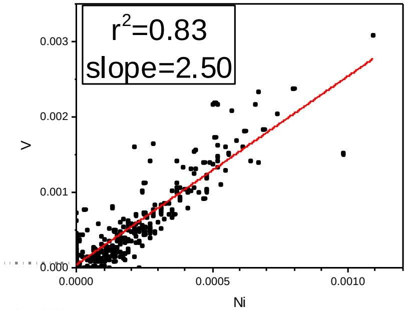
# North Cascades (2007-2011 data) IMPROVE Site V and Ni Data

**Note: V & Ni about 10x higher at the Makah site (previous slide)**



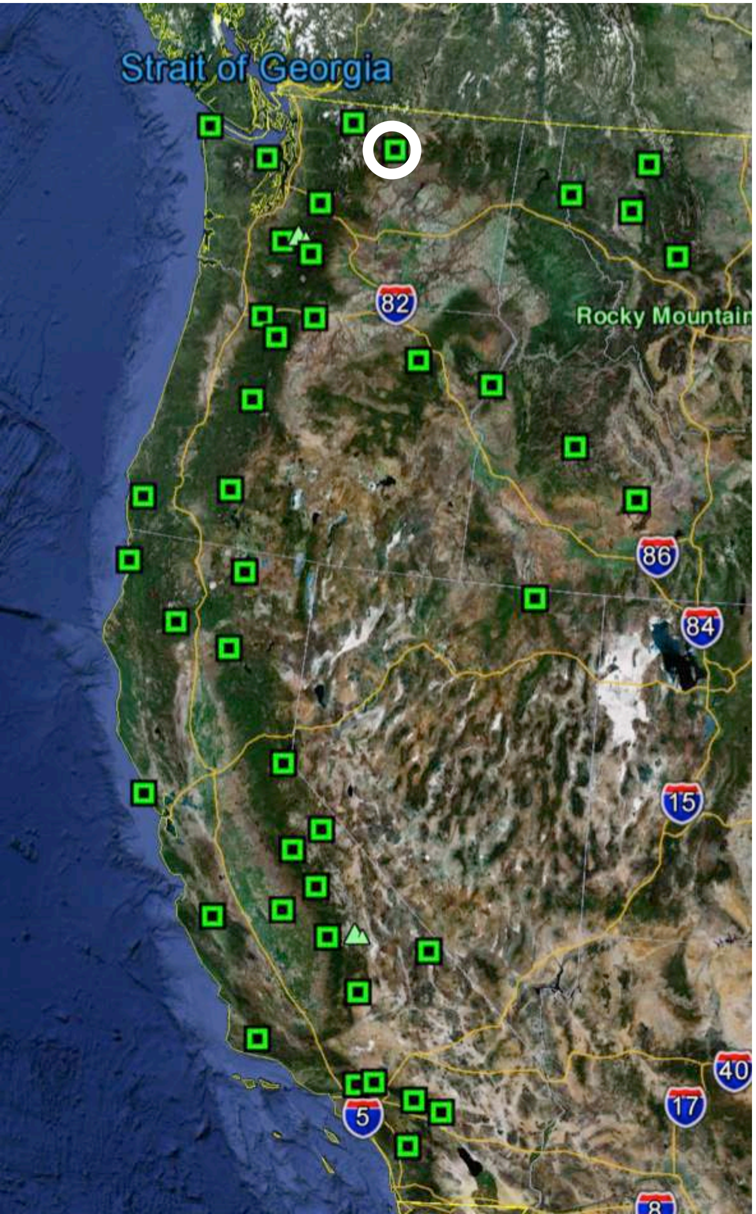



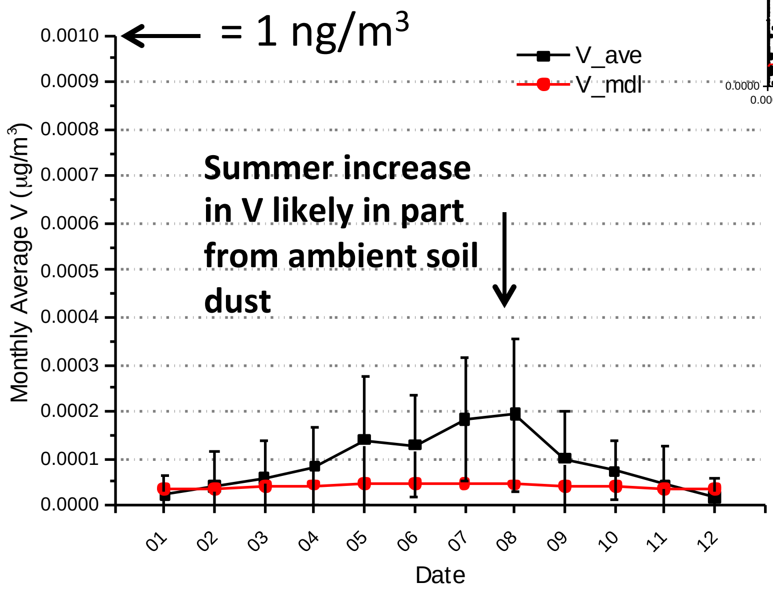

Note: still good correlation between V & Ni at the N. Cascades site

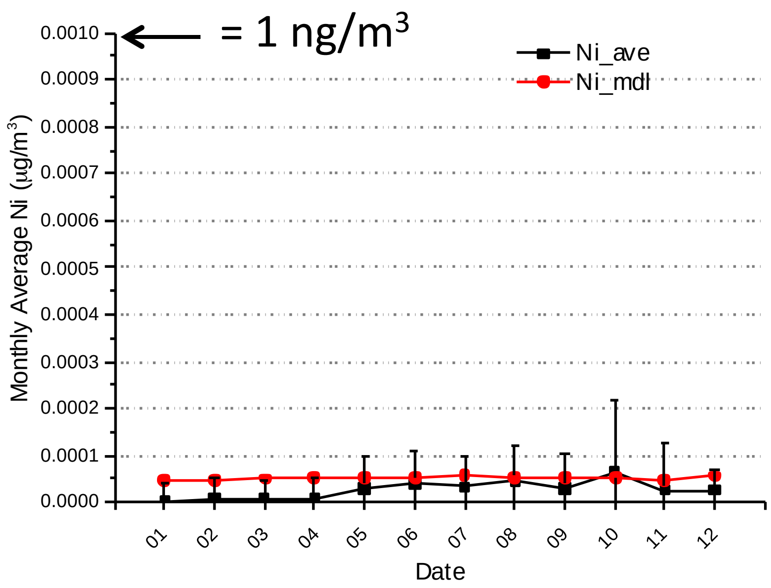
North Cascades
V : Ni
2.50 : 1

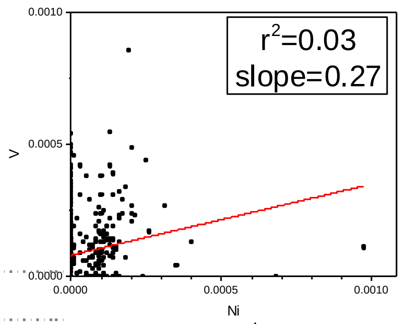
Marine vessels using residual fuel oil
V : Ni
~ 3 : 1

# Pasayten (2007-2011 data)
# IMPROVE Site V and Ni Data



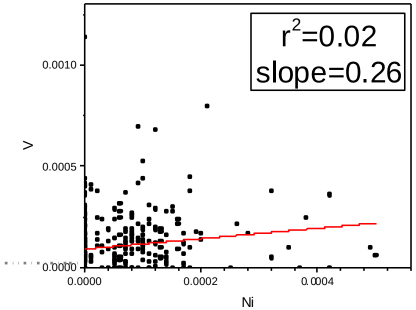



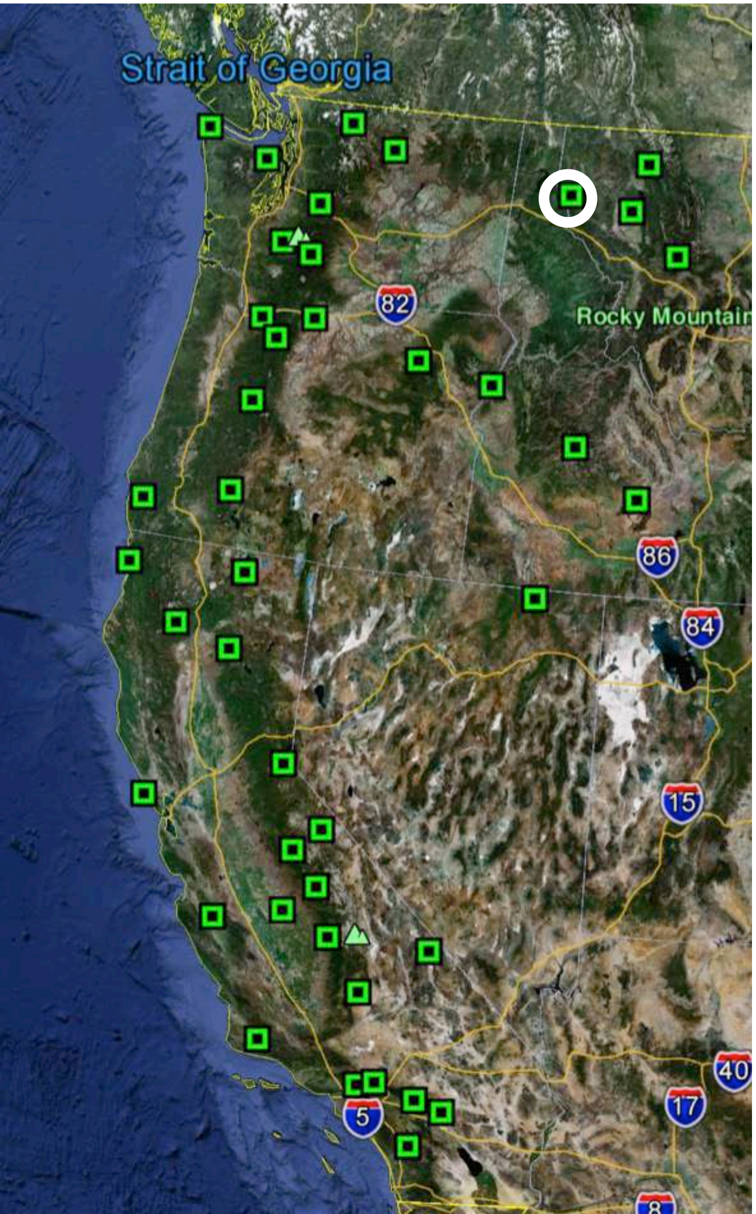



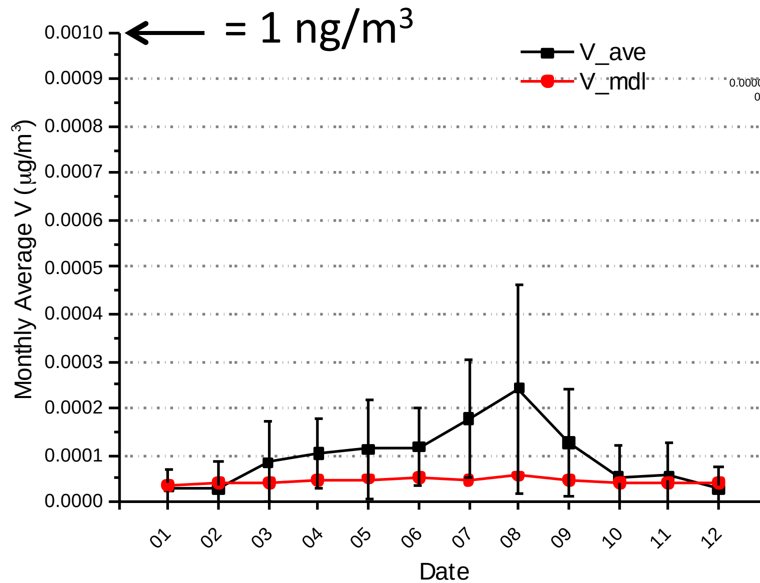

Note: correlation between V & Ni breaks down at the Pasayten site

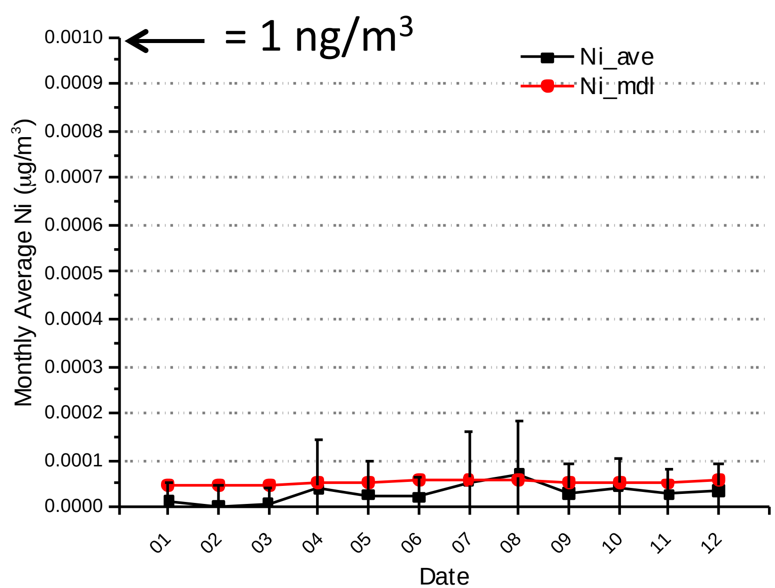
Majority of observed Ni falls below MDL

# Cabinet Mountains (2007-2011 data) IMPROVE Site V and Ni Data



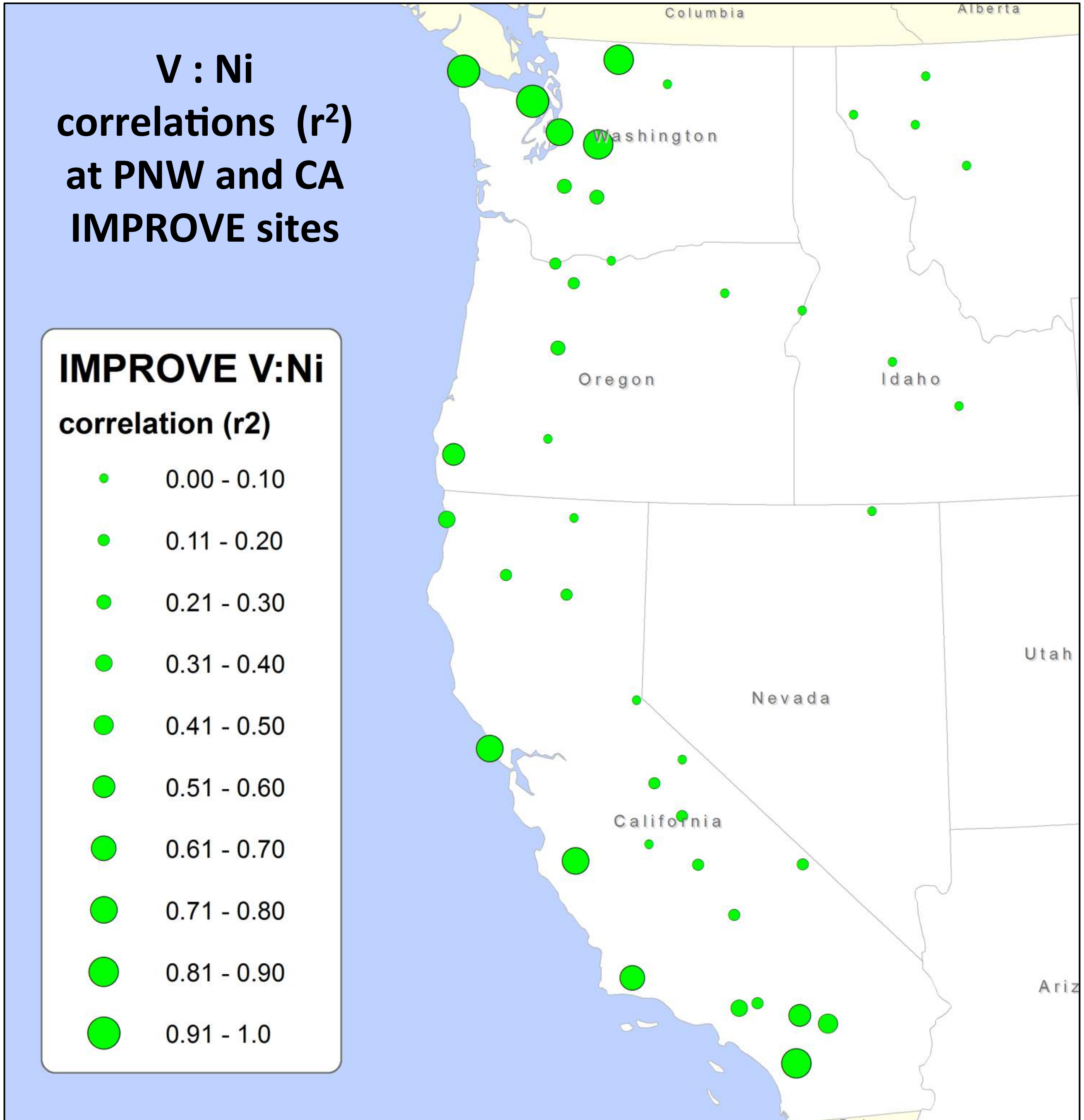




Note:

Very similar to the Pasayten site

poor V:Ni correlation and similar V and Ni concentrations.

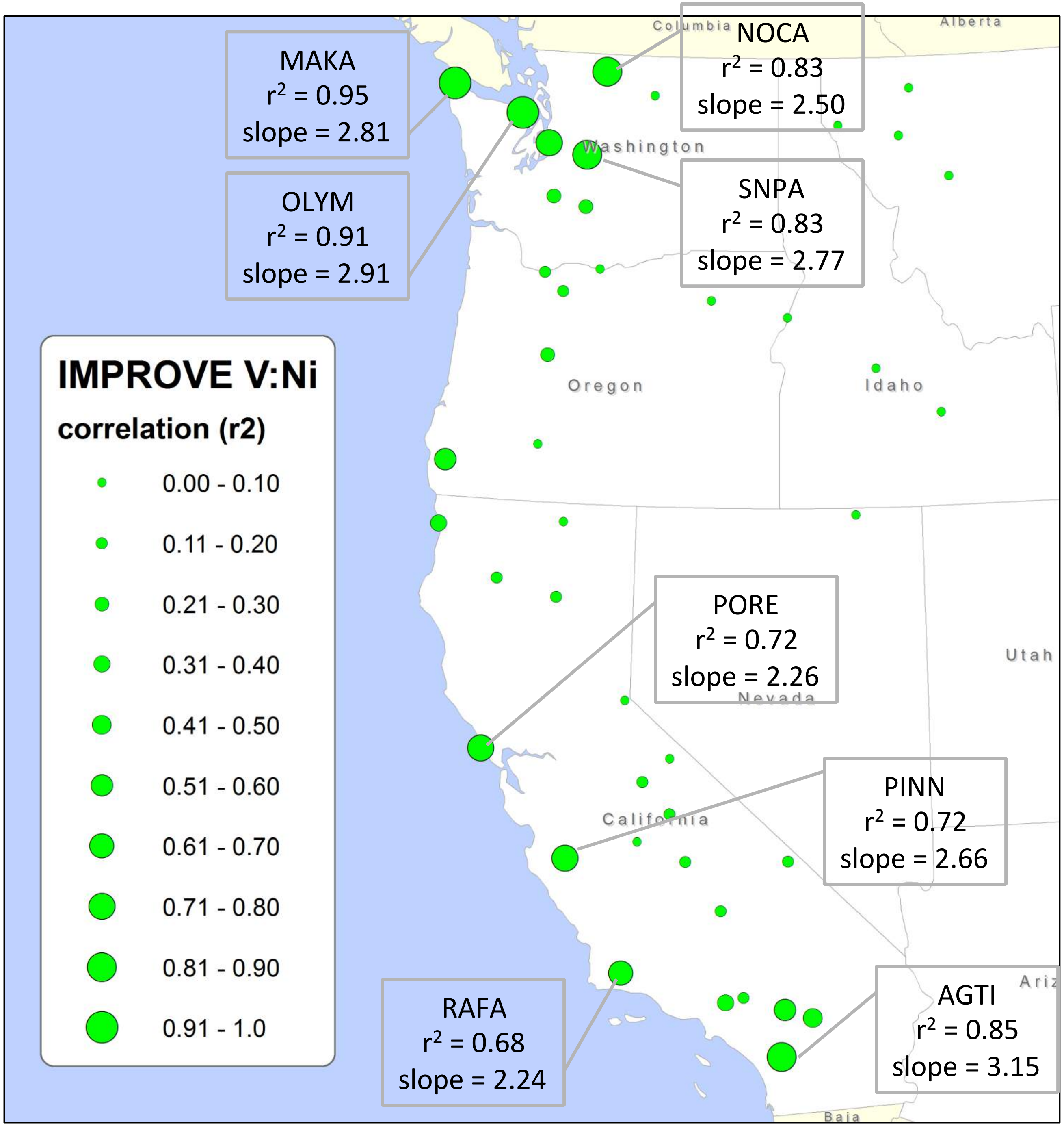



Note:

Highest correlations in coastal areas.

Two sites have $r^2 > 0.9$

- Makah WA site
- Olympic WA site




## V : Ni correlations ($r^2$) at PNW and CA IMPROVE sites

Note:

High correlation sites, V : Ni ratio (slope) ranges from 2.24 – 3.15 : 1

Average V : Ni ratio from the two sites with $r^2 > 0.9$

- Makah WA site
- Olympic WA site

is

V : Ni = 2.86 : 1

Marine vessels using residual fuel oil
V : Ni
~ 3 : 1

**To track marine vessels, could use just the sum of V+Ni, but we can do better by incorporating information about the V:Ni ratio.**


**The MAKA and OLYM IMPROVE sites have the strongest V:Ni correlations, $r^2 > 0.9$.**

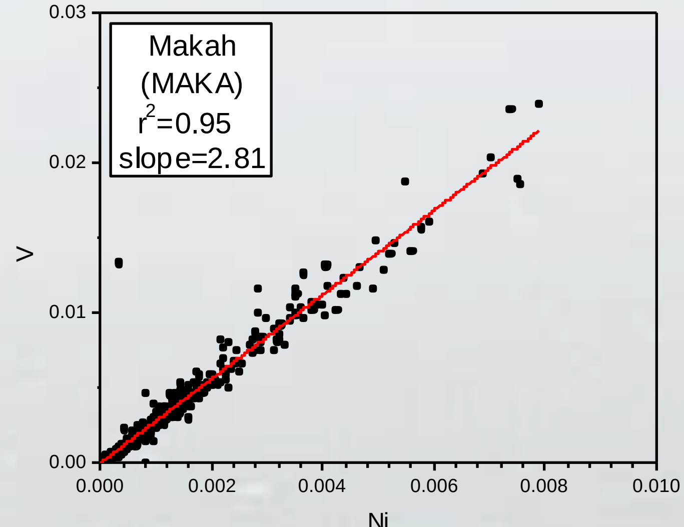
**If we assume V and Ni at MAKA and OLYM sites is from RFO combustion, we can use the average slope between the two sites as regional V:Ni ratio from marine vessels.** (average slope is 2.86:1)

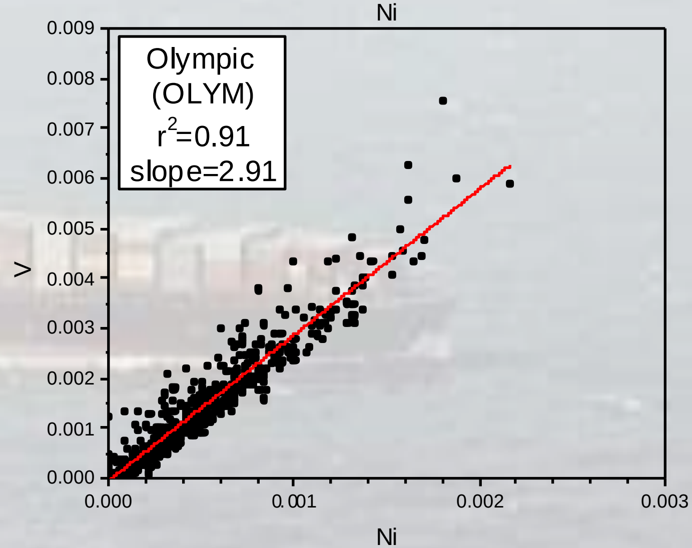
**V+Ni data can then be separated into two portions:**

V+Ni →

**Residual Fuel Oil combustion portion**
(portion of V&Ni with V:Ni = 2.86:1)
call this 'potential RFO' ('**pRFO**')

**Portion unrelated to RFO combustion**
(V and Ni not matching 2.86:1 ratio)
call this the '**remainder**'

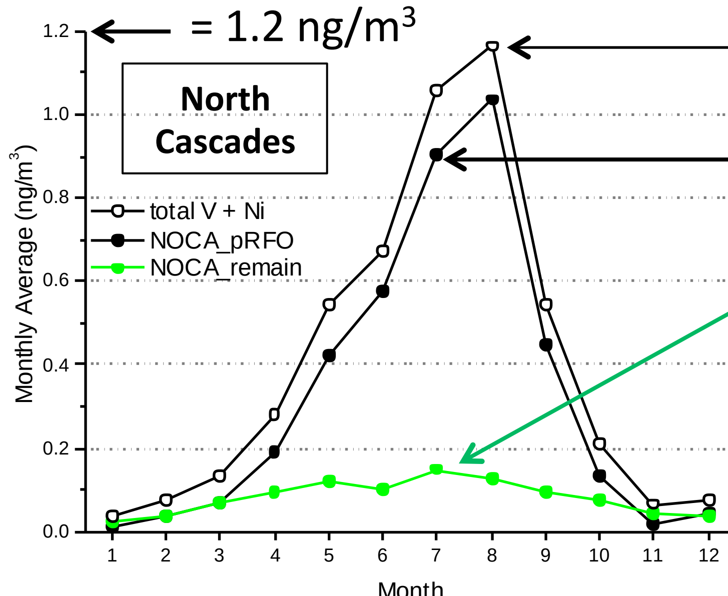


# Example of pRFO & remainder metric: North Cascades vs. Pasayten


**Benefits of approach**:
- Large V or Ni mass outliers not mistakenly attributed to RFO.
- May help identify sites impacted by RFO but not found in PMF modeling.
- May help remove seasonal V and Ni 'background' concentrations.

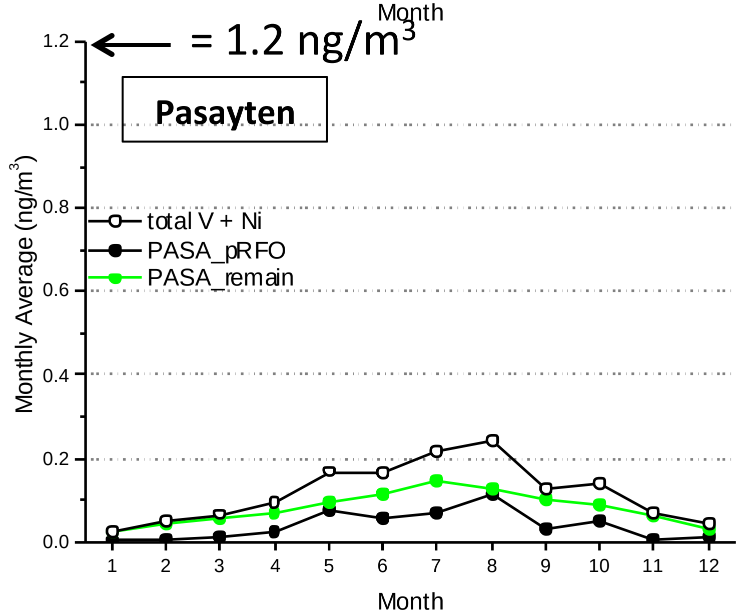
**Drawbacks of approach**:
- Small amount of background V and Ni that meets V:Ni 2.86:1 will be attributed to pRFO.
- A portion of other sources that emit both V and Ni will be attributed to pRFO.
- A ratio of V:Ni 2.86:1 may be less applicable the further you get from the PNW.




Original monthly average V + Ni

**potential RFO portion (V:Ni 2.86:1)**

**remainder portion**

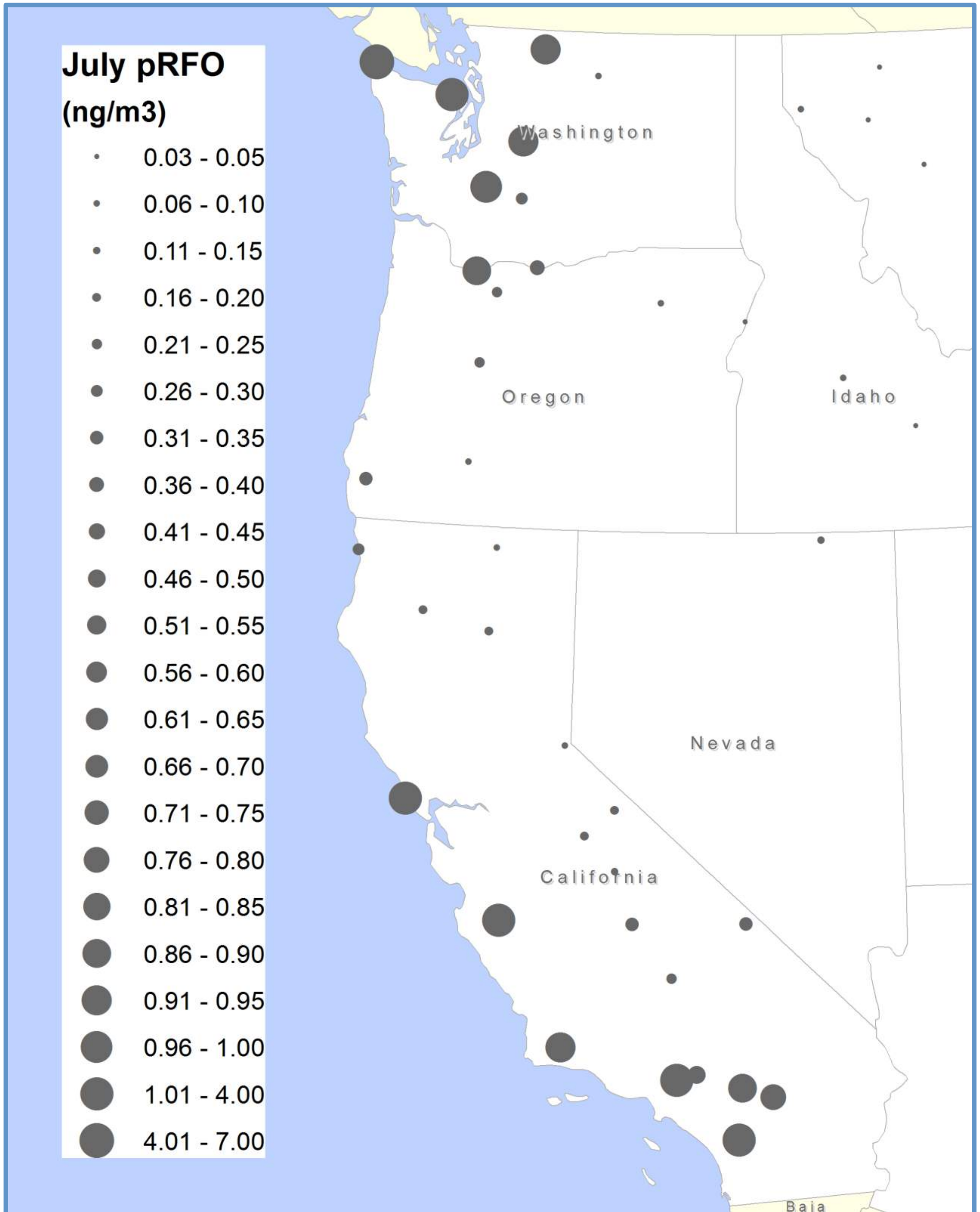



NOTE: monthly pattern of 'remainder' portion looks similar at North cascades and Pasayten

**Spatial distribution of 'potential RFO' metric for July data.**

Largest impacts correspond well to sites indicating marine vessel impacts from the PMF source apportionment analysis.

Reminder:
pRFO = the amount of measured V and Ni mass that has a ratio of V:Ni = 2.86:1.



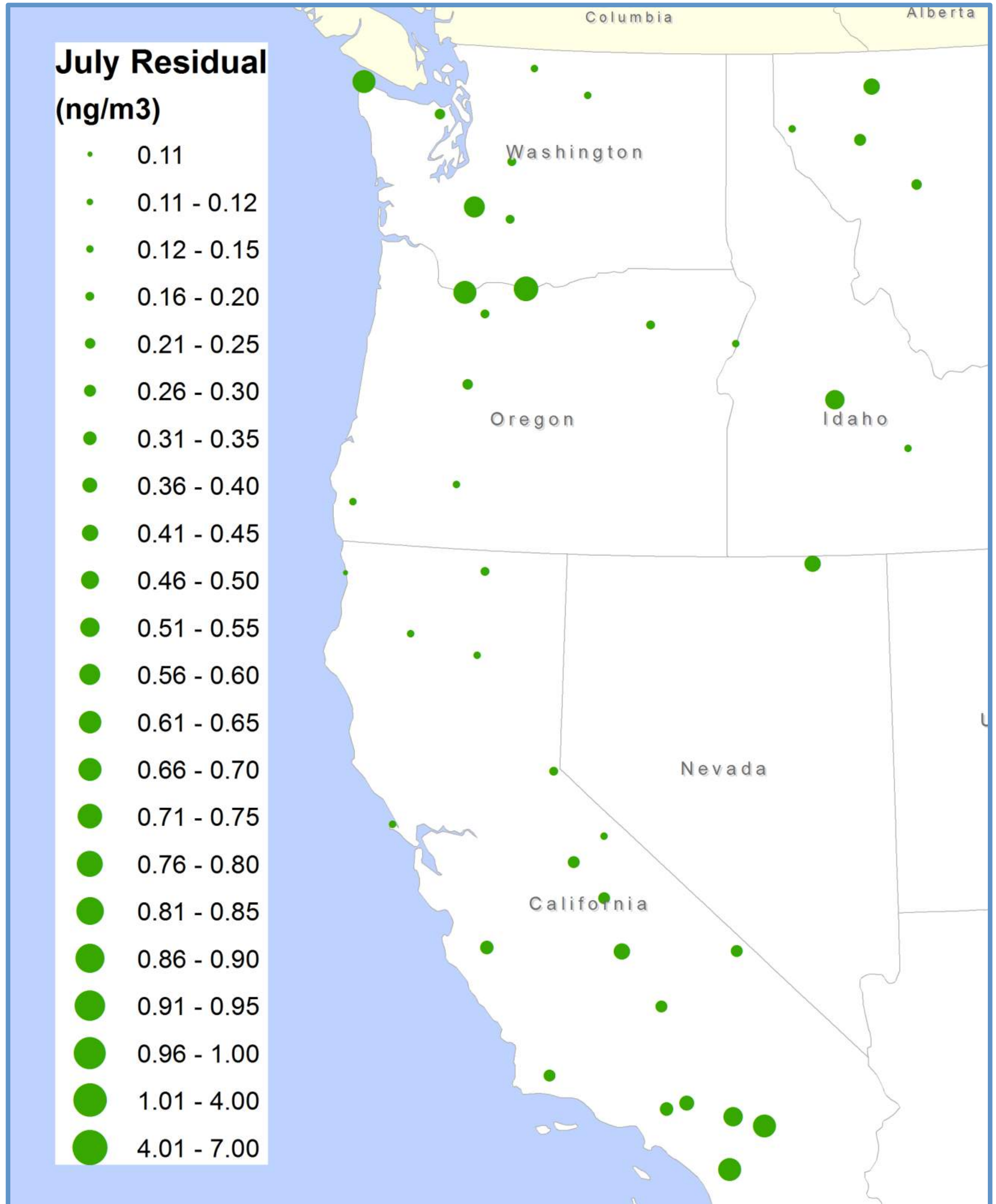
**Spatial distribution of 'remainder/residual' for July data.**

High values in southern CA correspond to counties with highest non marine vessel Ni emissions based on 2008 NEI.

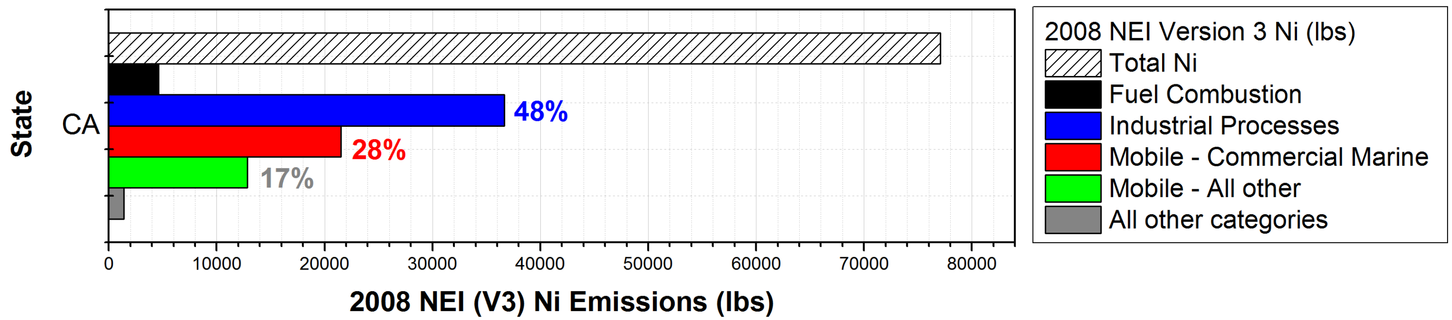
Larger values in ID/MT could be V from soil impacts.

Eastern Gorge value could be V and Ni from Boardman Coal combustion.

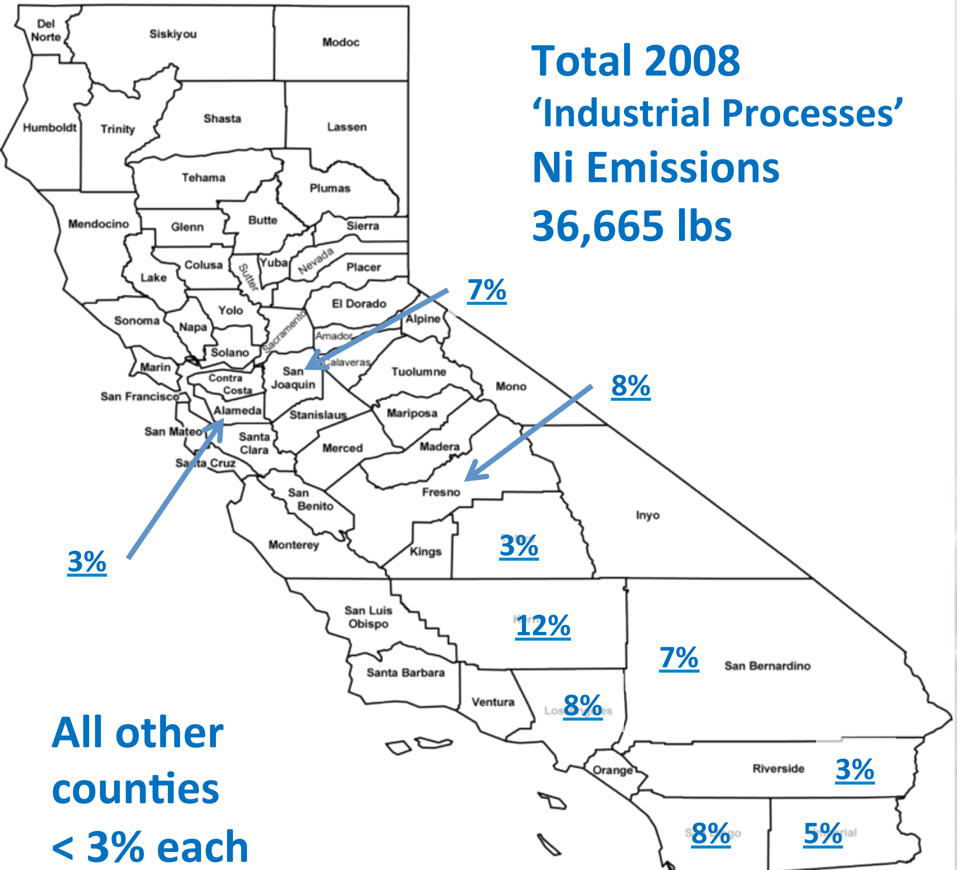
Reminder: 'remainder/residual' = the amount of measured V or Ni mass that does not have a ratio of V:Ni = 2.86:1.



# California Ni emissions (2008 NEI V3)



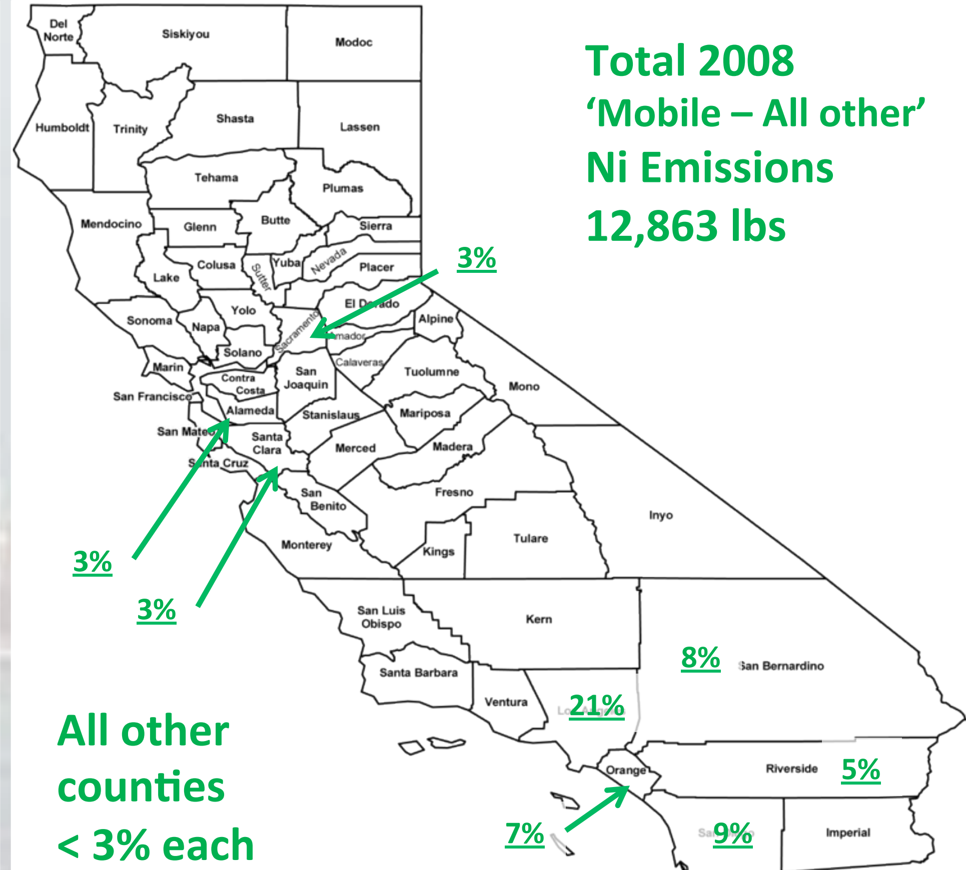

## Percentage of 'Industrial Processes' Ni Emissions




**Total 2008 'Industrial Processes' Ni Emissions 36,665 lbs**

**All other counties < 3% each**

## Percentage of 'Mobile – All other' Ni Emissions




**Total 2008 'Mobile – All other' Ni Emissions 12,863 lbs**

**All other counties < 3% each**

# Conclusions

- A metric based on ambient V and Ni data can be used as a direct tracer of primary PM2.5 emissions from marine vessels.

- The IMPROVE monitoring network is a much better source of data than the EPA urban CSN network for tracking V and Ni from marine vessels.

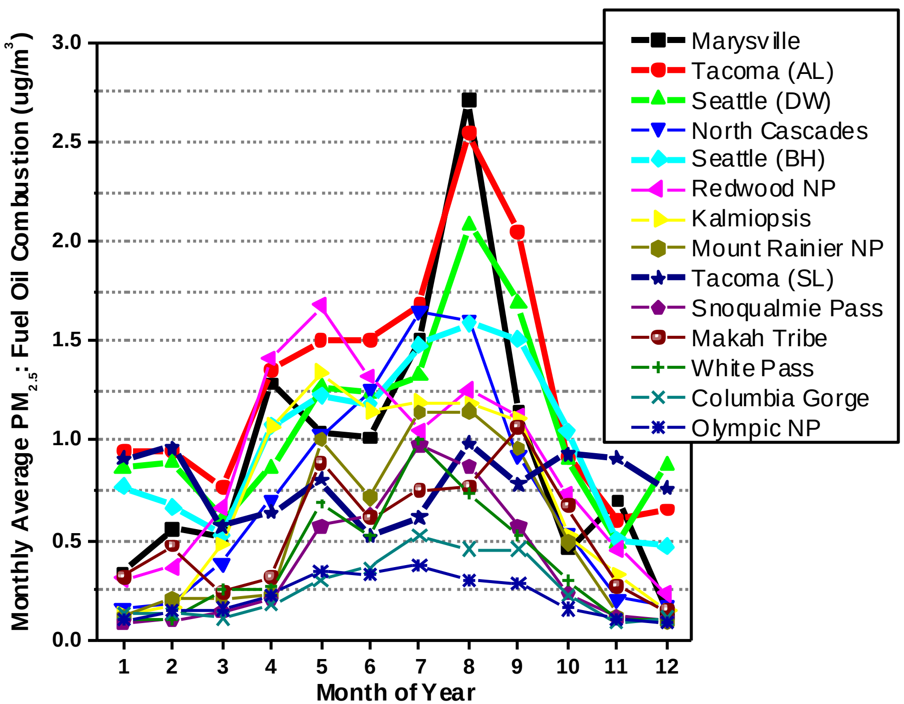
- Given the IMPROVE network time lag in posting data, we should start to see data from after the implementation of the ECA (after Aug. 2012) beginning in early 2014.


Thank you!
Questions?

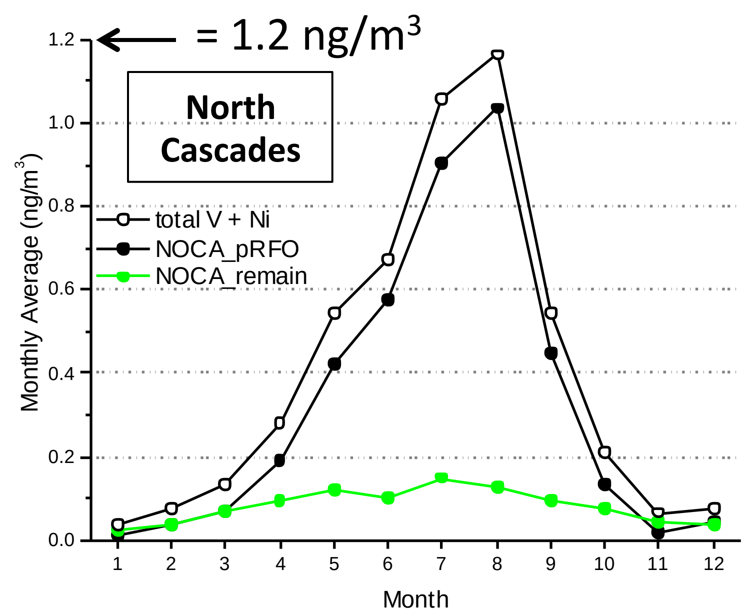
# Supplemental slides

**Note: all sites show a strong seasonal cycle in V and Ni data (mostly from marine vessels), suggesting seasonal cycle in PMF results is not from secondary PM production in summer.**

Pacific Northwest PMF results for Marine Vessel primary + secondary PM2.5 impacts.




V + Ni from direct primary PM2.5 emissions (2007-2011 North Cascades IMPROVE site)



# Why is there a strong seasonal cycle in primary marine vessel PM2.5 impacts?

**Meteorological effects on emissions? - no**

pRFO is a metric for direct primary emissions from marine vessels, so seasonal environmental shifts (e.g., ambient temperature, solar radiation) should not effect the amount of primary emissions.

**Seasonal source activity patterns? – mainly no**

Cruise Ships have a strong seasonal activity pattern. However, there is a much larger amount of cargo vessel traffic along the west coast and the seasonal activity pattern of cargo vessel traffic is weak or non-existent.

**Meteorological effects on dispersion? – most likely**

This suggests that seasonal meteorological variables may be influencing the fate of primary emissions. Some variables to explore are:

- Precipitation patterns – wetter seasons will have more wet deposition.
- Summer vs. winter mean wind speeds – more dispersion with higher winds.
- Summer vs. winter mean boundary layer height – are ship stacks high enough to emit above the marine boundary layer (or plume rise to above the MBL) in some seasons?
- Summer vs. winter mean wind direction.

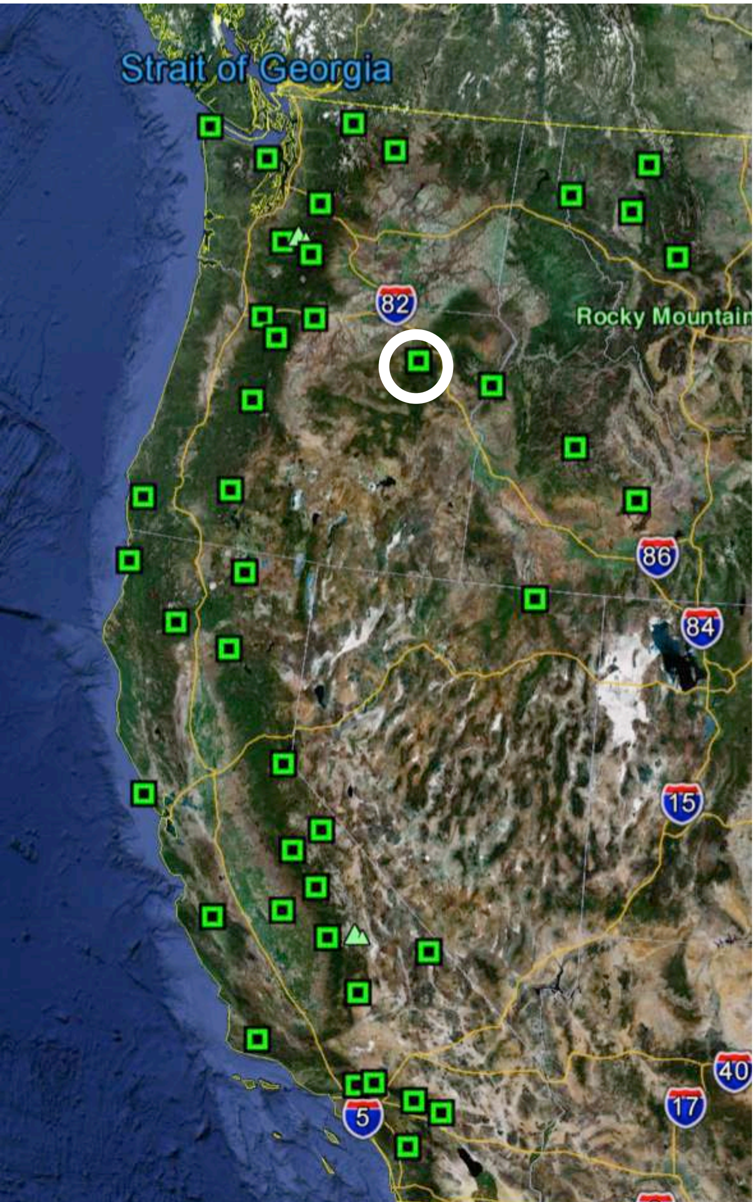
## Tracking emissions reductions

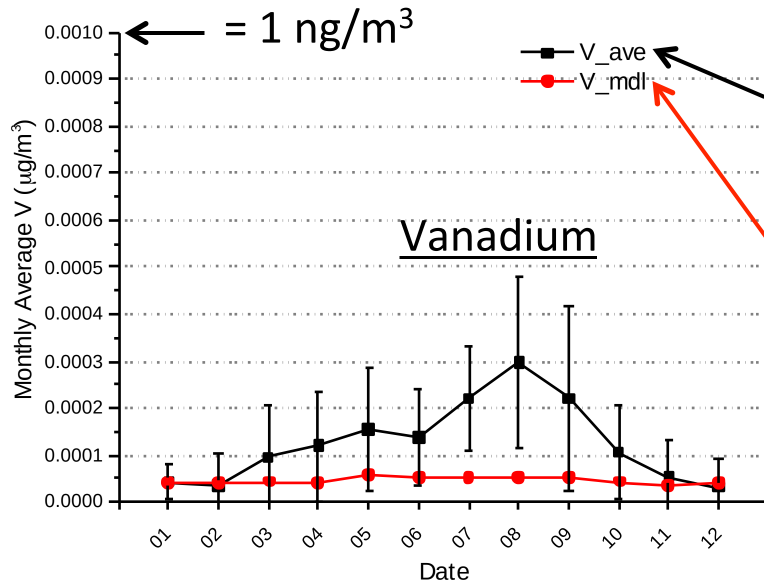

**V & Ni Data & Detection Limit Examples**

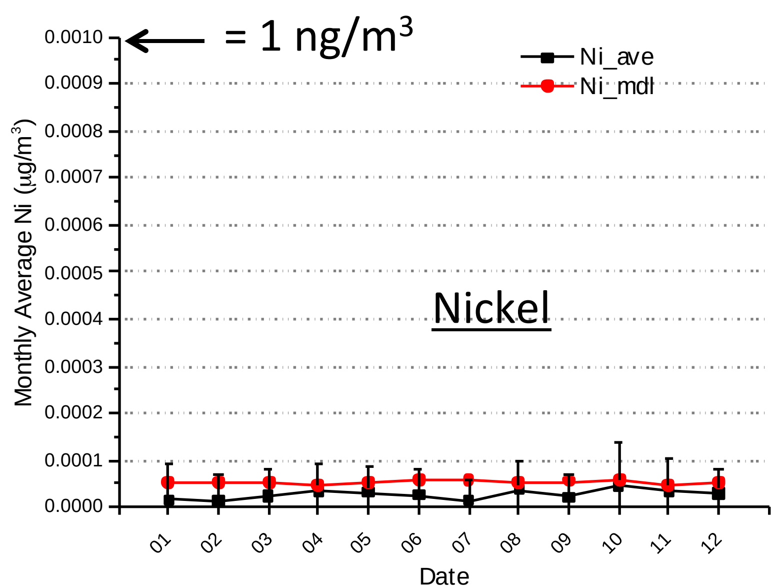
- Remote continental IMPROVE site:
  Starkey OR
- Smaller urban continental CSN site:
  Yakima WA
- Urban port site with co-located IMPROVE and CSN monitors:
  Seattle WA

# Rural Site - Starkey IMPROVE Site V and Ni Data

## What do ambient V and Ni concentrations look like?




Monthly Ave data from 2007-2011.

Average instrumental detection limit

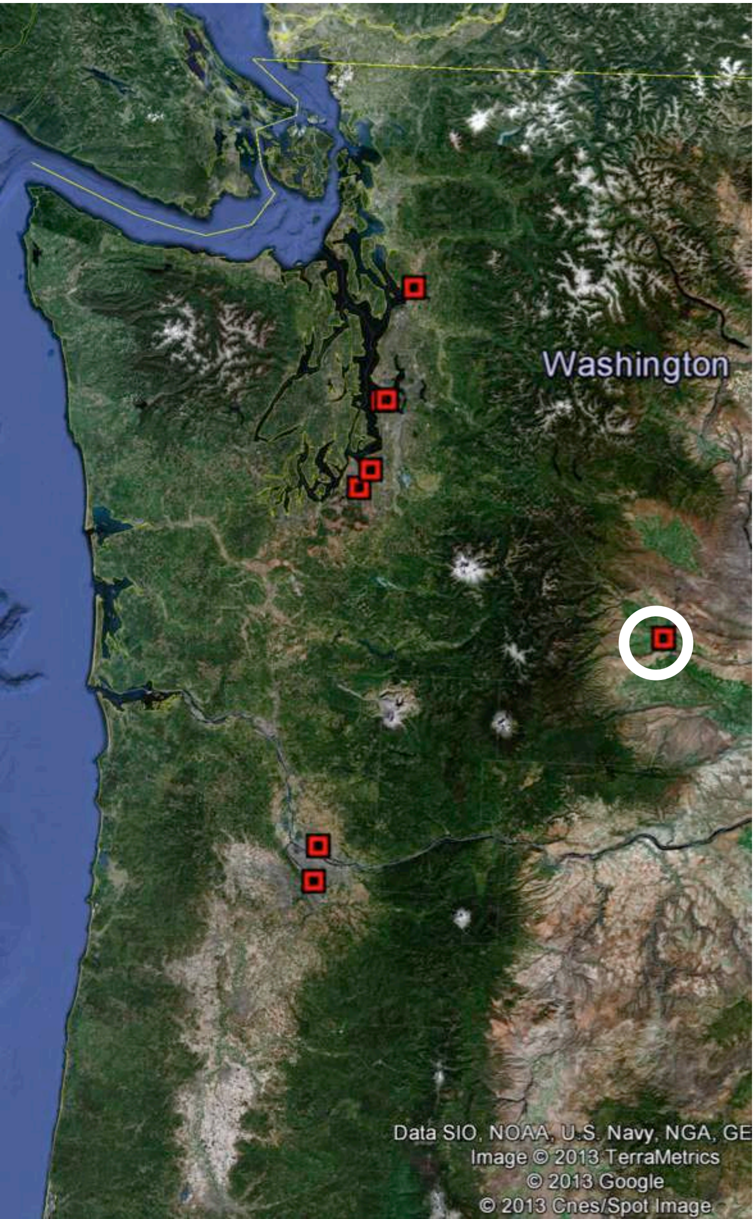
At Starkey Monthly average V levels in the tenths of ng/m³.

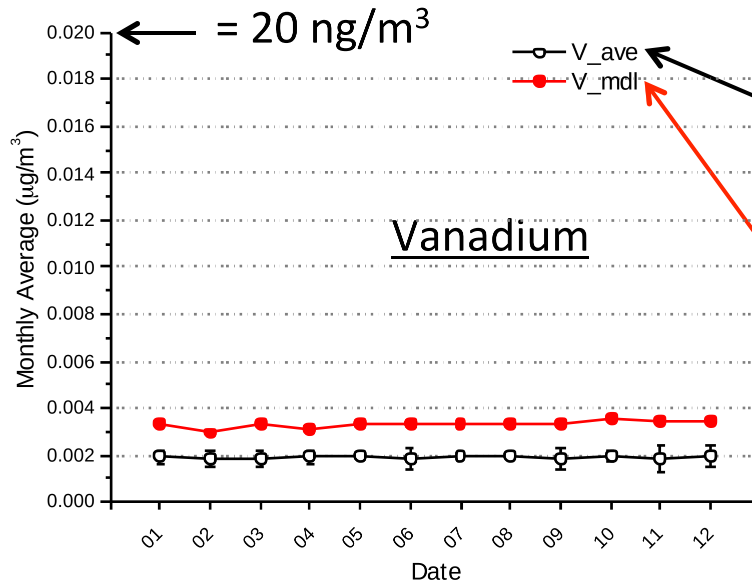
Seasonal summer increase in V (from soil dust?)

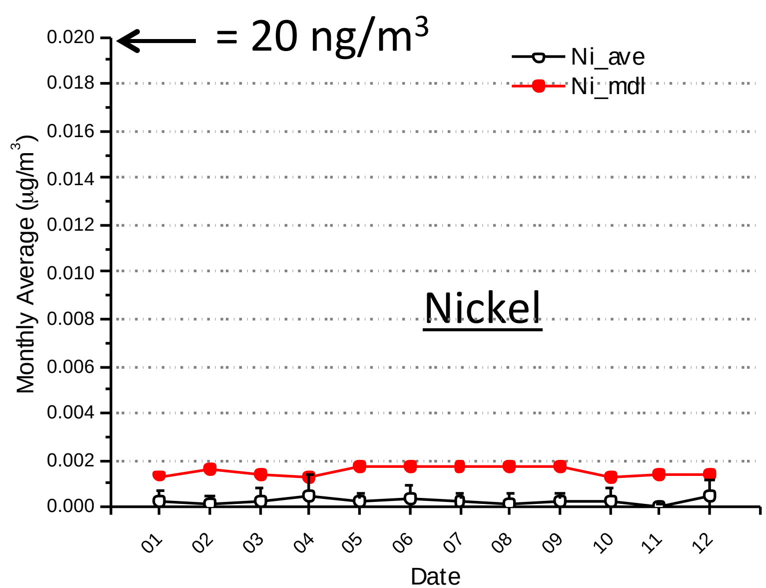
Average Ni below detection limits.

# Continental Urban Site - Yakima
# CSN Site V and Ni Data

## What do ambient V and Ni concentrations look like?




Monthly Ave data from 2007-2011.

Average instrumental detection limit

Instrumental detection limits for both V and Ni are much higher at CSN sites.

IMPROVE MDLs are ~ 0.05 ng/m3

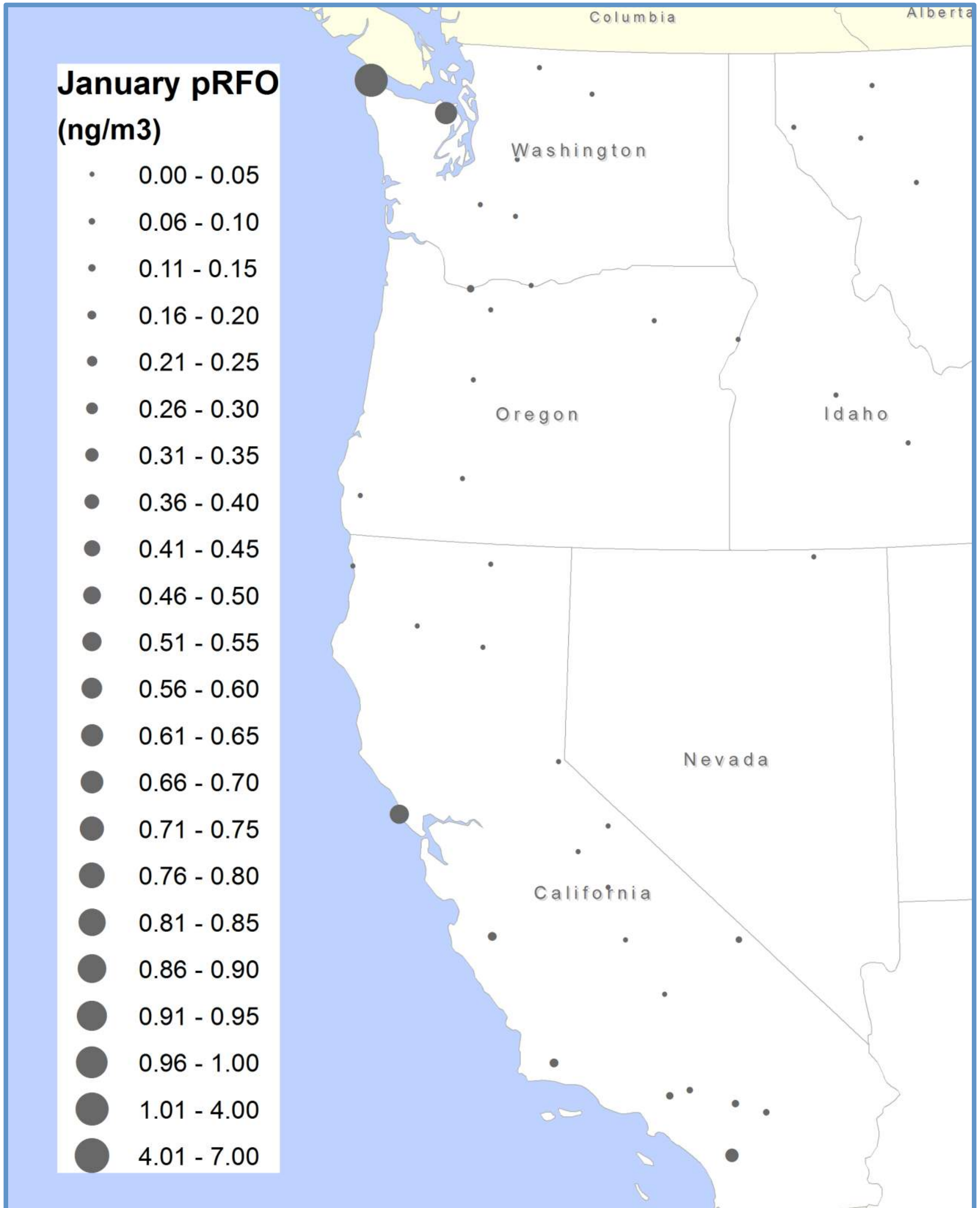
CSN MDLs are ~ 2 ng/m3 (~40x higher than IMPROVE)

January average (2007-2011) pRFO impacts at western IMPROVE sites.

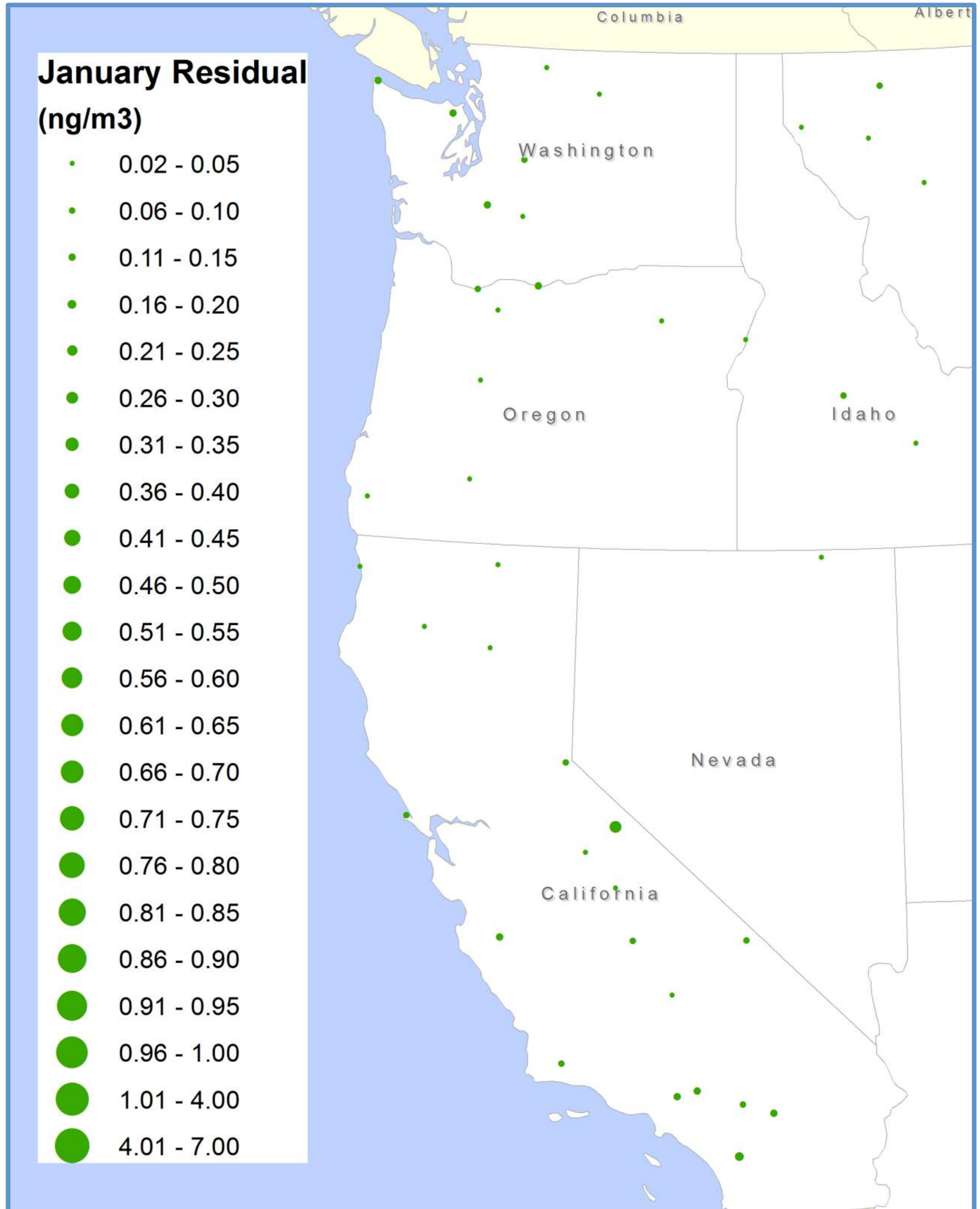
Highest pRFO impacts are at coastal sites.

Much smaller average January pRFO values demonstrate that there is a strong seasonal cycle. Winter low and summer high.

Reminder:
pRFO = the amount of measured V and Ni mass that has a ratio of V:Ni = 2.86:1.



January average (2007-2011) 'remainder' impacts at western IMPROVE sites.




Reminder:
'remainder' = the amount of measured V or Ni mass that does not have a ratio of V:Ni = 2.86:1.

**Summarizing Ni and V emissions:**

- NEI tracks Ni emissions but not V
- Most western US Ni emissions are in WA and CA, where major ports are located.

- Most WA Ni emissions (86%) are from from CMV.
- Most CA Ni emissions are split between
  - Industrial Processes (48%)
  - Mobile – Commercial Marine (28%)
  - Mobile – All other (17%)
- CA Ni emissions from 'Industrial Processes' and 'Mobile – All other' are mostly located in southern CA counties.

**Monitored Ni data could be useful for tracking Commercial Marine emissions in most areas, but might be more troublesome in southern CA.**