Assessing $PM_{2.5}$ Emissions Impacts from Ocean-Going Ships:

How Effective have Regulations Been on the U.S. West Coast?

Robert Kotchenruther Ph.D.
EPA Region 10

Why be concerned about ship emissions?

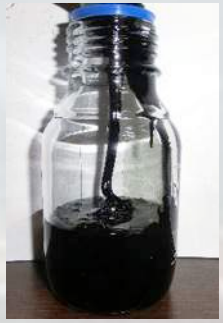
Dirty Fuel

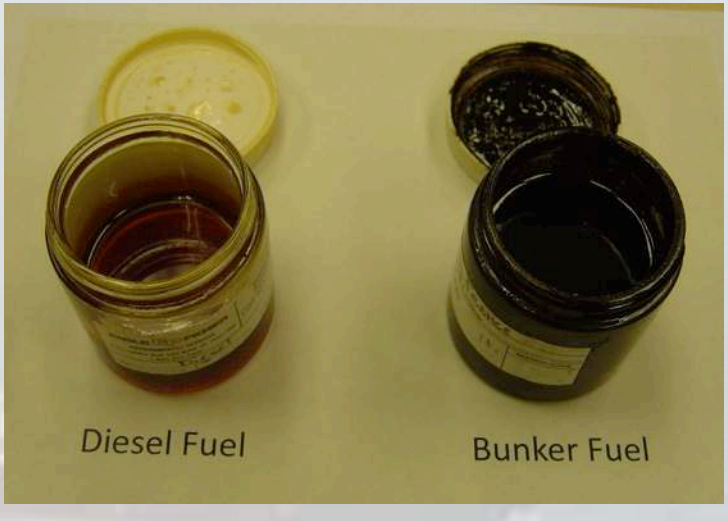
Many ocean going ships use a very dirty fuel - residual fuel oil

- Residual fuel oil -

The waste product of the refining process.

a.k.a. 'bunker fuel'
'Fuel oil No. 6'





World-wide average fuel sulfur content ~ 2.7% (27,000 ppm S)

Combustion emissions are also very dirty: rich in metals and toxics.

Emissions have been regulated by targeting fuel sulfur content, which is proportional to emissions of $PM_{2.5}$ & SO_2

There have been 2 fuel sulfur regulations effecting ocean-going ships on the U.S. West Coast

California Ocean-Going Vessel Clean Fuel Regulation:
24 mile coastal zone, California only

24 NM zone

Important differences:

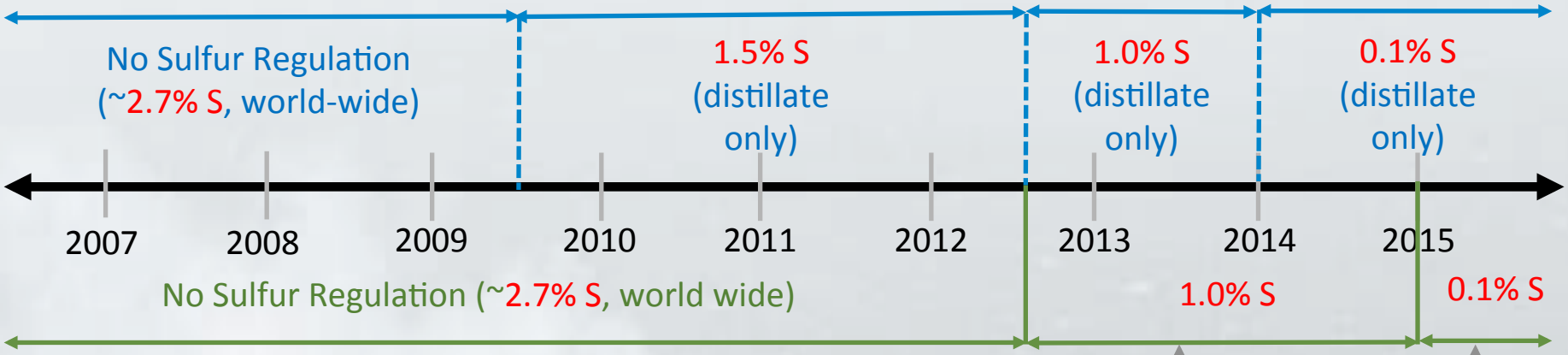
- **Regulated off-shore distance**
  California = 24 NM
  NA-ECA = 200 NM
- **California mandates the use of distillates**
  NA-ECA, fuel S achieved by any means
- **Implementation timelines**

North American Emissions Control Area (NA-ECA):
200 mile coastal zone, U.S. & Canada

200 NM zone

Implementation timelines

California Ocean-Going Vessel Clean Fuel Regulation:
24 mile coastal zone, California only



North American Emissions Control Area (NA-ECA):
200 mile coastal zone, U.S. & Canada

I analyzed available data through this period

We are here

How can one identify and quantify marine vessel impacts?

Combustion emissions of residual fuel oil have a unique chemical signature.

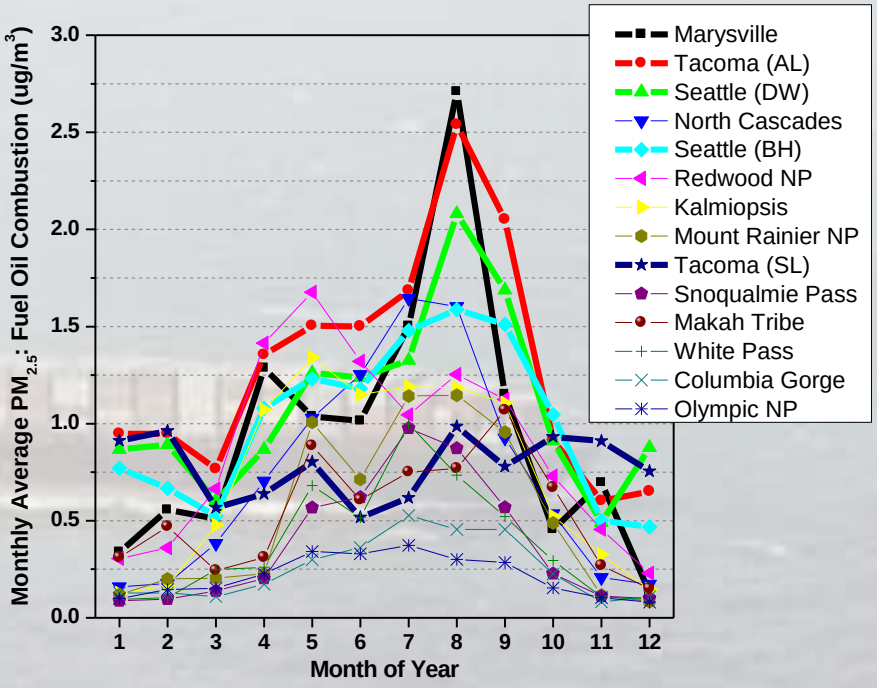
This chemical signature can be identified in $PM_{2.5}$ measurements using certain statistical methods akin to pattern recognition methods (PMF receptor modeling). These methods can determine ***if*** a monitoring site is impacted by residual fuel oil combustion, and ***by how much***.

Back in 2012, I showed this group results (analysis by Positive Matrix Factorization, PMF) for the Pacific Northwest, for data just prior to the implementation of the North American ECA.

From 2012 Analysis:

Monitors showing marine vessel impacts.

Monthly average PM2.5 impact from ships burning RFO.



New Analysis to Determine the Effects of Regulations

Using the same analysis methodology.

Analyzed monitoring sites that had the strongest marine vessel signatures.

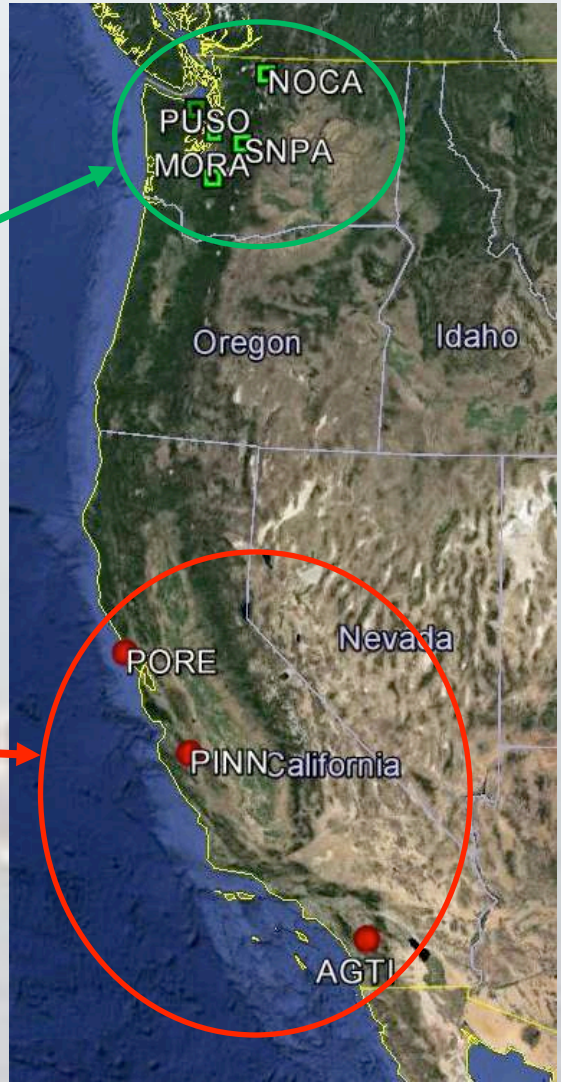
8 sites were analyzed in this new analysis,

5 in Washington

- **North Cascades Park (NOCA)**
- **Olympic National Park (OLYM)**
- **Seattle (PUSO)**
- **Snoqualmie Pass (SNPA)**
- **Mount Rainier (MORA)**

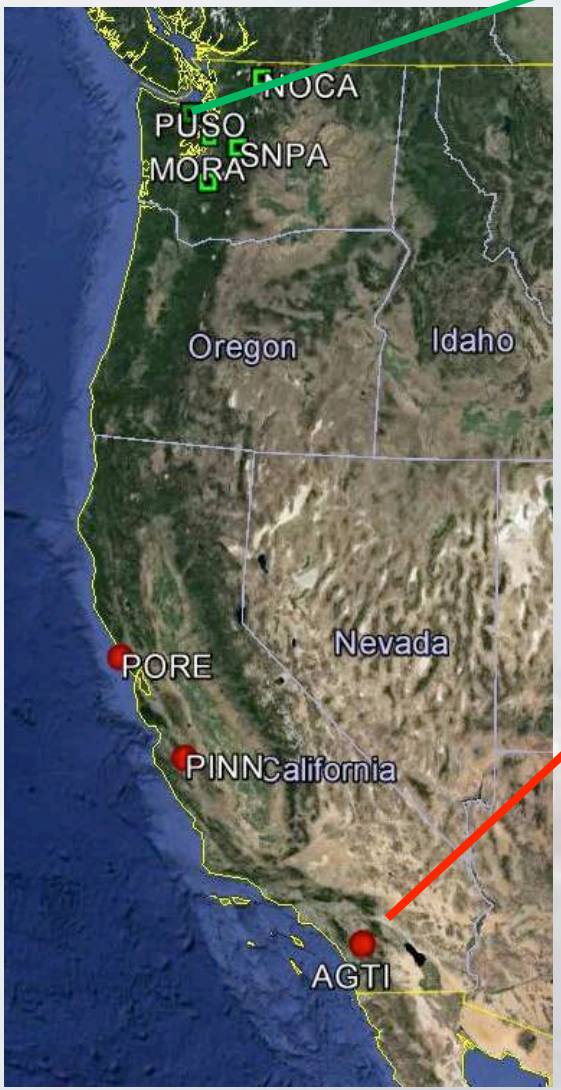
3 in California

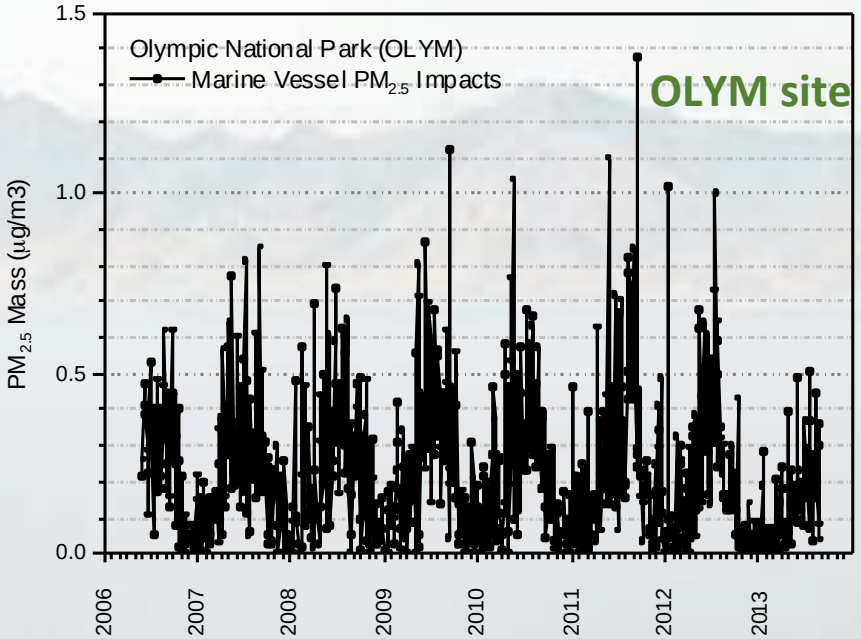
- **Point Reyes (PORE)**
- **Pinnacles (PINN)**
- **Agua Tibia (AGTI)**

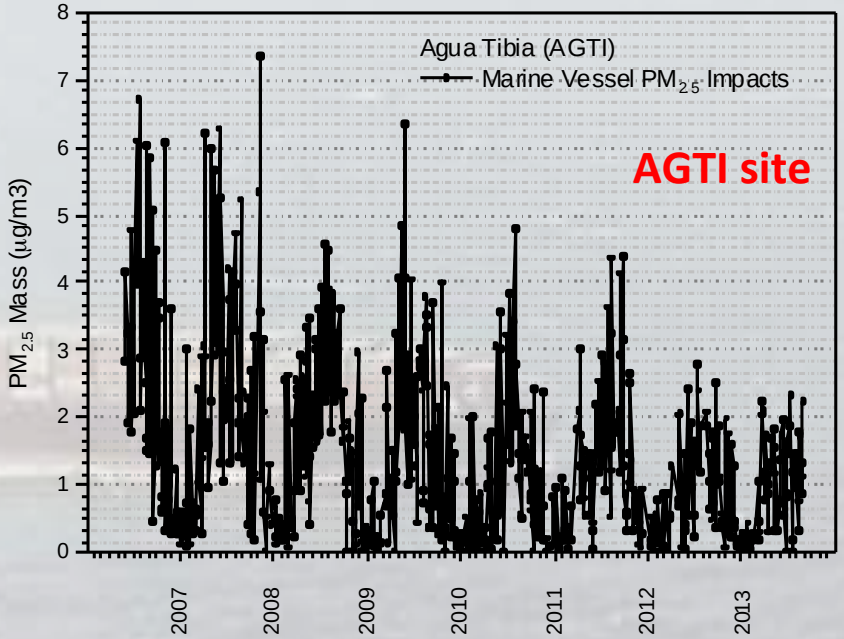


New Analysis, Examples:

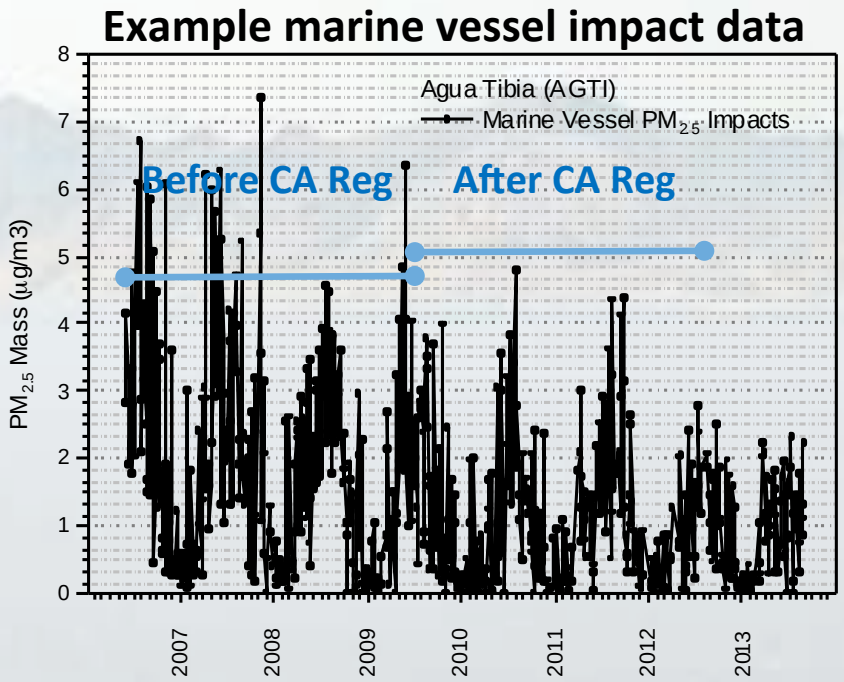
Example Time Series of Marine Vessel $PM_{2.5}$ Impacts, 2006-2013







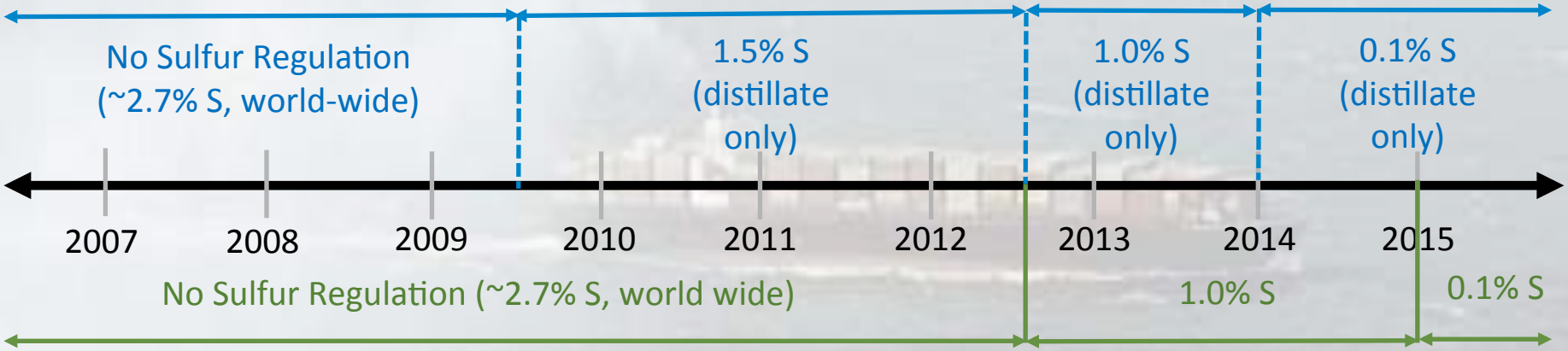
Determining the Effects of California's Ocean-Going Vessel Clean Fuel Regulation



Compared marine vessel $PM_{2.5}$ impacts between two 3-year periods

3 years before CA regulation
7/2006 – 6/2009

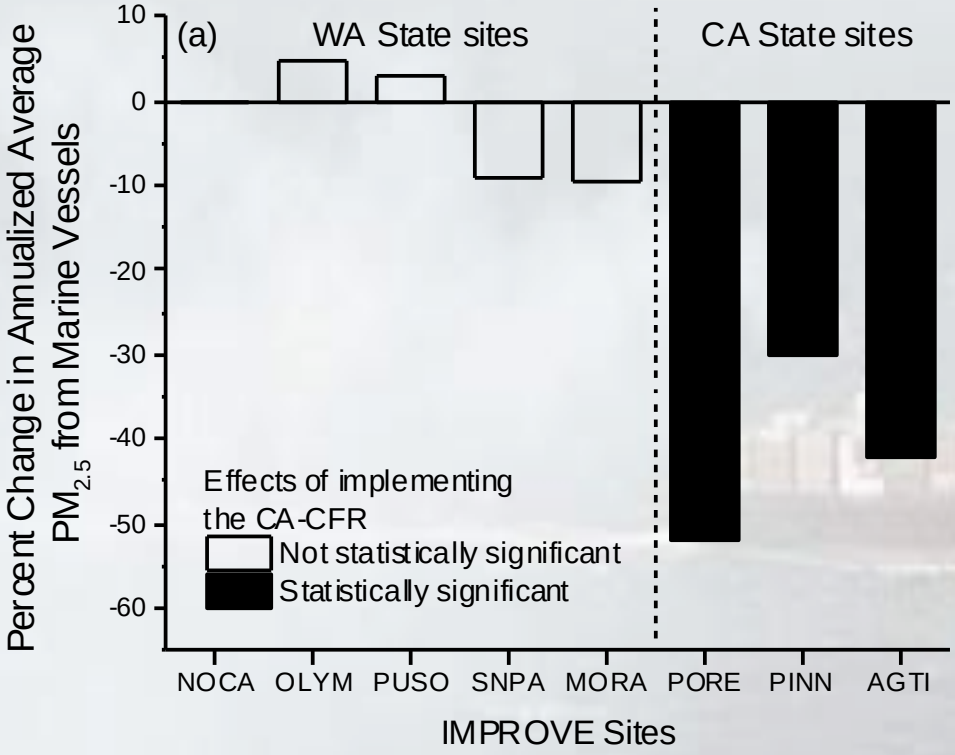
3 years after CA regulation
8/2009 – 7/2012



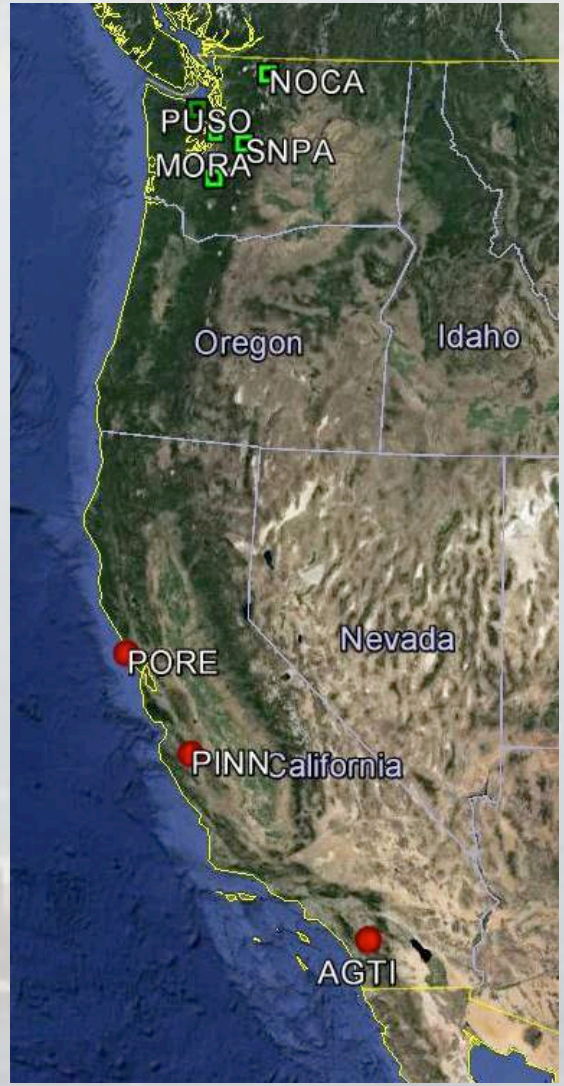
Results: Effects of California Ocean-Going Vessel Clean Fuel Regulation

Washington
Percent change in average $PM_{2.5}$ from
7/2006 – 6/2009
(unregulated, ~2.7% S)
vs.
8/2009 – 7/2012
(unregulated, ~2.7% S)

California
Percent change in average $PM_{2.5}$ from
7/2006 – 6/2009
(unregulated, ~2.7% S)
vs.
8/2009 – 7/2012
(1.5 % S & distillate only in CA)



Because CA regulations mandate distillate use, the effective average fuel S was 0.3% based on enforcement data.



Determining the Effects of California's Ocean-Going Vessel Clean Fuel Regulation

We can also look at all IMPROVE sites and test to see which sites had statistically significant reductions in measured V+Ni data.

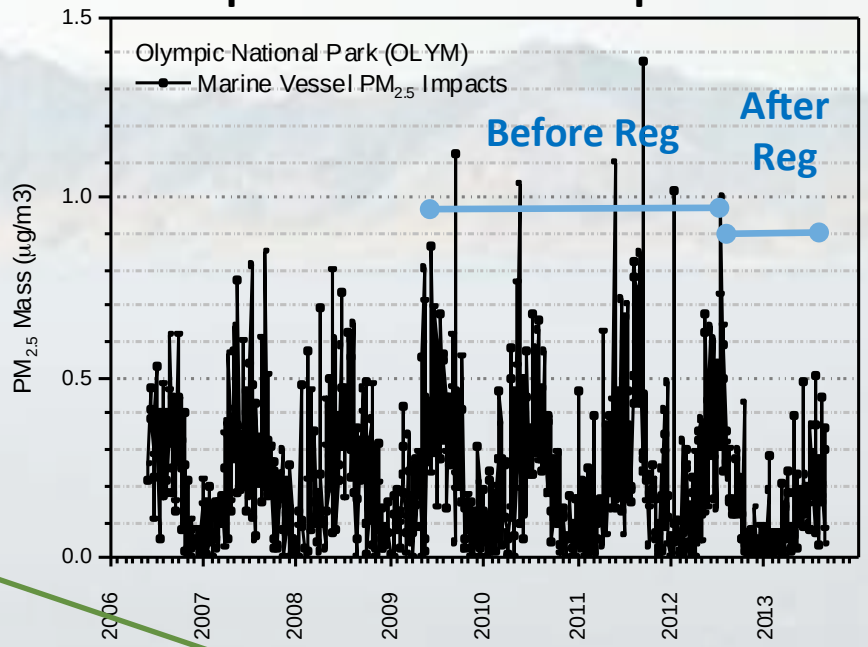
Green circles in the map to the right are sites where there was statistically significant reductions in V+Ni comparing the 3 years prior to the CA regulation and 3 years after:
7/2006 – 6/2009 vs 8/2009 – 7/2012.

Only Sites in CA show statistically significant reductions.

Determining the Effects of the North American Emissions Control Area Regulation

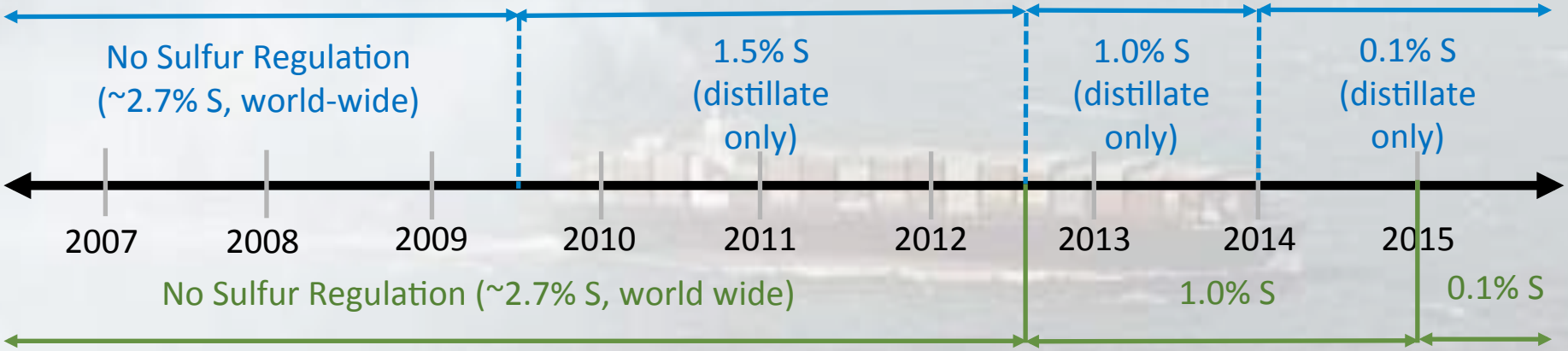
Compared marine vessel $PM_{2.5}$ impacts from 3-years prior to regulation and 1 year after.

Example marine vessel impact data



8/2009 – 7/2012 (3-year period)

9/2012 – 8/2013 (1-year period)



Results: Effects of the North American Emissions Control Area

Washington

Percent change in average $PM_{2.5}$ from

8/2009 – 7/2012

(unregulated, ~2.7% S)

vs.

9/2012 – 8/2013

(ECA, 1.0% S)

California

Percent change in average $PM_{2.5}$ from

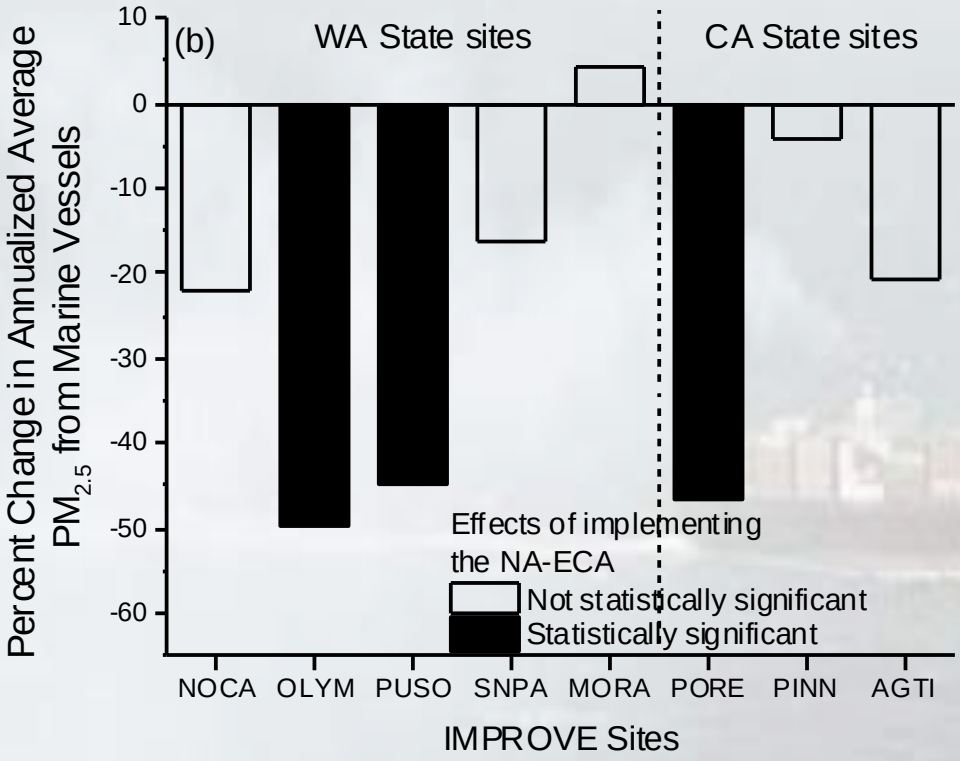
8/2009 – 7/2012

(1.5 % S & distillate only in CA)

vs.

9/2012 – 8/2013

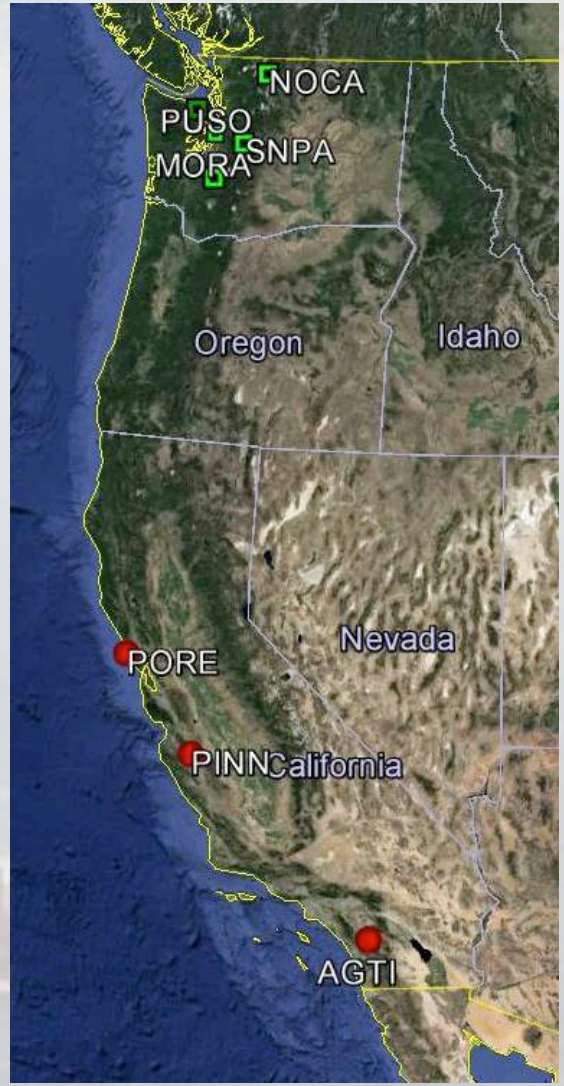
(1.0 % S & distillate only in CA within 24 NM)



Notes:

Authority to enforce the ECA in Canada was not authorized until May 2013.

Effective fuel S in CA likely ~ 0.3% for both periods for CA regs, but second period adds ECA regs out to 200 NM.



Determining the Effects of the North American Emissions Control Area Regulation

We can also look at all IMPROVE sites and test to see which sites had statistically significant reductions in measured V+Ni data.

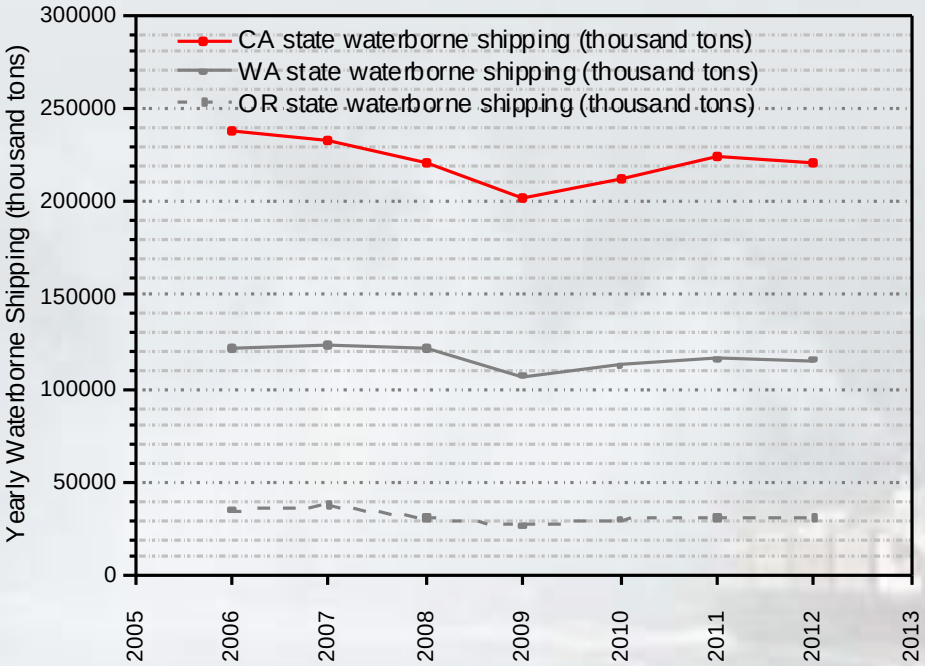
Green circles in the map to the right are sites where there was statistically significant reductions in V+Ni comparing the 3 years prior to the ECA regulation and 1 year after:
8/2009 – 7/2012 vs 9/2012 – 8/2013.

Sites in both WA & CA show statistically significant reductions.

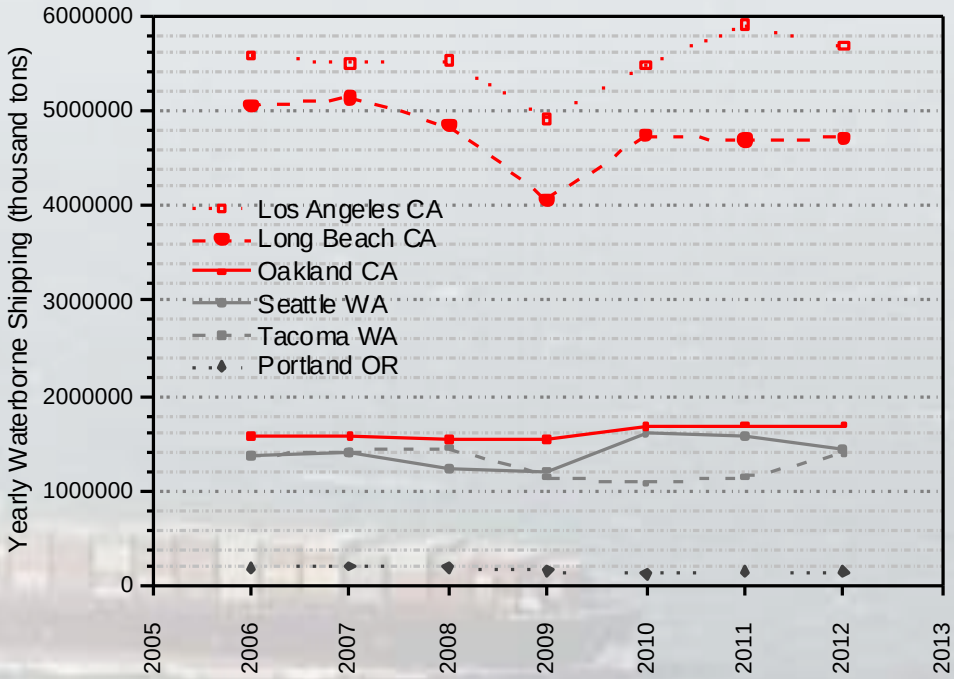
A common question ….

Could annual changes in shipping volume have effected these results?

Yearly Waterborne Tonnage by State



Major West Coast Port Shipping Container Traffic



(US Army Corps of Engineers, Waterborne Commerce Statistics Center. http://www.navigationdatacenter.us/wcsc/wcsc.htm)

Conclusions:

- California regulations have been effective at reducing $PM_{2.5}$ impacts from ocean-going ships at all sites analyzed … by ~30-50% (from 2007 – 2009 vs. 2009 – 2012).

- Mixed results for ECA. Many sites showed PM2.5 reductions in first year of implementation, but some were not statistically significant.

Future work:

- I intend to revisit this analysis one a full year of data is available for 2015 (first year of 0.1% S phase of ECA).

More Information:

- See: Kotchenruther, R. A., Atmospheric Environment 103 (2015) 121-128.

Thank you!