Characterization of Particulate Emissions from Ships from in situ Measurements

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This work was funded in part by National Center for Environmental Research (NCER), EPA, Grant RD833558

and NOAA, Grant NA09OAR4310124

Why Ships?

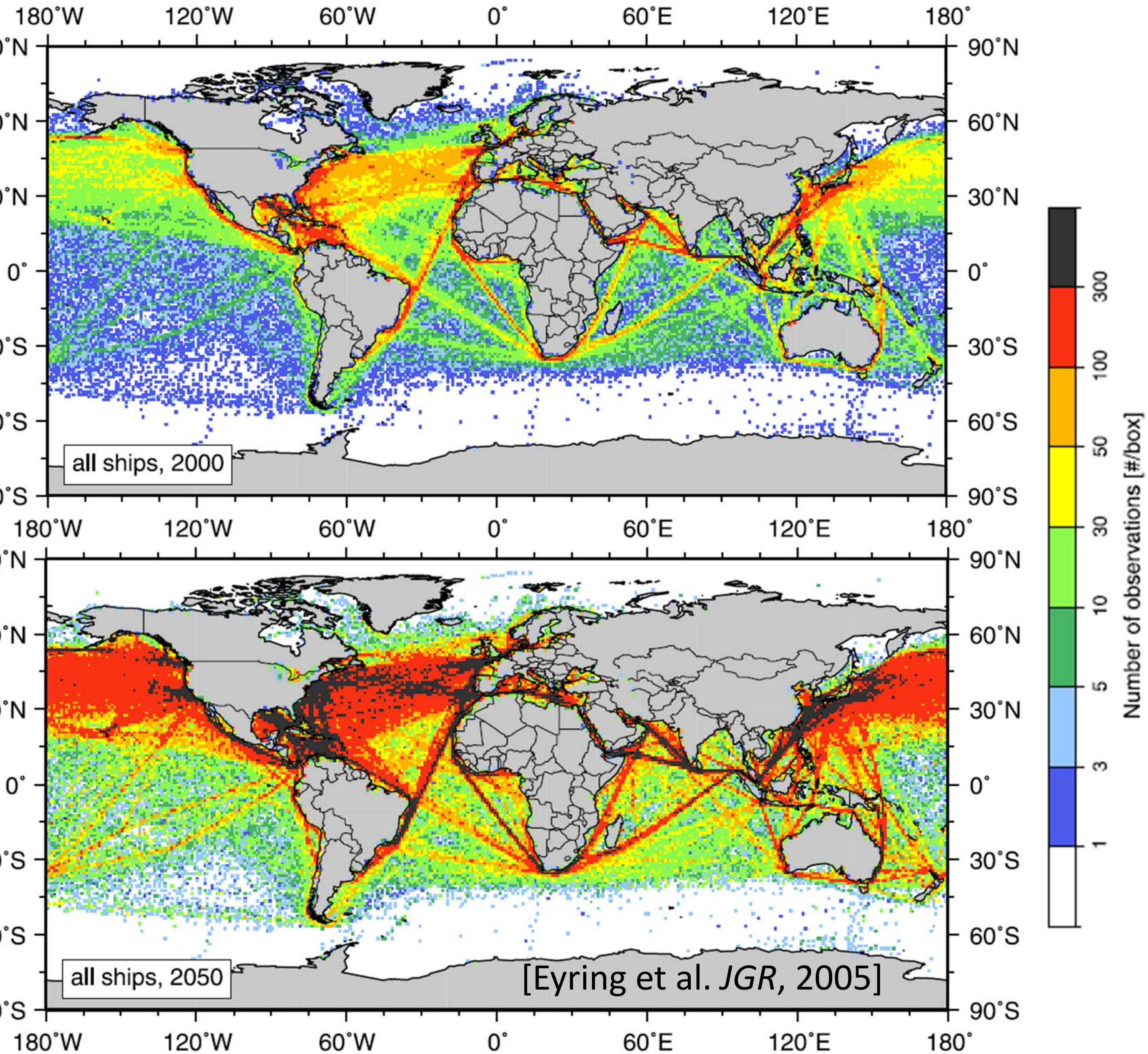
- ca. 8% of primary organic particulate emissions from global fossil and biofuels
- 2% of global black carbon emissions

- Emissions into
  - Pristine marine environments
    - Sea-ice
    - Ship tracks
  - Near large population centers (e.g. ports)
    - Estimated 60,000 premature deaths/year worldwide

- Traffic may increase at 2-6%/year

[Corbett et al., *ES&T*, 2007]
[Lack et al., *GRL*, 2008]
[Ito & Penner, *GBC*, 2005]
[Eyring et al. *JGR*, 2005]

Ocean Going Vessel Traffic Density

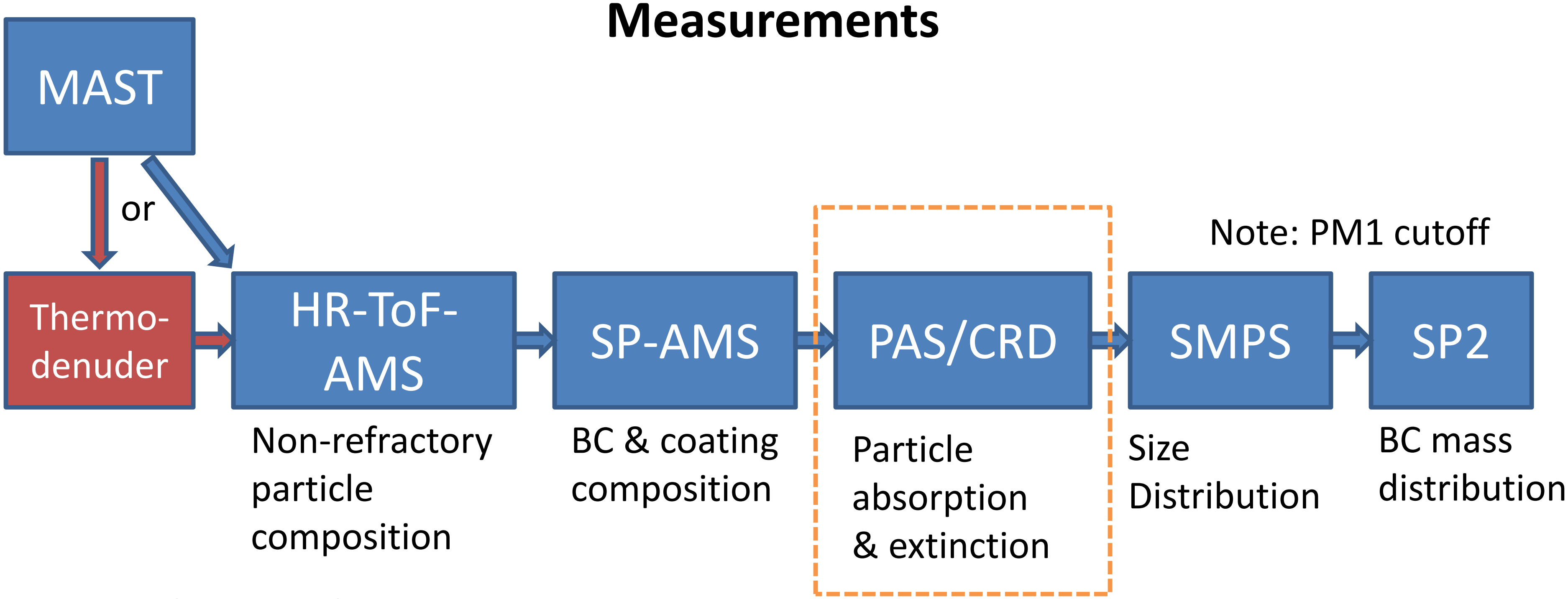


[Eyring et al. *JGR*, 2005]

Objective

Characterize and quantify emissions of particulate matter from a suite of ocean going vessels, with a particular focus on emissions of black carbon

Measurements



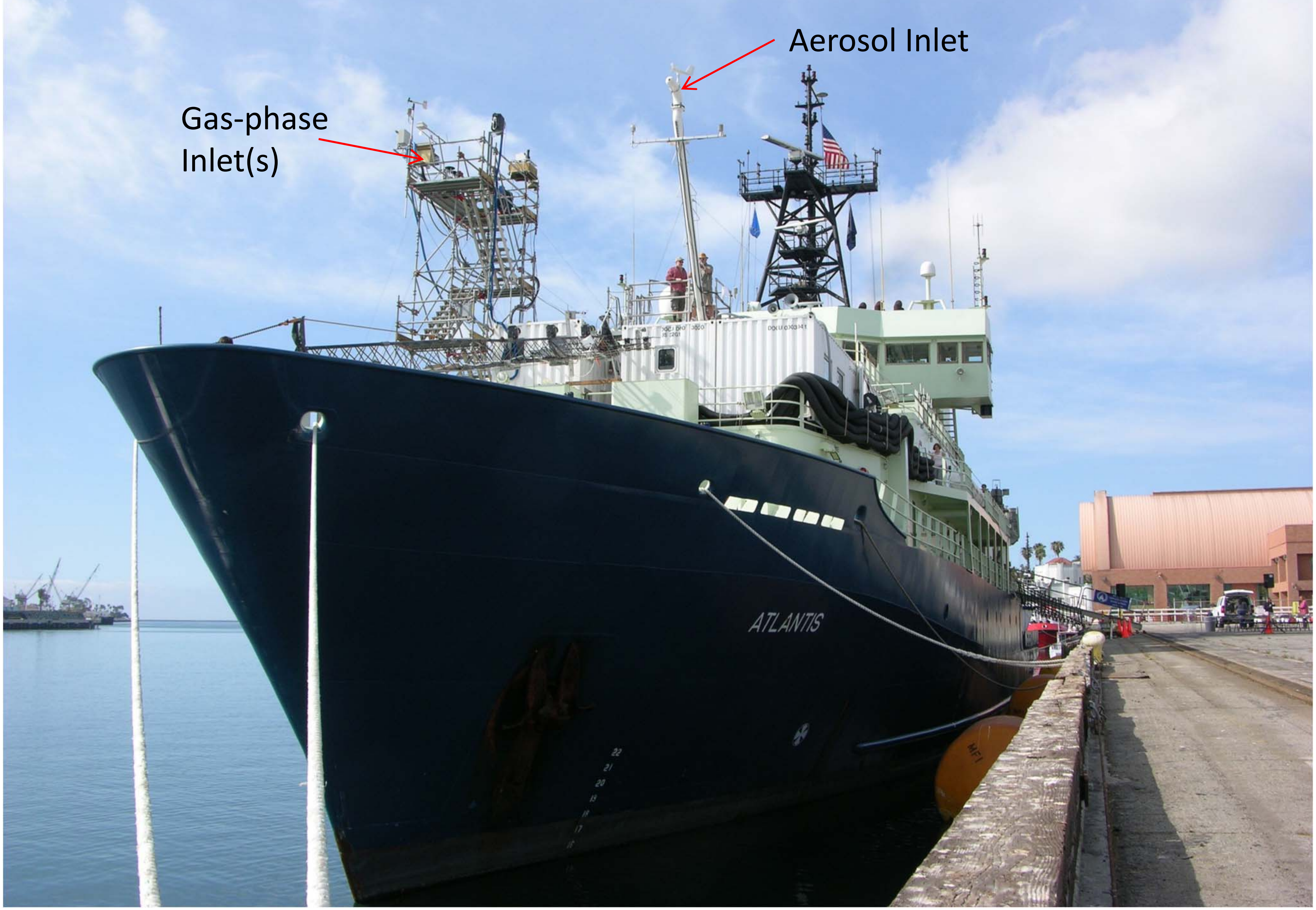
Other particle measurements:

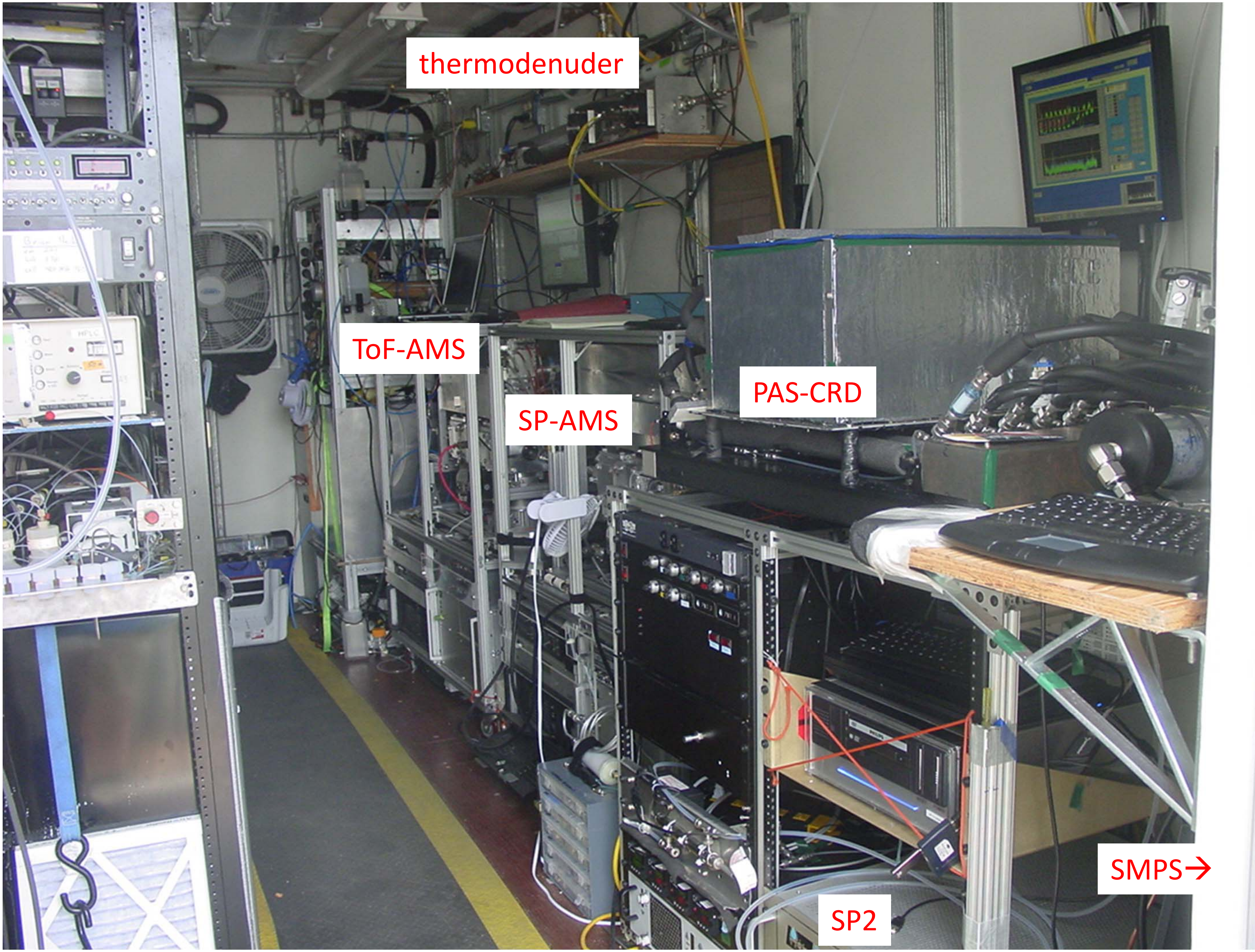
Particle Number (< 5 nm; < 13 nm; < 50 nm; < 100 nm), CPC, 1 second
Particle Size Distributions, SMPS, 3 minute
Cloud Condensation Nuclei (CCN), 1 second
Particle Scattering, Nephelometer, 1 second
Particle Absorption, PSAP, 1 second (w/ 30 second running mean)
Optical hygroscopicity, CRD-AES, 5 seconds
Single particle composition, ATOFMS, fast

Gas Phase:

SO_2, 1 second CO, 1 second NOx, 1 second
CO_2, 1 second O_3, 1 second

Our Research Platform: The Woods Hole R/V Atlantis




thermodenuder
ToF-AMS
SP-AMS
PAS-CRD
SMPS→
SP2

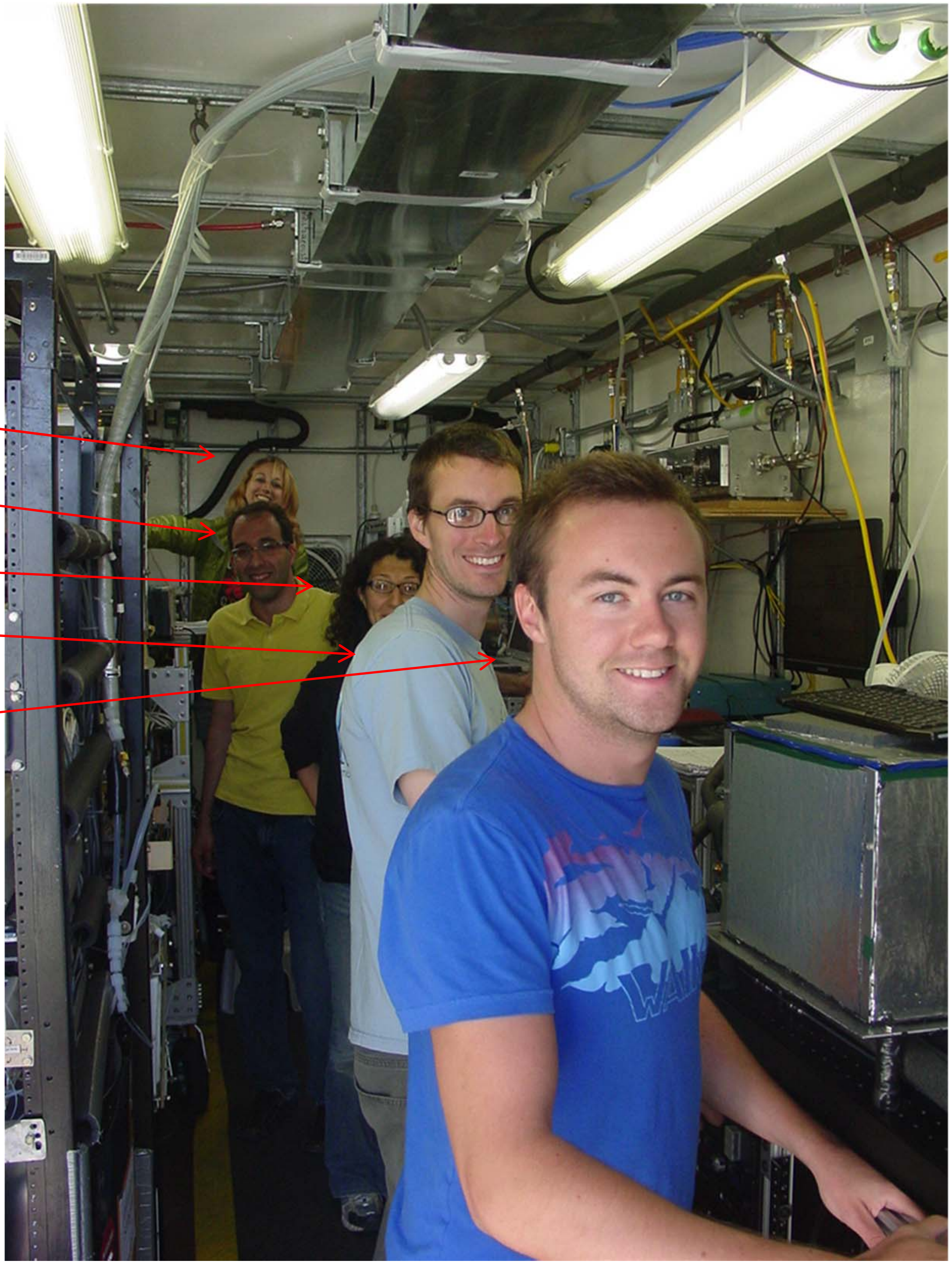
Cassie

Ibrahim

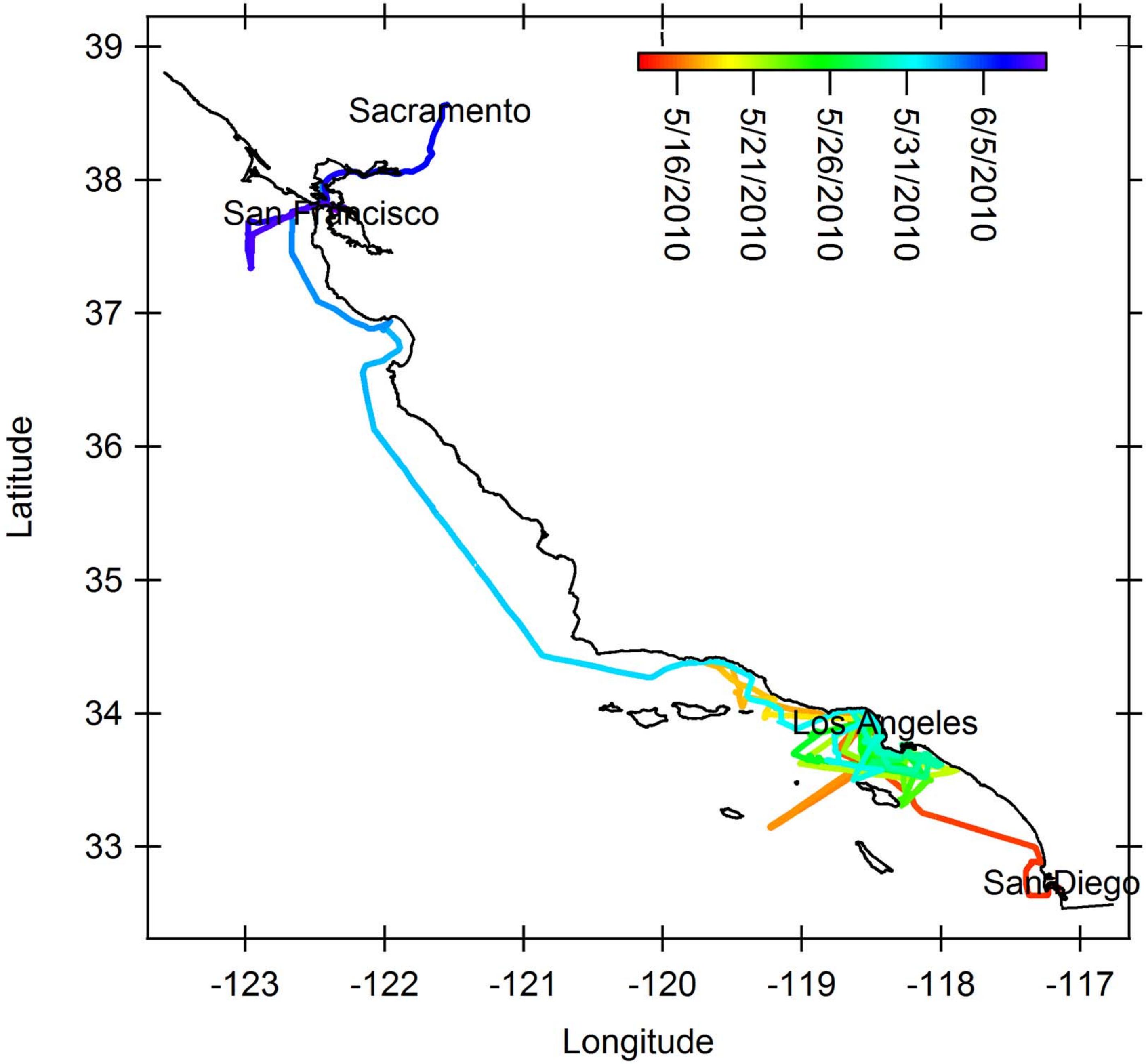
Paola

Me

Dan

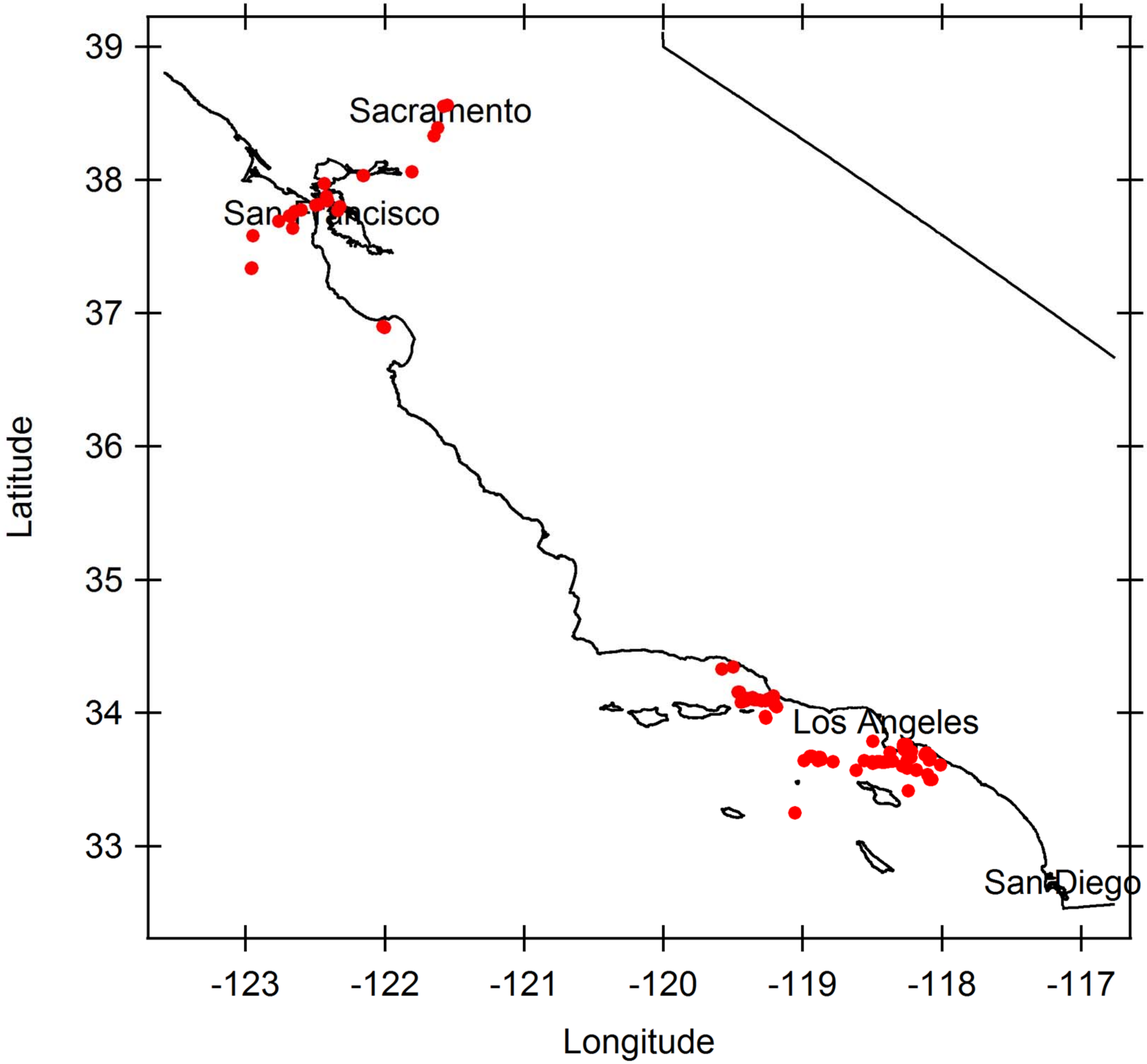


Study Area



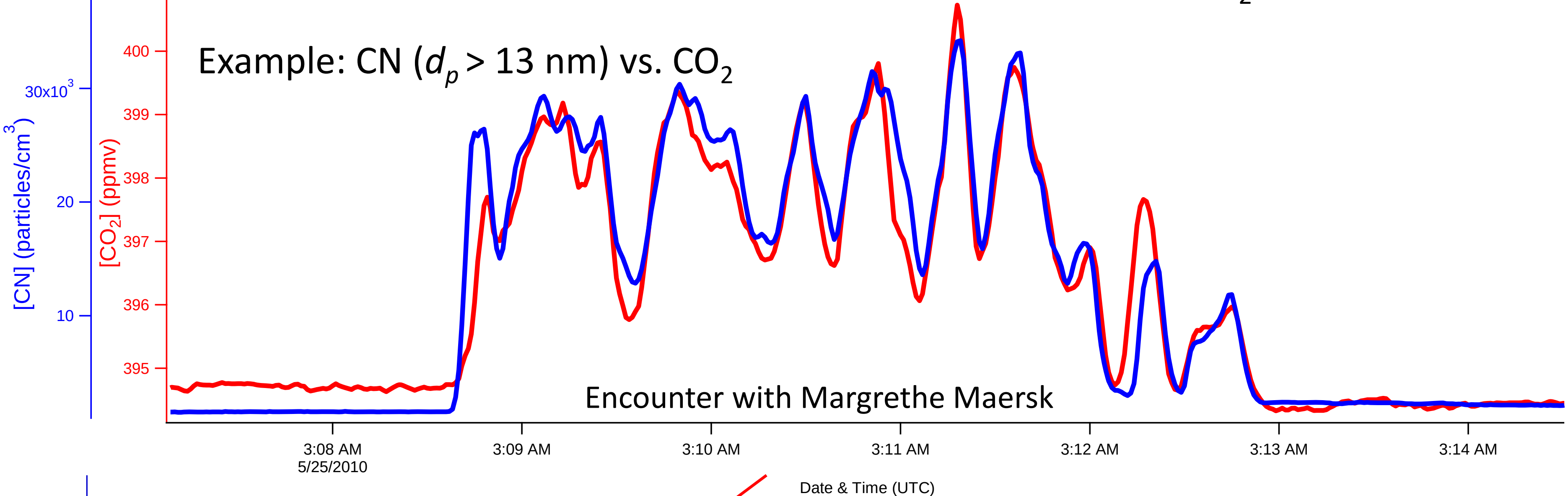
Sacramento
San Francisco
Los Angeles
San Diego
5/16/2010
5/21/2010
5/26/2010
5/31/2010
6/5/2010
39
38
37
36
35
34
33
Latitude
-123
-122
-121
-120
-119
-118
-117
Longitude

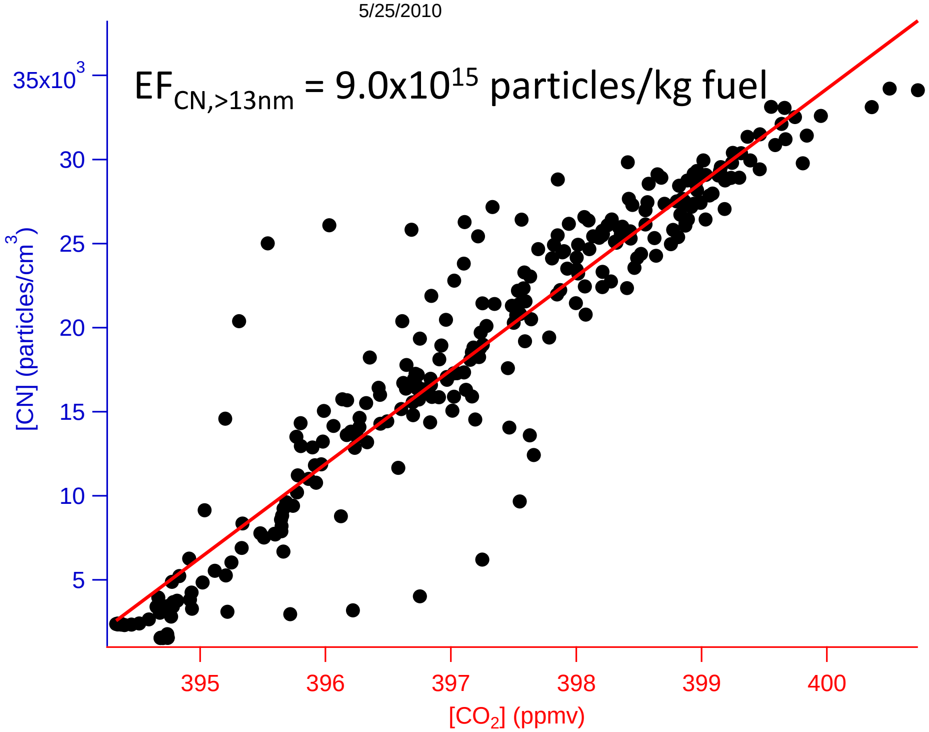
Ship Encounters



Measuring and Quantifying Ship Emissions

Measure emissions factors, i.e. emissions relative to CO_2





$$EF_{Chemical}(g\ kg^{-1}) = \frac{Chemical\ Parameter(\mu g m^{-3})}{CO_2(ppmV)} \times f_{fuel-chemical} \tag{1}$$

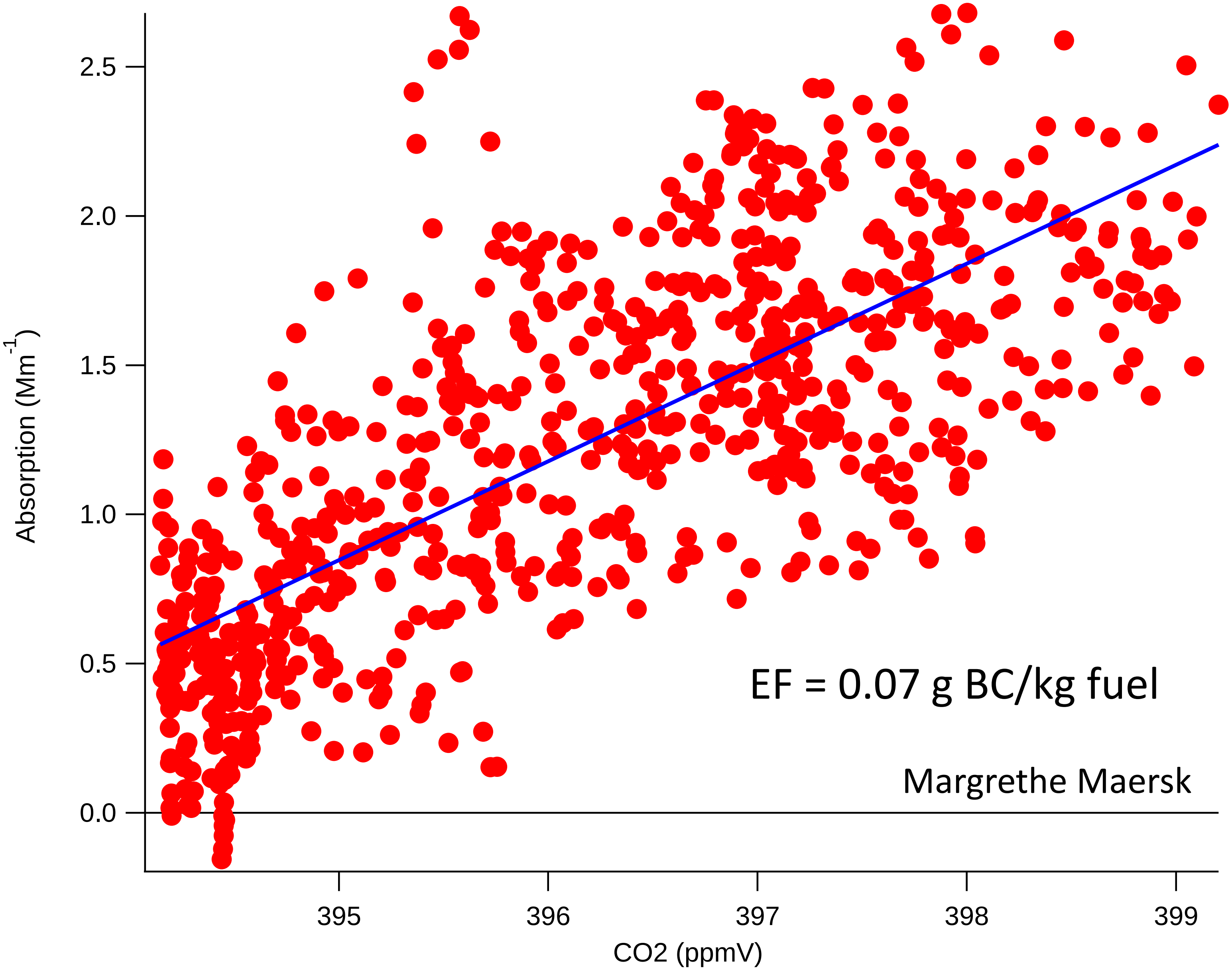
$$EF_{Physical}(kg^{-1}) = \frac{Physical\ Parameter(cm^{-3})}{CO_2(ppmV)} \times f_{fuel-physical} \tag{2}$$

$$EF_{Optical}(m^2 kg^{-1}) = \frac{Optical\ Parameter(Mm^{-1})}{CO_2(ppmV)} \times f_{fuel-optical} \tag{3}$$

[Lack et al., *JGR*, 2009]

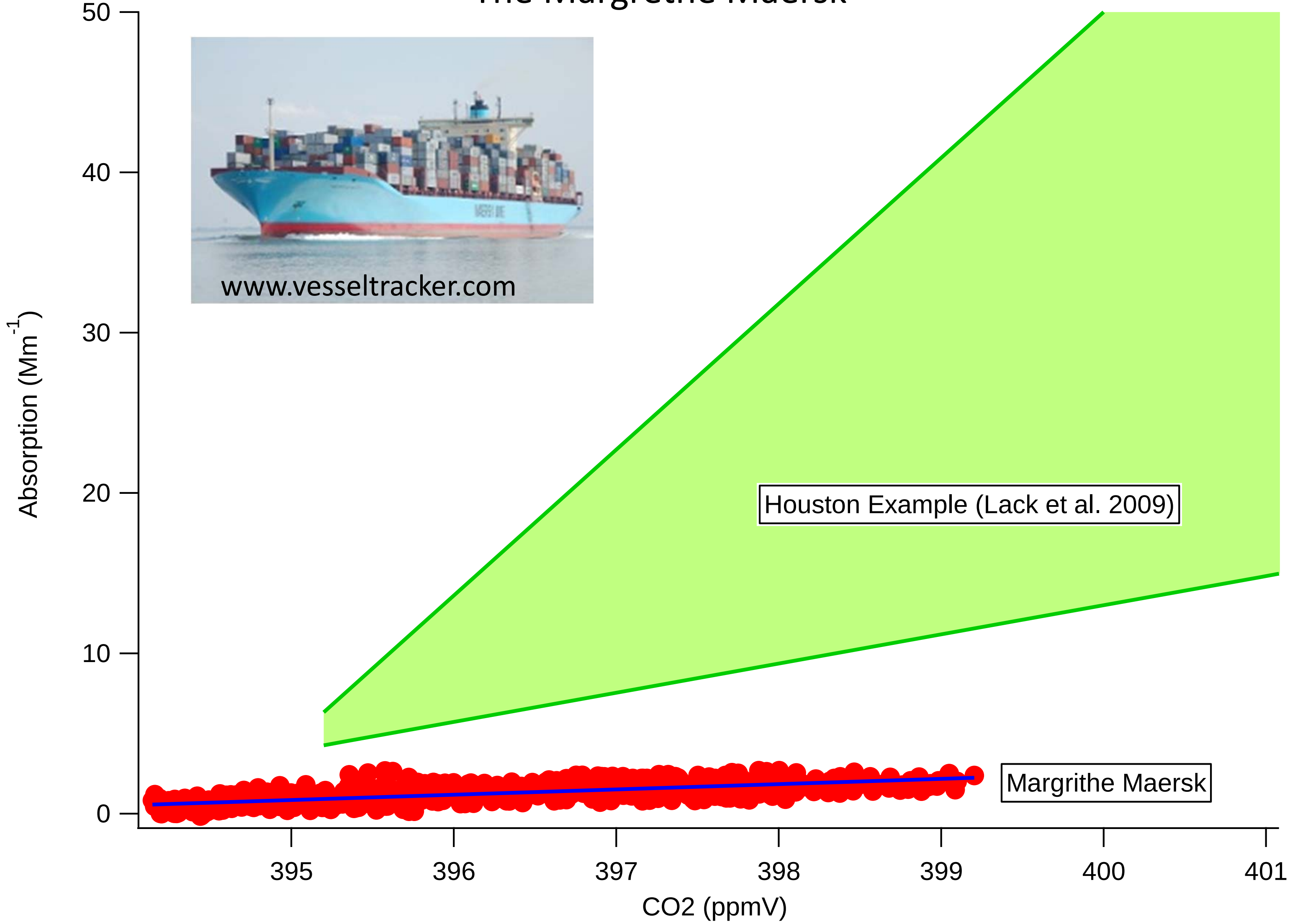
Measuring and Quantifying Ship Emissions

Example for BC emissions factor from a single ship



Measuring and Quantifying Ship Emissions

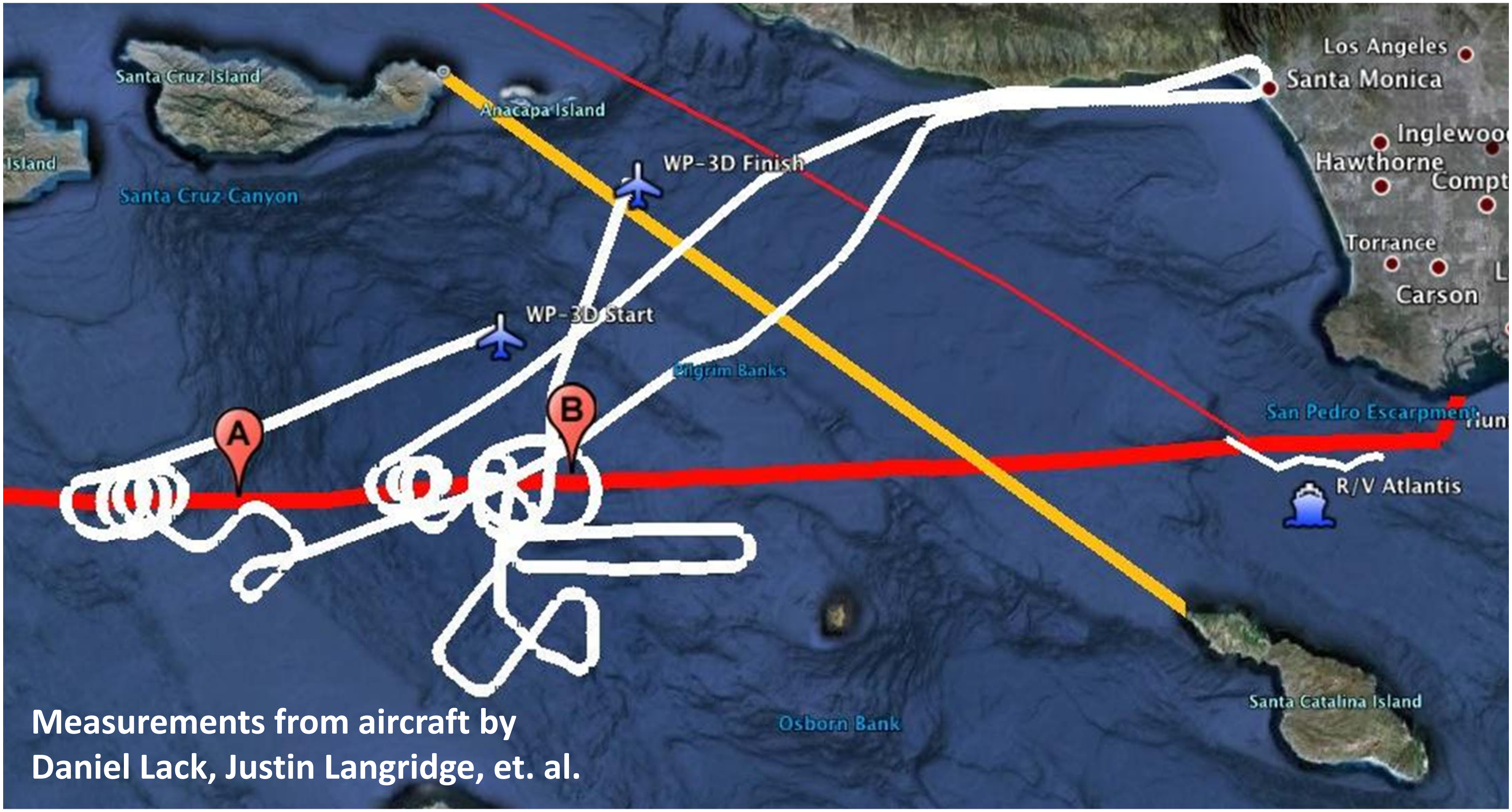
Example for BC emissions factor from a single ship
The Margrethe Maersk



Measuring and Quantifying Ship Emissions

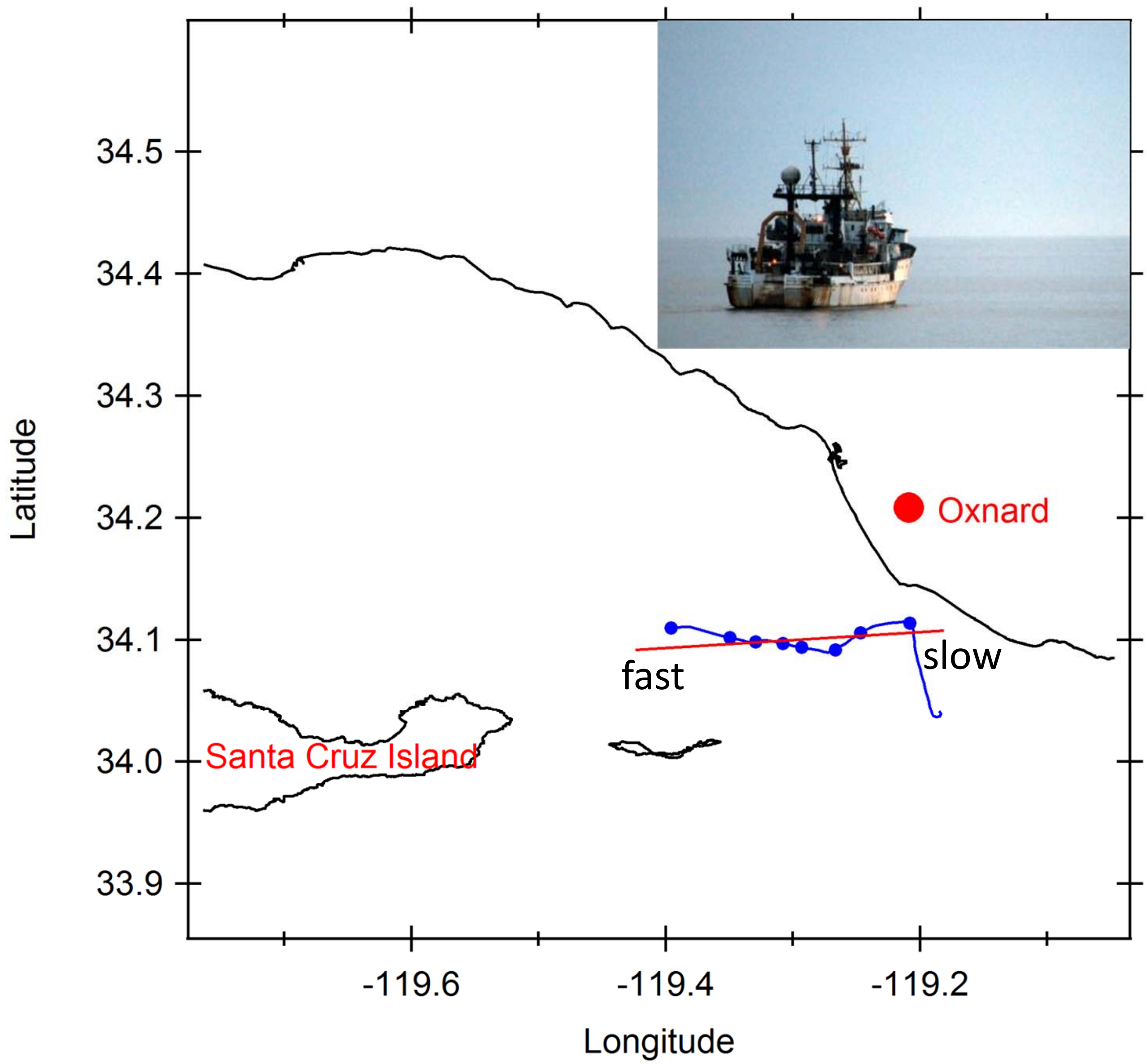
Effects of Changing Fuel Sulfur Content on BC Emissions
The Margrethe Maersk

California ARB requirement for switching to low-sulfur fuel within 24 nautical miles of shore



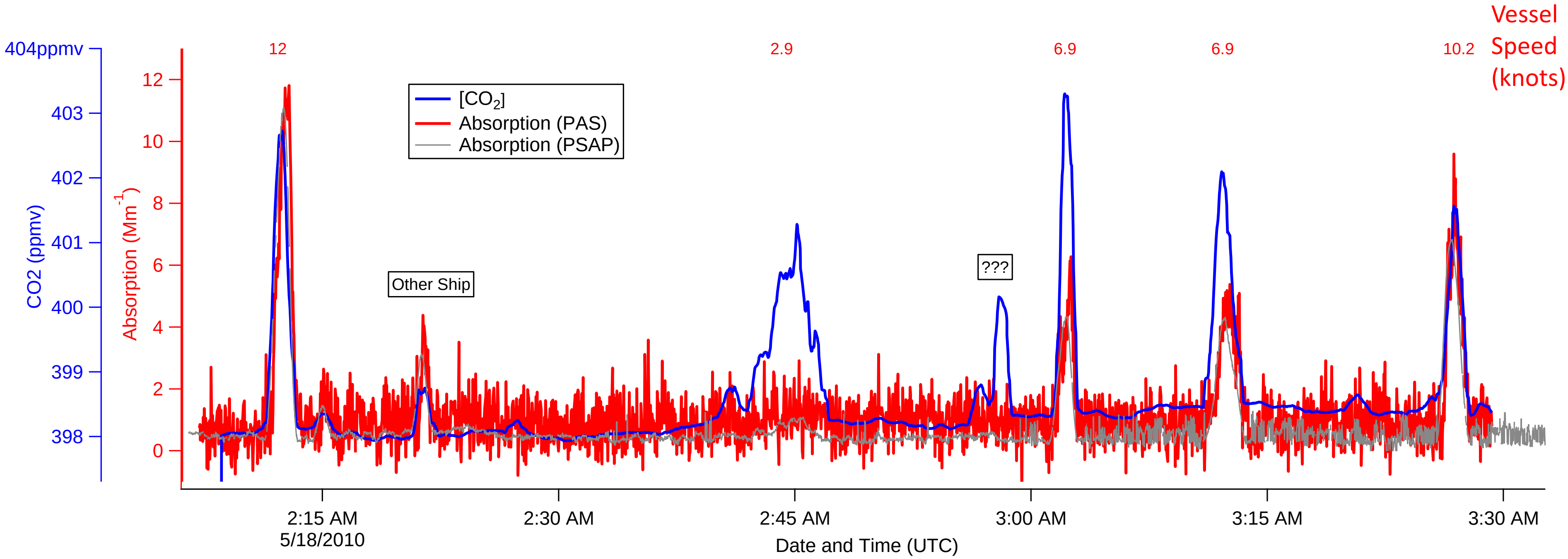
Measuring and Quantifying Ship Emissions

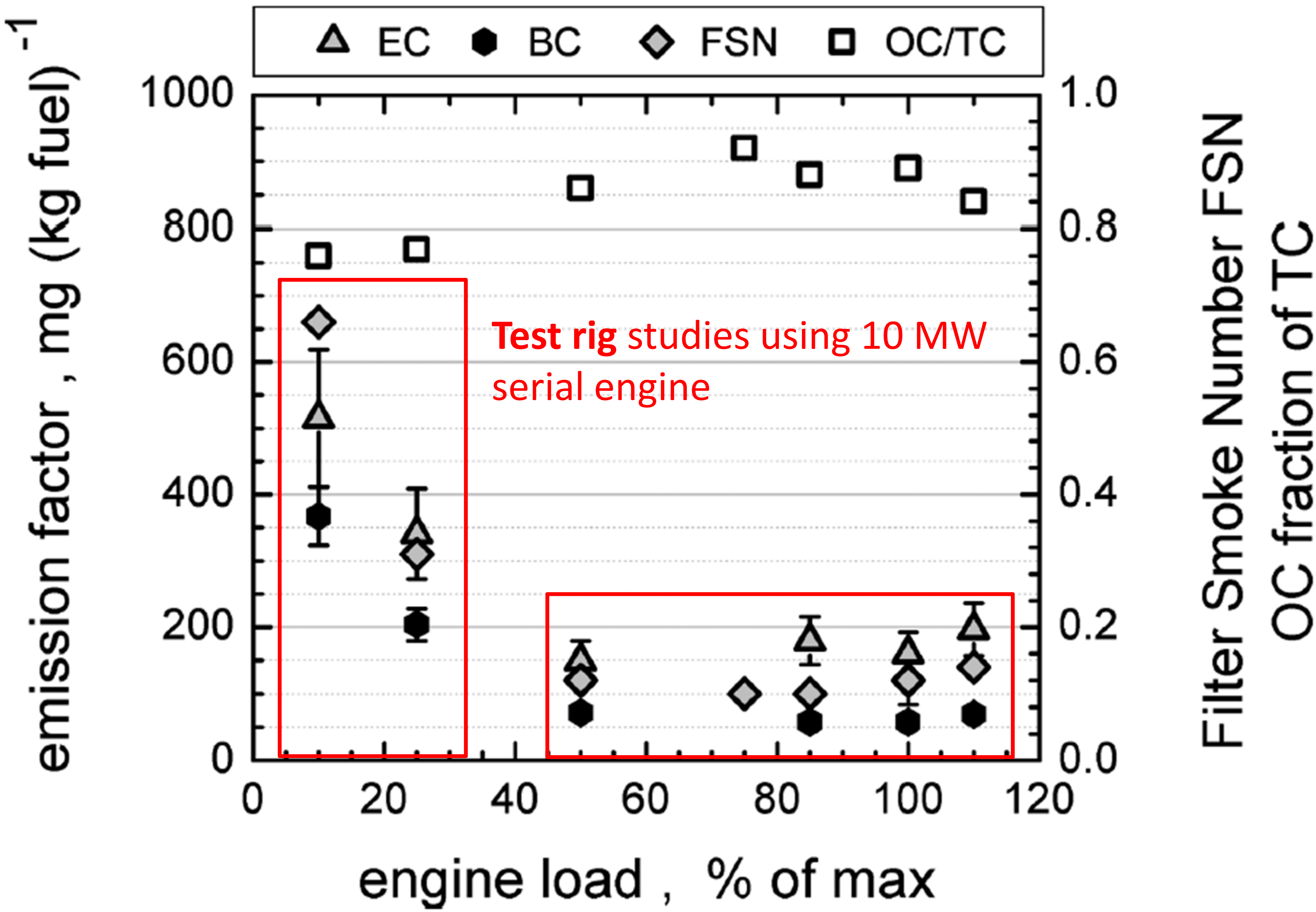
Effects of Changing Ship Speed on BC Emissions
The Miller Freeman



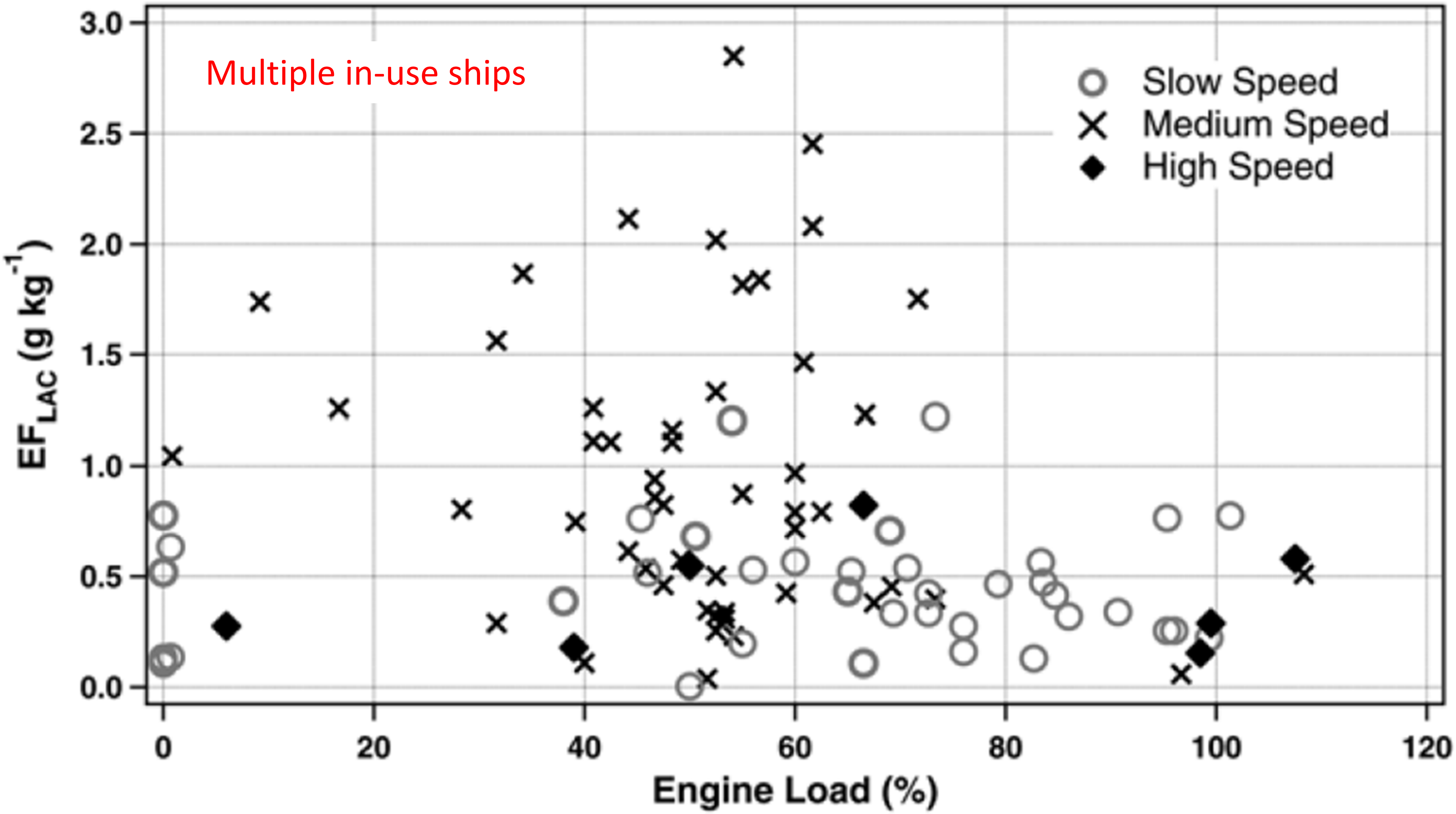
Measuring and Quantifying Ship Emissions

Effects of Changing Ship Speed on BC Emissions
The Miller Freeman





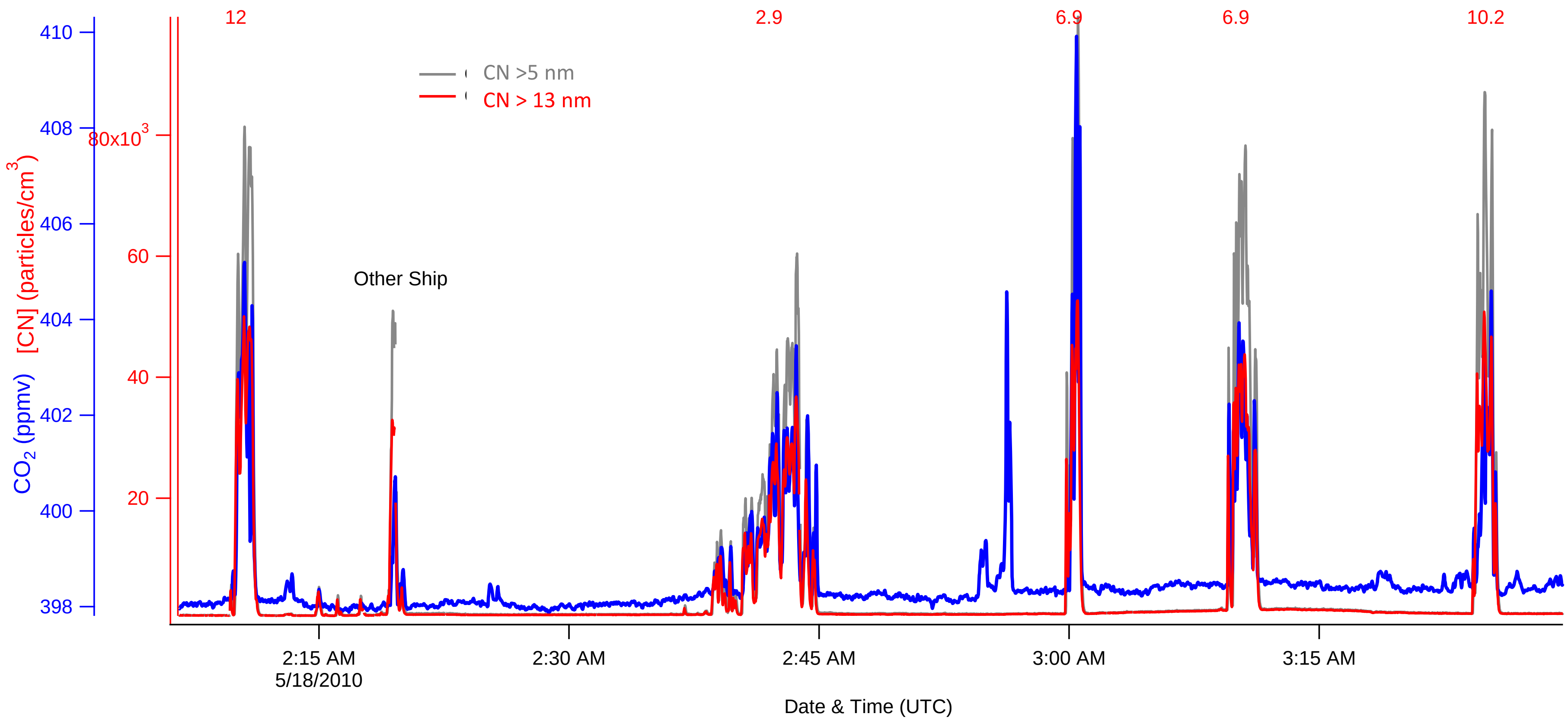
[Petzold et al., *ES&T*, 2010]



[Lack et al., *GRL*, 2008]

Measuring and Quantifying Ship Emissions

Effects of Changing Ship Speed on CN Emissions
The Miller Freeman



Conclusions and Future Work

1. Measurements of aerosol physical, chemical and optical properties were made during CalNex 2010
2. ca. 50-100 individual ships were encountered
3. Characterization of specific case-studies is underway
    1. BC emissions decreases with fuel sulfur content?
    2. BC emissions increases with vessel speed.
    3. Particle number unaffected by vessel speed.
    4. CCN activity
5. Next Steps: build statistics on BC emissions from different ships
6. Take advantage of other measurements to fully characterize case studies w.r.t. composition, size, etc.

This research is funded by
U.S. EPA - Science To Achieve Results (STAR) Program
Grant # RD833558