# Ballast Water Exchange Verification: Discrimination Using Chemical Characteristics of Oceanic Water

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# Aims

**Identify** characteristics that reliably discriminate between ballast water of coastal vs. oceanic origin.

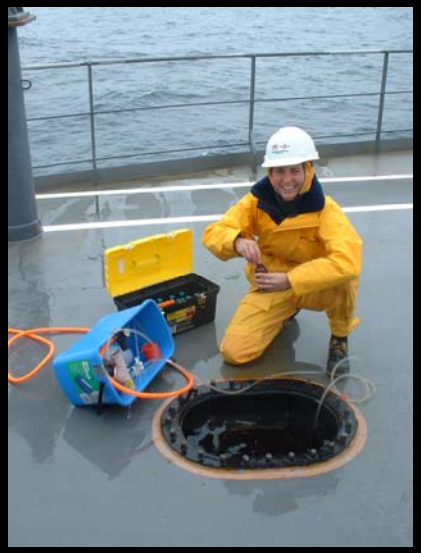
**Inform** the development of an in-situ (field) instruments for BWE verification.

**Tracer Qualities:**

- Unambiguous discrimination between coastal and oceanic water
- Robust to potential contaminants from ships and tanks
- Easily and reliably measured in ships
- Stable over time in ballast tanks
- Consistent results for varying source and exchange regions

# Potential tracers of mid-ocean exchange

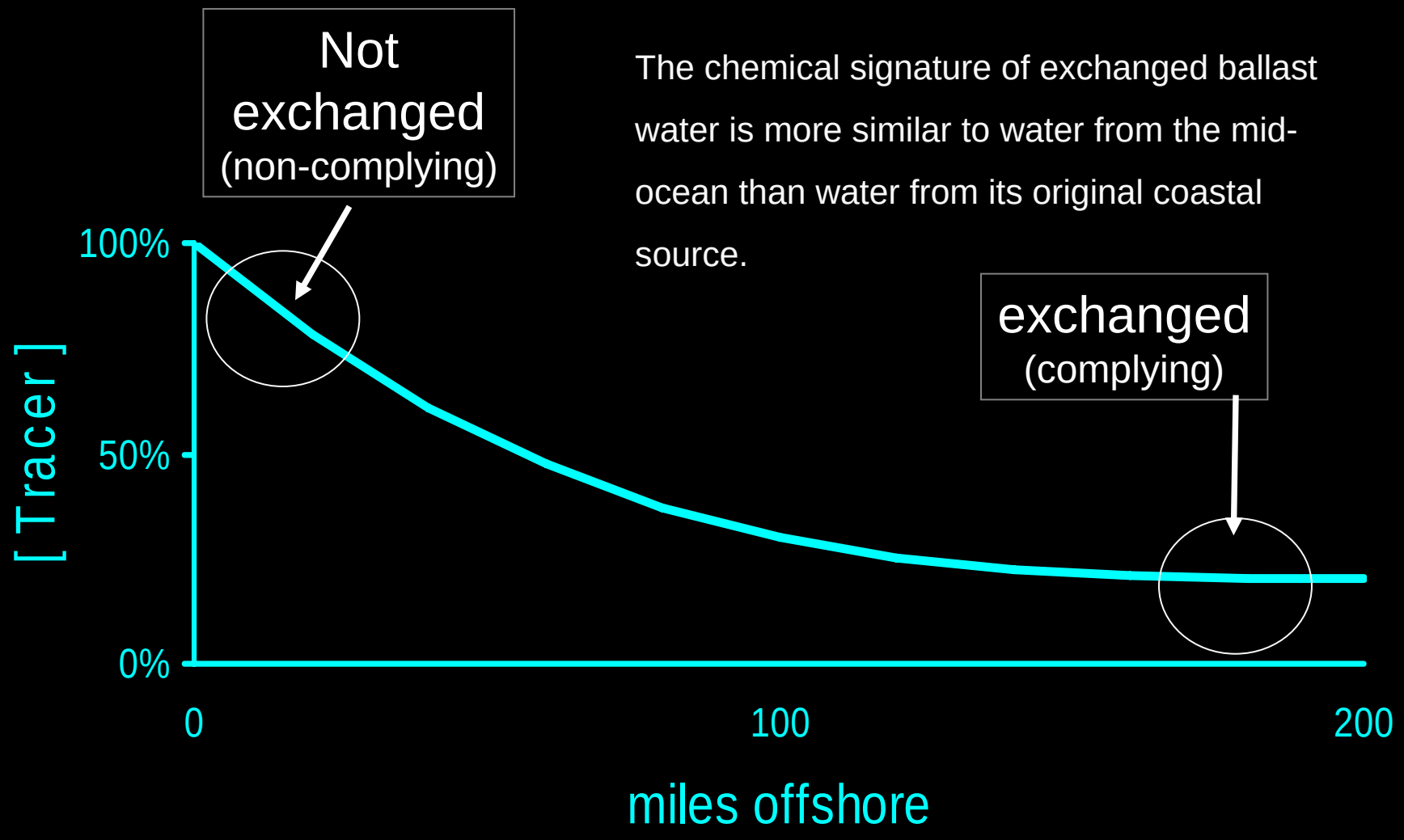
**Biological tracers (plankton)**
BUT –
difficult to identify
difficult to quantify
populations vary greatly in space and time



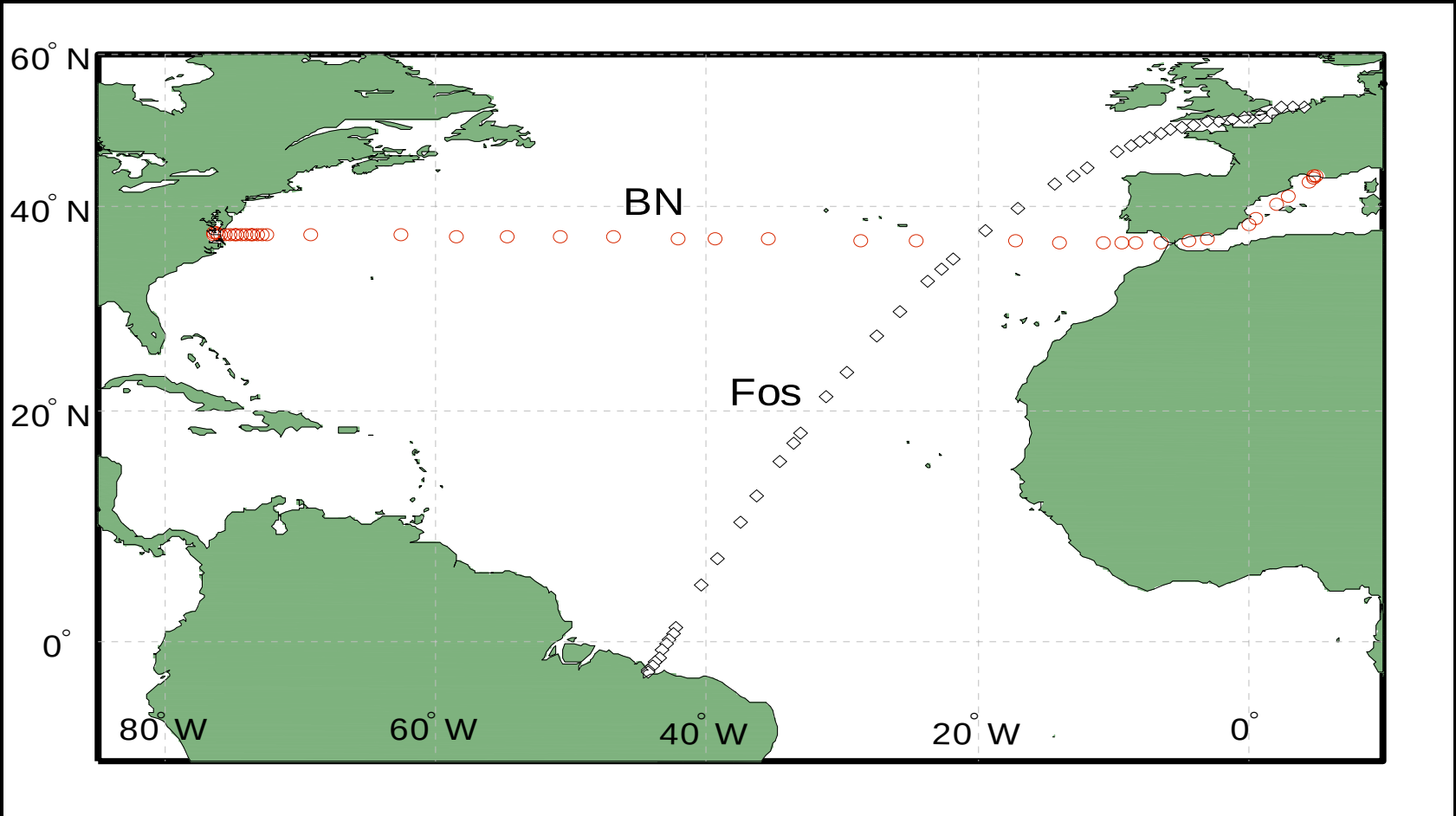
**Chemical tracers**
easier to quantify
distribution easier to predict, both
* within ballast tanks
* globally

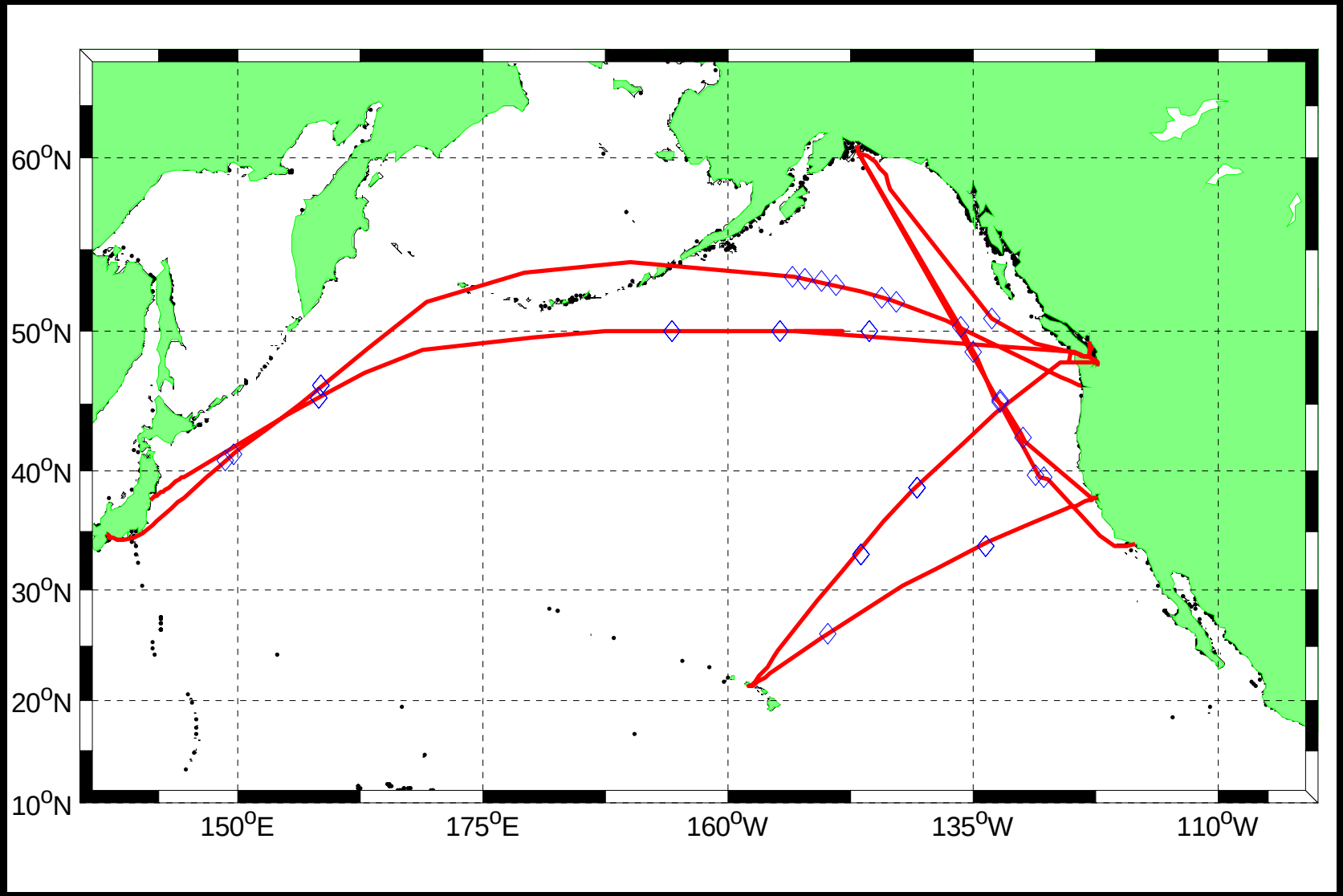
# Hypothesis

The chemical signature of exchanged ballast water is more similar to water from the mid-ocean than water from its original coastal source.



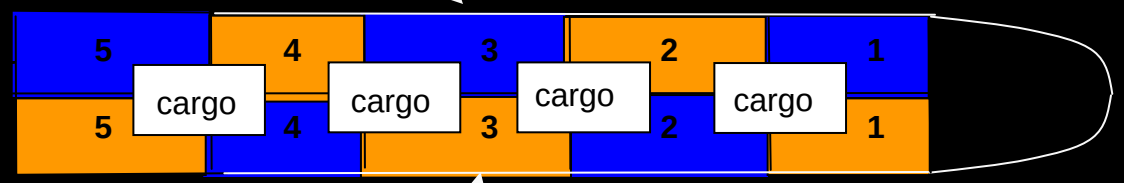
# Cruise Tracks: N. Pacific & N. Atlantic




60°N
50°N
40°N
30°N
20°N
10°N
150°E
175°E
160°W
135°W
110°W

# Experimental Design

**1. CONTROL = not exchanged**




**2. TREATMENT = exchanged**

**3. SHIPSIDE = Ocean Reference Set**

# Objective

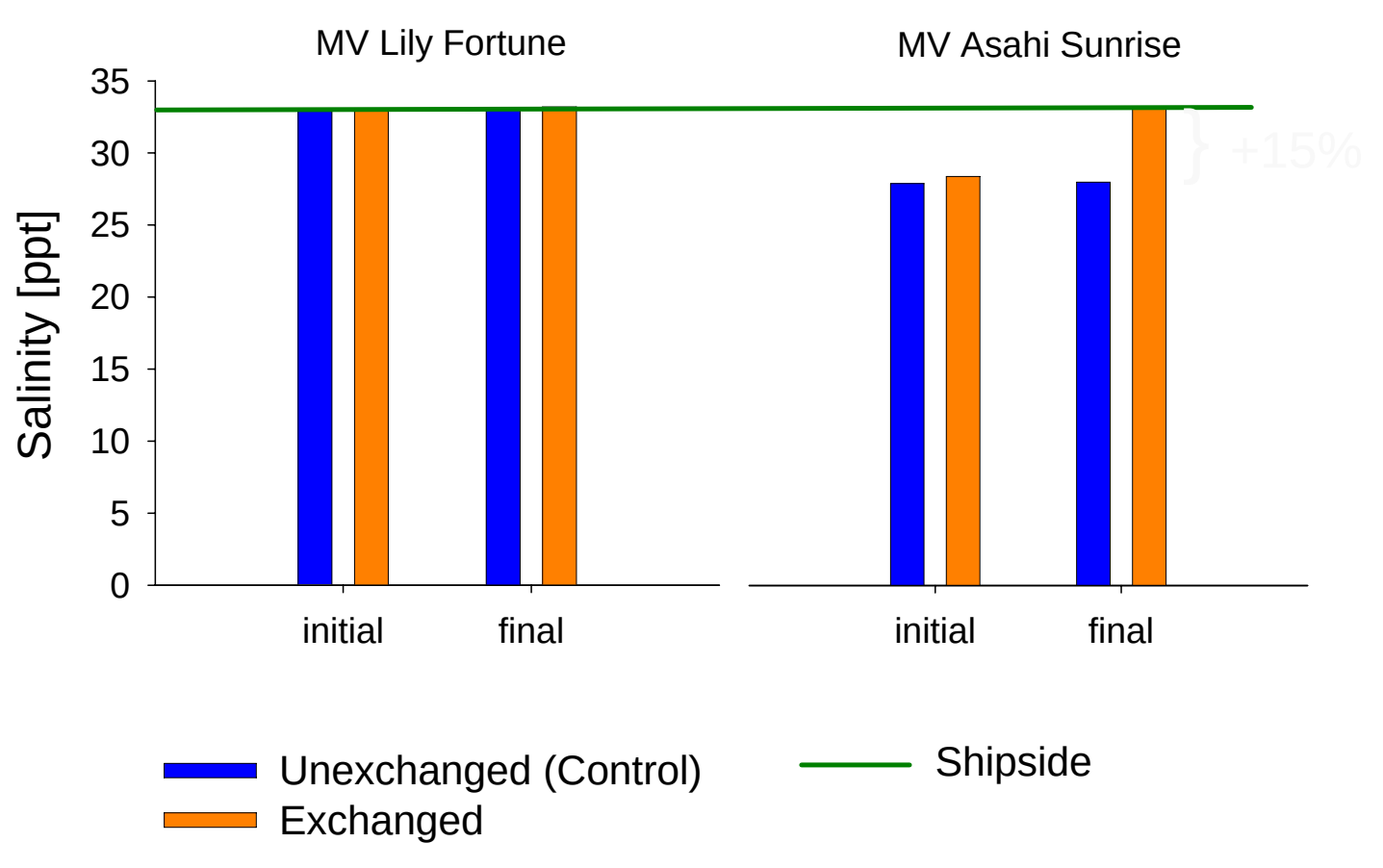
Identify tracers that, alone or in combination, reliably discriminate between ballast water of coastal vs. oceanic origin.

## Tracers:

- Salinity
- Radium ($^{223}Ra$, $^{226}Ra$, $^{228}Ra$)
- Trace elements (Ag, Ba, Mn, Mo, P, U, V)
- CDOM fluorescence signatures

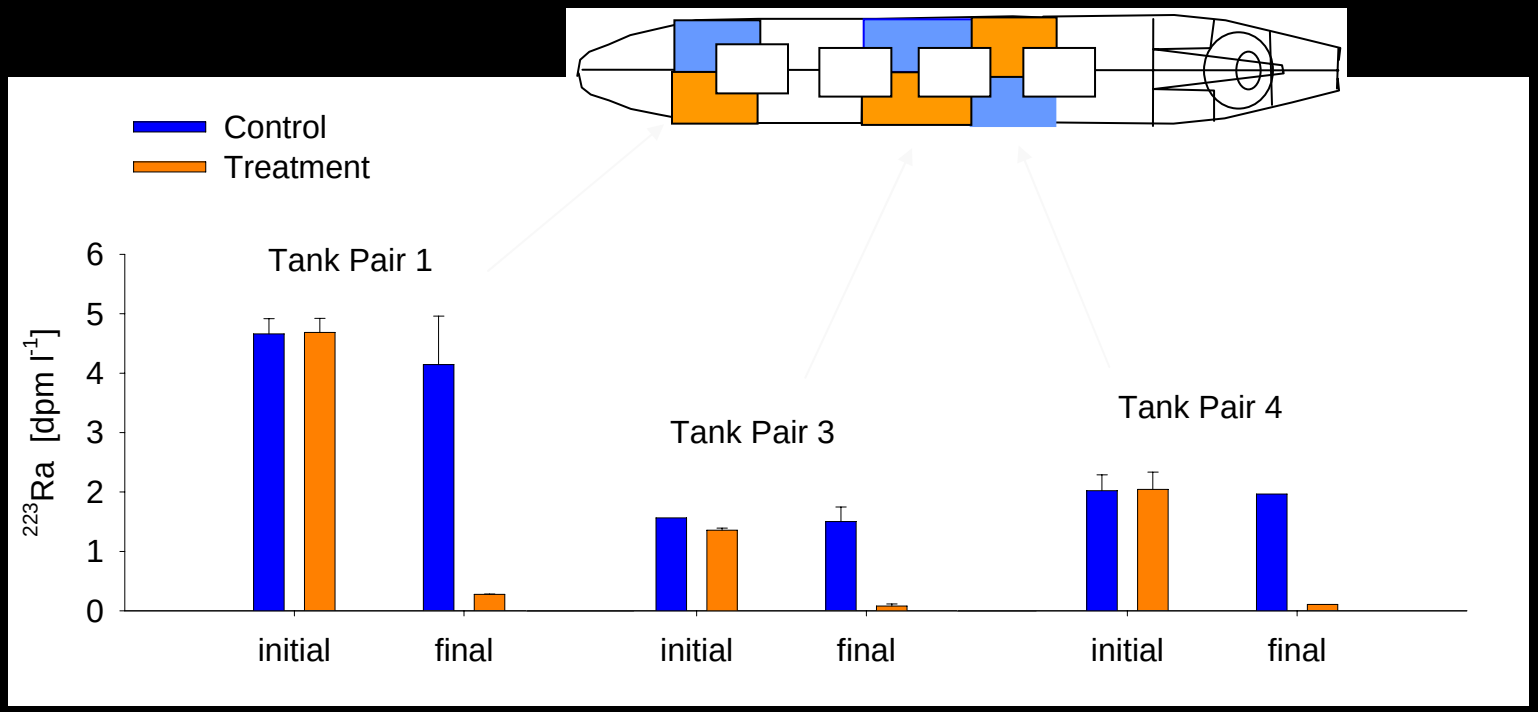
  (chromophoric dissolved organic matter)

# Results: Salinity

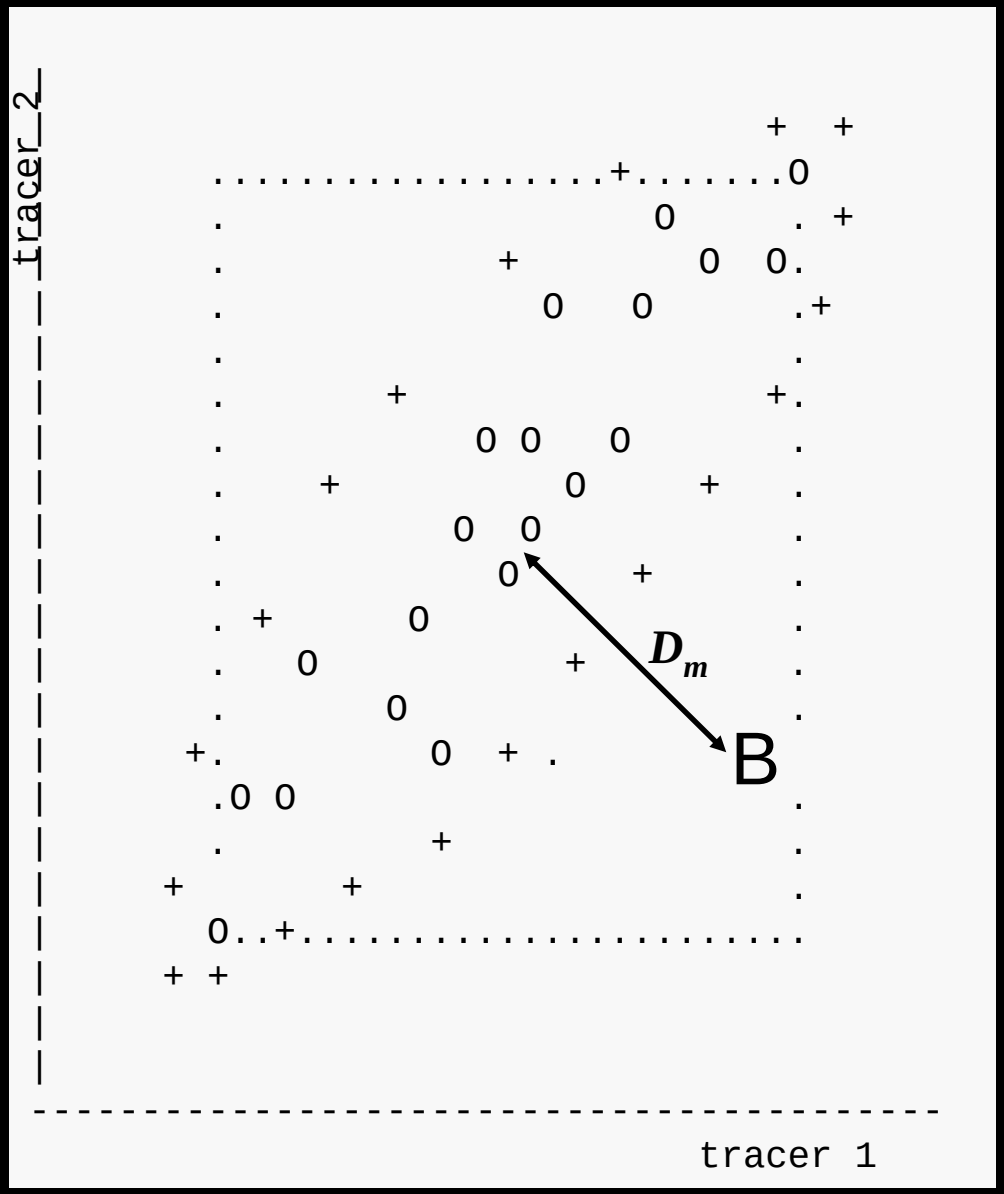


# Results: $^{223}Ra$

(Data from "MV *Asahi Sunrise*")



# Multivariate Model: Trace Metals




**Define an "ocean reference set"**

$\boldsymbol{x}$ = tracer mean in open ocean

S = tracer covariance matrix

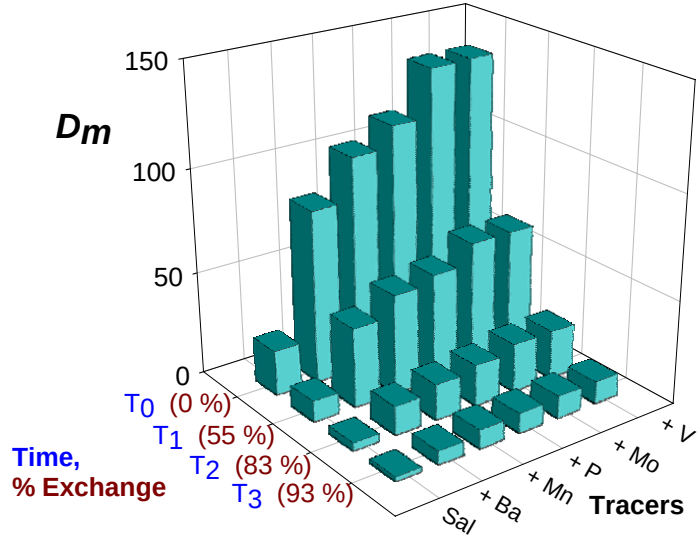
**Compare with ballast water samples**

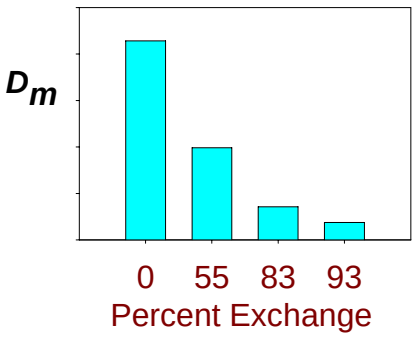
$$D_m^2 = (\mathbf{x_i} - \mathbf{x})' \, \mathbf{S}^{-1} (\mathbf{x_i} - \mathbf{x})$$

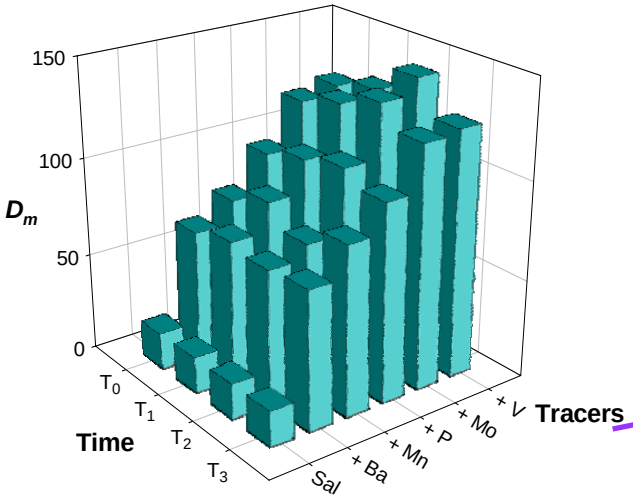
(Mahalanobis Distance Statistic)

# Results: Trace Metals

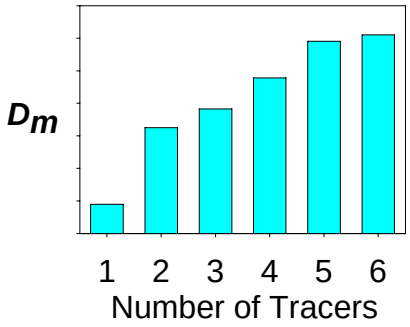
Exchanged Ballast Water



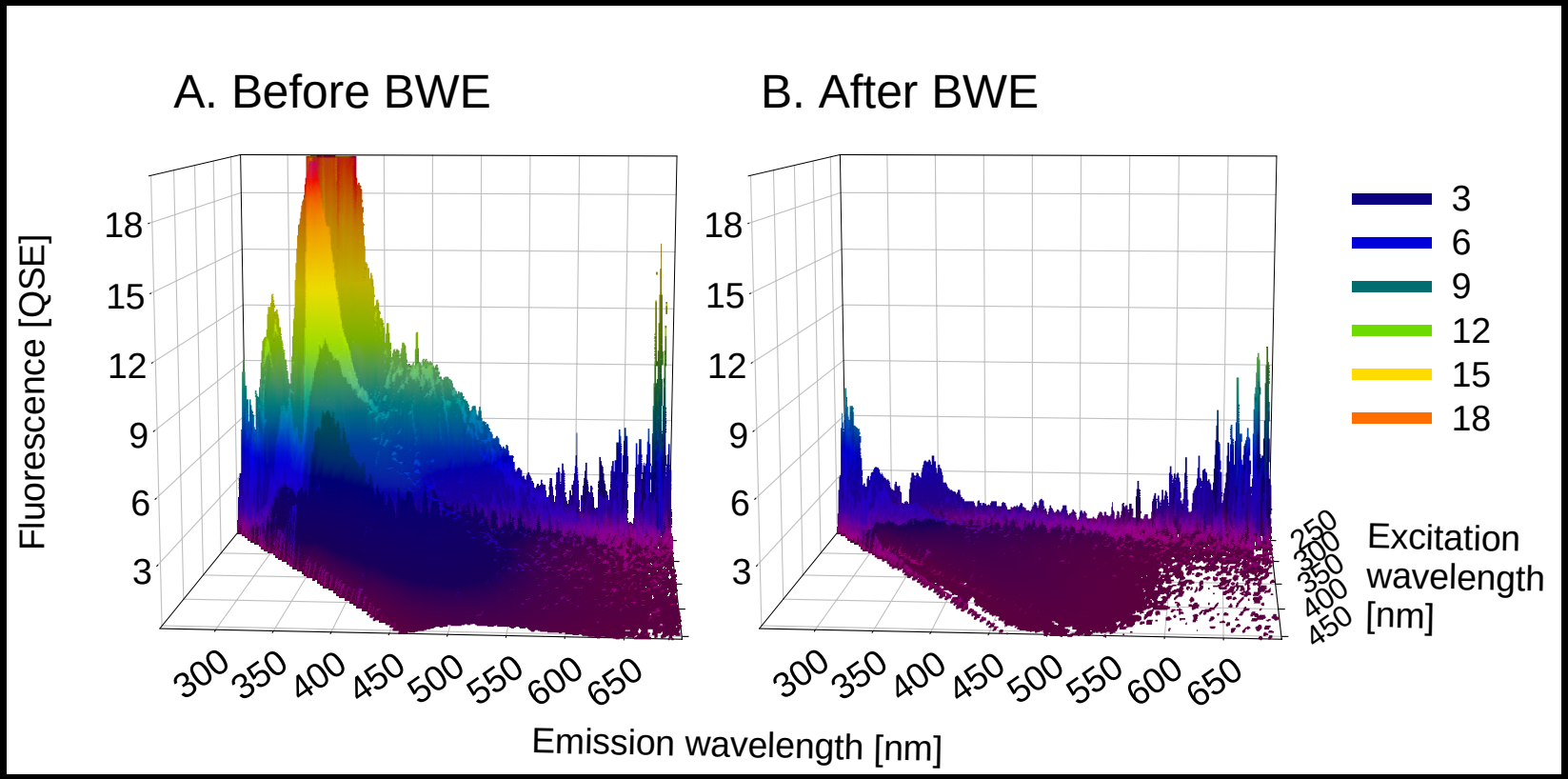




Unexchanged Ballast Water



# Results: CDOM

(Data from "MV *Asahi Sunrise*")



# CDOM Analysis

BWE Experiments on trans-oceanic cruises on commercial ships (N. Pacific & N. Atlantic).

2 treatments (Control, Exchanged) per cruise
3 – 5 ballast tanks per treatment
3 – 5 time-points per ballast tank
2 – 4 replicates per depth

Ocean dataset: 12-30 / cruise

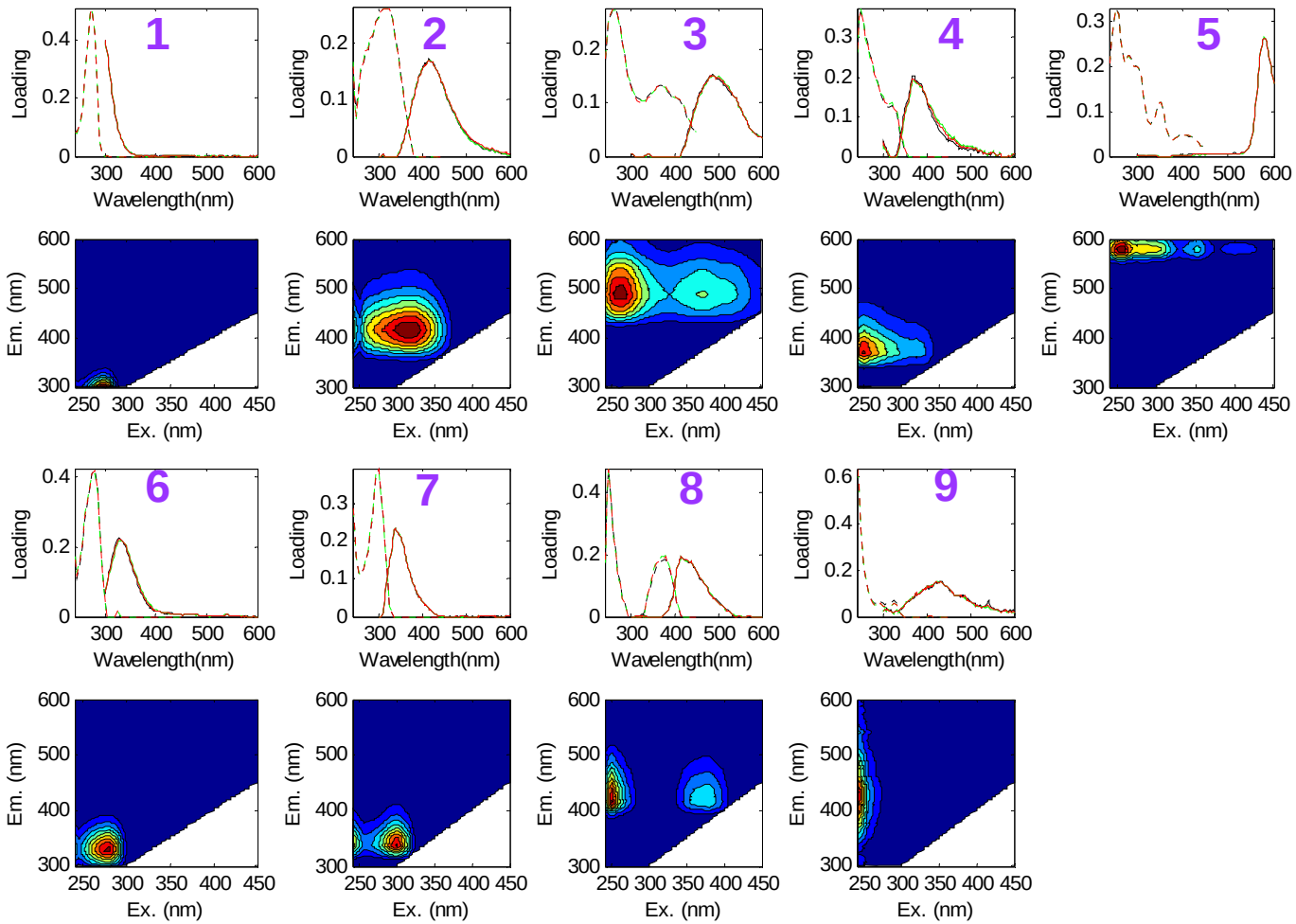
*> 690 samples in database*

Samples collected in amber glass DOM-clean bottles and analyzed at one of 3 analytical labs (i.e. 3 different instruments).

Excitation-Emission Fluorescence Spectroscopy used to generate 'EEMs'.

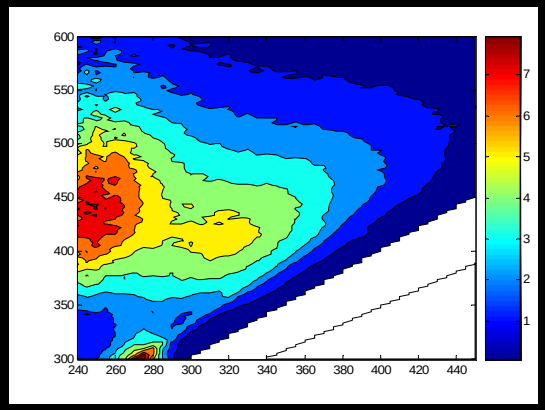
Data Analysis via Parallel factor analysis (PARAFAC)

# PARAFAC – 9 component model



# PARAFAC – Parallel Factor Analysis

**Raw Data**

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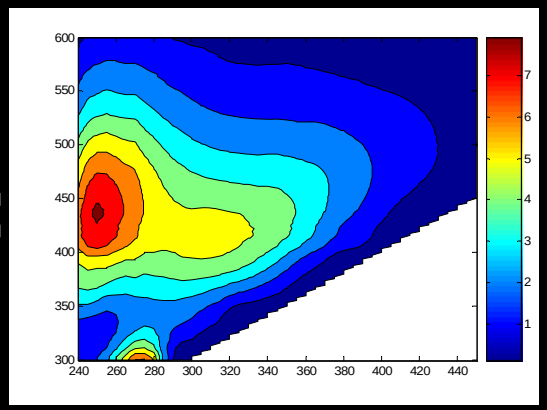
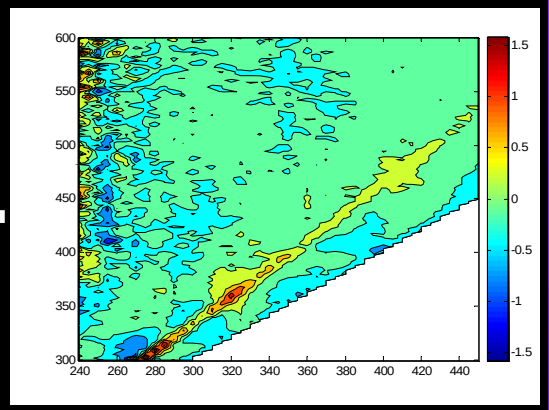
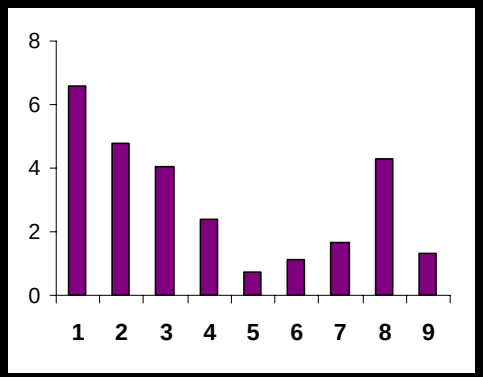
**Model**




+

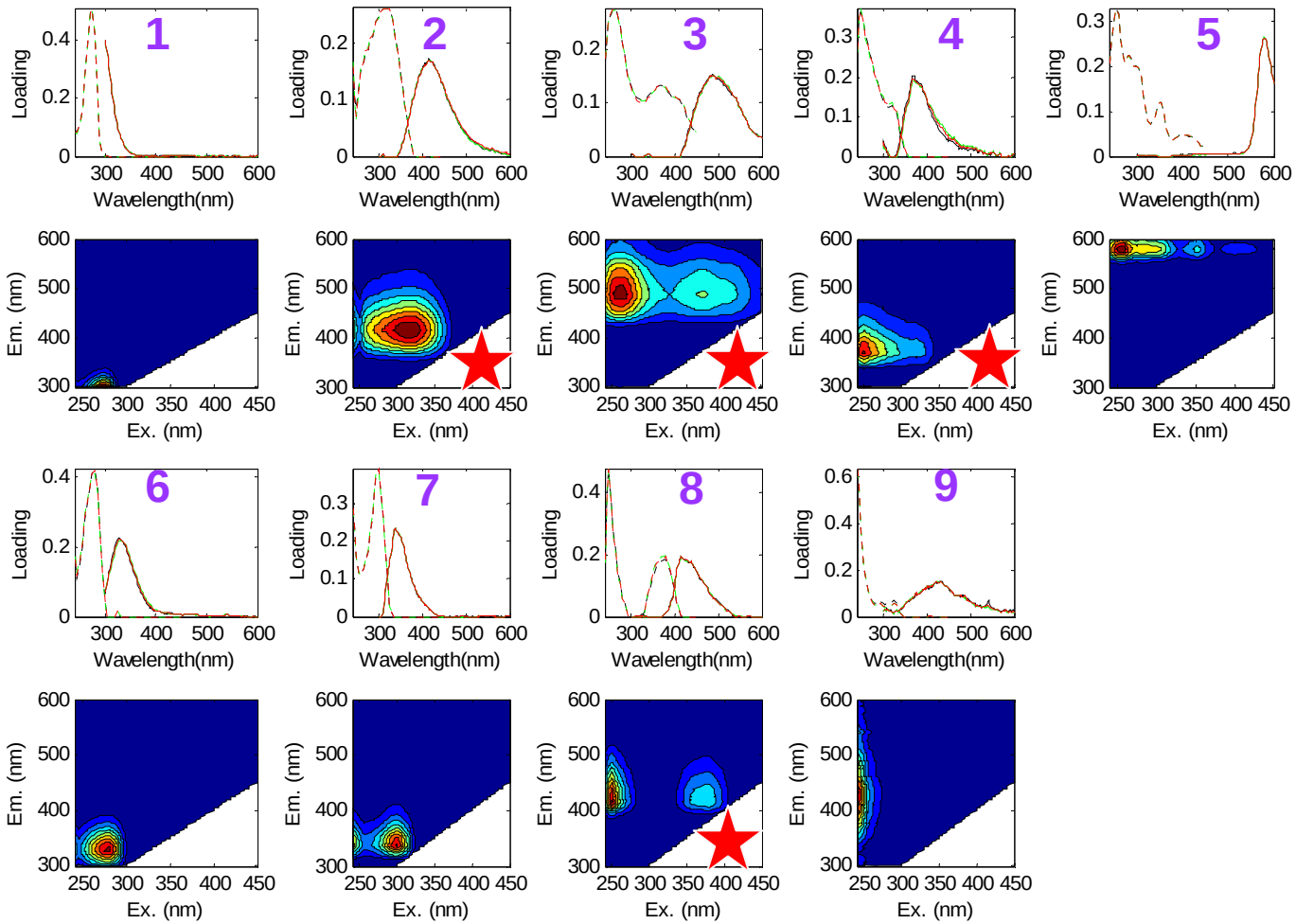
**Residuals**



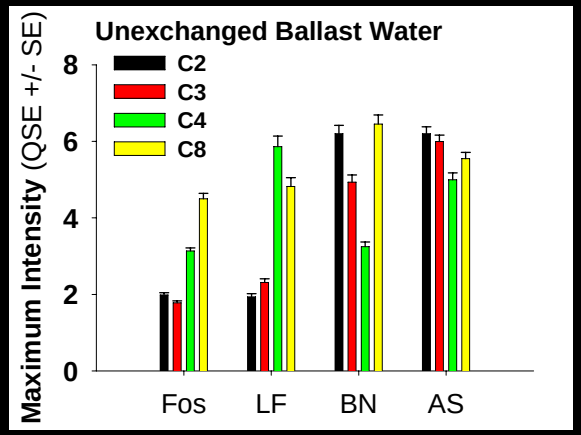




**9 Components**

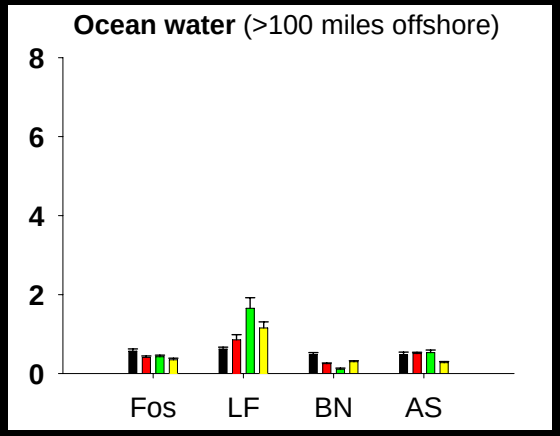
# PARAFAC – 9 component model



# Effect of Ballast Water Exchange

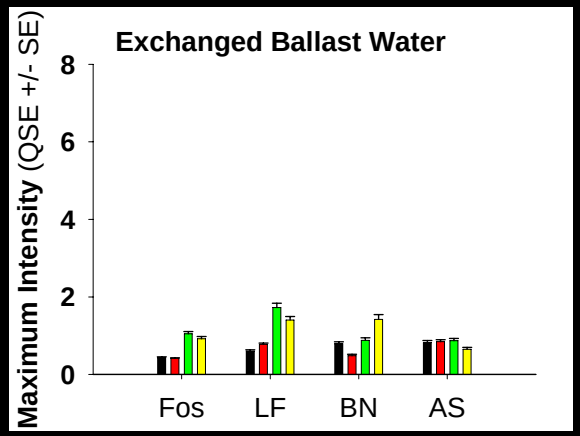



salinity: 36 33 30 27



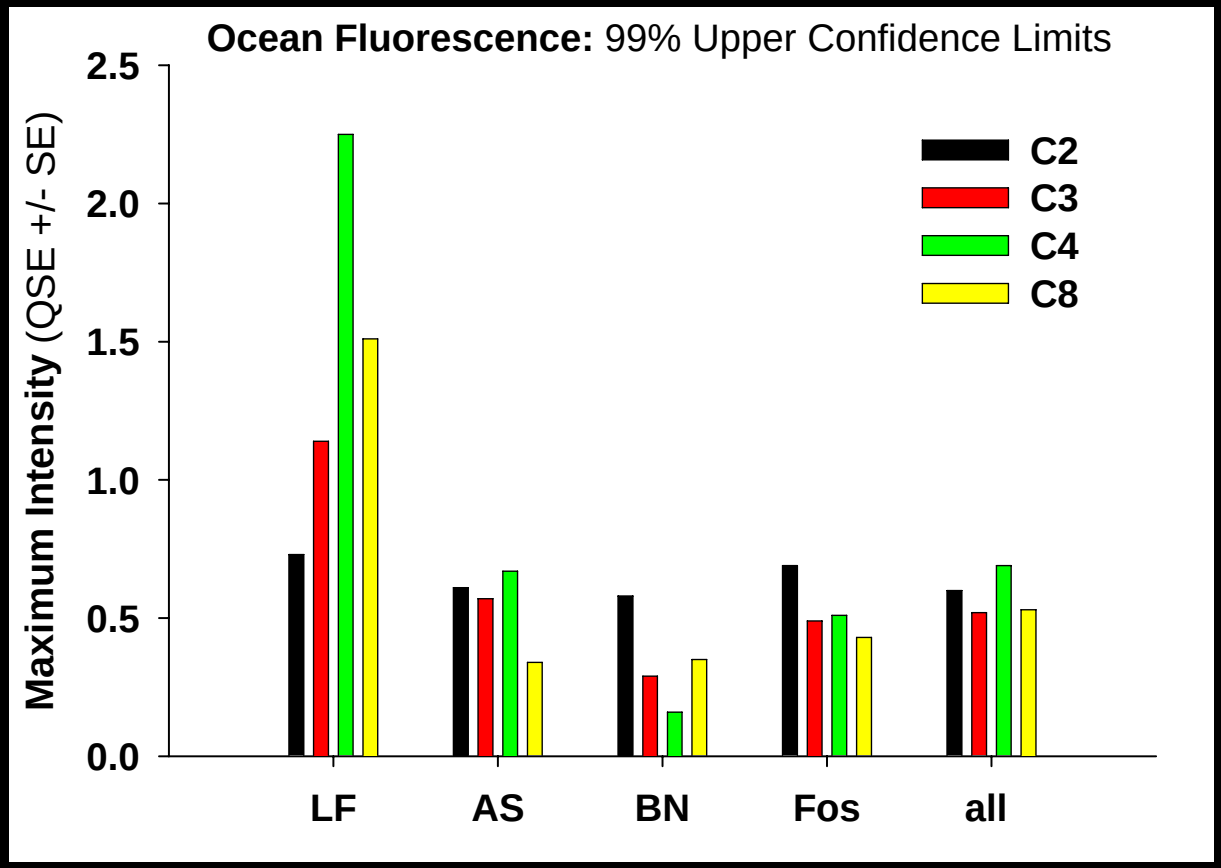

salinity: 36 33 36 33

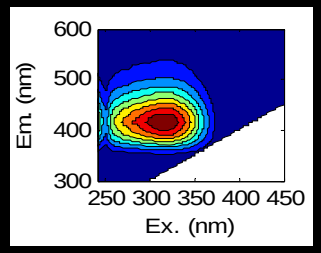
- BWE greatly reduces concentrations of fluorescent components
- Exchanged CDOM > Ocean CDOM
- Signatures from all high salinity sources are similar



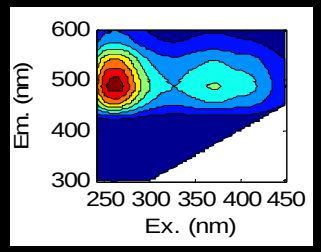

salinity: 36 33 36 33

# Is fluorescence predictable in the ocean?

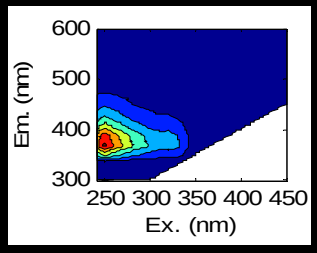


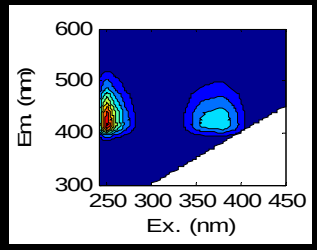

C2




C3

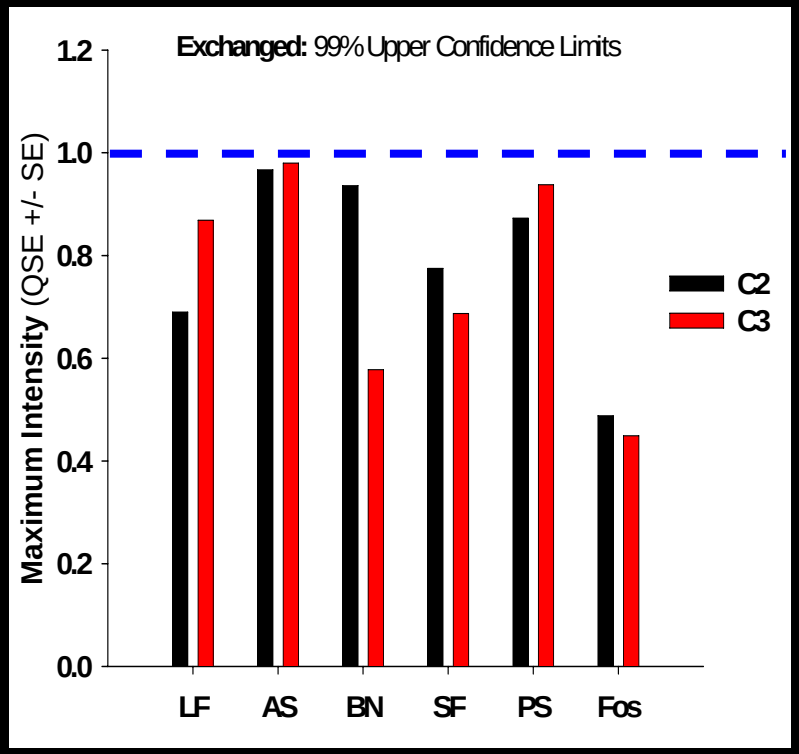


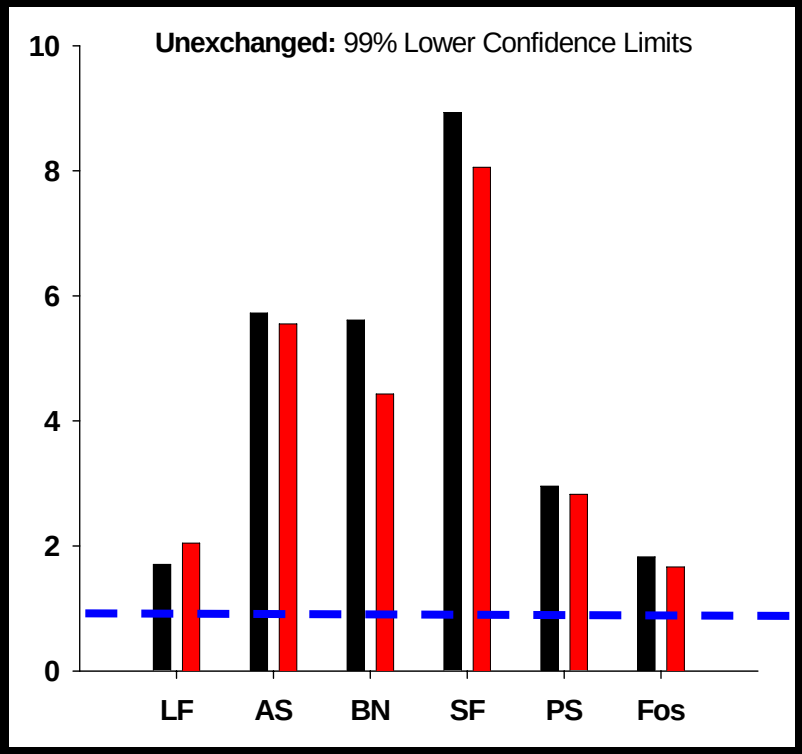

C4

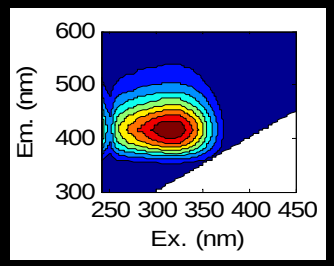



C8

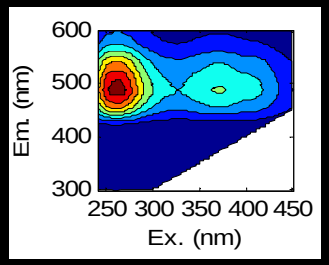
# Is fluorescence predictable following BWE?



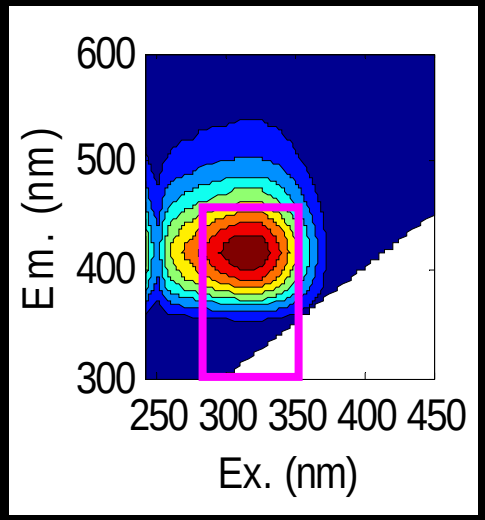




C2

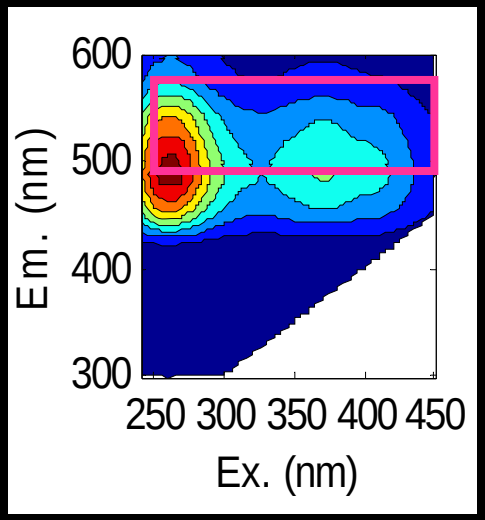



C3

# Design parameters for handheld fluorometers




Component 2




Component 3

# Future Directions

**What are the best tracer sets?**

- Maximize discrimination & minimize noise
- Robust to many sources of variation:
  (e.g. ships, source regions, ocean, residence time..)

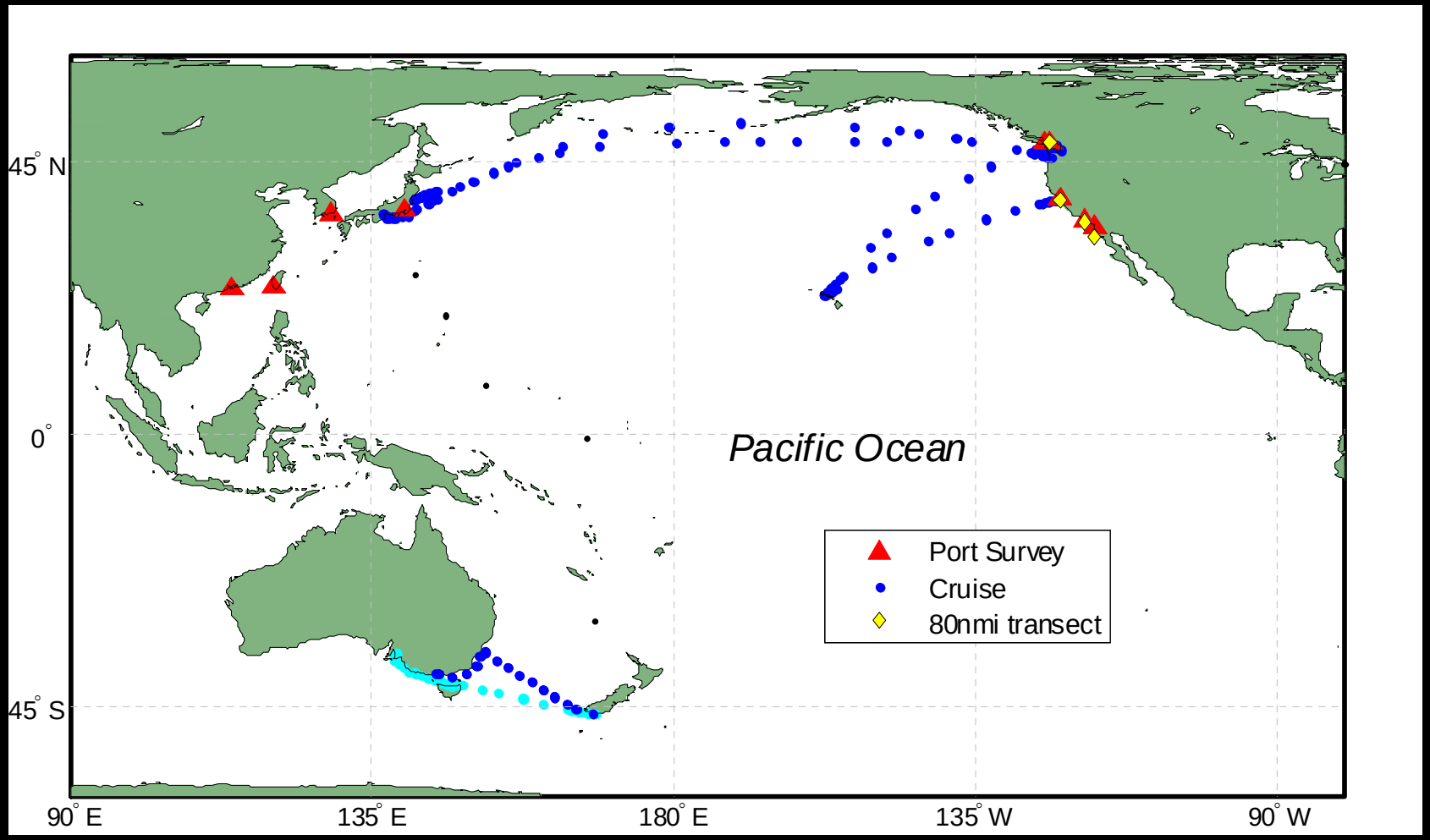
**How robust is approach to different global regions and ports?**

- Collaborative expansion project with Singapore & New Zealand

**How does approach perform for Overseas and Coastwise Traffic to the U.S. Pacific coast, as a Model System?**

- Distance from shore (decay function) – seasonal measures
- Within bay (port) variation – seasonal / spatial measures

# Pacific Basin as a Model System



# Acknowledgements


Host Shipping Companies:

•NYK Bulkship (USA) LTD., Gateway Maritime Corp. / Sincere Industrial Corp., Matson Navigation Company, Bergesen DY ASA., Sea River Maritime, the Alaska Tanker Company, BP Amoco PLC and Krupp Seeschiffahrt GmbH

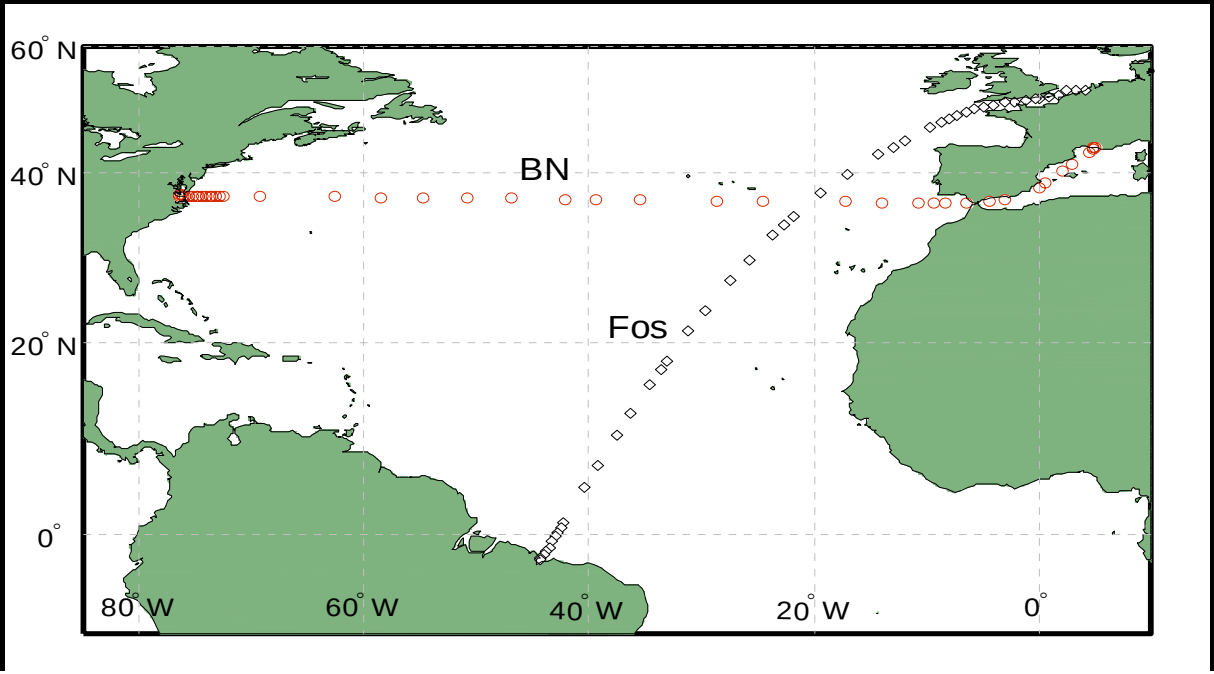
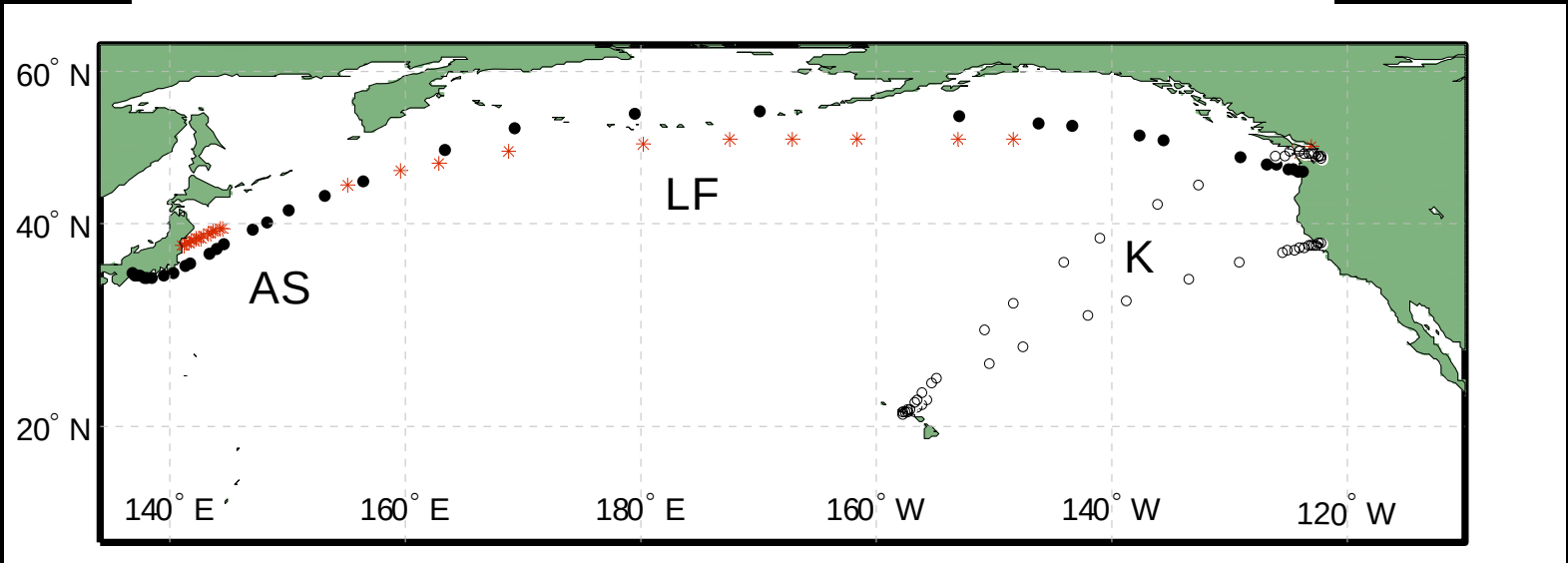
CDOM Analysis:

- University of S. Florida (P. Coble, R. Conmy)
- University of Maine (J. Boehme)
- Denmark National Environmental Research Institute (W. Martinsen)

PARAFAC:

- Denmark National Environmental Research Institute (C. Stedmon)
- Denmark Royal Veterinary and Agricultural University (R. Bro)

**Sponsors:**

- California State Lands Commission
- National Sea Grant Program
- New Zealand Government (MAF)
- U.S. Coast Guard

# Cruise Tracks: N. Pacific & N. Atlantic