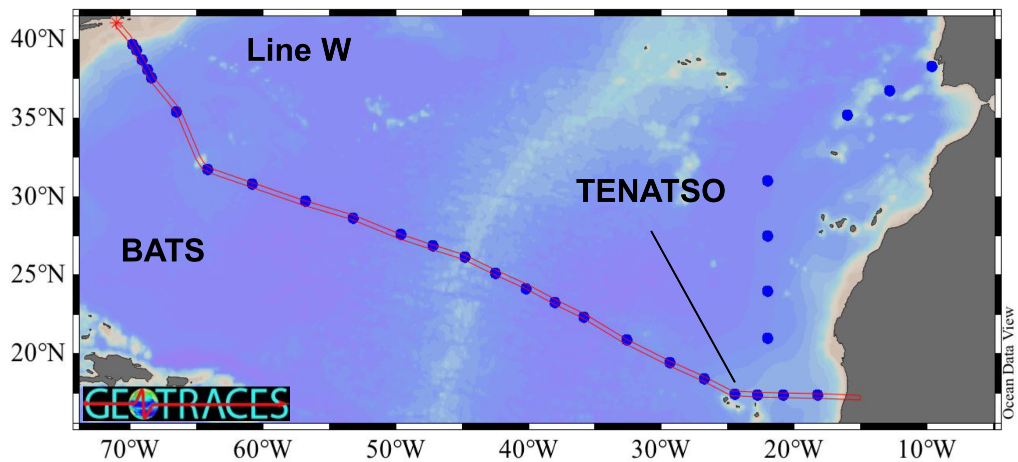
U.S. GEOTRACES North Atlantic Cruise (2010-2011)

A Progress Report in 25 minutes or less…



Outline

- **Introduction**
- Overview of results so far
- Two vignettes

Outline

- Introduction
  - **An apology**
  - Program/cruise objectives
  - Strategy & implementation
- Overview of results so far
- Two vignettes

An Apology

- I am presenting the hard work of many, many people
- I am not a card-carrying T-M chemist
  - any errors in presenting this are mine alone
- I have been given an impossible task
  - Too much to cover in too little time
  - Incomplete data sets (too early)
  - No modeling/synthesis yet

This presentation + all slide contributions from P.I.s available on laptop in Foyer

GEOTRACES

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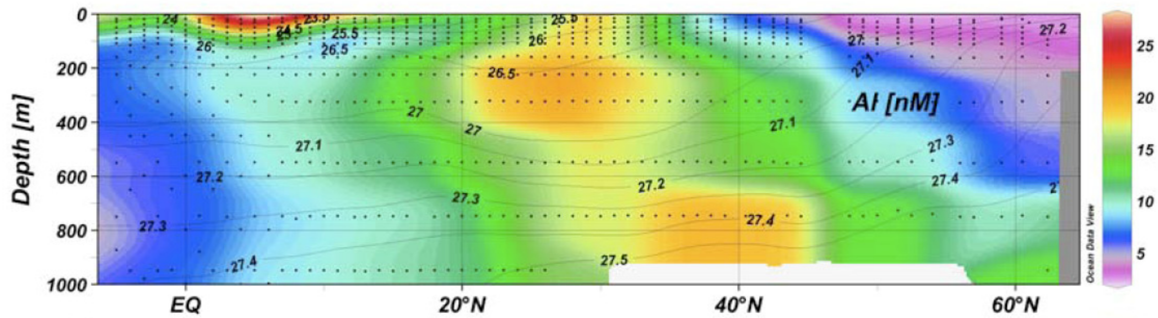
NSF



Program/Cruise Objectives

- To identify processes and quantify fluxes of key trace elements and isotopes (TEIs) in the ocean
  - That play a role in the global carbon cycle
  - That are diagnostic of biological, chemical, and geological marine processes
- To determine the global distributions of these TEIs (because very little is known)
  - Large-scale maps/inventories
  - Critical regions and boundaries/interfaces

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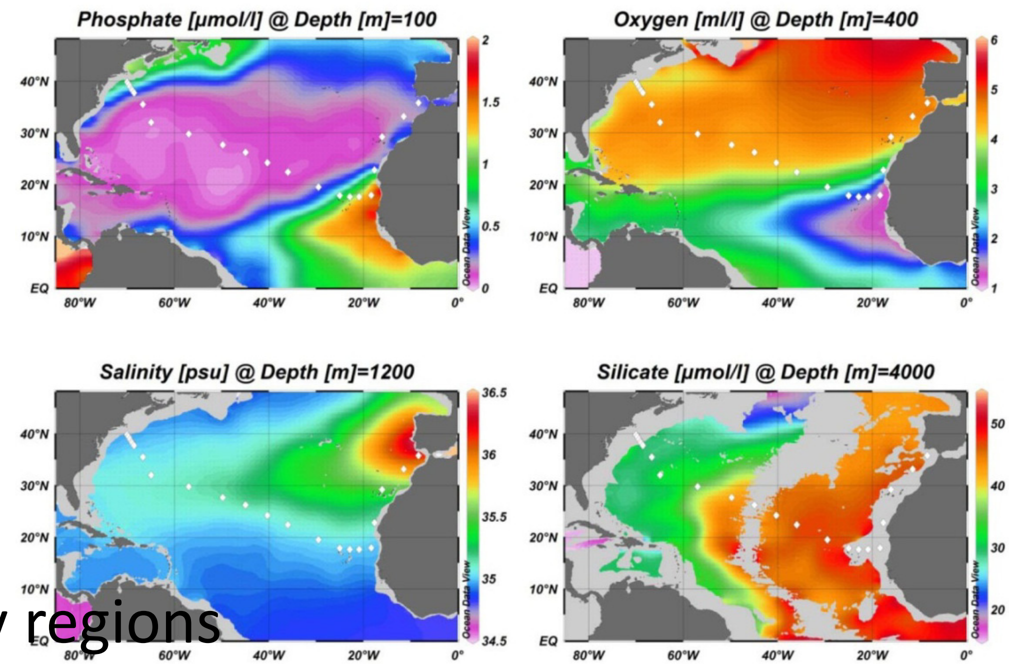
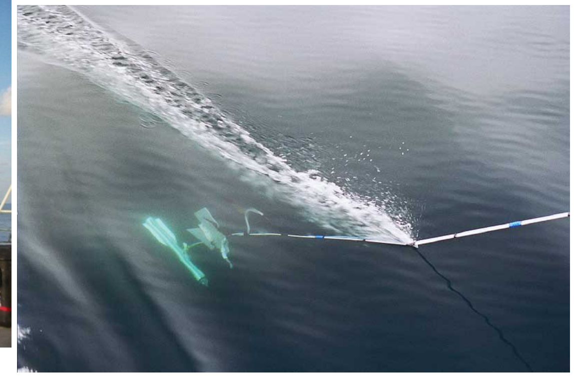
Strategy



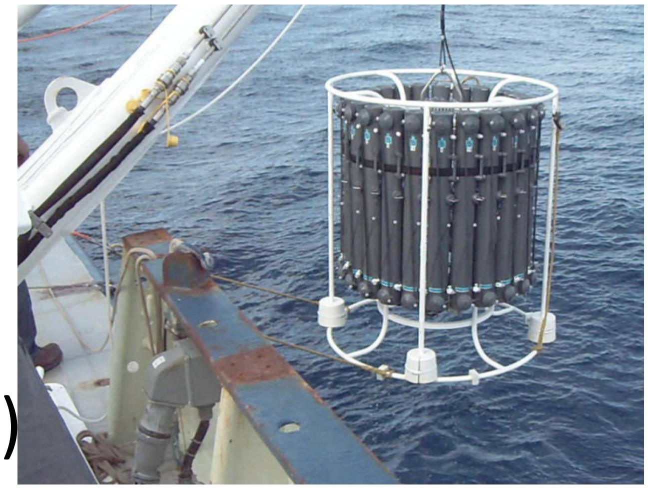
- Global “mapping” and key regions
  - Documenting water masses & biomes
  - Redox contrasts (*e.g.,* Mauritanian OMZ)
  - Hydrothermal venting (*e.g.,* TAG)
  - Ocean margins & interfaces
- Measure the key TEIs and their speciation
  - As a complete suite, all at the same time
  - Measure the ancillary properties/tracers
    - That give the rates and fluxes, all at the same time
  - A uniform, high quality, consistent data set
    - Including good hydrography, CTD, metadata

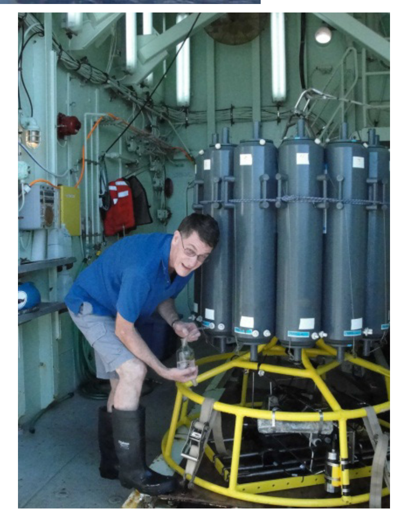
GEOTRACES

Implementation



- Multiple sampling systems:
  - Aerosol sampling
  - Underway TM-clean “fish”
  - T-M clean rosette (24 x 12L)
  - Hydrographic rosette (12 x 30L)
  - Particle pump-sampling
  - And…



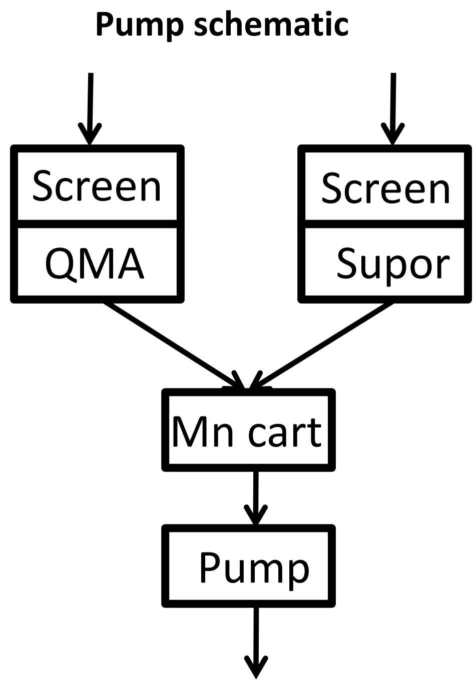


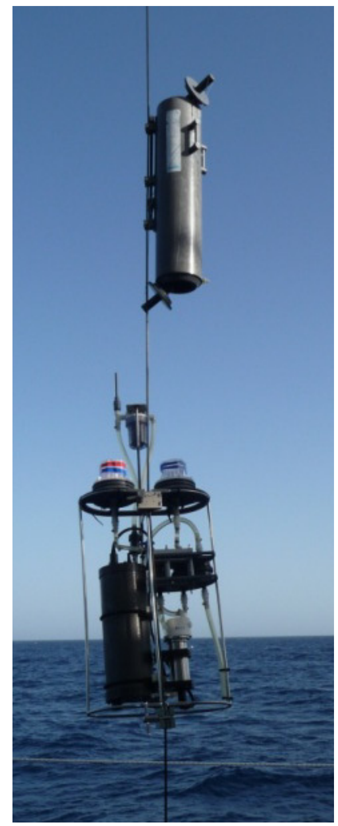
NSF

In Situ pumps – Particles & Diss. Radionuclides

Paul Morris, Phoebe Lam, Dan Ohnemus, Stephanie Owens, Kuanbo Zhou, Steve Pike, Paul Henderson, Matt Charette, Ken Buesseler, Billy Moore

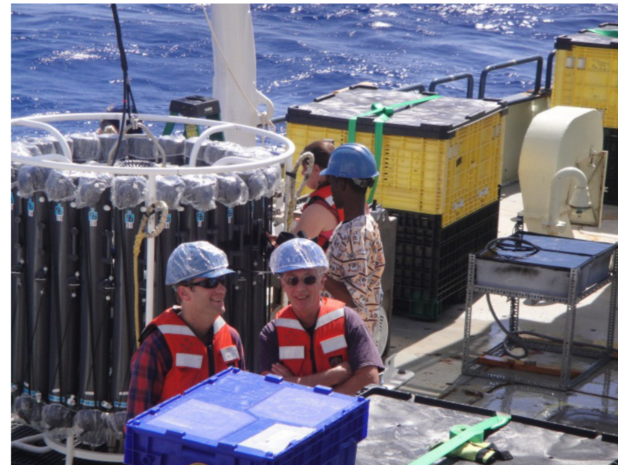
- In situ pumps fitted dual flow filter heads and a Mn-sorption cartridge
- Niskin bottles collect ^{226}Ra & ^{234}Th samples to calibrate Mn-cartridge scavenging eff.
- Pump is a modified McLane pump. Modifications are patent pending (Lam & Morris)





Implementation

- 6 chemistry vans on deck
- Intensive use of lab space on the ship
  - Modified internal space (a lot of plastic partitioning)
- High degree of coordination between groups
- Organization of sample distribution



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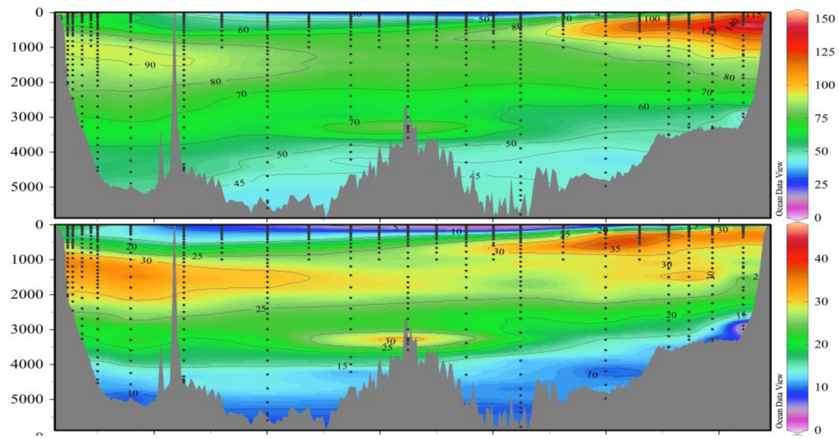
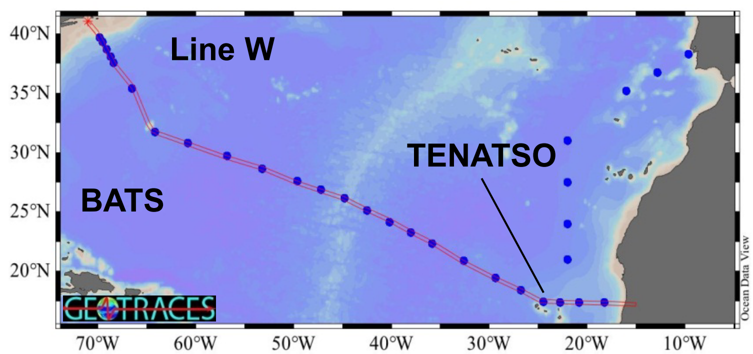
  - Some (really!) quick pictures
- Two vignettes

NSF

Total & labile Co: Noble & Saito

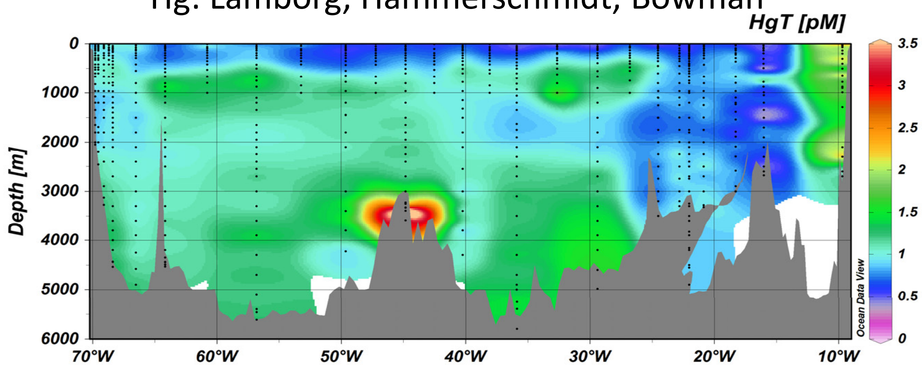




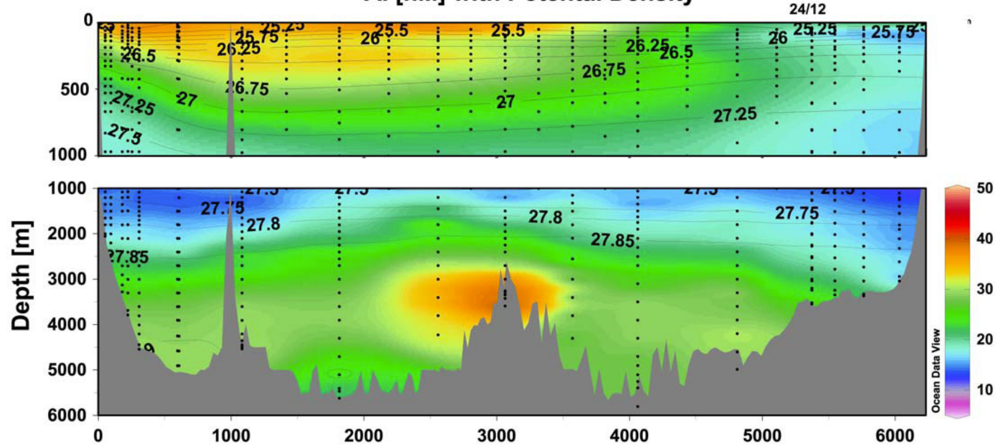
Trace Metals

Al, Fe, Mn: Hatta &Measures ➔

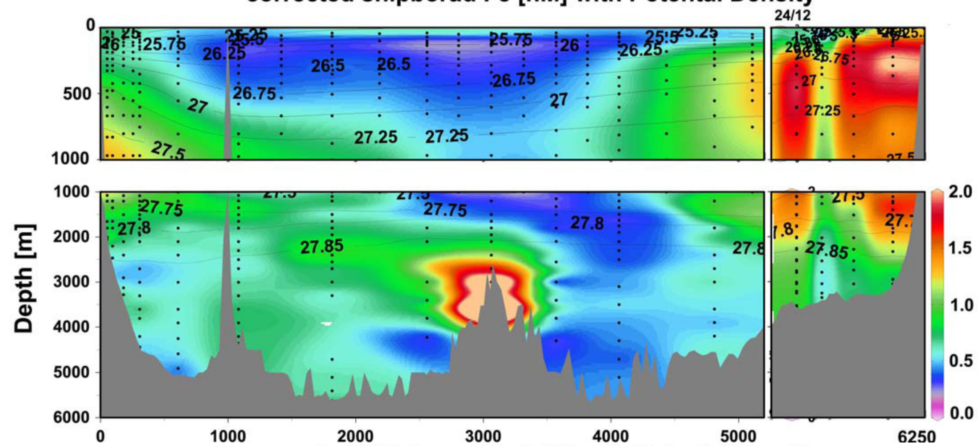
Hg: Lamborg, Hammerschmidt, Bowman



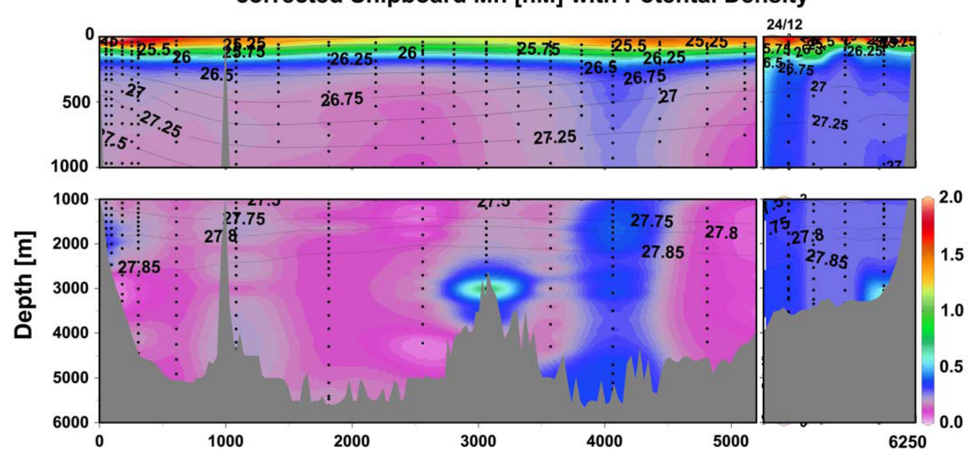
Al [nM] with Potental Density



corrected shipborad Fe [nM] with Potental Density

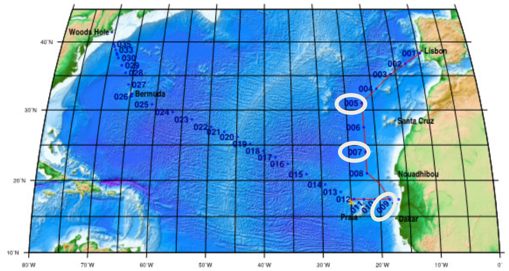


corrected Shipboard Mn [nM] with Potental Density

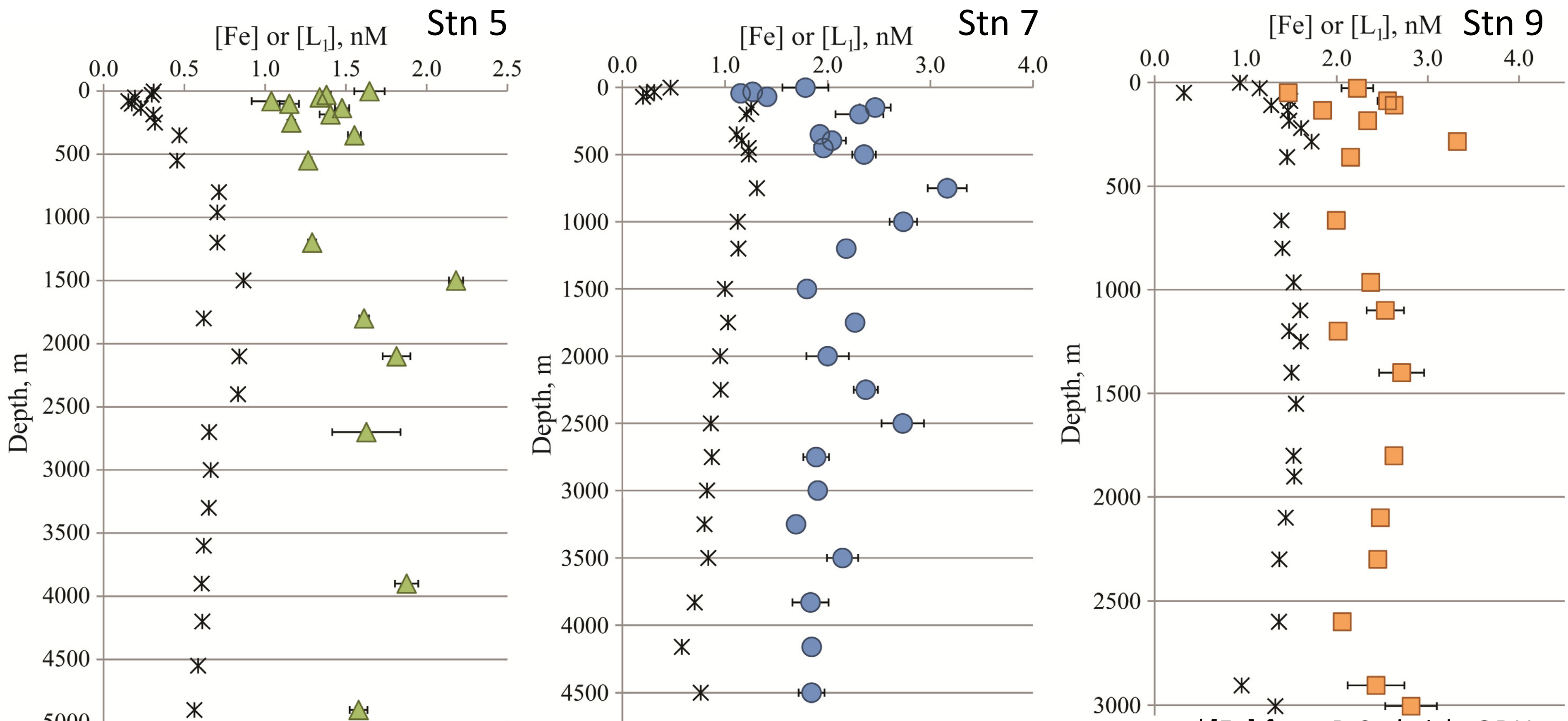


Organic complexation of dissolved Fe: Profiles from U.S. GEOTRACES North Atlantic section, Leg 1

Kristen N. Buck
Preliminary Data
Bermuda Institute of Ocean Sciences
NSF Award OCE-0927453



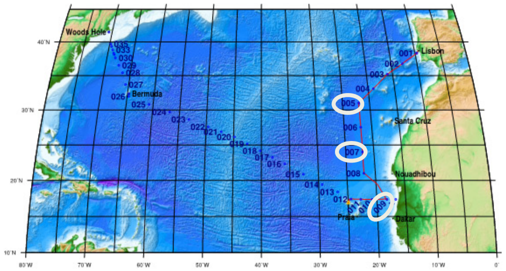
GEOTRACES 2010 Cruise Track 2010-11-09 23:45



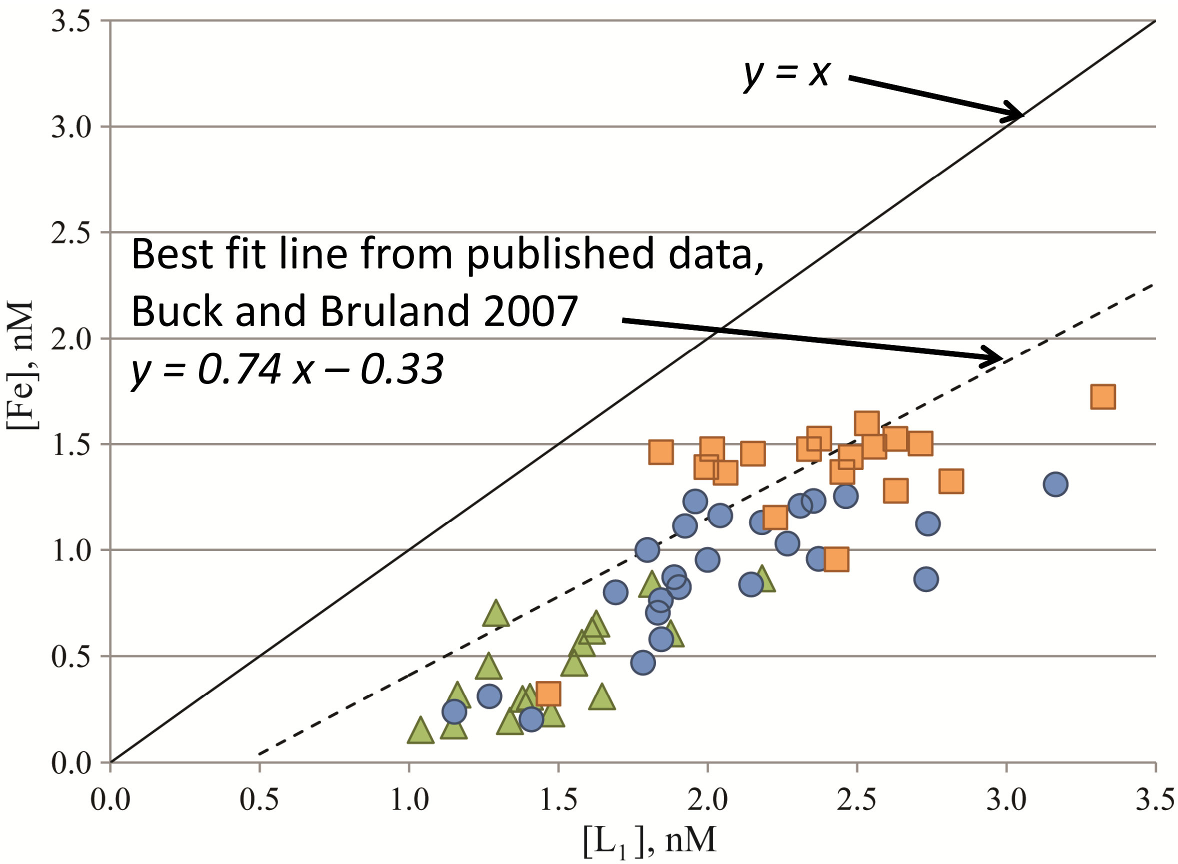
*[Fe] from P. Sedwick, ODU

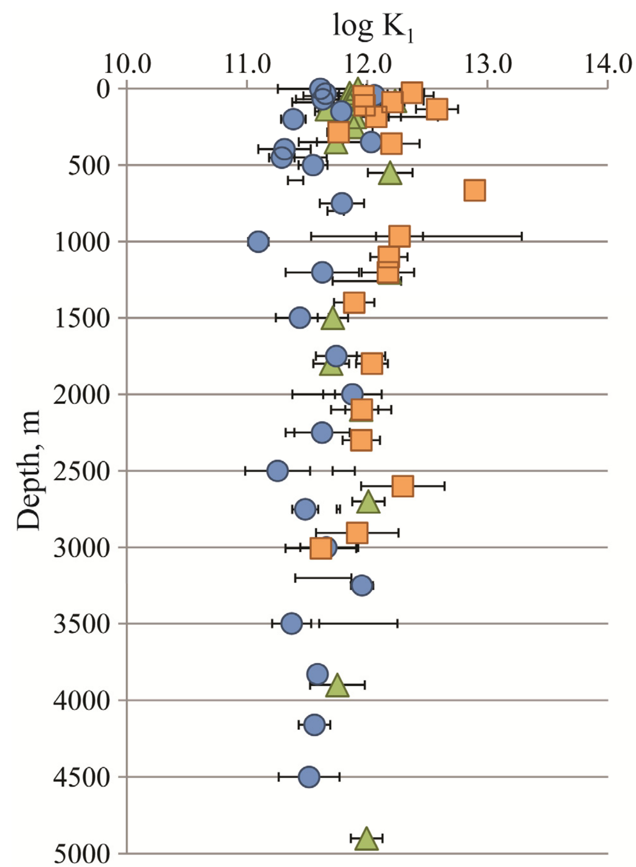
- Ligands ([L_1], colored symbols) in excess of [Fe] at all depths
- Trends in [L_1] – [Fe] not simply reflecting [Fe]

BIOS



GEOTRACES 2010 Cruise Track 2010-11-09 23:45



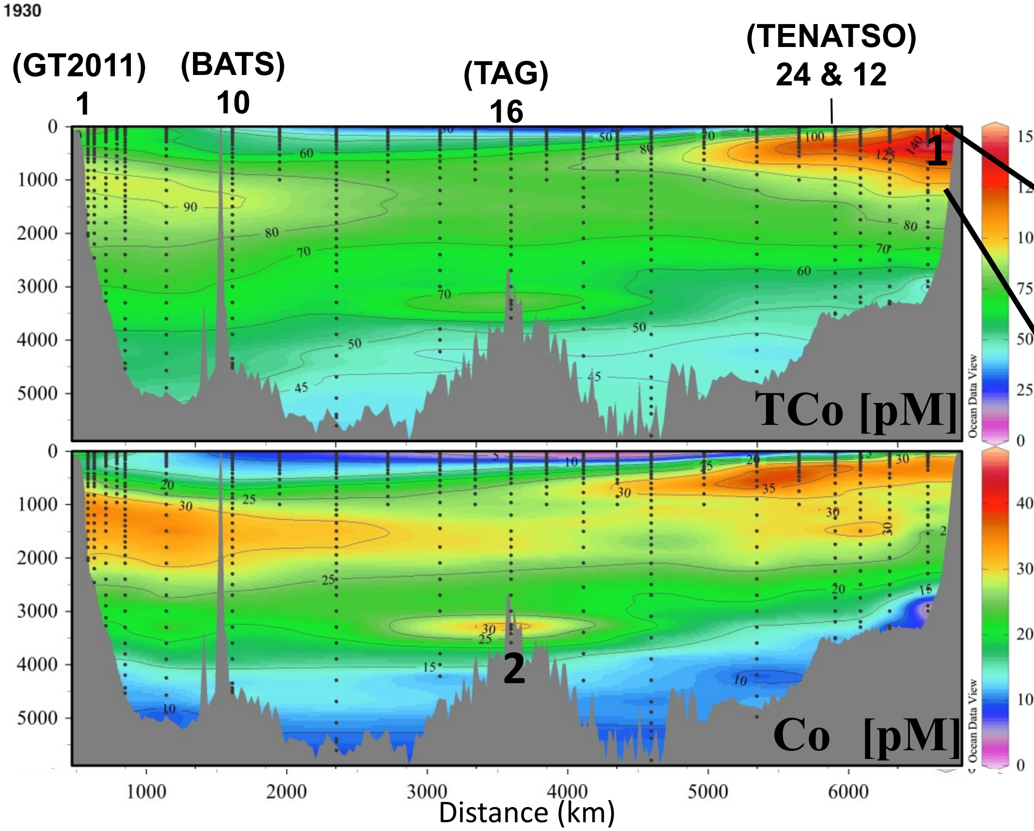


- [L_1] vs [Fe] consistent with previous, maybe slightly higher [L_1]
- Strong (log K_1 > 11) Fe-binding ligands at all depths

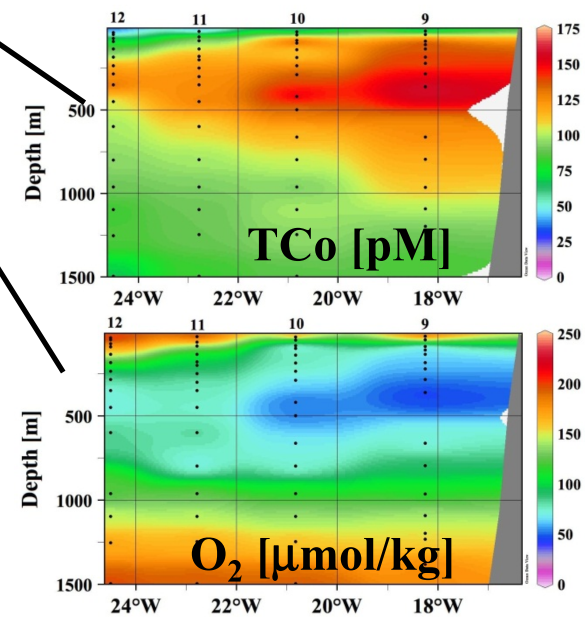
BIOS

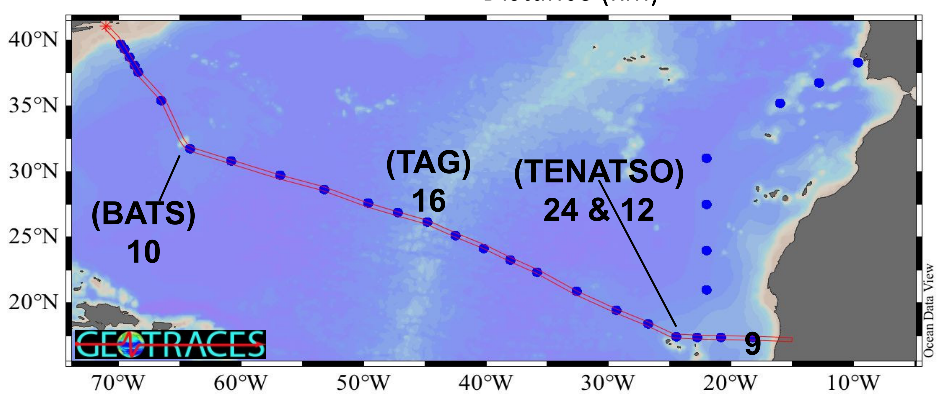
Dissolved total and labile Cobalt

Cobalt is the scarcest of metal micronutrients



Large scale plumes of cobalt and labile cobalt are observed in the North Atlantic Basin



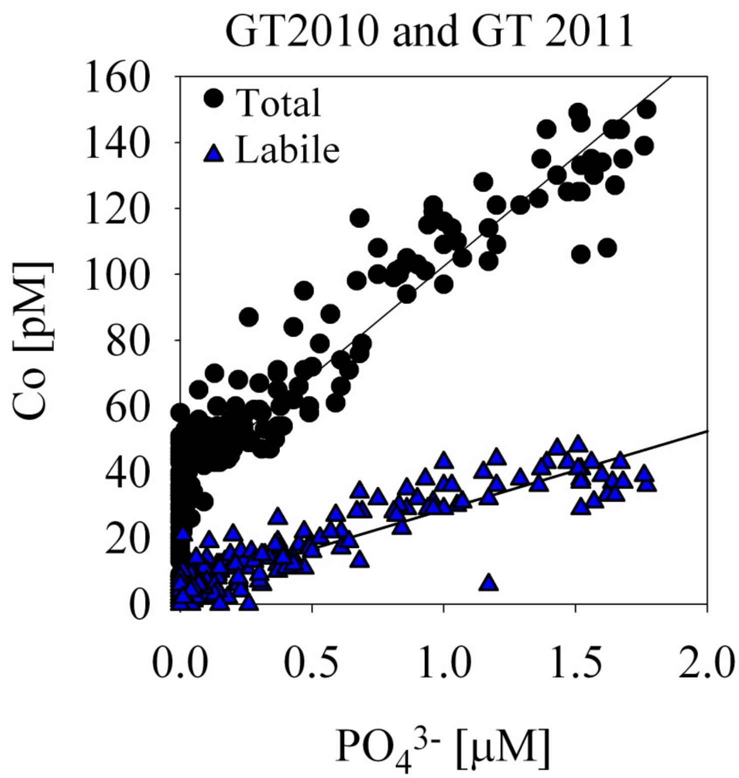


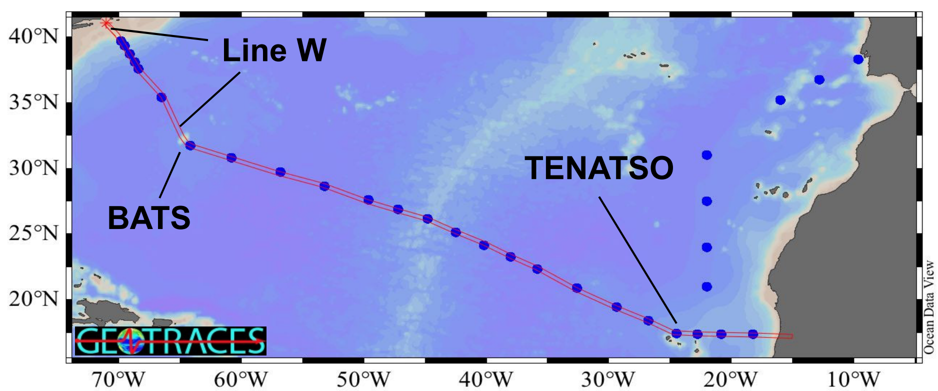
1. **Inverse relationship with O_2 in the OMZ:**
   Reductive dissolution is a source of cobalt to the basin and with continued deoxygenation in the ocean, this may lead to a potential increase in metals such as cobalt and iron (Noble et al. 2012)
2. **Hydrothermal enrichment at TAG**
   (most notable for labile cobalt)

A. Noble and M. Saito in prep

Dissolved total and labile Cobalt

0-400m for stations from both cruises excluding Line W

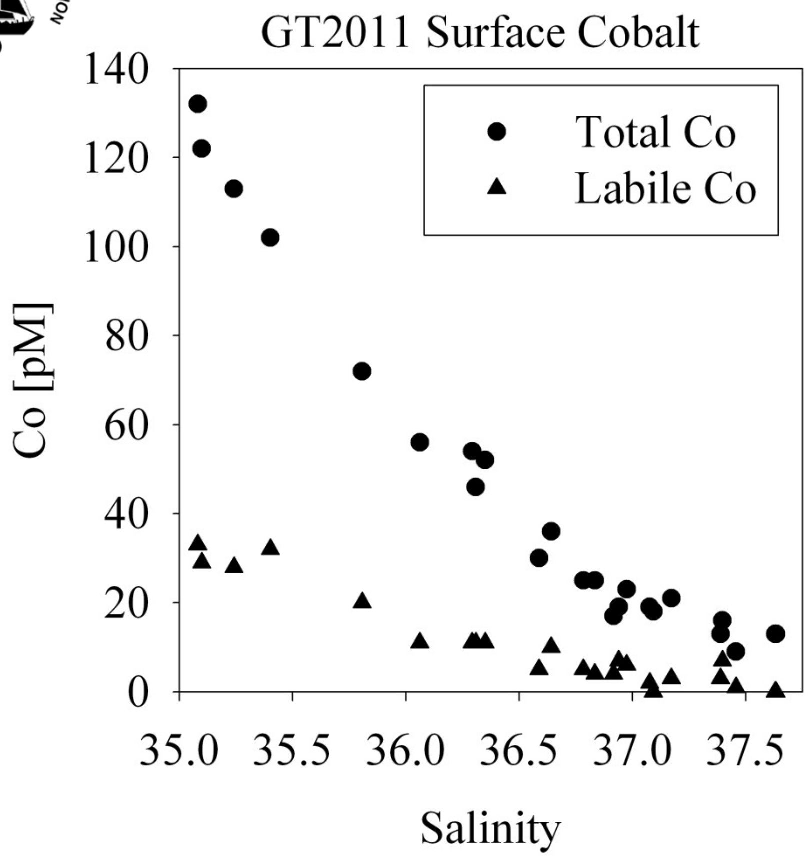




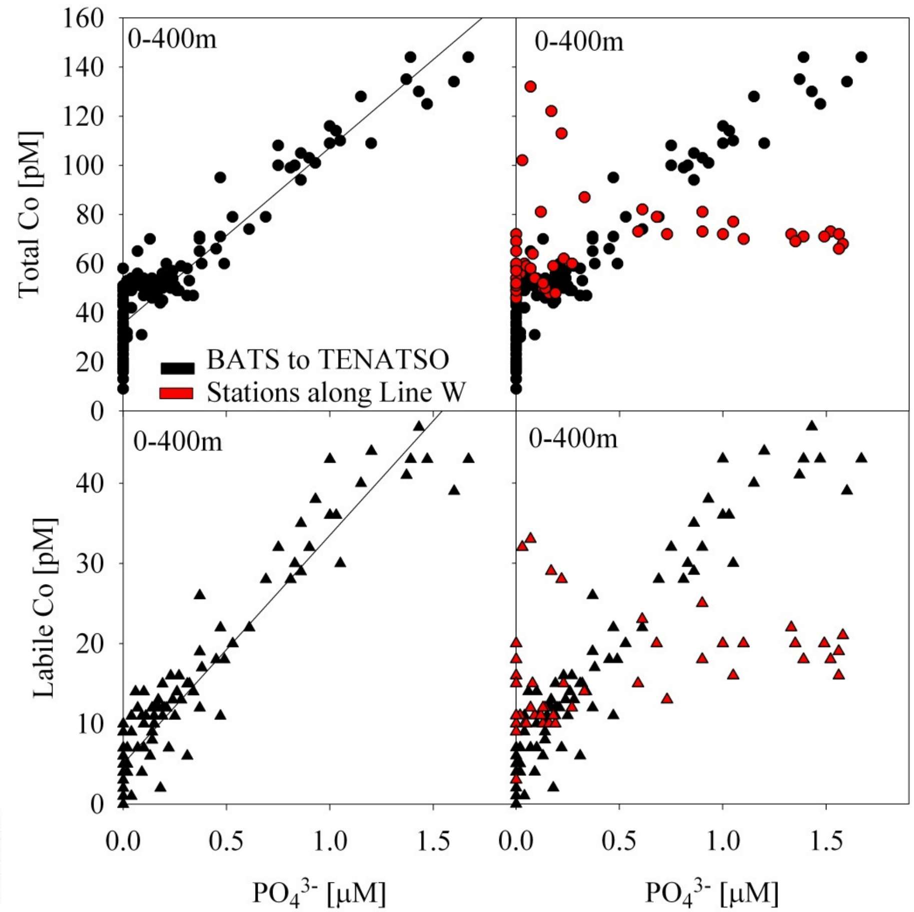
A. Noble and M. Saito in prep

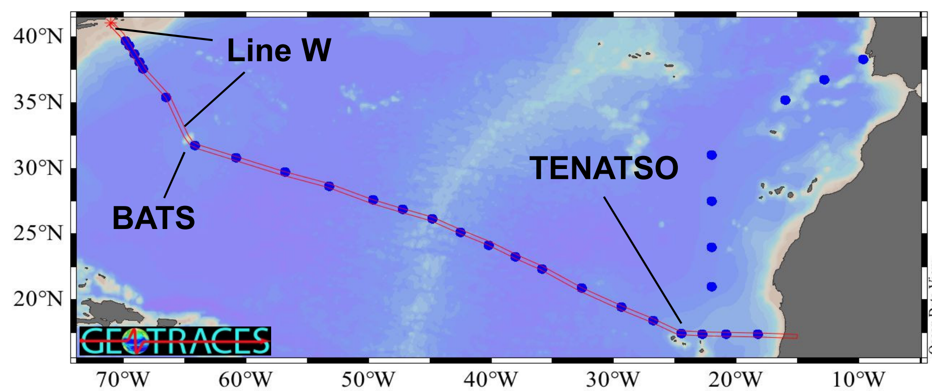
3. **Despite removal of cobalt in intermediate and deep waters by scavenging:**
   - **A correlation with phosphate is found in shallow waters**
   - **The slope of which reflects the integrated ecological stoichiometry of cobalt by marine microbial processes**

Dissolved total and labile Cobalt



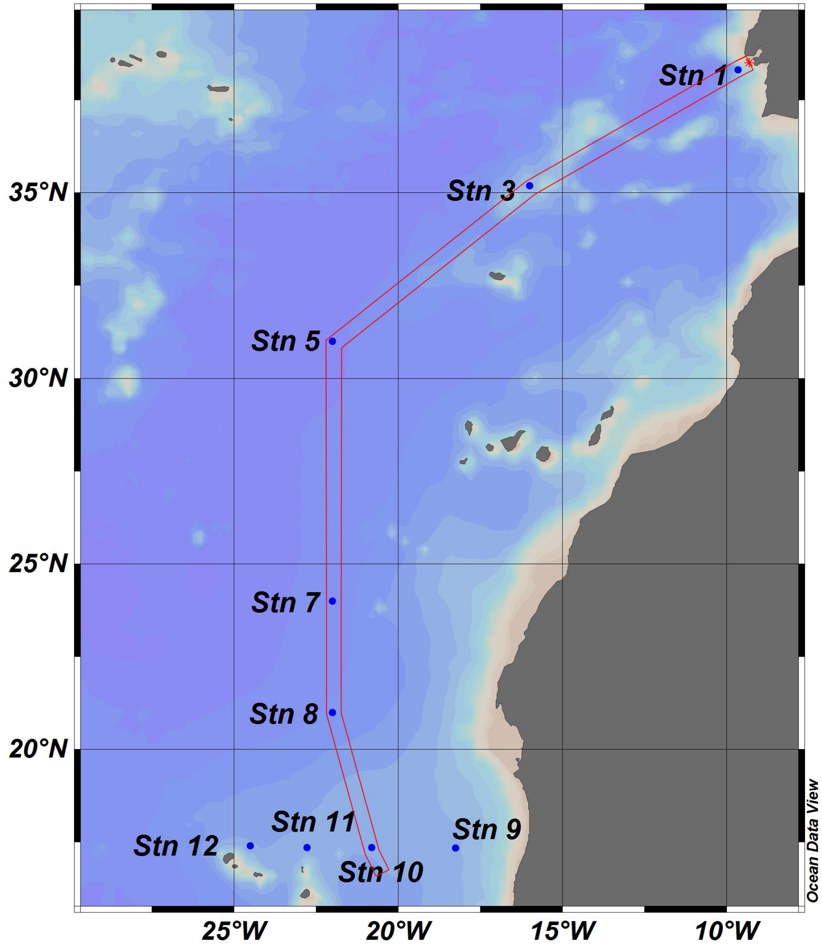
4. Approaching the East Coast of North America, the relationship with phosphate disappears and is replaced by a correlation with salinity, indicative of coastal fluxes.

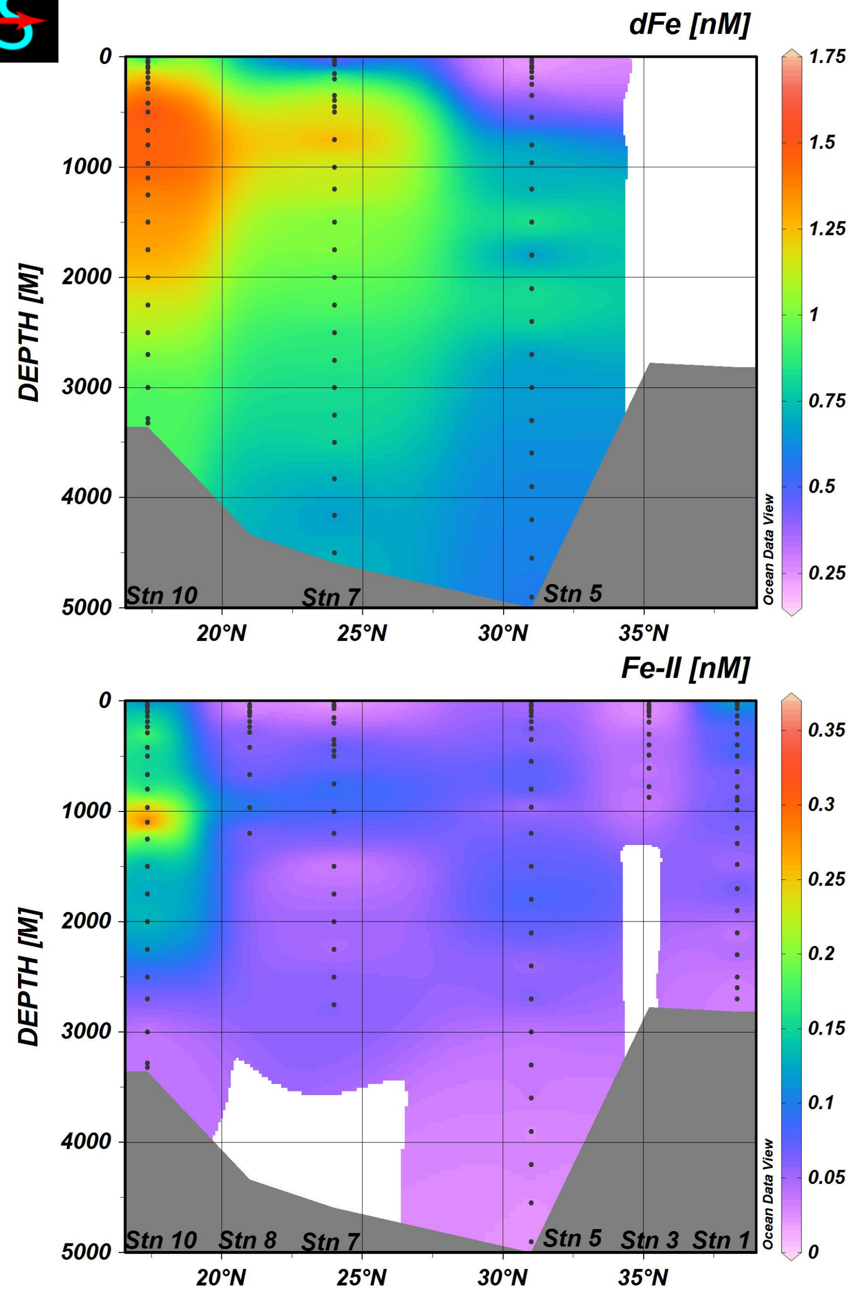




A. Noble and M. Saito in prep

U.S. GEOTRACES

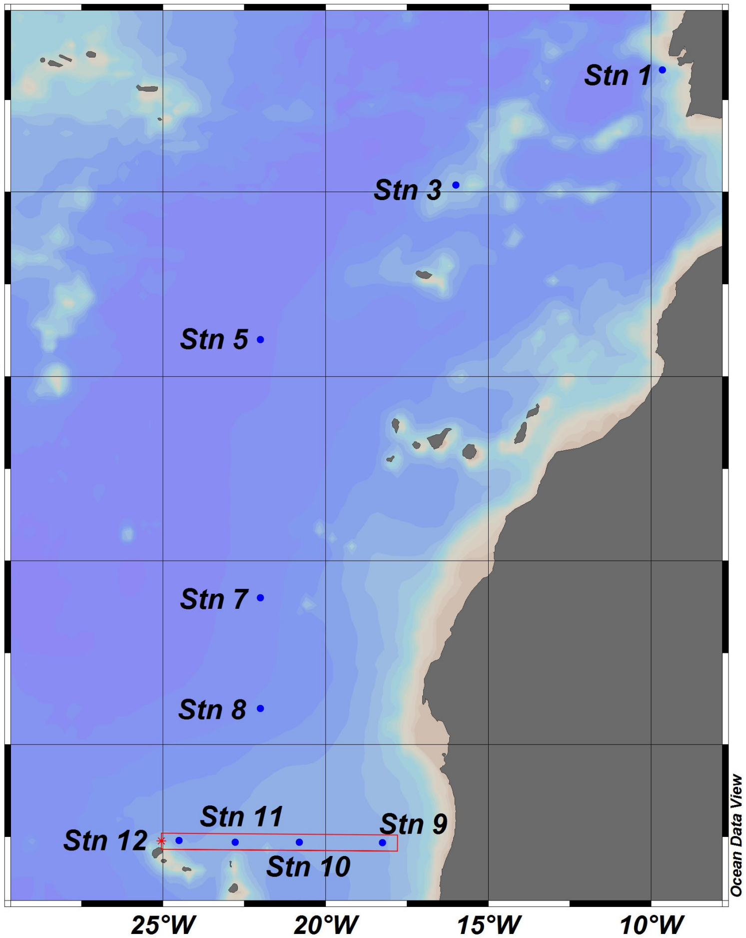


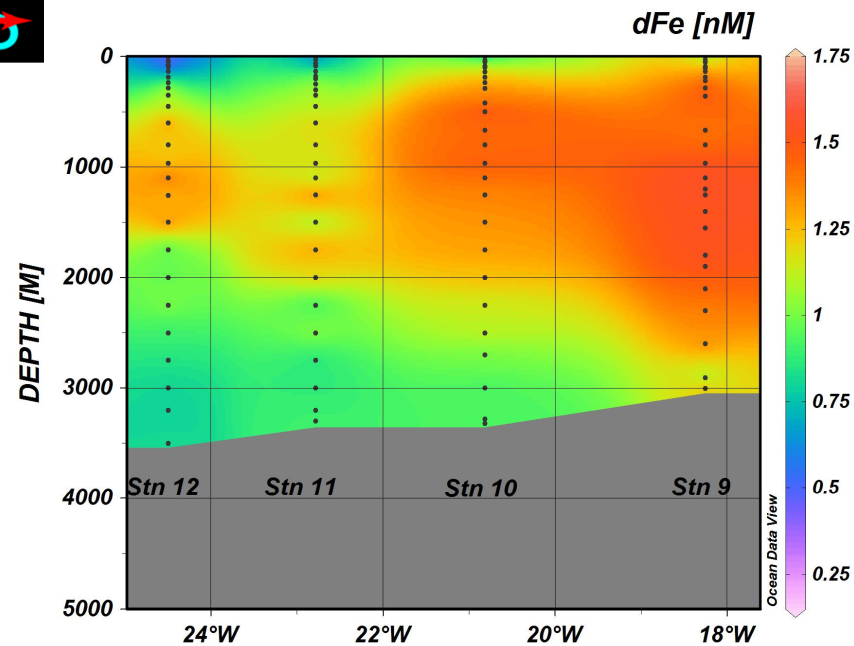


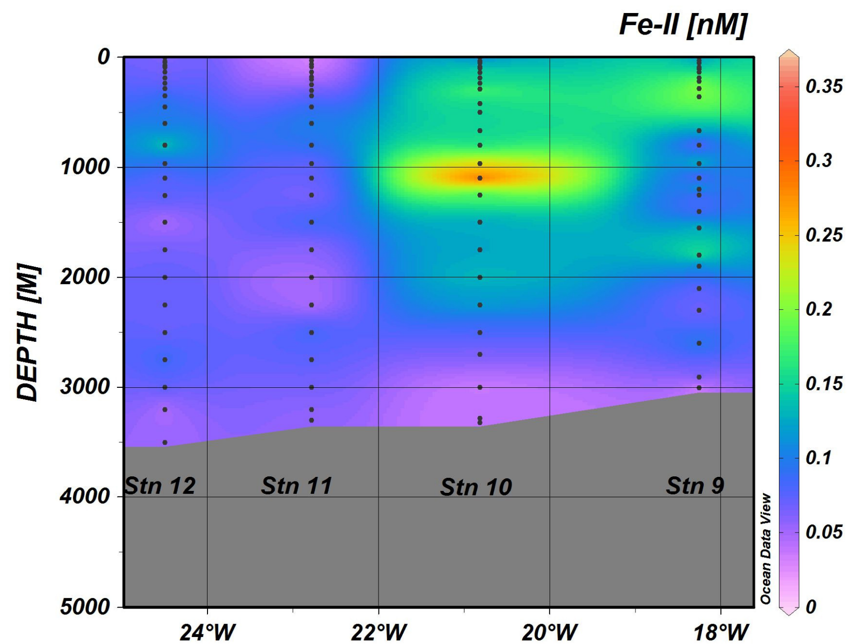
Location map showing quasi-meridional section of GEOTRACES North Atlantic cruise Leg 1 (left), and interpolated sections of dissolved Fe (*dFe*, top right) and dissolved Fe(II) (*Fe-II*, bottom right).

Data: P. Sedwick, A. Bowie and B. Sosht.

U.S. GEOTRACES

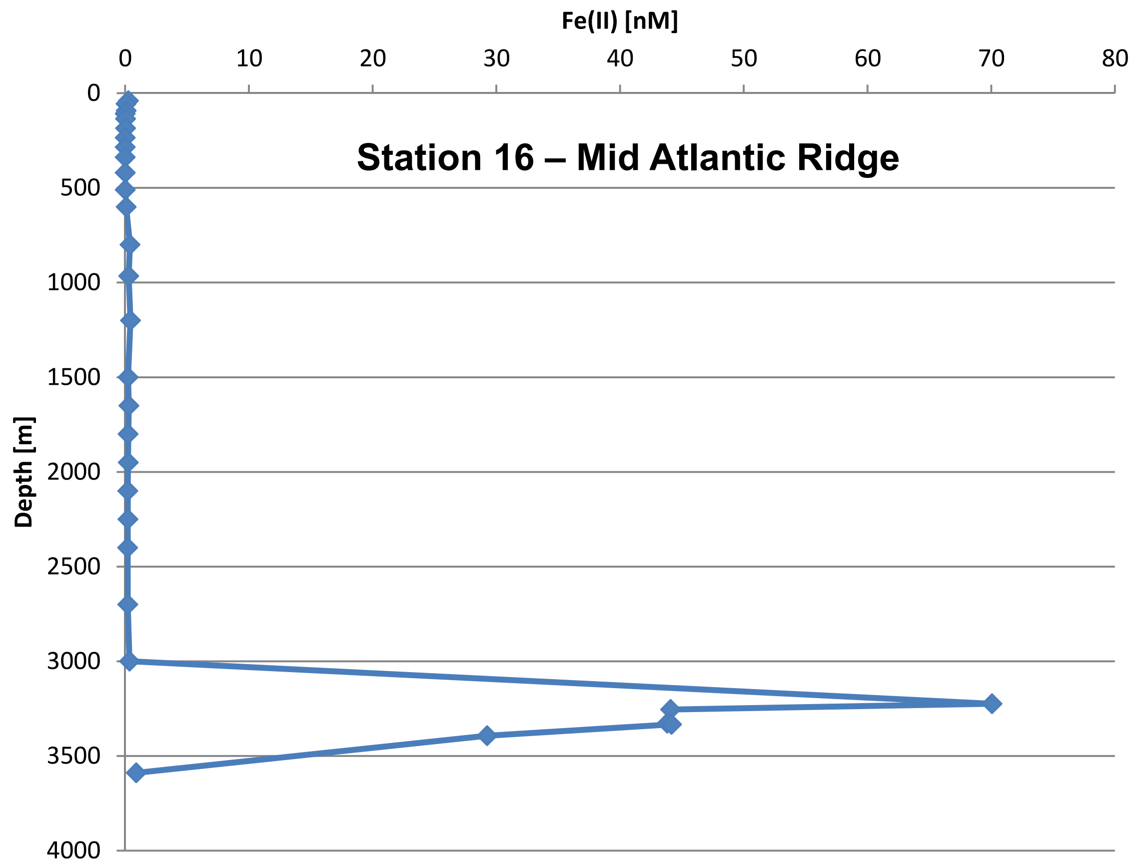






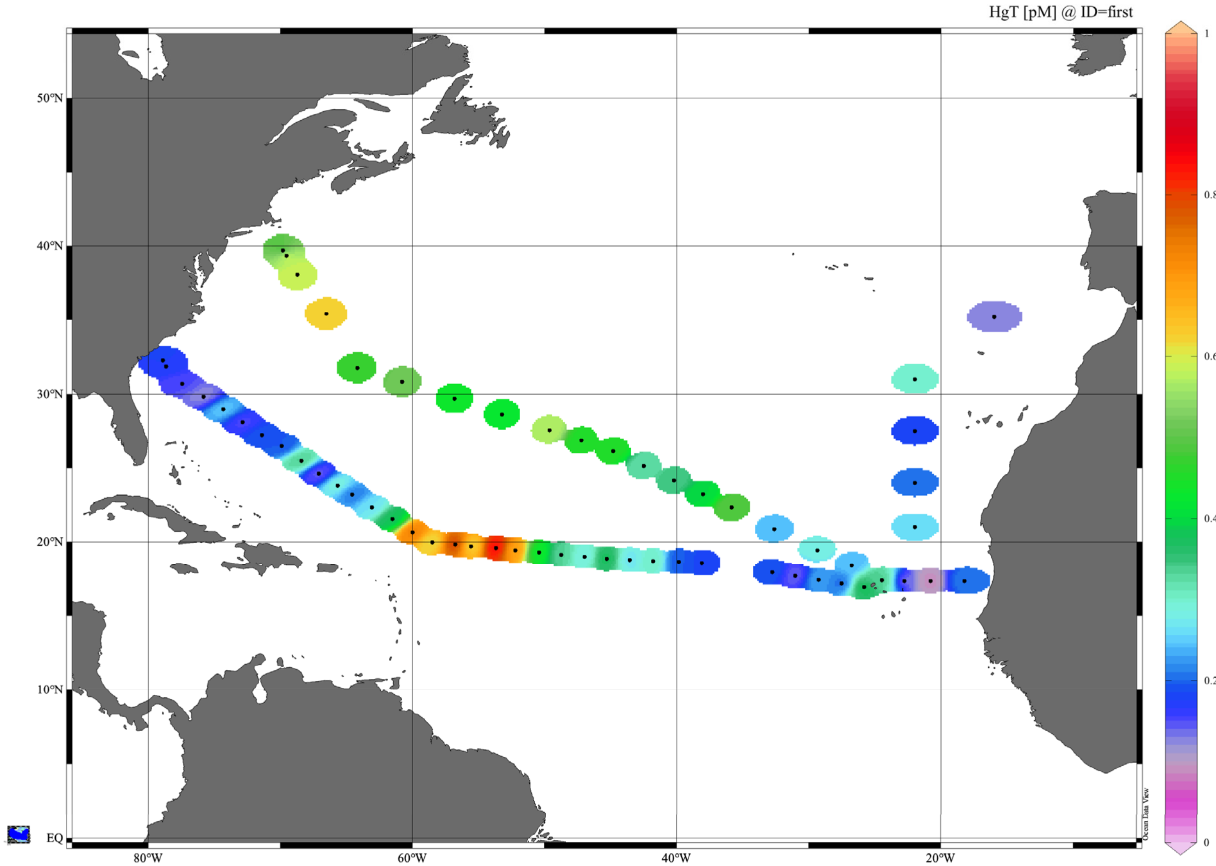
Location map showing zonal section of GEOTRACES North Atlantic cruise Leg 1 (left) and corresponding interpolated sections of dissolved Fe (*dFe*, top right) and dissolved Fe(II) (*Fe-II*, bottom right).

Data: P. Sedwick, A. Bowie and B. Sosht.



Full water-column profile of dissolved Fe(II) showing relatively high concentrations in hydrothermal plume sampled over the Mid-Atlantic Ridge during Leg 2 of the GEOTRACES North Atlantic cruise.

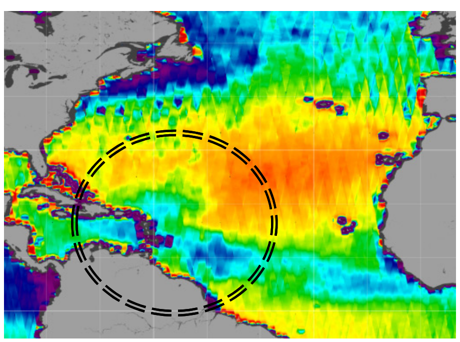
Data: P. Sedwick, A. Bowie and B. Sosht.



Surface Total Dissolved Hg (pM)

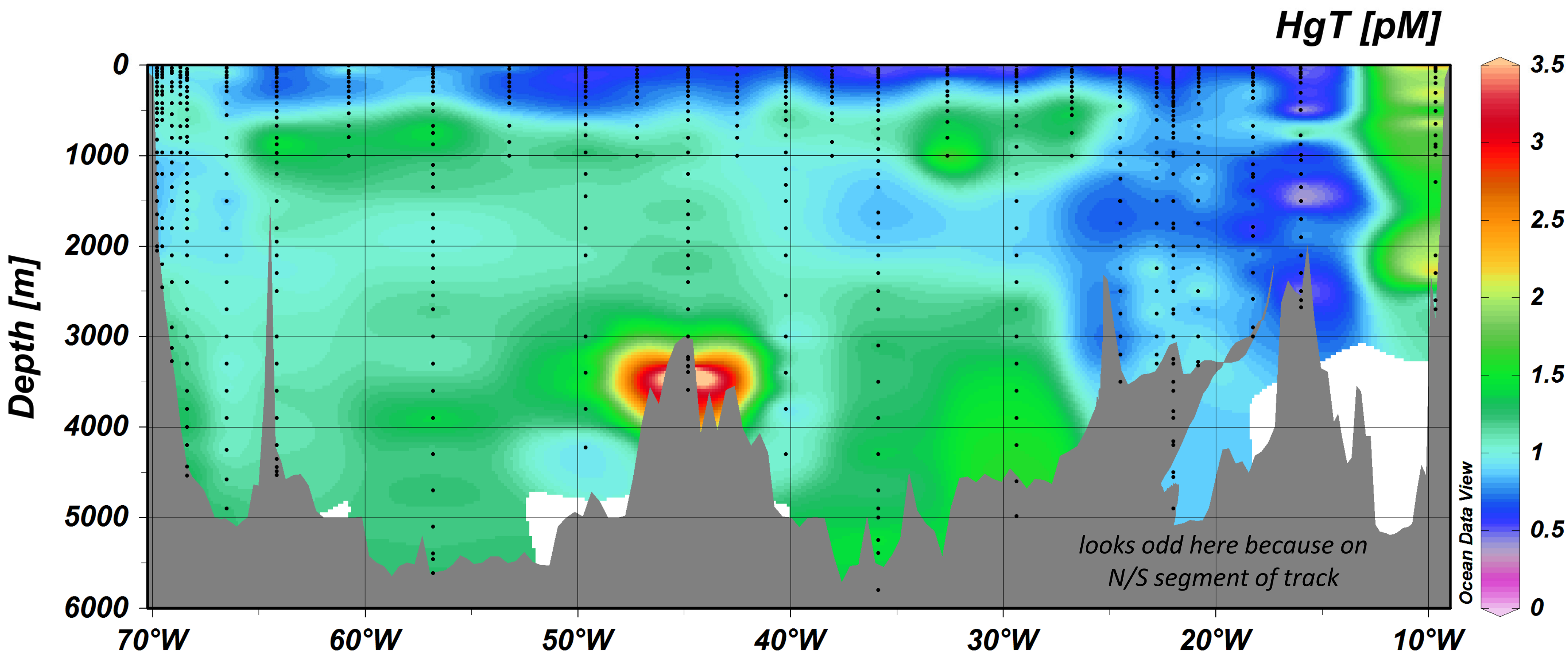
Concentration of total dissolved Hg shows spatial trends:

•Northern limb (2011) decreases from west to east. CoFeMUG in subtropical South Atlantic was the same.
•Southern limb (2010) very low in most locations, except where ITCZ or river plumes stray north.
•Productivity + Trade winds/westerlies distinction?

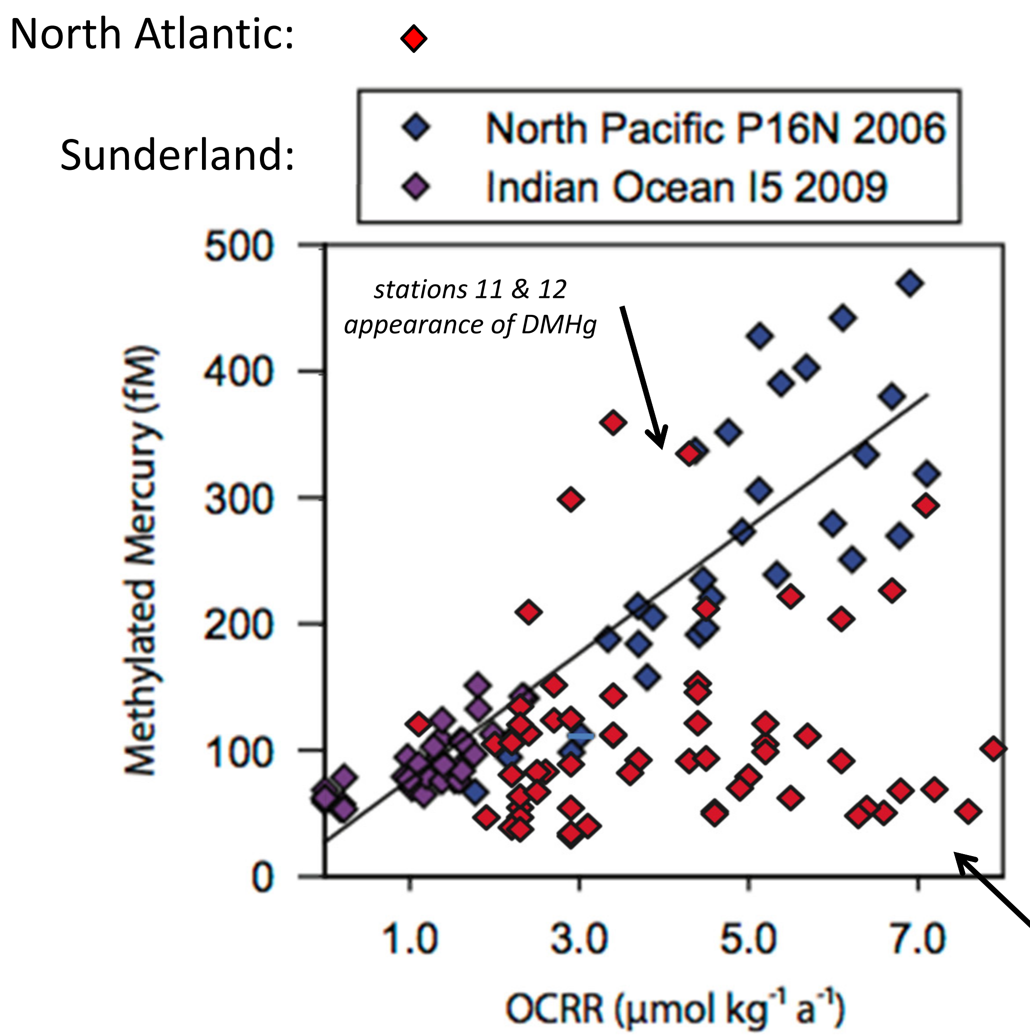


Satellite salinity data for November 2011, from Aquarius (NASA).

Total Hg: Bio-active, Hybrid-type Profiles



•Depleted at surface, with frequent mesopelagic maxima…biological scavenging.
•NE Atlantic seems generally depleted compared to the rest of the basin, except in Mediterranean Overflow region.
•Dramatic peak at the TAG hydrothermal station…consistent with plume dilution of highly enriched vent fluids (ca. 1000 pM).



all other stations virtually no DMHg

Elsie Sunderland and colleagues have documented a highly significant relationship between MMHg+DMHg (MeHg) and organic carbon remineralization rates (not AOU) <u>within mesopelagic.</u>

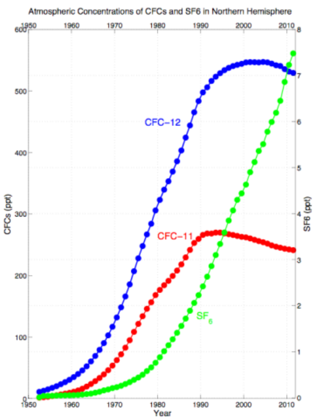
Implies dynamic production/destruction…not just low oxygen is important…and limitation by carbon and/or other components.

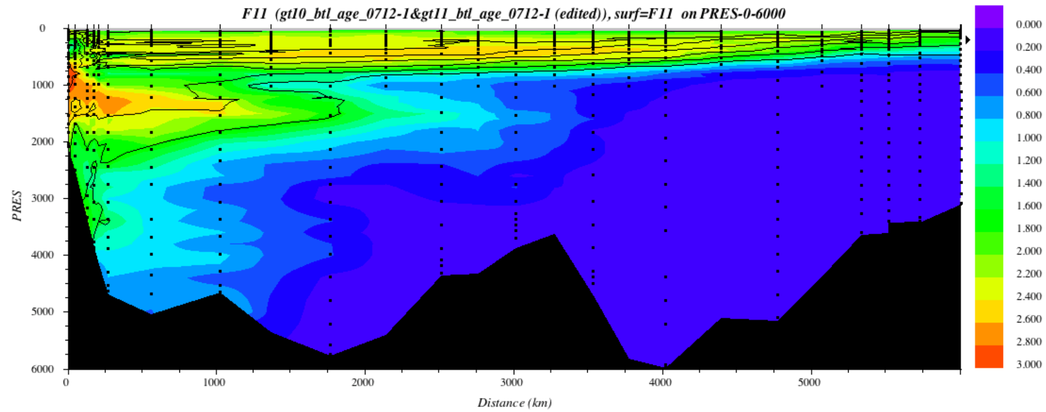
Many N. Atlantic data off the line. Additional limitation? Different metabolism? Western Basin distinction?

$OCRR = \Delta C_{org}/AGE = (R_{C:O}*AOU)/AGE$ (***Feely et al.*, 2004**)

Pacific and Indian Data courtesy of Elsie Sunderland, Harvard Sch. of Public Health
Age data courtesy of Bill Smethie - LDEO

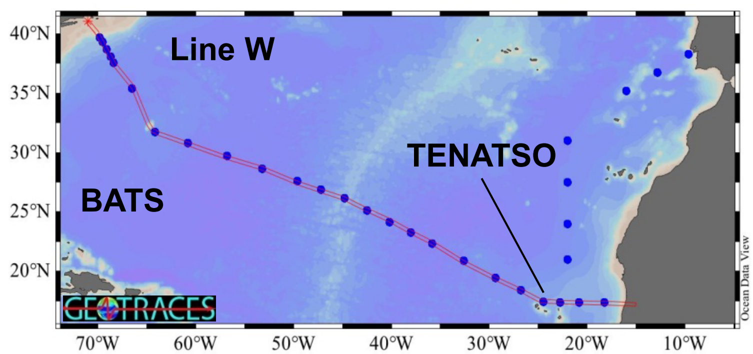
CFCs & SF_6 : Smethie

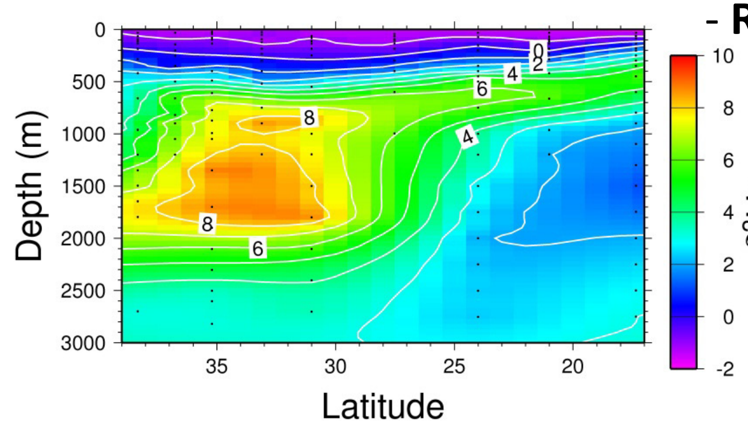




Ventilation and Advection-Diffusion Tracers

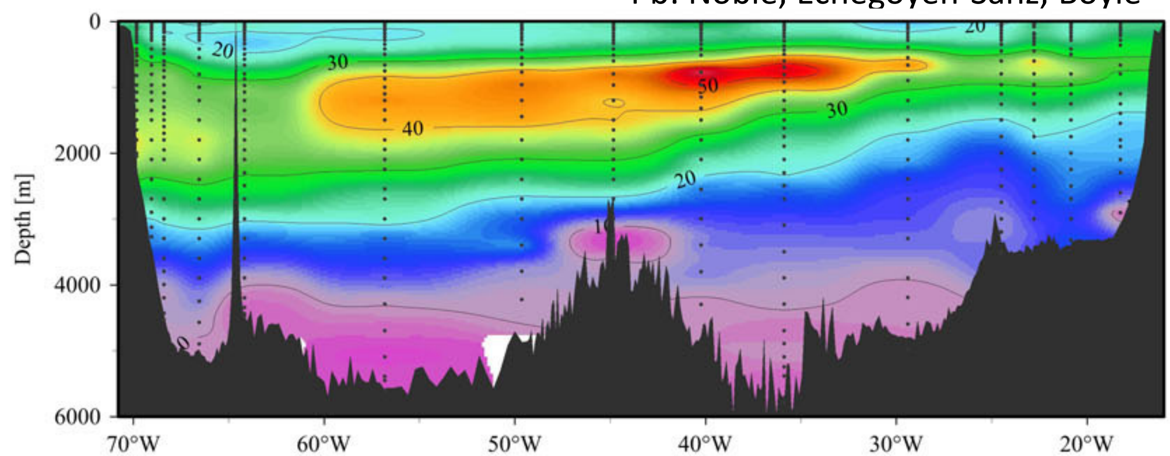
- * Anthropogenic:
  - **CFCs, SF_6**
  - **^3H-^3He, ^{14}C**
  - **Lead**
- * Natural:
  - **Ra isotopes**





^{3}He: Jenkins

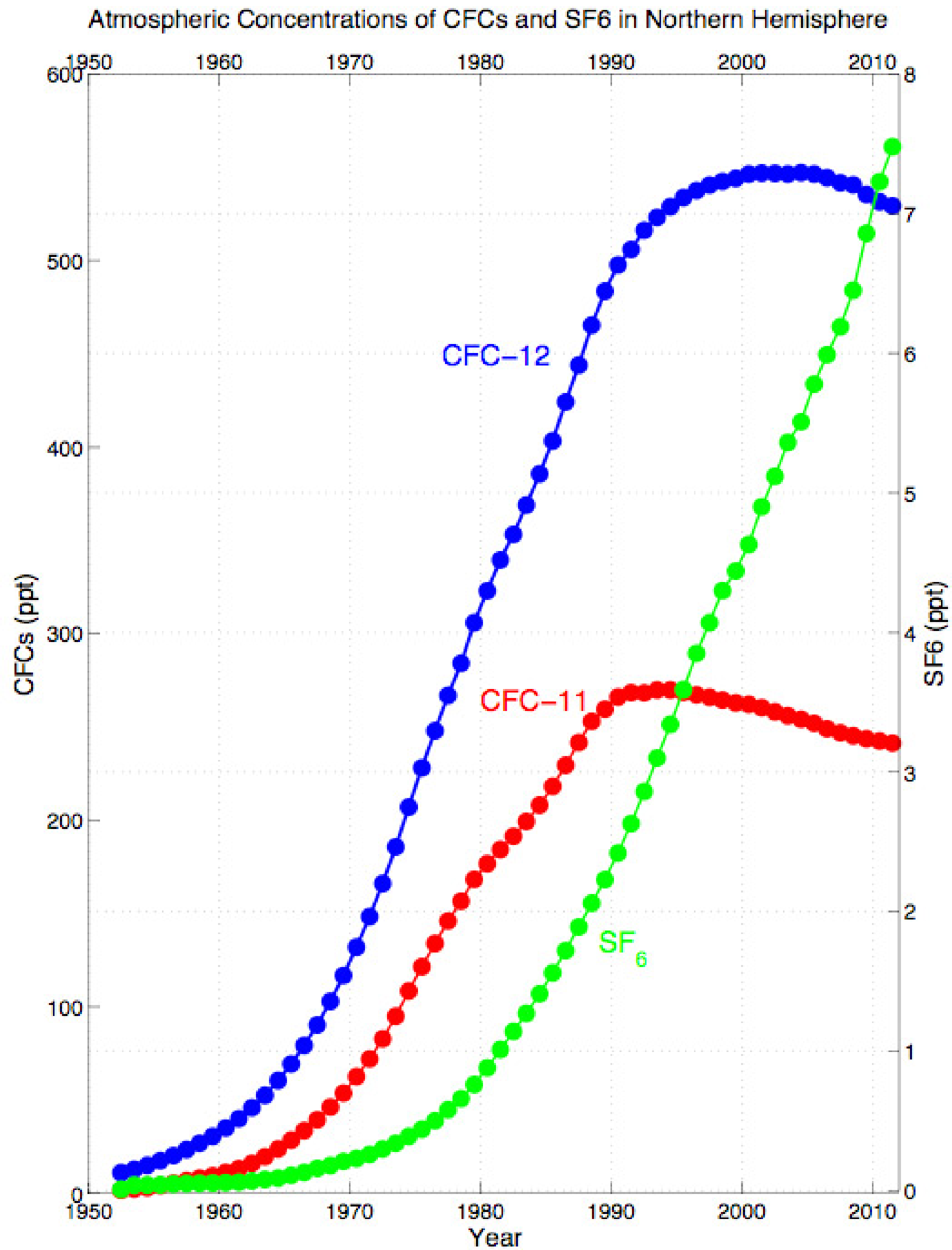
Pb: Noble, Echegoyen-Sanz, Boyle

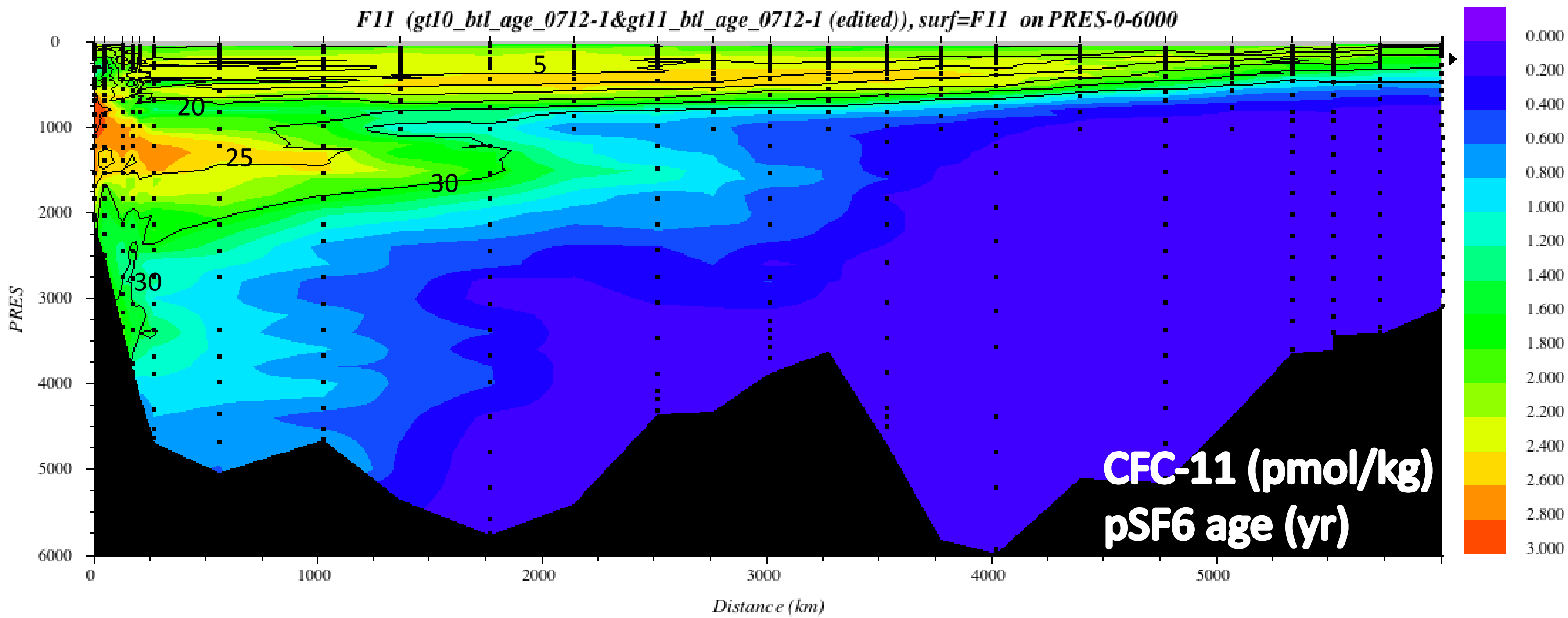


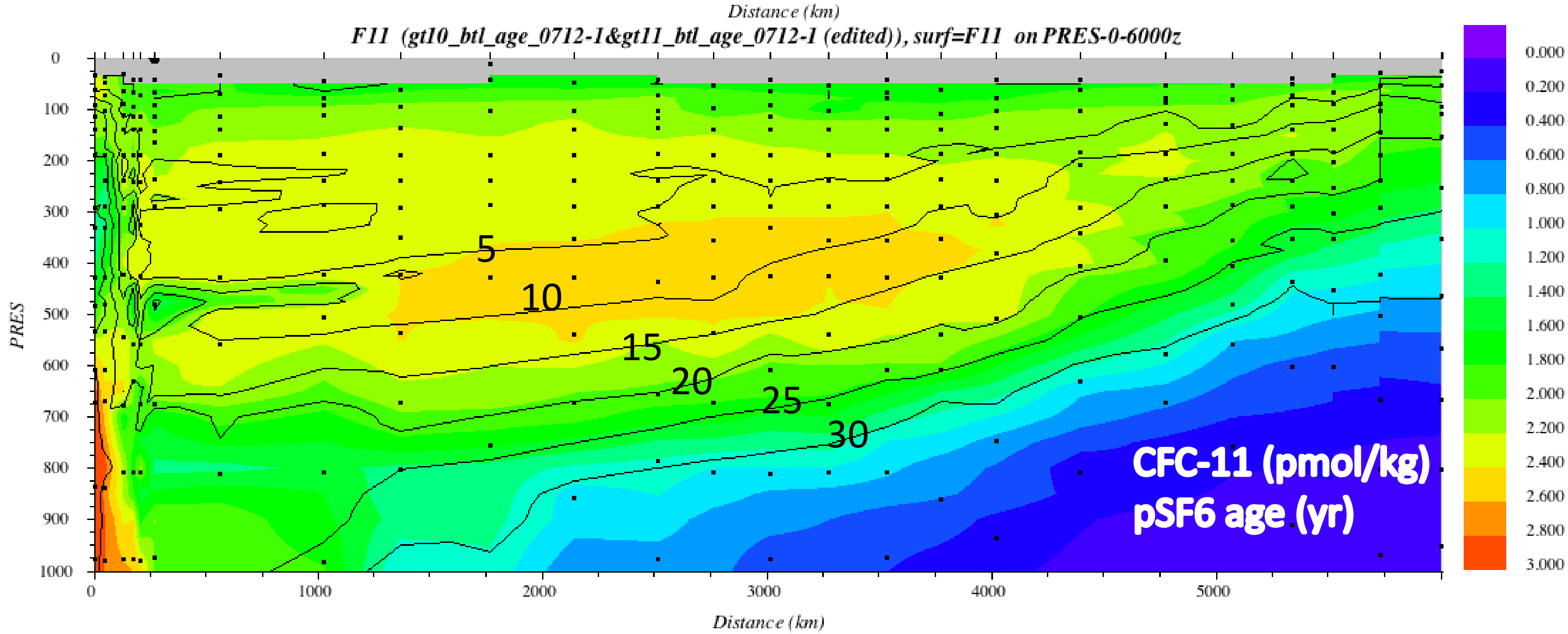
Chosen to quantify physics in order to quantify biogeochemical rates.

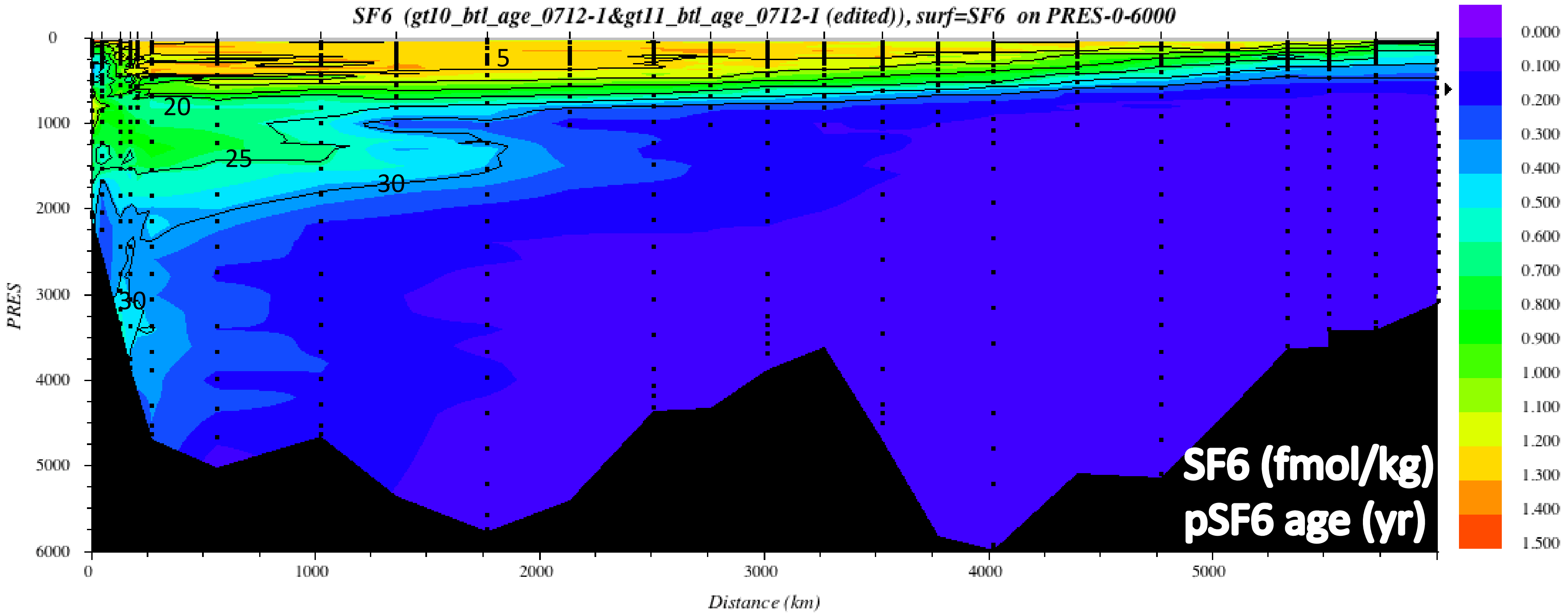
Each tracer system has different/unique boundary conditions, time history, and space/time-scales.

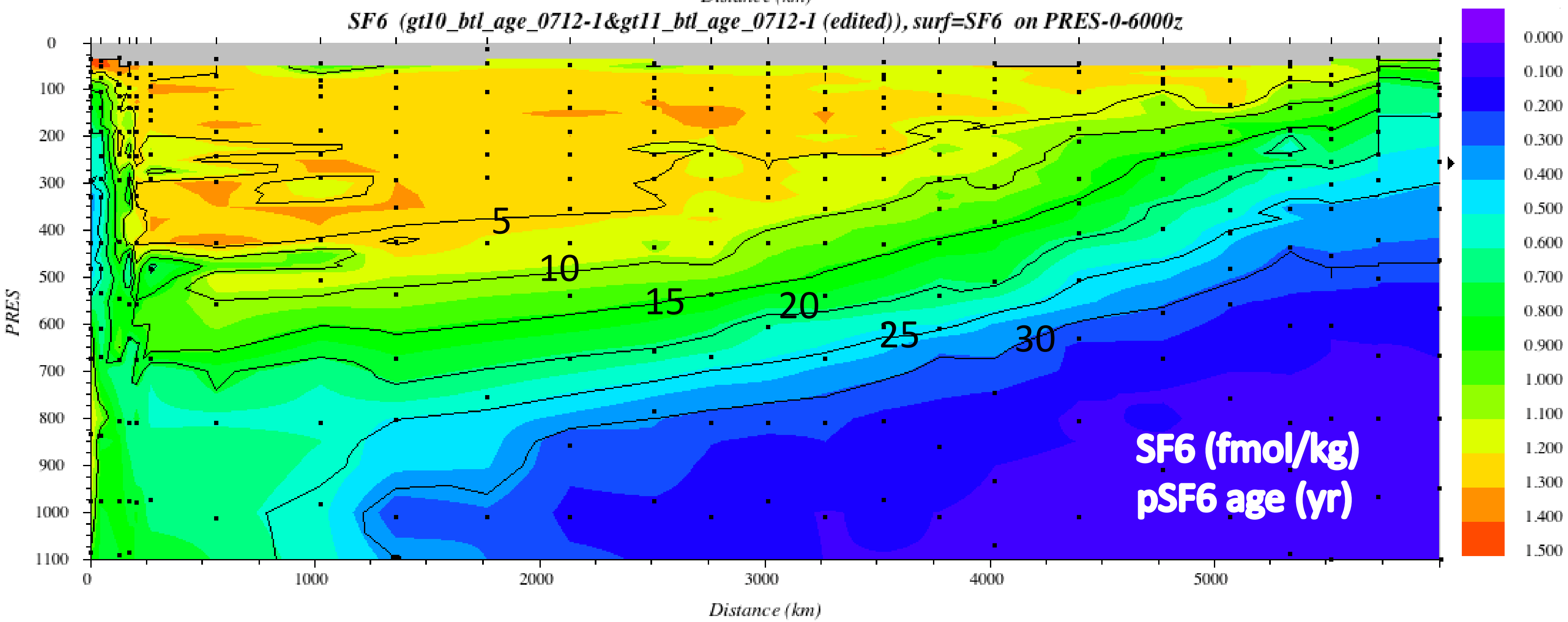
Results from Smethie Lab

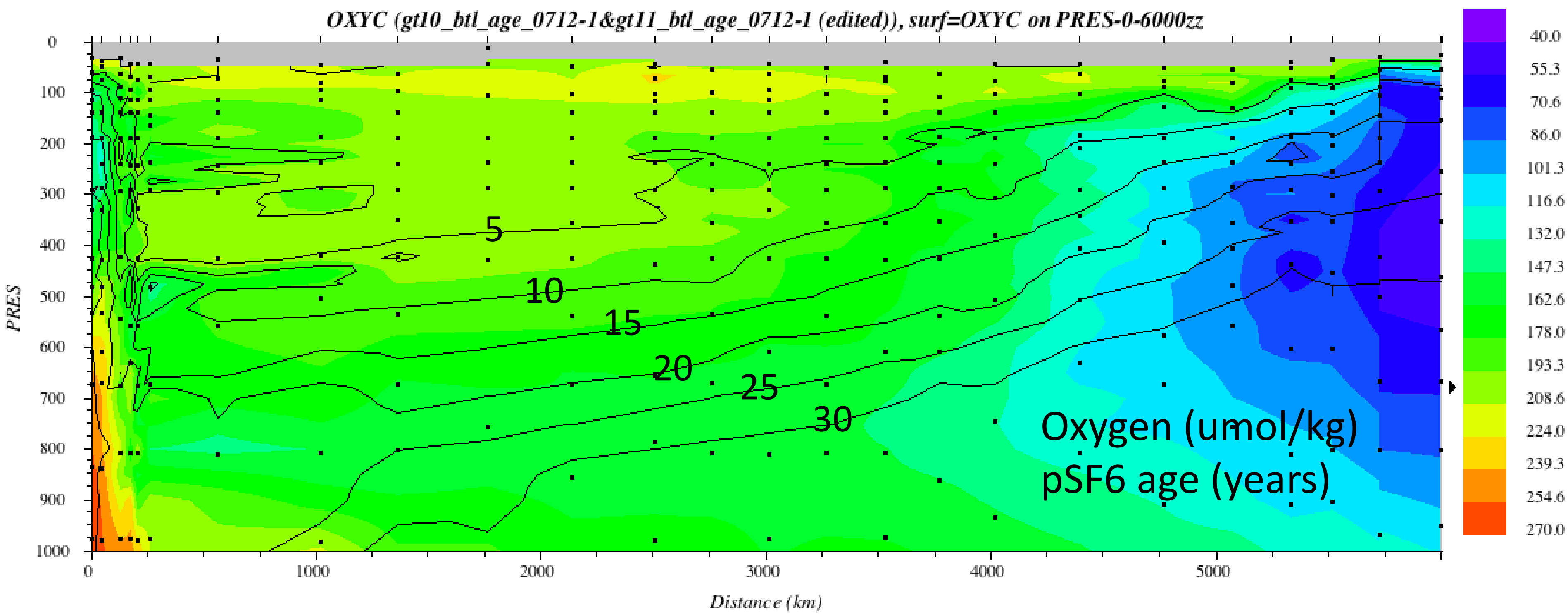



F11 (gt10_btl_age_0712-1&gt11_btl_age_0712-1 (edited)), surf=F11 on PRES-0-6000
PRES
Distance (km)
CFC-11 (pmol/kg)
pSF6 age (yr)
0.000
0.200
0.400
0.600
0.800
1.000
1.200
1.400
1.600
1.800
2.000
2.200
2.400
2.600
2.800
3.000
5
20
25
30
30

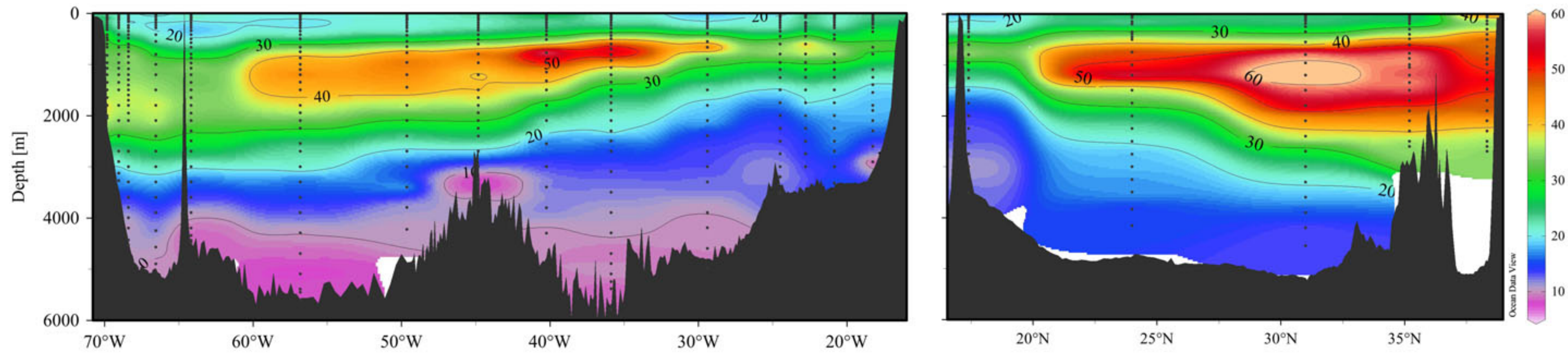

F11 (gt10_btl_age_0712-1&gt11_btl_age_0712-1 (edited)), surf=F11 on PRES-0-6000z
PRES
Distance (km)
CFC-11 (pmol/kg)
pSF6 age (yr)
0.000
0.200
0.400
0.600
0.800
1.000
1.200
1.400
1.600
1.800
2.000
2.200
2.400
2.600
2.800
3.000
5
10
15
20
25
30

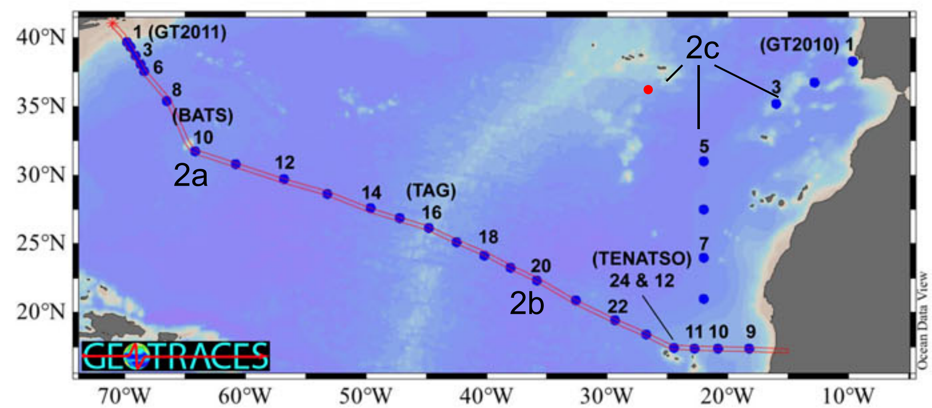

SF6 (gt10_btl_age_0712-1&gt11_btl_age_0712-1 (edited)), surf=SF6 on PRES-0-6000
PRES
Distance (km)
SF6 (fmol/kg)
pSF6 age (yr)
5
20
25
30
30
0.000
0.100
0.200
0.300
0.400
0.500
0.600
0.700
0.800
0.900
1.000
1.100
1.200
1.300
1.400
1.500


SF6 (gt10_btl_age_0712-1&gt11_btl_age_0712-1 (edited)), surf=SF6 on PRES-0-6000z
PRES
Distance (km)
SF6 (fmol/kg)
pSF6 age (yr)
5
10
15
20
25
30
0.000
0.100
0.200
0.300
0.400
0.500
0.600
0.700
0.800
0.900
1.000
1.100
1.200
1.300
1.400
1.500


OXYC (gt10_btl_age_0712-1&gt11_btl_age_0712-1 (edited)), surf=OXYC on PRES-0-6000zz
PRES
Distance (km)
0
100
200
300
400
500
600
700
800
900
1000
0
1000
2000
3000
4000
5000
5
10
15
20
25
30
Oxygen (umol/kg)
pSF6 age (years)
40.0
55.3
70.6
86.0
101.3
116.6
132.0
147.3
162.6
178.0
193.3
208.6
224.0
239.3
254.6
270.0

Dissolved Pb data from the US GEOTRACES North Atlantic Transect

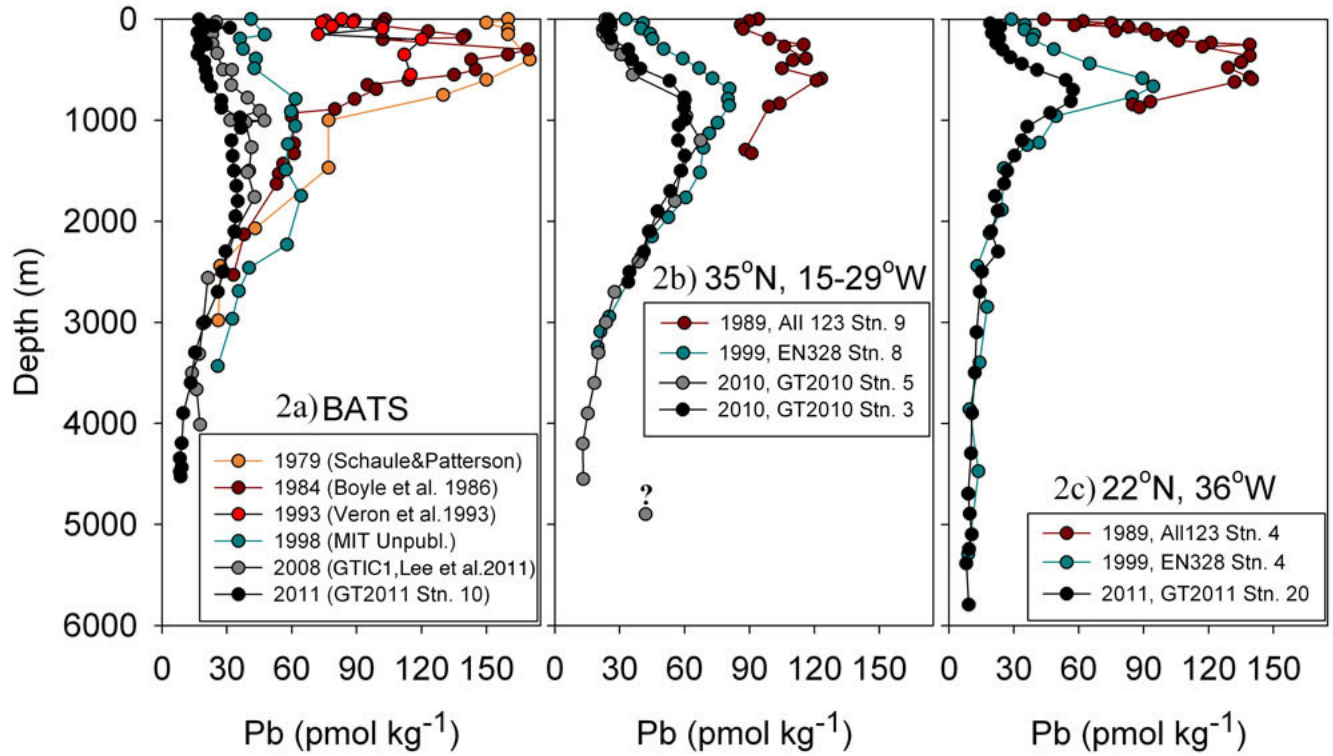




[Pb] sections (pmol/kg] are plotted west to east across the basin (above left) and eastern basin stations running south to north (above right). High Pb in intermediate waters remains from ventilation during previous decades when surface Pb concentrations were an order of magnitude higher than today. Surface and thermocline concentrations have decreased significantly relative to MIT profiles from the North Atlantic in 1989 and 1999 (see following figure). Station 16 sampled the TAG hydrothermal plume, and Pb appears to be scavenged within this oceanographic feature.

MIT Pb data by Abigail Noble and Yolanda Echegoyen-Sanz

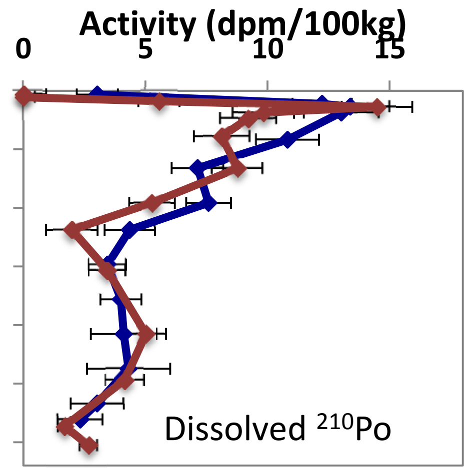
Temporal evolution of Pb in the western and eastern North Atlantic during the past 20-30 years

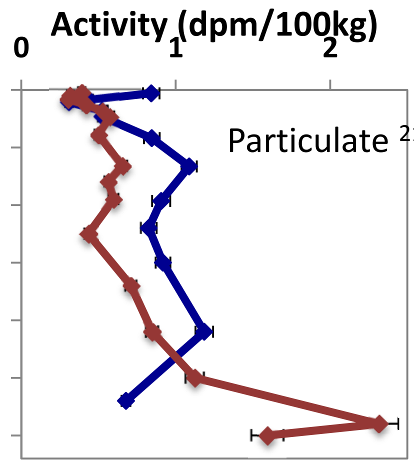


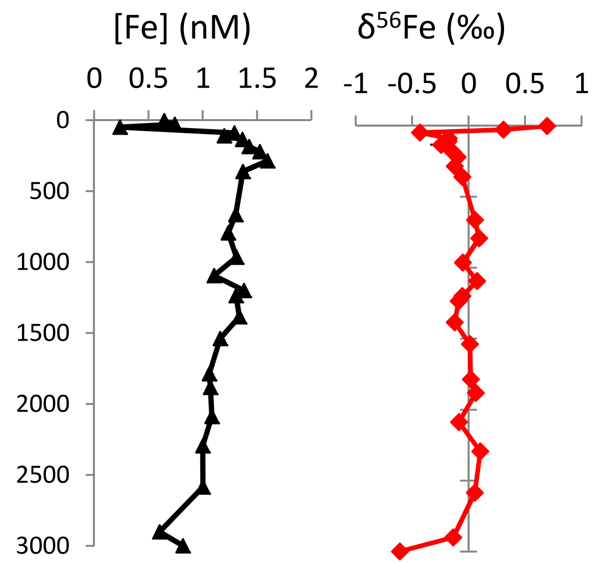
With the phasing out of leaded gasoline, the flux of Pb to the ocean's interior has decreased significantly over the last three decades. Stations that were previously occupied by our lab and others allow for a decadal "time-series" showing the gradual decrease in Pb concentrations in thermocline and intermediate waters from 1979 to 2011. See map on previous slide for locations of 2a, 2b, and 2c.

MIT Pb data by Boyle, Wu, Kayser, Echegoyen-Sanz, and Noble

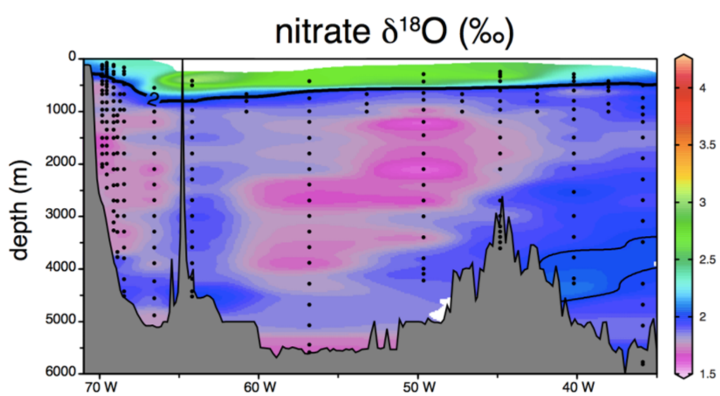
Other Isotopic Tracers:

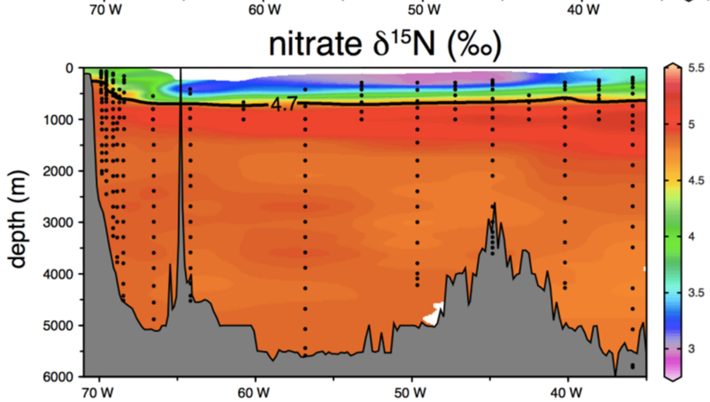




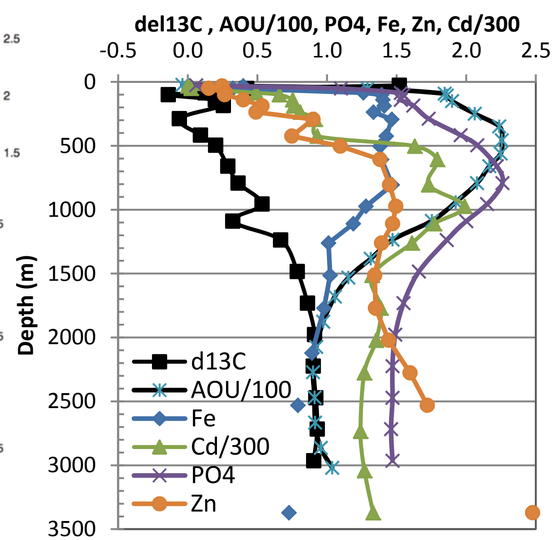


^{210}Po: Church, Rigaud, Baskaran, Stewart, Choi

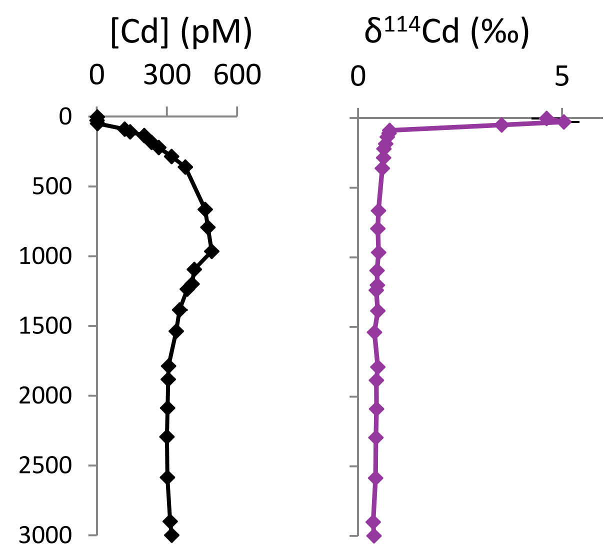




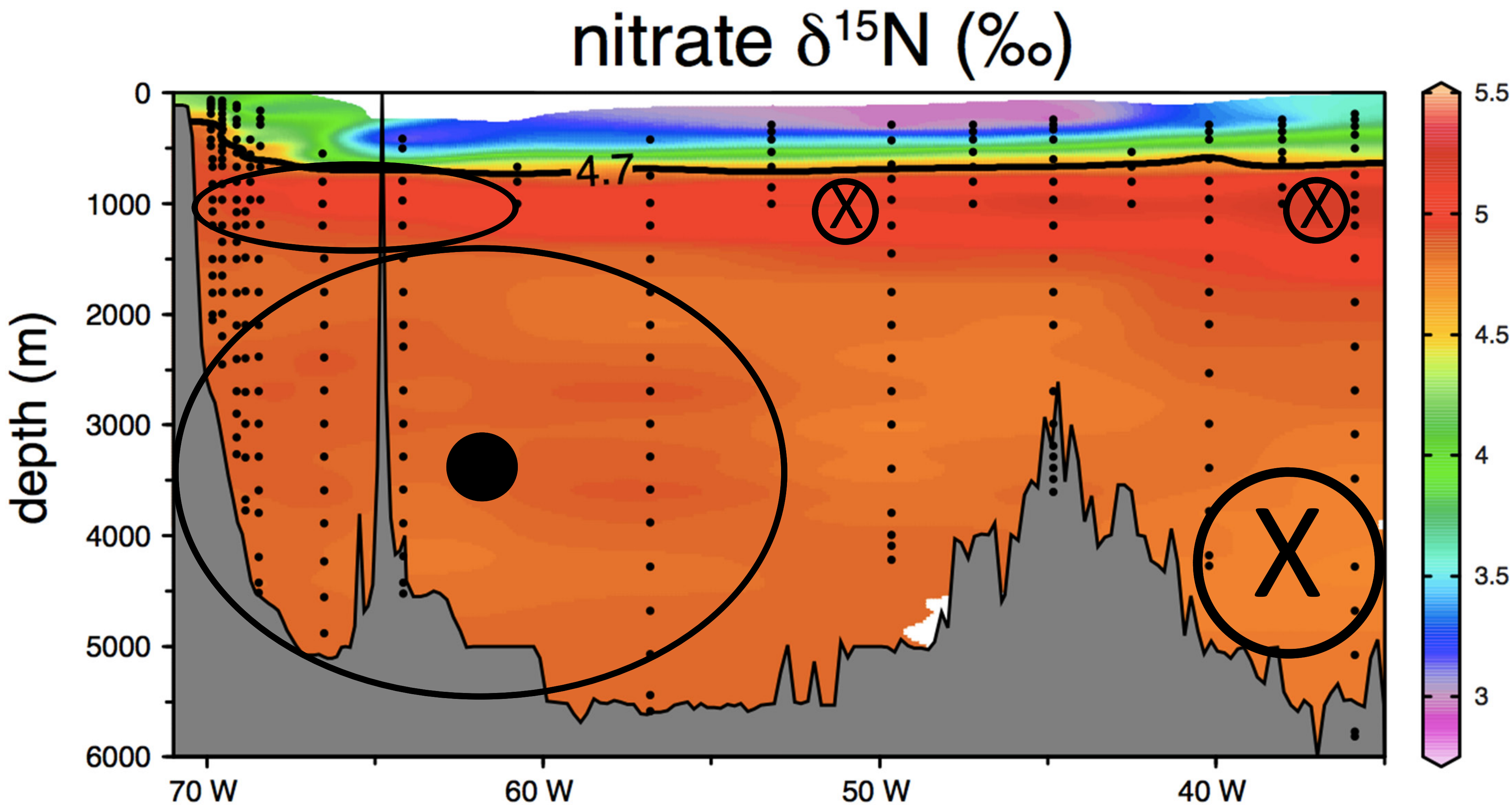
Danny Sigman's group



^{13}C : Paul Quay

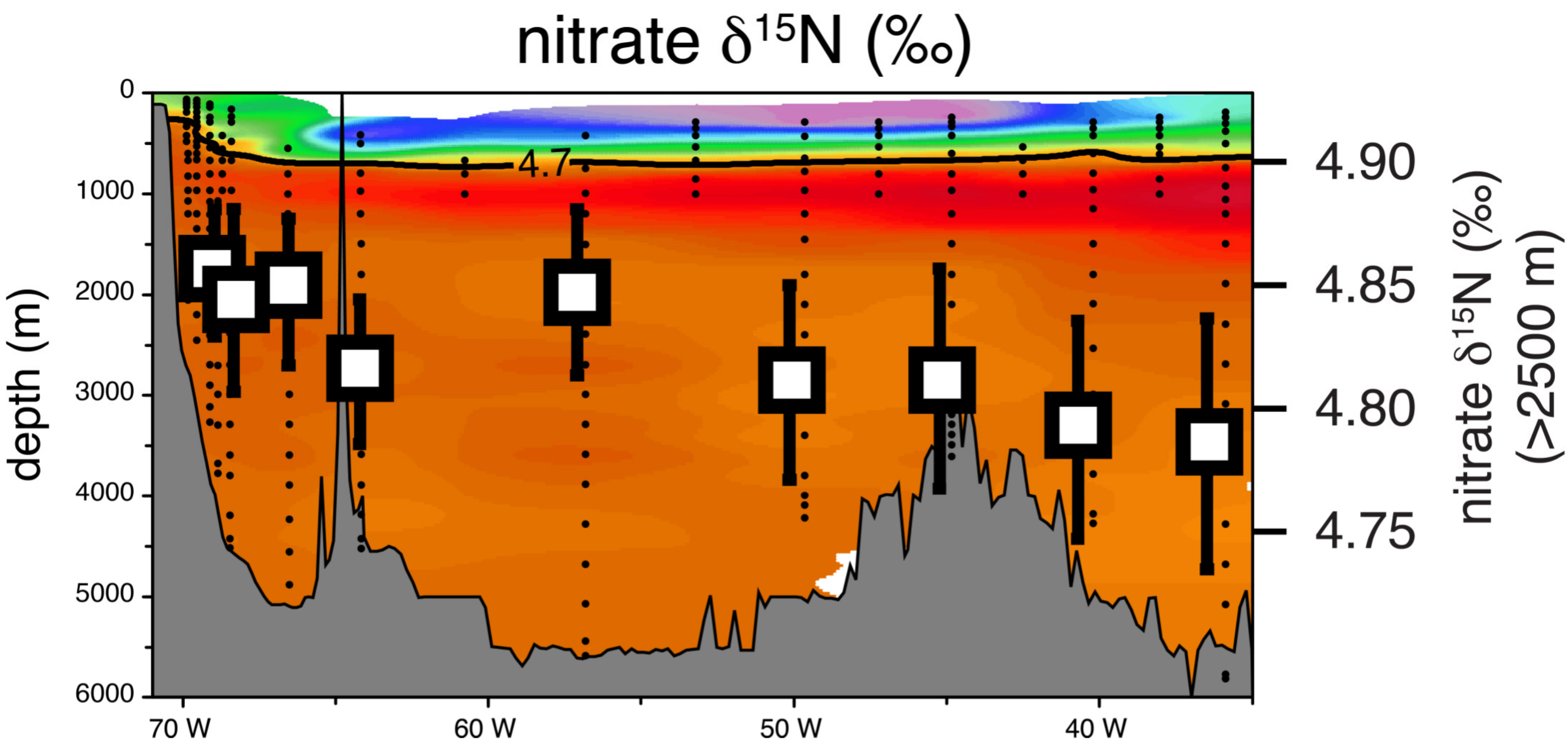


Fe & Cd : Seth John

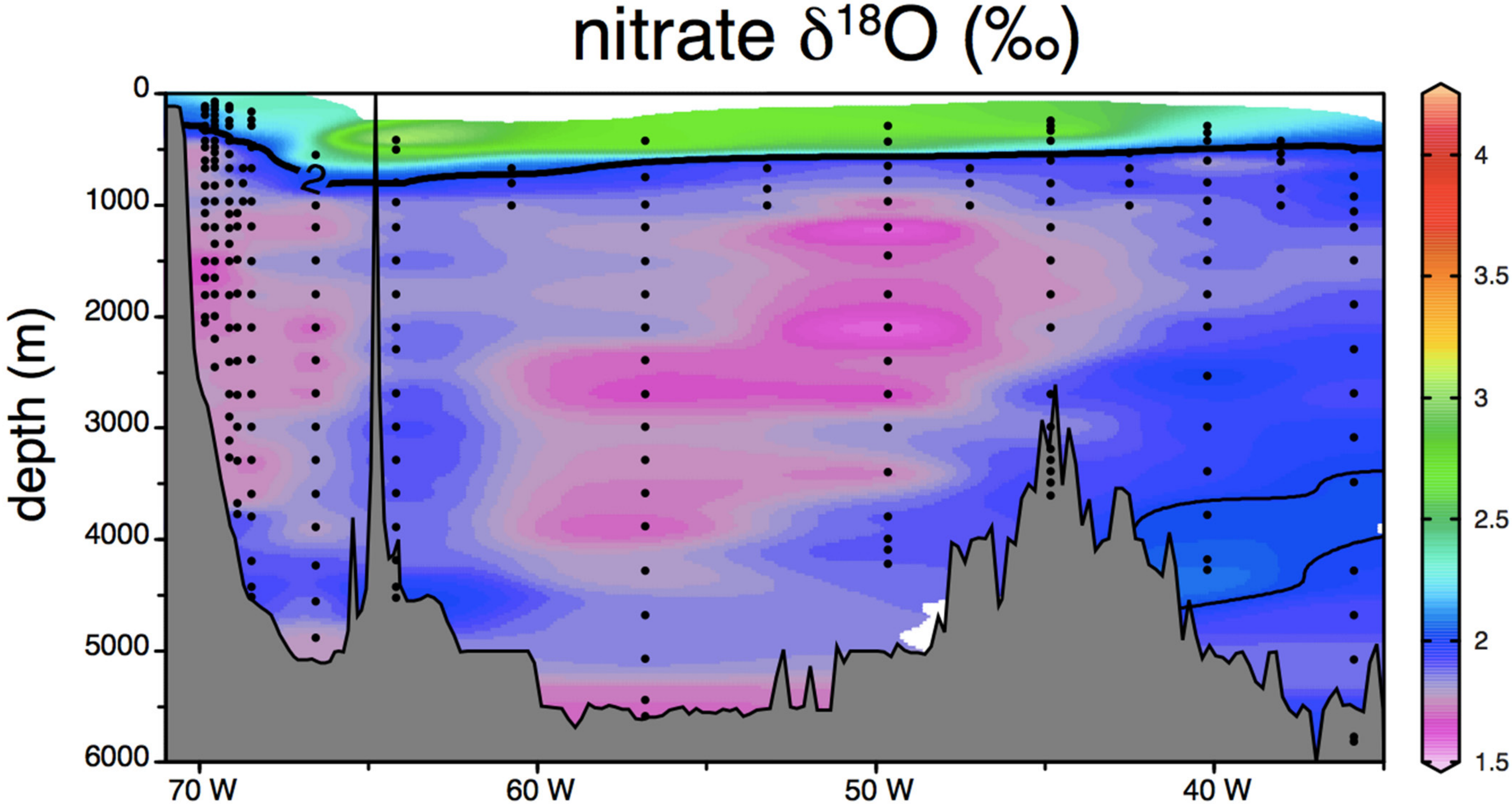


Sigman group (D. Marconi, P. Rafter, A. Weigand)

The weak deep $\delta^{15}N$ increase to the west: NADW?

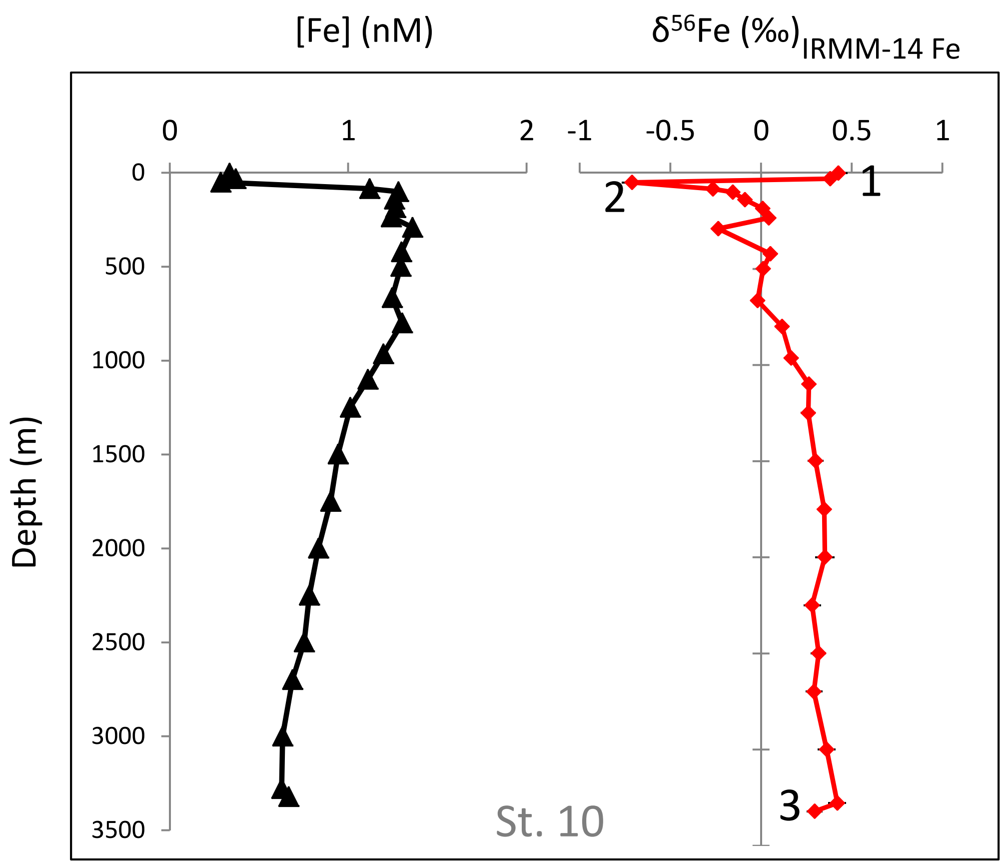


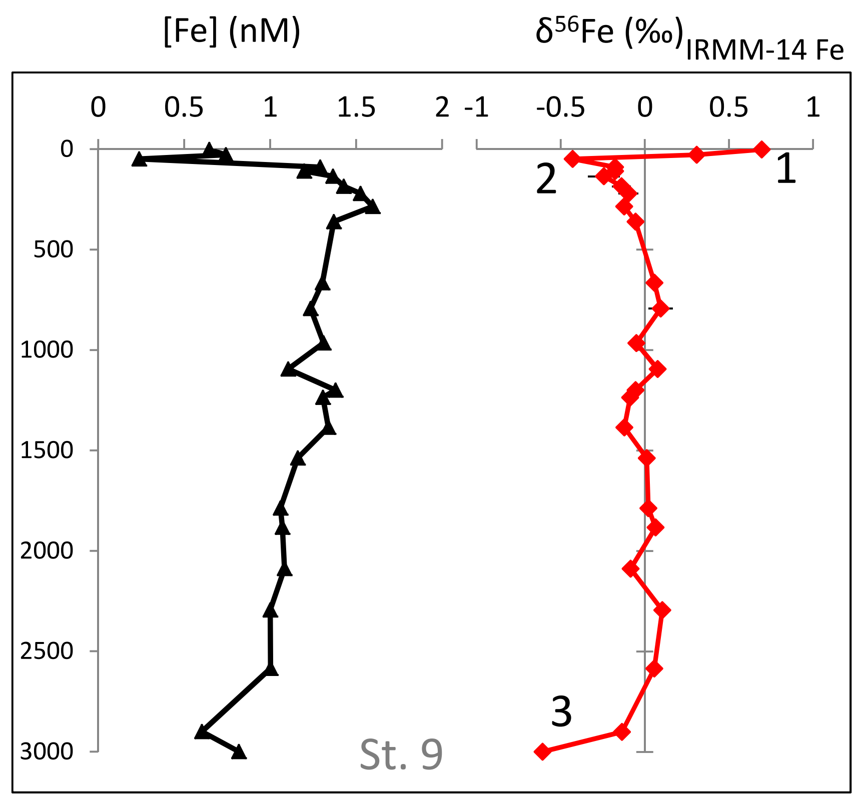
Sigman group (D. Marconi, P. Rafter, A. Weigand)



Sigman group (D. Marconi, P. Rafter, A. Weigand)

Iron Isotopes from (2010 Leg) Stations 9 and 10





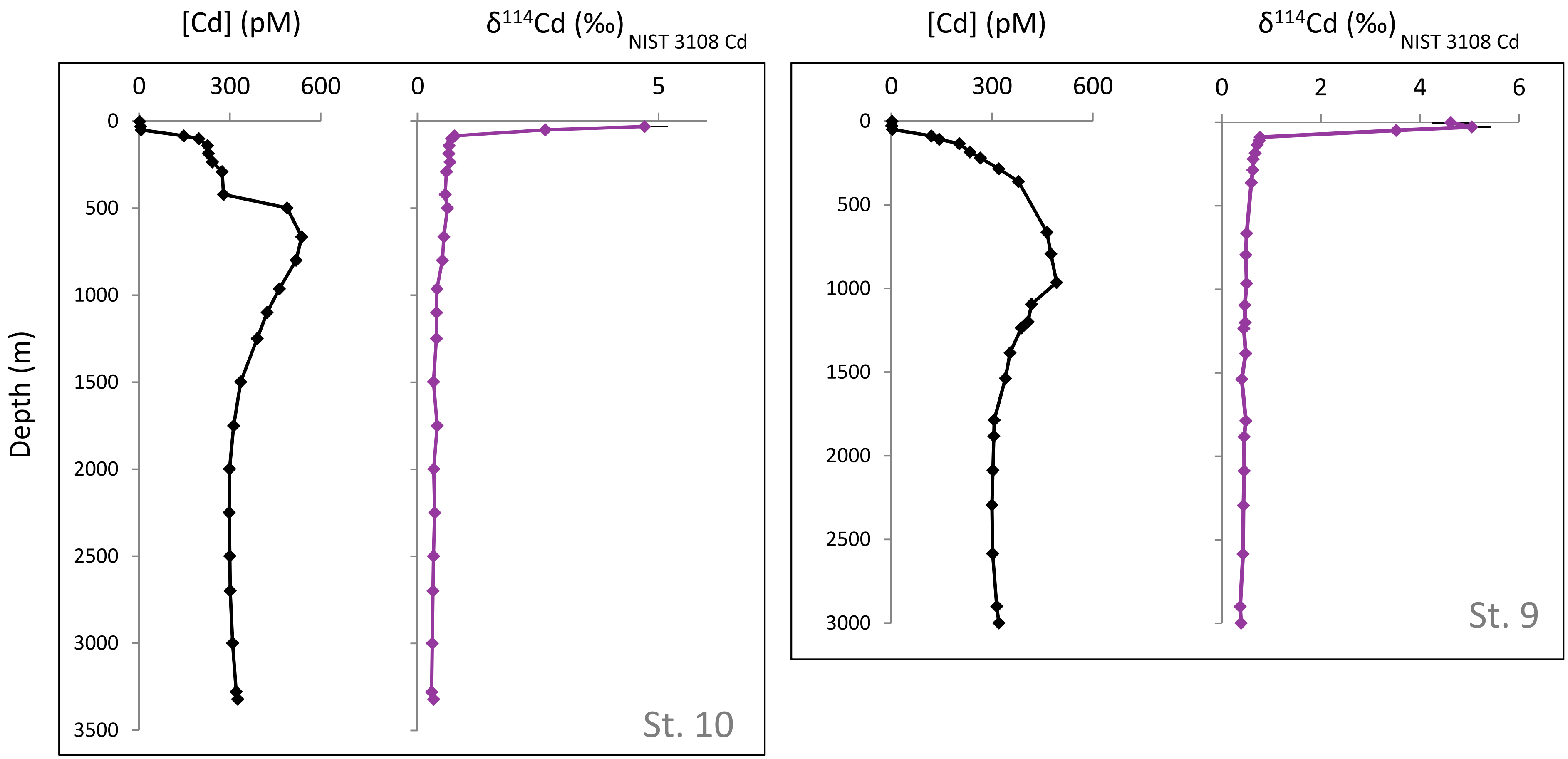
Both stations exhibit similar patterns

Seth John and Tim Conway
Marine Trace Element Lab,
University of South Carolina

<u>Several hypothesized features visible:</u>

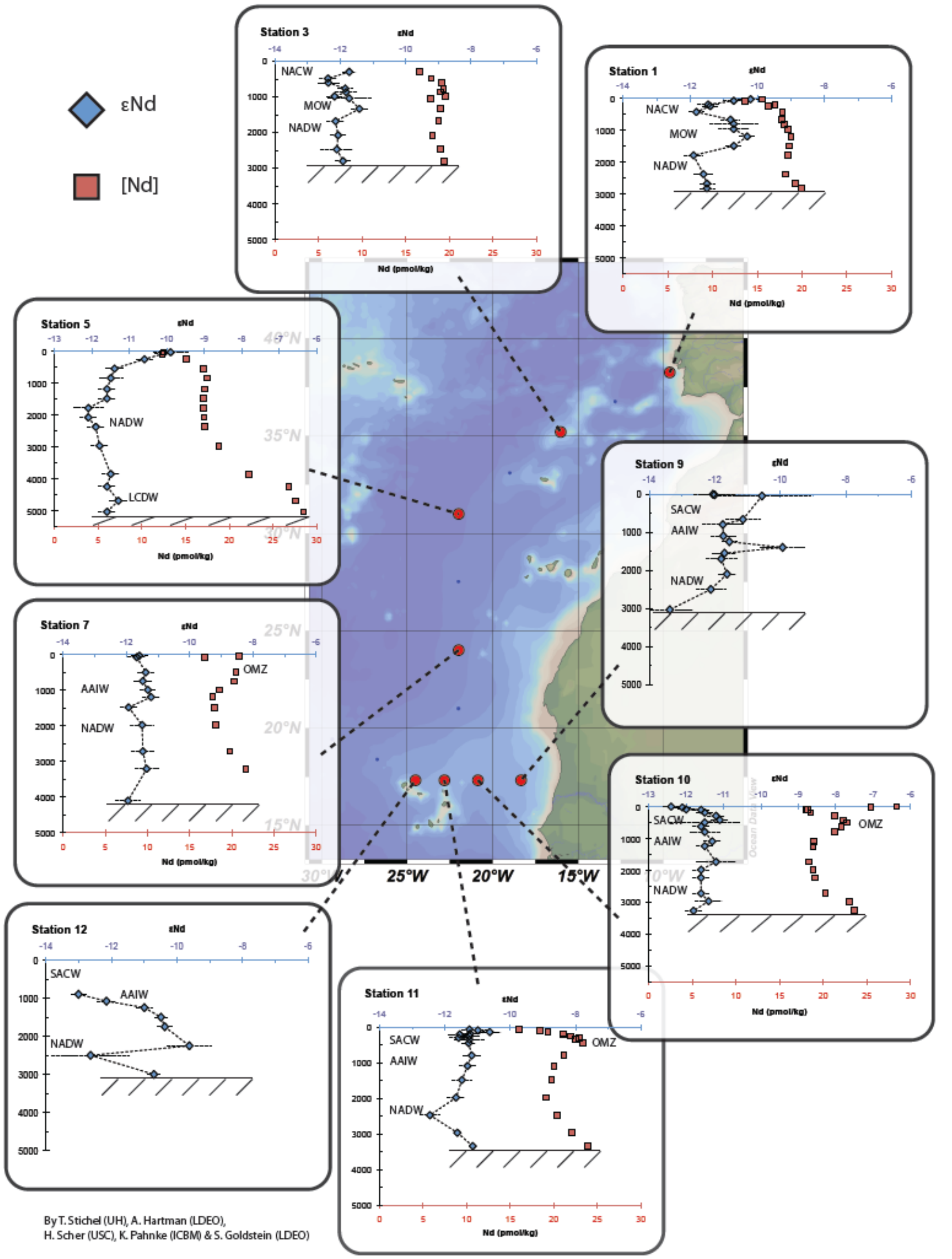
1. Dust input (+0.5-0.8 ‰)
2. Biological uptake of Fe
3. Deep sedimentary input of Fe

Cadmium Isotopes from (2010 Leg) Stations 9 and 10



Seth John and Tim Conway
Marine Trace Element Lab,
University of South Carolina

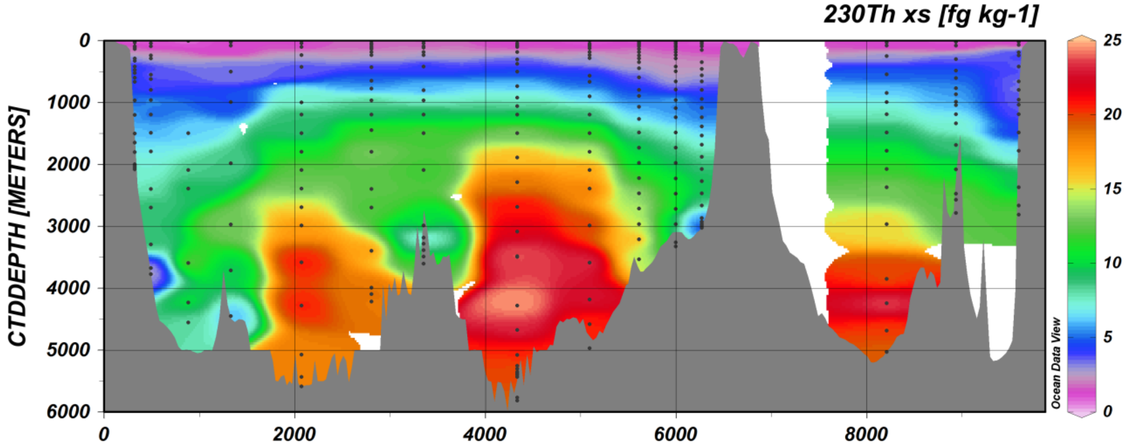
- Cd Isotope and concentration profiles reflect nutrient uptake and remineralization.
- Low concentration and high $\delta^{114}Cd$ at surface
- Deep water $\delta^{114}Cd$ stable at 0.3 - 0.4 ‰

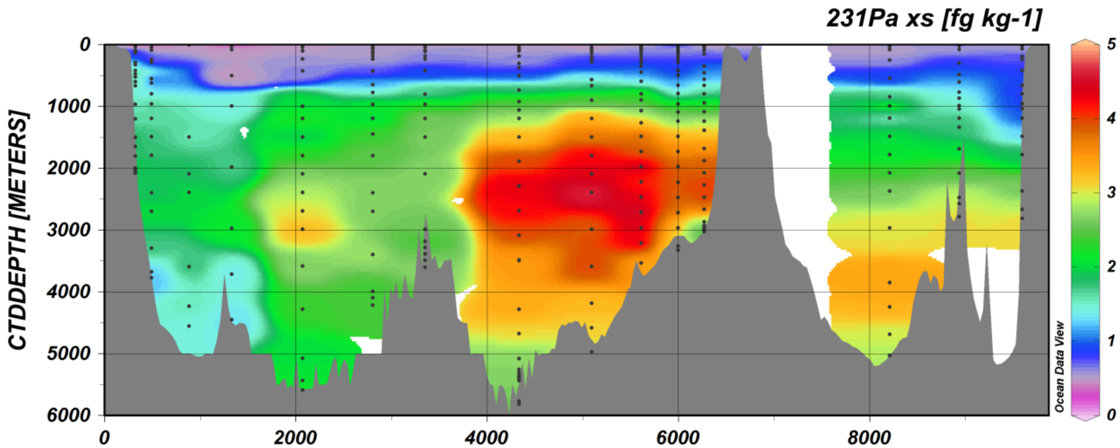


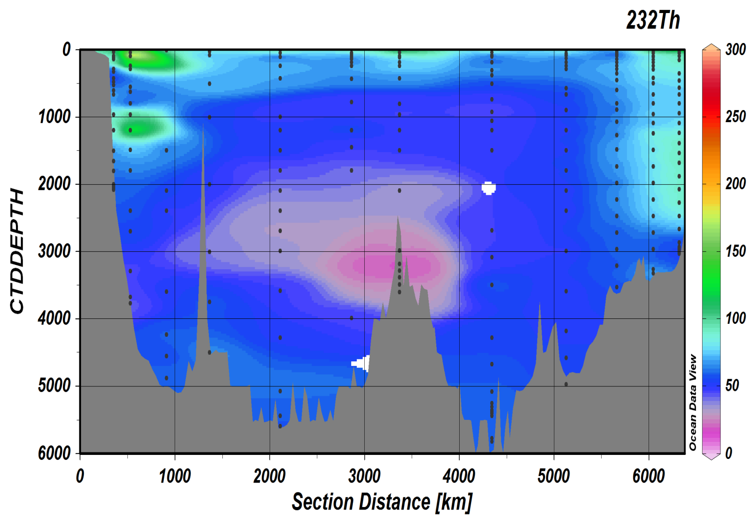
By T. Stichel (UH), A. Hartman (LDEO),
H. Scher (USC), K. Pahnke (ICBM) & S. Goldstein (LDEO)

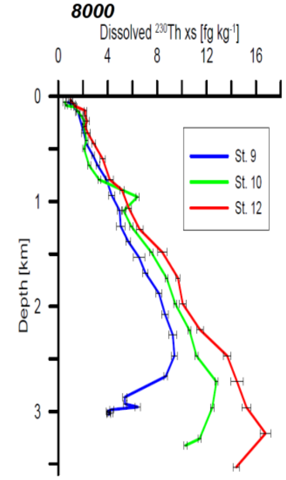
Particle reactive isotopes

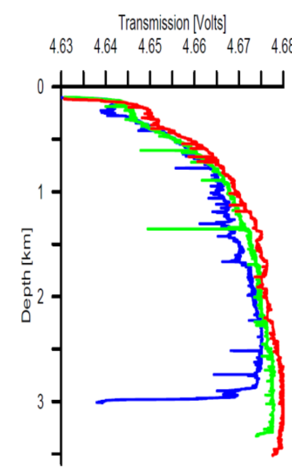
Differences in sorption between elements in the U-Th decay series highlights the particle and productivity dynamics in the water column, especially in hydrothermal plumes, bottom nepheloid layers and near boundaries.





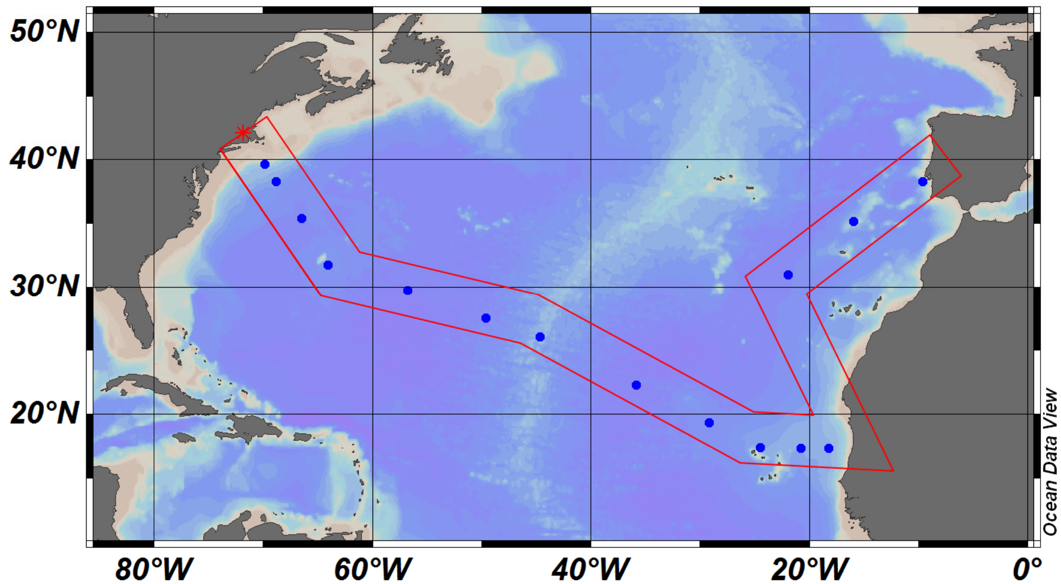






Hayes, Anderson, Fleisher (LDEO); Robinson, Auro, Huang (WHOI); Cheng,, Edwards (UMinn); Moran (URI)

Results from the ^{230}Th-^{231}Pa-^{232}Th group

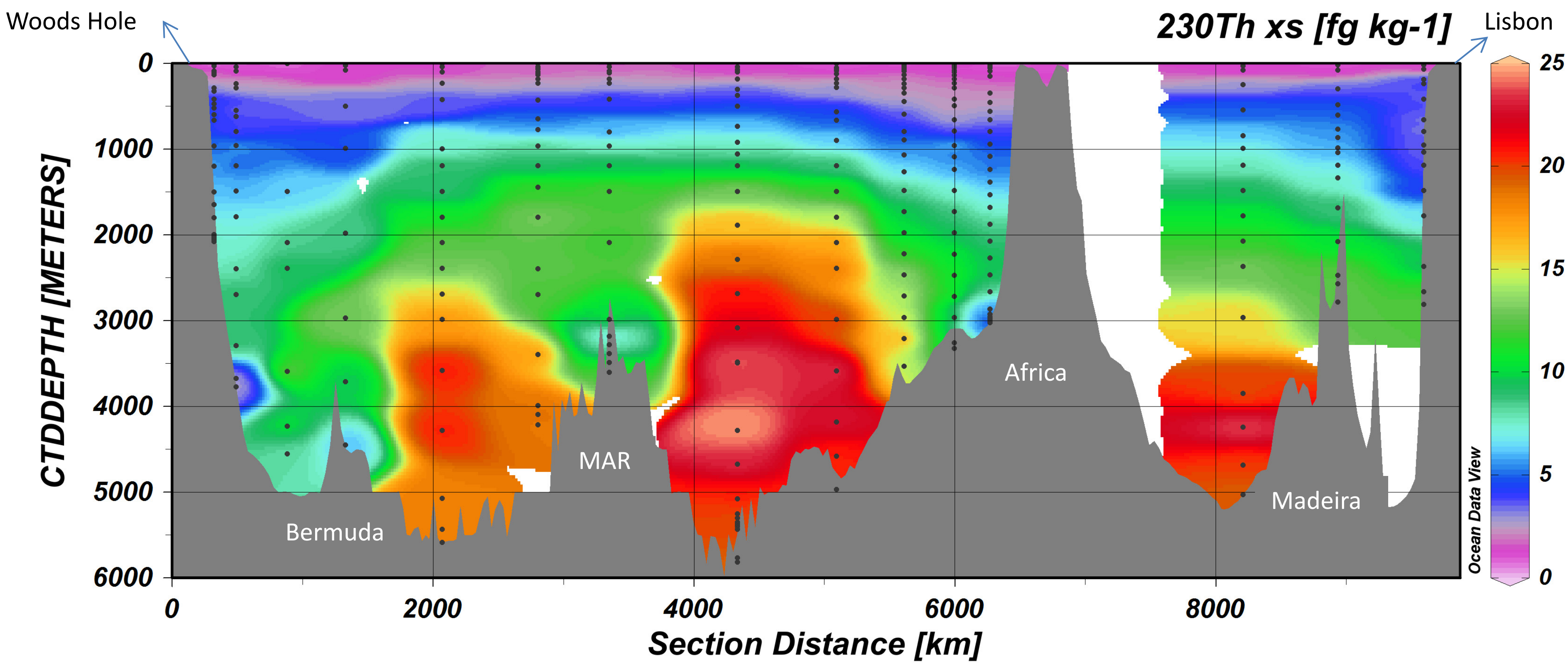


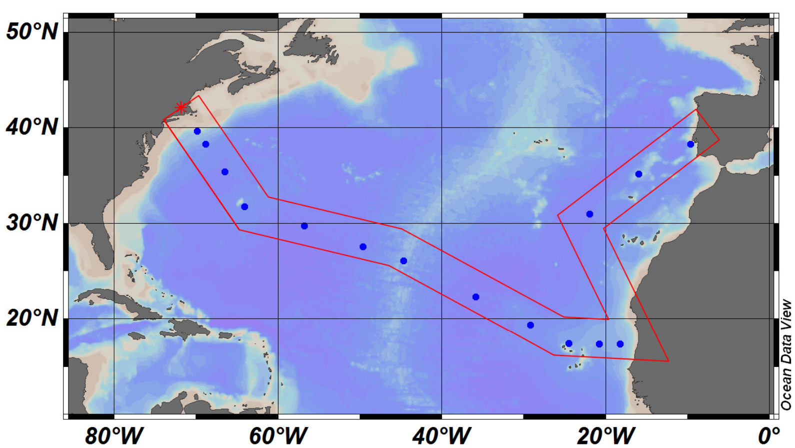
Hayes, Anderson, Fleisher (LDEO);

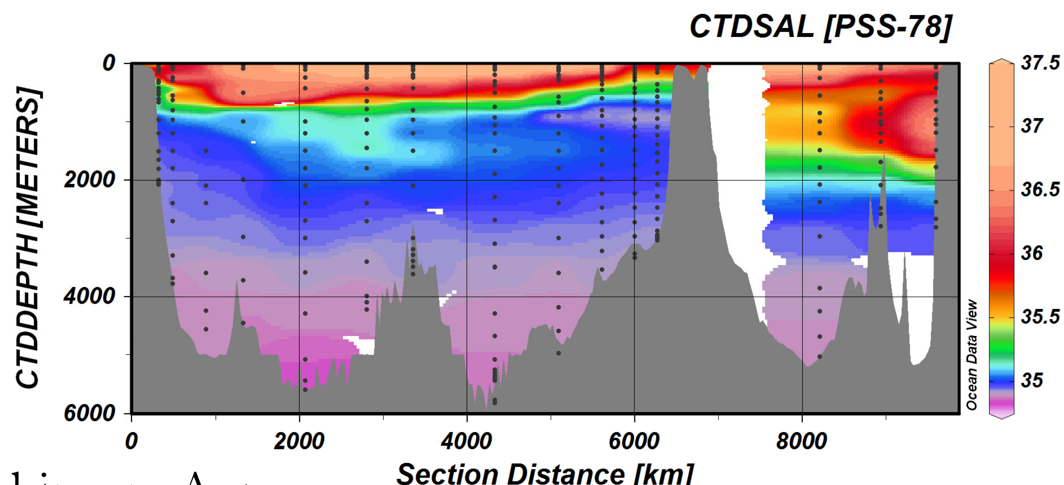
Robinson, Auro, Huang (WHOI);

Cheng, Edwards (UMinn);

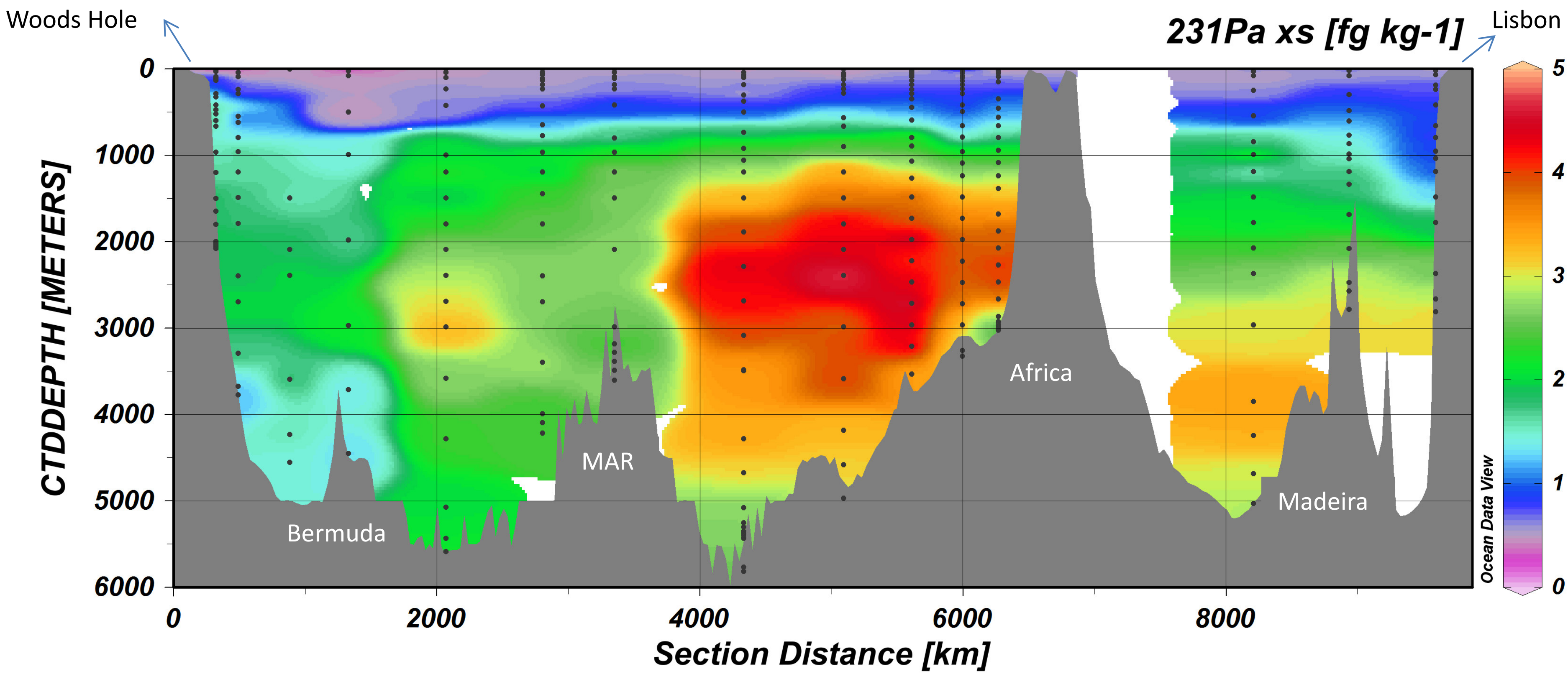
Moran (URI)

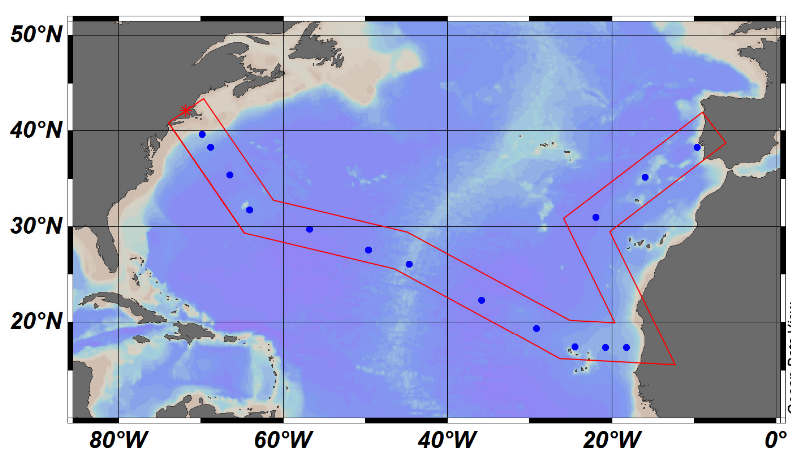


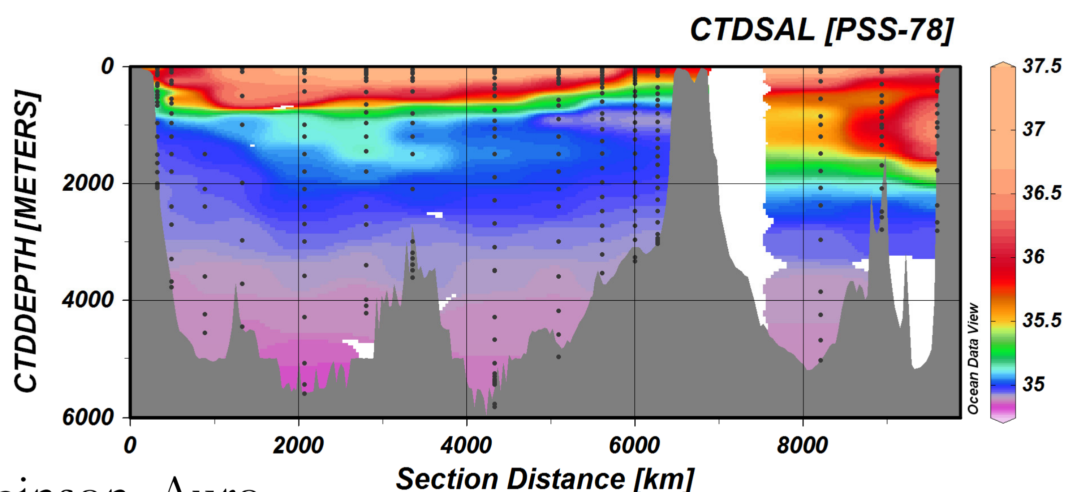




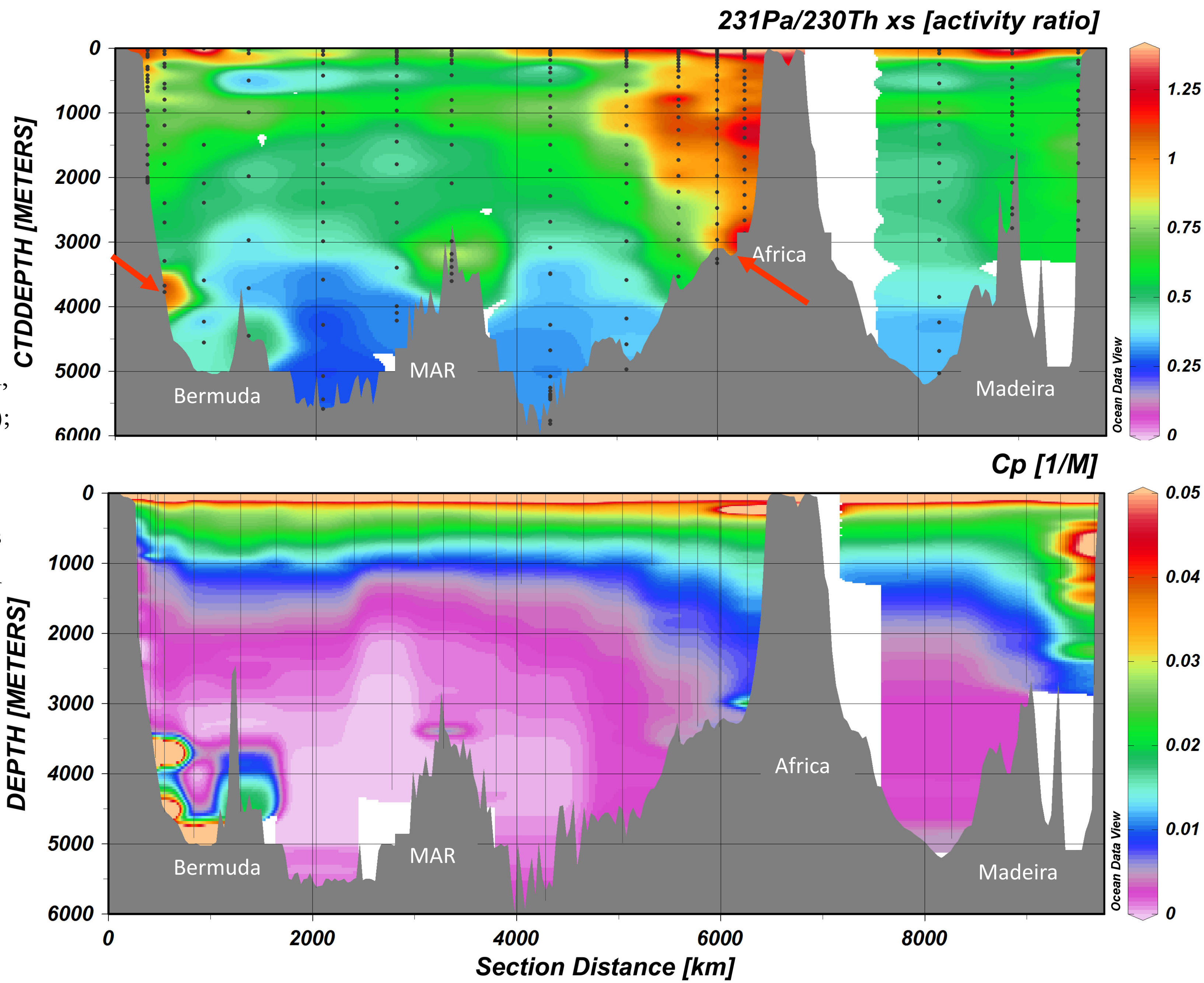
Hayes, Anderson, Fleisher (LDEO); Robinson, Auro, Huang (WHOI); Cheng,, Edwards (UMinn); Moran (URI)



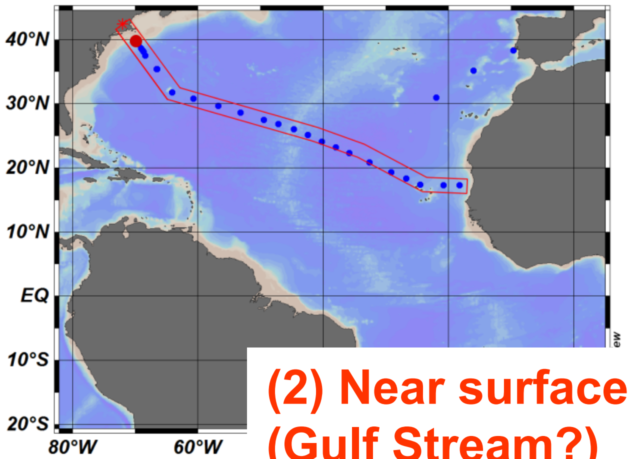




Hayes, Anderson, Fleisher (LDEO); Robinson, Auro, Huang (WHOI); Cheng,, Edwards (UMinn); Moran (URI)

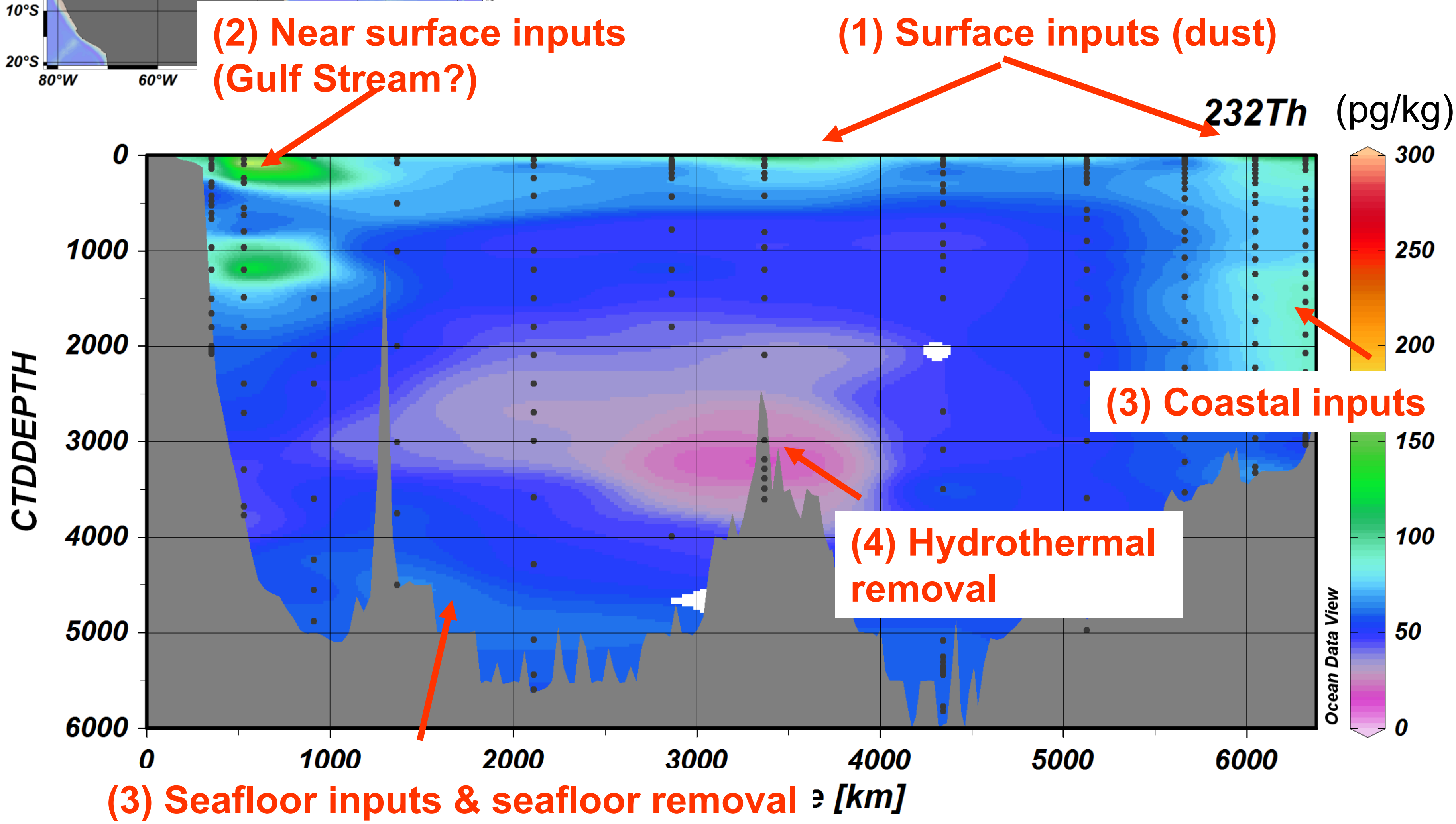


Hayes, Anderson, Fleisher (LDEO); Robinson, Auro, Huang (WHOI); Cheng,, Edwards (Uminn); Moran (URI)

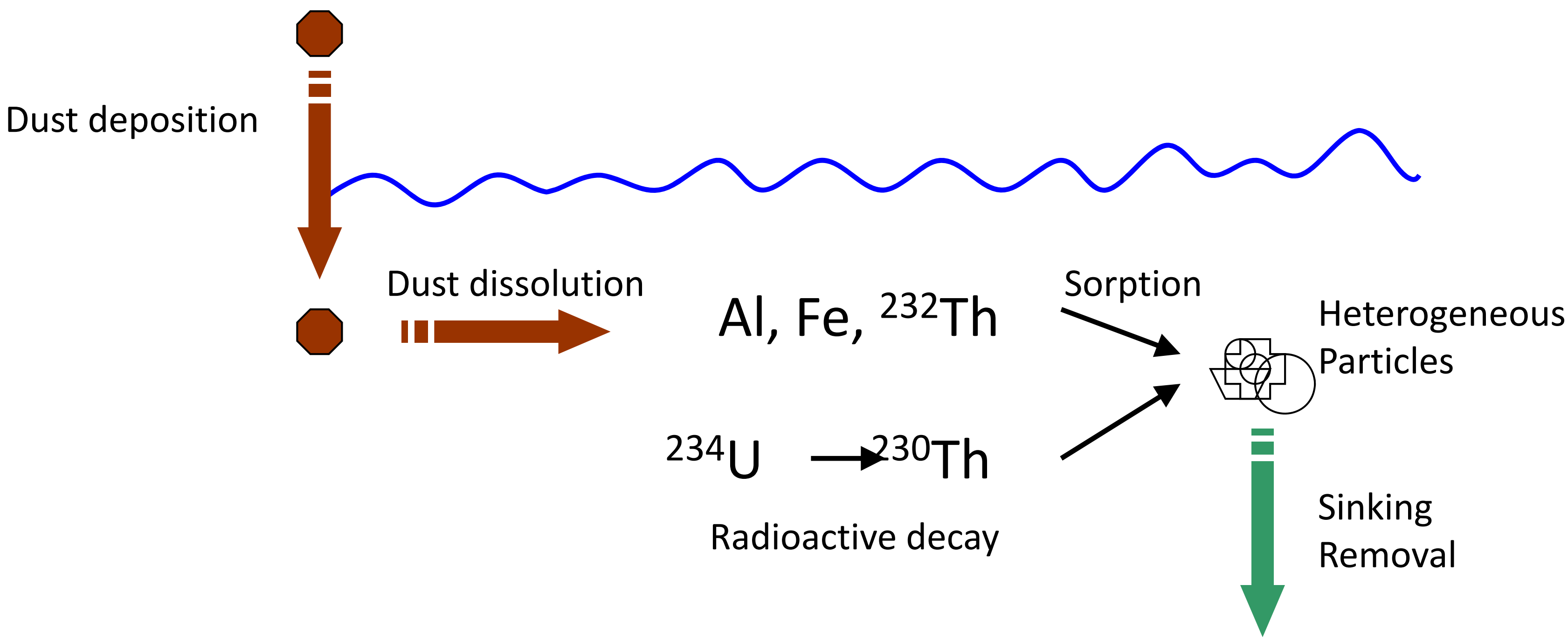


^{232}Th in US Geotraces North Atlantic section

Hayes, Anderson, Fleisher (LDEO); Robinson, Auro, Huang (WHOI); Cheng,, Edwards (UMinn); Moran (URI)



New strategy to estimate trace element supply from aerosol deposition



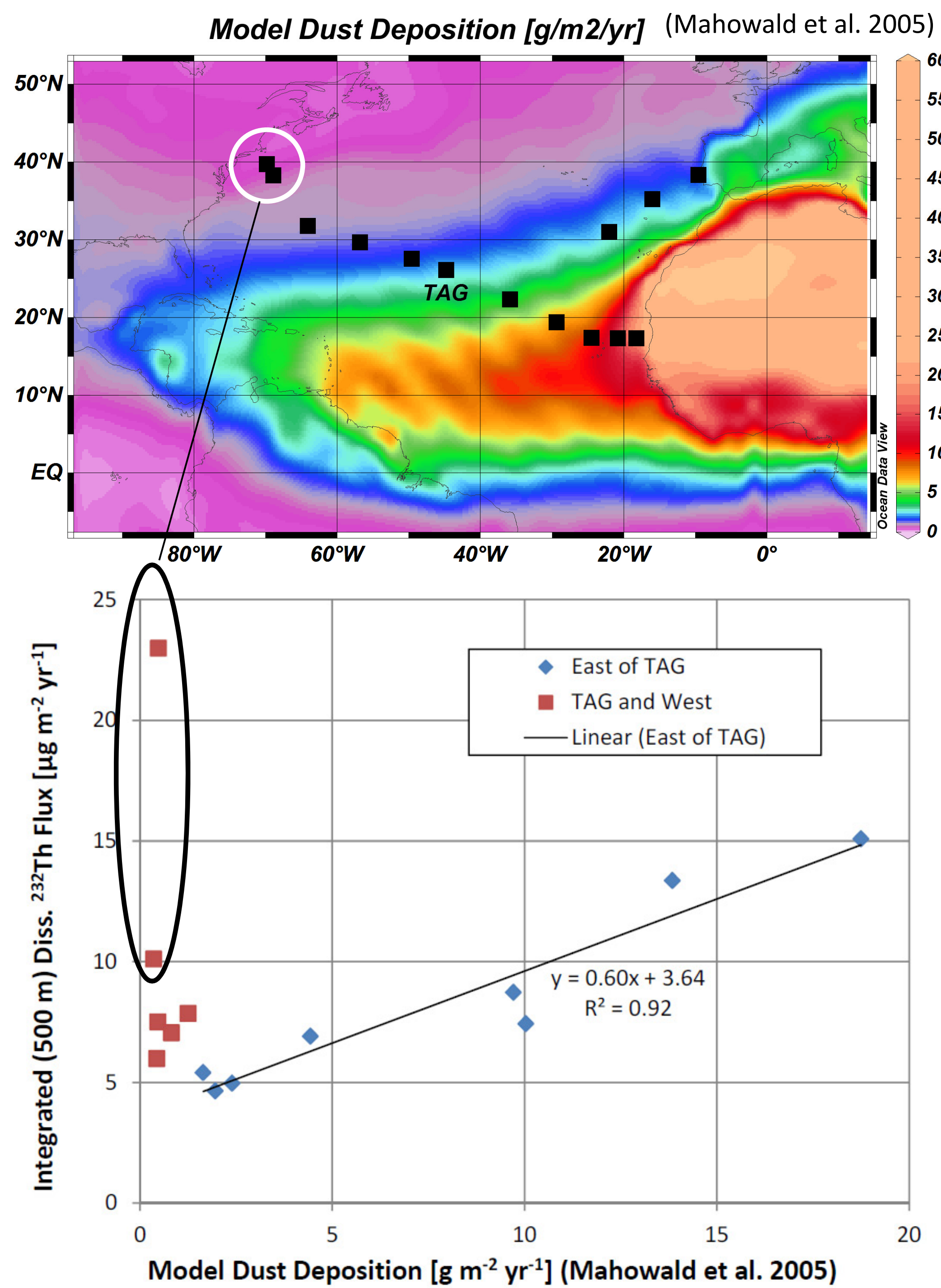
Residence time of Th derived from $^{230}Th/^{234}U$ disequilibrium,
Applied to dissolved ^{232}Th gives *rate* of Th supply from dust.

(Hirose and Sugimura, 1987; Hsieh et al., 2011)

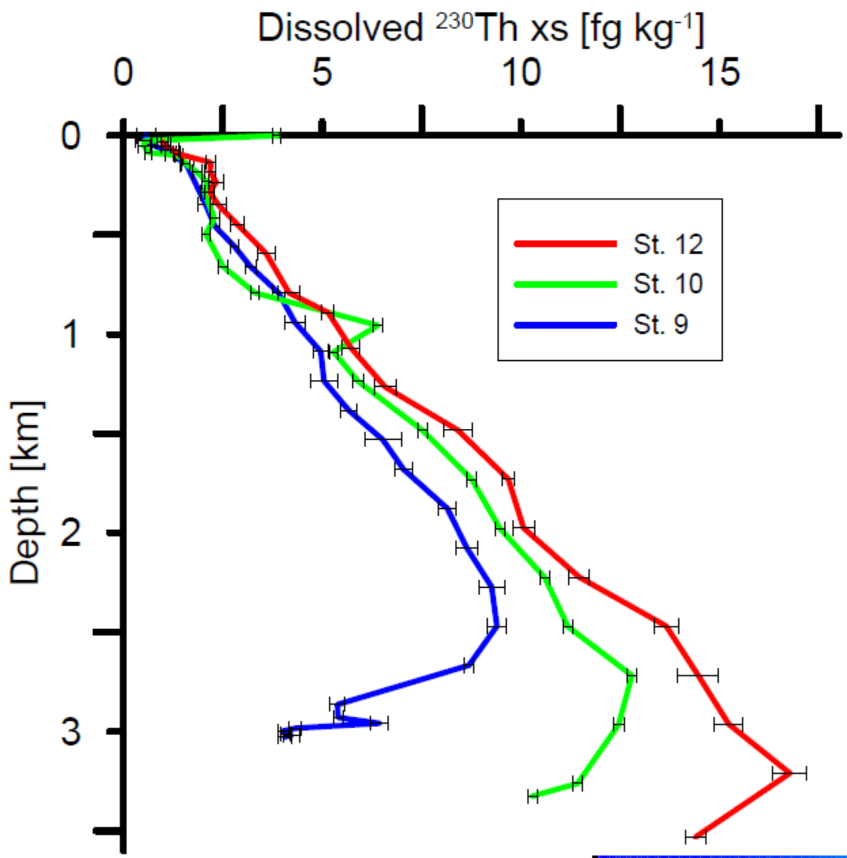
Paired Th isotopes to estimate soluble trace element supply by dust deposition:

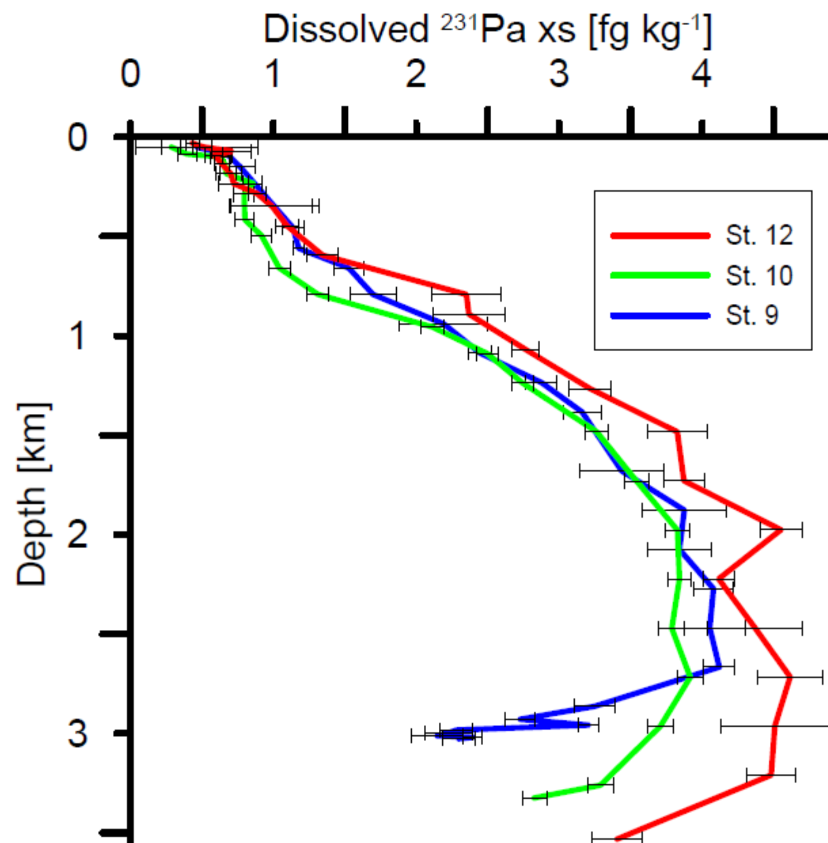
$$\text{Dust Flux} = \frac{Diss.\,^{232}Th\ flux}{S * [Th]_{dust}}$$

Hayes, Anderson, Fleisher (LDEO);
Robinson, Auro, Huang (WHOI);
Cheng, Edwards (UMinn);
Moran (URI)

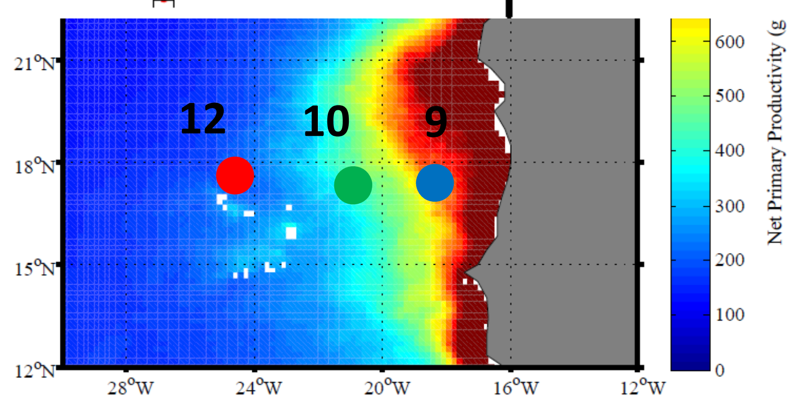


Boundary Scavenging



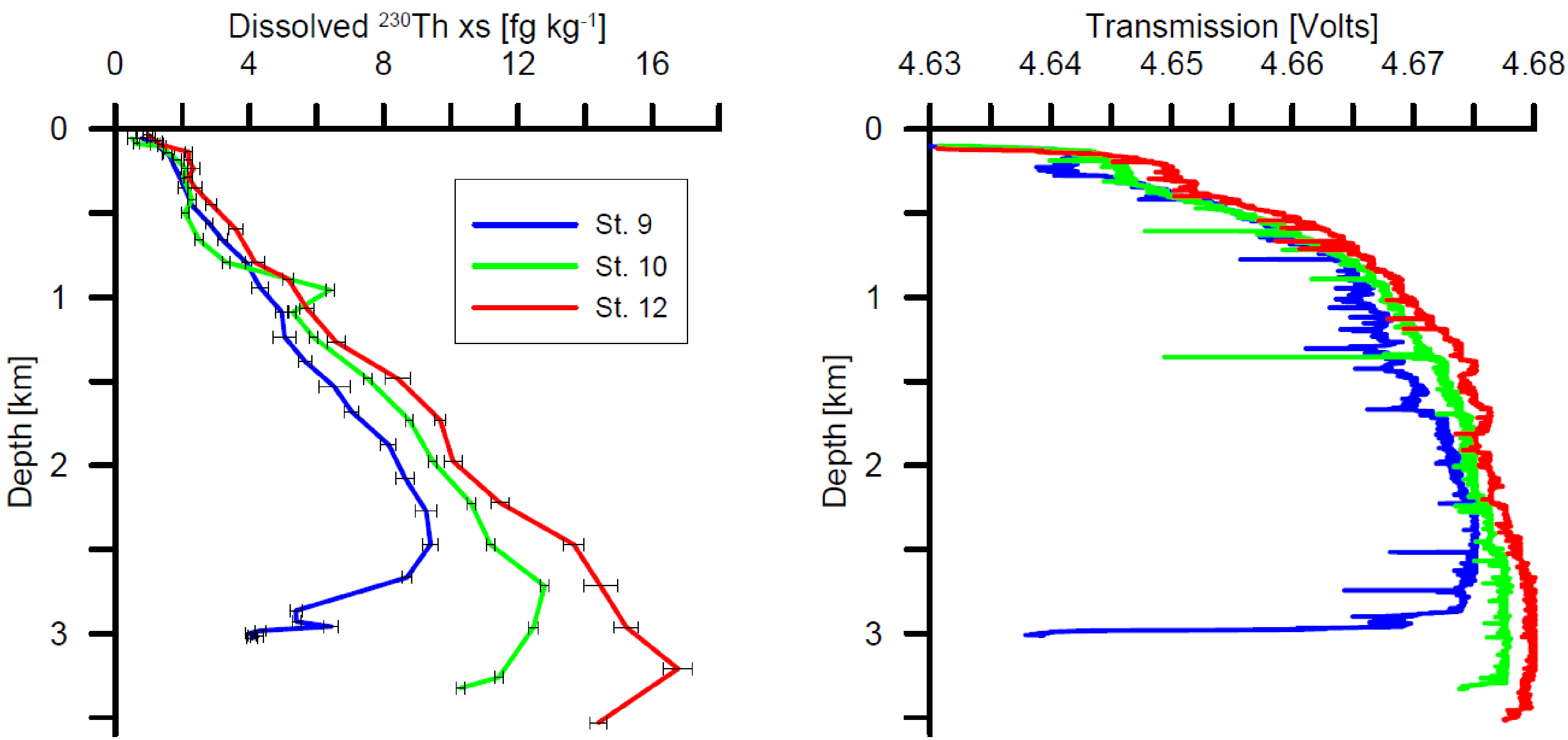


Hayes, Anderson, Fleisher (LDEO); Robinson, Auro, Huang (WHOI); Cheng,, Edwards (UMinn); Moran (URI)



NPP from SEAWIFS and VGPM (Behrenfeld)

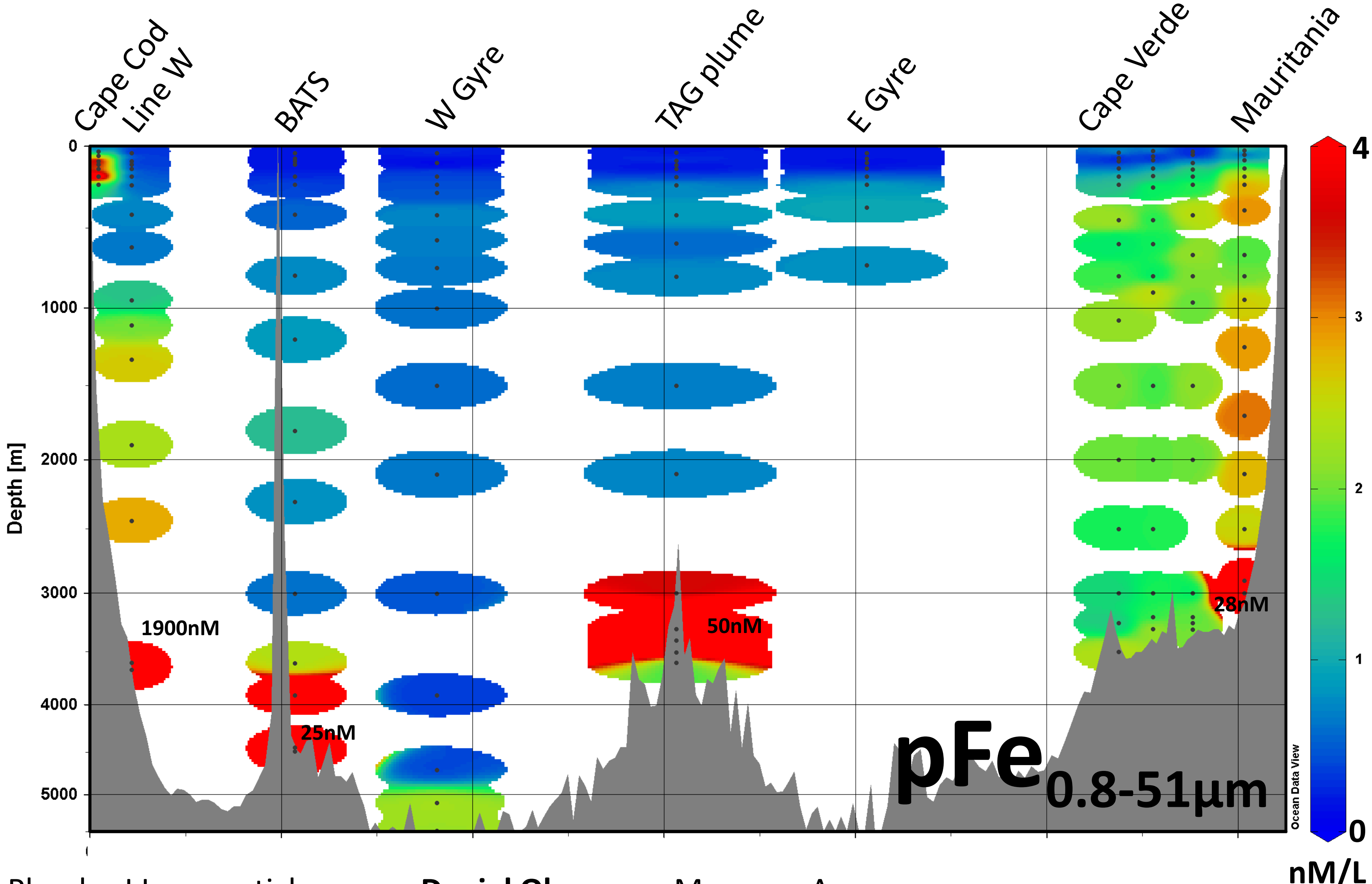
Greatest Lateral Gradient Associated with Nepheloid Layer – Bottom Scavenging



Hayes, Anderson, Fleisher (LDEO); Robinson, Auro, Huang (WHOI); Cheng,, Edwards (UMinn); Moran (URI)

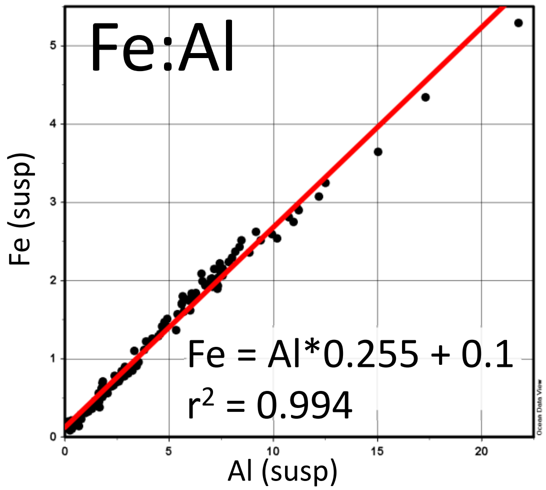
Basin-Wide, Size-Fractionated Particulate TEIs

Suspended (<51µm) and sinking (>51µm) concentrations for >20 pTEIs, in progress…

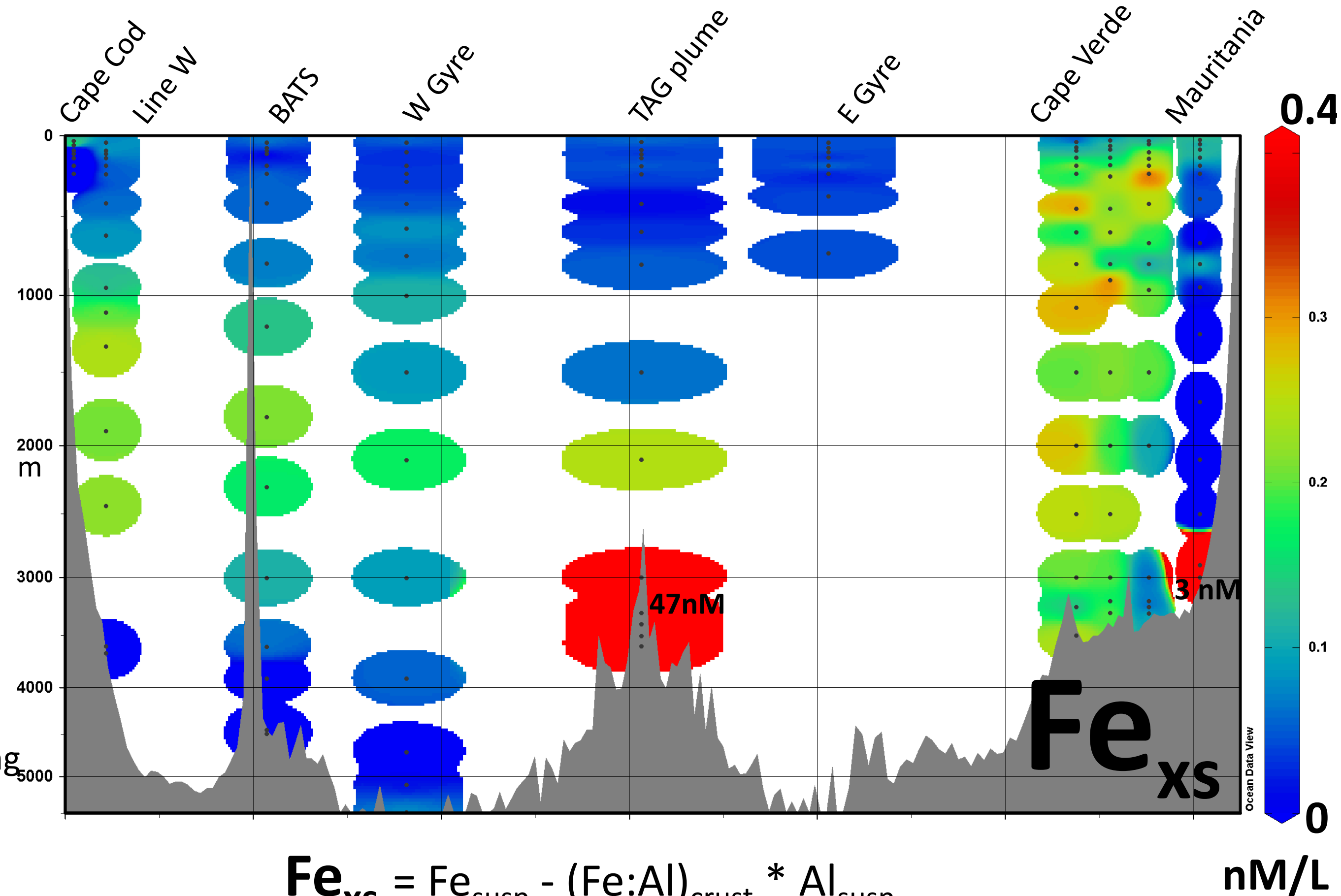


Phoebe J Lam particle group: **Daniel Ohnemus**, Maureen Auro

Fe_{xs} plumes in W. Basin, TAG, and near Mauritania



pFe and pAl are tightly correlated throughout the basin. Crustal composition ratios (0.2-0.3 Fe:Al [Taylor; Rudnick]) indicate close co-transport of these (and other) pTEIs within lithogenic particles. Correcting for this lithogenic material, we can also examine authigenic phases:

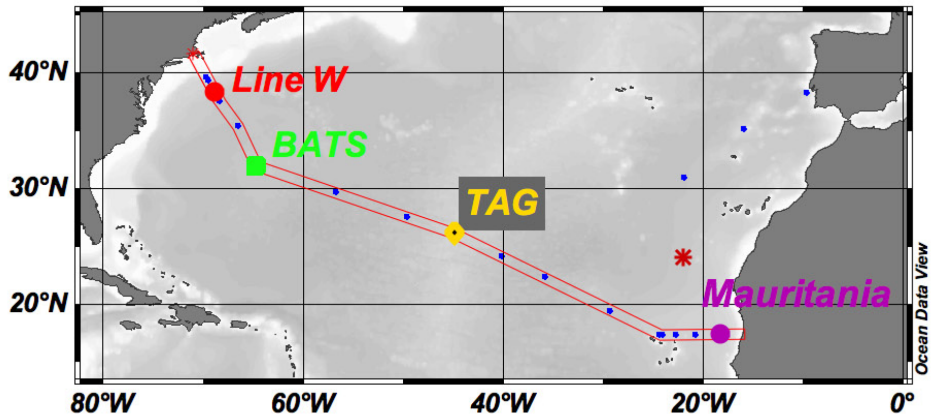


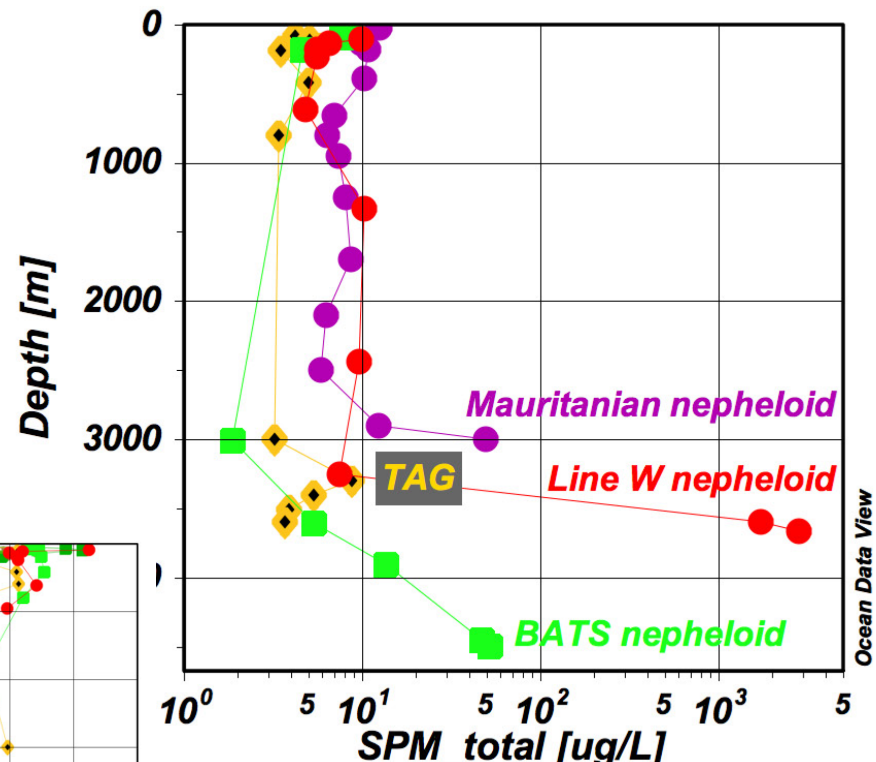
$$Fe_{xs} = Fe_{susp} - (Fe:Al)_{crust} * Al_{susp}$$

Fe_{xs} fully removes the strong benthic nepheloid signals in the deep western basin, indicating these layers are strongly terrestrial in nature. Strong Fe excesses (presumably from authigenic precipitation of Fe) are observed in particles at the TAG hydrothermal site and near reducing sediments at the Maruritanian coast. Weaker signals are found associated with Labrador seawater in the intermediate-depth west basin, and in the water column beneath the Saharan dust plume.

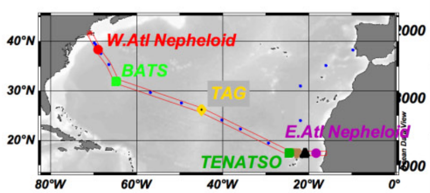
Phoebe J Lam particle group: **Daniel Ohnemus**, Maureen Auro

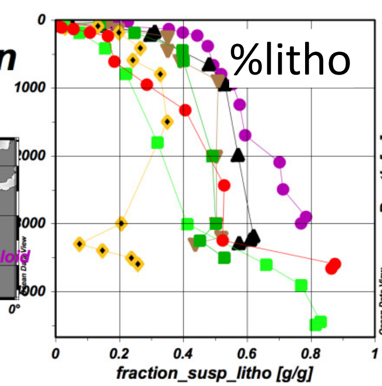
Particles (from pumps)

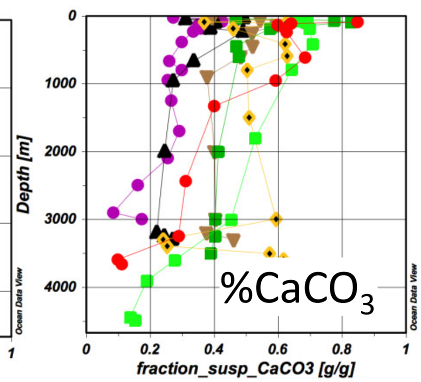


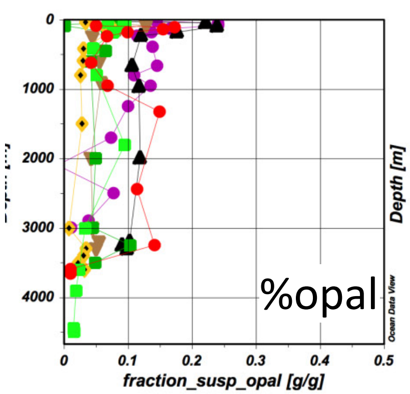


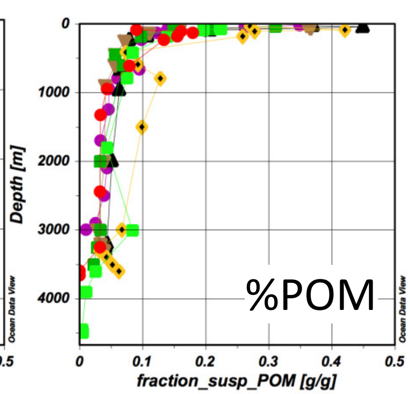
Suspended Particle Composition









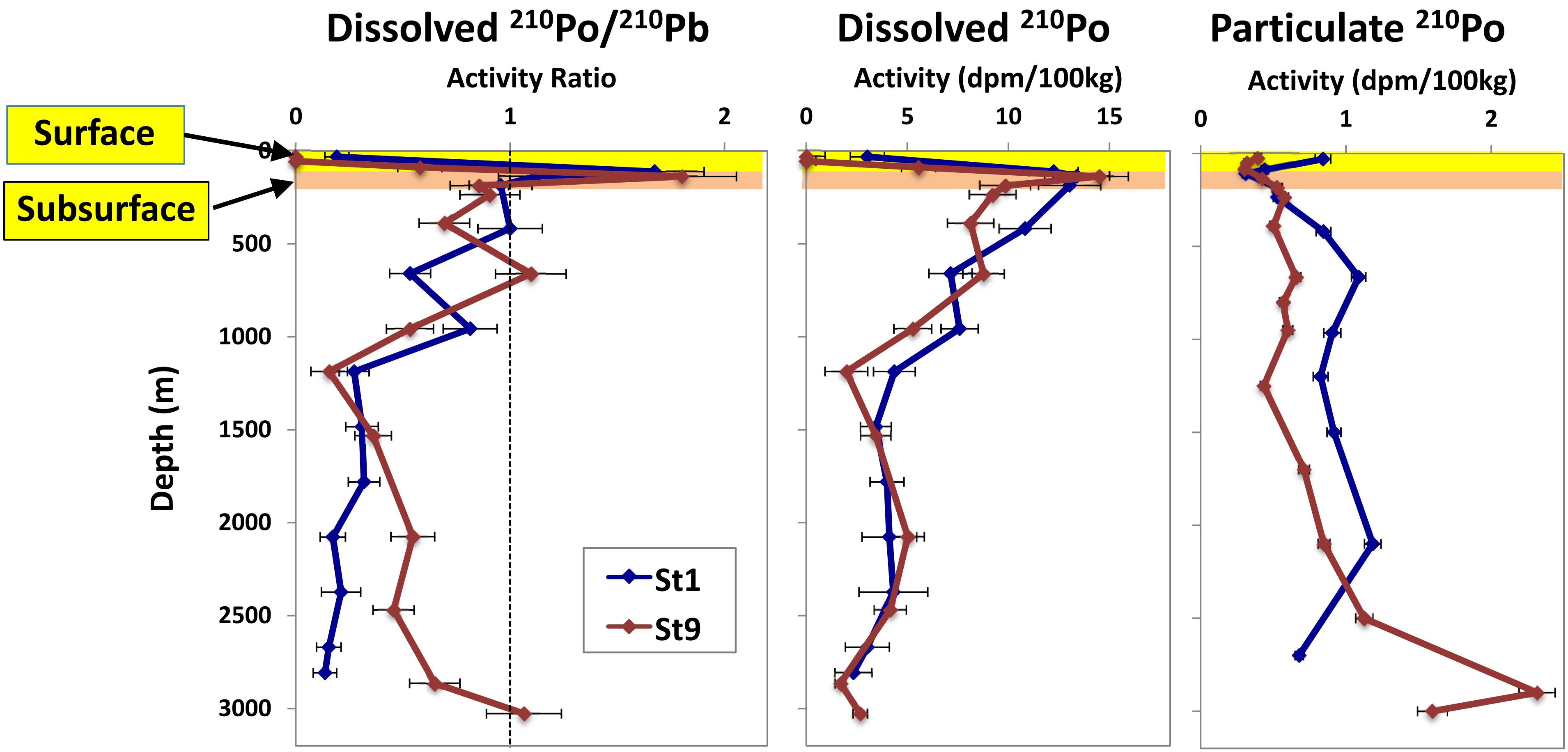


Paul Morris, Phoebe Lam, Dan Ohnemus, Stephanie Owens, Kuanbo Zhou, Steve Pike, Paul Henderson, Matt Charette, Ken Buesseler, Billy Moore

US-GT-NAT at the Ocean Carbon and Biogeochemistry meeting

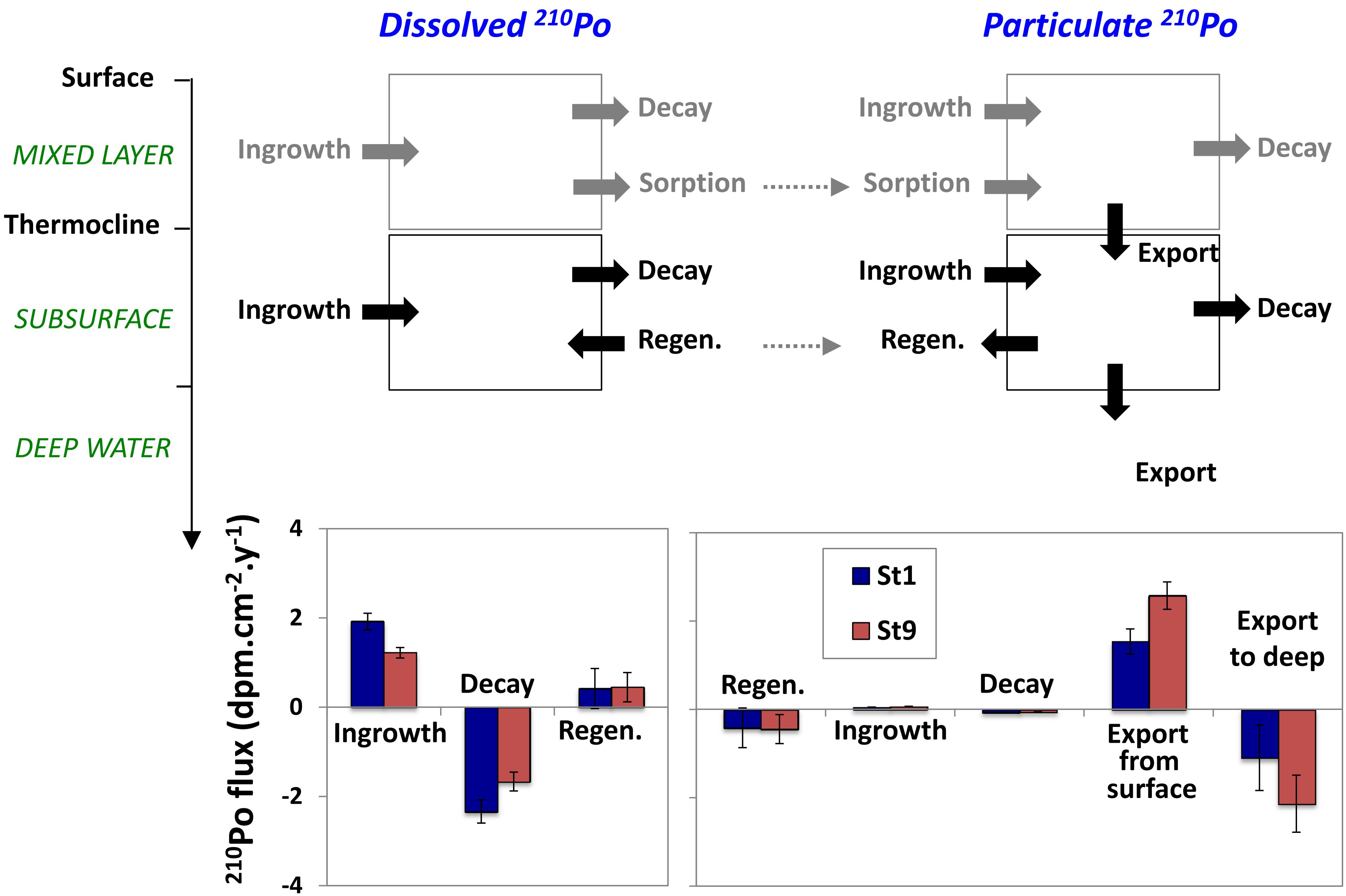
Contribution on ^{210}Po and ^{210}Pb activity in profiles from the GEOTRACES:
- Assessment of particles scavenging rate using $^{210}Po/^{210}Pb$ disequilibrium (soprtion+bioaccumulation processes) and $^{210}Pb/^{226}Ra$ (sorption process only)
- Assessment of POC export from surface ocean and biogenic particles regeneration in subsurface

Analysis of dissolved profiles	*University of Delaware: T. Church, S. Rigaud*
Analysis of small (<51 µm) particulate profiles + aerosols	*Wayne State University: M. Baskaran*
Analysis of large (>51 µm) particulate profiles	*CUNY: G. Stewart, Y. Choi*



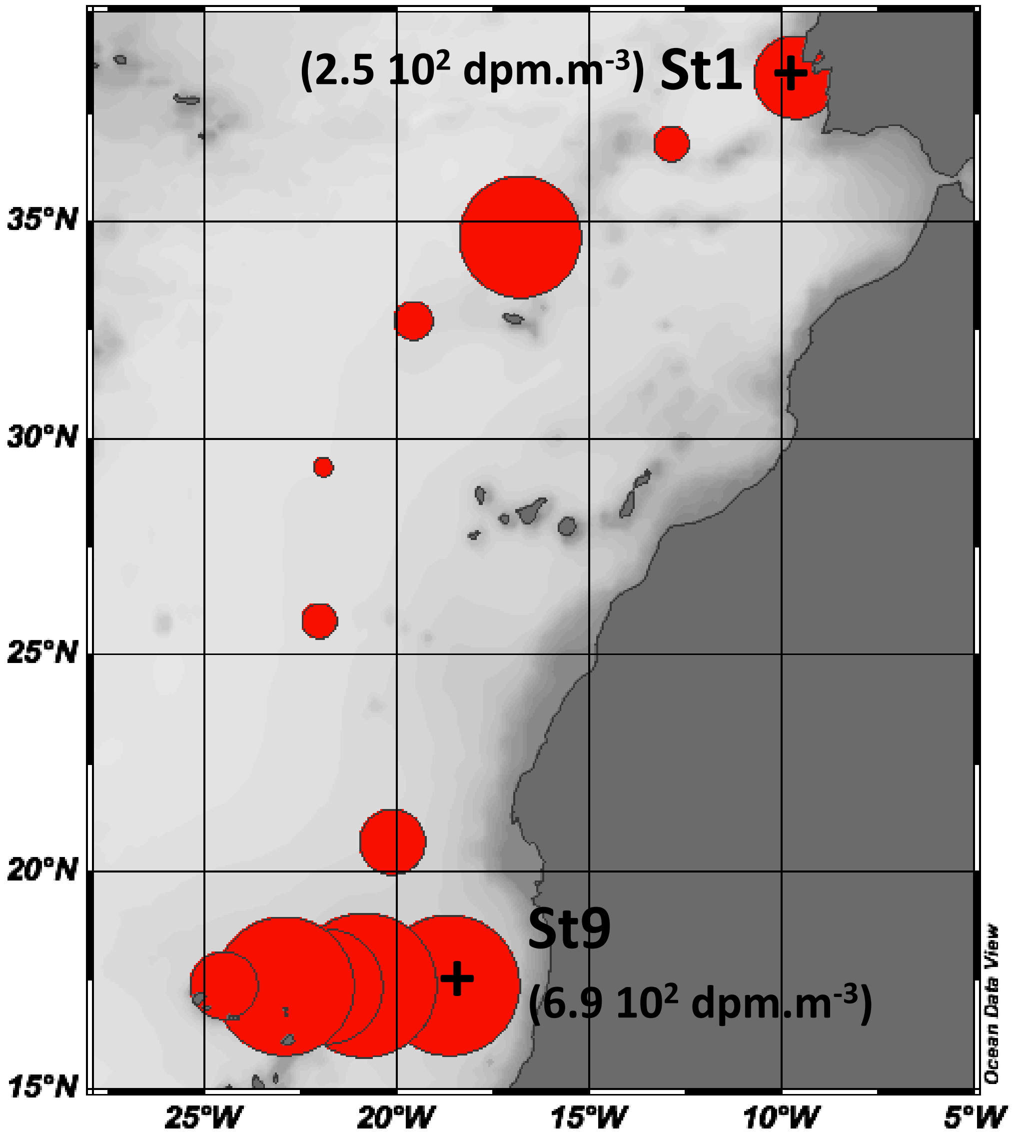
Dissolved $^{210}Po/^{210}Pb$
Activity Ratio
Dissolved ^{210}Po
Activity (dpm/100kg)
Particulate ^{210}Po
Activity (dpm/100kg)
Surface
Subsurface
Depth (m)
St1
St9

Box model calculation



^{210}Pb atmospheric deposition

^{210}Pb activity in aerosols



<u>Total ^{210}Pb deposition fluxes</u>

$$F_{210Pb,T} = [^{210}Pb].v \qquad (v = 1\ cm.s^{-1})$$

<u>Dissolved vs Particulate fluxes</u>

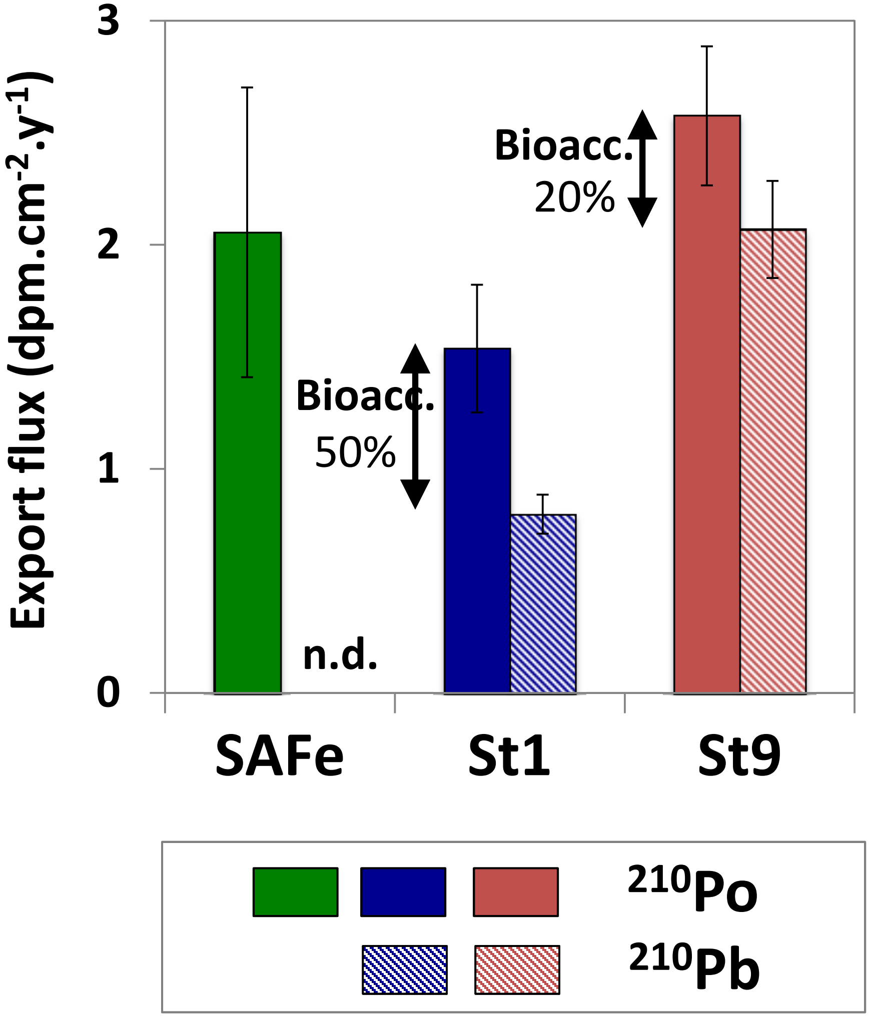
$$F_{210Pb,D} = F_{210Pb,T}\, f_{Pb,s}$$

$$F_{210Pb,P} = F_{210Pb,T}\, (1 - f_{Pb,s})$$

$f_{Pb,s}$ = 25% (St1) ; 2% (St9)

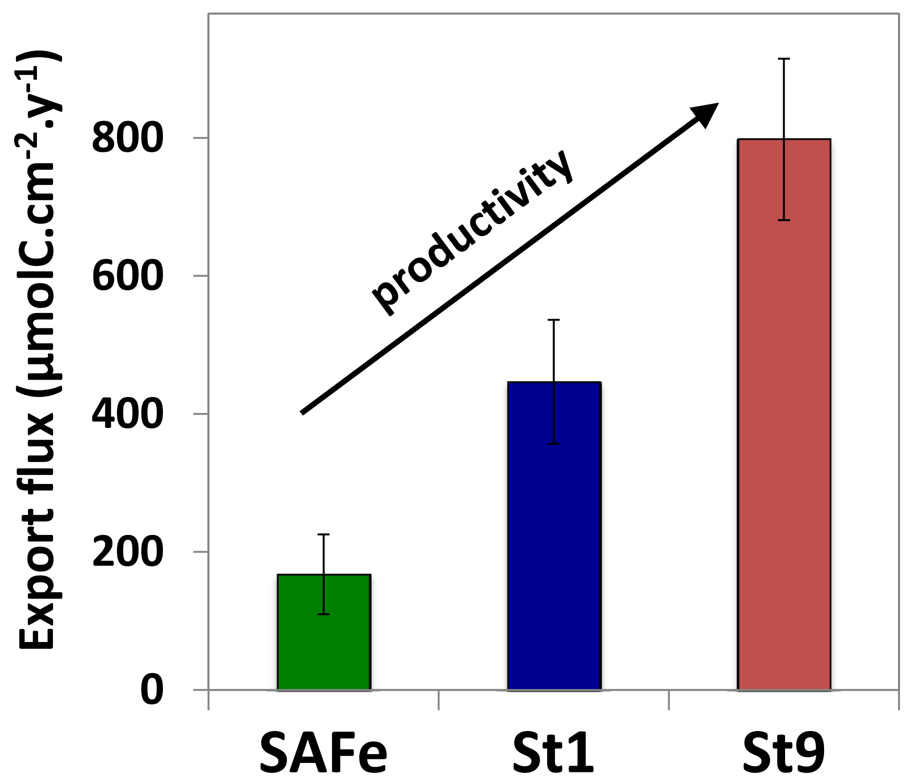
[Shelley & Landing, Pers. Com.]

^{210}Po and ^{210}Pb Particulate export



POC export

[Lam, pers. Com.]



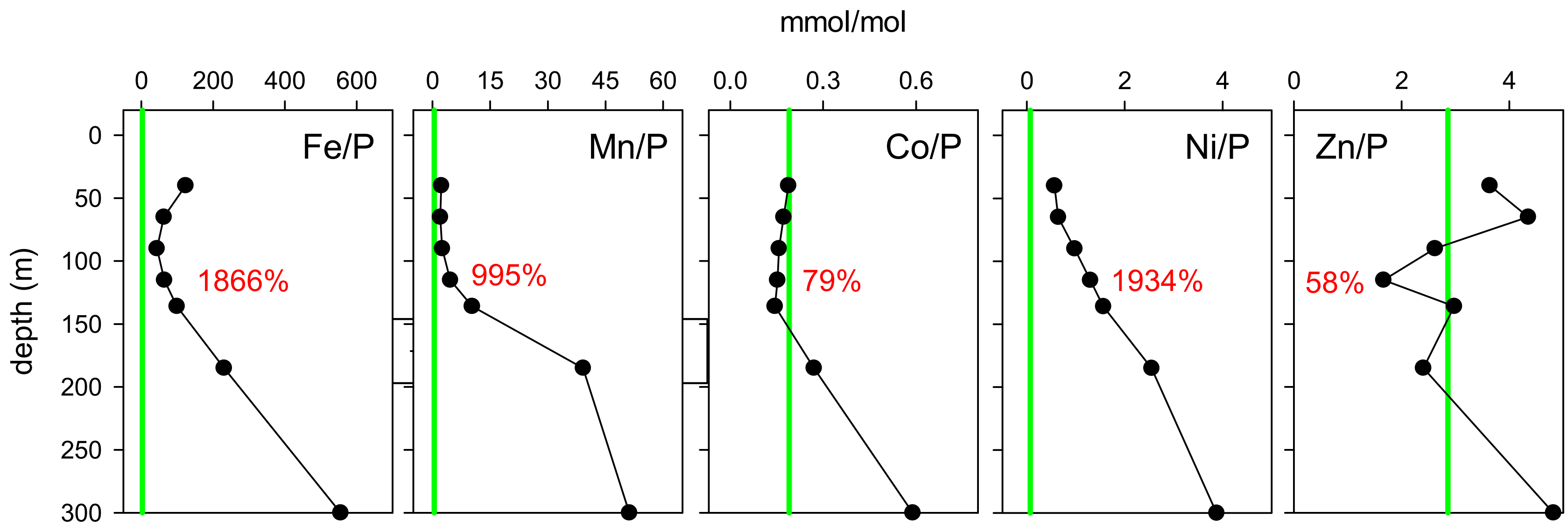
$$F_{POC} = \frac{POC}{^{210}Po_P} F_{^{210}Po}$$

Measurements of biogenic particulate trace metals in the North Atlantic

Ben Twining

Bigelow Laboratory for Ocean Sciences

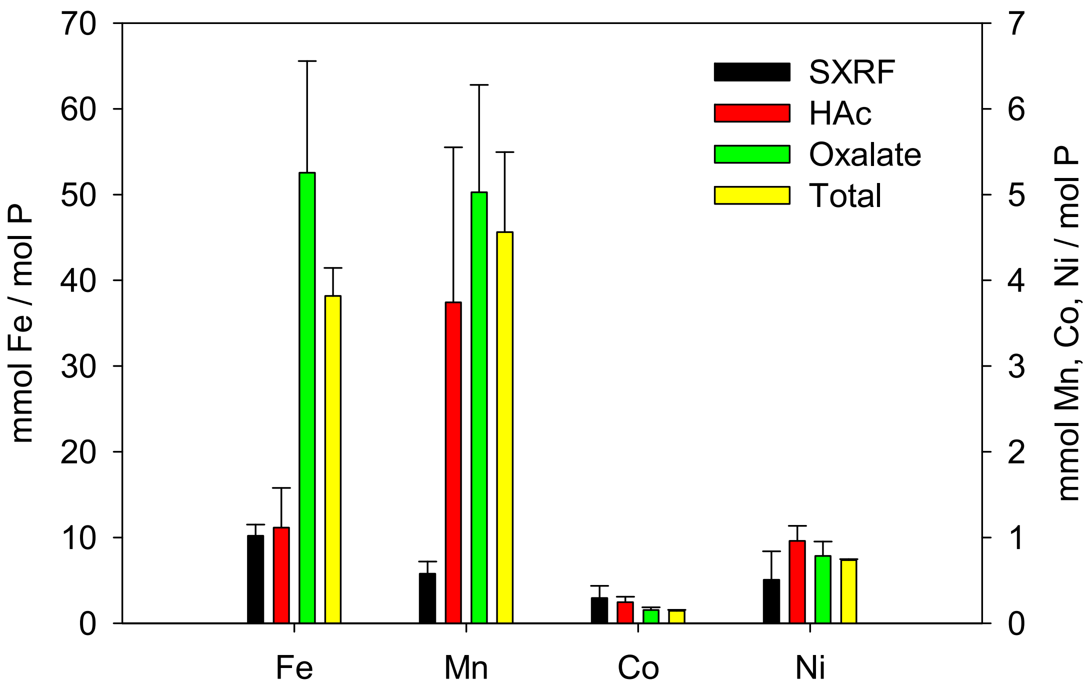
Particulate metal stoichiometries in the upper water column



- Only a small percentage of many particulate metals are associated with phytoplankton.
- Bulk particulate P-normalized Fe, Mn and Ni are 10- to 20-fold above stoichiometries in ambient plankton (shown in green), even in the DCM. Co and Zn are comparable at DCM.
- See additional explanation in slide notes.

Ben Twining

Use of operational rinses to isolate biogenic fraction of particulate material

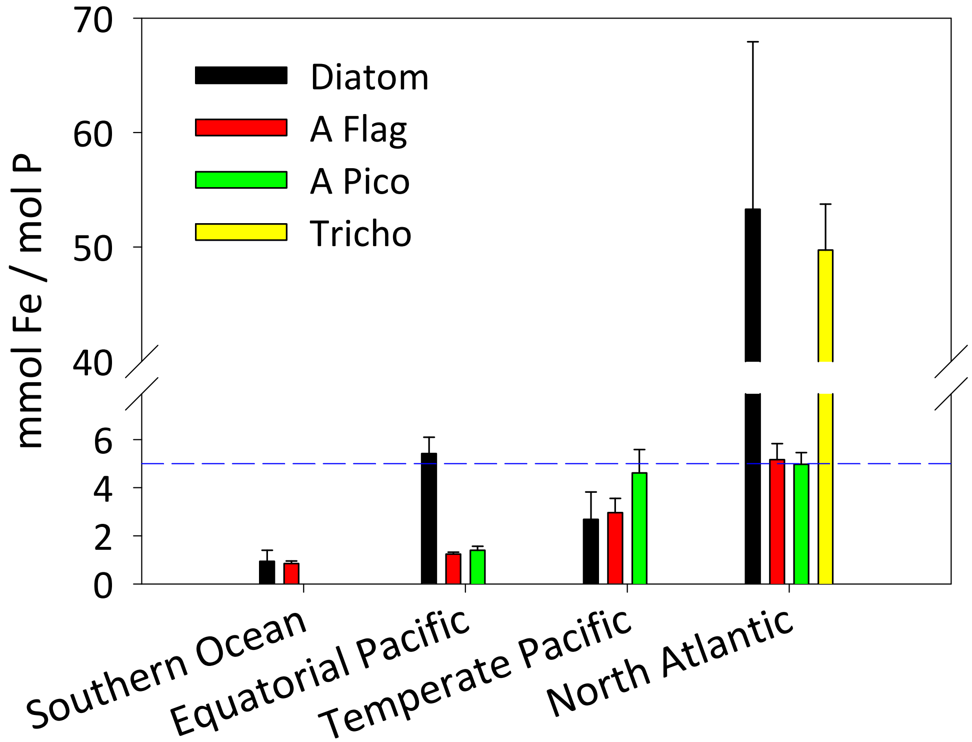


Comparison of operational rinses

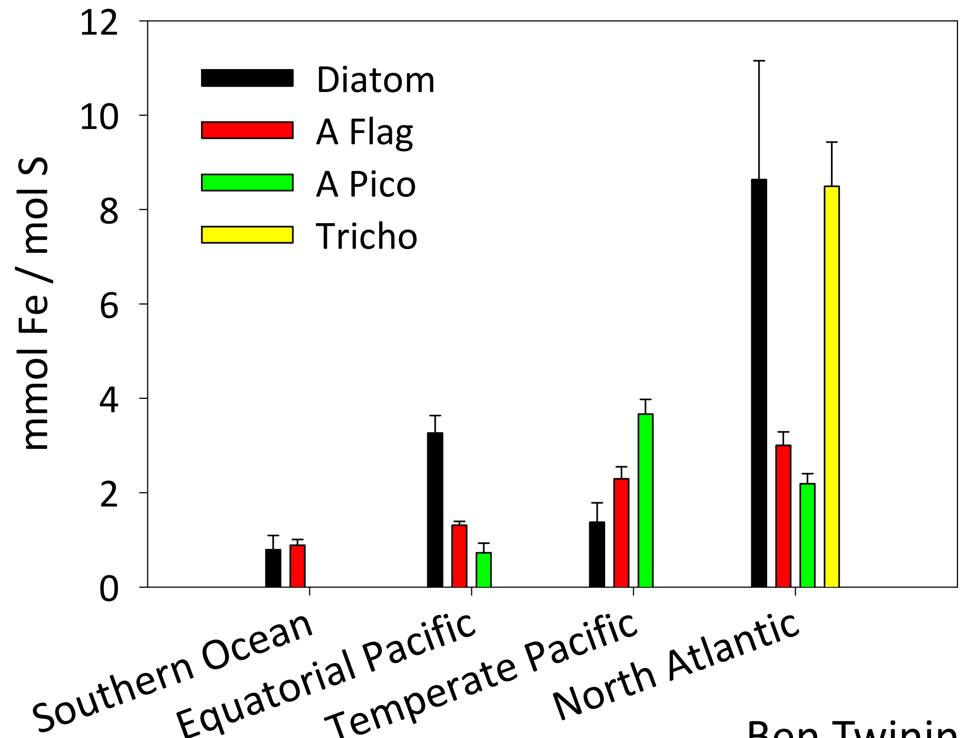
Element	**% in HAc fraction**	**% remaining after oxalate**
Lithogenic		
Al	4.2 ± 0.2%	66%
Fe	14 ± 0.3%	80%
Ti	1.5 ± 0.3%	--
Biogenic		
P	63 ± 5%	70%
Cd	95%	--
Co	92 ± 6%	64%
Ni	76 ± 5%	60%
Cu	71 ± 10%	63%
V	89 ± 30%	26%
Intermediate		
Mn	43 ± 17%	48%

Ben Twining

Phytoplankton Fe quotas in different ocean basins



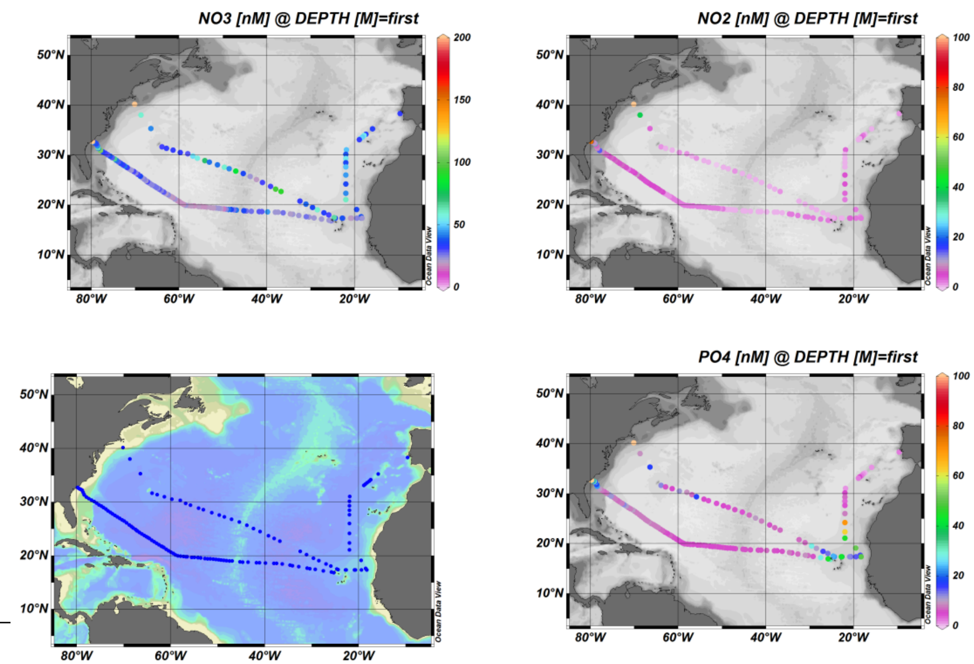
- Diatoms and Trichodesmium in the North Atlantic were extremely P-depleted (compare P-normalized to S-normalized Fe quotas)
- Diatoms have elevated Fe quotas in the North Atlantic, while picophytoplankton and nanoflagellates have similar Fe quotas in the North Atlantic and equatorial Pacific (is this due to different requirements or Fe storage abilities?)



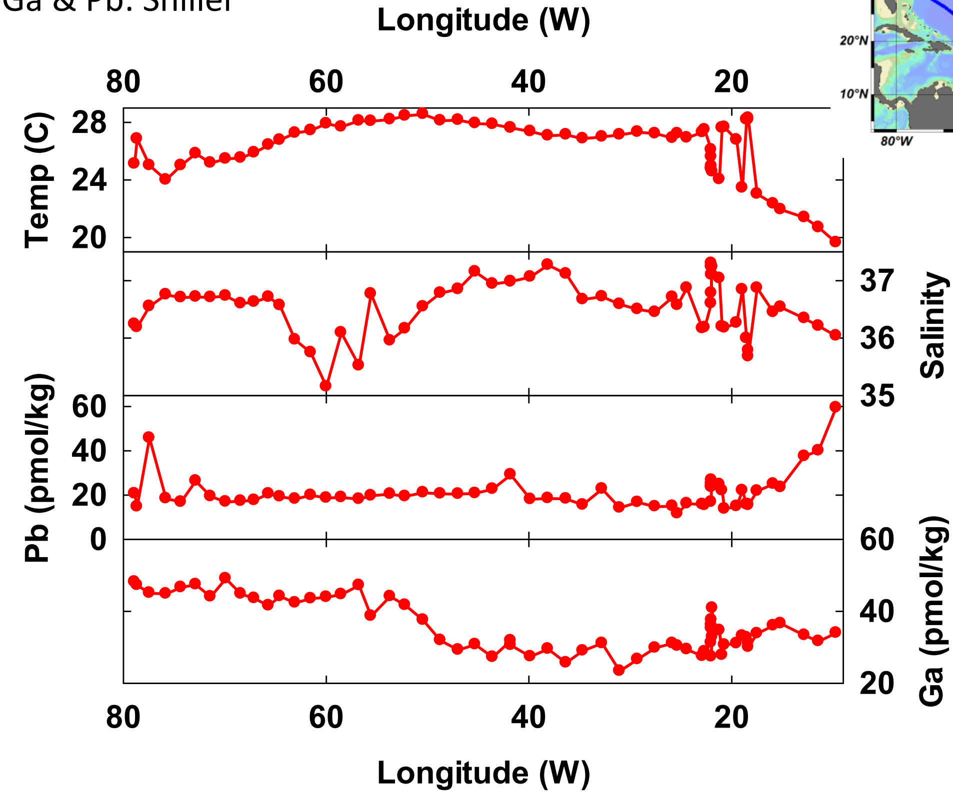
Ben Twining

Surface water & underway chemistry

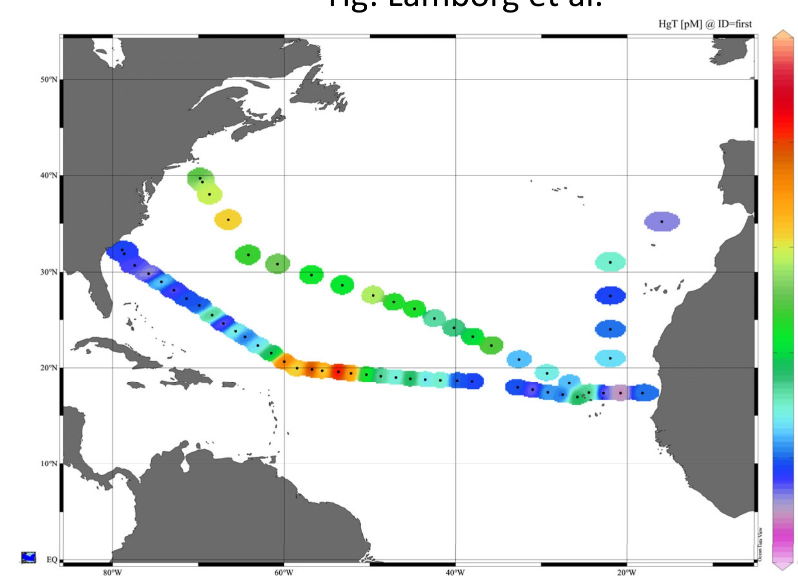
Nanomolar nutrients: Cutter et al



Ga & Pb: Shiller



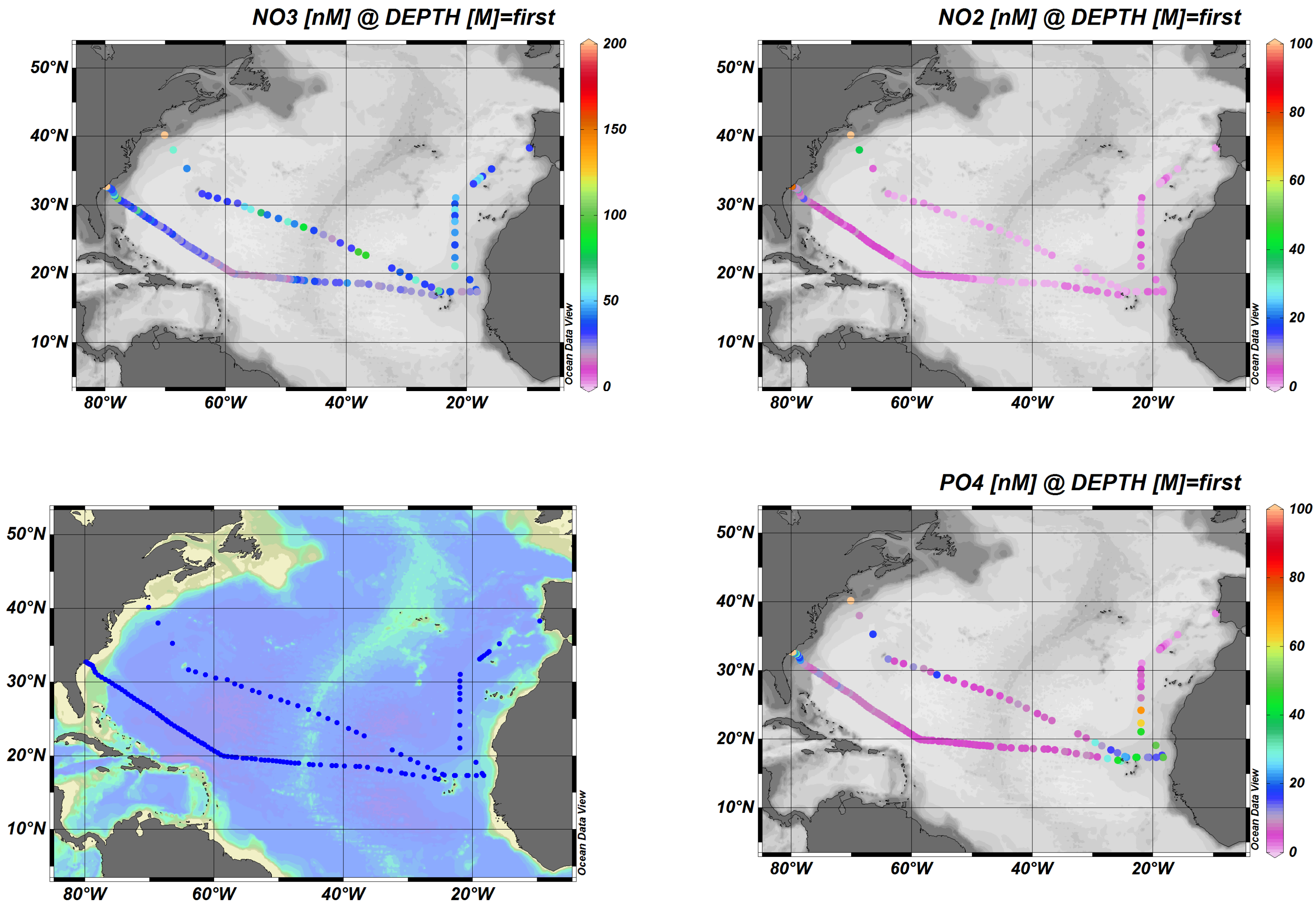
Hg: Lamborg et al.



Selected plots from Cutter Lab

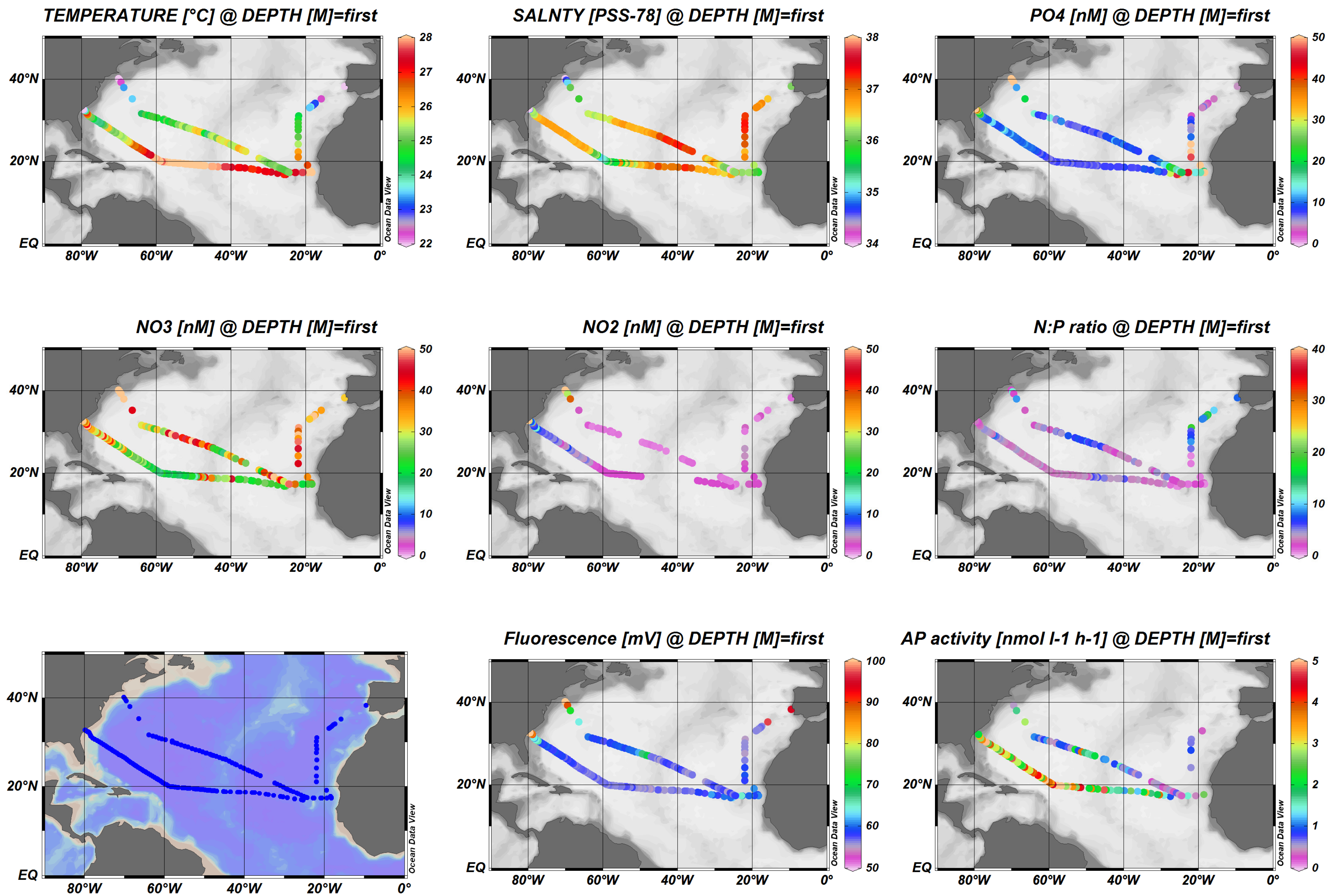
2010 and 2011 US GEOTRACES North Atlantic Expeditions

Surface water nutrients (nmol/L) along 2010 and 2011 transects



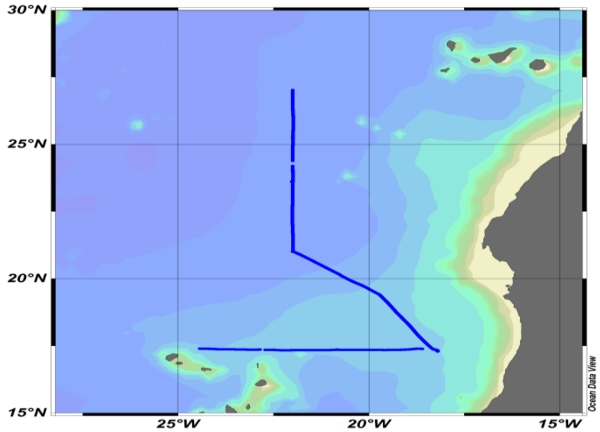
G. Cutter, ODU

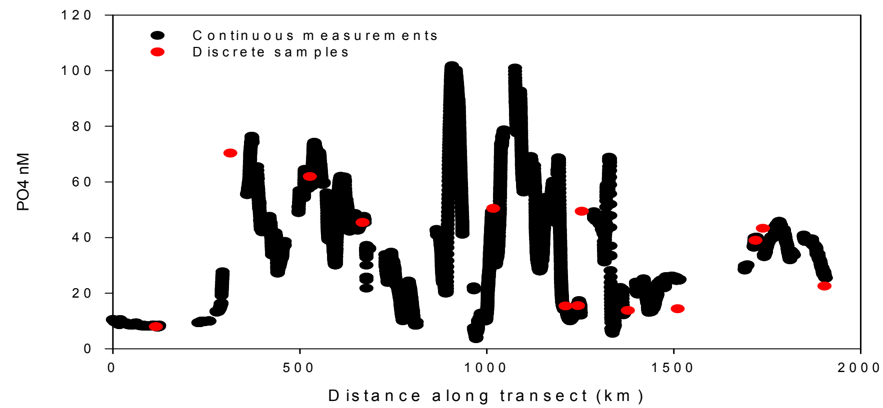
All surface water data along 2010-2011 transects

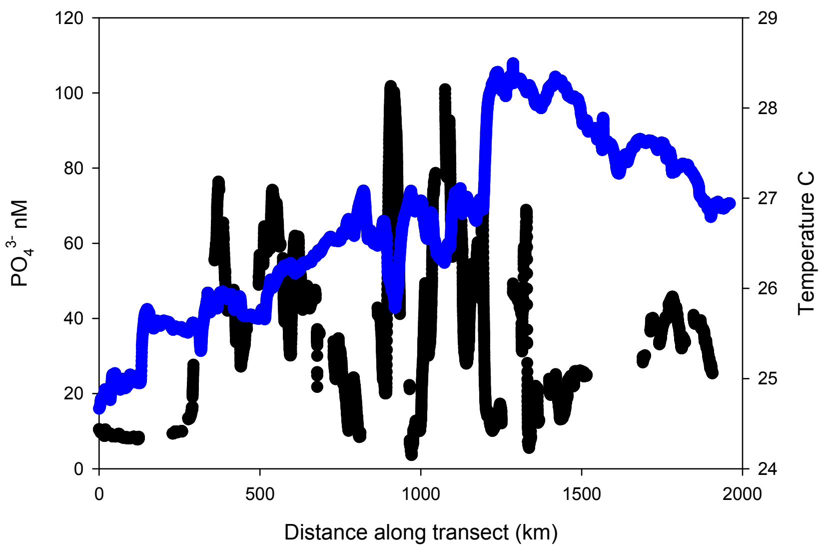


G. Cutter, ODU

High resolution nutrients along N. African upwelling regime



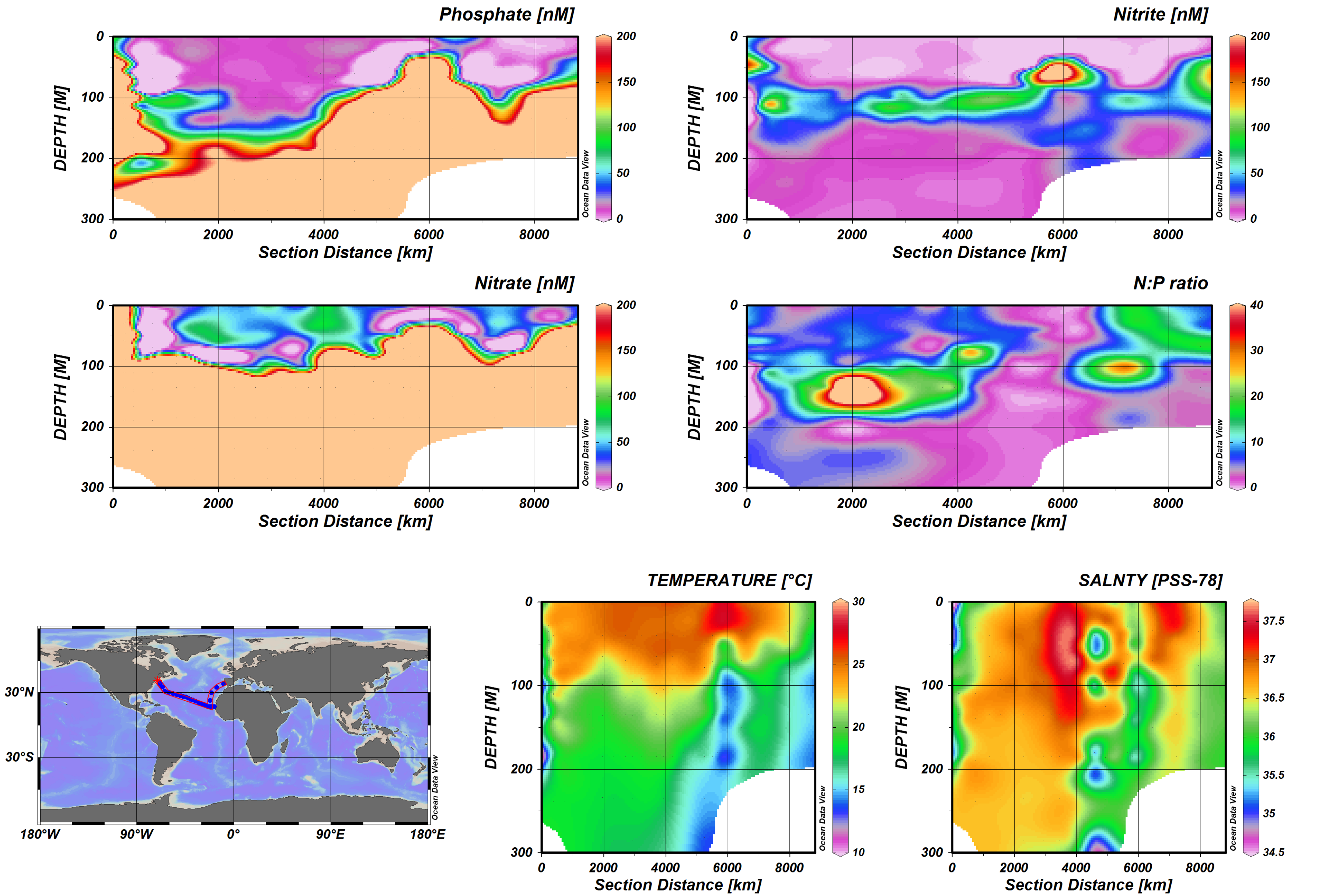




Detailed behavior largely missed by conventional (4 h discrete) sampling. Elevated phosphate appears to correlate with lower temperature, an indicator of upwelled water.

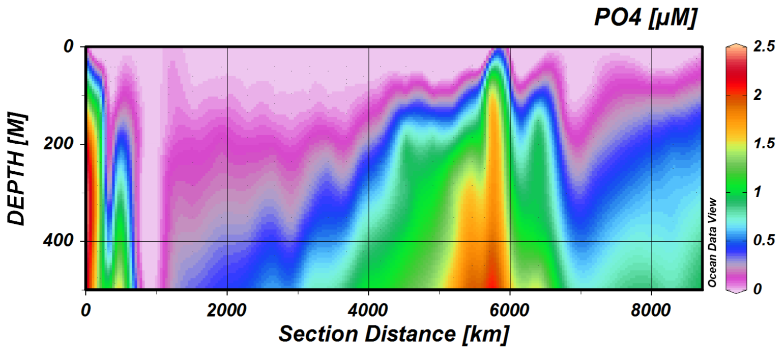
G. Cutter, ODU

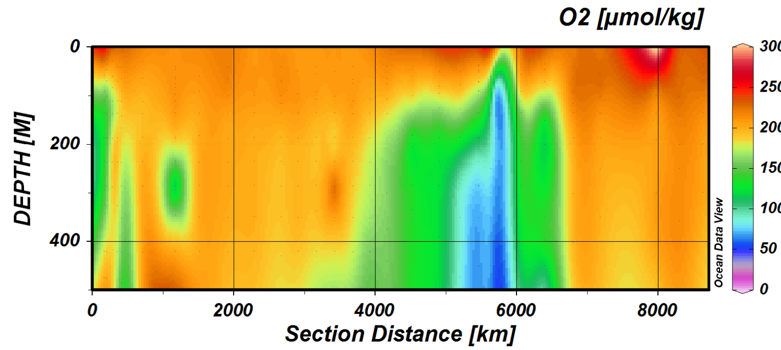
Combined 2010-2011 contoured nanomolar nutrient results

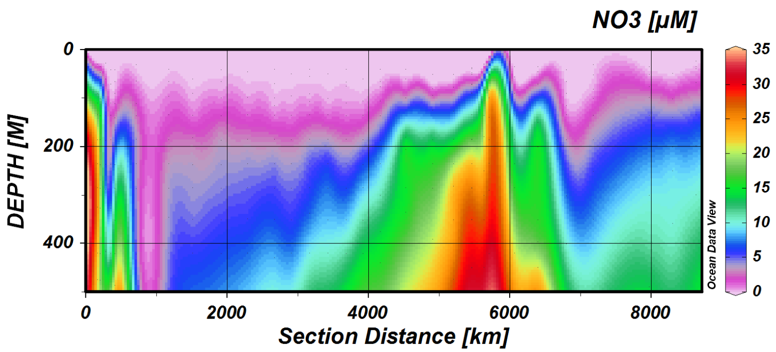


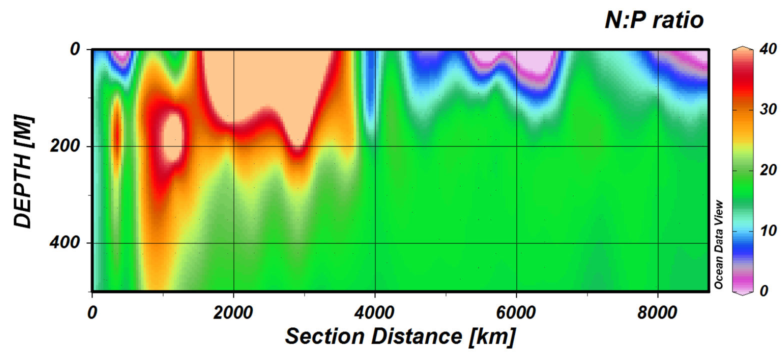
G. Cutter, ODU

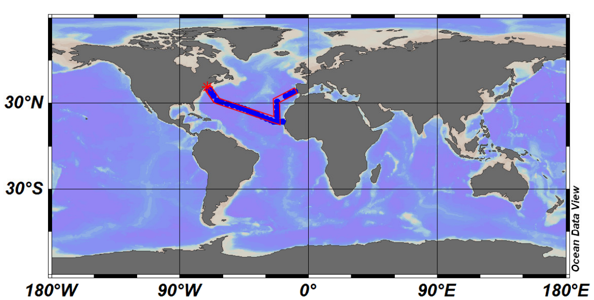
Compare to 2010-2011 contoured conventional nutrient results

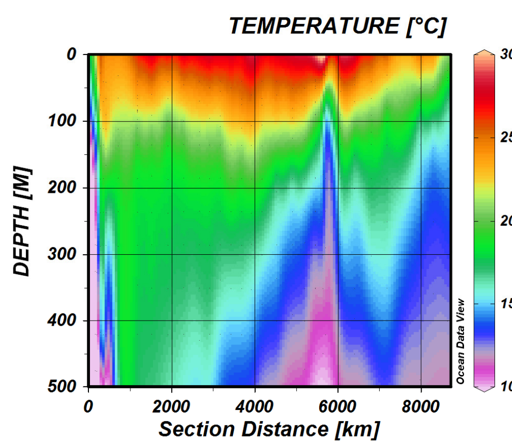


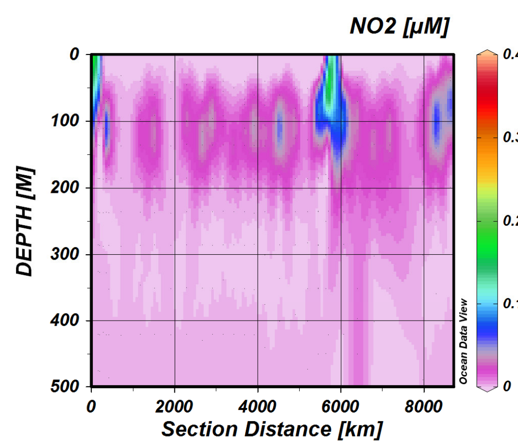




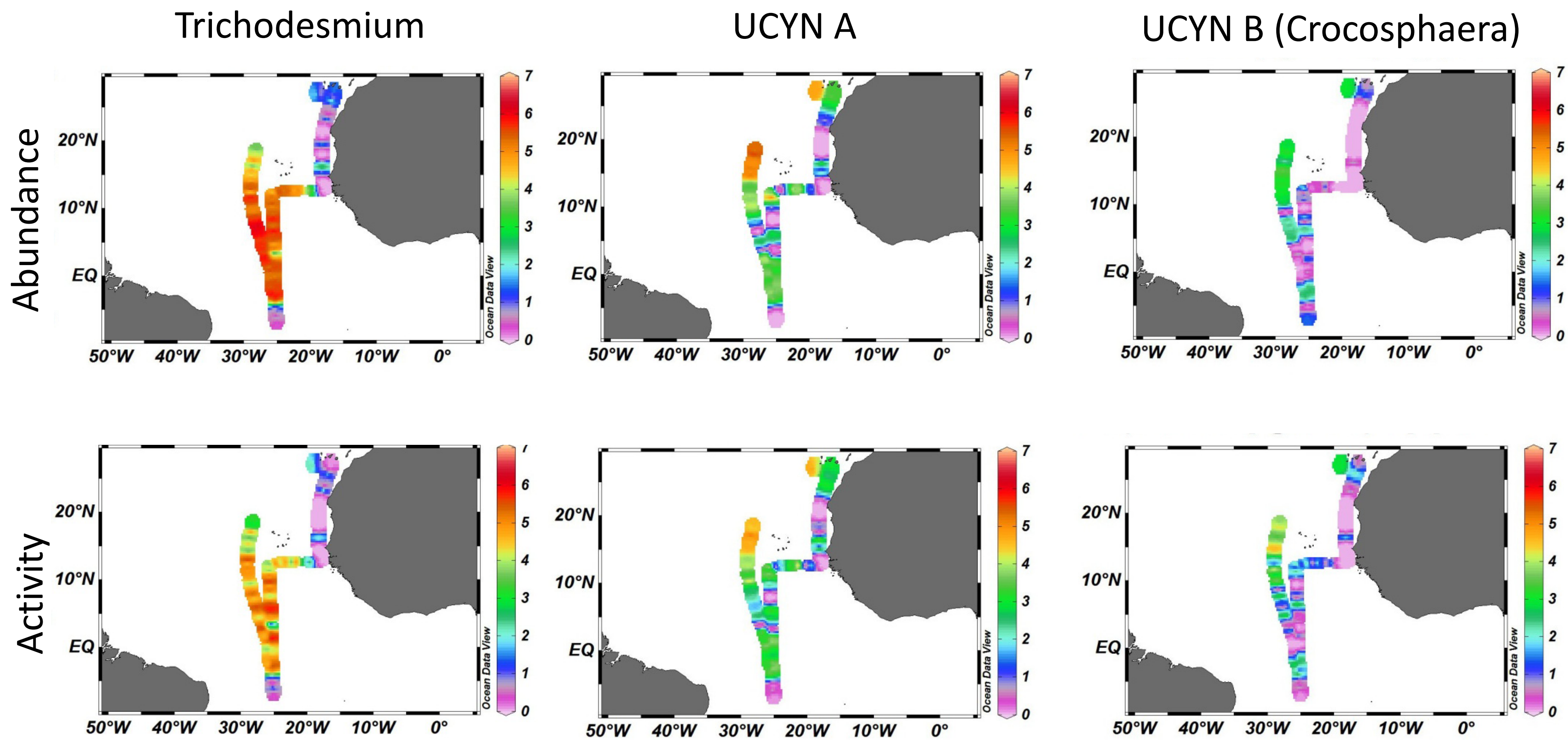








Underway Surface Data: Abundances



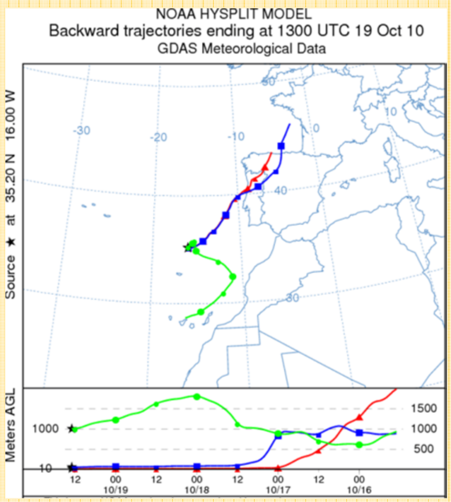
Log (*nifH* DNA copies*L^{-1})

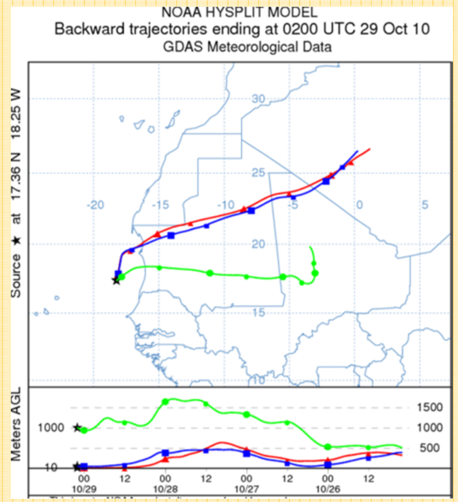
Log (*nifH* cDNA copies*L^{-1})

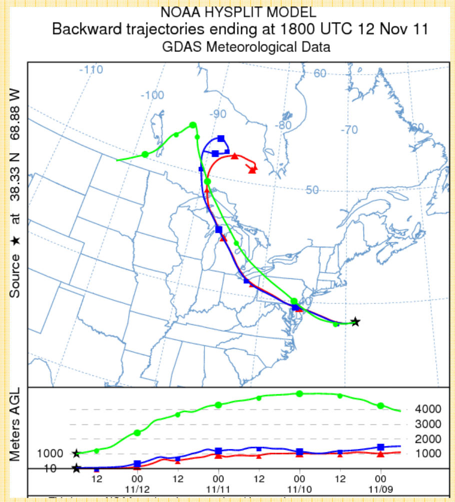
Data from D361- UK GEOTRACES

R. Langlois, J. LaRoche, T. Großkopf, E. Achterberg

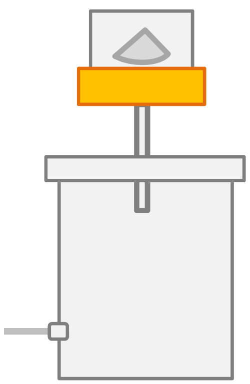
Time-dependent fractional aerosol Fe solubility





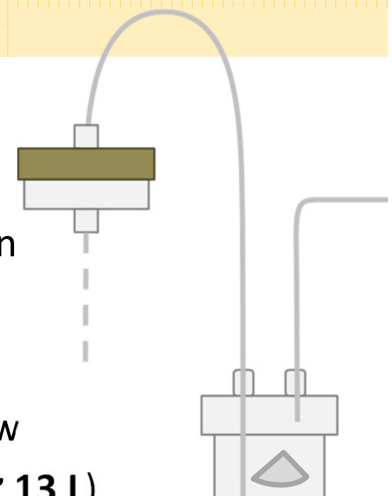


Back trajectory simulations showing air mass provenance for three aerosol collections during the US GEOTRACES Atlantic cruises.

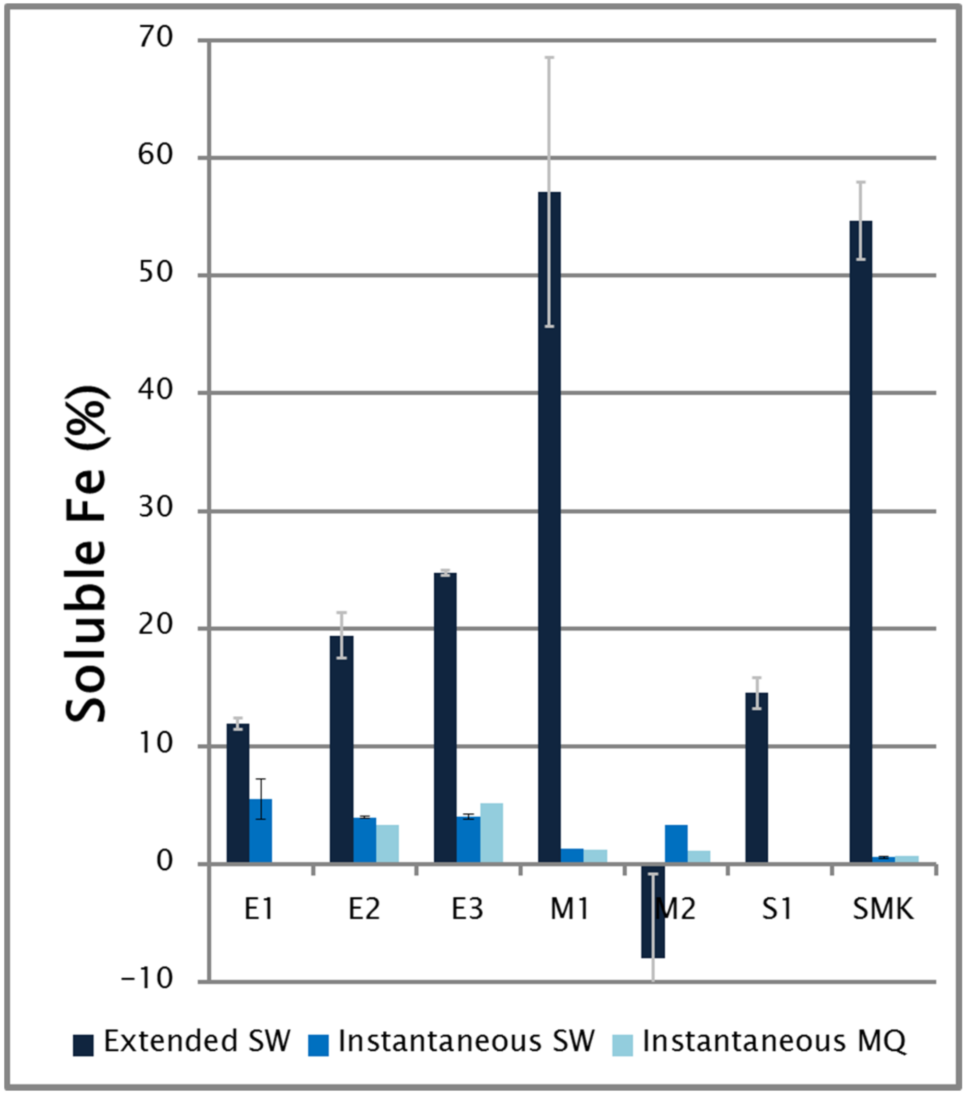


Instantaneous Leaches: leached in duplicate with same seawater as the extended leaches, and without replication using MQ (volume **~ 150 ml**). Solubility was calculated from the dissolved Fe in leachate and particulate Fe in unleached filters

Extended Leaches: Leached in triplicate with homogenized freshly collected filtered seawater for **~ 24 hrs** at a flow rate of 9.3 ml min^{-1} (volume **~ 13 L**). Solubility was calculated as the difference in particulate Fe from leached and unleached filters.



Time-dependent fractional aerosol Fe solubility

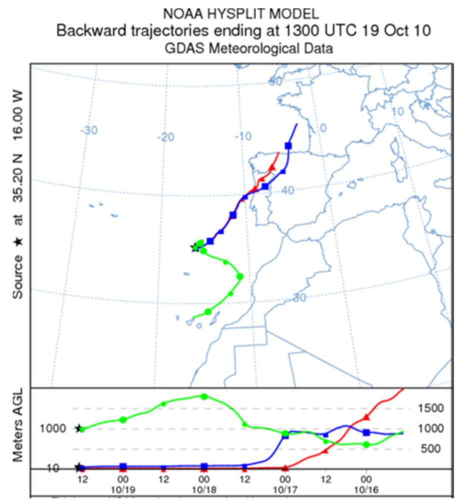


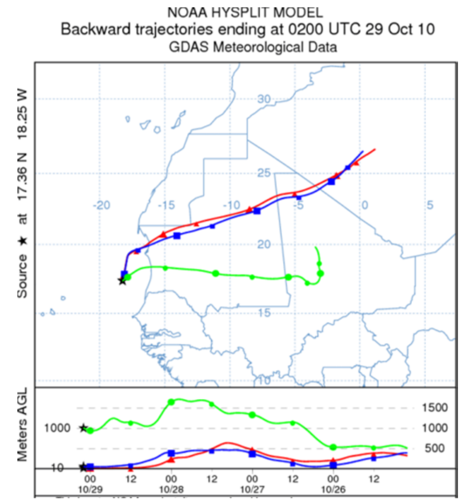
Air mass provenance:
E = Europe, M = Maritime, S = Sahara, SMK = biomass smoke

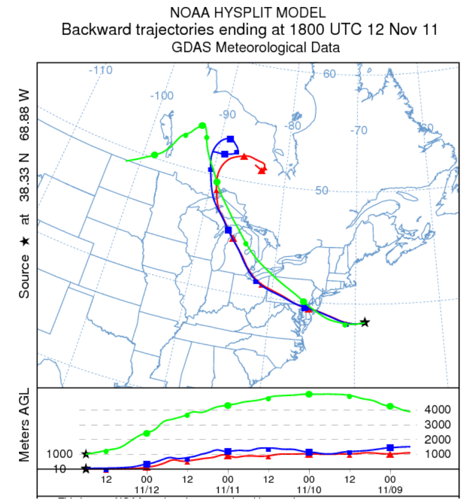
Aguilar-Islas preliminary data

- The fraction of soluble aerosol Fe obtained with instantaneous MQ and sea water leaches was comparable and lower than the fraction obtained with the extended leaches.
- Free **natural organic Fe-binding ligands** were present in the leaching seawater and likely contributed to the enhanced Fe solubility in the extended leaches

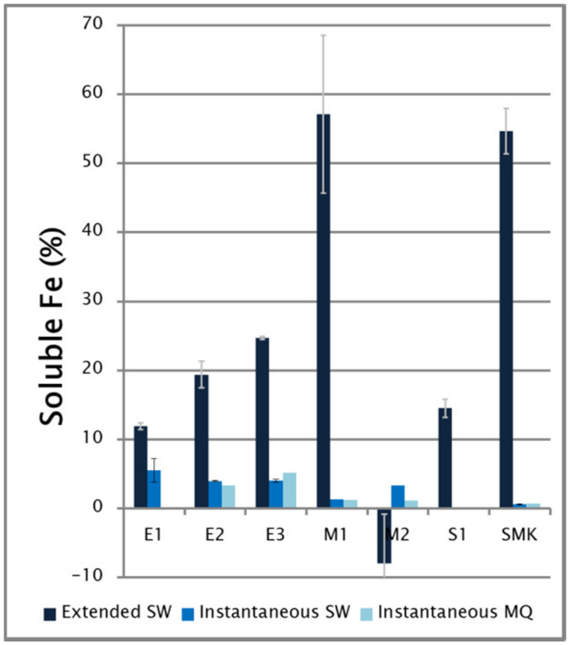
Aerosols



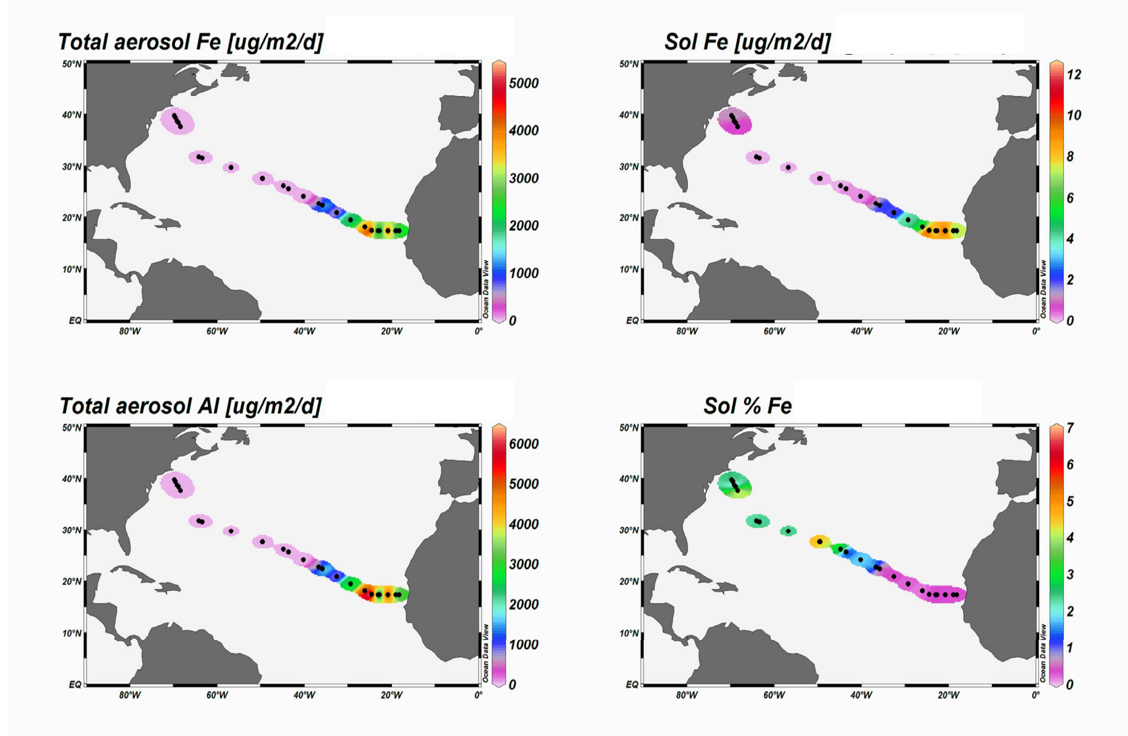


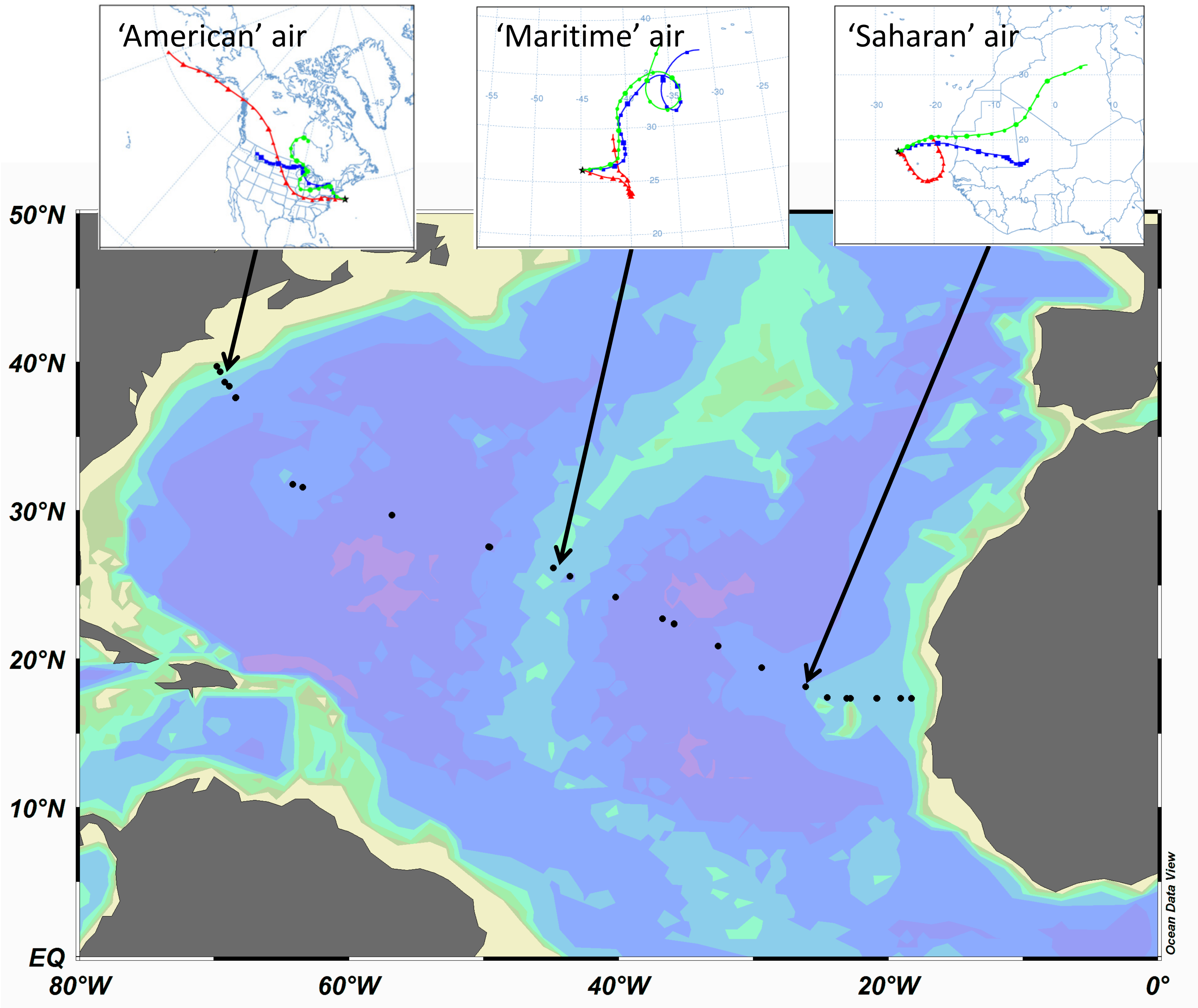


Aguilar-Islas

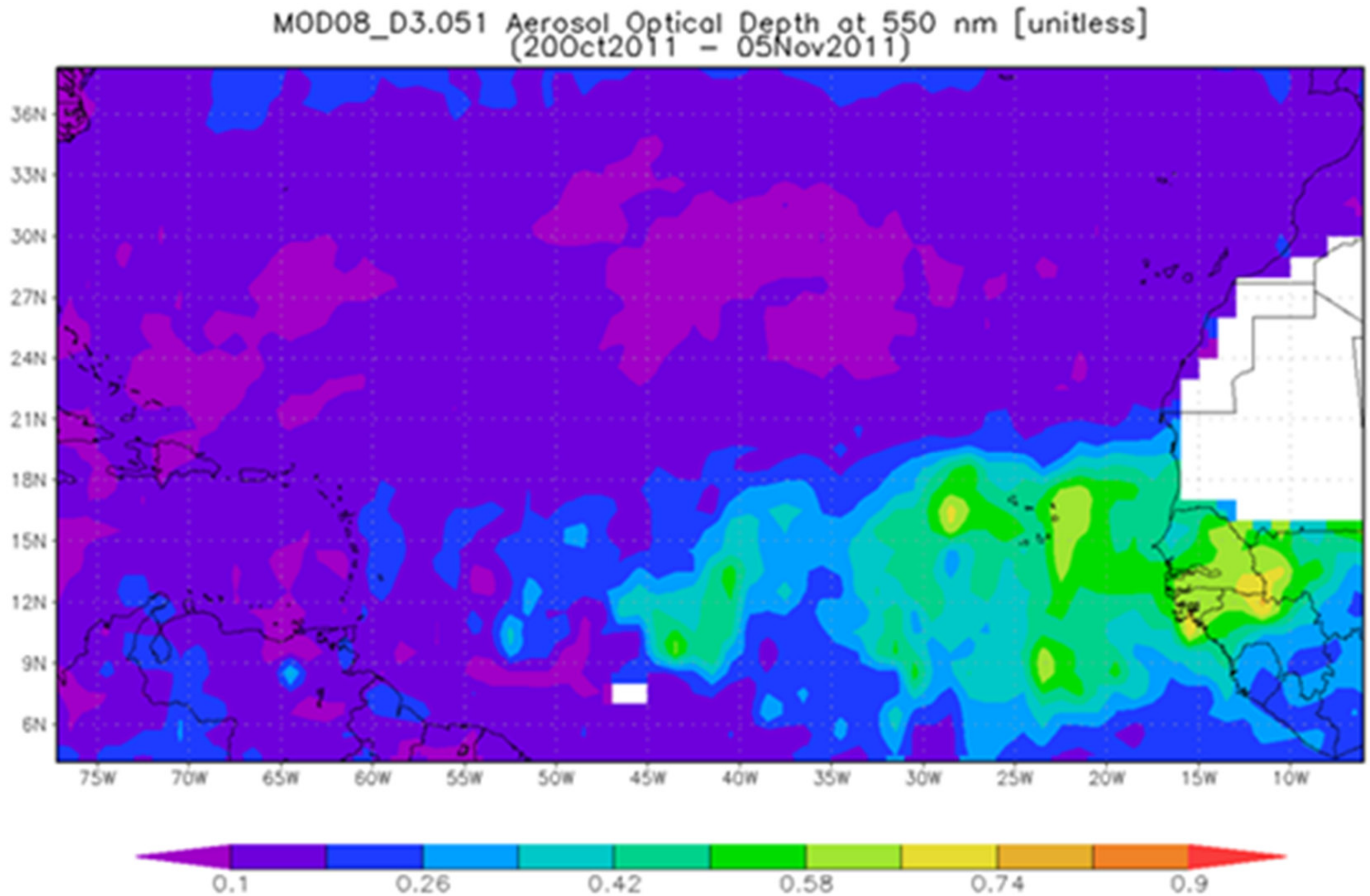


Shelly & Landing





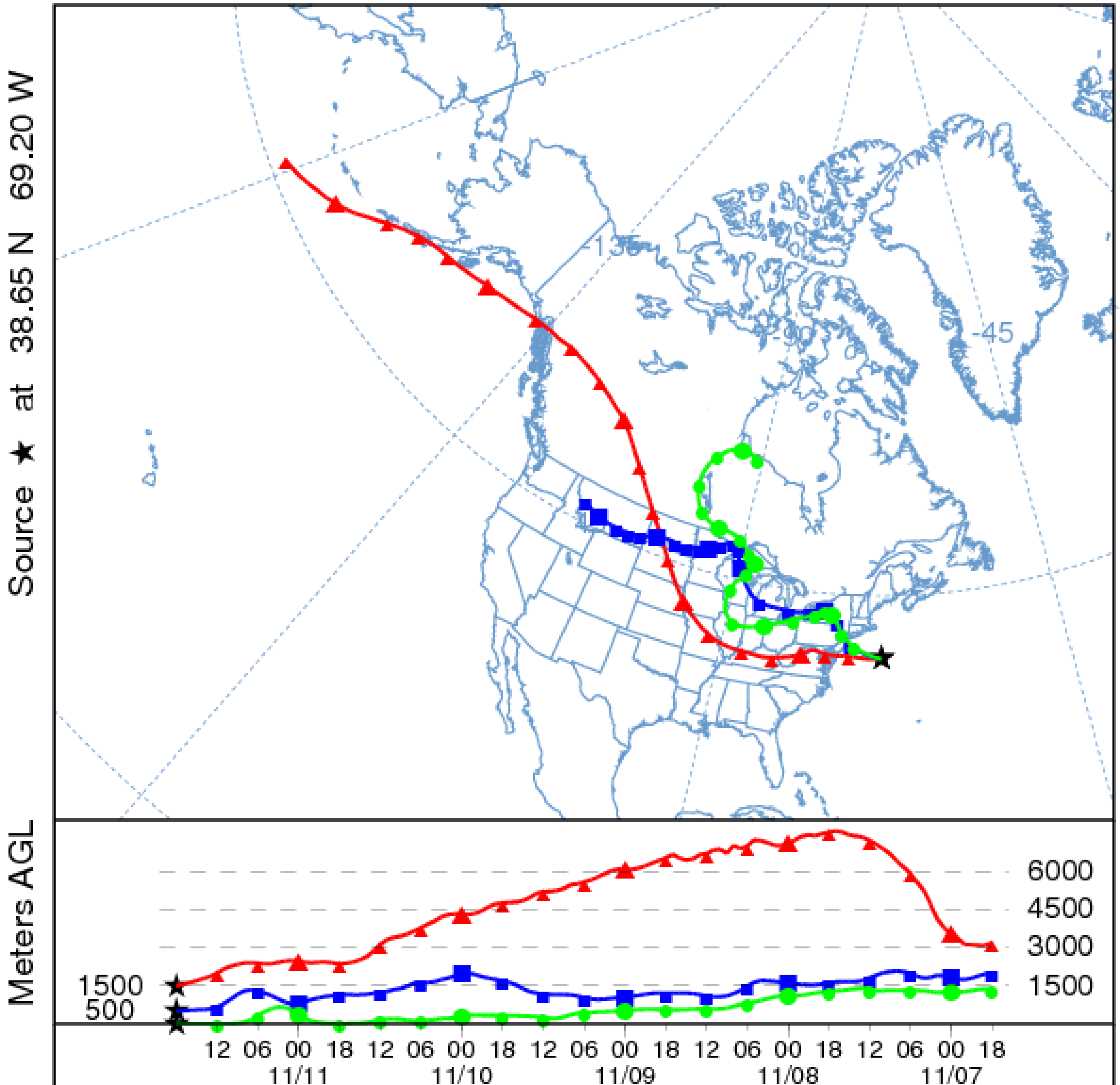
'American' air
'Maritime' air
'Saharan' air
50°N
40°N
30°N
20°N
10°N
EQ
80°W
60°W
40°W
20°W
0°
Ocean Data View


MOD08_D3.051 Aerosol Optical Depth at 550 nm [unitless]
(20Oct2011 - 05Nov2011)
36N
33N
30N
27N
24N
21N
18N
15N
12N
9N
6N
75W
70W
65W
60W
55W
50W
45W
40W
35W
30W
25W
20W
15W
10W
0.1
0.26
0.42
0.58
0.74
0.9

NOAA HYSPLIT MODEL

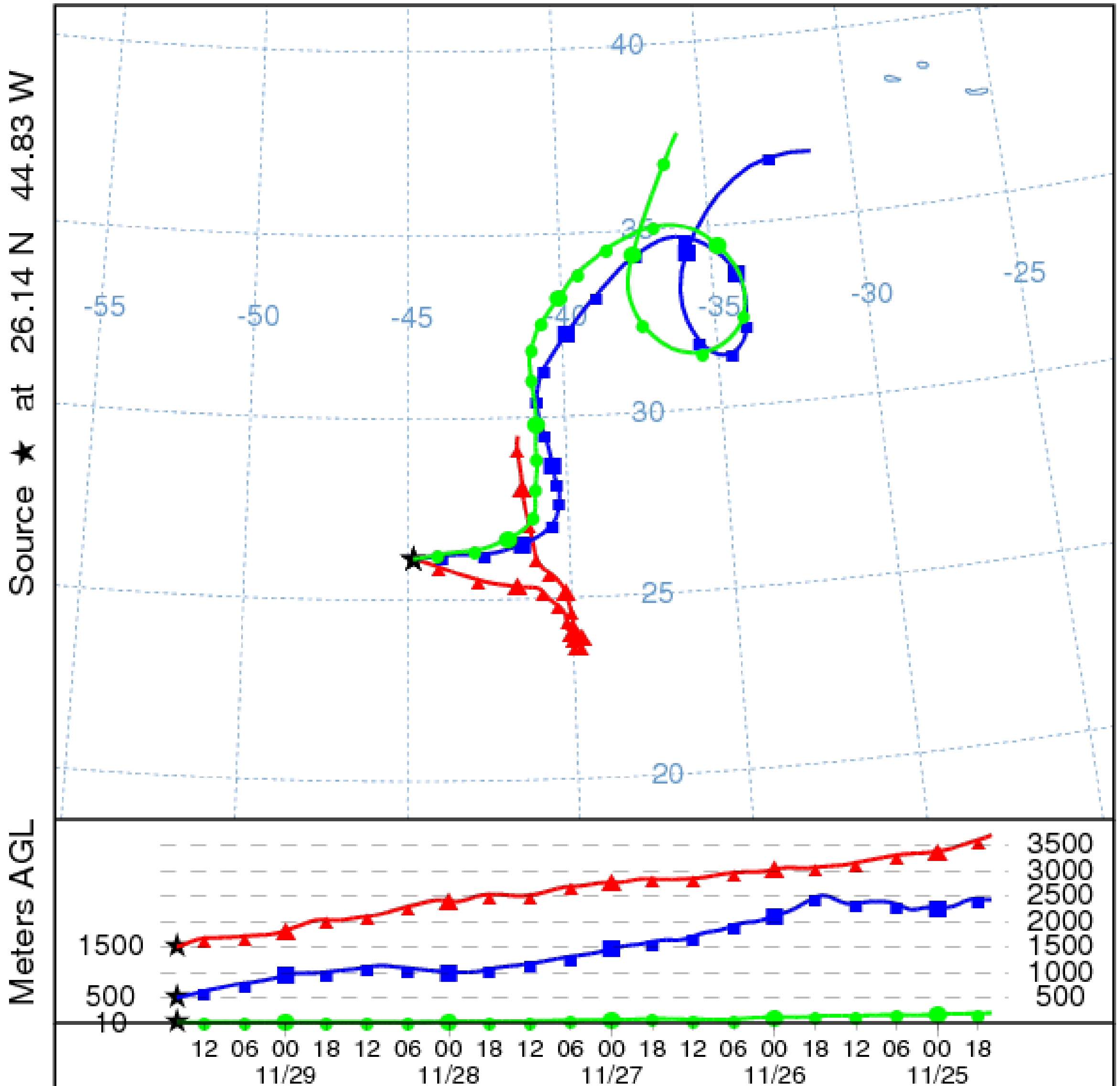
Backward trajectories ending at 1800 UTC 11 Nov 11

GDAS Meteorological Data



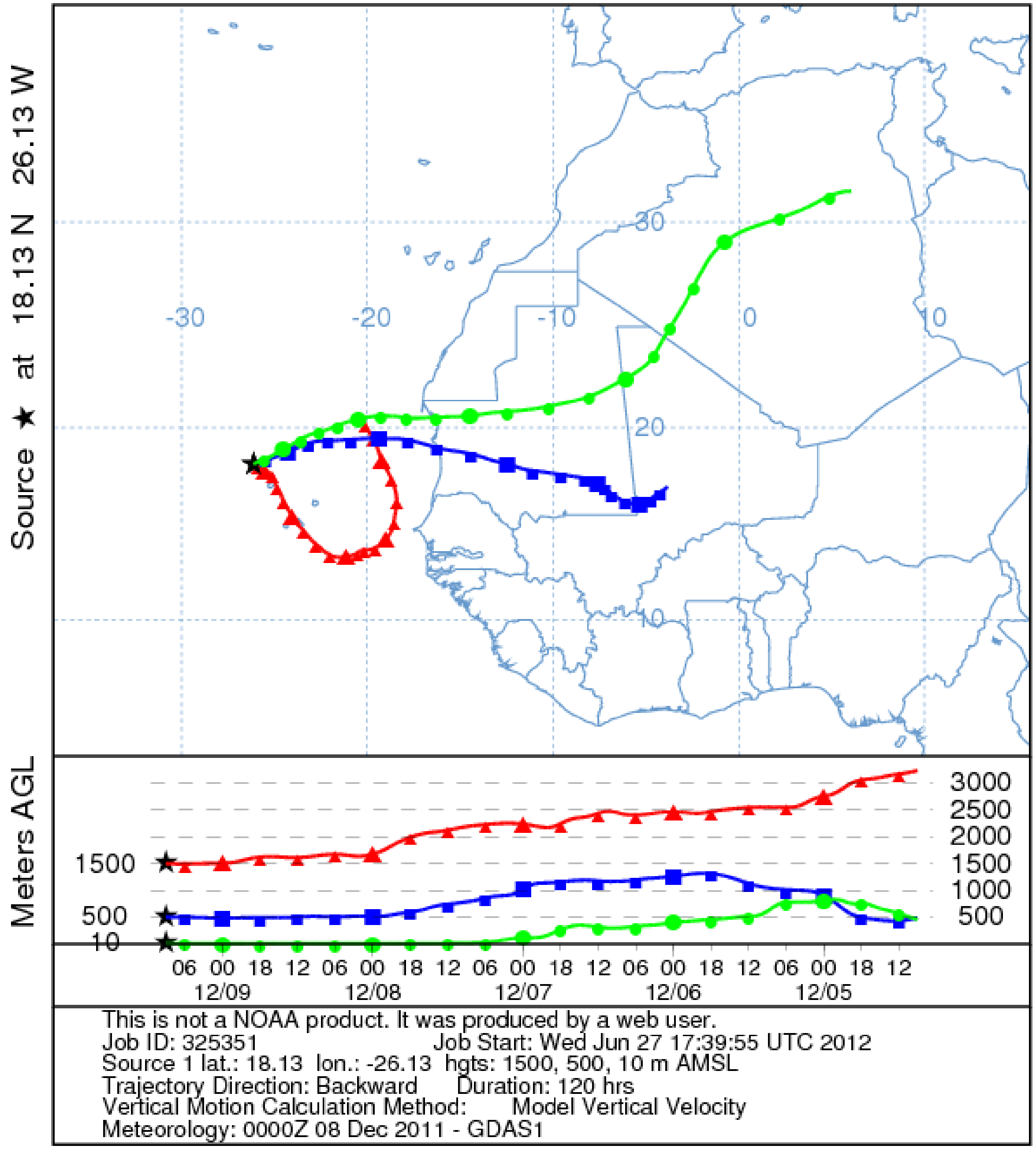
This is not a NOAA product. It was produced by a web user.
Job ID: 307278 Job Start: Wed Feb 15 19:44:09 UTC 2012
Source 1 lat.: 38.65 lon.: -69.20 hgts: 1500, 500, 10 m AGL
Trajectory Direction: Backward Duration: 120 hrs
Vertical Motion Calculation Method: Model Vertical Velocity
Meteorology: 0000Z 08 Nov 2011 - GDAS1

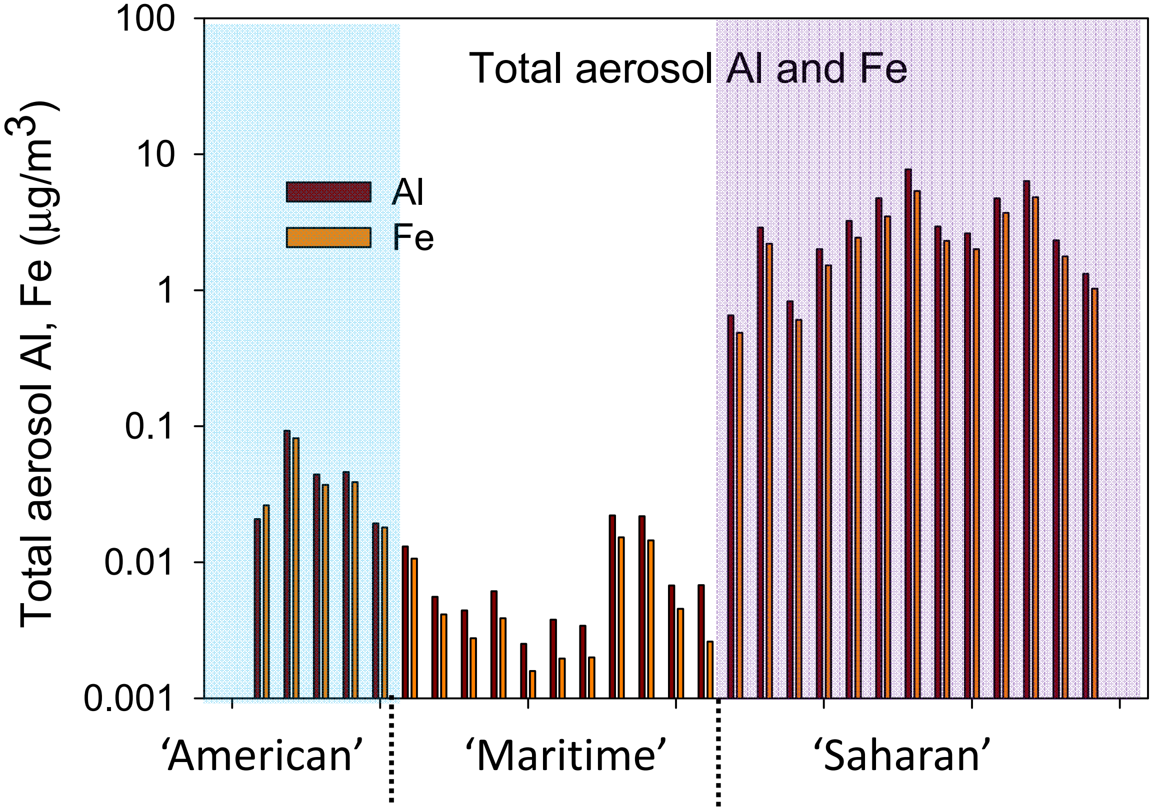
NOAA HYSPLIT MODEL
Backward trajectories ending at 1600 UTC 29 Nov 11
GDAS Meteorological Data

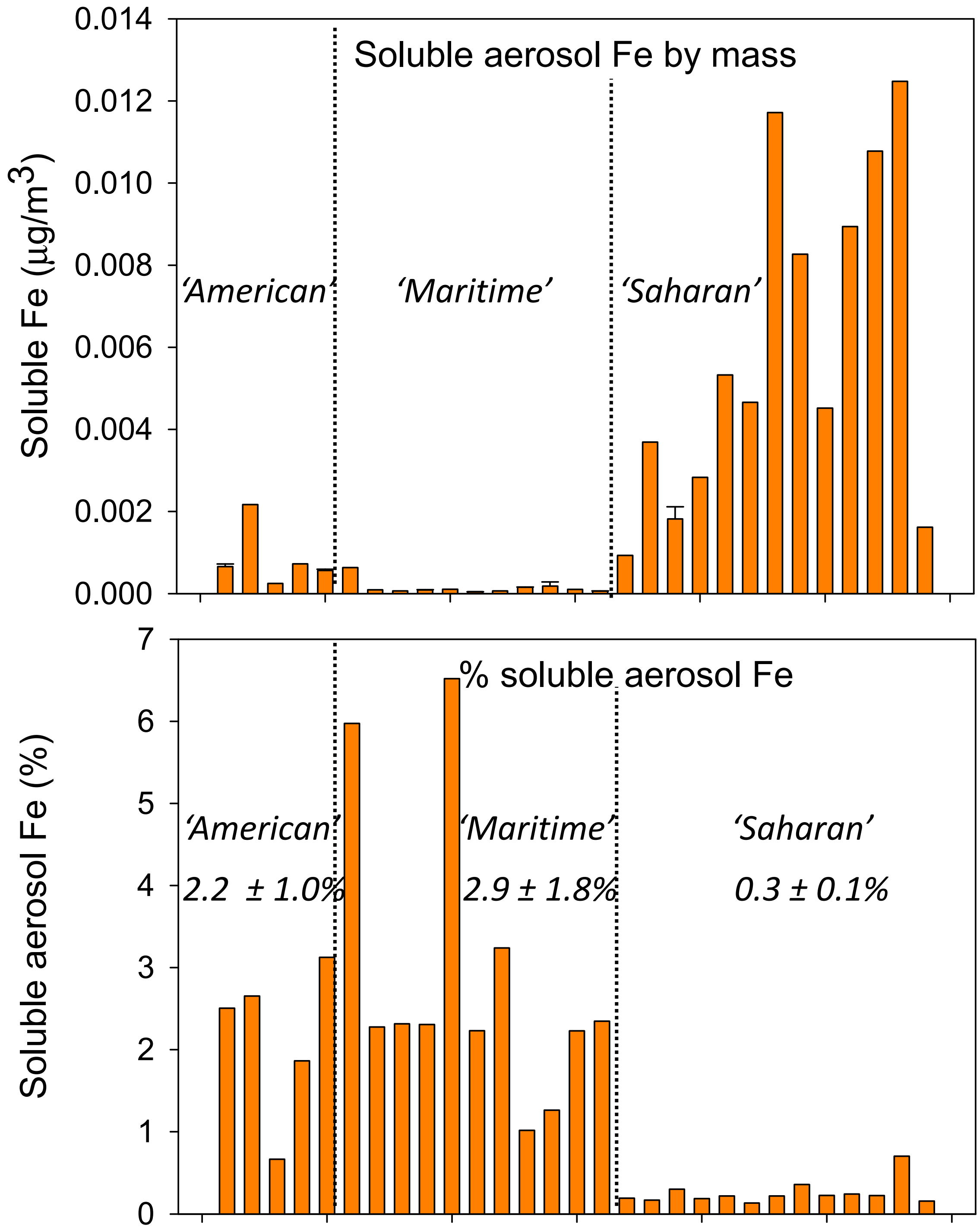


This is not a NOAA product. It was produced by a web user.
Job ID: 345339 Job Start: Wed Jun 27 17:29:43 UTC 2012
Source 1 lat.: 26.14 lon.: -44.83 hgts: 1500, 500, 10 m AGL
Trajectory Direction: Backward Duration: 120 hrs
Vertical Motion Calculation Method: Model Vertical Velocity
Meteorology: 0000Z 29 Nov 2011 - GDAS1

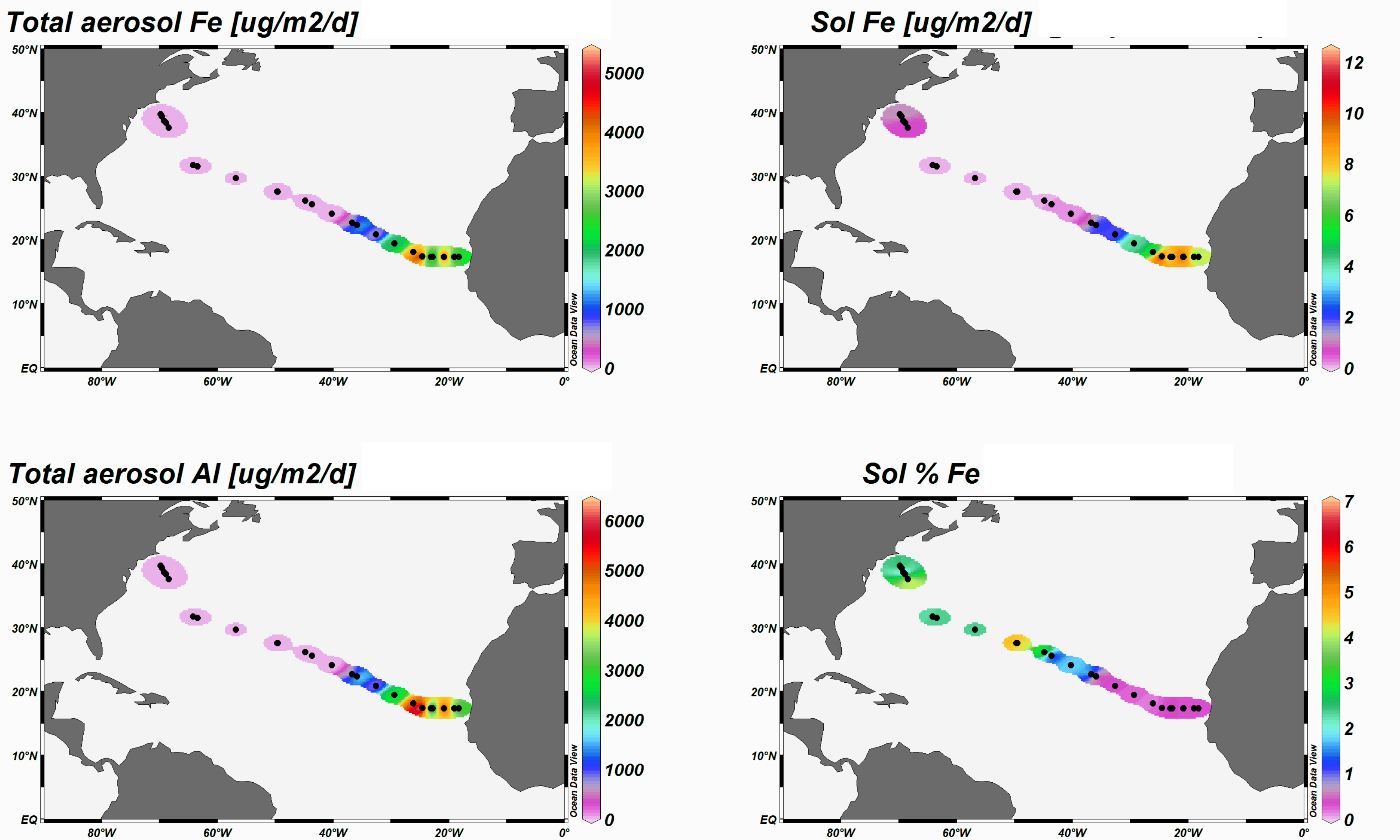
NOAA HYSPLIT MODEL
Backward trajectories ending at 0900 UTC 09 Dec 11
GDAS Meteorological Data



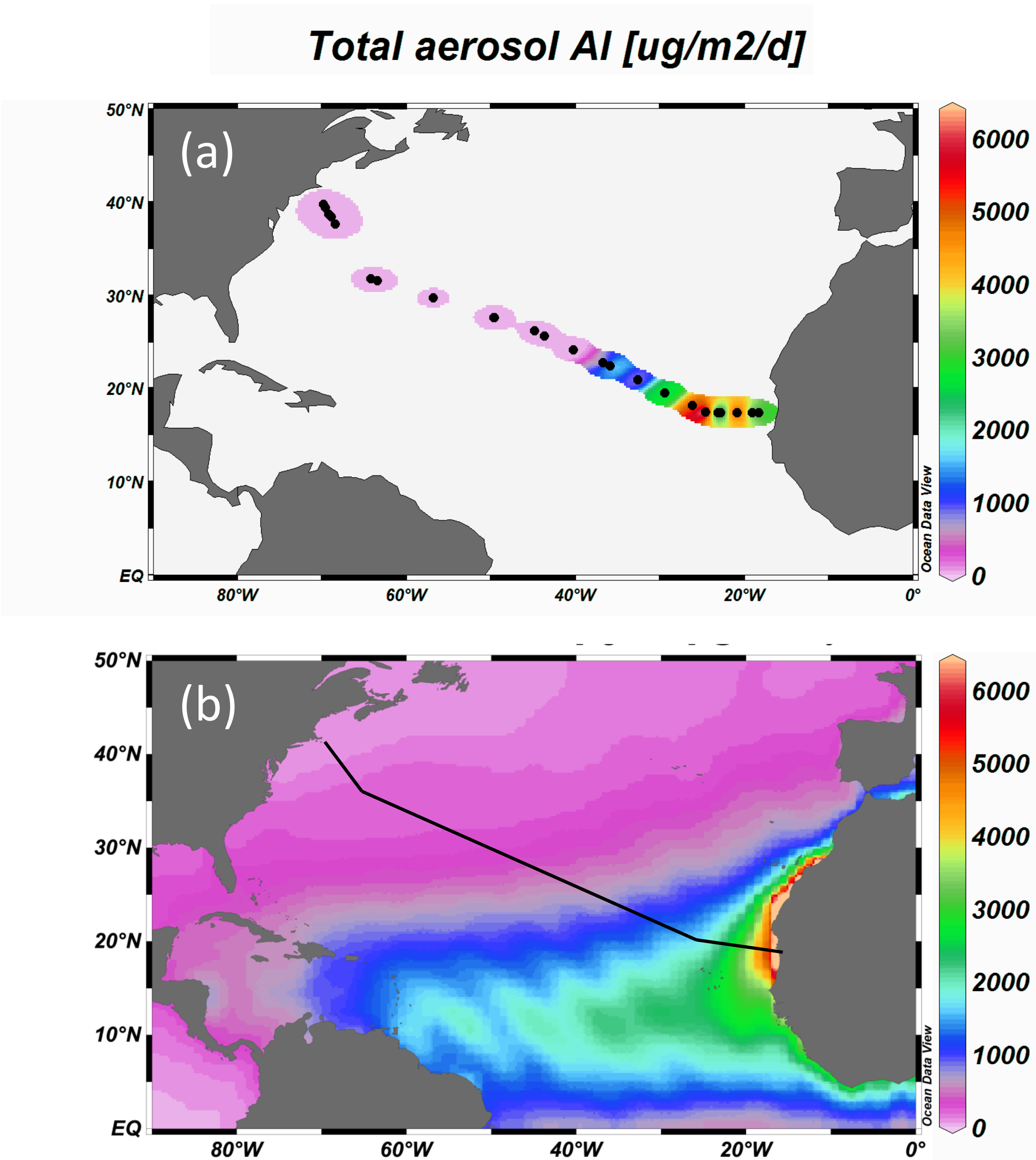

Total aerosol Al and Fe
Total aerosol Al, Fe (µg/m3)
100
10
1
0.1
0.01
0.001
Al
Fe
'American'
'Maritime'
'Saharan'



Soluble aerosol Fe by mass
Soluble Fe (µg/m3)
0.014
0.012
0.010
0.008
0.006
0.004
0.002
0.000
'American'
'Maritime'
'Saharan'
% soluble aerosol Fe
Soluble aerosol Fe (%)
7
6
5
4
3
2
1
0
'American'
2.2 ± 1.0%
'Maritime'
2.9 ± 1.8%
'Saharan'
0.3 ± 0.1%



Total aerosol Fe [ug/m2/d]
Sol Fe [ug/m2/d]
Total aerosol Al [ug/m2/d]
Sol % Fe
50°N
40°N
30°N
20°N
10°N
EQ
80°W
60°W
40°W
20°W
0°
Ocean Data View
5000
4000
3000
2000
1000
0
12
10
8
6
4
2
0
6000
5000
4000
3000
2000
1000
0
7
6
5
4
3
2
1
0



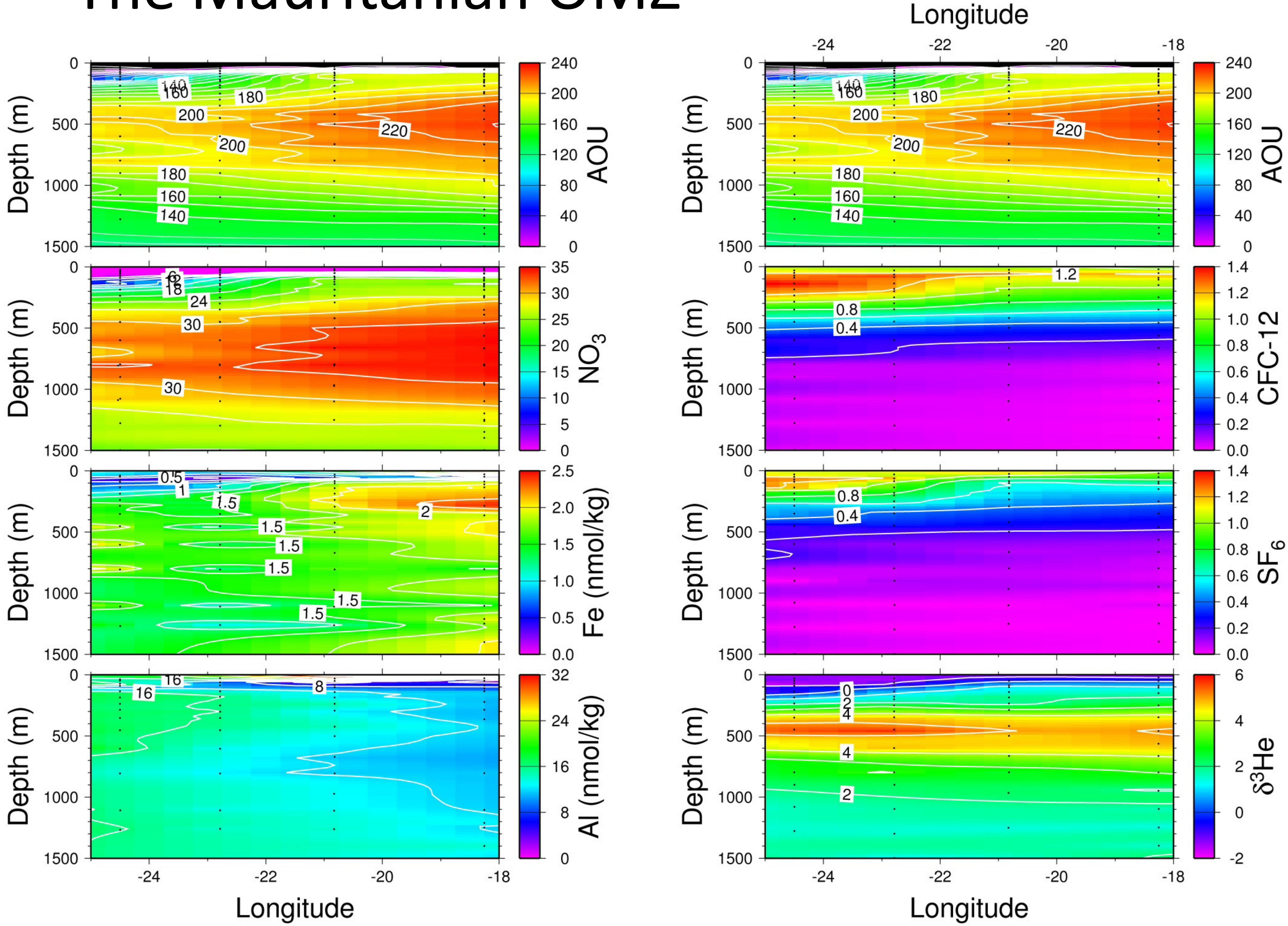
(a) N. Atlantic GEOTRACES total Al deposition

(b) Modeled N. Atlantic total Al deposition (Mahowald et al. 2009)

Outline

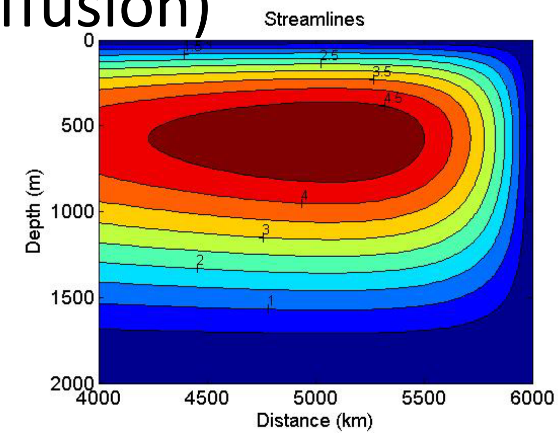
- Introduction
- Overview of results so far
- **Two vignettes**
  - **A slice of an oxygen minimum zone**
  - The TAG hydrothermal plume

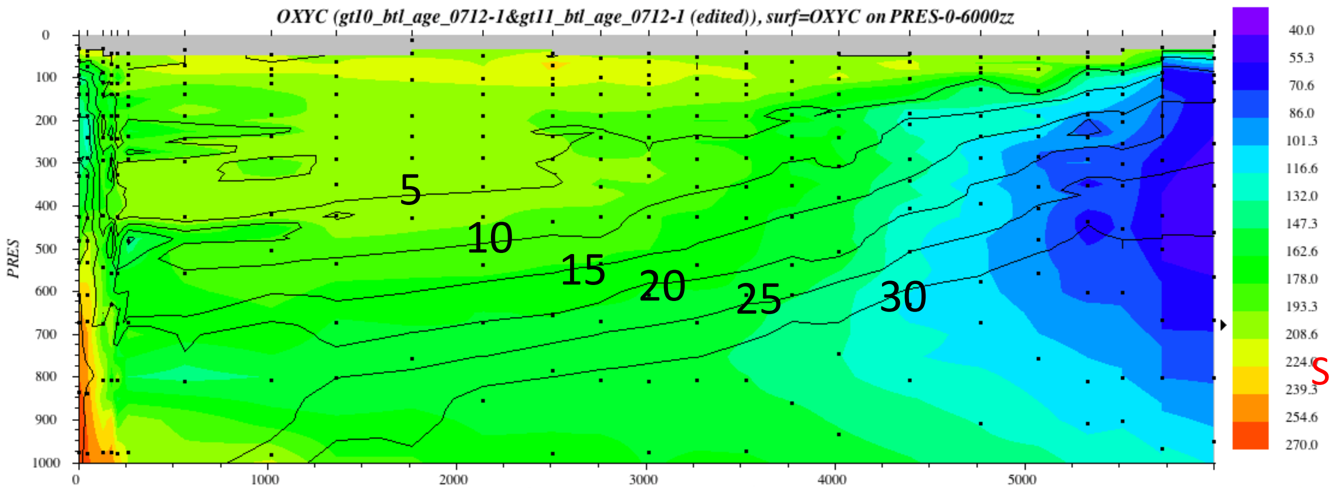
The Mauritanian OMZ



Rates deduced by 2-D upwelling model calibrated by

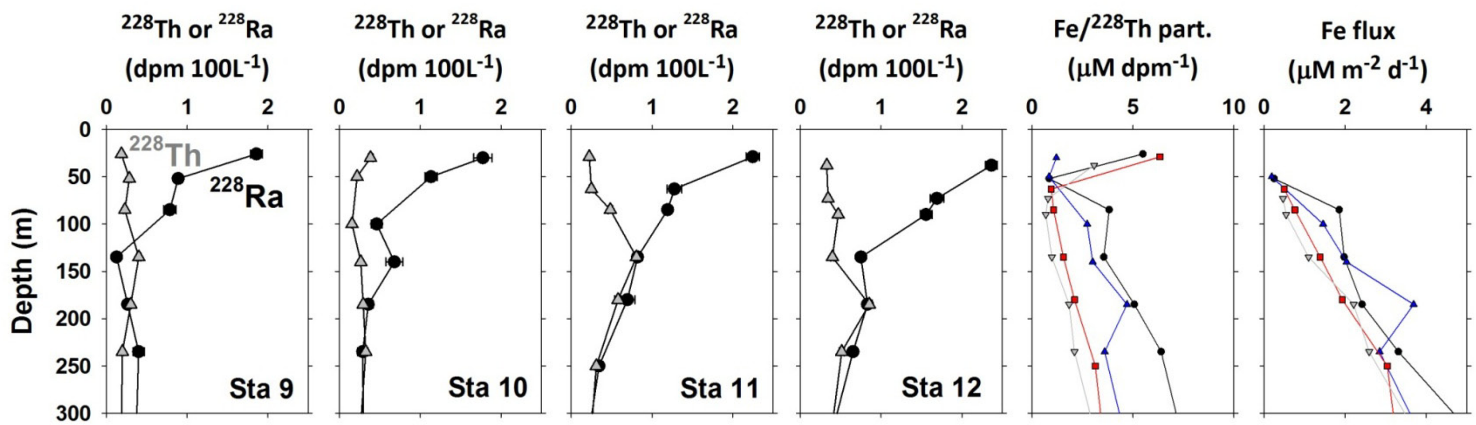
- CFCs, SF_6, Pb, ^3H-^3He (ventilation, vertical/lateral diffusion)
- ^{14}C, ^3He (upwelling velocities via G.E.R. Δ balance)
- ^{228}Th (remineralization), ^{228}Ra (lateral diffusion)
- Forward modeling & TTD analysis*





Significant CFC & SF_6 ages in OMZ

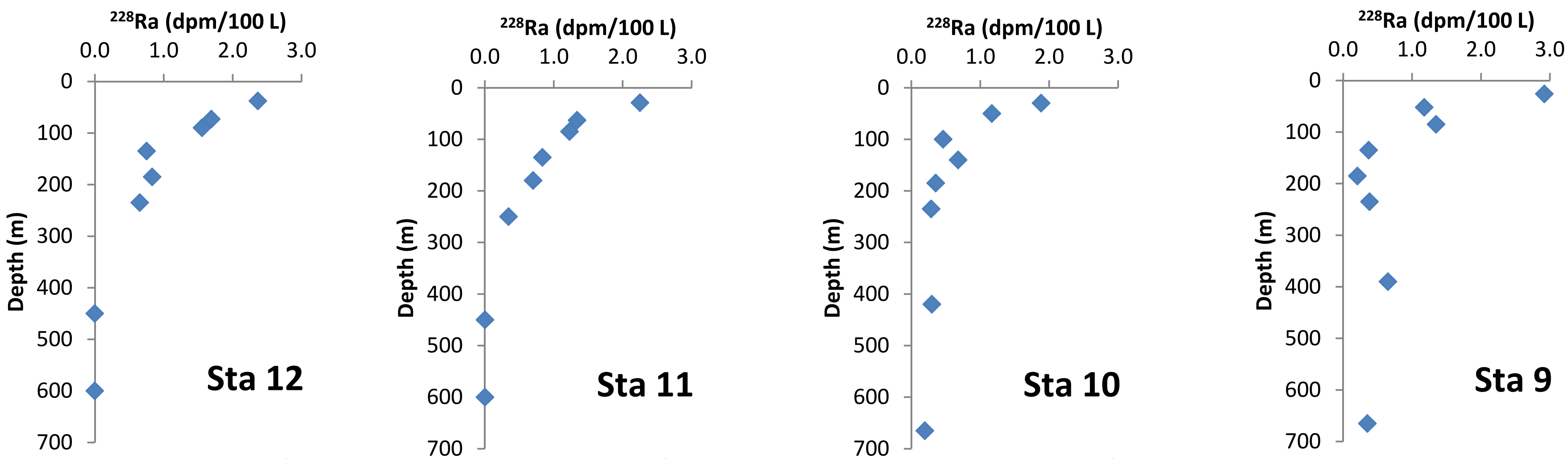
*Many tracers with different Green's Functions & sources/sinks



^{228}Ra-derived vertical mixing – 1D

Paul Morris, Matt Charette, Paul Henderson, Billy Moore

Offshore ← Nearshore



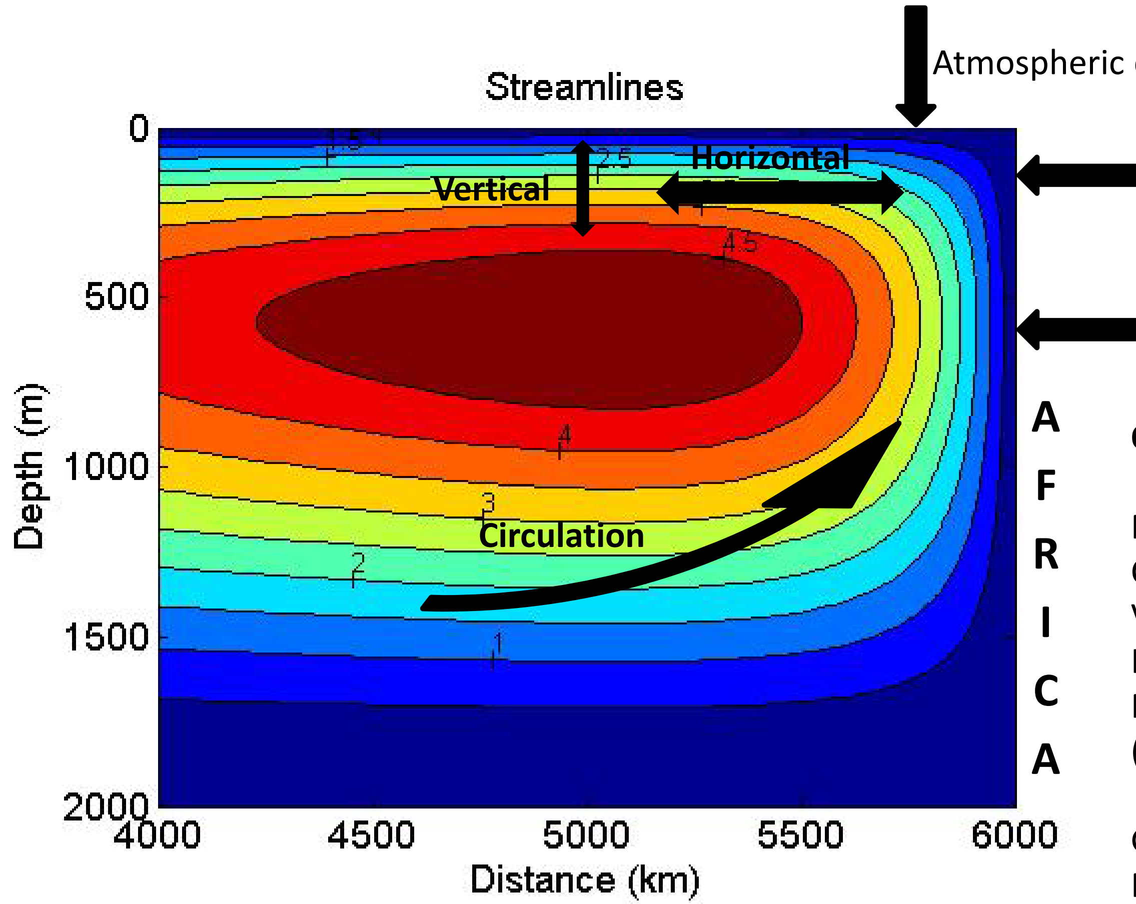
0.88 cm^2/s | 0.63 cm^2/s | 0.54 cm^2/s | 0.33 cm^2/s

- Diapycnal vertical mixing (K_v) calculated using a 1D steady-state diffusion model
- Vertical mixing increases as we move away from the coastline
- Data too sparse to perform the same calculation for horizontal mixing
- Questionable results – higher than expected based on literature values
- Progress to a 2D modeling analysis

2D Model – Parameters & Model Runs

Paul Morris, Bill Jenkins, Matt Charette

- Physical – Circulation, vertical & horizontal mixing
- Geochemical ^{228}Ra supply – ML, deep, & atmospheric



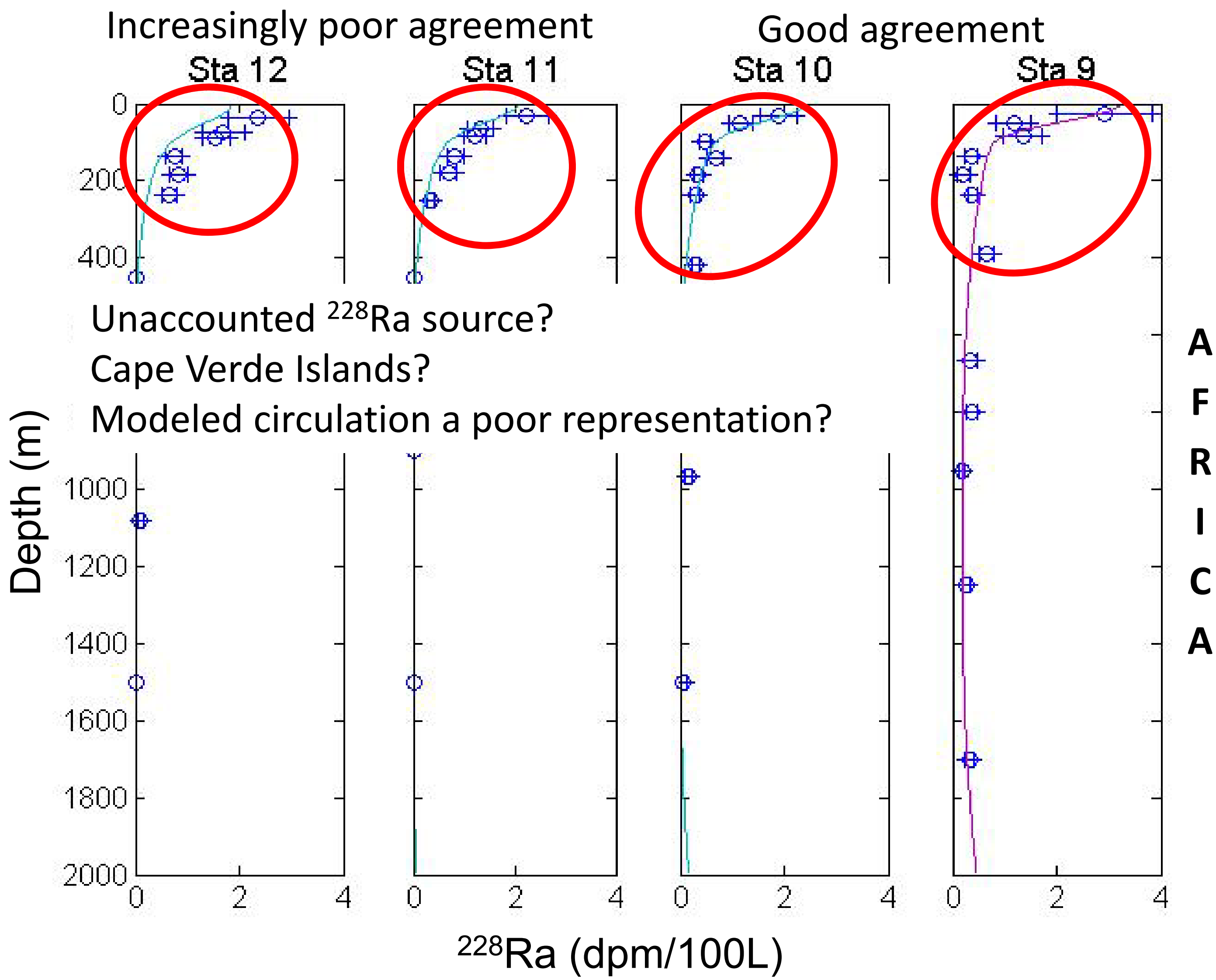
Optimum parameters from model runs

Physical (1D model K_v 0.33-0.88 $cm^2\ s^{-1}$)
Circulation – 5.6 Sv
Vertical mixing (K_v) – 0.35 $cm^2\ s^{-1}$
Horizontal mixing (K_h) – 433 $m^2\ s^{-1}$
NATRE: K_v=0.14 $cm^2\ s^{-1}$ K_h=1000 $m^2\ s^{-1}$
(Ledwell et al. 1993, 1998)

Geochemical – supply of ^{228}Ra
ML – 4.5 dpm/100L
Deep – 0.9 dpm/100L
Atmospheric – 0.1 dpm/100L

Model results – Modeled vs Obs.

Paul Morris, Bill Jenkins, Matt Charette



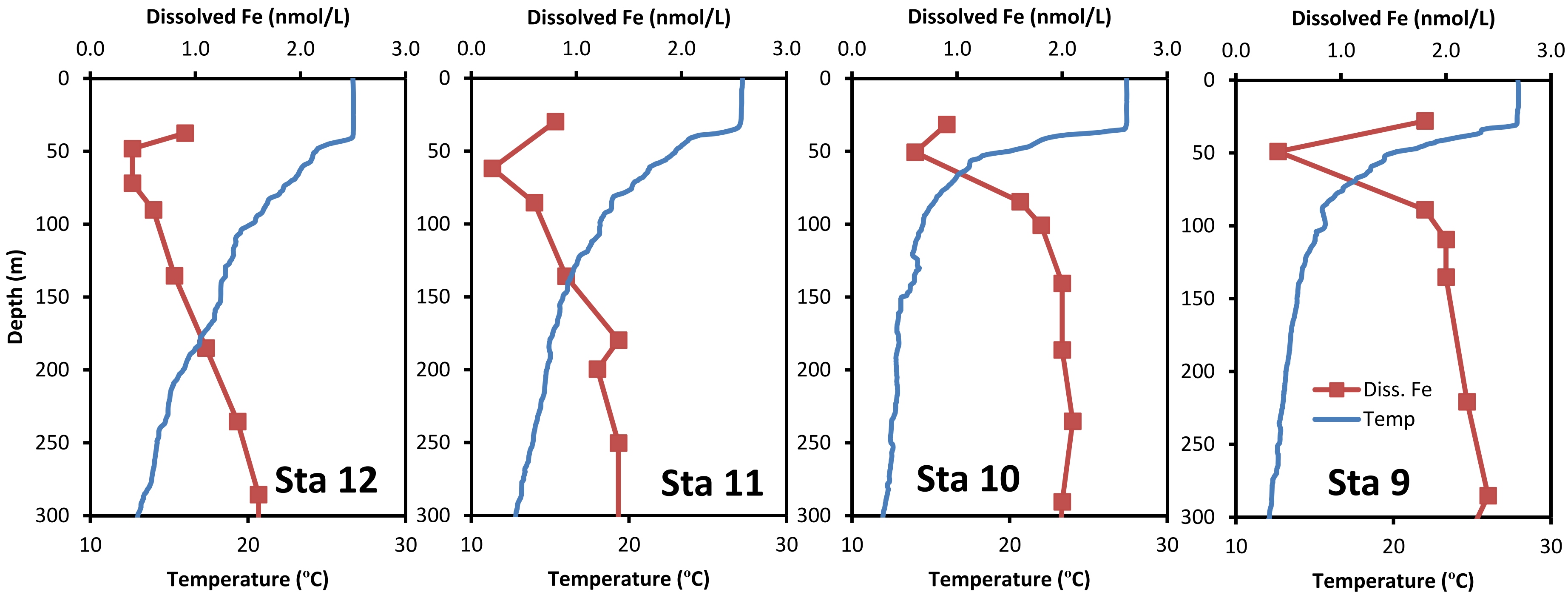
Unaccounted ^{228}Ra source?

Cape Verde Islands?

Modeled circulation a poor representation?

Uses of ^{228}Ra-derived mixing

DFe data from Measures, Hatta & Wu – Hawaii & Miami



Utility of measuring mixing rates in parallel to other measurements

Calculate vertical and horizontal mixing of DFe using ^{228}Ra-derived mixing rate

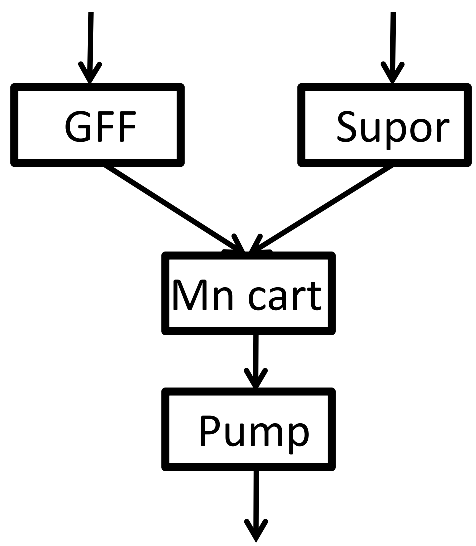
DFe gradient x K = DFe mixing rate

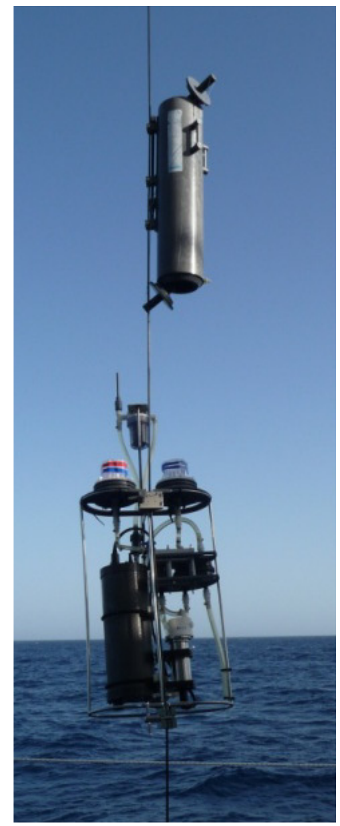
In Situ pumps – Particles & Diss. Radionuclides

Paul Morris, Phoebe Lam, Dan Ohnemus, Stephanie Owens, Kuanbo Zhou, Steve Pike, Paul Henderson, Matt Charette, Ken Buesseler, Billy Moore

- In situ pumps fitted dual flow filter heads and a Mn-sorption cartridge
- Niskin bottles collect ^{226}Ra & ^{234}Th samples to calibrate Mn-cartridge scavenging eff.
- Pump is a modified McLane pump. Modifications are patent pending (Lam & Morris)

Pump schematic





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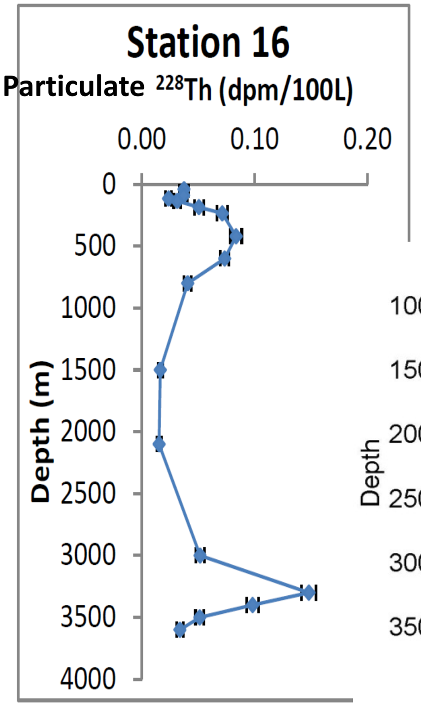
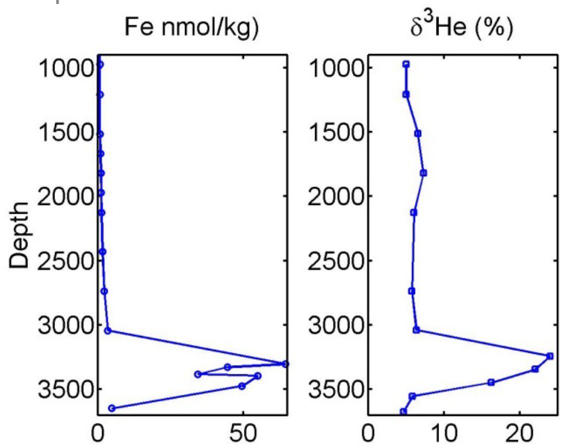
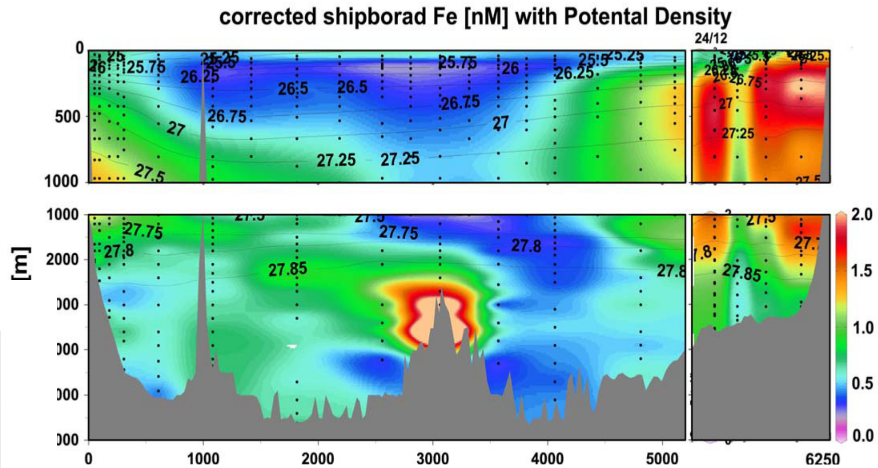
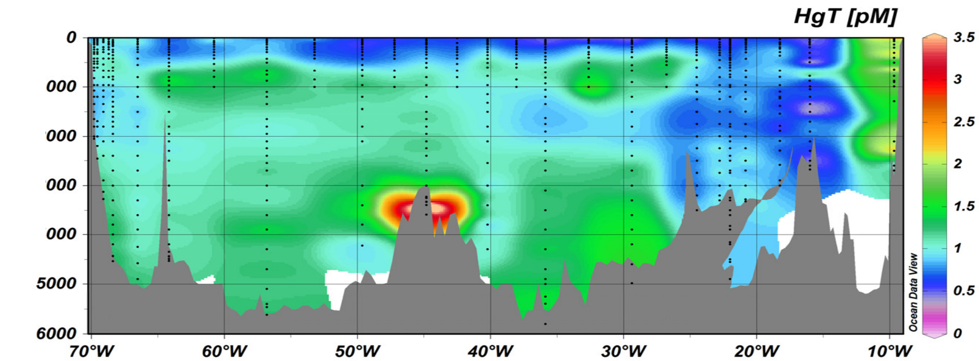
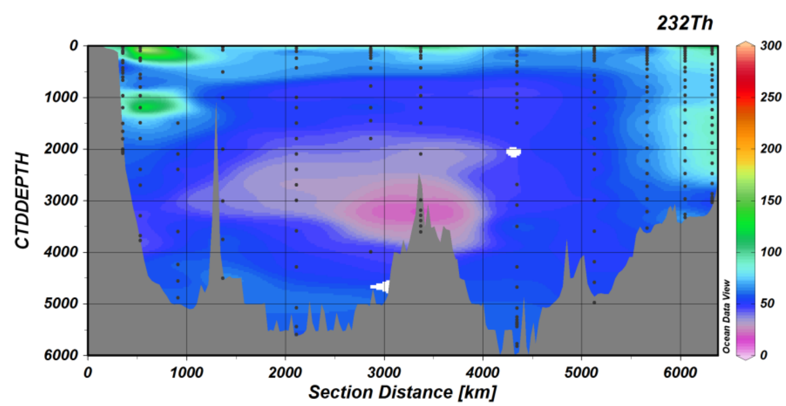
The TAG Hydrothermal Plume











Caveats:

Fe and ^{3}He drawn on separate casts

(Fe on multiple casts)

Need to relate using CTDs with:

(1) Neutral surface analysis

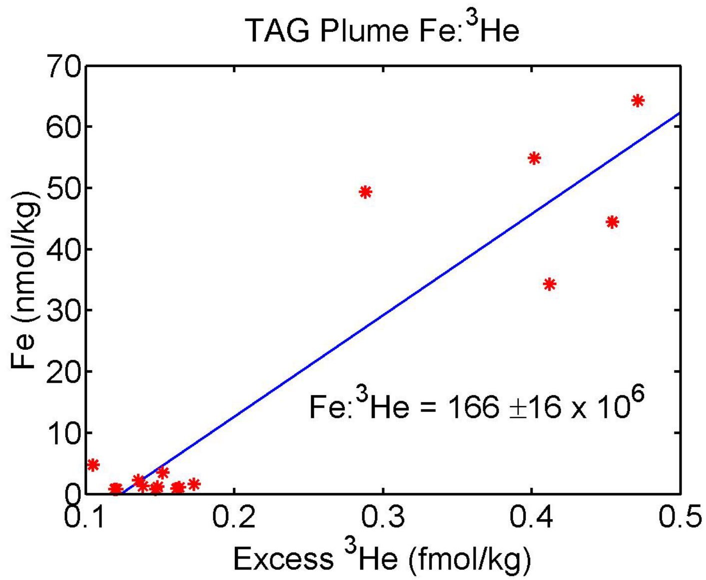
(2) Thermal anomalies on T-S

Global Fluxes and Rates

- ^3He is stable & inert: a dilution tracer
  - TE:^3He relation diagnostic of loss/gain
- Global hydrothermal ^3He flux is known
  - (~750 mol a^{-1})
- Use TE:^3He to infer TE hydrothermal flux
  - Western South Pacific* Fe:^3He ~ 10^6 ➔ 0.9 Gmol a^{-1}
  - South Atlantic** Fe:^3He ~ 70 x 10^6 ➔ ~2 Gmol a^{-1}
  - North Atlantic???? Is chemistry different for slow spreading ridges?

*Boyle & Jenkins (2008) from EPR **Saito et al (2012) from MAR

TAG (N. Atl. M.A.R.) Fe:^{3}He



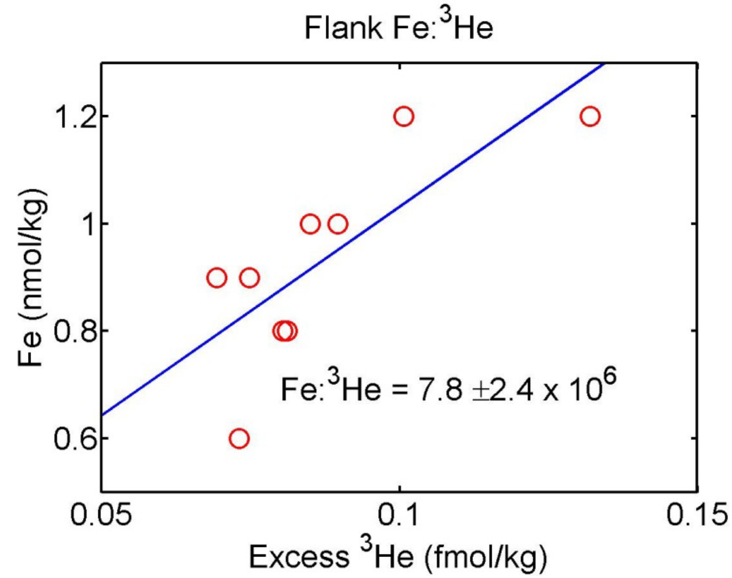
- But ^{228}Th says this is "fresh" Fe…
- Must look at flank relationship (d>2000m):

Fe:^{3}He ratio ~ 2X Saito et al, 200X Boyle & Jenkins

Intermediate result (on a log scale)

Caveat:

- Need to do detailed OMPA to assess "non-local" ^{3}He



GEOTRACES

Summary

- The first U.S. GEOTRACES transect a success*
- Wide range of properties (TEIs) measured
- Data sets emerging
  - Beautiful pictures
  - Clear process diagnostics (e.g., OMZ & TAG)
  - Completion and synthesis in progress
  - Modeling to follow

*Despite ship propulsion problems

NSF

Outline

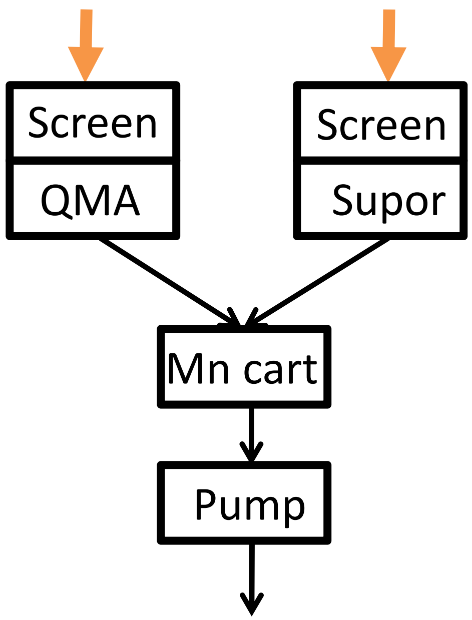
- Introduction
- Overview of results so far
- Two vignettes
- Acknowledgements
  - Bob, Gideon, and many others
  - US-GNAZT co-conspirators
  - Don Rice, NSF, & helpful reviewers
  - The community at large

In Situ pumps – Particles & Diss. Radionuclides

Paul Morris, Phoebe Lam, Dan Ohnemus, Stephanie Owens, Kuanbo Zhou, Steve Pike, Paul Henderson, Matt Charette, Ken Buesseler, Billy Moore

Photo: Paul Morris

Pump schematic



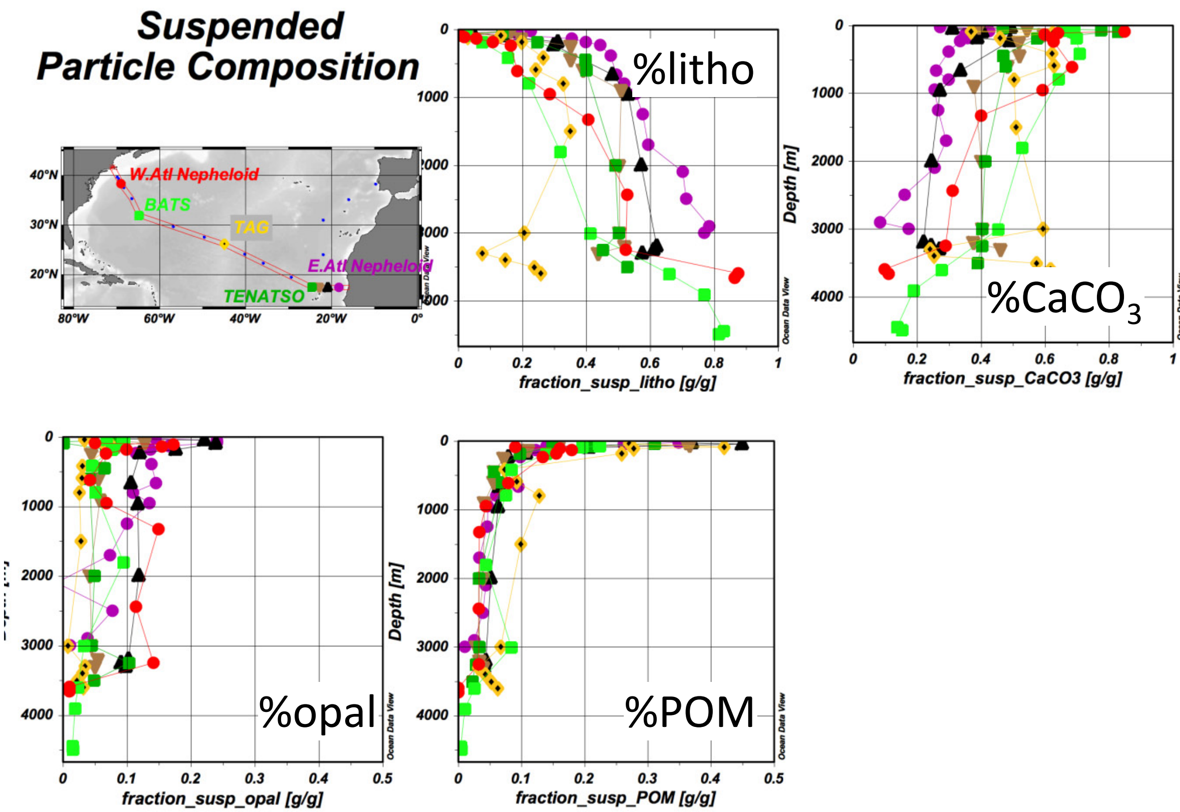
- In situ pumps fitted with dual flow filter holders and a Mn-sorption cartridge downstream of the filter holders
- 30L Niskin bottles collect ^{226}Ra & ^{234}Th samples to calibrate Mn-cartridge scavenging efficiency
- Pump is a modified McLane pump. Modifications are patent pending (Lam & Morris)
- Dual flow filter holders allow simultaneous particle collection on pre-combusted quartz fiber filters (QMA) and acid-leached polyethersulfone (Supor) filters. Both sides have a 51um prefilter for size fractionation

Suspended particulate matter concentration and composition

Phoebe J. Lam, Daniel C. Ohnemus, Maureen E. Auro, Stephanie Owens, Ken Buesseler

- Suspended particulate matter (SPM) *concentration* and *composition* are key parameters determining the scavenging removal of particle-reactive elements
- We measure the major chemical constituents of marine particles. SPM concentration is determined as their sum:

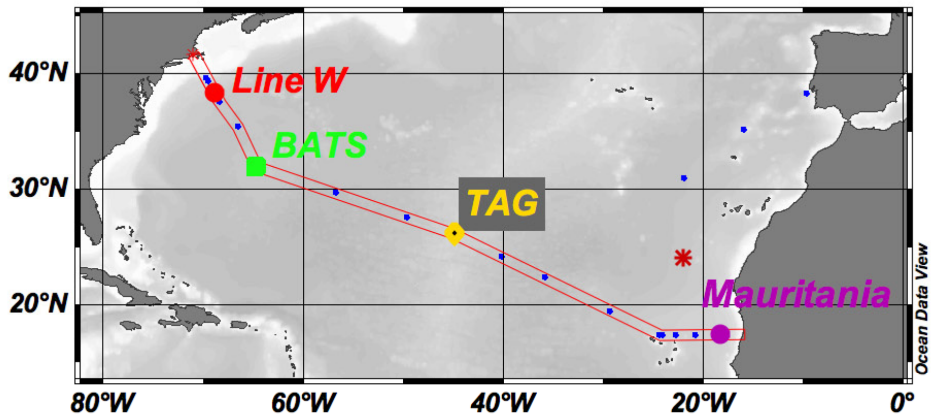
SPM = Σ(lithogenics, $CaCO_3$, opal, POM, oxyhydroxides)

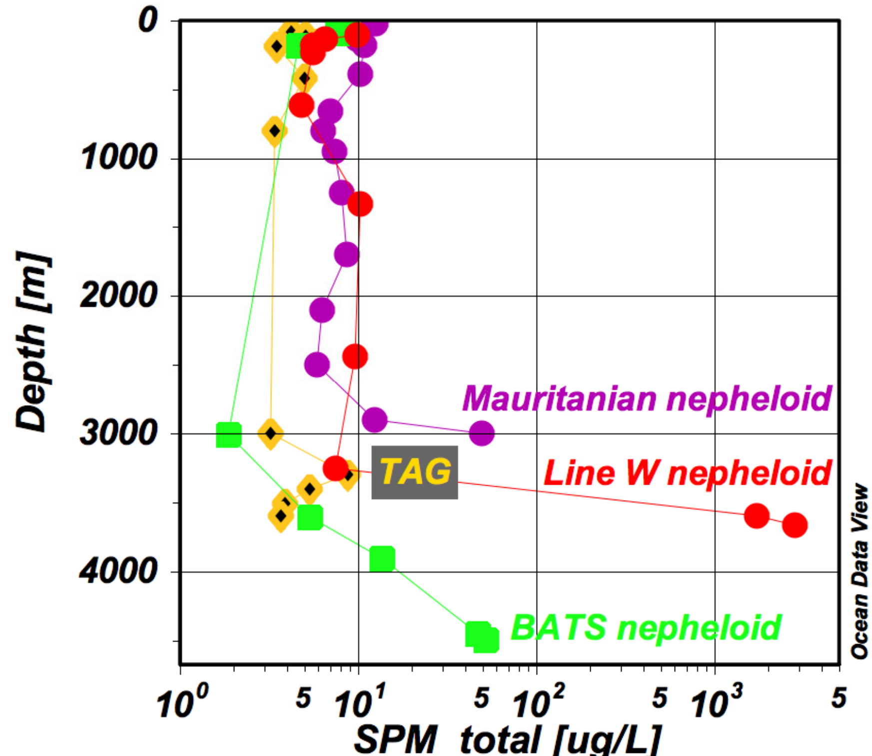


- Lithogenic material dominates particle composition, especially under the Saharan plume (eg. Mauritanian coast) and in benthic nepheloid layers
- $CaCO_3$ is the next most abundant particle phase (20-60%)
- Opal varies by 10x from the coastal stations to the oligotrophic gyres, but is overall low (<20%)

4 “charismatic” particle features

Phoebe J. Lam, Daniel C. Ohnemus, Maureen E. Auro, Stephanie Owens, Ken Buesseler





Note log scale!

- **TAG hydrothermal plume**: SPM is 3x above bkgd and composed of *60% FeOOH* (typical FeOOH is 1%)
- **Mauritanian nepheloid layer**: SPM is 10x above bkgd, and is the only nepheloid layer enriched in FeOOH and MnOOH
- **BATS nepheloid layer**: SPM is also 10x above bkgd and enriched in lithogenics compared to the water column above, and extends *1000m* up from the ocean bottom
- **Line W nepheloid layer** is *500x* (!) above background and is primarily lithogenic

- These samples provide a wide range of particle mass and composition to test hypotheses about particle control of scavenging