Connecting Phytoplankton Size to Export Flux in the Global Ocean

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Photo credit: Chris Strait

Goal

- Improve understanding of how phytoplankton size structure controls particle export and remineralization.

Background

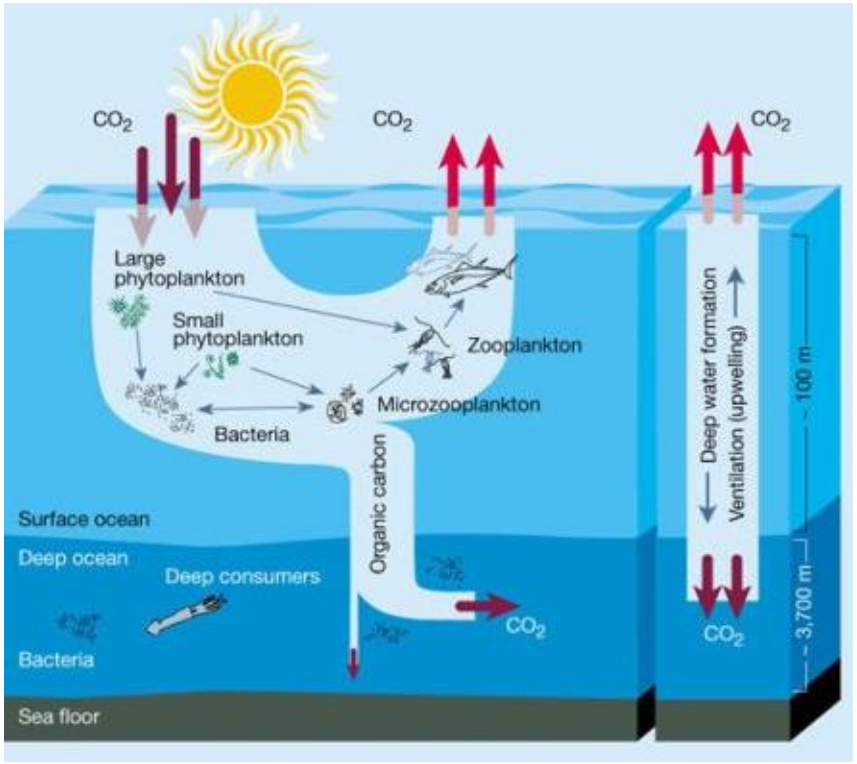
- Work to date has been able to capture site-to-site variability, but have difficulty in capturing the variability at specific sites.
- Dunne et al. 2005 suggests biomass controls 59% of the variance in export flux, while size structure is the next most important control, explaining 28% of the variance.
- Guidi et al. 2009 suggest that phytoplankton composition explained 68% of flux at 400m.

Now with satellite estimates of phytoplankton size structure, can we gain a greater understanding of the relative contribution of phytoplankton size to export flux?

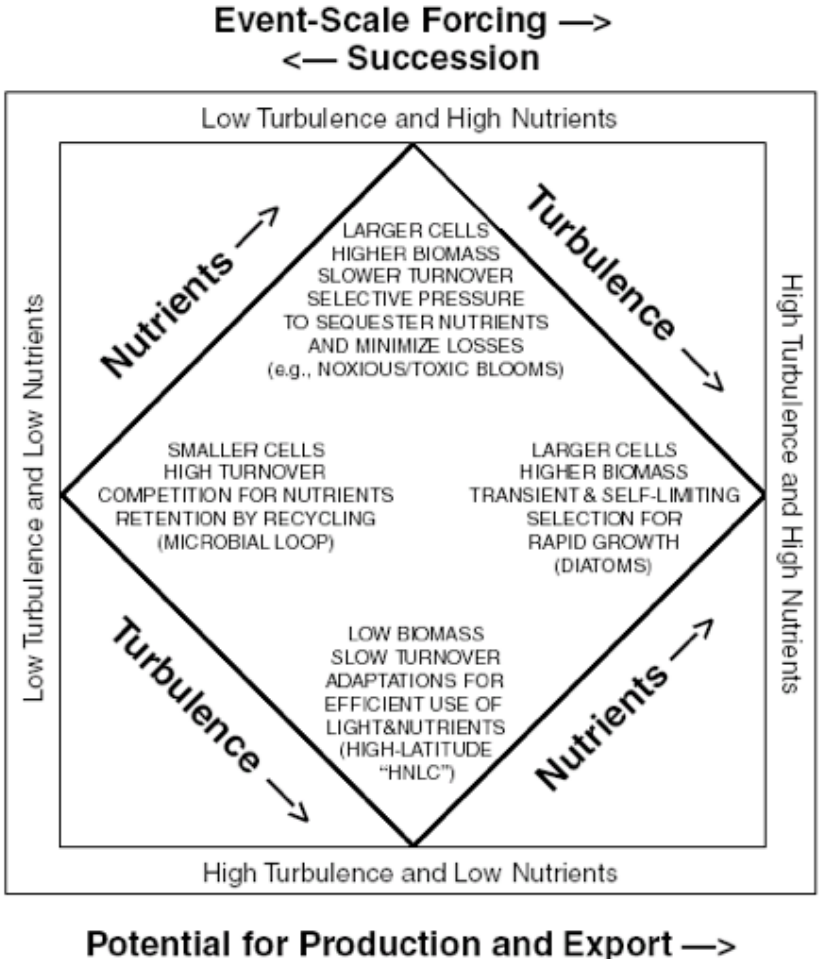
Outline

- Phytoplankton Size and Satellite Retrievals
- Data Mining
  - Global
  - Regional
  - Time series
    - Connection to satellite estimated cell size distribution
- Working toward mechanistic understanding
  - A work in progress

Ecological Importance of Cell Size



Chisholm, 2000



Cullen et al. (2002); Based on Margalef (1978)

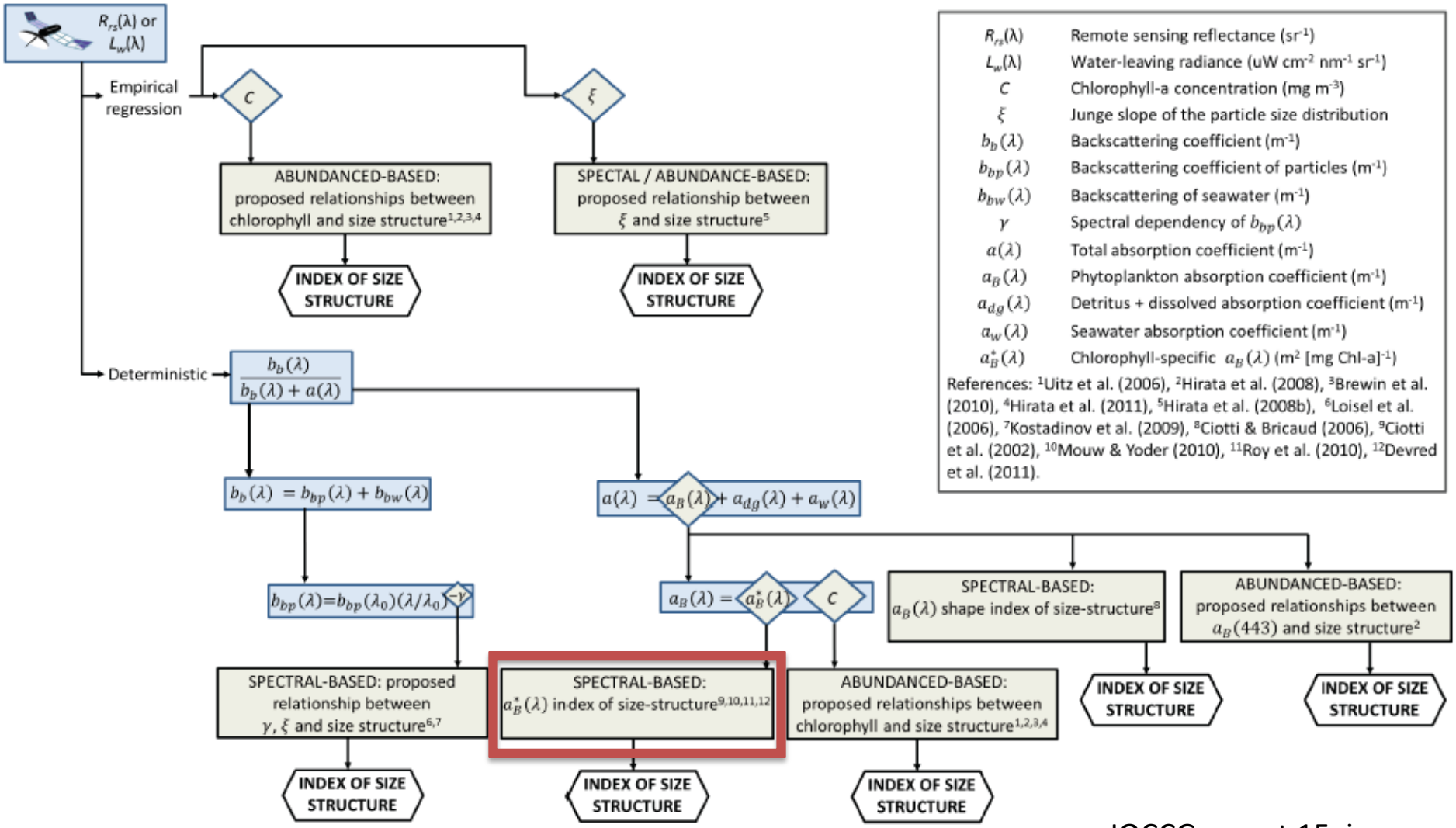
Small cells:

- recycled within euphotic zone
- utilizing regenerated nutrients
- Prefer stratified high light conditions

Large cells:

- sink out of the euphotic zone
- utilize new nutrients efficiently
- Prefer turbulent, low light conditions

Hierarchical Classification of Satellite Phytoplankton Size Class Detection



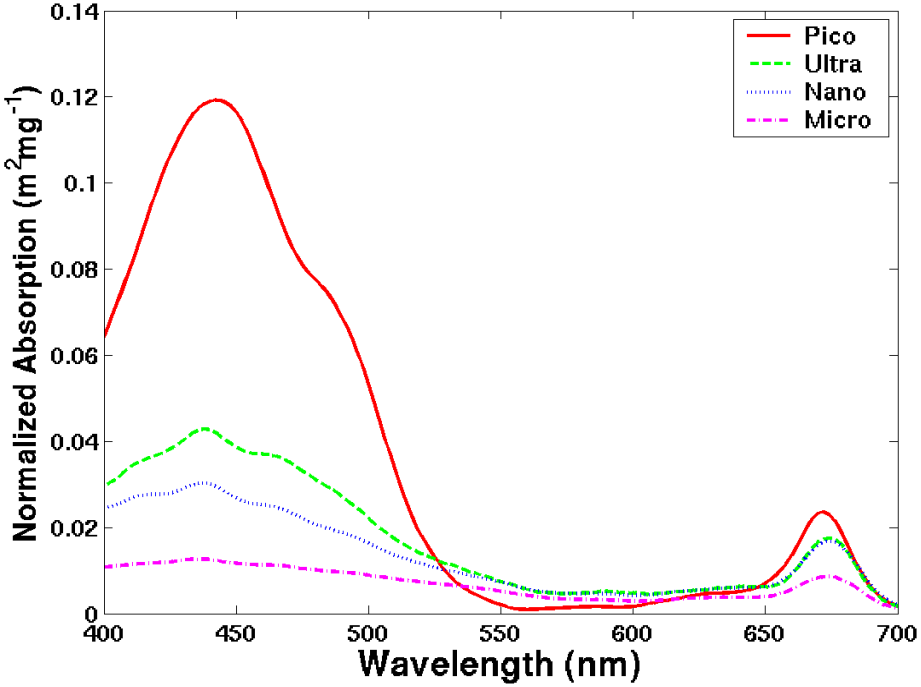
$R_{rs}(\lambda)$	Remote sensing reflectance (sr^{-1})
$L_w(\lambda)$	Water-leaving radiance (uW cm^{-2} nm^{-1} sr^{-1})
C	Chlorophyll-a concentration (mg m^{-3})
ξ	Junge slope of the particle size distribution
$b_b(\lambda)$	Backscattering coefficient (m^{-1})
$b_{bp}(\lambda)$	Backscattering coefficient of particles (m^{-1})
$b_{bw}(\lambda)$	Backscattering of seawater (m^{-1})
γ	Spectral dependency of $b_{bp}(\lambda)$
$a(\lambda)$	Total absorption coefficient (m^{-1})
$a_\phi(\lambda)$	Phytoplankton absorption coefficient (m^{-1})
$a_{dg}(\lambda)$	Detritus + dissolved absorption coefficient (m^{-1})
$a_w(\lambda)$	Seawater absorption coefficient (m^{-1})
$a^*_\phi(\lambda)$	Chlorophyll-specific $a_\phi(\lambda)$ (m^2 [mg Chl-a]$^{-1}$)

References: [1]Uitz et al. (2006), [2]Hirata et al. (2008), [3]Brewin et al. (2010), [4]Hirata et al. (2011), [5]Hirata et al. (2008b), [6]Loisel et al. (2006), [7]Kostadinov et al. (2009), [8]Ciotti & Bricaud (2006), [9]Ciotti et al. (2002), [10]Mouw & Yoder (2010), [11]Roy et al. (2010), [12]Devred et al. (2011).

IOCCG report 15, in prep

Optical Importance of Cell Size

Despite the physiological and taxonomic variability, variation in spectral shape can be defined by changes in the dominant size class.



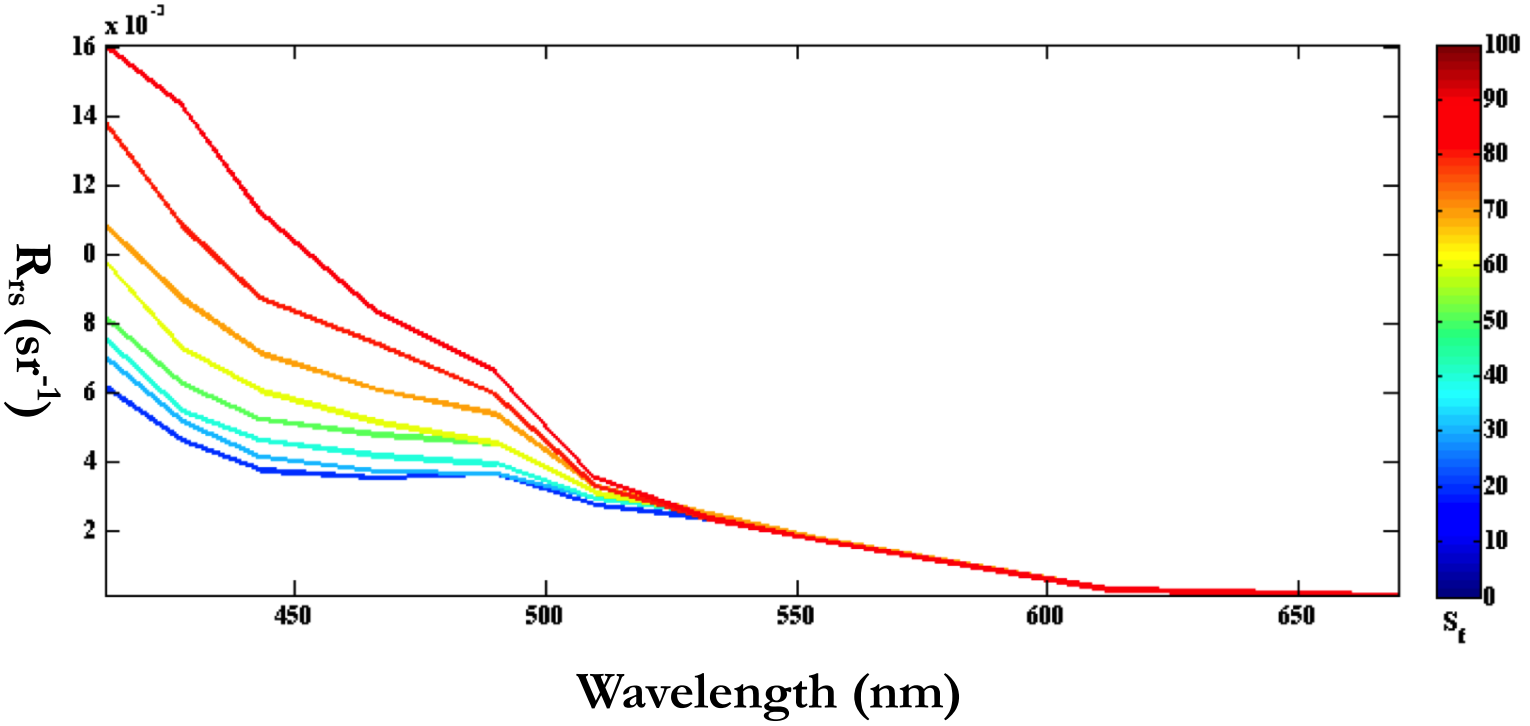
(Ciotti et al. 2002)

$$a^*_{ph}(\lambda) = [(1-S_{fm}) \times a^*_{pico}(\lambda)] + [S_{fm} \times a^*_{micro}(\lambda)]$$

Effect of Cell Size on $R_{rs}(\lambda)$

S_{fm} varying
Constant [Chl] = 0.5 mg m^{-3}
Constant $a_{CDM}(443)$ = 0.002 m^{-1}

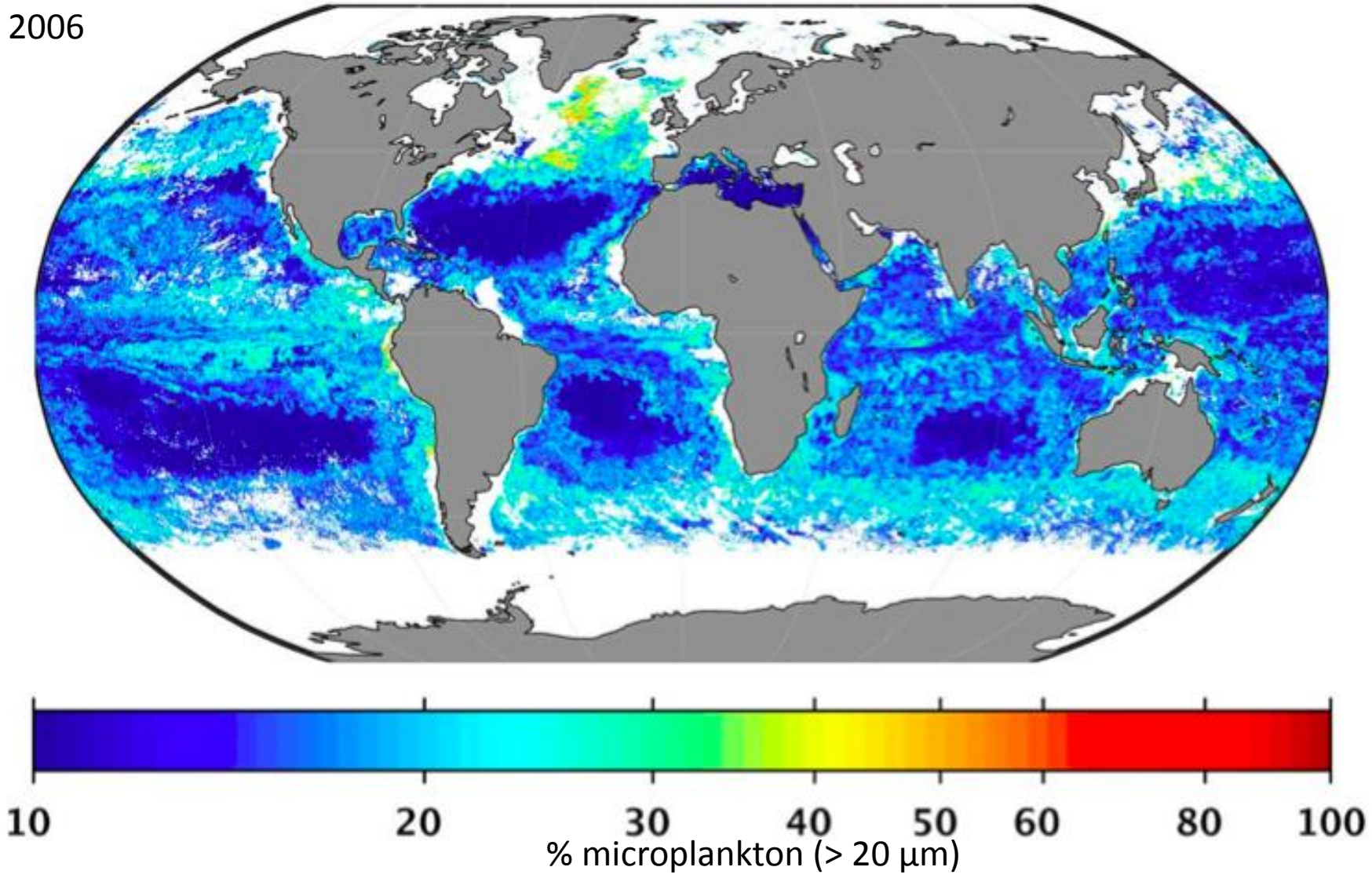
Magnitude shift!



Mouw & Yoder, 2010

Phytoplankton Size Distribution

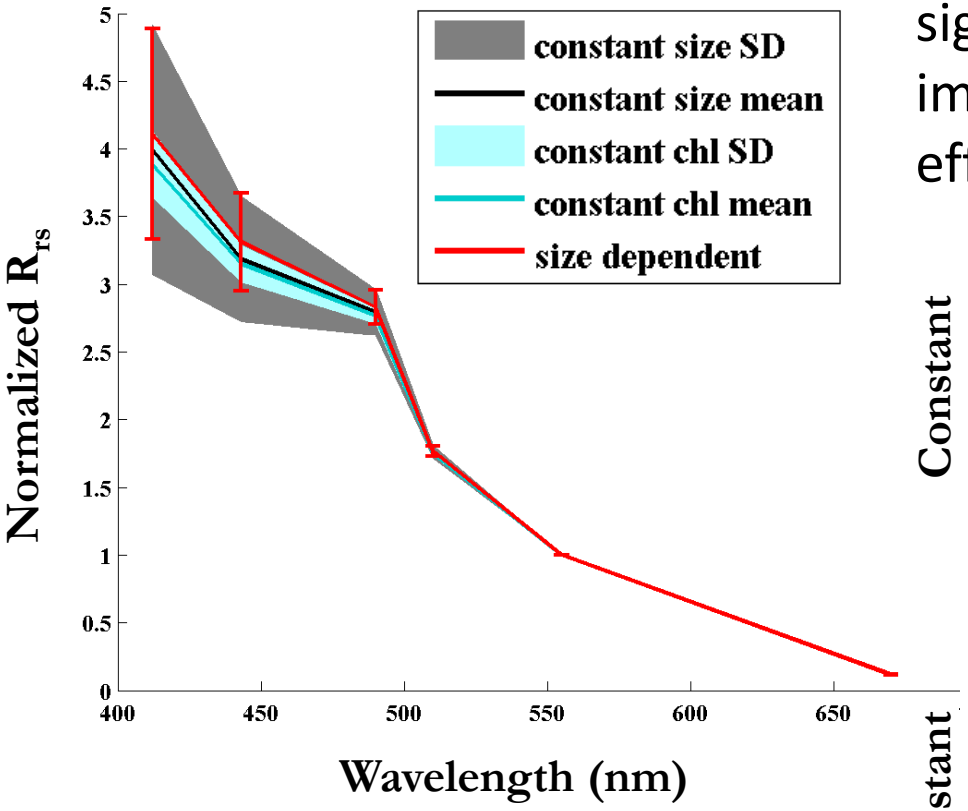
May 2006

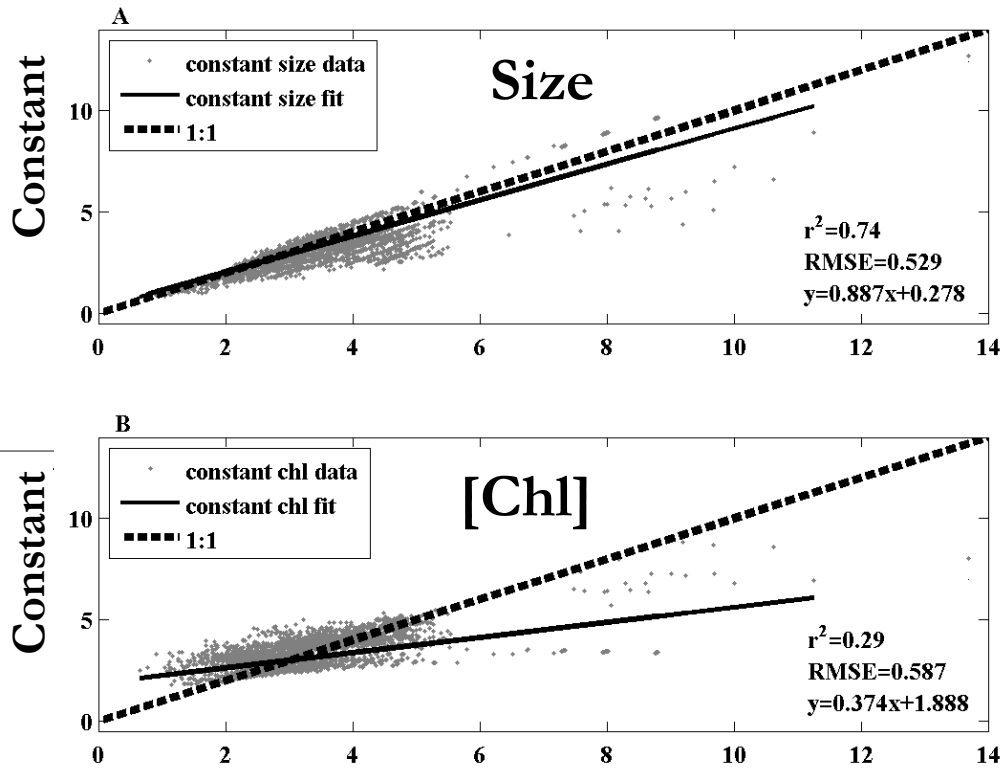


Mouw & Yoder 2010

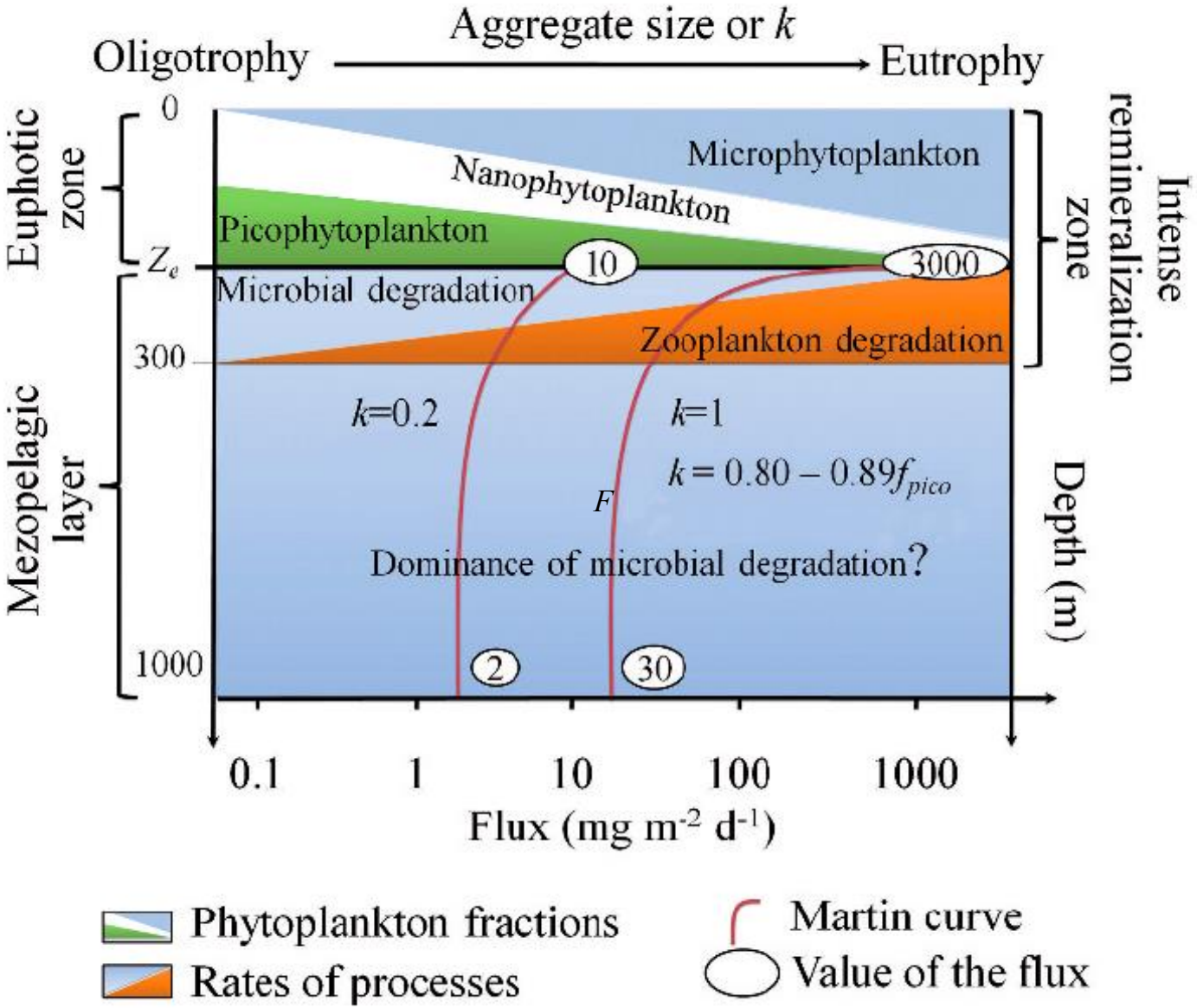
Contribution of Size & [Chl] to $R_{rs}(\lambda)$

Variations in [Chl] impact $R_{rs}(\lambda)$ more significantly than size, but size is an important and detectable second order effect.





Mouw et al., 2012



$$F_z = F_{100}(z/100)^{-k}$$

Guidi et al. 2009

Export and Phytoplankton

- High latitudes (larger cells dominate)
  - High export efficiency but low transfer efficiency
    - Exported organic material is relatively liable and prone to remineralization in the upper mesopelagic

- Low latitudes (smaller cells dominate)
  - Low export efficiency but high transfer efficiency
    - The effective microbial loop ensures much of the organic matter is recycled and thus refractory before it is exported resulting in comparatively less degradation at mesopelagic depths

Henson et al. 2012, Guidi et al. 2009

Export Flux & Transfer Efficiency

Export Flux

$$F_{z-z_e} = f\ NPP(ae^{-\frac{1}{l}(z-z_e)} + (1-a))$$ Lima et al. 2014

f = fraction of exported vertically integrated NPP
α = labile fraction of POC
λ = remineralization length scale
z_e = export depth

Transfer Efficiency

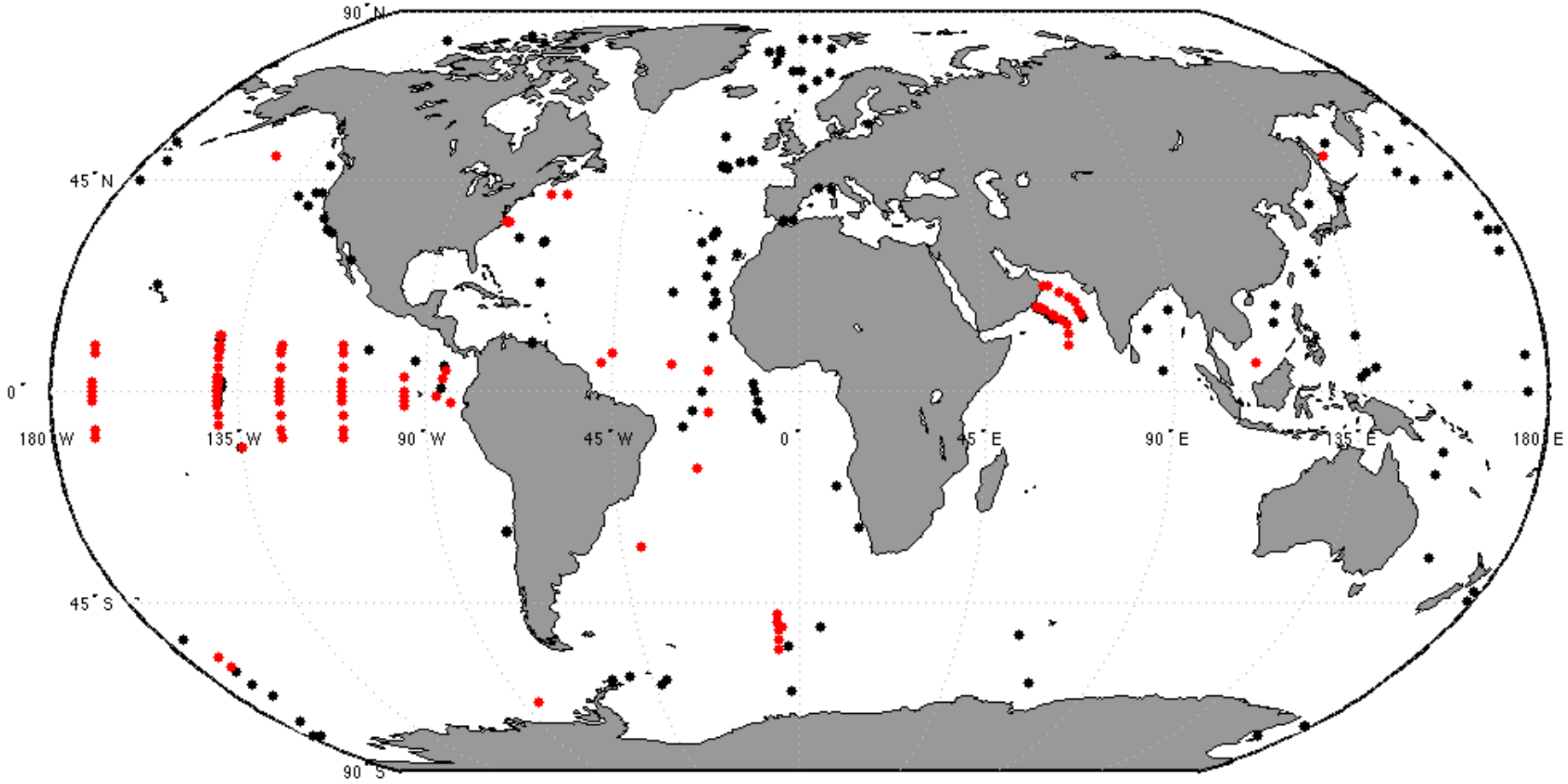
$$TE_{z-z_e} = \frac{F_{z-z_e}}{F_{z_e}}$$ Buesseler & Boyd 2009

The ratio of export to production at the based of the euphotic zone or mixed layer depth, whichever is deeper

Data Mining

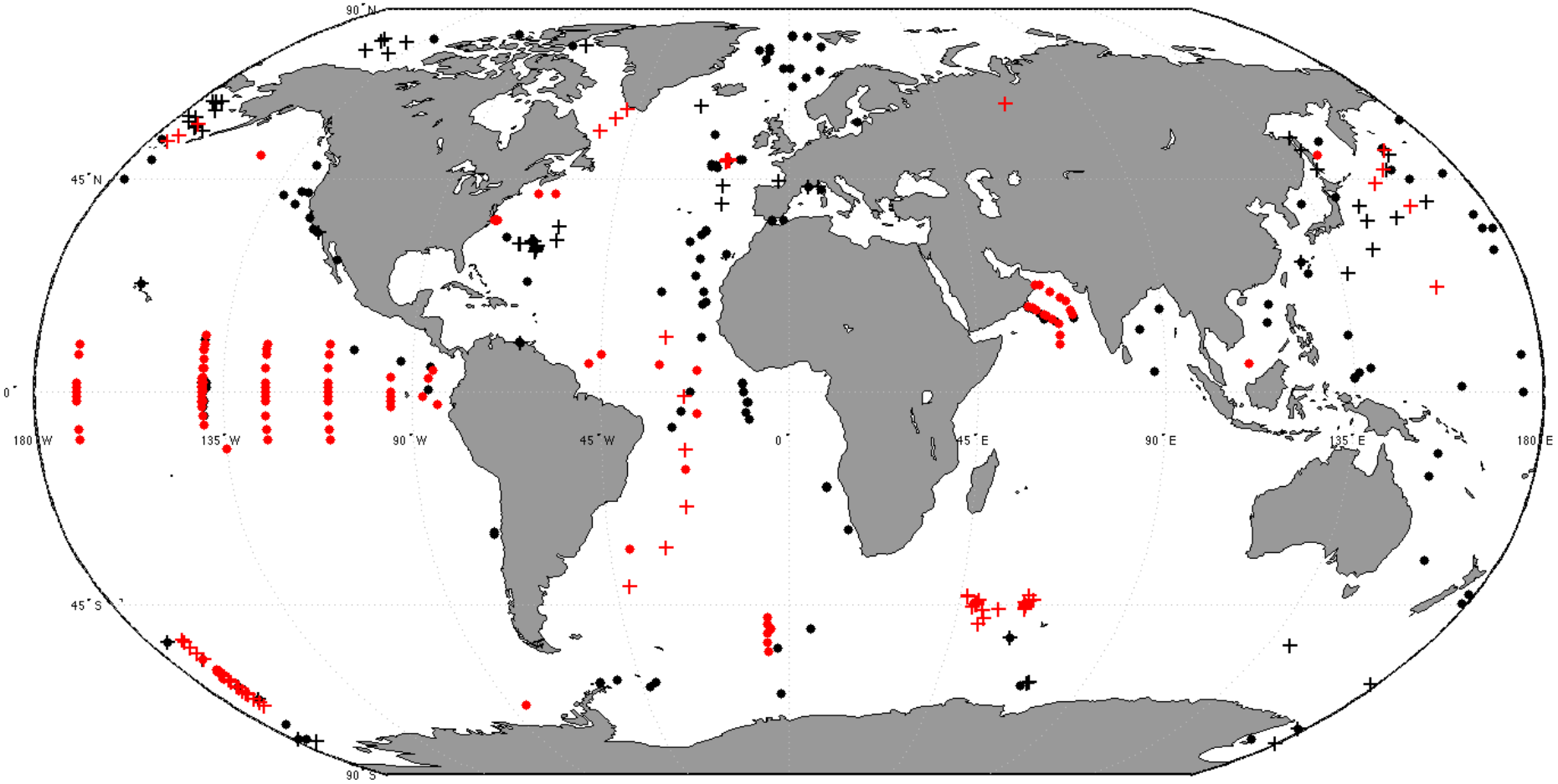
Data Distribution

Prior to satellite record



Data Distribution

Prior + coincident with satellite record



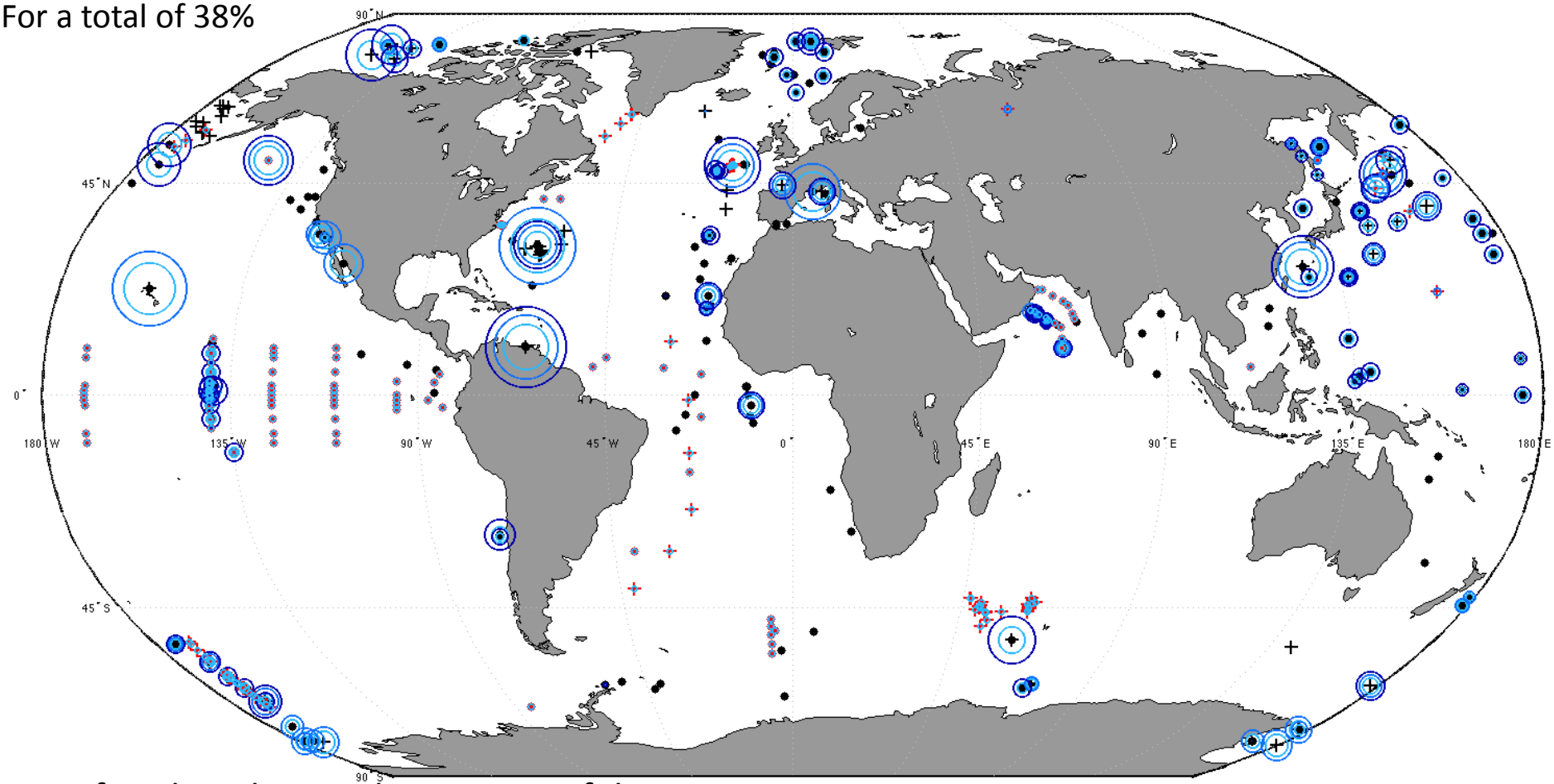
● 234-Thorium (41%)

● Sediment Trap (26%)

✚ Coincident with satellite

BATS = 11%
HOT = 6%
CARIACO = 21%
For a total of 38%

Data Distribution

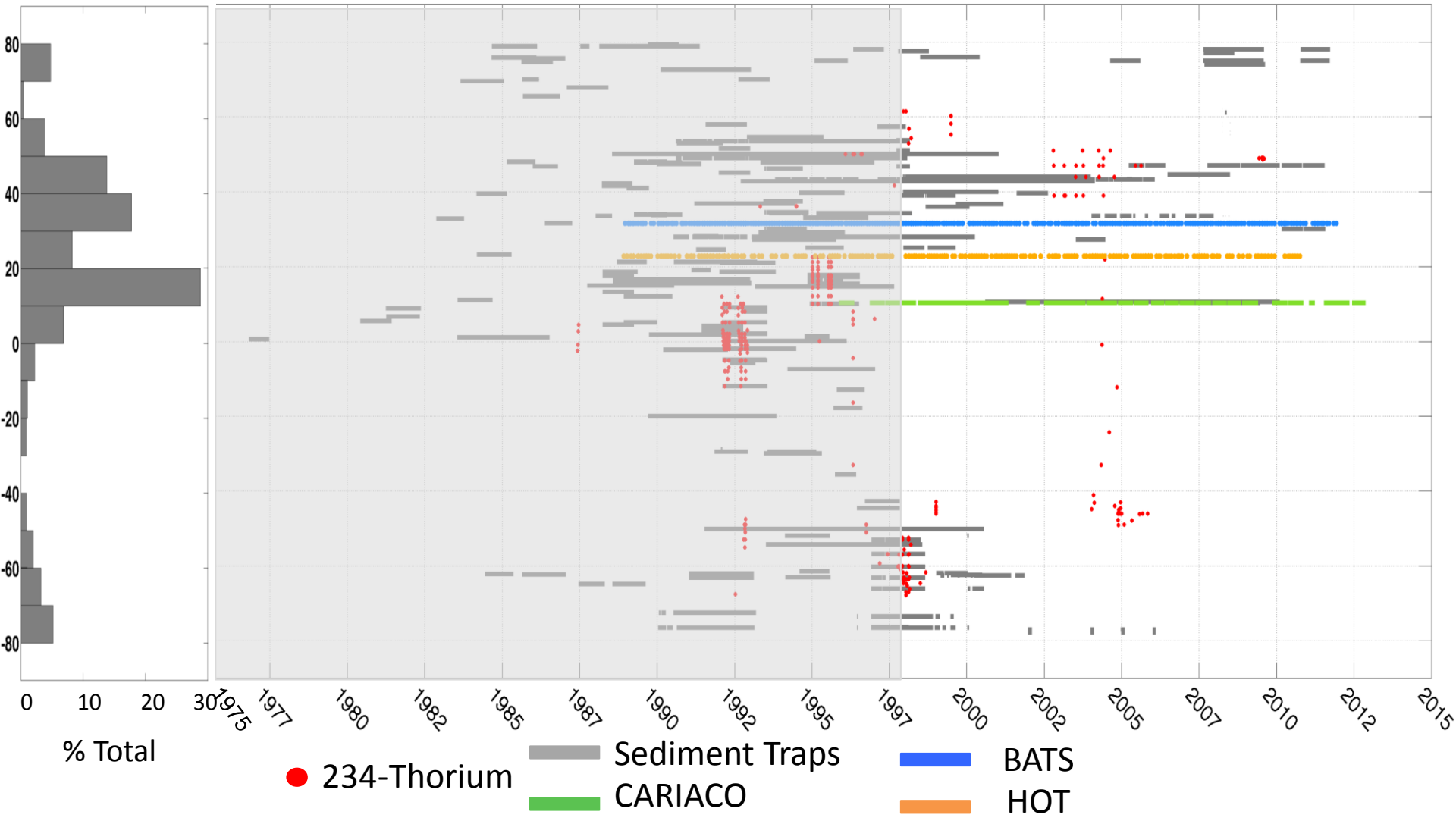


Size of circle indicates the amount of data present at a given site
Color or circle indicates depths of observation

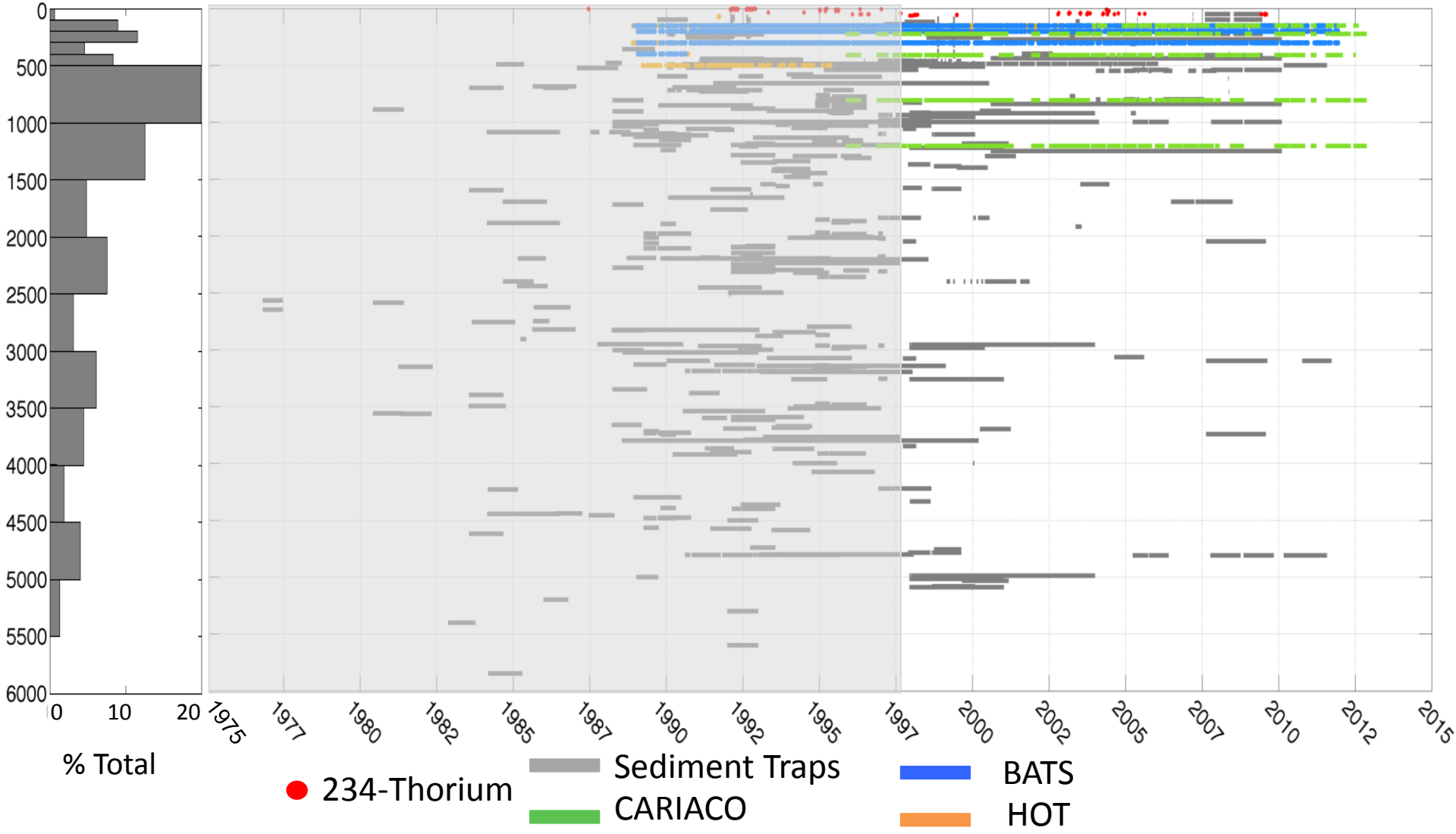
- light blue: <= 100 m
- medium blue: >100 m & <=1000 m
- dark blue: > 1000 m

- 234-Thorium
- Sediment Trap
- Coincident with satellite

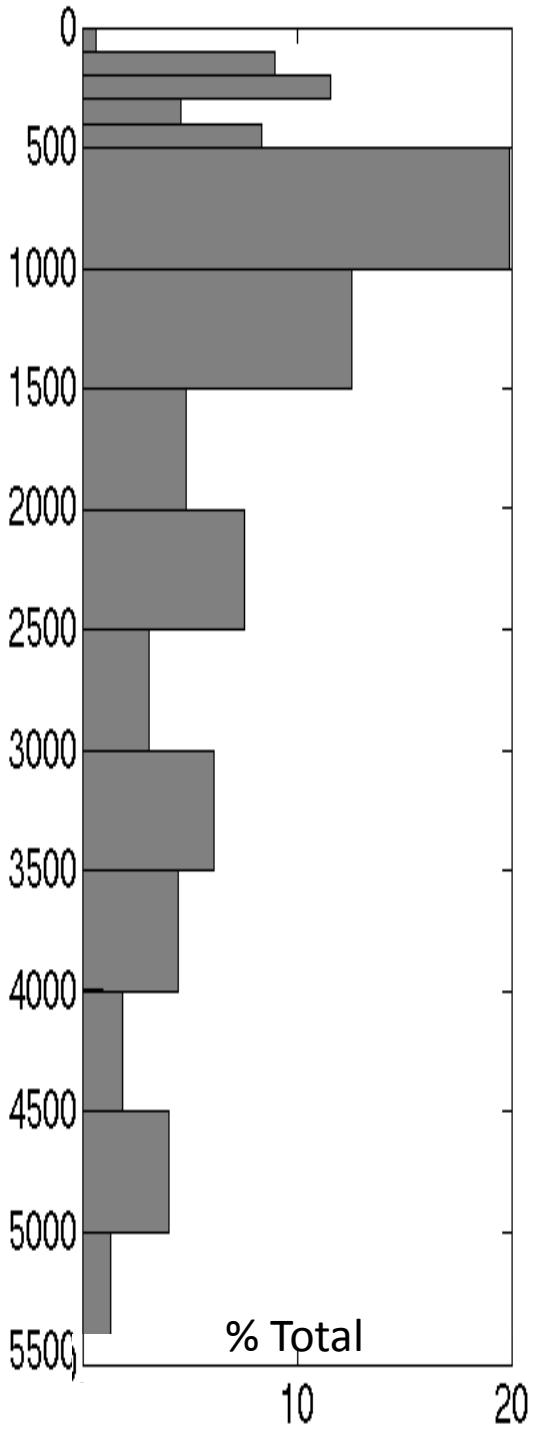
Latitudinal Distribution

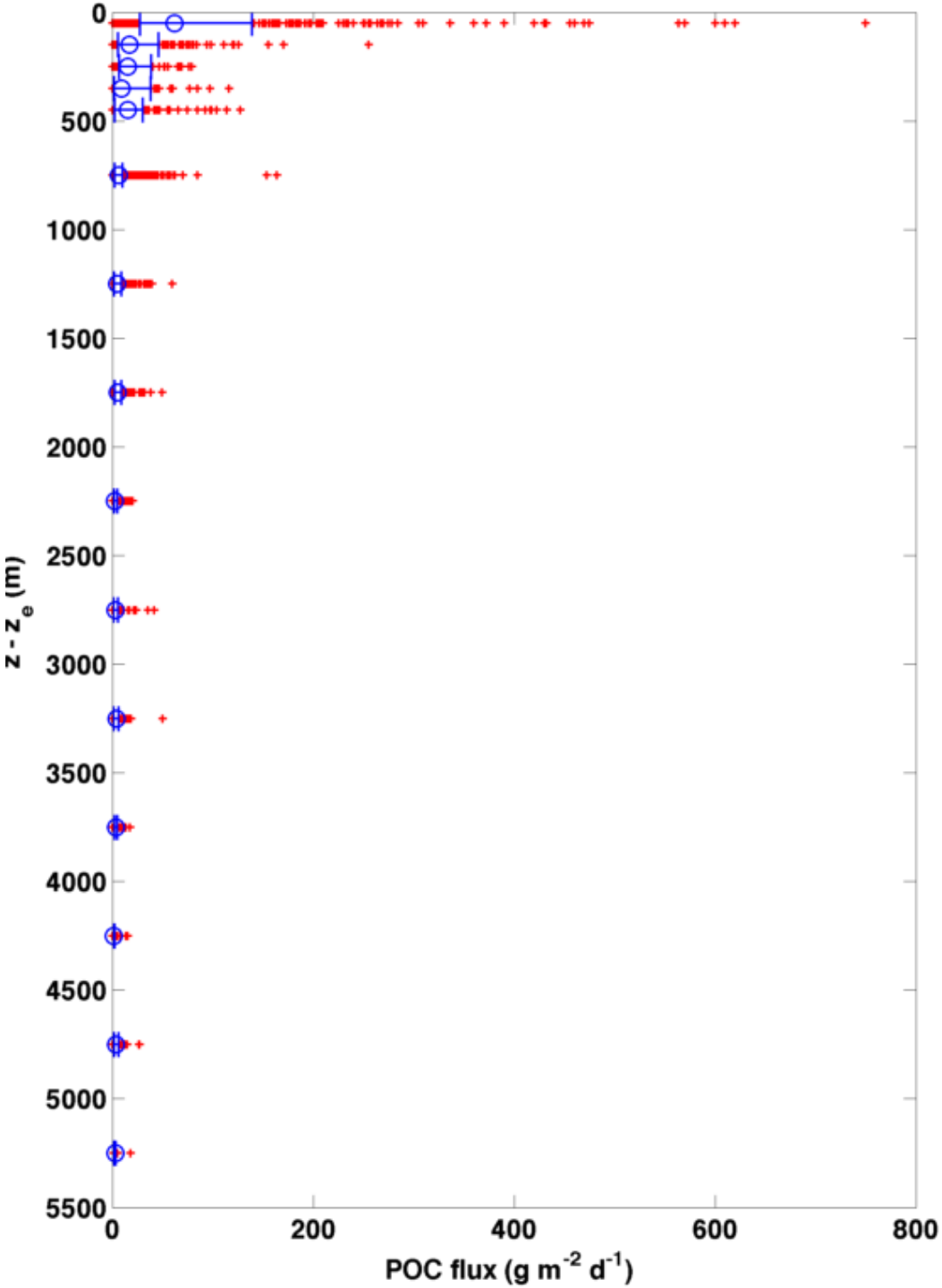


Depth Distribution



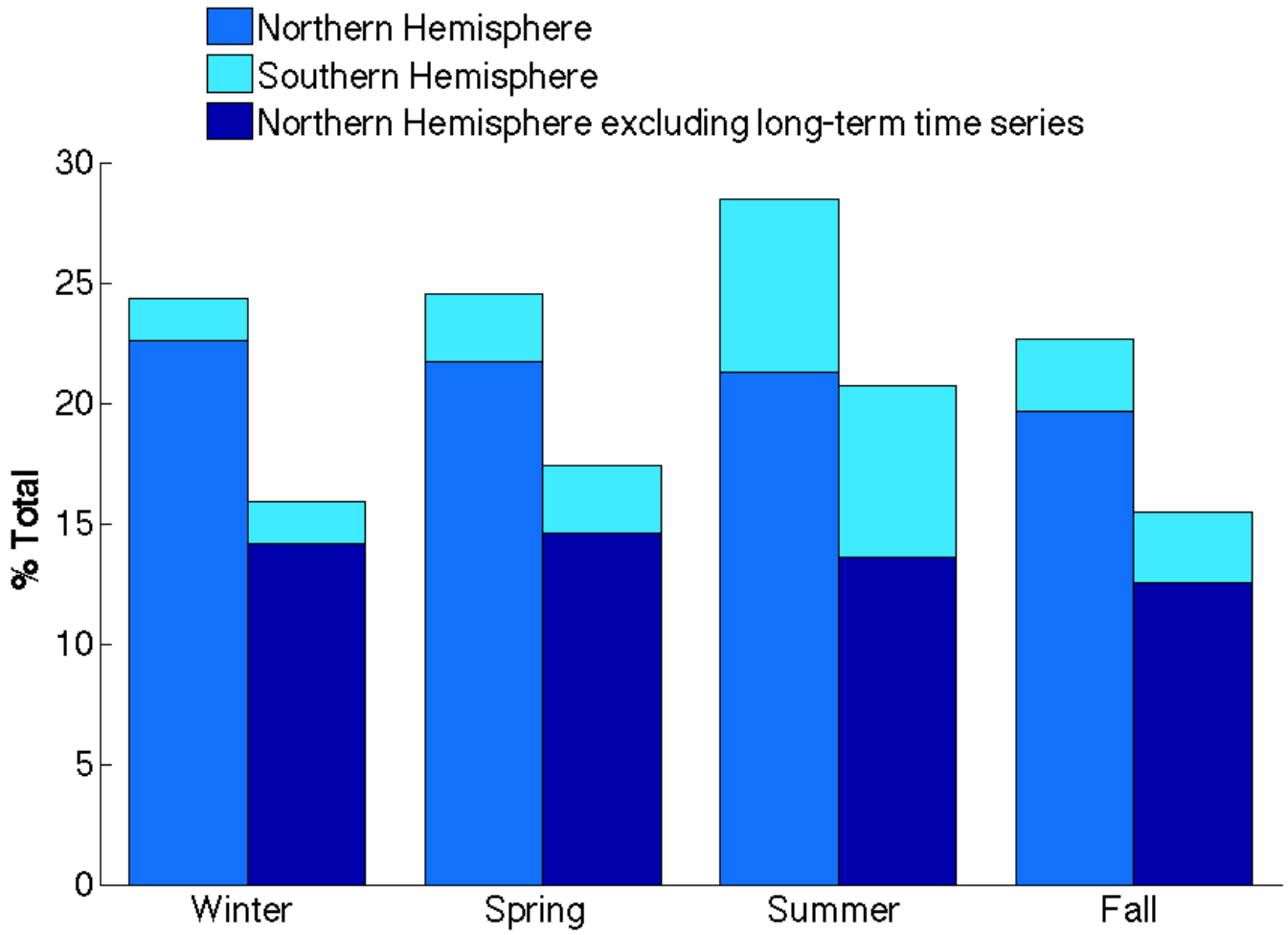
Global POC flux



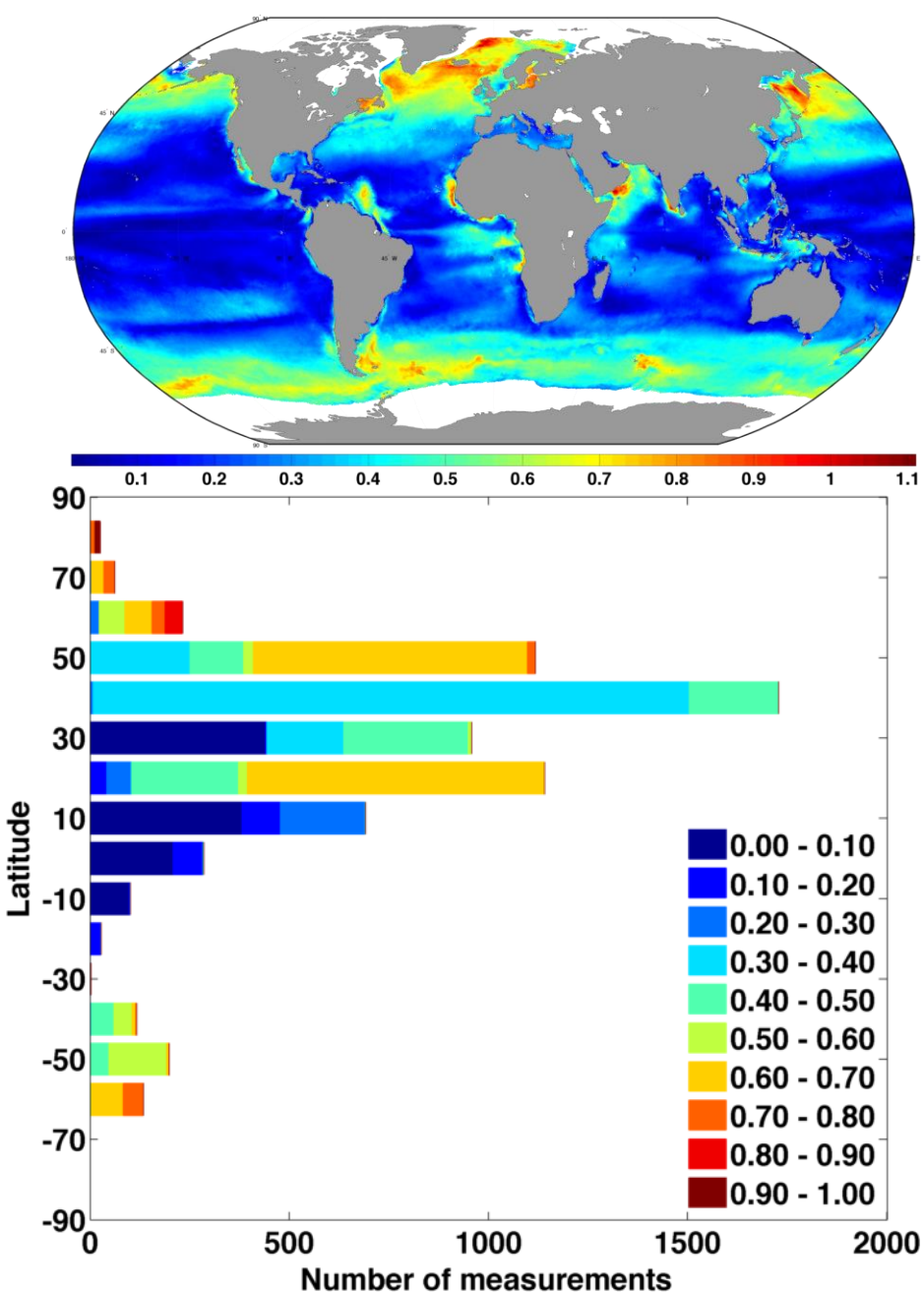


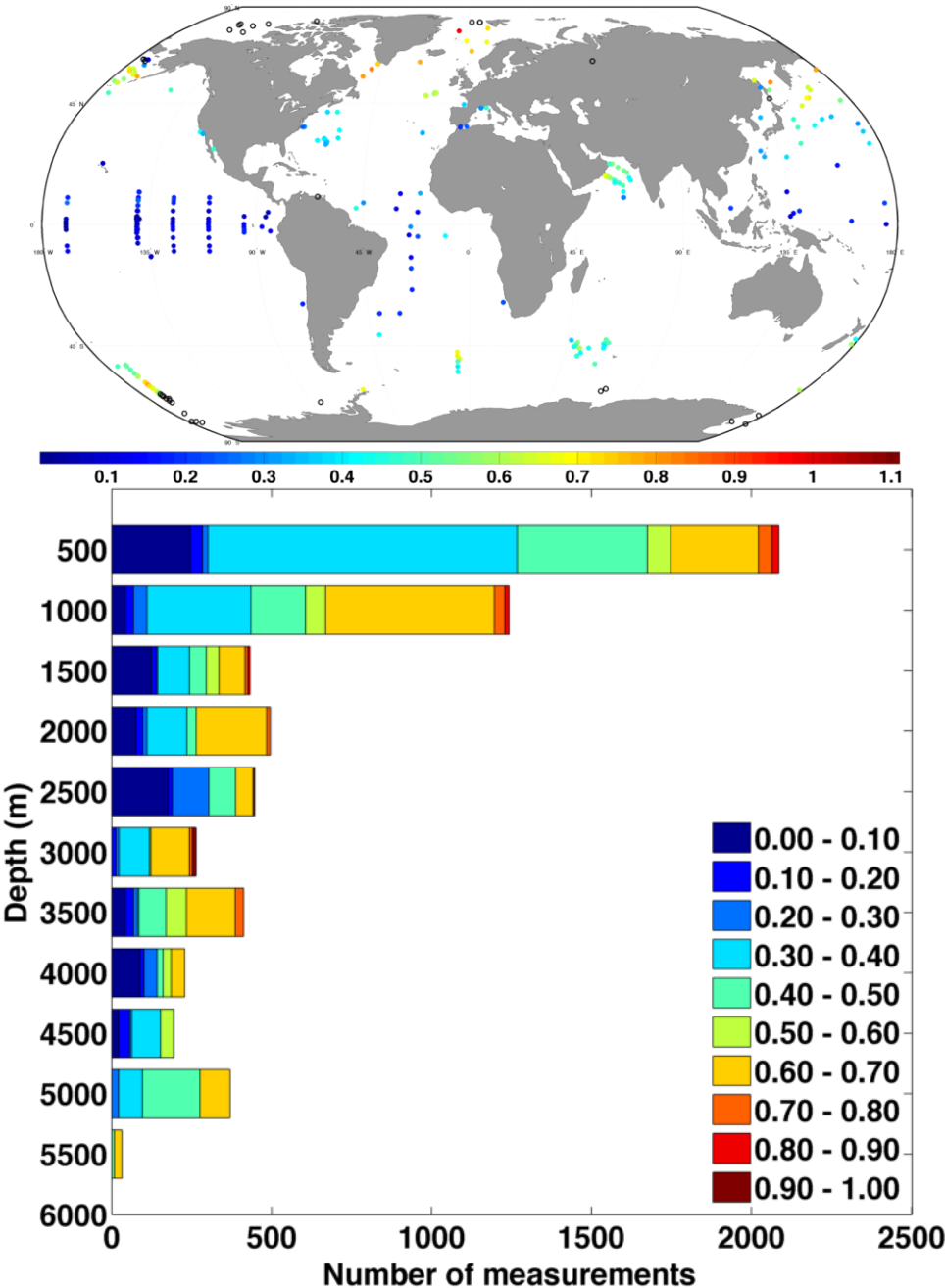
Global Seasonality

Seasonal Distribution

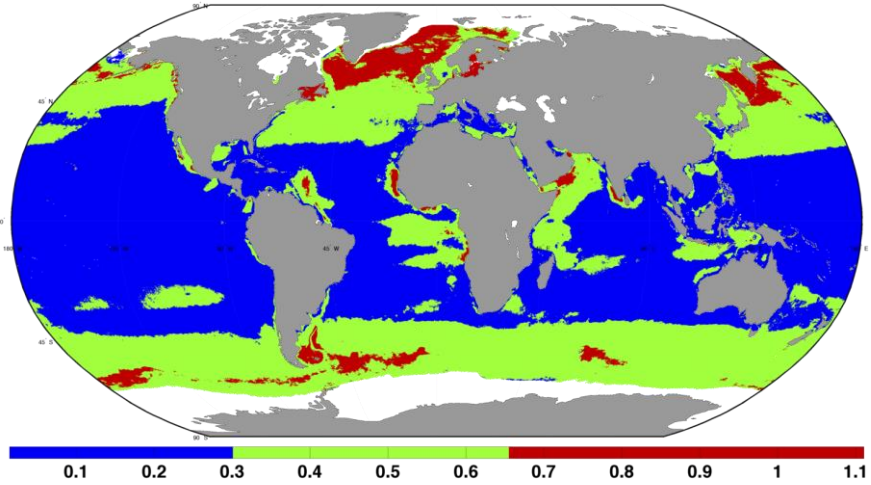


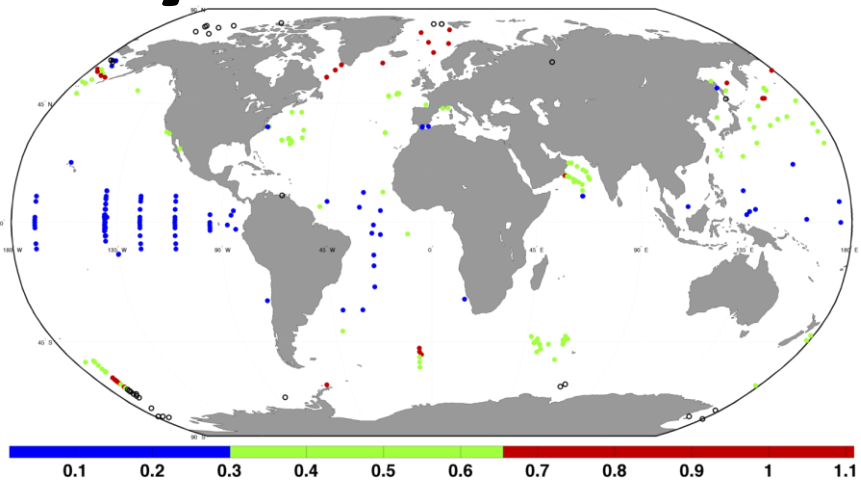
NPP Seasonal Variability

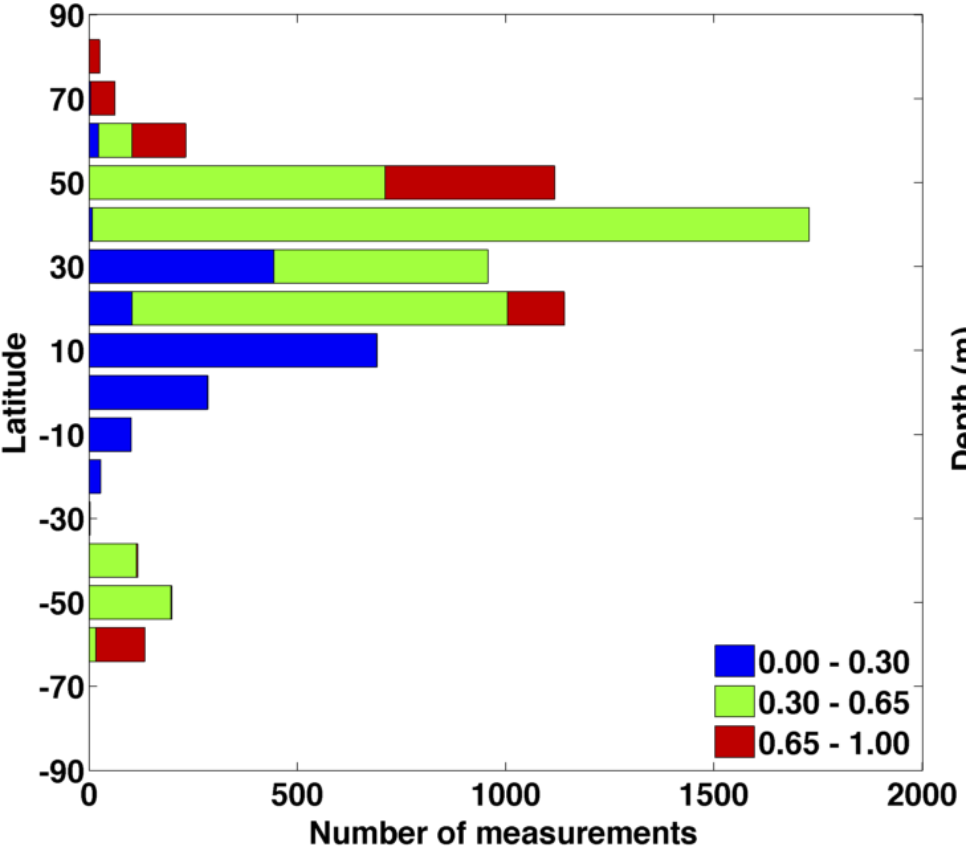


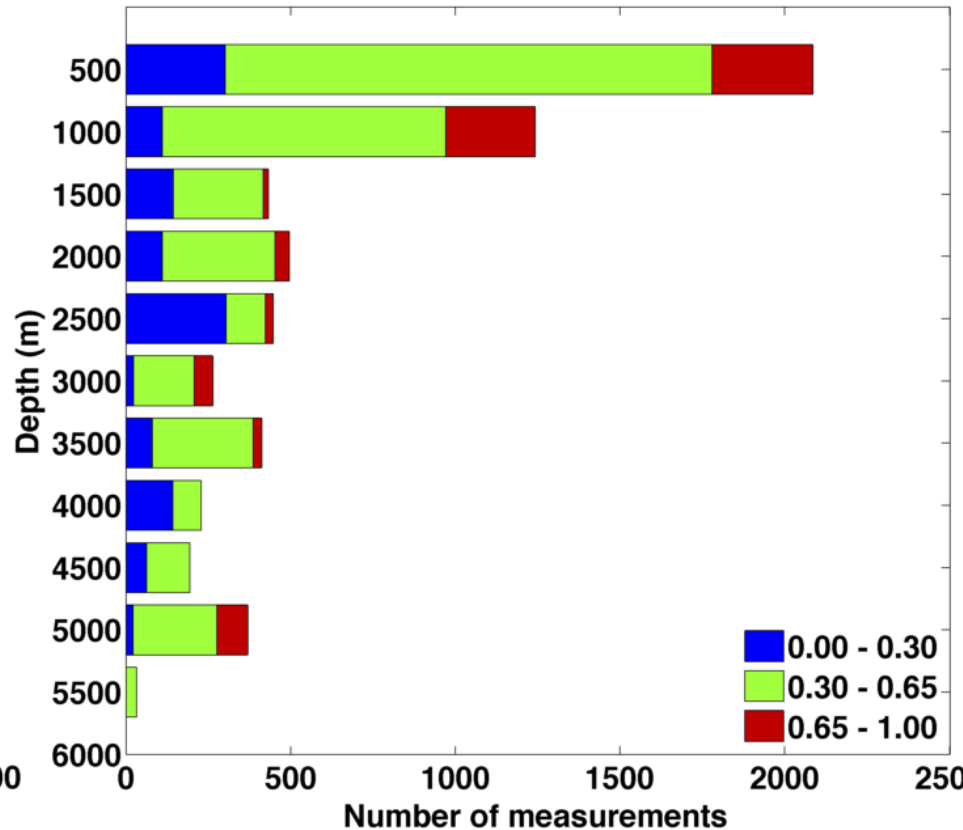


NPP Seasonal Variability

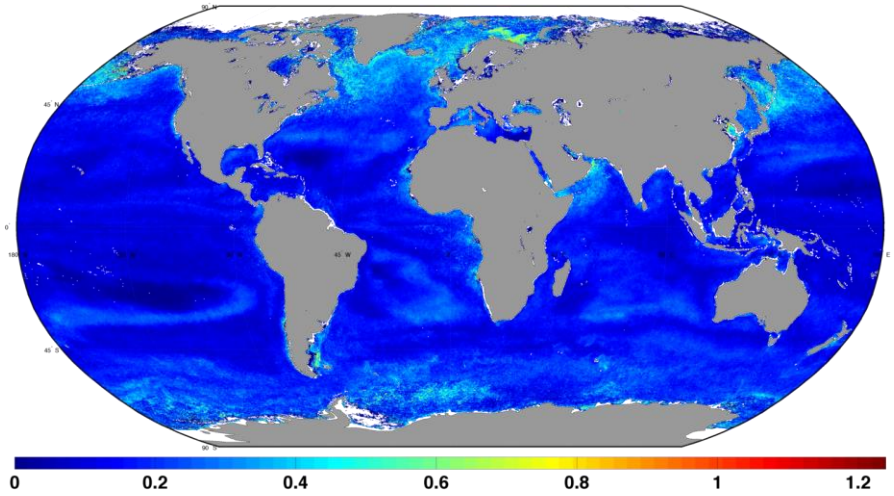


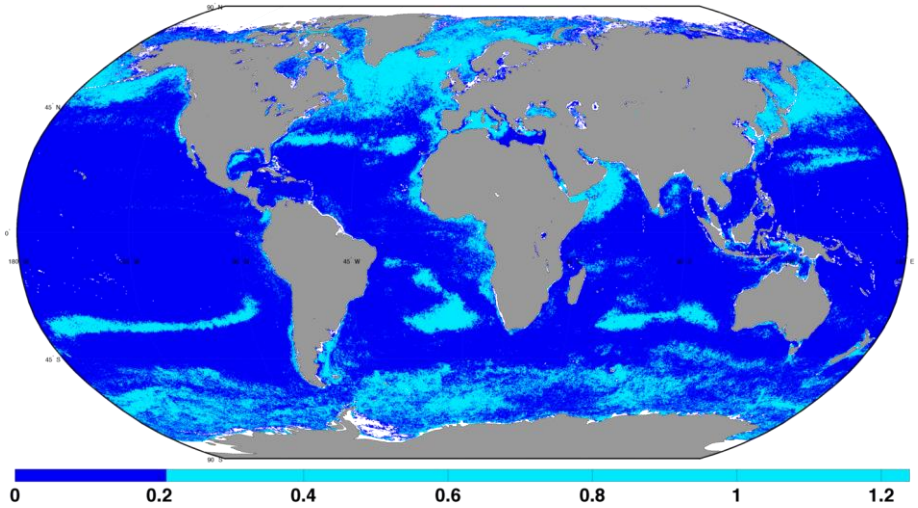




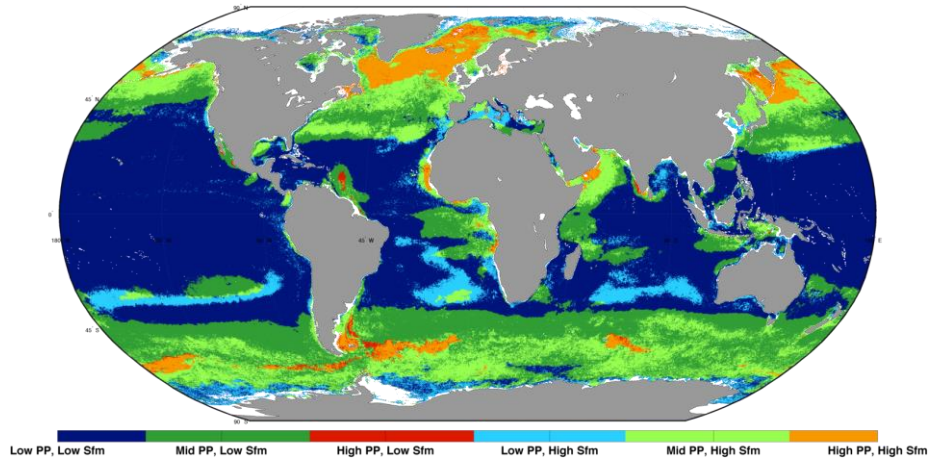


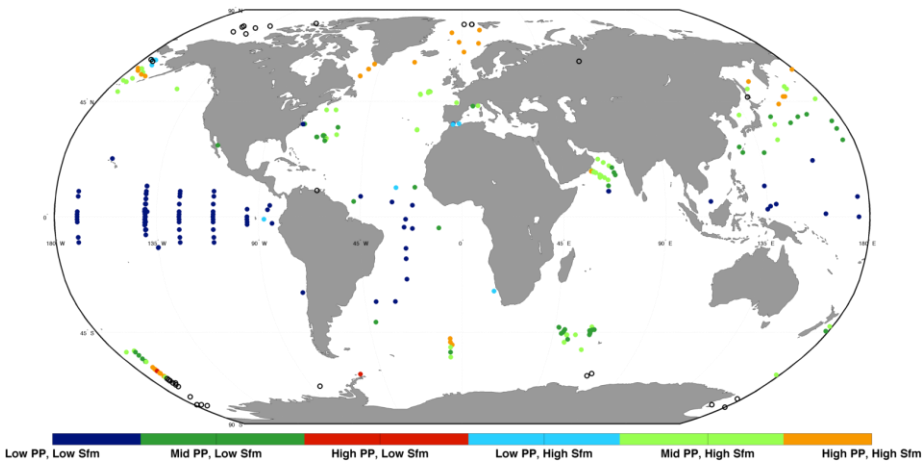
S_{fm} Seasonal Variability

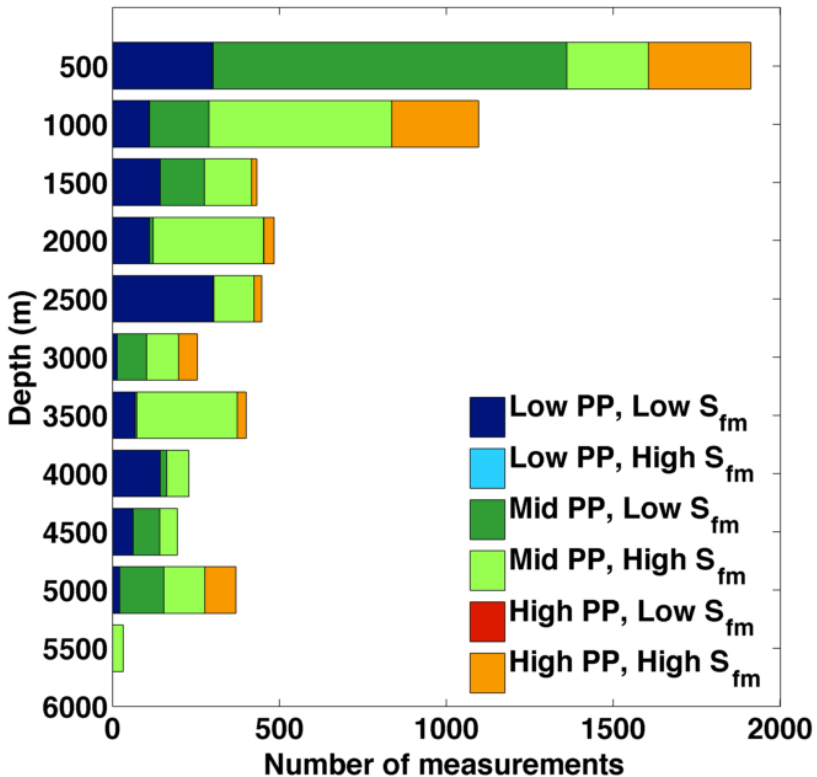


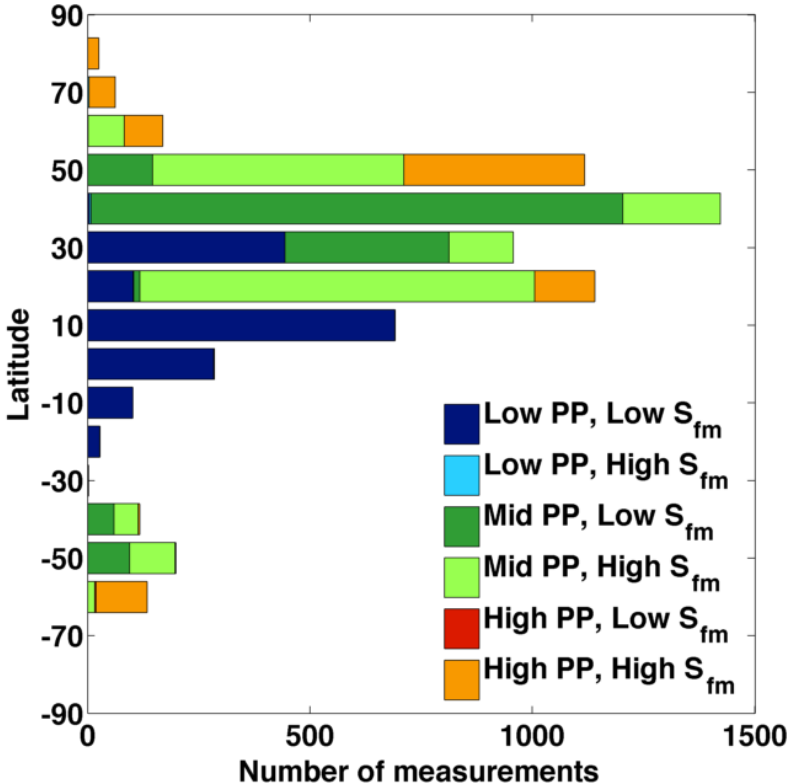


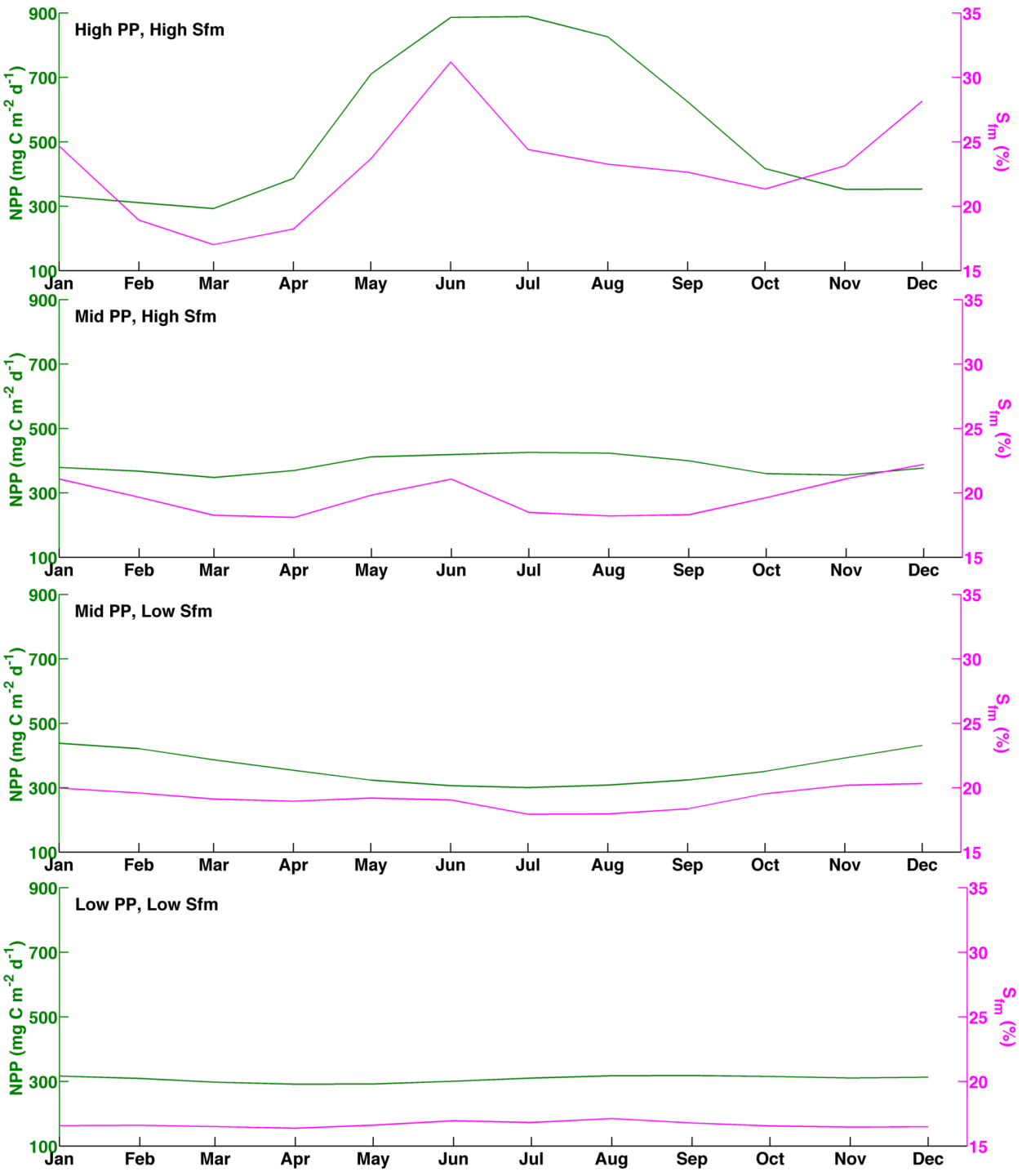
NPP and S_{fm} Seasonal Variability



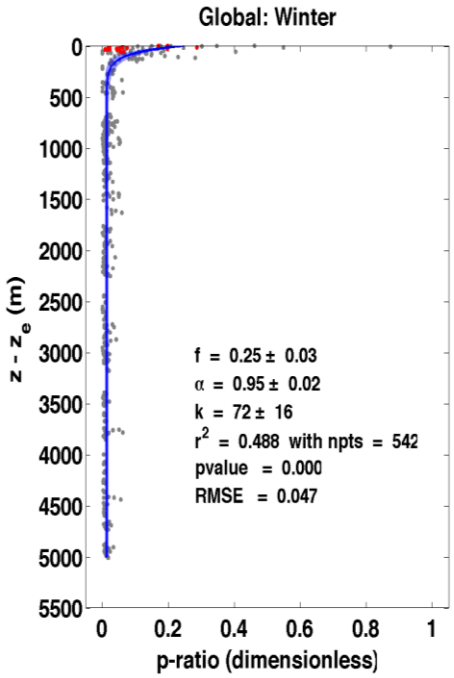


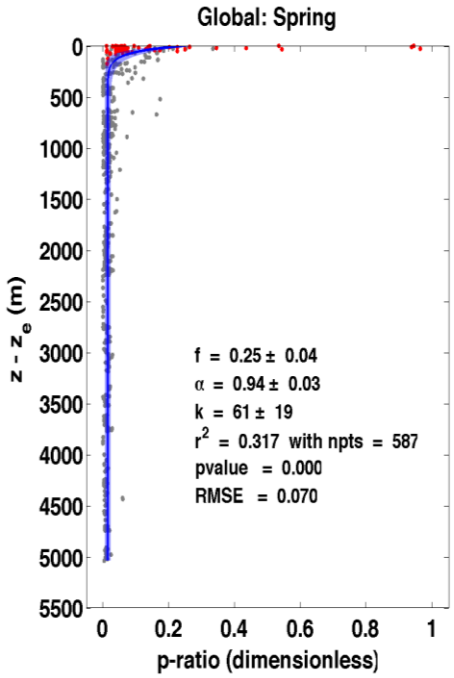


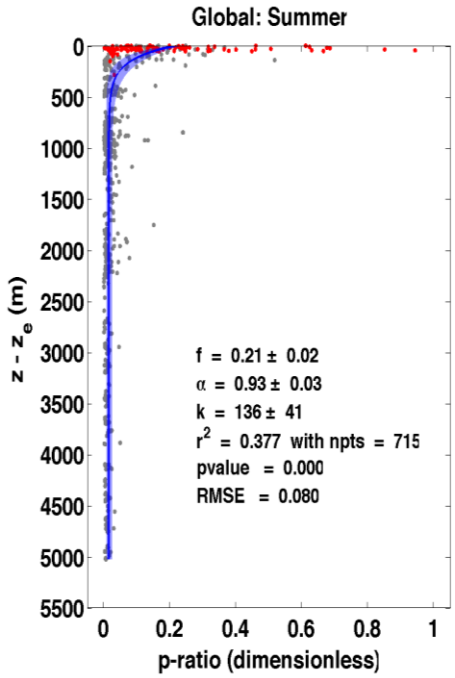


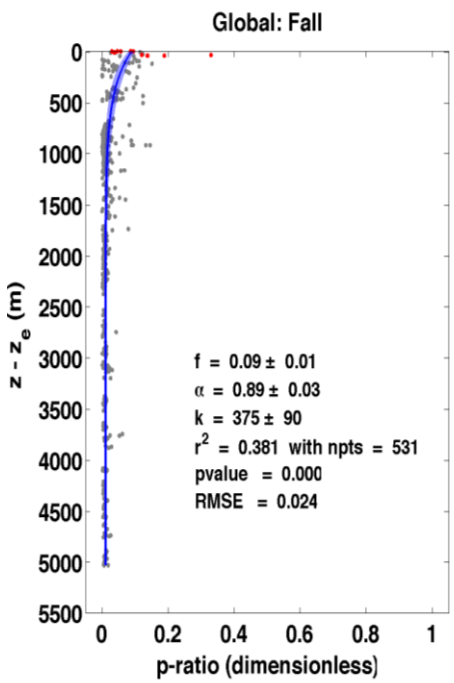

High PP, High Sfm
Mid PP, High Sfm
Mid PP, Low Sfm
Low PP, Low Sfm
NPP (mg C m-2 d-1)
Sfm (%)
900
700
500
300
100
35
30
25
20
15
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec

Global Seasonality



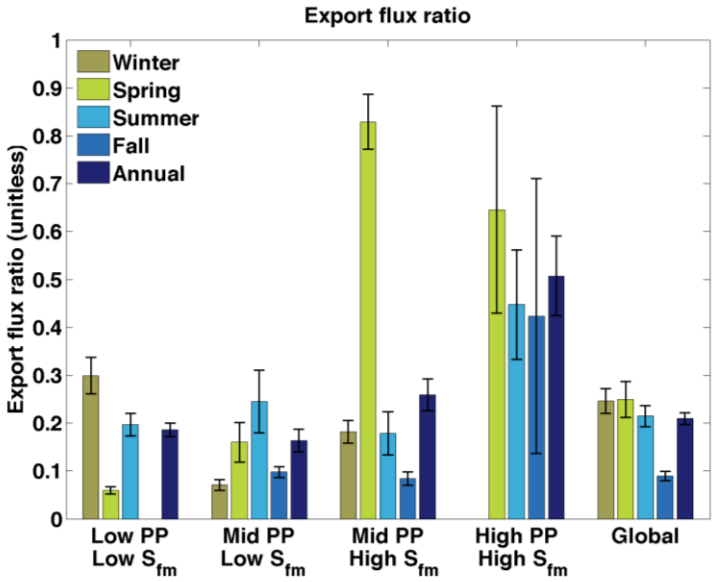


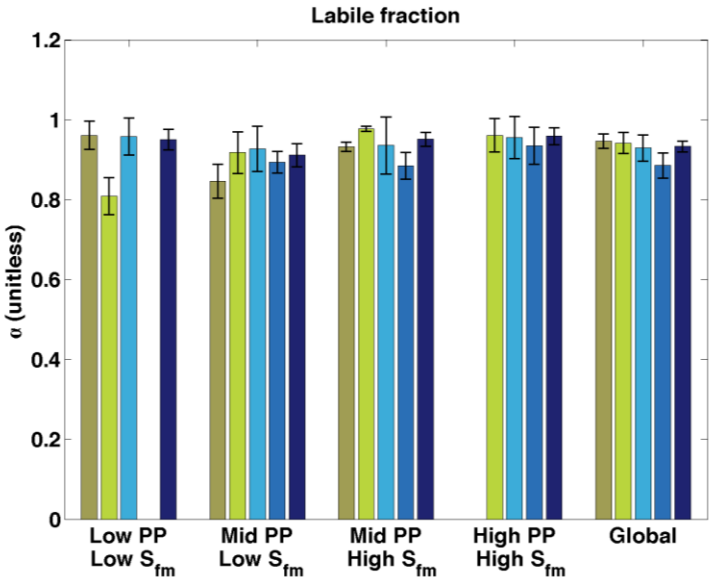


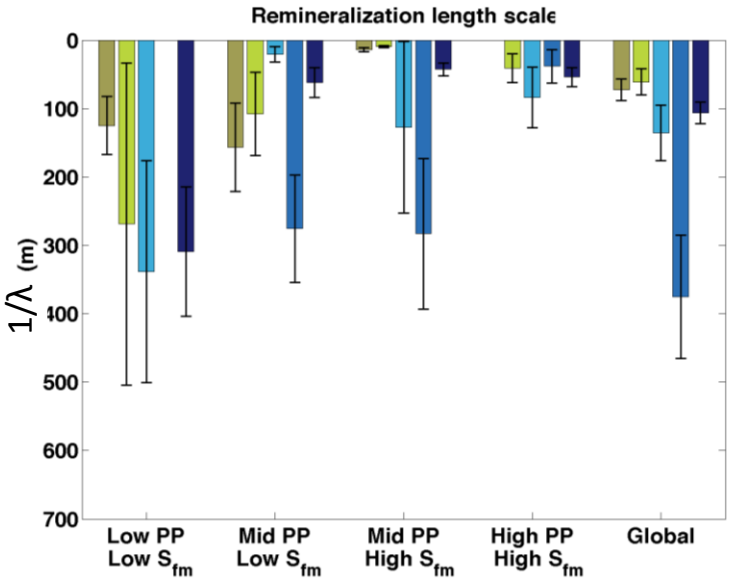


$$F_{z-z_e} = f\ NPP(ae^{-\frac{1}{l}(z-z_e)} + (1-a))$$

Export Flux, NPP and Size



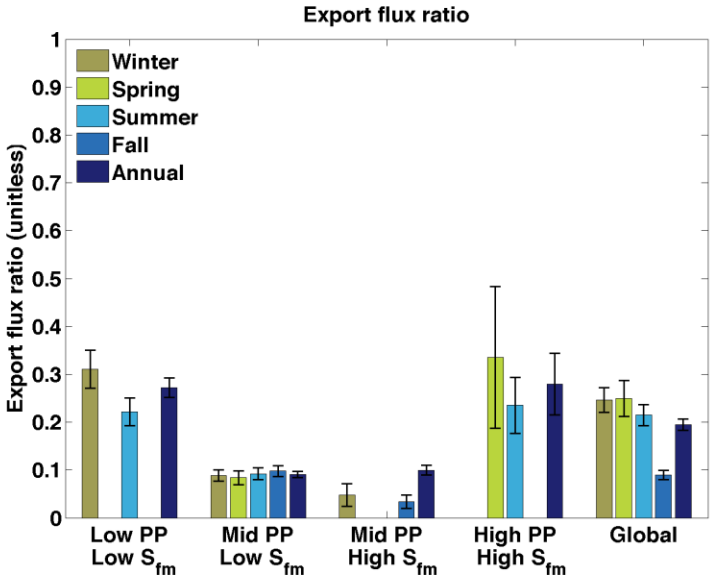


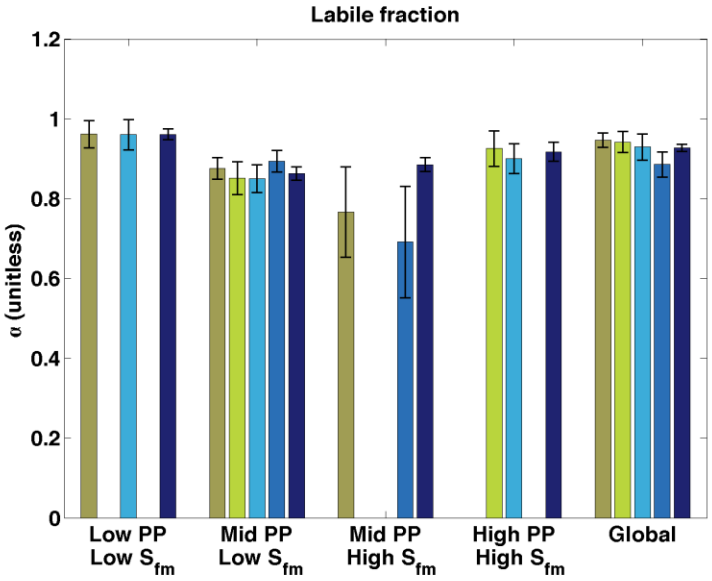


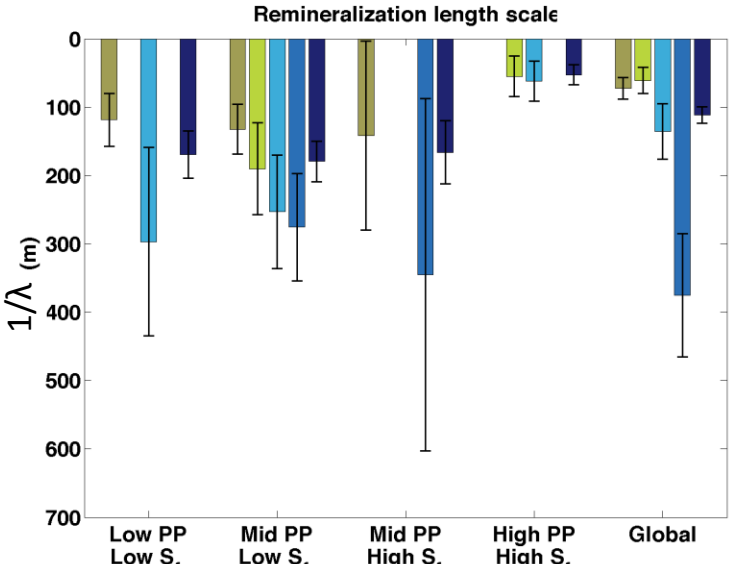
$$F_{z-z_e} = f\ NPP(ae^{-\frac{1}{l}(z-z_e)} + (1-a))$$

Sediment trap & Thorium

Export Flux, NPP and Size



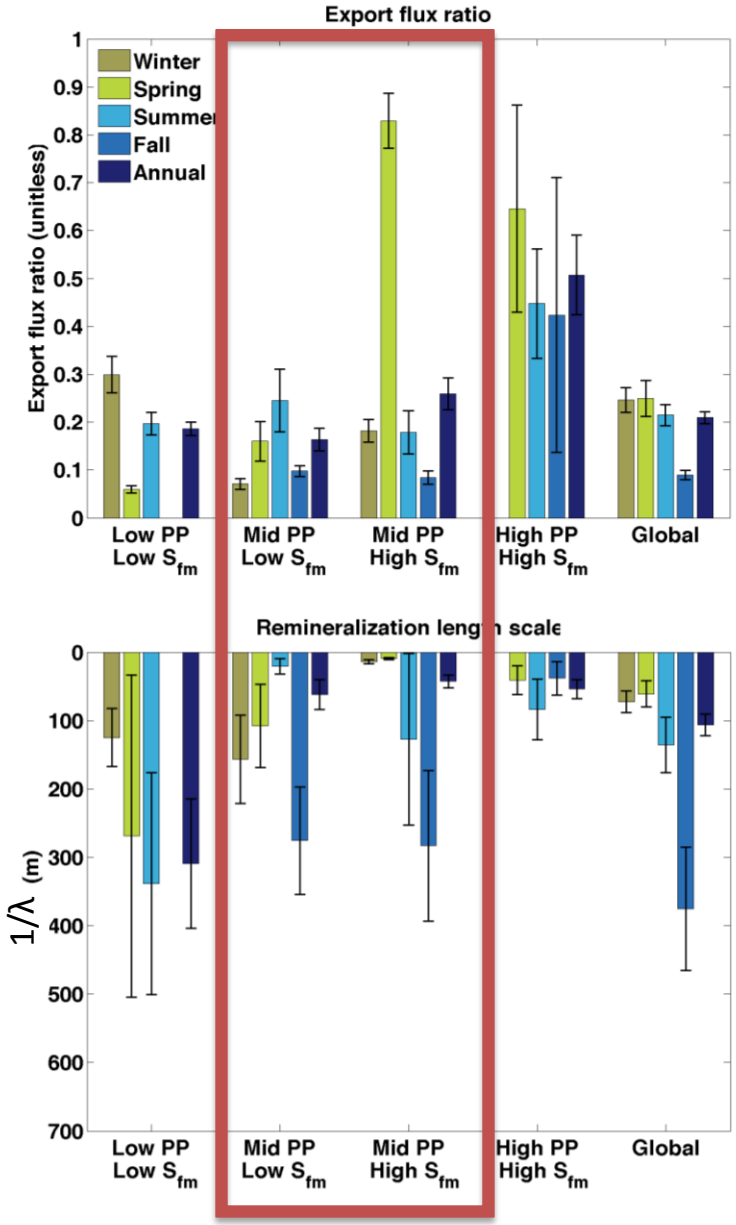




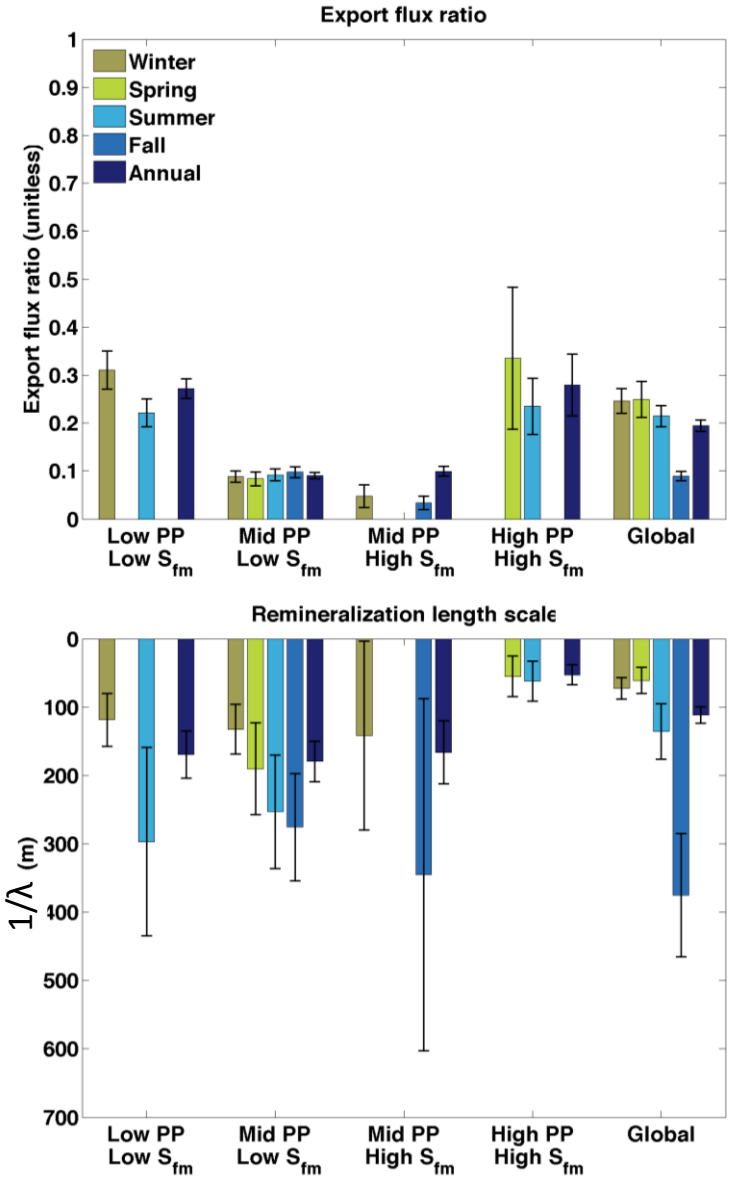
$$F_{z-z_e} = f\ NPP(ae^{-\frac{1}{l}(z-z_e)} + (1-a))$$

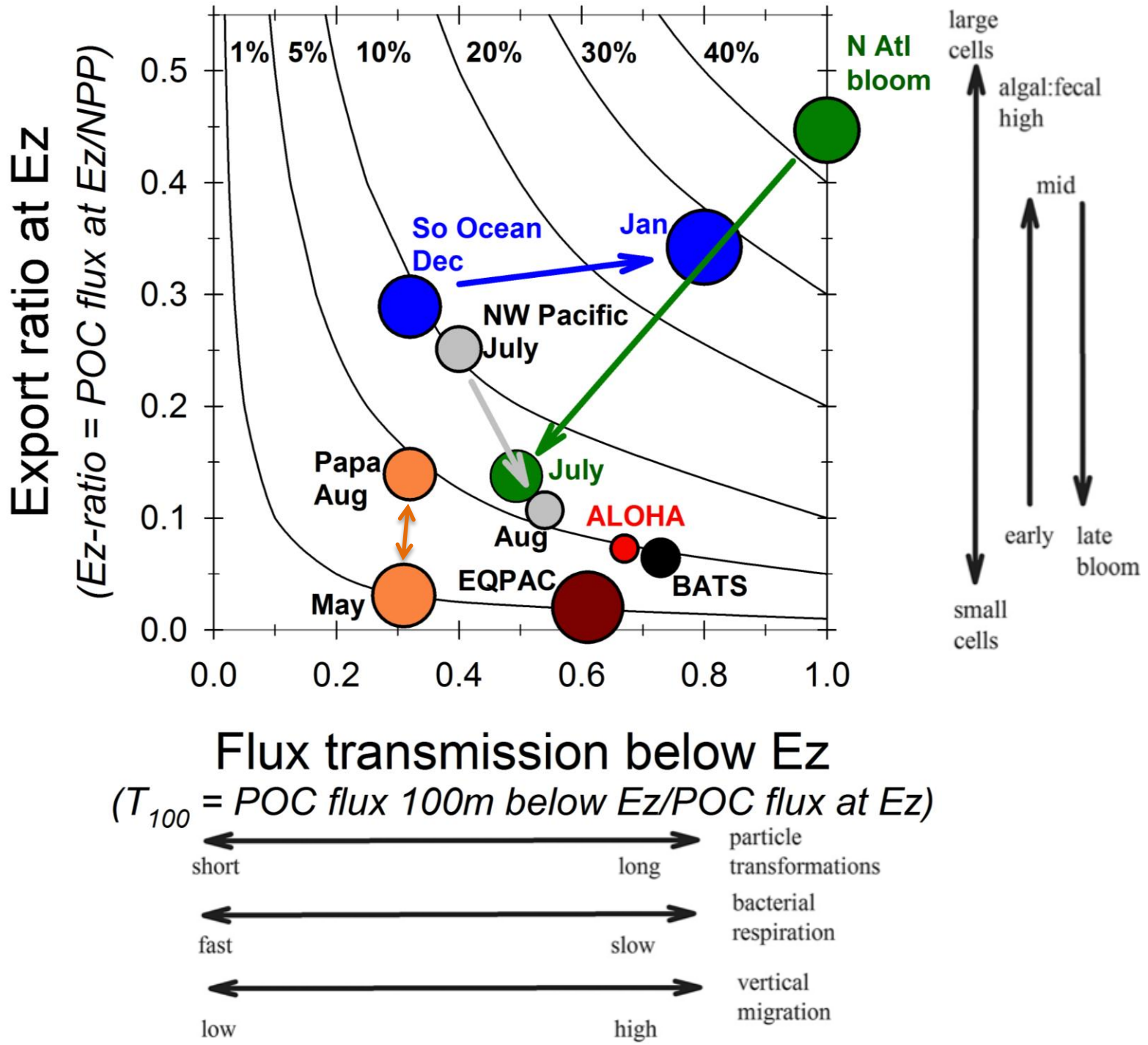
Sediment trap only

Sediment trap & Thorium

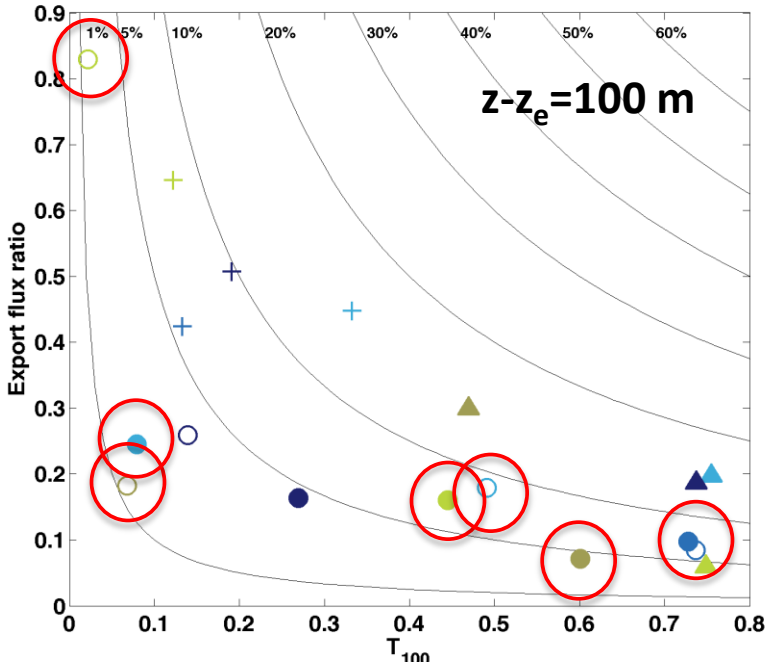


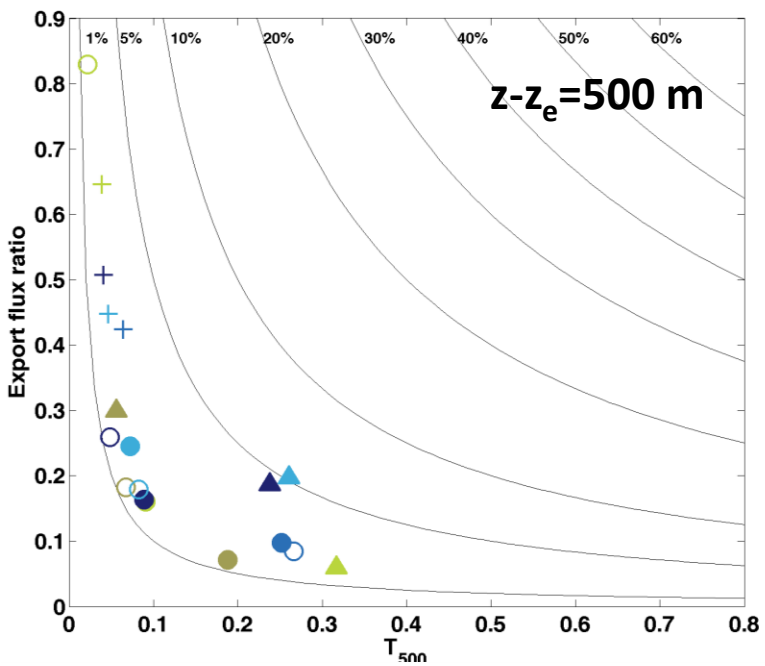
Sediment trap only

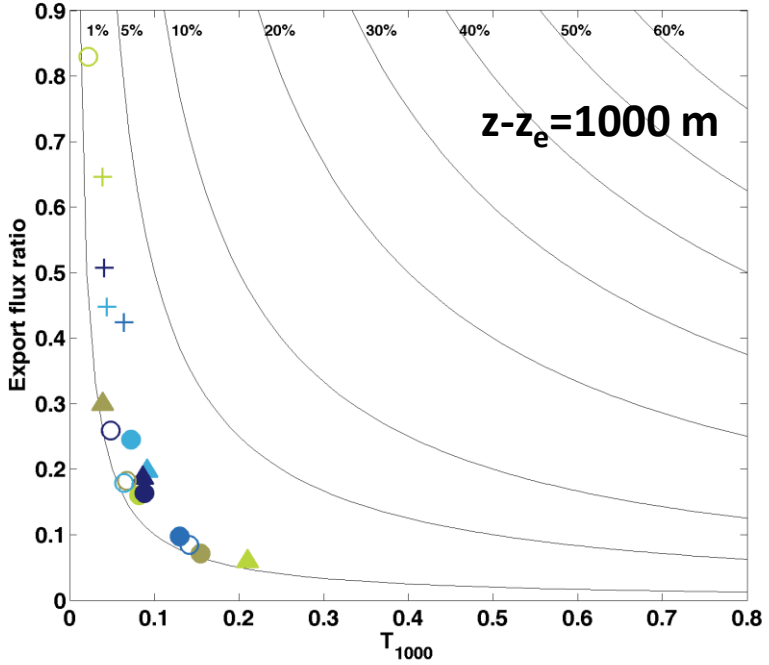


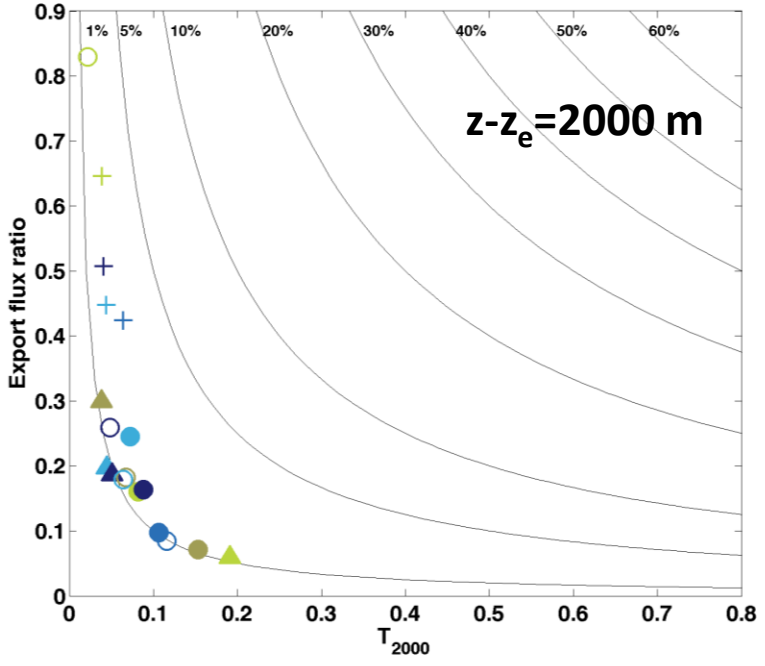


Buesseler & Boyd, 2009







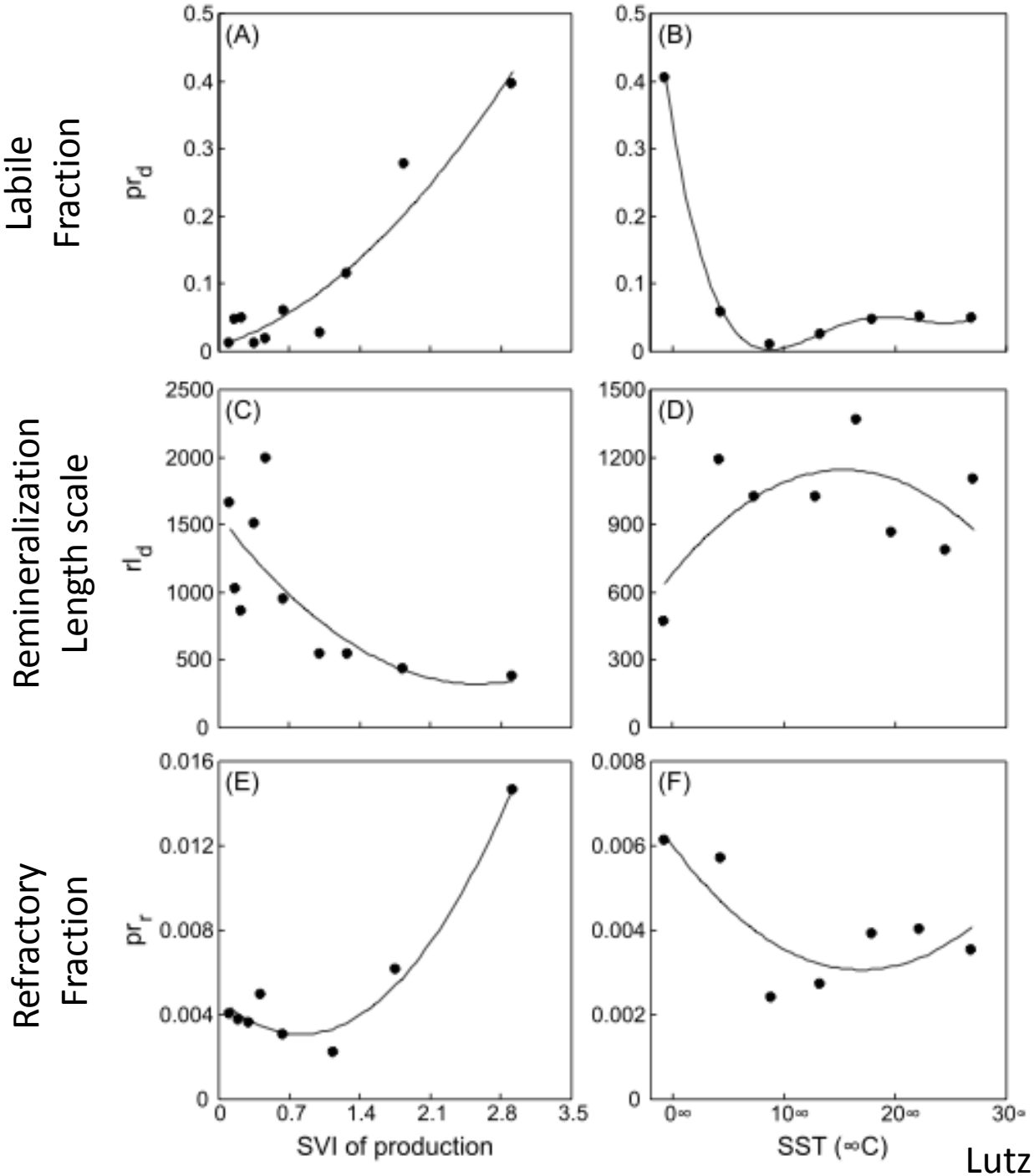


Winter
Spring
Summer
Fall
Annual

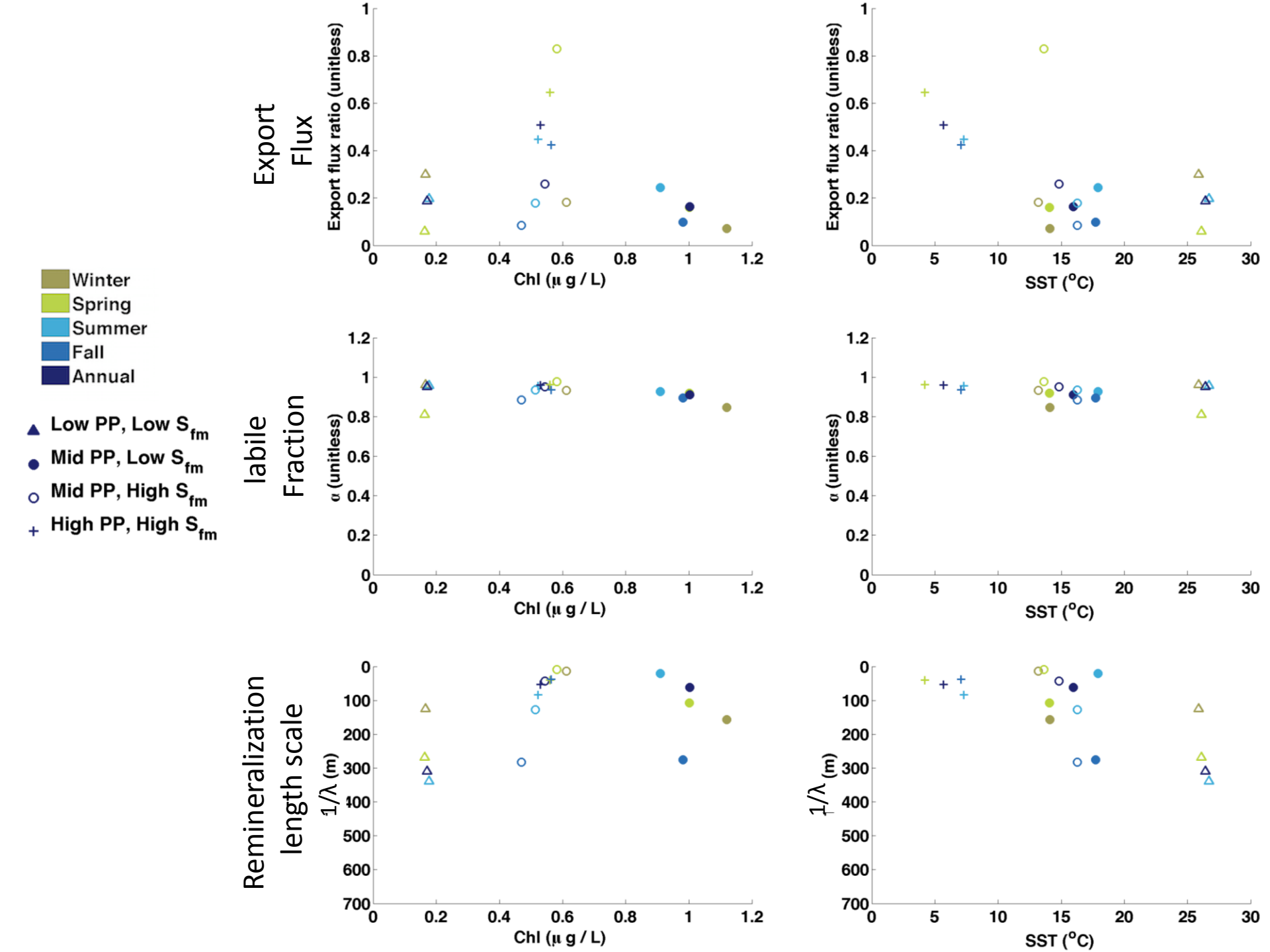
▲ Low PP, Low S_{fm}
● Mid PP, Low S_{fm}
○ Mid PP, High S_{fm}
\+ High PP, High S_{fm}

Statistical fits

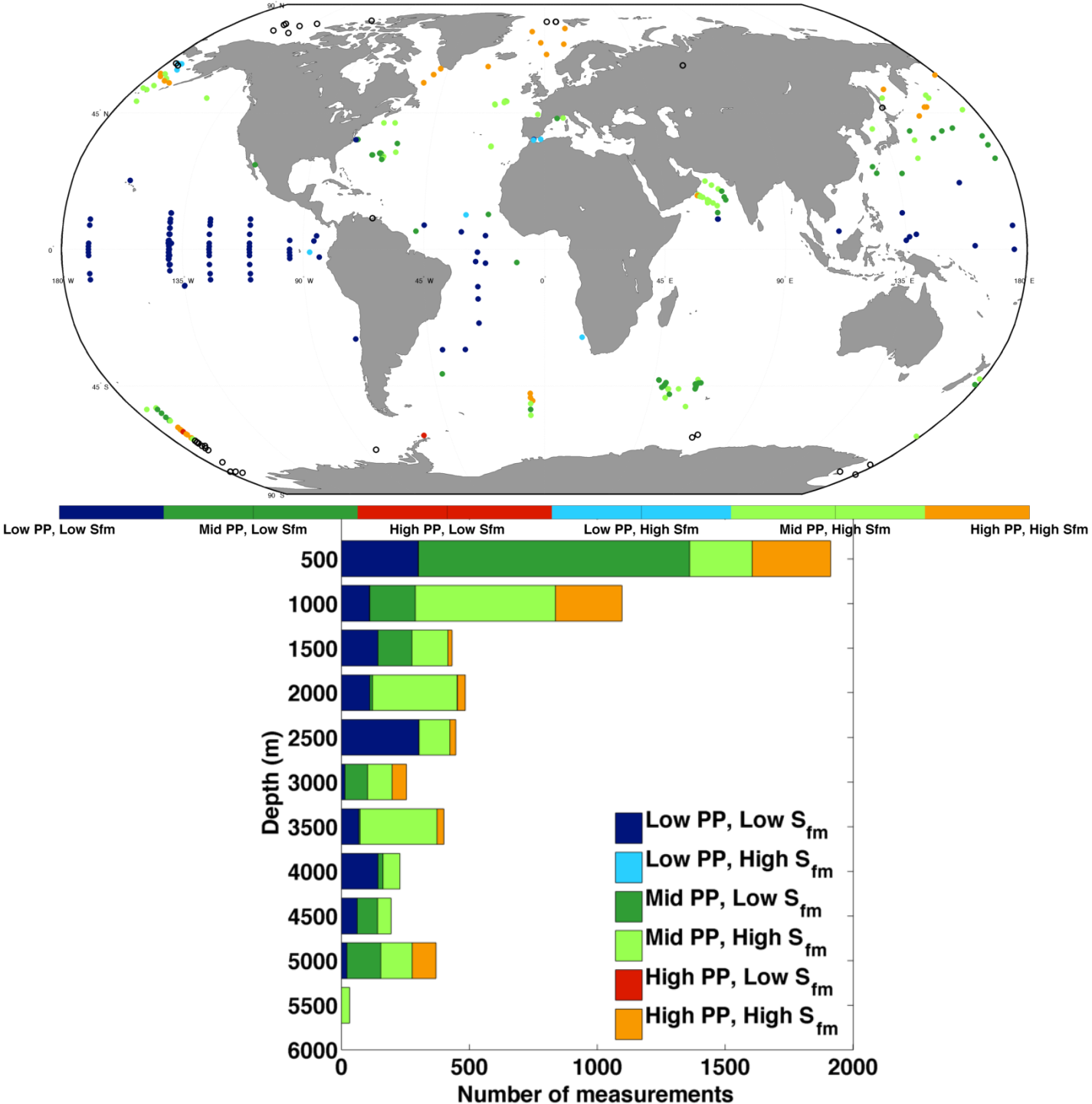
Lacking mechanistic understanding



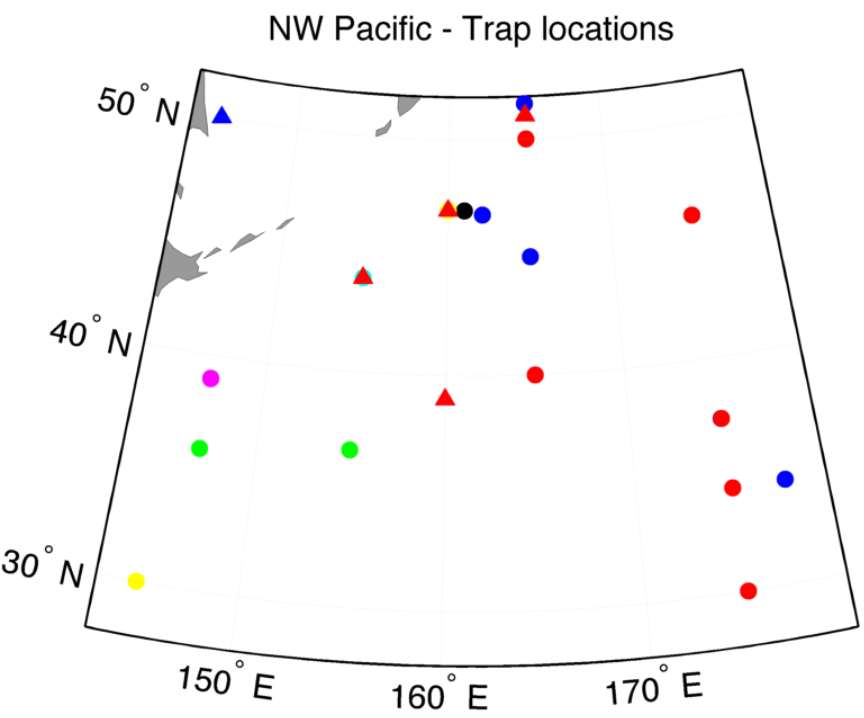
Lutz et al. 2007

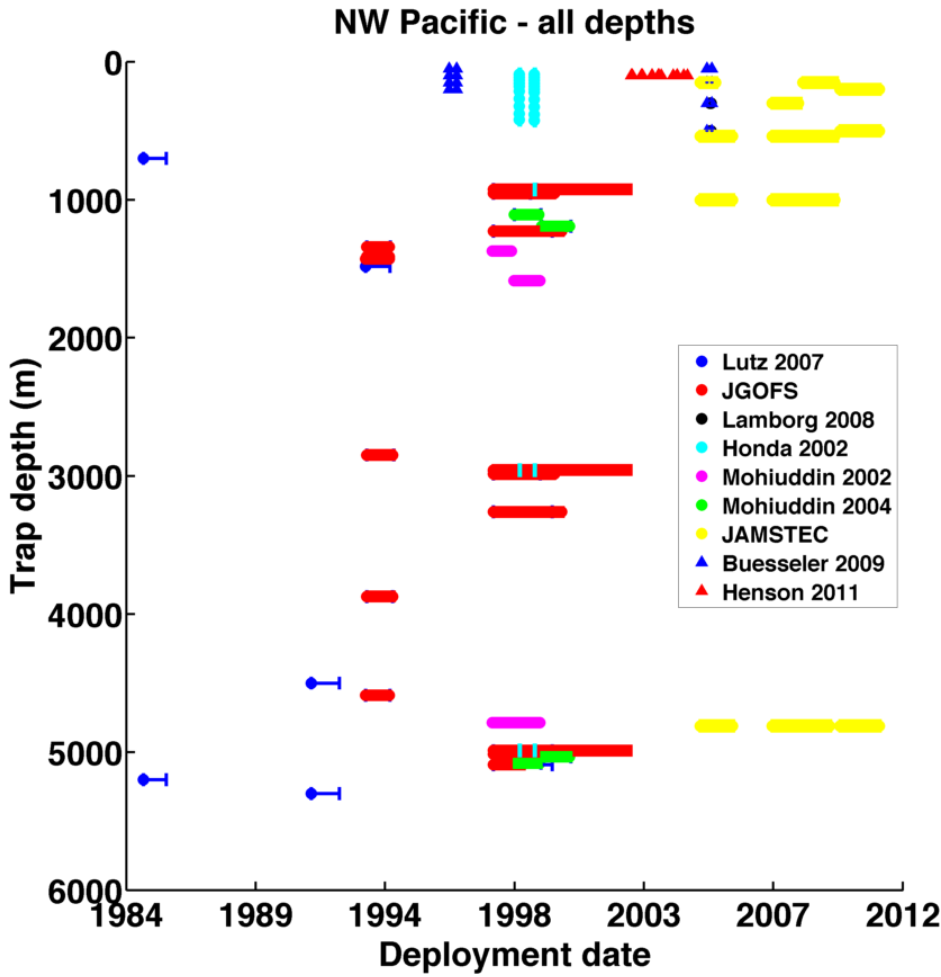

Export Flux
labile Fraction
Remineralization length scale
Export flux ratio (unitless)
α (unitless)
1/λ (m)
Chl (μ g / L)
SST (°C)
Winter
Spring
Summer
Fall
Annual
Low PP, Low S_fm
Mid PP, Low S_fm
Mid PP, High S_fm
High PP, High S_fm

Regional Seasonality

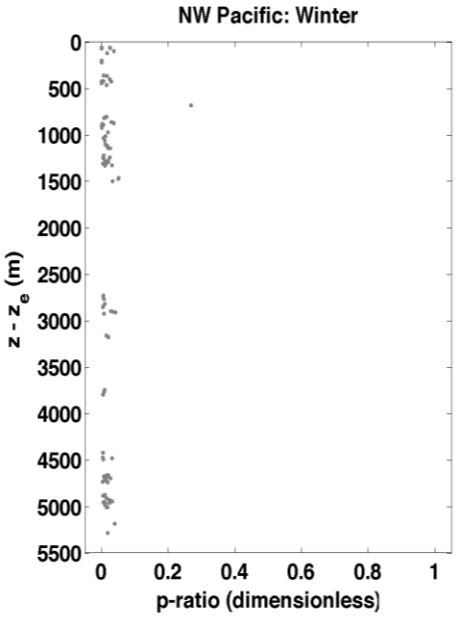

90 N
45 N
0
45 S
90 S
180 W
135 W
90 W
45 W
0
45 E
90 E
135 E
180 E
Low PP, Low Sfm
Mid PP, Low Sfm
High PP, Low Sfm
Low PP, High Sfm
Mid PP, High Sfm
High PP, High Sfm
Depth (m)
500
1000
1500
2000
2500
3000
3500
4000
4500
5000
5500
6000
0
500
1000
1500
2000
Number of measurements
Low PP, Low S fm
Low PP, High S fm
Mid PP, Low S fm
Mid PP, High S fm
High PP, Low S fm
High PP, High S fm

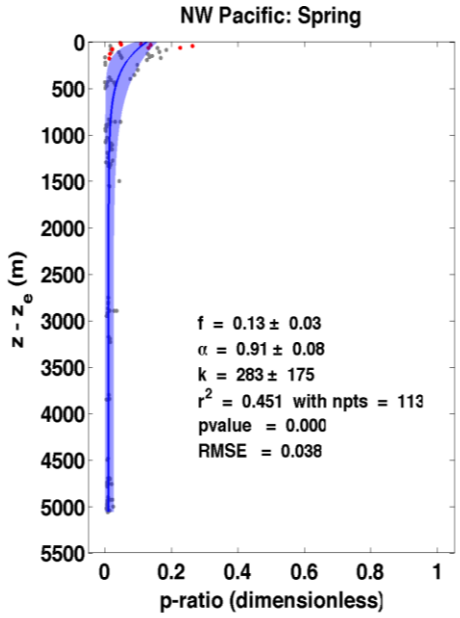
NW Pacific - Regional Seasonal

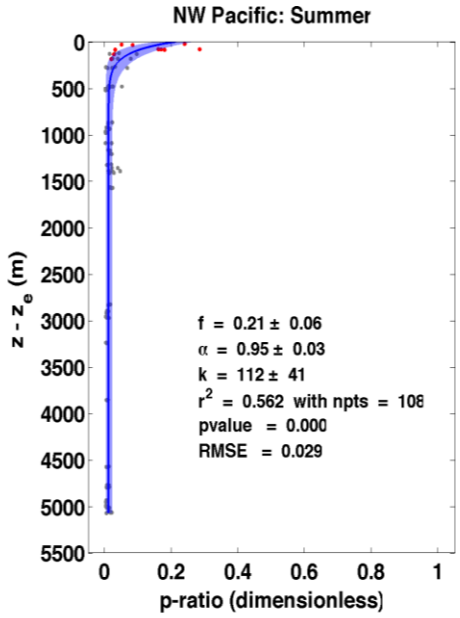


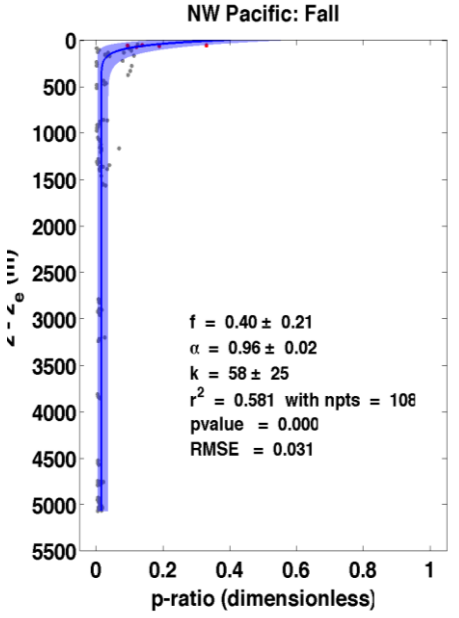


NW Pacific Regional Seasonality

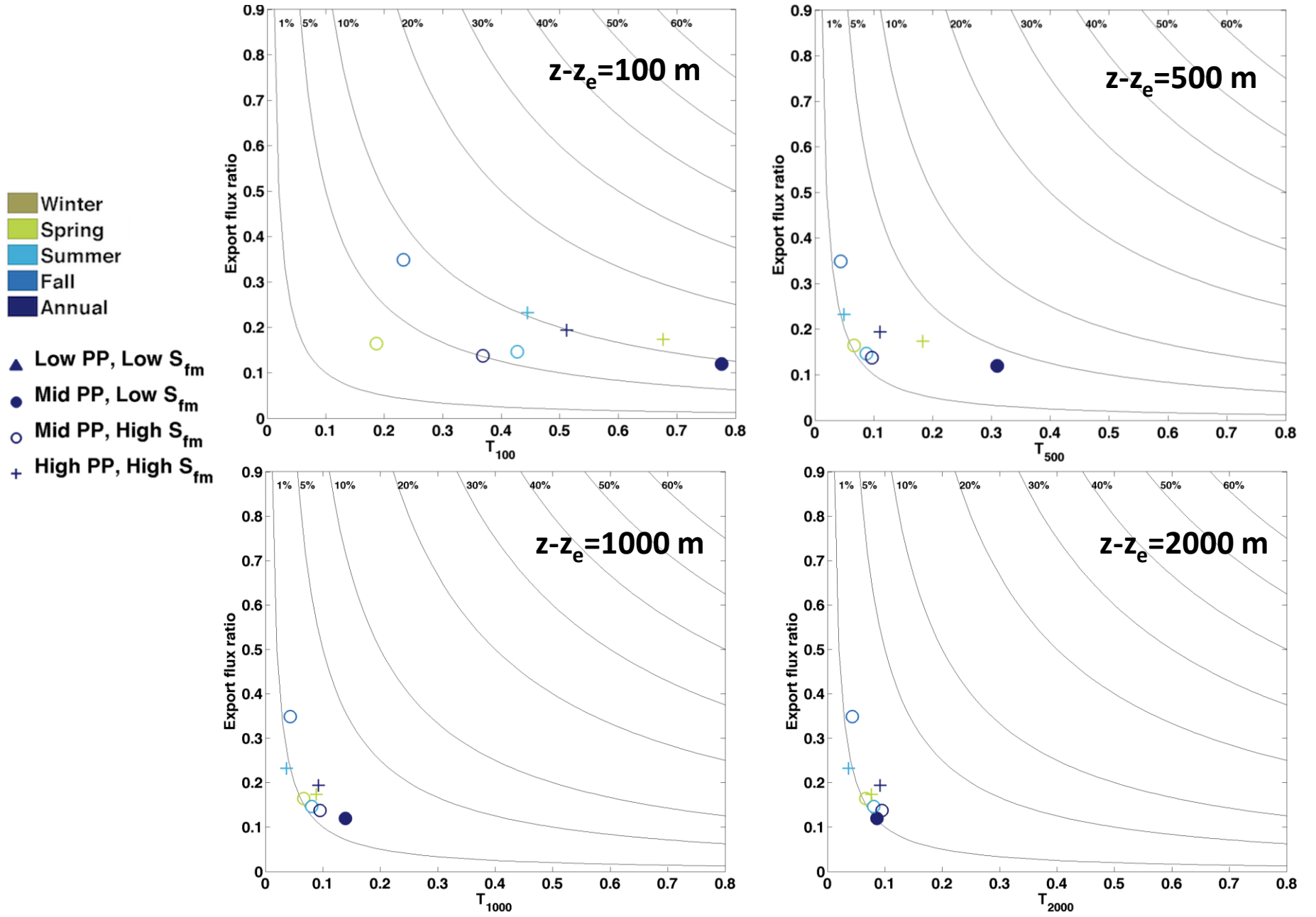




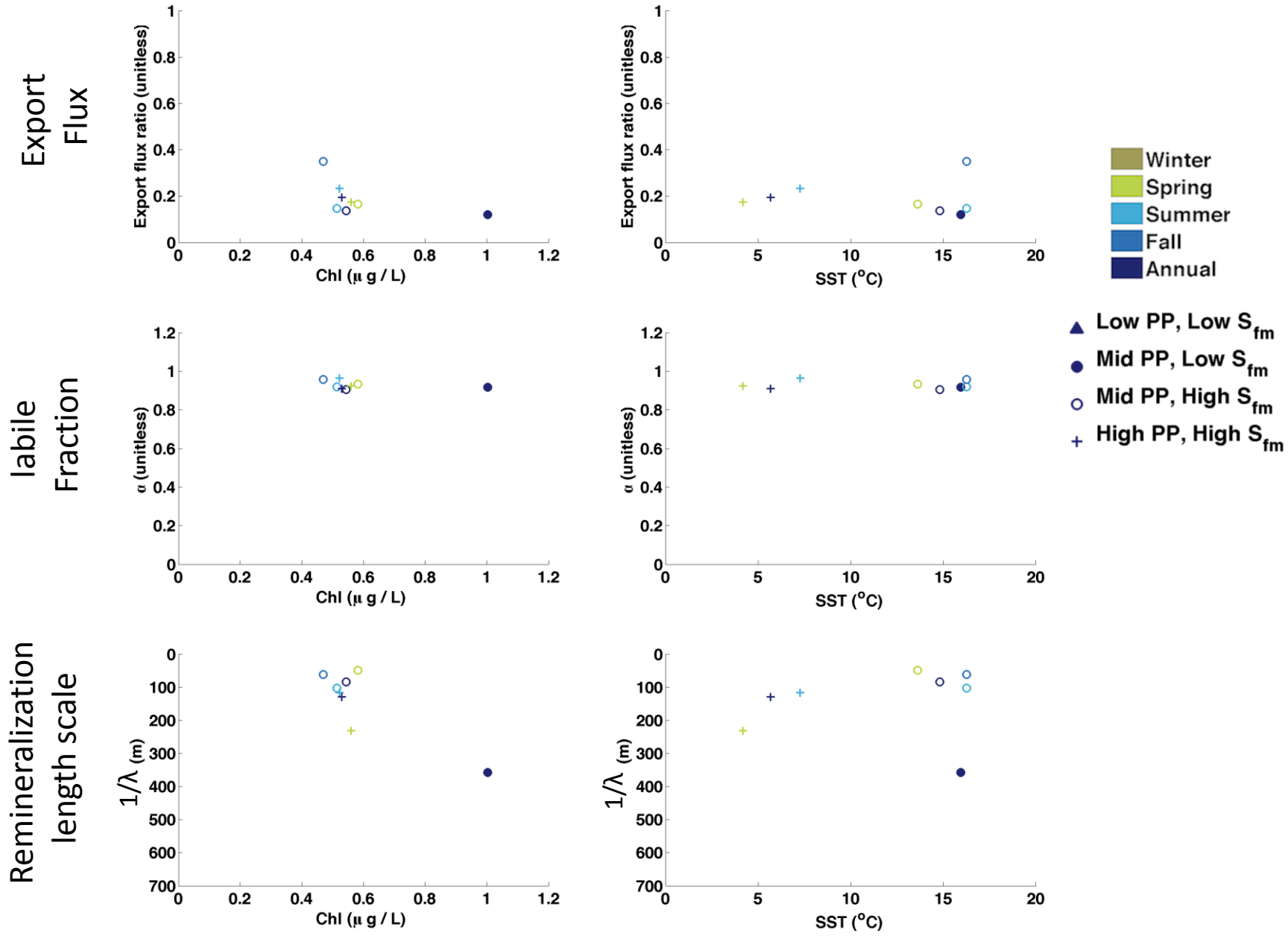




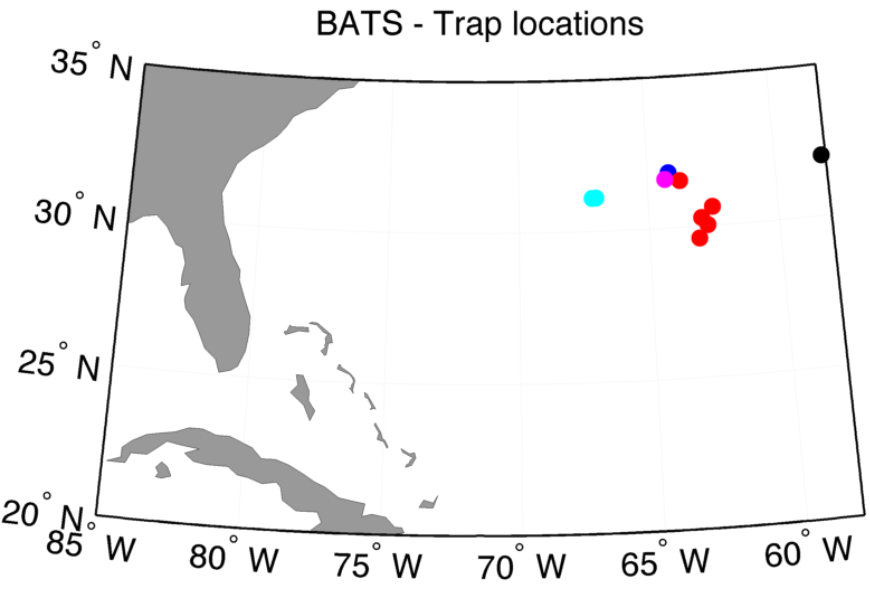
NW Pacific – Regional Seasonality

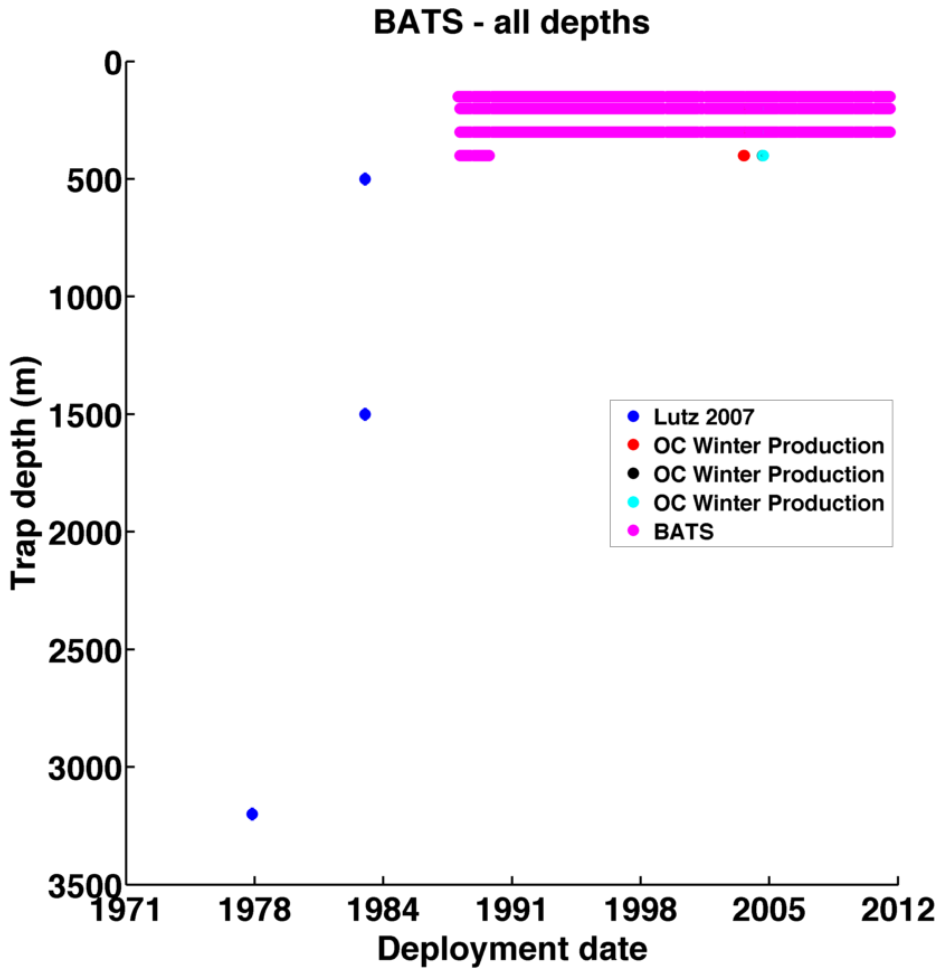


NW Pacific – Regional Seasonality

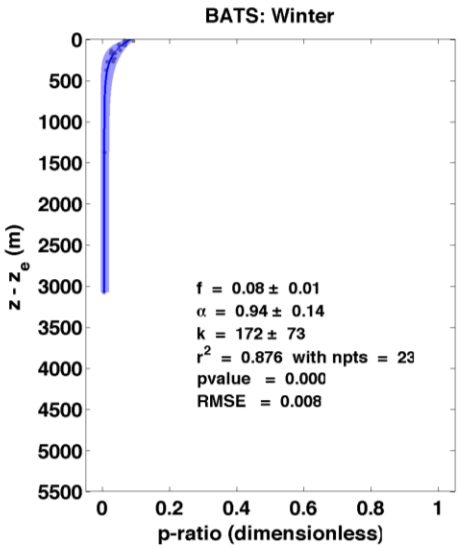


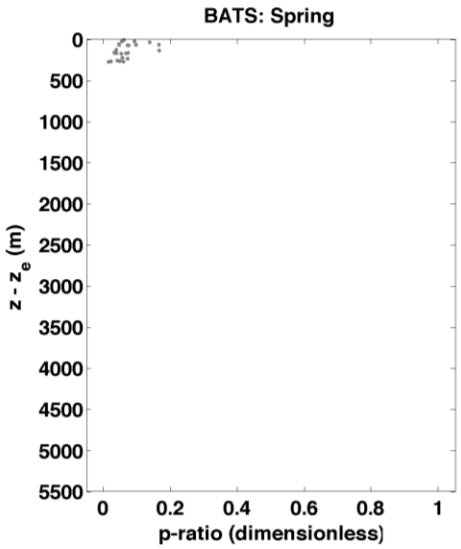
BATS – Regional Seasonality

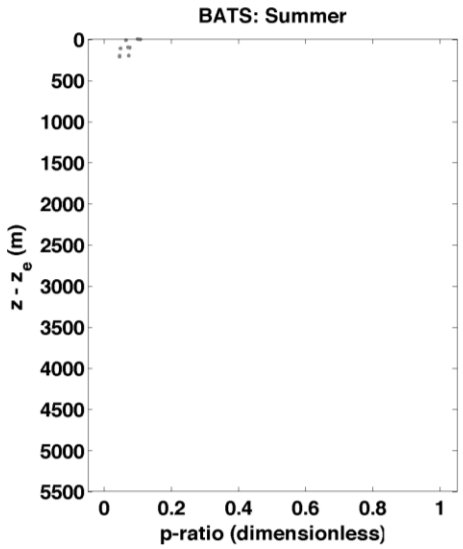


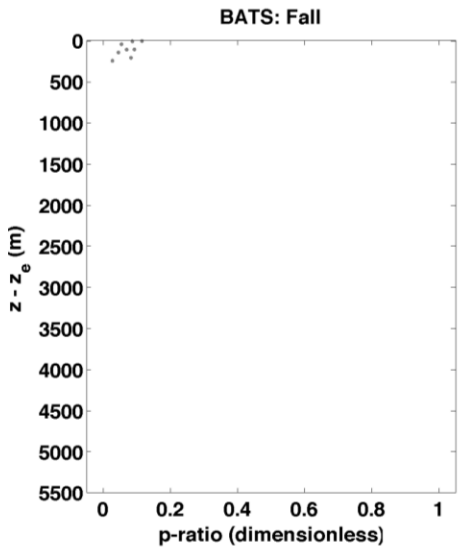


BATS – Regional Seasonality

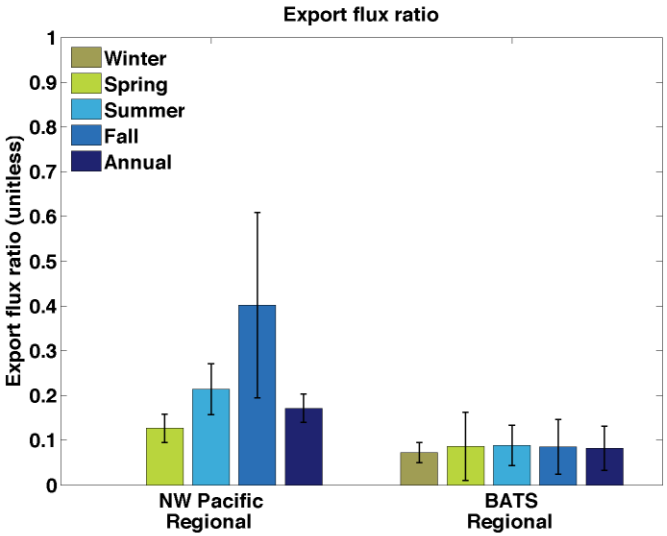


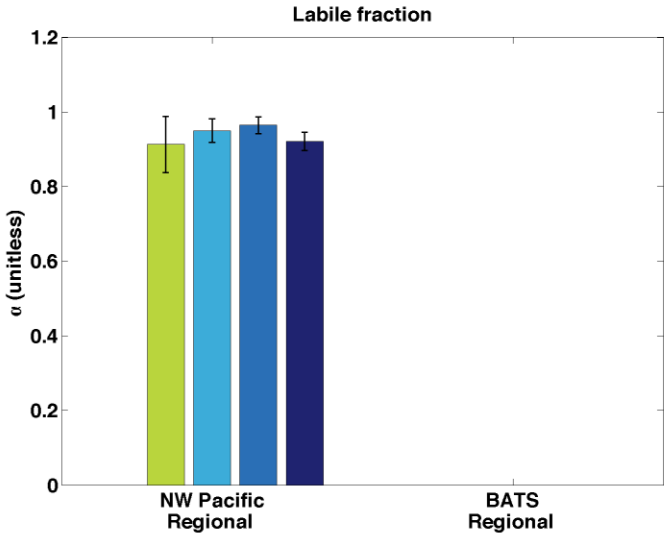


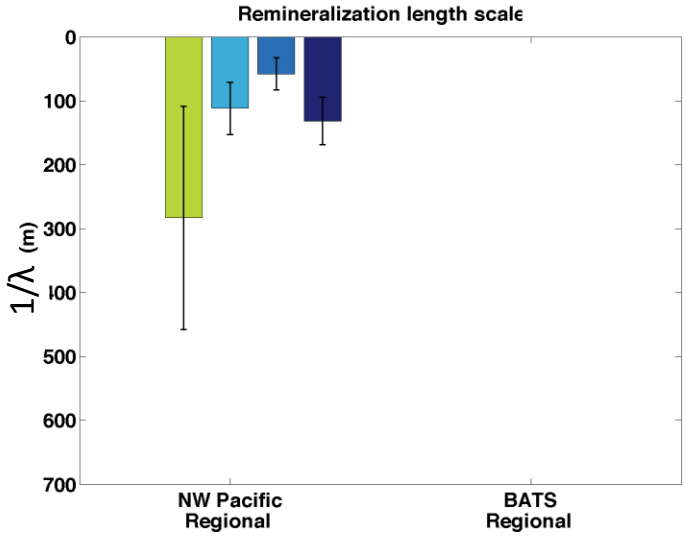




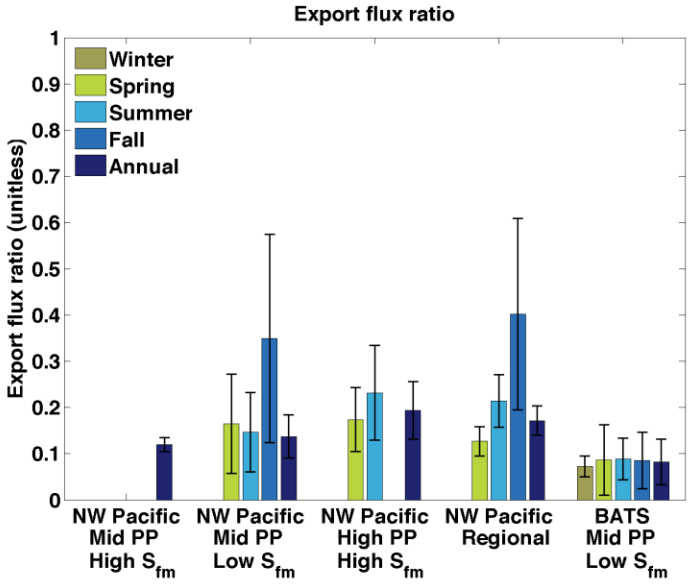
Regional Seasonality

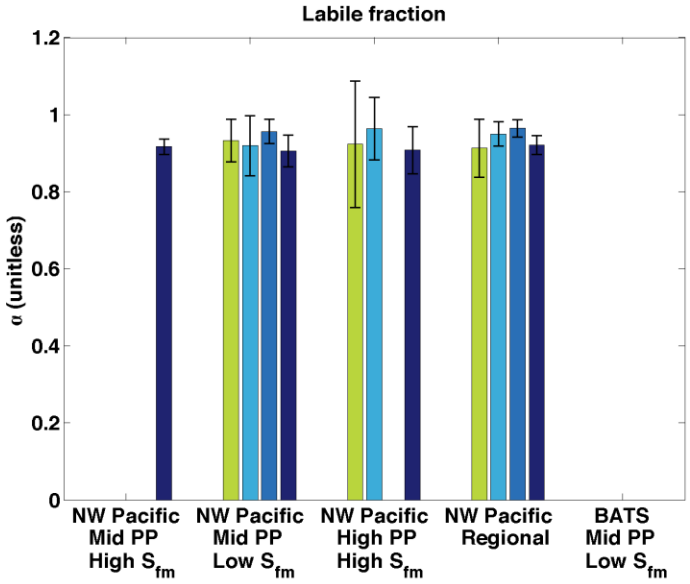


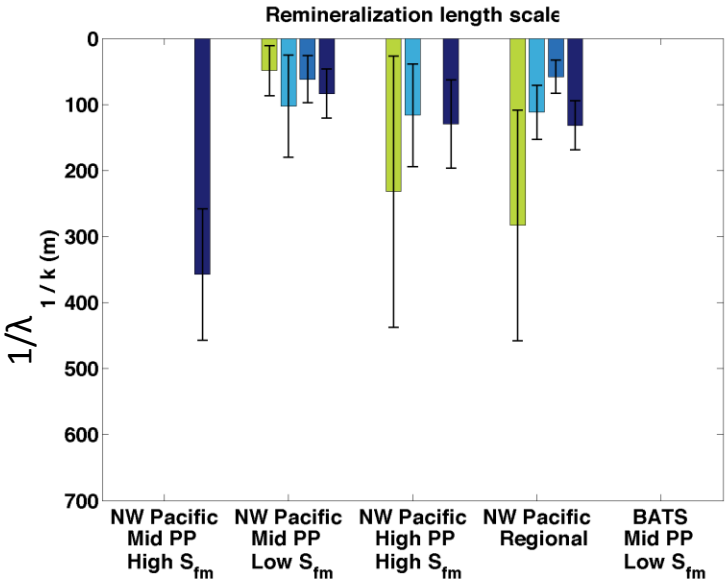




Regional Seasonality



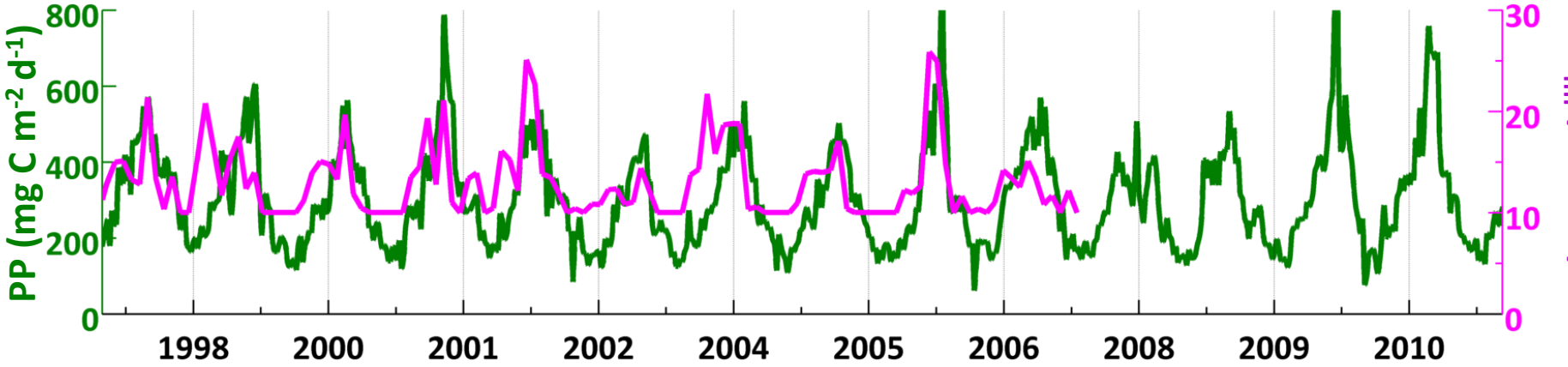


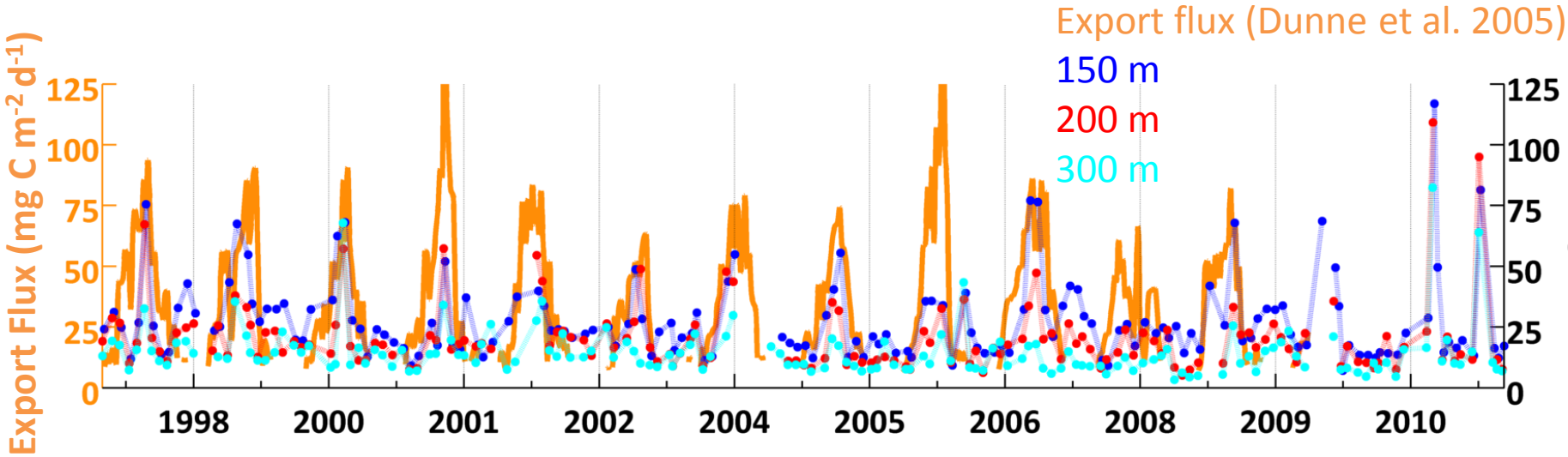


Time Series

BATS

[32 N, 64 W]

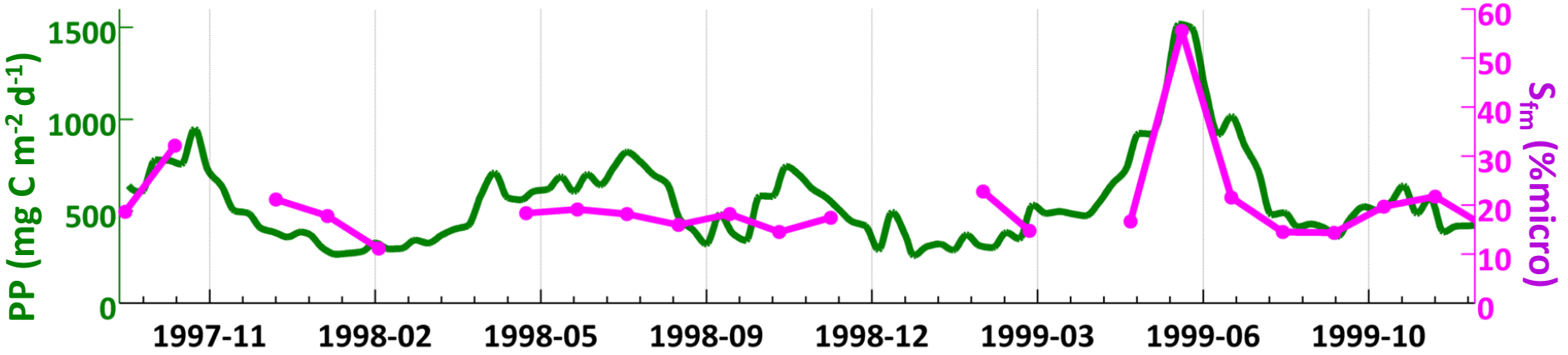


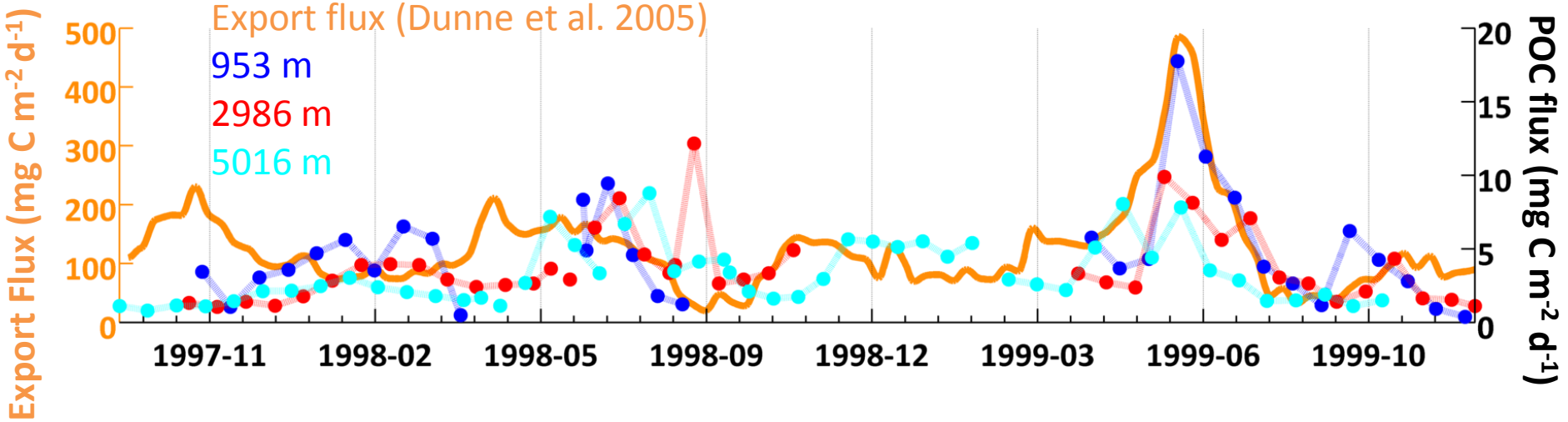


3 day median trap deployment

NW Pacific

[40 N, 165 E]

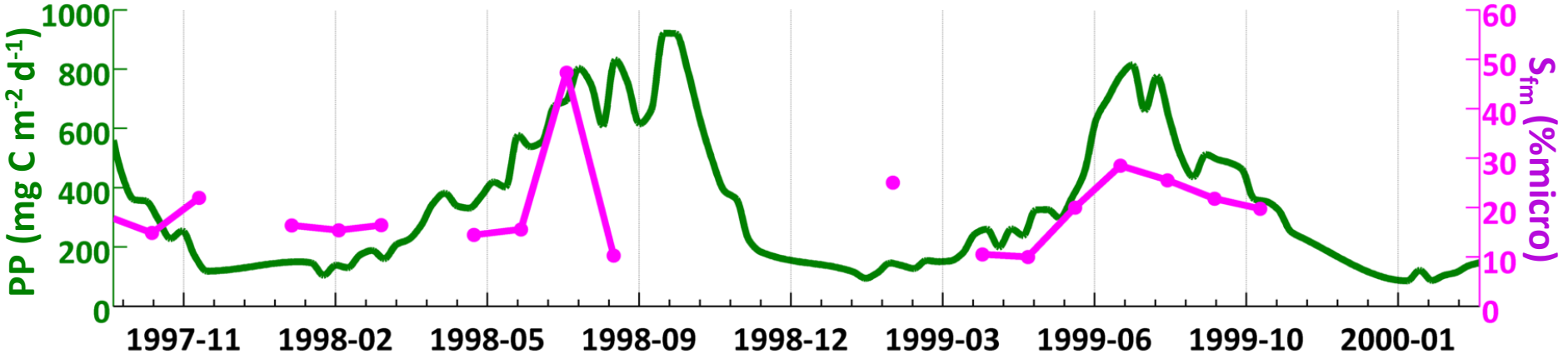


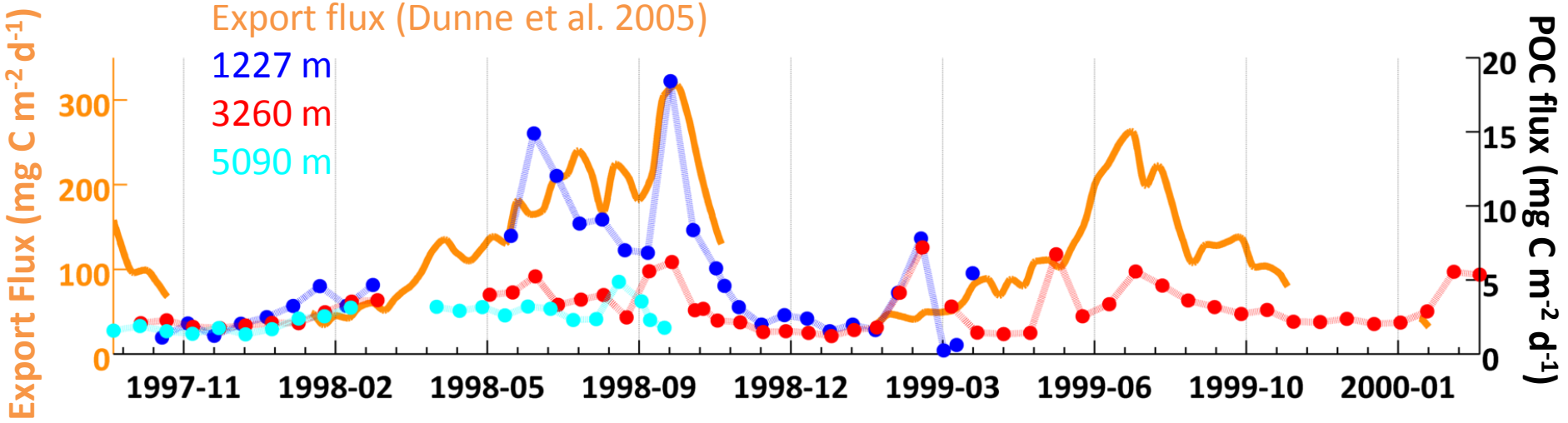


17 day median trap deployment

NW Pacific

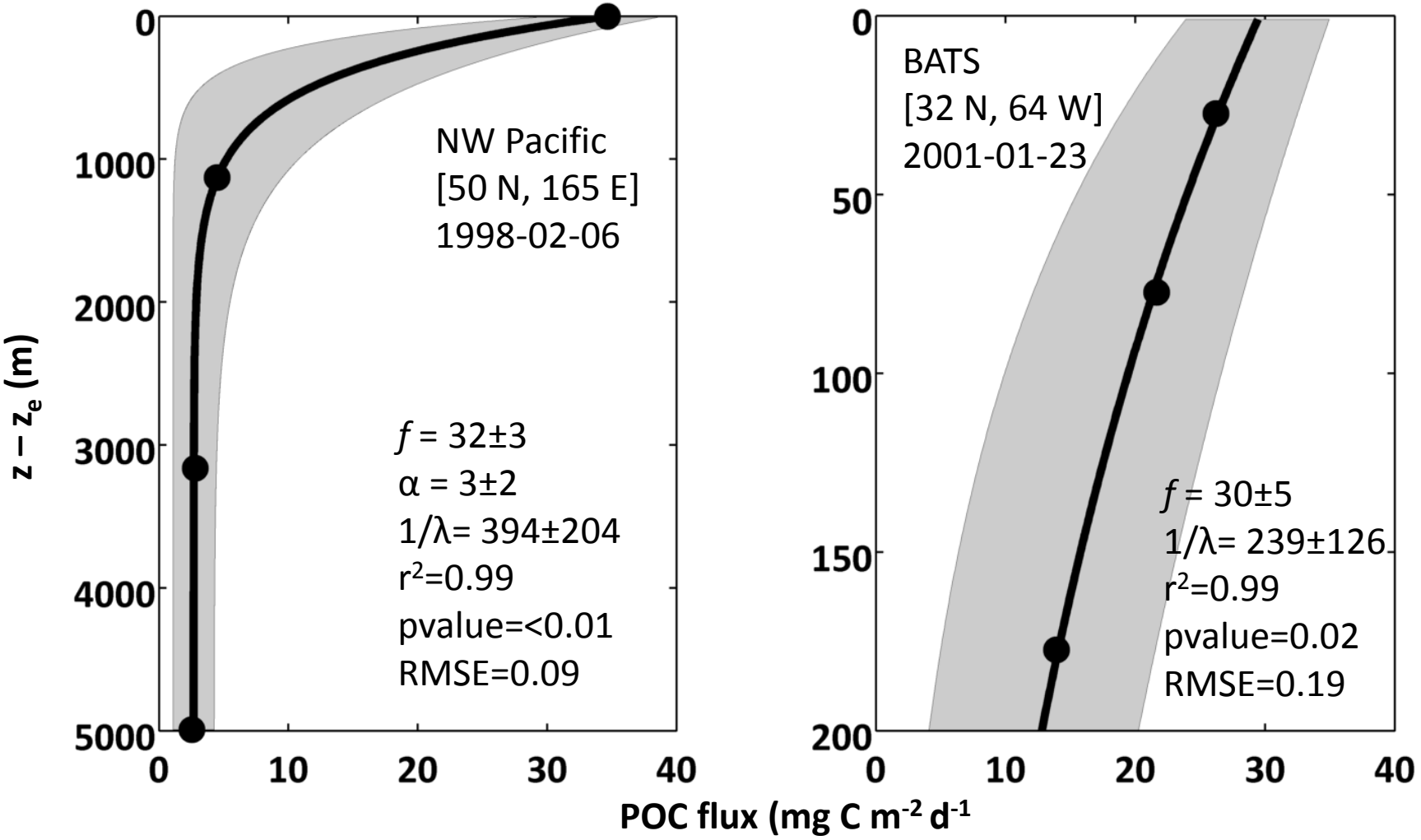
[50 N, 165 E]





17 day median trap deployment

Time Series Export



Conclusions

- Shallow observations are needed to capture phytoplankton size impact. Sediment traps alone due not reveal size differences.
- Seasonal variability in export flux and remineralization length scales with evident size impacts are observed.
- Depth resolution and/or parameter variability make the discrimination of interannual, site-specific size impacts difficult to discern (but we'll keep trying)
- A step forward, but much yet to consider.

Acknowledgements

- Audrey Barnett, John Trocha, Brice Grunert (Michigan Tech U.)
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- AVHRR SST: NASA JPL PO.DAAC
- Mixed layer Depth Climatology: Ifremer