Tour of “dead”* particles in the ocean

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Ocean Optics class 2025

* Alive = metabolizing and self-reproducing? What about: dead cells? byproducts of living things (molts, excreta)? bacteria attached to non-living particles? viruses?

Discuss: What are the optically-important constituents of seawater?

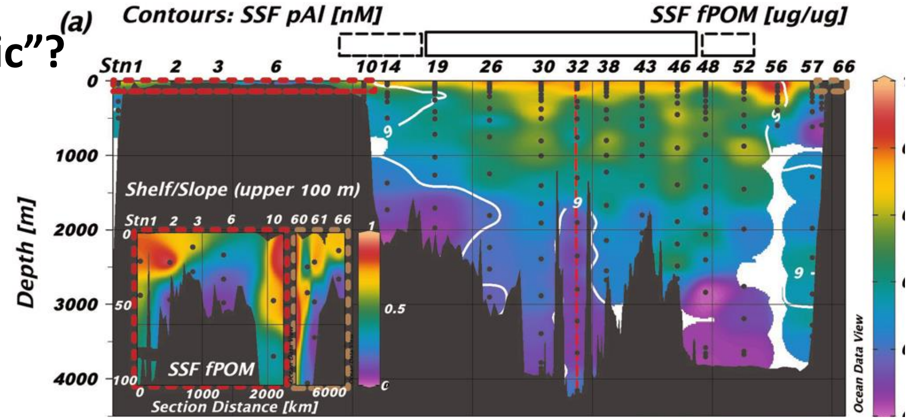
High-level overview of “non-living” particulate matter in the ocean (or at least lacking pigments)

Things to consider:

- Bulk composition
- Size
- Relationships to phytoplankton
- Changes in optical properties during decay
- Boundaries between particle and fluid

Some examples of IOP proxies for non-living matter in the ocean

What fraction of particles are “organic”?

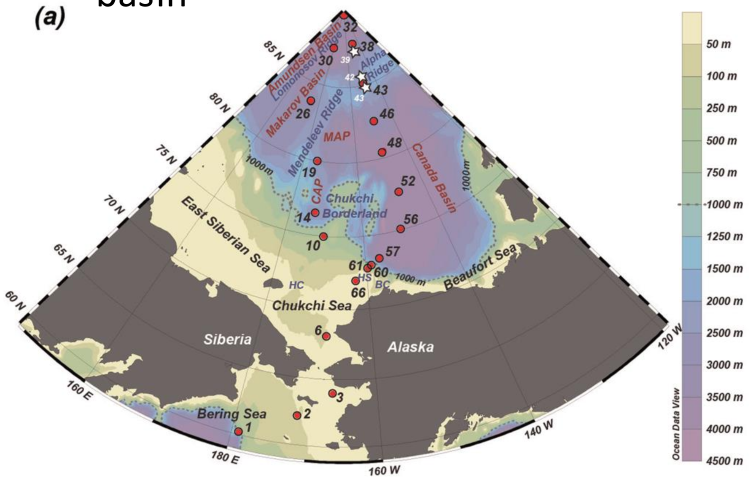


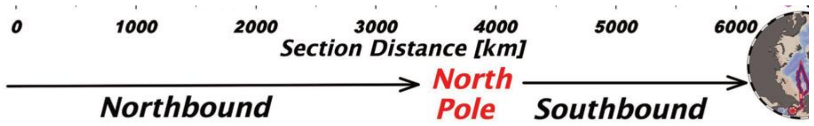
Particle composition during Arctic GEOTRACES cruise, 2015.

- August-October
- 1-51 μm particles collected with in situ pumps
- Composition estimated from major and trace element concentrations

Arctic Ocean

- Strong halocline ~100-300 m
- Red dashed line @~4000 km→brief crossing from Canadian to Eurasian basin





Figures: Xiang and Lam 2020. 10.1029/2020JC016144

How much of particulate organic matter is “alive”?

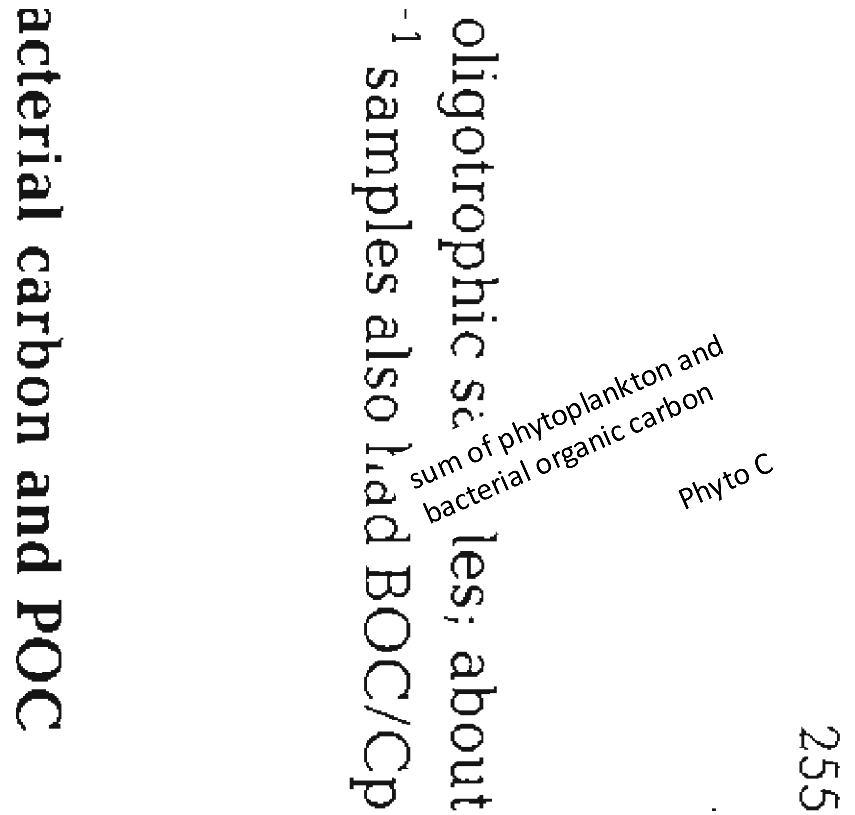


Figure: Cho and Azam, 1990. 10.3354/meps063253

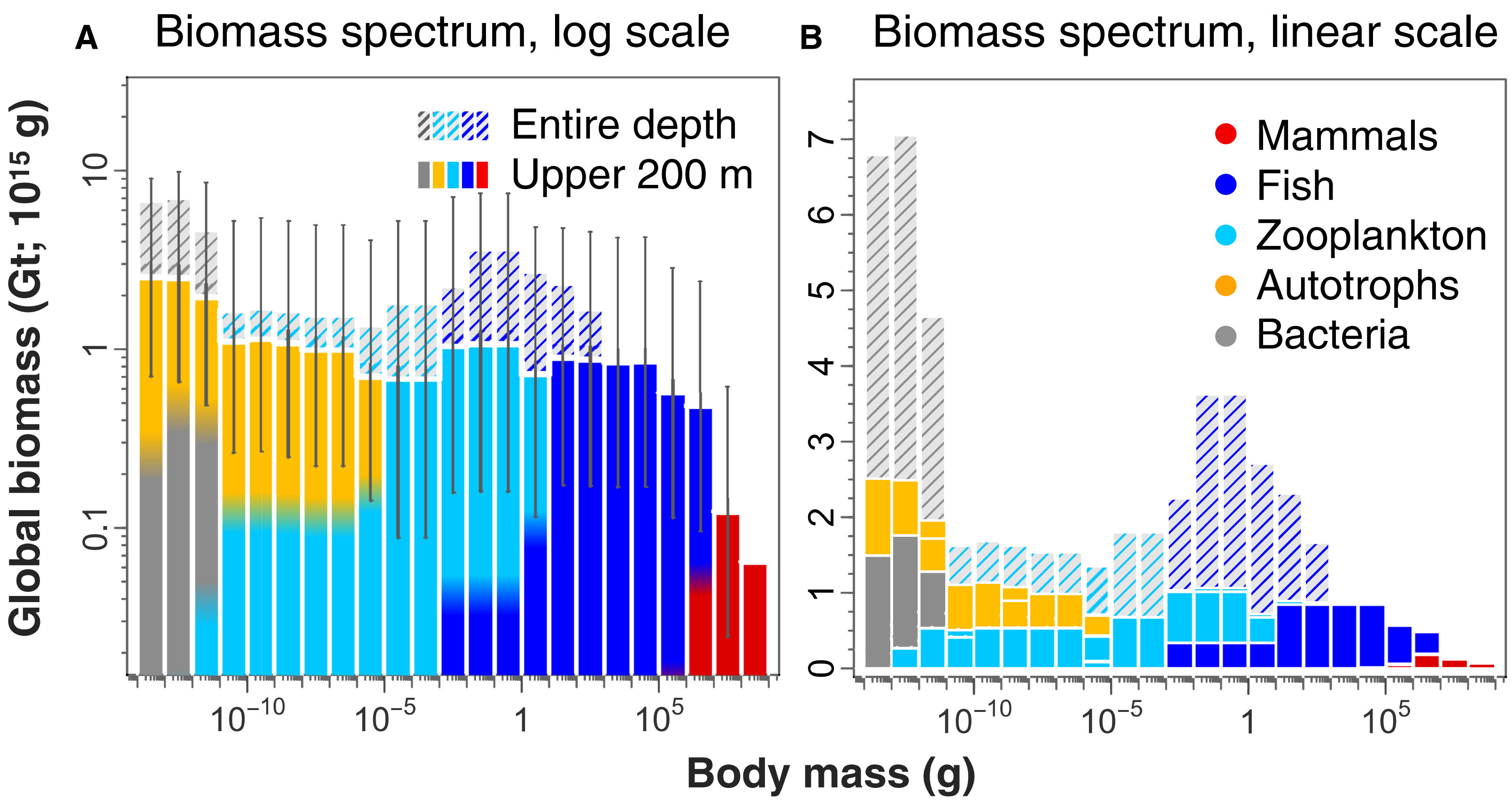


Figure: Hatton et al., 2020. 10.1126/sciadv.abh3732

- Sheldon et al., 1972 was not too far off!
- Rest of Hatton paper projects future human impacts on the biomass PSD… an interesting read.

How much of particulate organic matter is "alive"?

Ducklow 1999 review of Joint Global Ocean Flux Study (JGOFS) process cruise data

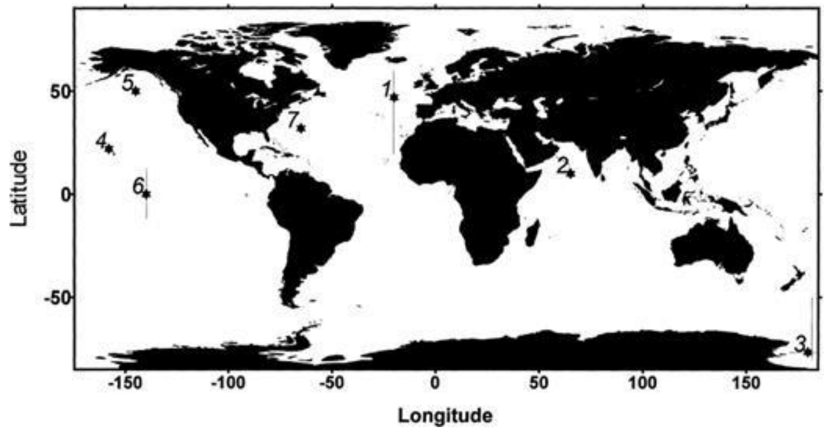
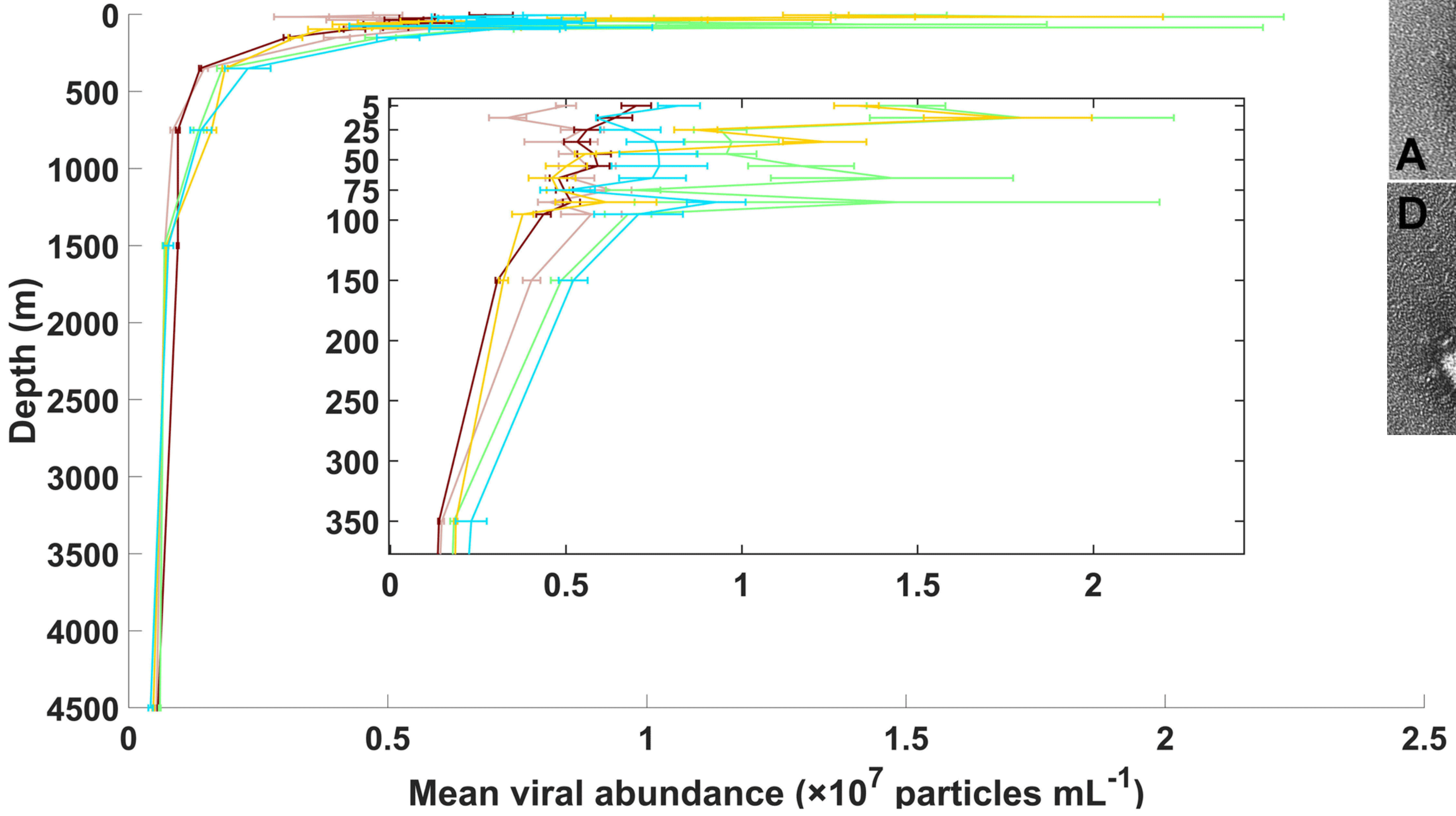


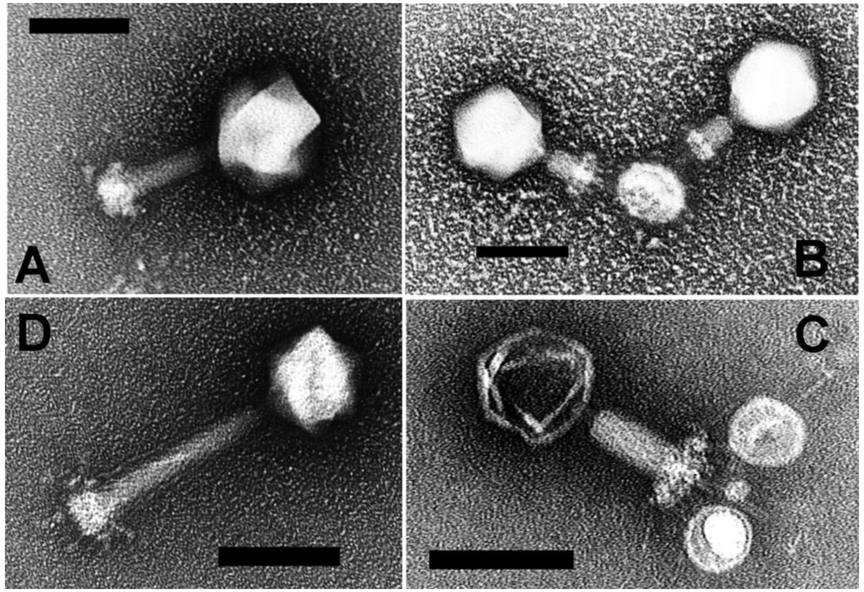
Table 1
Bacterioplankton and phytoplankton properties in the open sea[a]

Property	North Atlantic	Equatorial Pacific, spring	Equatorial Pacific, fall[b]	Sub north Pacific[c]	Arabian	Hawaii	Bermuda[d]	Ross Sea[e]
Euphotic zone (m)	50	120	120	80	74	175	140	45
Biomass (mg C m^{-2})								
Bacteria	1000	1200	1467	1142	1448	1500[f]	1317	217
Phytoplankton	4500	1700	1940	1274	1248	447	573	11450
Ratio (B:P)	0.2	0.7	0.75	0.9	1.2	3.6	2.7	0.02
Production (mg C m^{-2} day^{-1})								
Bacteria	275	285	176	56	257	nd	70	55
Phytoplankton	1083	1083	1548	629	1165	486[g]	465	1248
Ratio (B:P)	0.25	0.26	0.11	0.09	0.22	nd	0.18	0.04
Growth rates (day^{-1})								
Bacteria	0.3	0.13	0.12	0.05	0.18	nd	0.05	0.25
Phytoplankton	0.3	0.64	0.8	0.50	0.93	1.1	0.81	0.11
Ratio (B:P)	1	0.2	0.15	0.1	0.19	nd	0.06	2.3

Ducklow, 1999. "The bacterial component of the oceanic euphotic zone". https://doi.org/10.1111/j.1574-6941.1999.tb00630.x

How much of particulate organic matter is “alive”?



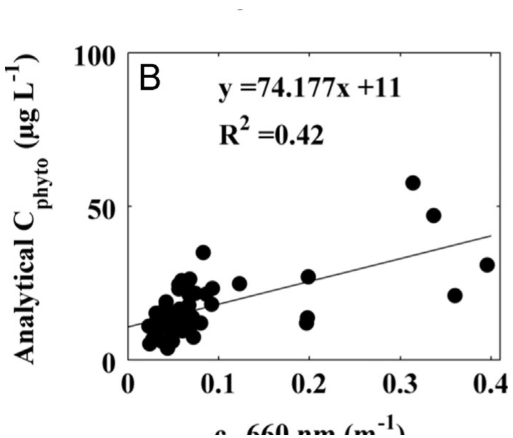


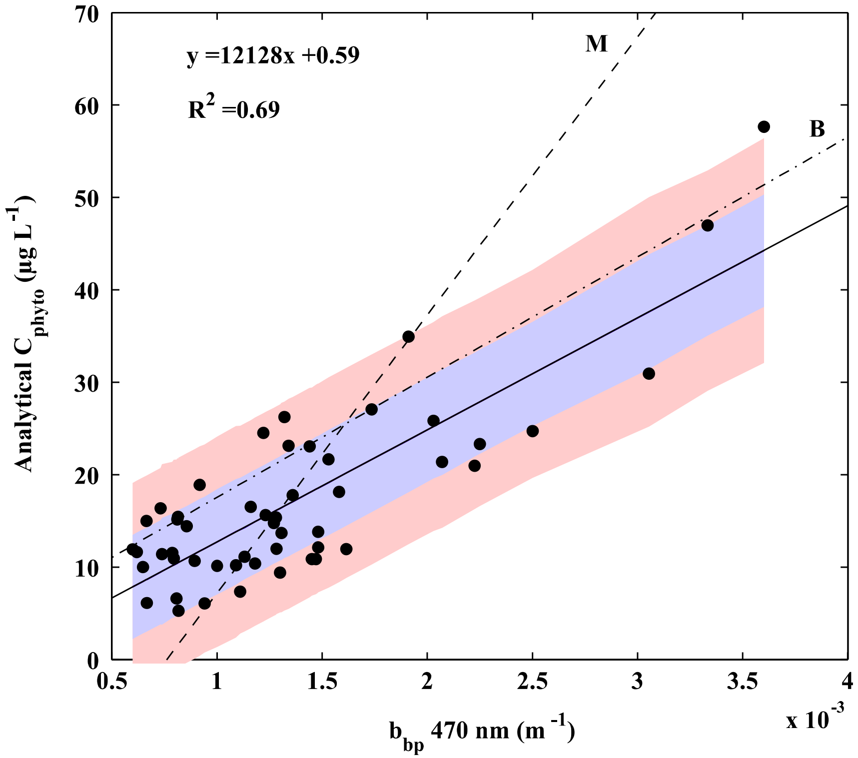
Cyanophages (infect cyanobacteria). Scale bar 200 nm.

Sullivan MB, Coleman ML, Weigele P, Rohwer F, Chisholm SW. 2005. Three Prochlorococcus Cyanophage Genomes: Signature Features and Ecological Interpretations. doi:10.1371/journal.pbio.0030144, CC BY 2.5, https://commons.wikimedia.org/w/index.php?curid=1428177

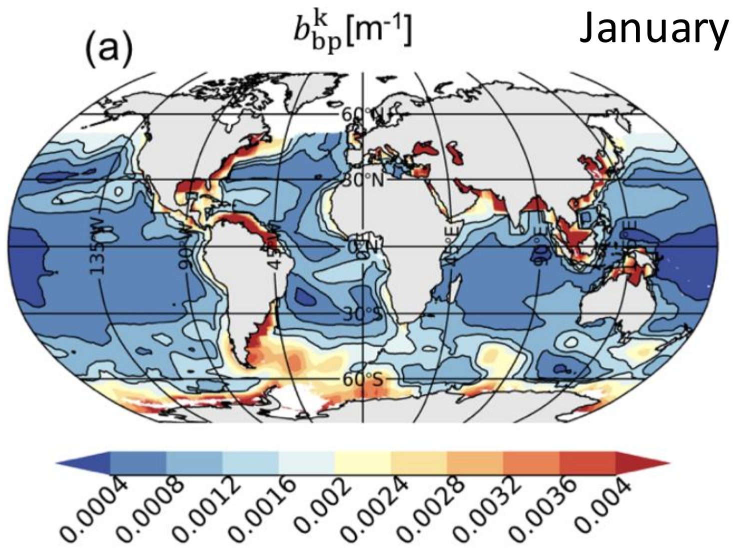
Viral abundance in the global ocean: Xie et al., **A global viral oceanography database (gVOD),** https://doi.org/10.5194/essd-13-1251-2021

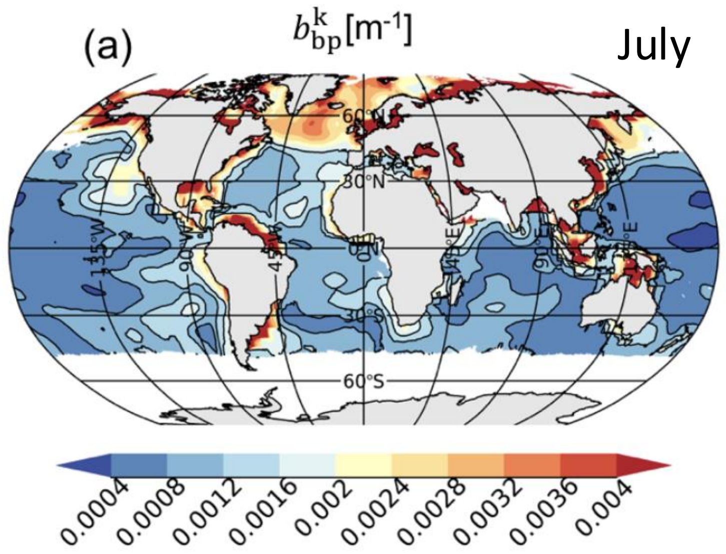
How much of particulate backscattering is due to phytoplankton?
Is this fraction constant everywhere?





Figures: Graff et al. 2015. 10.1016/j.dsr.2015.04.006



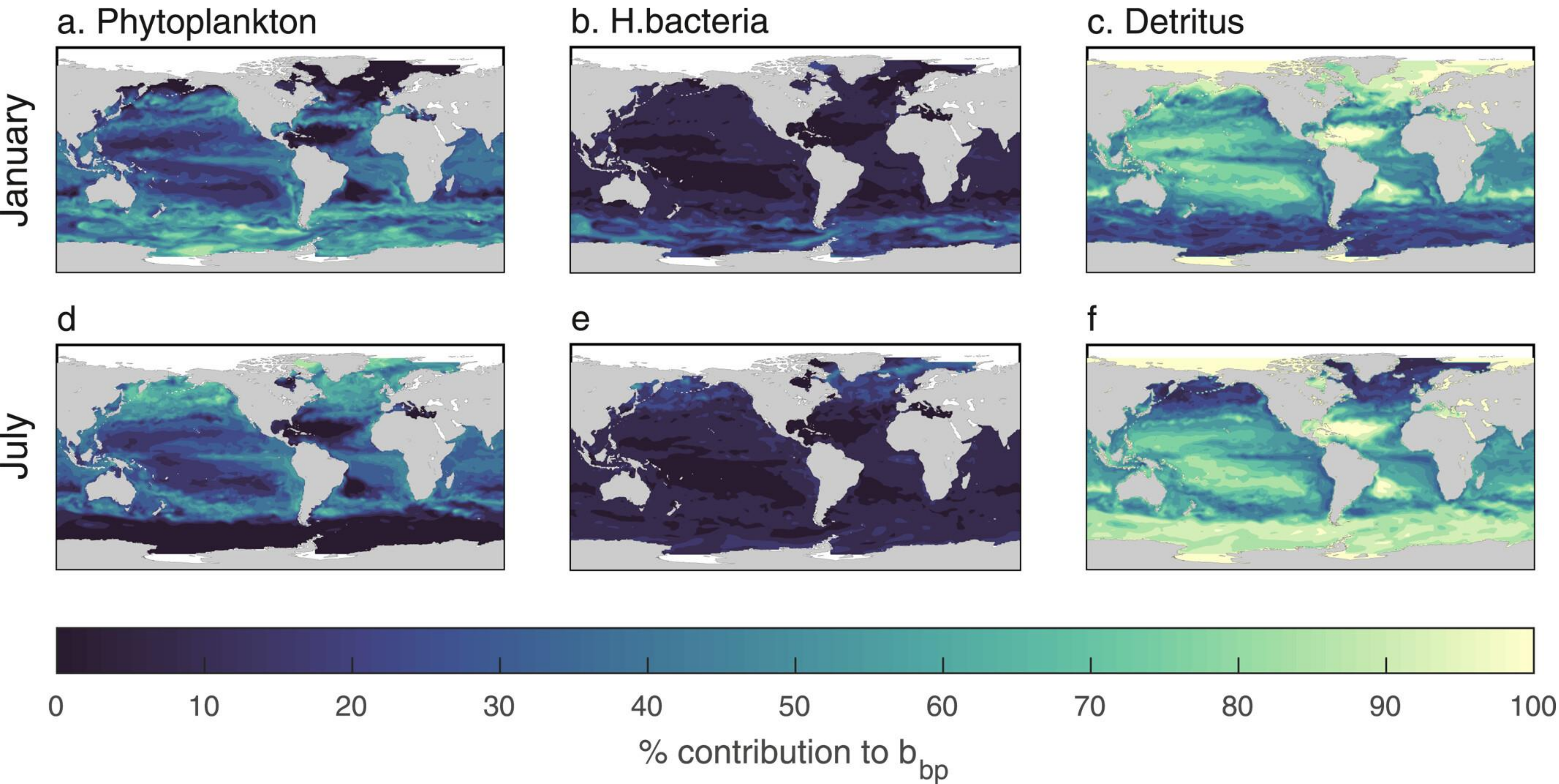


- b_{bp}^{k} is the intercept of the regression of b_{bp} against Chl
- Map figures show January and July means of monthly determinations from merged satellite data

Map figures: Supplement to Bellacicco et al., 2020. 10.3390/rs12213640

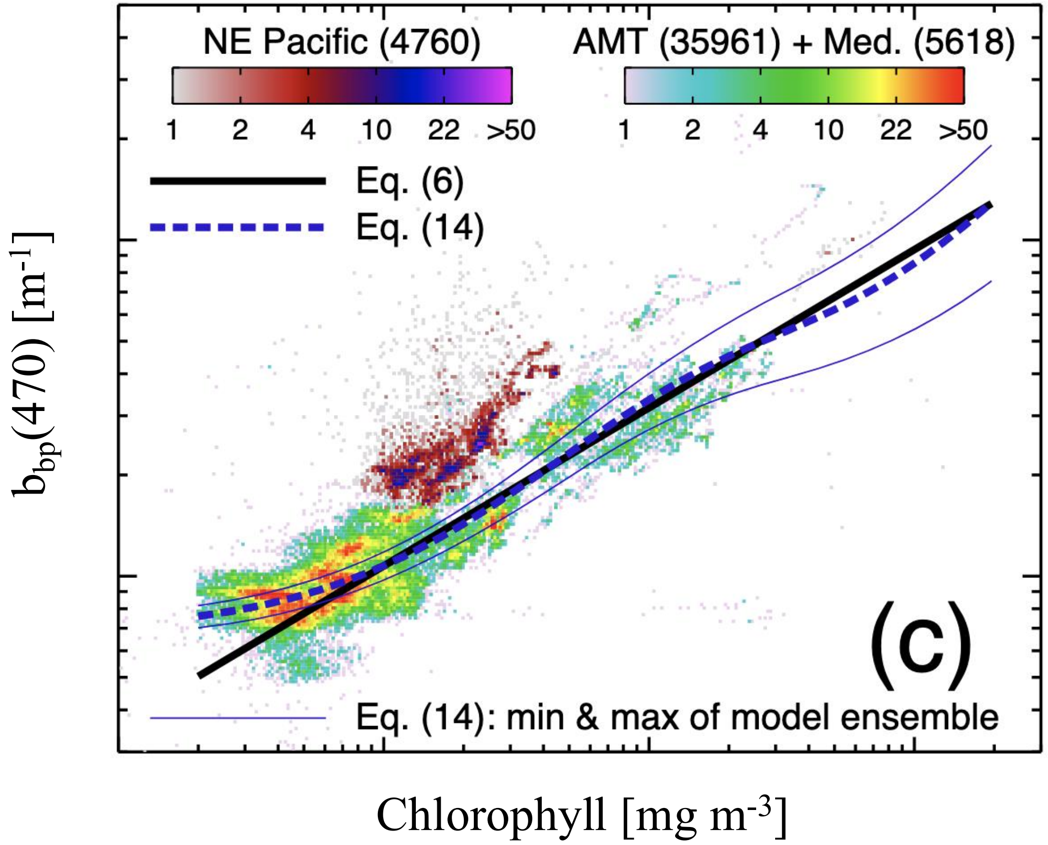
How much of particulate backscattering is due to phytoplankton?

Serra-Pompeii et al. 2023. https://doi.org/10.1029/2022GB007556. Largest uncertainty in phytoplankton retrieval from b_{bp} is due to poor constraints on non-phytoplankton backscattering.



Balance of phytoplankton and detritus contributions to b_{bp} can vary with scale (regional/local vs. global, coastal vs. open ocean)

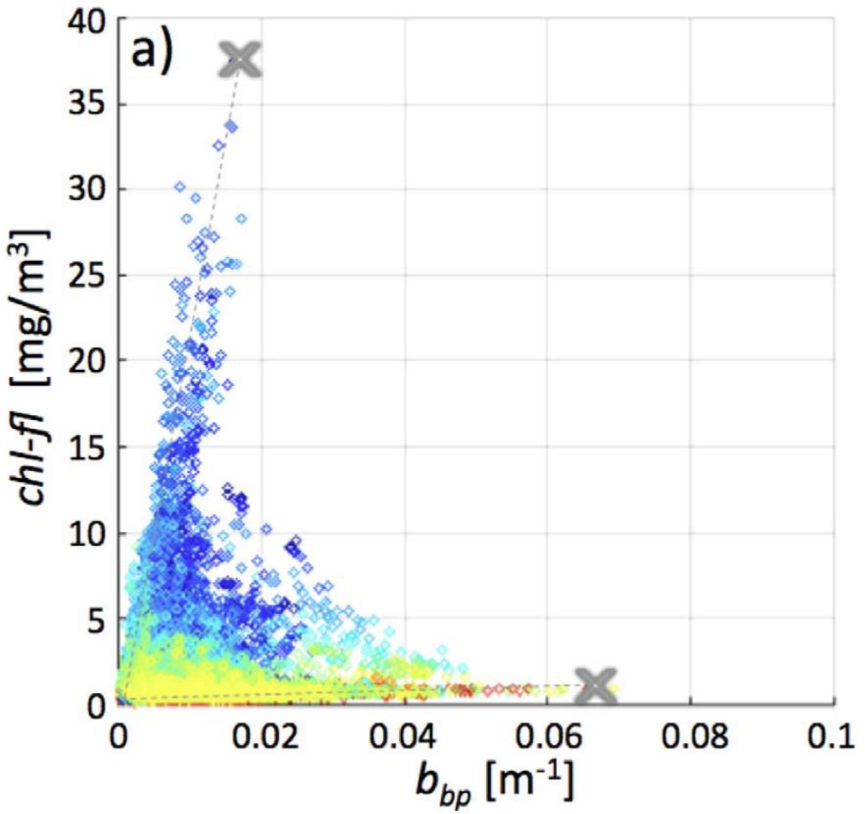
Open ocean



It is important to stress that these retrieved chlorophyll-specific backscattering coefficients are representative of not just the phytoplankton, but also their co-varying constituents (e.g. detrital matter, bacteria and viruses).

Brewin et al., 2012

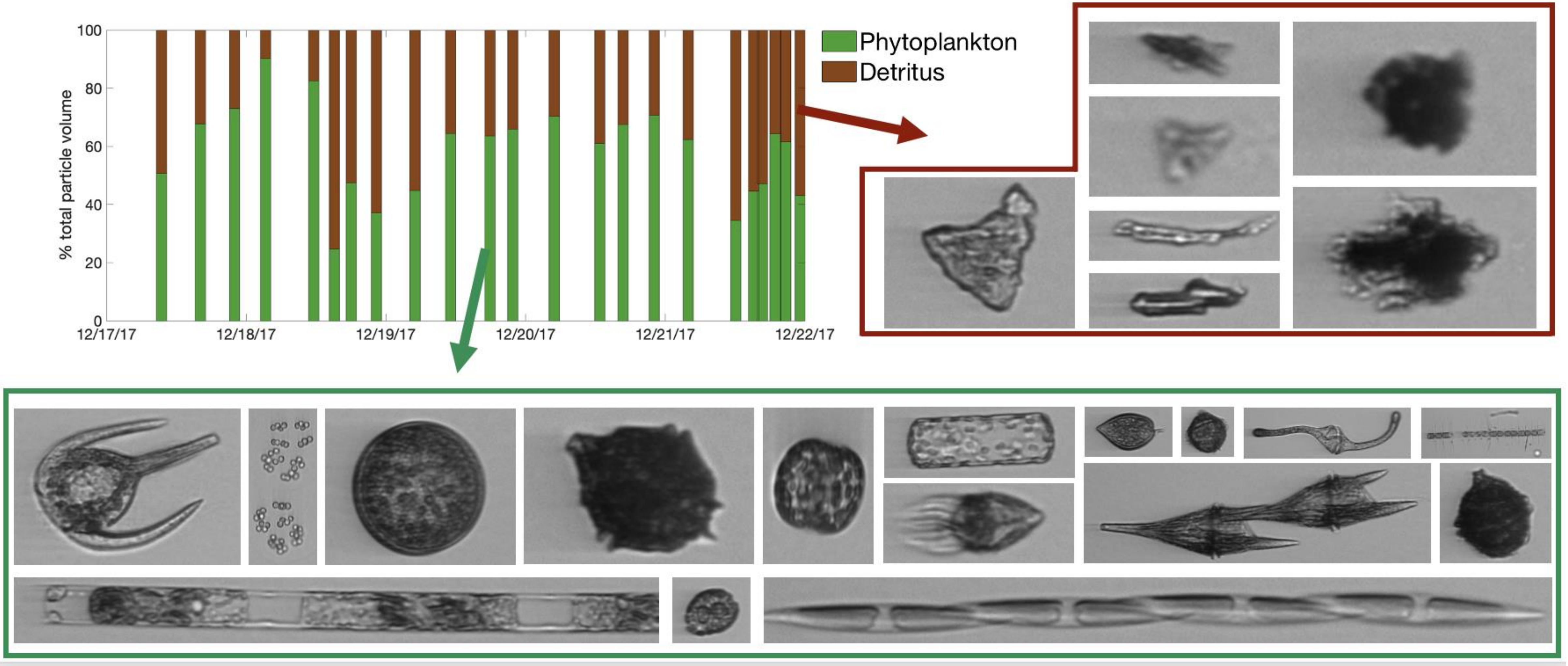
Coastal



Henderikx Freitas et al., 2016

Observing phytoplankton and detritus under dynamic conditions

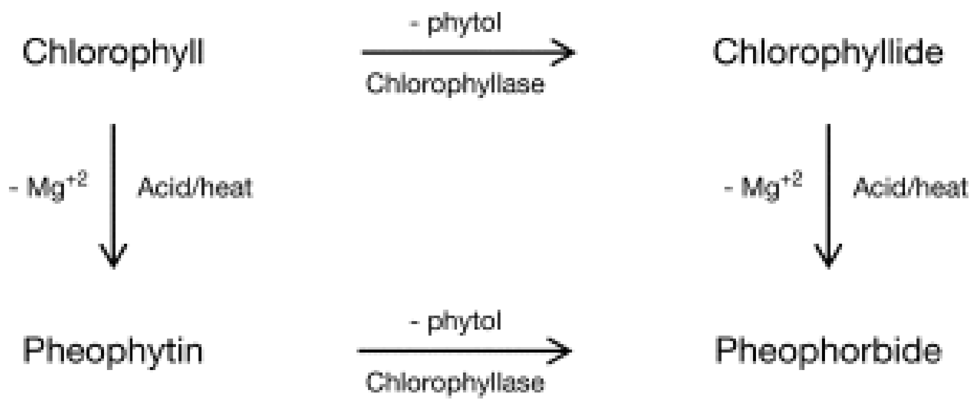
Example IFCB images collected using the scattering trigger during the Thomas Fire in the Santa Barbara Channel. Ash particles vary in composition, shape, and color but are in the same size range as phytoplankton! Ash ranged from 10-65% of the total particle volume.



Kramer et al., 2020

What happens to phytoplankton as they turn into detritus?

Chlorophyll is converted into degradation pigments (phaeophytin, pheophorbide, chlorophyllide)

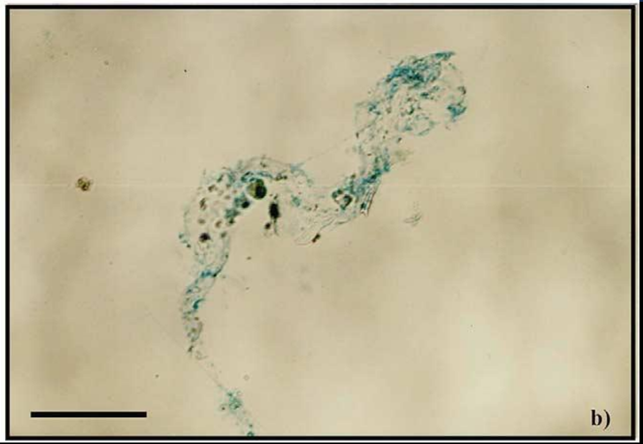


Yilmaz & Golkim, 2016

In a sediment trap gel: sinking phytoplankton cells, fecal pellets, zooplankton

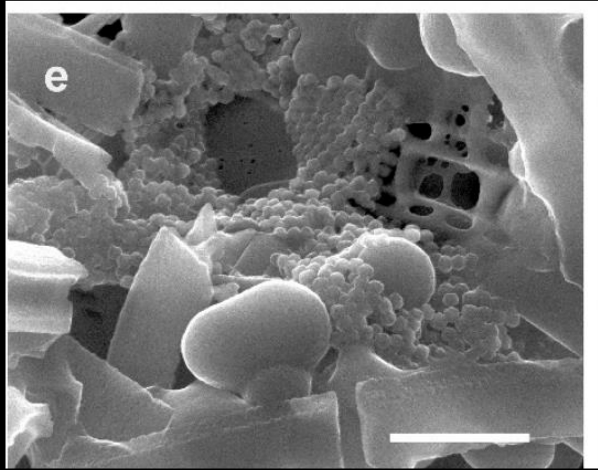
Annie Bodel
Colleen Durkin

What constitutes the boundary between a particle and the surrounding fluid?



TEP aggregate stained with Alcian Blue, scale = 0.1 mm. Passow and Alldredge 2002. doi: 10.1016/S0079-6611(02)00138-6

SEM photomicrograph of hydrothermal plume particle at EPR axis, scale = 1 µm. Hoffman et al., 2020. 10.1021/acsearthspacechem.0c00067



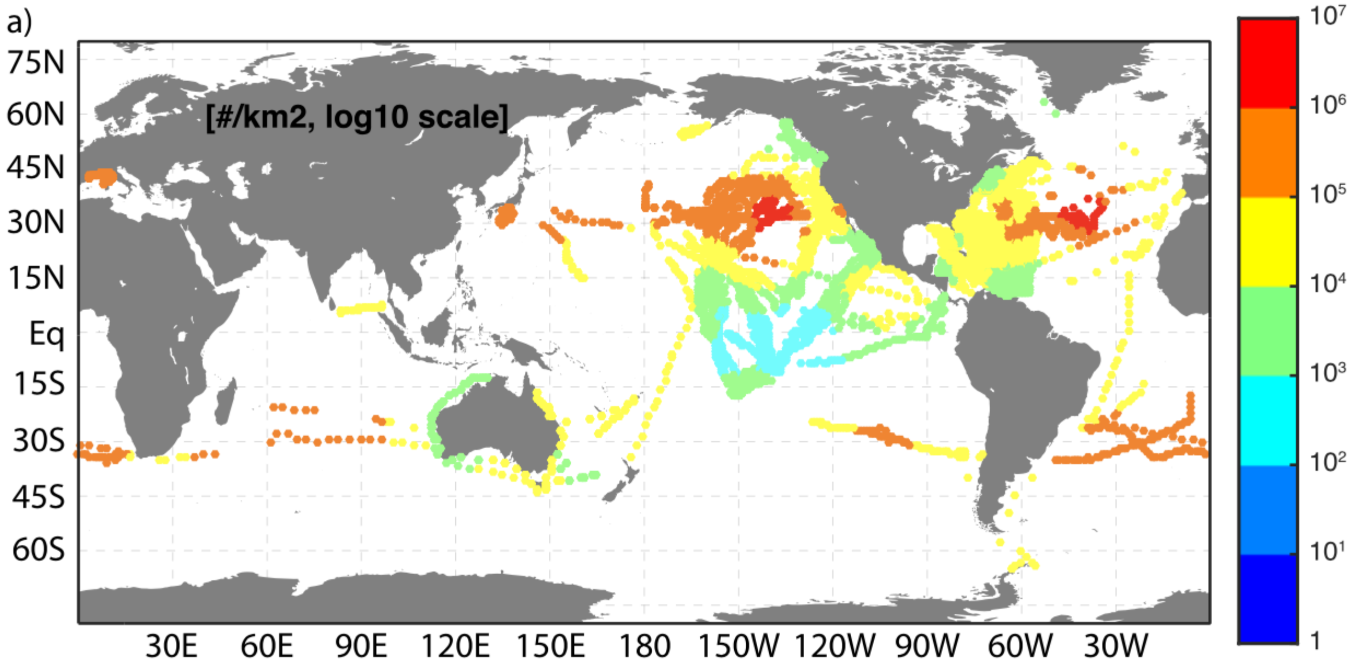
Pseudonitzchia australis, Phyto'pedia. Scale 50 µm. https://phytoplankton.eoas.ubc.ca/research/phytoplankton/diatoms/pennate/pseudonitzschia/p_pungens_australis.html

What are the advantages of optics/remote sensing methods?

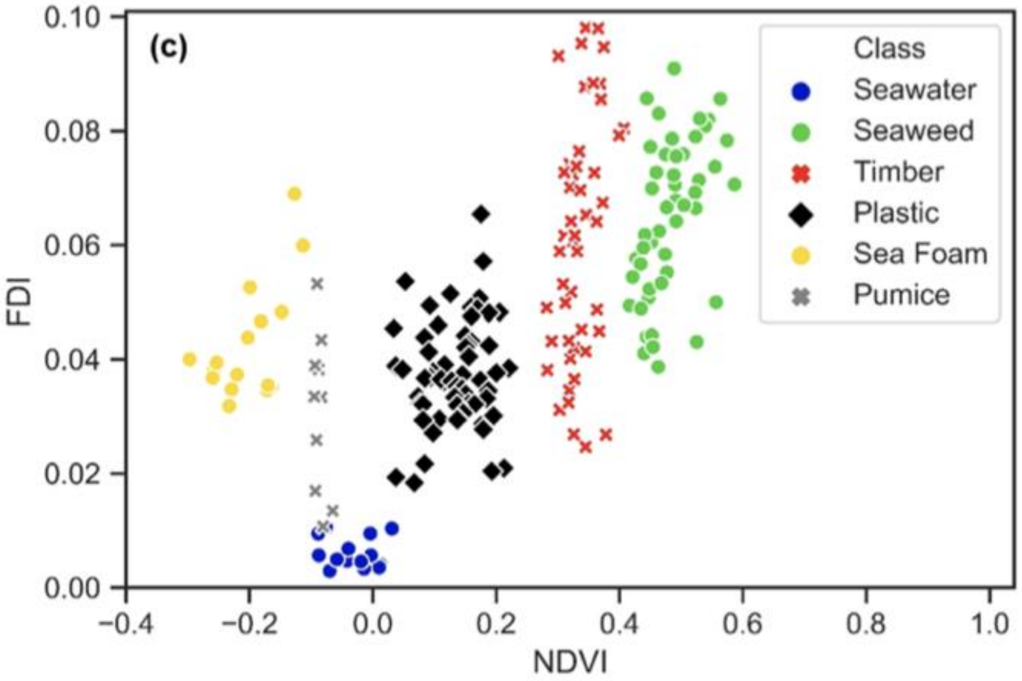
- Synoptic (“see it all at once”), large scale sampling
- High depth resolution
- Ability to directly or synthetically sample large volumes and rare particles/events
- Combine the extent and resolution of optical methods with the less ambiguous/more detailed analyses available for discrete samples.
  - Examples here are distinct from “proxy building” – to which we will return later this afternoon
  - They represent what could be thought of as the earliest stage of proxy development

Example: Remote sensing of marine debris

Anthropogenic marine debris is widespread...can we develop an optical index to separate plastic from other surface ocean constituents?



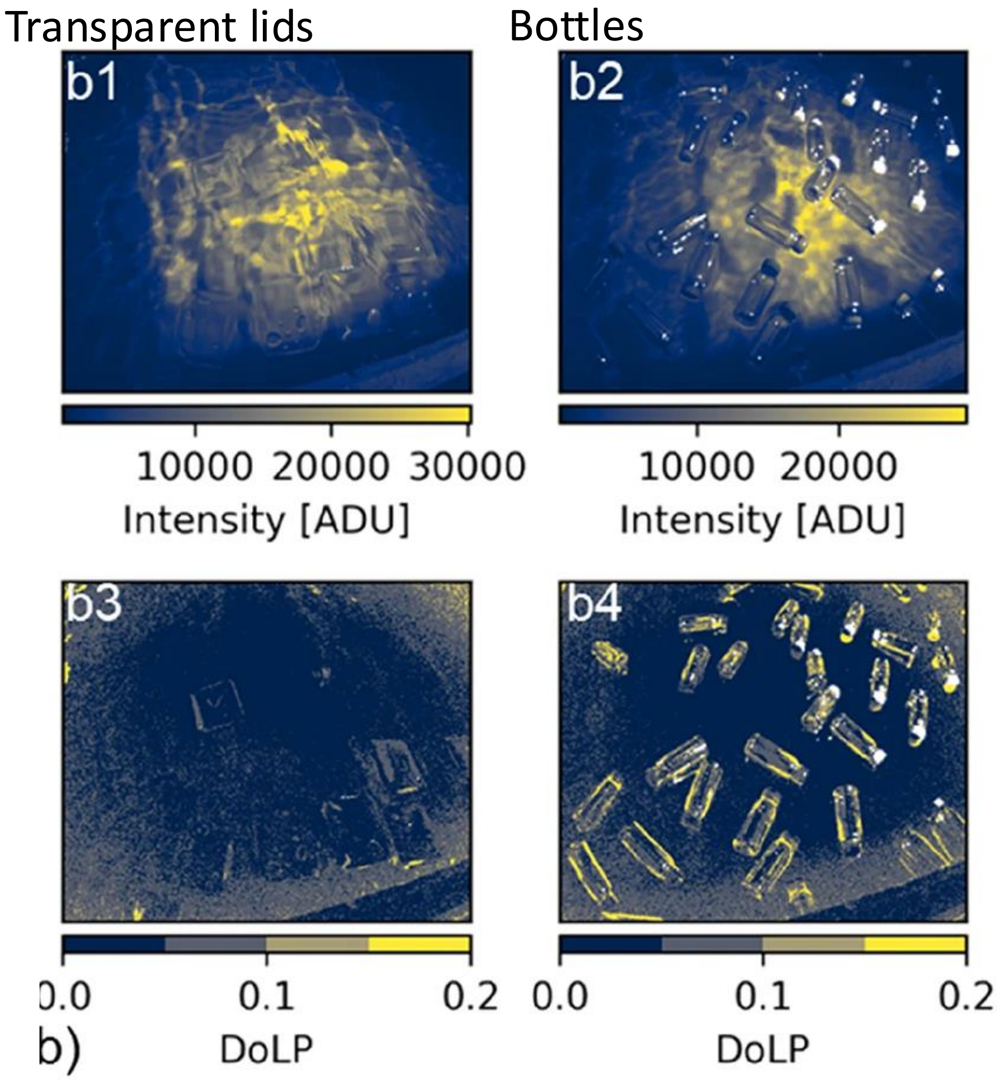
van Sebille et al., 2015



Biermann et al., 2020

Example: Remote sensing of marine debris: Still difficult to distinguish plastic from other seawater constituents

DeFockert et al., 2024. *Nat. Sci. Rep.* 10.1038/s41598-024-74332-5

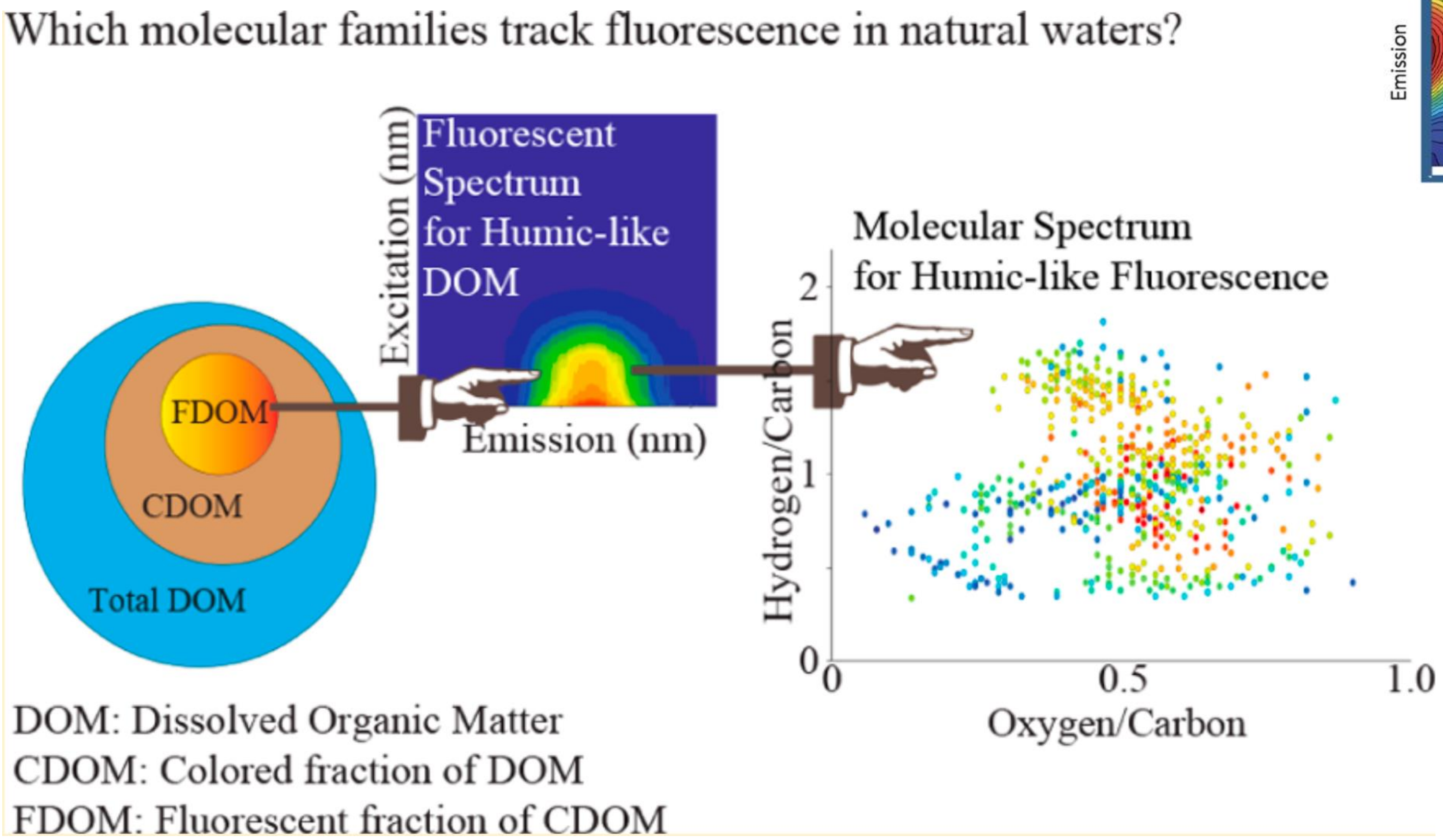


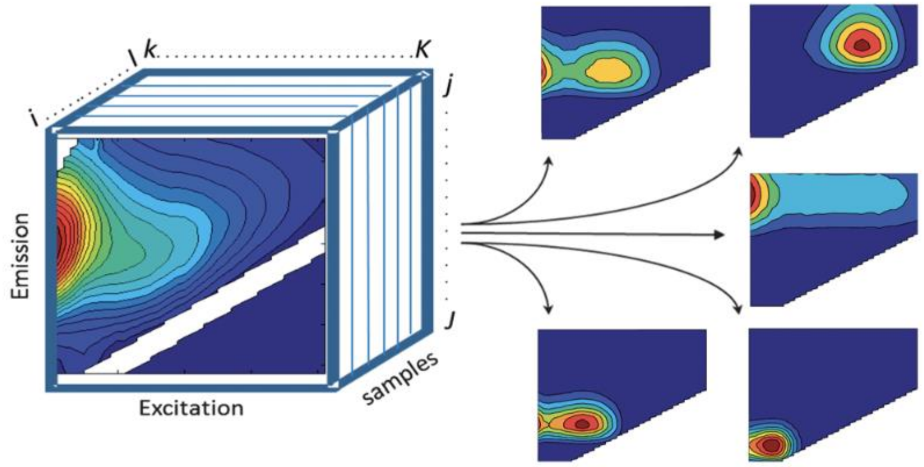
Tests carried out in controlled indoor setting. Optical methods shown here. Visible radiance and DoLP were sufficient to detect bottles but not lids.

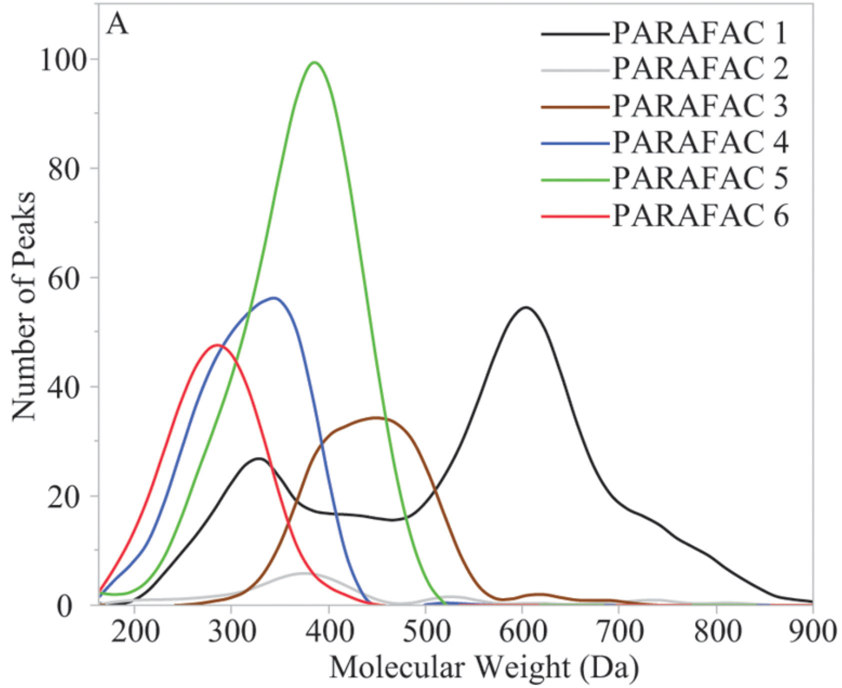
plastics		size (cm)	Hs (cm)			
spheres	PP	2	9			
foam cyl.	PE	5	9			
foam cyl.	PE	10	9			
foam cyl.	PE	20	9			
foam cyl.	PE	raft	5			
foam cyl.	PE	raft	9			
bubble wrap		30				
straws	PP	24	9			
straws	PP	6	9			
straws	PP	12	17			
straws	PP	raft	0			
straws	PP	raft	5			
straws	PP	raft	9			
bottles	PET	15.5	0			
bottles	PET	15.5	5			
bottles	PET	15.5	9			
bottles	PET	15.5	17			
lids	PP	19	5			
lids	PP	19	9			
lids	PP	19	17			
lids no edge	PP	16	9			
lids no edge	PP	16	17			
nets	PA	0.15	5			
nets	PA	0.15	9			
nets	PA	0.15	17			
org. sheets	LDPE	20	9			
styrofoam	PS	30	9			
	Wavelength (nm)		λmin	470	400	400
			λmax	870	900	700
	Optical instrument			** ASD fieldspec	GroundSPEX	BlackFly pol. camera
	Detectibility (%)			**88**	**43**	**46**

not measured
not detectable
sometimes detectable
detectable

Example: linking DOM fluorescence with high-resolution molecular spectroscopy

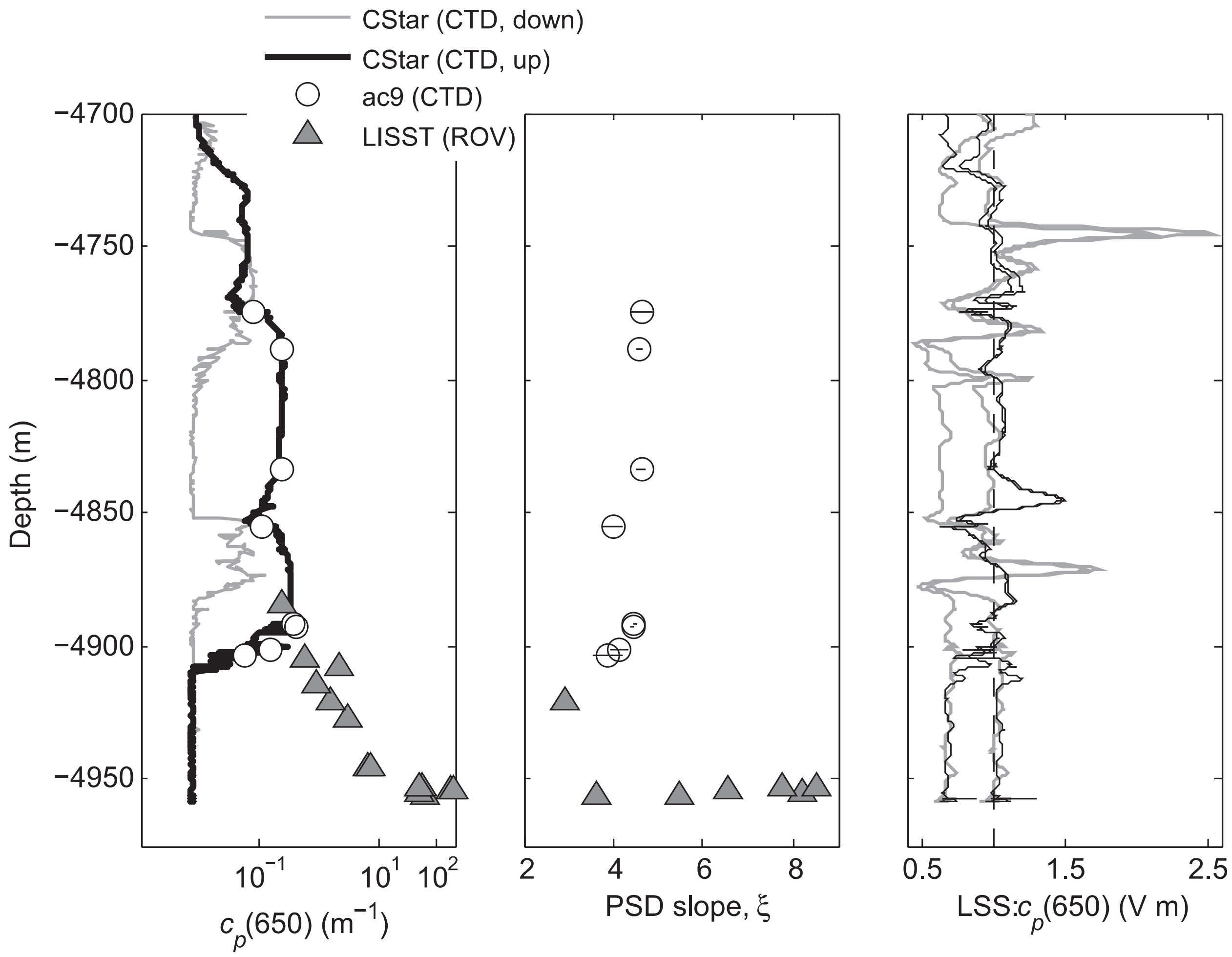


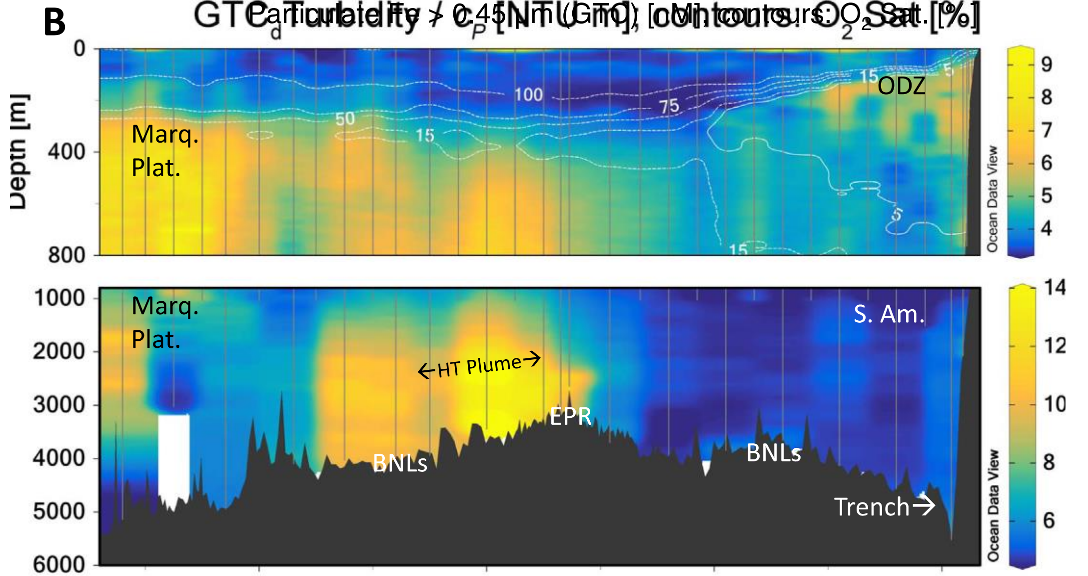


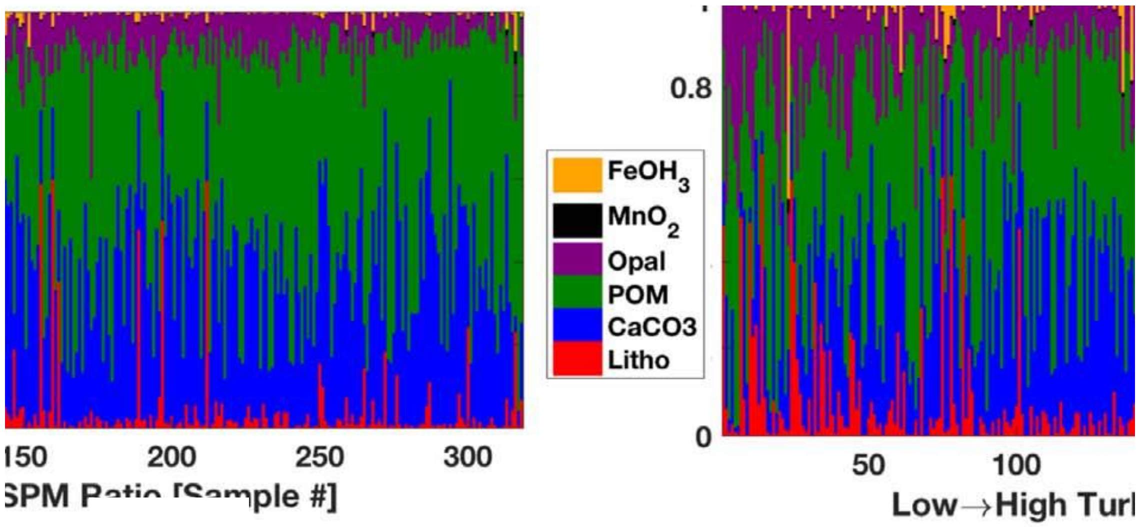


Graphical abstract and lower left figure are from Stubbins et al., 2014. 10.1021/es502086e
Upper left method figure is from Murphy et al., 2013. 10.1039/c3ay41160e

Example: Using in situ optical sensors (beam attenuation and turbidity/side-scattering) to detect tiny iron hydroxide particles from hydrothermal vent plumes

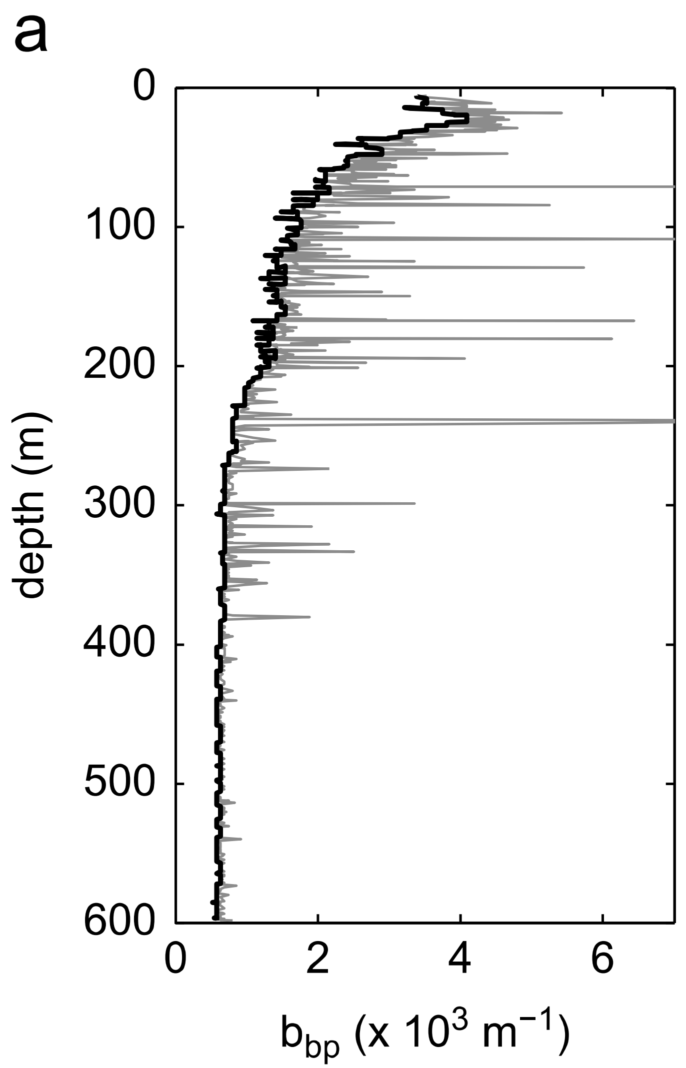


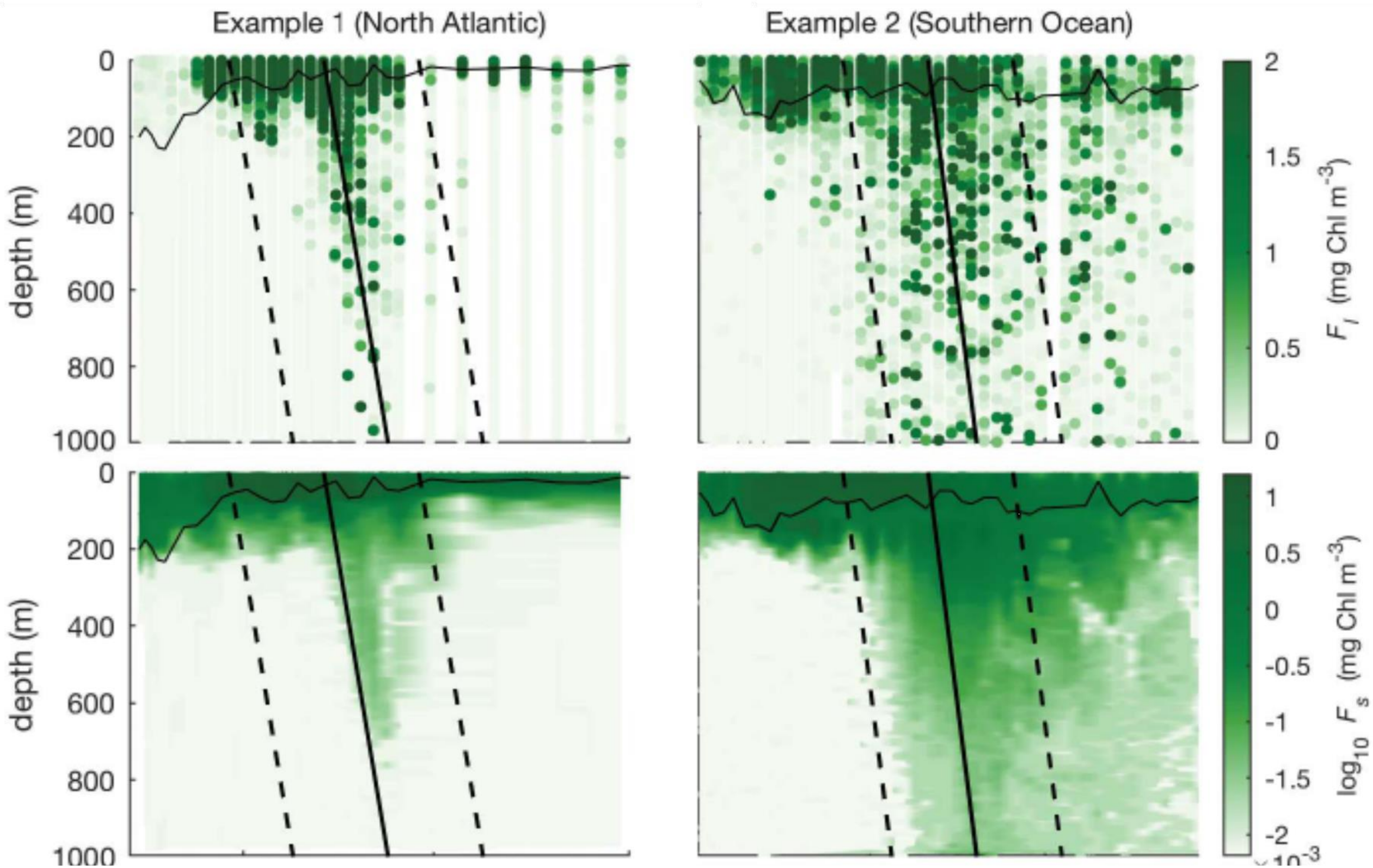




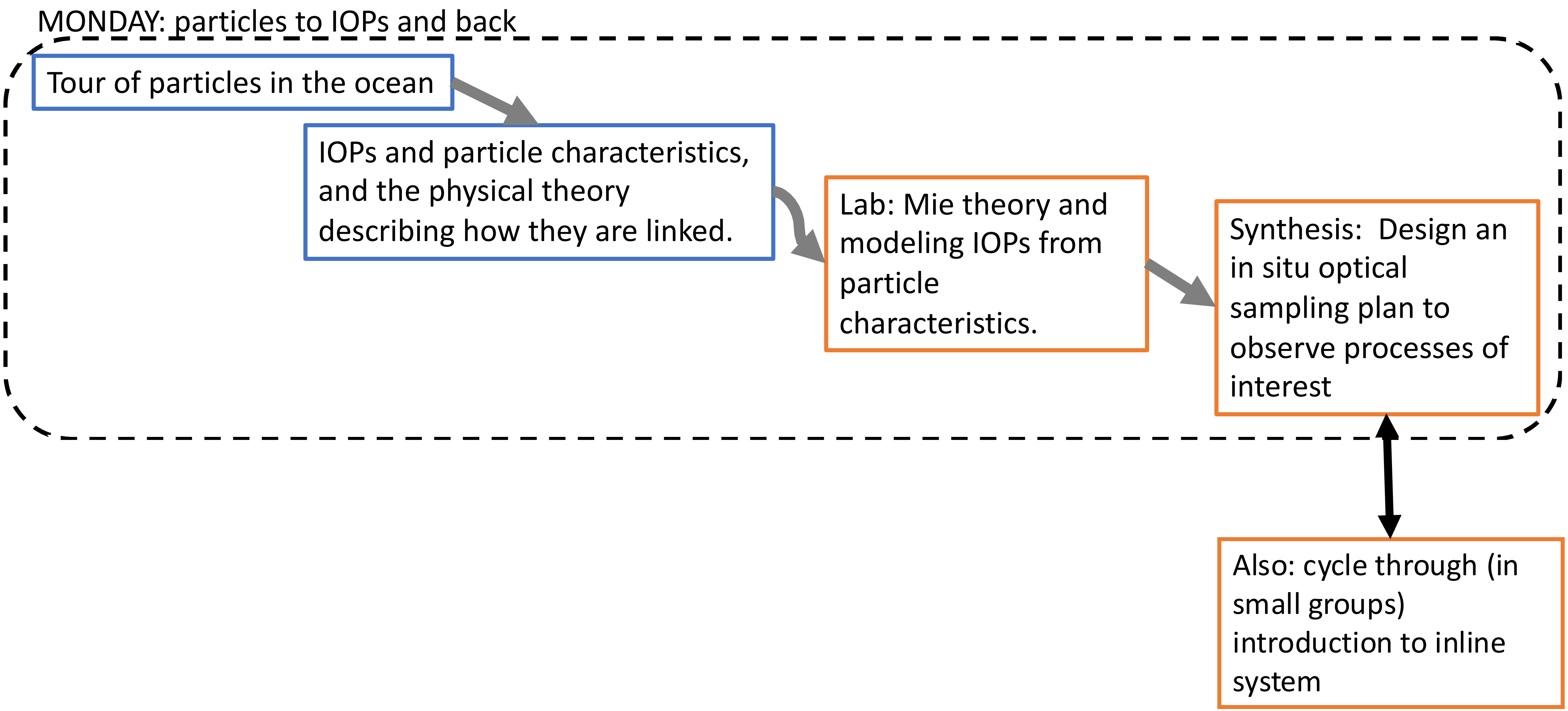
Figures: above: Estapa et al. (2015) 10.1002/2015GC005831
right: Ohnemus et al. (2016) 10.1016/j.marchem.2017.09.004

Example: Use of high frequency fluctuations in optical signals to quantify large particle stocks and observe their fragmentation rates





Figures: left, Briggs et al. 2011. 10.1016/j.dsr.2011.07.007. Right, Briggs et al. 2020. 10.1126/science.aay1790


MONDAY: particles to IOPs and back
Tour of particles in the ocean
IOPs and particle characteristics, and the physical theory describing how they are linked.
Lab: Mie theory and modeling IOPs from particle characteristics.
Synthesis: Design an in situ optical sampling plan to observe processes of interest
Also: cycle through (in small groups) introduction to inline system