OCEAN COLOR SCIENCE: A NEED FOR MEASUREMENTS BASED ON A REDUCTIONIST APPROACH

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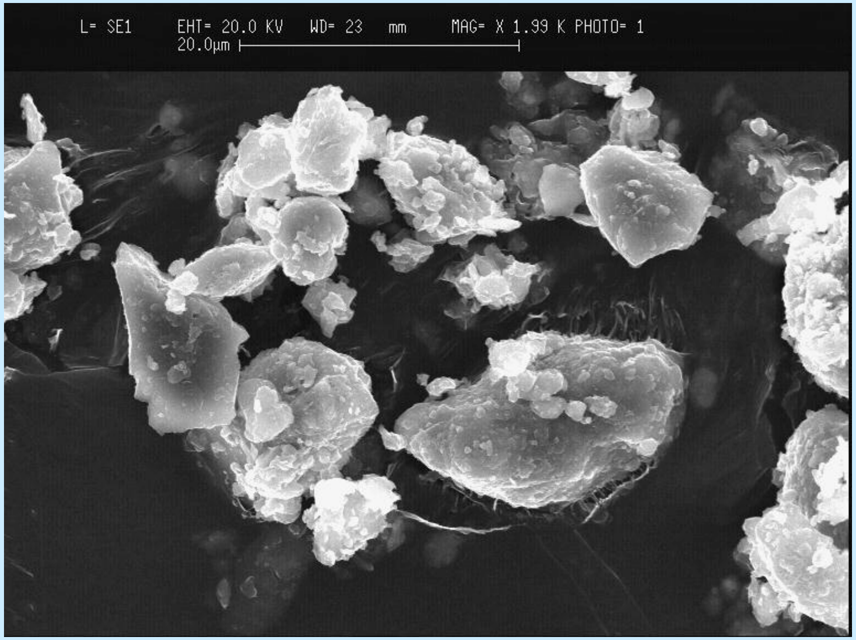
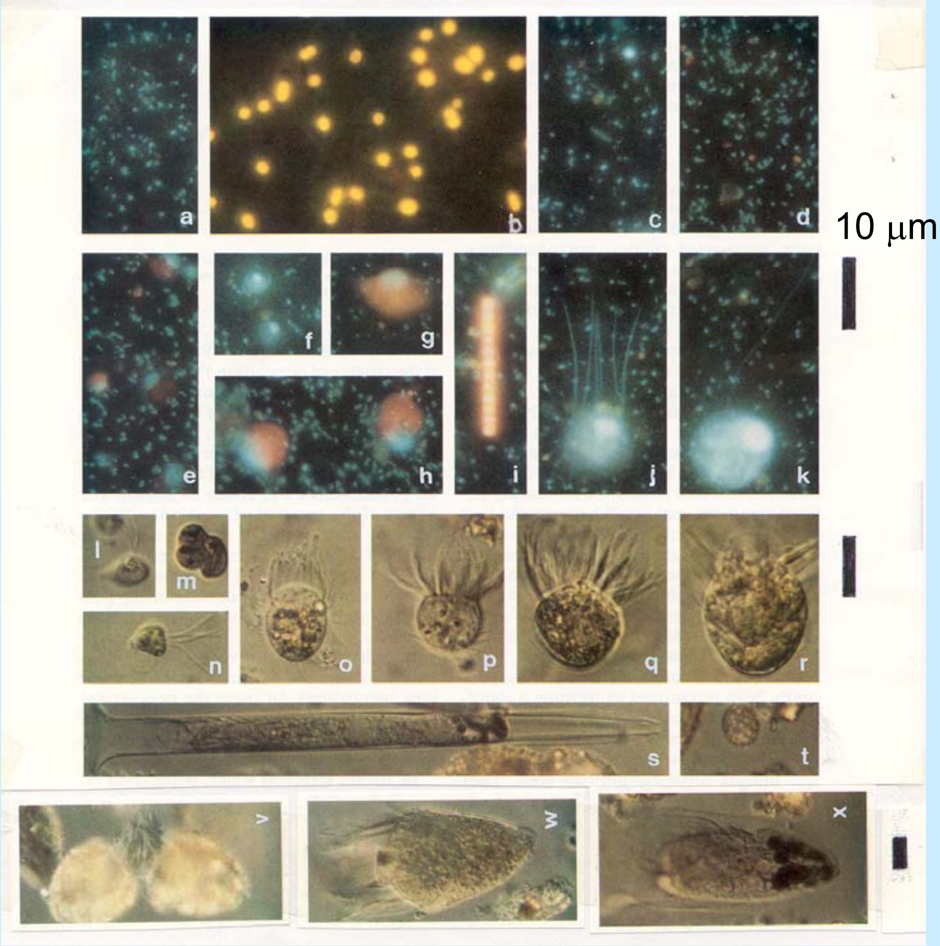
Seawater is a complex optical medium with a great variety of particle types and soluble species





10 μm

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$R(\lambda)$ = f [seawater constituents]

= f [$IOPs(\lambda)$]

= f [$a(\lambda)$, $\beta^{E}(\psi, \lambda)$, $\beta^{I}(\psi, \lambda'$□ $\lambda)$]

¡ f [$b_b(\lambda) / (a(\lambda) + b_b(\lambda))$]

¡ f [$b_b(\lambda) / a(\lambda)$]

$IOPs(\lambda)$ = f [seawater constituents]

$$IOP(\lambda) = IOP_w(\lambda) + IOP_p(\lambda) + IOP_{CDOM}(\lambda)$$

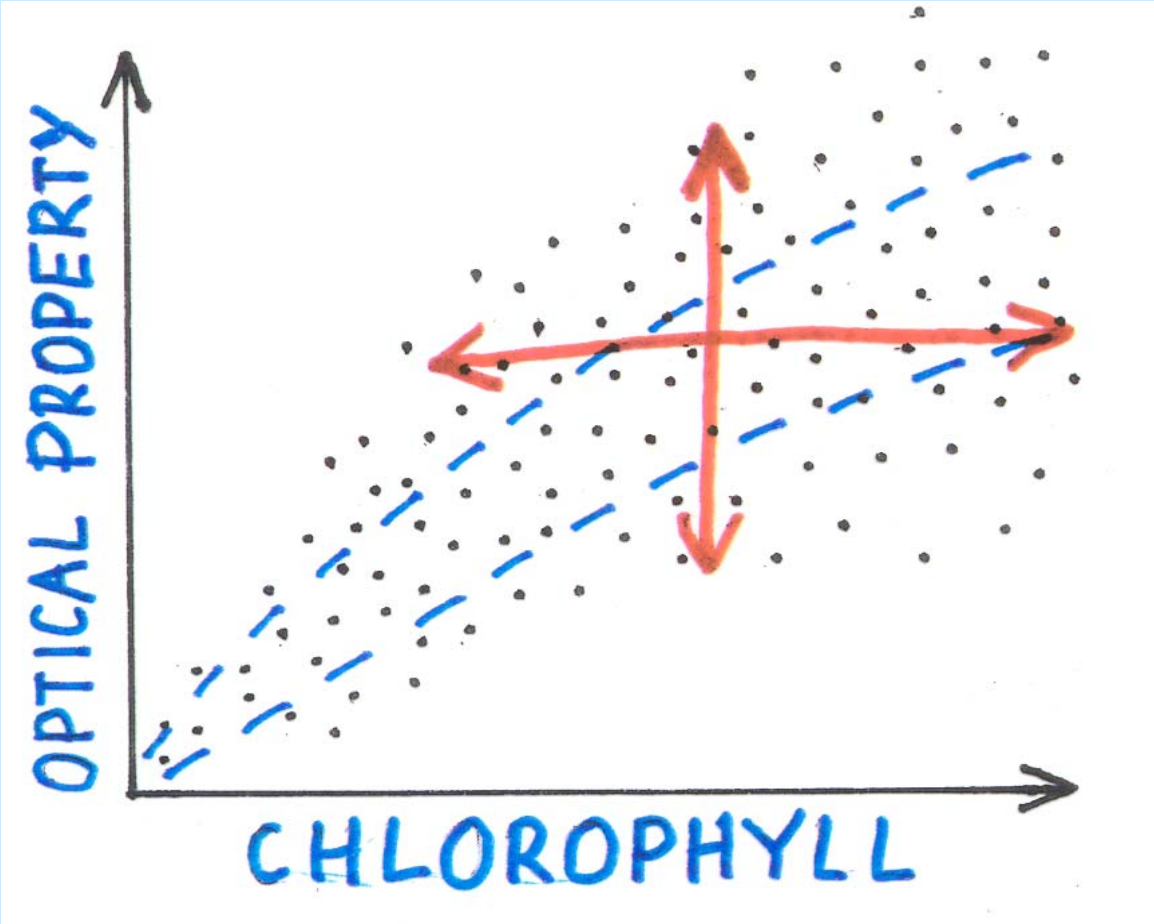
$$IOP_p(\lambda) = IOP_{ph}(\lambda) + IOP_d(\lambda)$$

$$IOP_{d+CDOM}(\lambda) = IOP_d(\lambda) + IOP_{CDOM}(\lambda)$$

$$IOP_{ph}(\lambda) = f\,[\,Chl\,]$$

$$IOP_p(\lambda) = f\,[\,Chl\,]$$

$$IOP(\lambda) = IOP_w(\lambda) + f\,[\,Chl\,]$$



- Average trends
- Large, seemingly random, variability

REDUCTIONIST APPROACH

$$IOP_{\mathrm{p}}(\lambda) = \sum_{k} IOP_{k,\,pla}(\lambda) \quad \text{plankton}$$

$$+ \sum_{m} IOP_{m,\,min}(\lambda) \quad \text{minerals}$$

$$+ \sum_{n} IOP_{n,\,det}(\lambda) \quad \text{detritus}$$

$$+ \sum_{j} IOP_{j,\,bub}(\lambda) \quad \text{bubbles}$$

EXAMPLE PLANKTONIC COMPONENTS

viruses, heterotrophic bacteria, prokaryotic and eukaryotic picophytoplankton, small and larger nanophytoplankton and microphytoplankton, microzooplankton (different taxa).

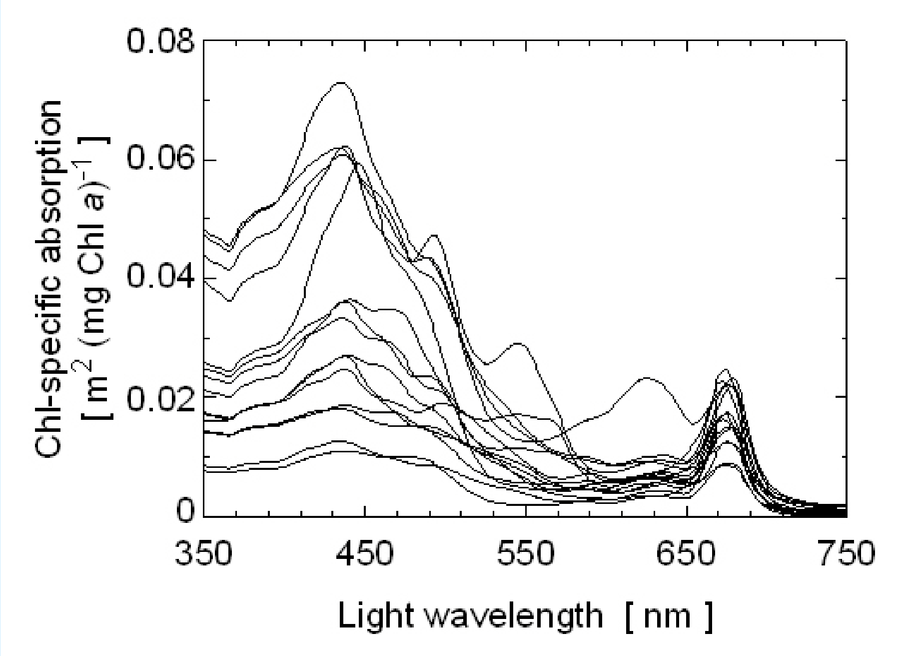
EXAMPLE CRITERIA

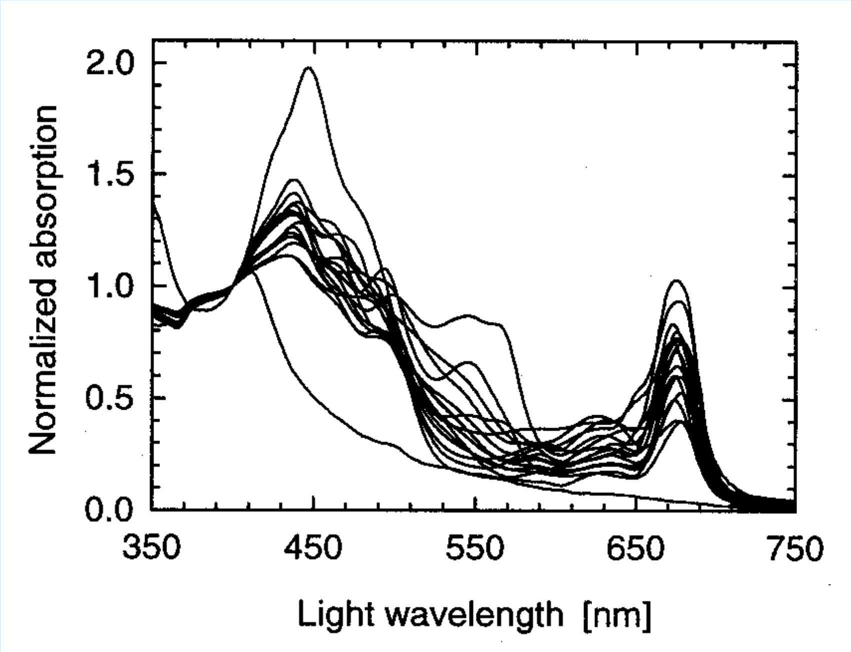
- Manageable number of components
- The sum of components should account for the total bulk *IOPs* as accurately as possible
- The components should play a specific well-defined role in marine biogeochemistry

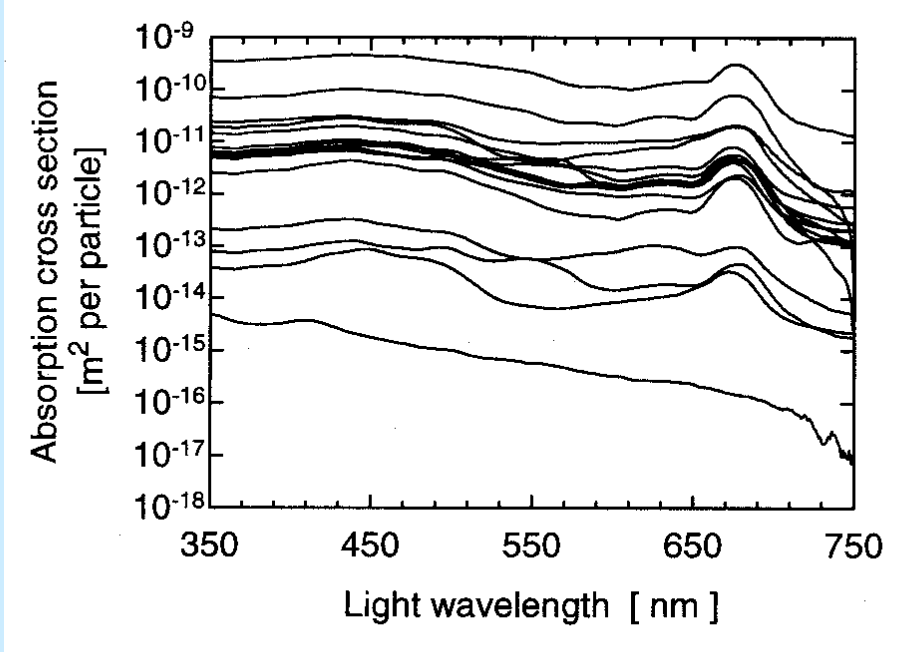
Label	Planktonic Component	D (μm)	n 550 nm	$n' \times 10^3$ 440 nm	$n' \times 10^3$ 675 nm	$\mathrm{Chl}_{\mathrm{cell}}$ (pg)
VIRU	Viruses	0.07	1.050	0	0	0
HBAC	Heterotrophic bacteria	0.55	1.055	0.509	0.057	0
PROC	Generic *Prochlorophyte*; the average of	0.66	1.051	18.51	10.30	1.466×10^{-3}
	Prochlorococcus strain MED	0.59	1.055	23.25	13.77	1.433×10^{-3}
	average of *Prochlorococcus* strains NATL and SARG	0.70	1.046	13.78	6.687	1.499×10^{-3}
SYNE	Generic *Synechococcus*; the average of:	1.05	1.051	5.587	2.930	2.015×10^{-3}
	Synechococcus strain MAX41 (*Cyanophyceae*)	0.92	1.047	5.415	2.905	1.173×10^{-3}
	Synechococcus strain MAX01 (*Cyanophyceae*)	0.94	1.049	4.505	2.547	1.521×10^{-3}
	Synechococcus strain ROS04 (*Cyanophyceae*)	1.08	1.049	4.516	2.154	1.260×10^{-3}
	Synechococcus strain DC2 (*Cyanophceae*)	1.14	1.050	4.249	2.375	1.495×10^{-3}
	Synechococcus strain WH8103 (*Cyanophyceae*)	1.14	1.062	9.251	4.668	4.626×10^{-3}
SYMA	Generic phycocyanin-rich picophytoplankton; the average of	1.41	1.055	6.495	2.757	4.497×10^{-3}
	Synechocystis (*Cyanophyceae*)	1.39	1.050	4.530	1.910	3.644×10^{-3}
	Anacystis marina (*Cyanophyceae*)	1.43	1.060	8.460	3.603	5.350×10^{-3}
PING	*Pavlova pinguis* (*Haptophyceae*)	3.97	1.046	4.177	2.709	1.198×10^{-1}
PSEU	*Thalassiosira pseudonana* (*Bacillariophyceae*)	3.99	1.045	9.231	7.397	3.091×10^{-1}
LUTH	*Pavlova lutheri* (*Haptophyceae*)	4.26	1.045	5.767	2.403	1.082×10^{-1}
GALB	*Isochrysis galbana* (*Haptophyceae*)	4.45	1.056	7.673	5.101	3.210×10^{-1}
HUXL	*Emiliania huxleyi* (*Haptophyceae*)	4.93	1.050	5.012	2.950	2.397×10^{-1}
CRUE	*Porphyridium cruentum* (*Rhodophyceae*)	5.22	1.051	3.351	2.443	2.861×10^{-1}
FRAG	*Chroomonas fragarioides* (*Cryptophyceae*)	5.57	1.039	4.275	2.904	3.294×10^{-1}
PARV	*Prymnesium parvum* (*Haptophyceae*)	6.41	1.045	2.158	1.329	2.889×10^{-1}
BIOC	*Dunaliella bioculata* (*Chlorophyceae*)	6.71	1.038	10.49	7.839	2.270
TERT	*Dunaliella tertiolecta* (*Chlorophyceae*)	7.59	1.063	6.260	5.076	1.705
CURV	*Chaetoceros curvisetum* (*Bacillariophyceae*)	7.73	1.024	2.877	1.480	3.314×10^{-1}
ELON	*Hymenomonas elongata* (*Haptophyceae*)	11.77	1.046	13.87	7.591	9.384
MICA	*Prorocentrum micans* (*Dinophyceae*)	27.64	1.045	2.466	1.710	25.38

Stramski et al. (2001)

Interspecies variability in absorption







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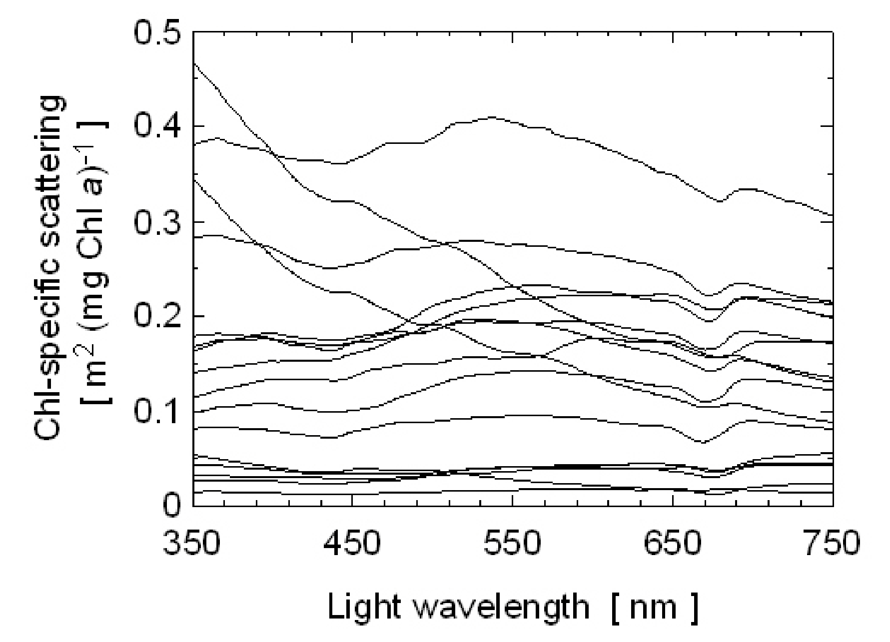
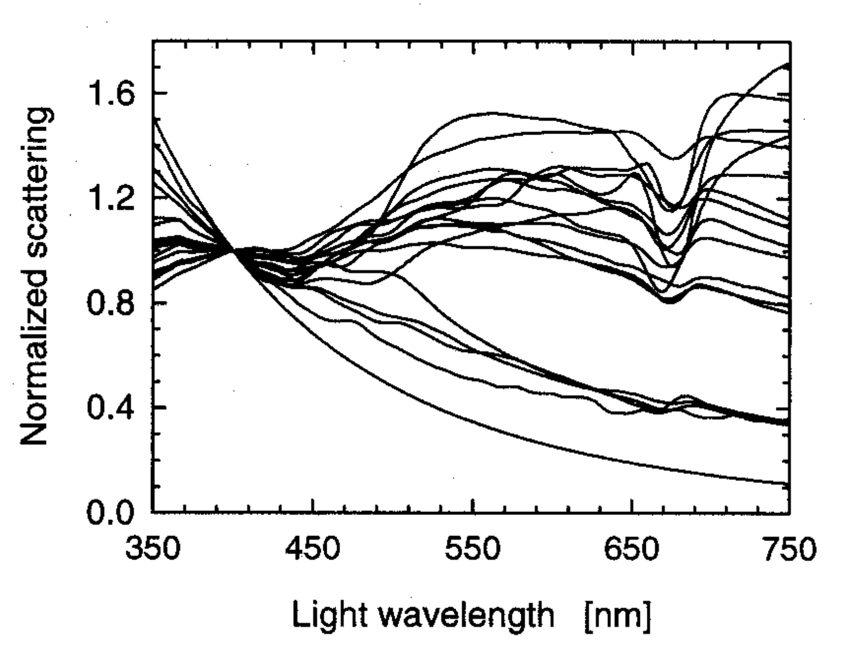
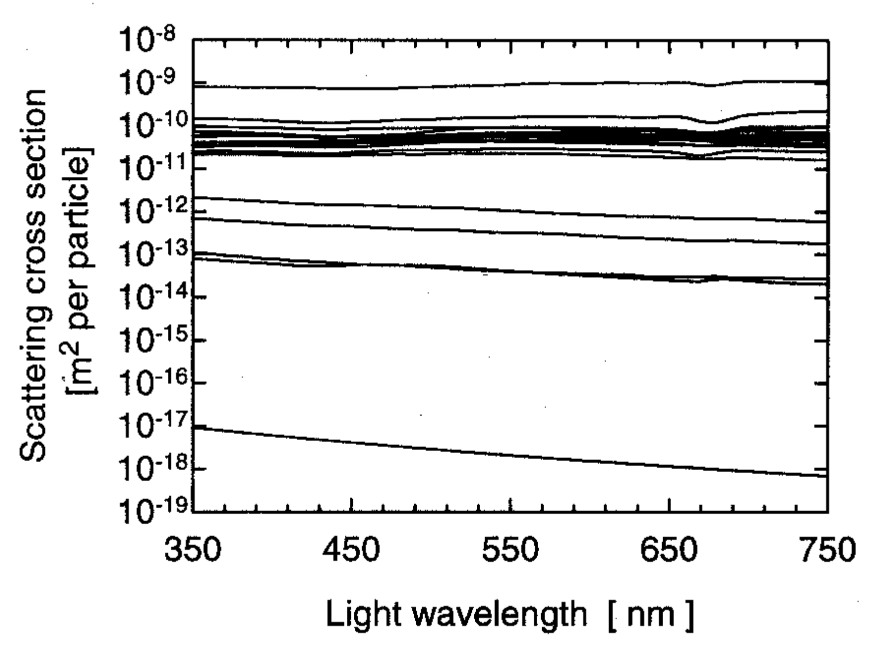
Stramski et al. (2001)

Interspecies variability in scattering







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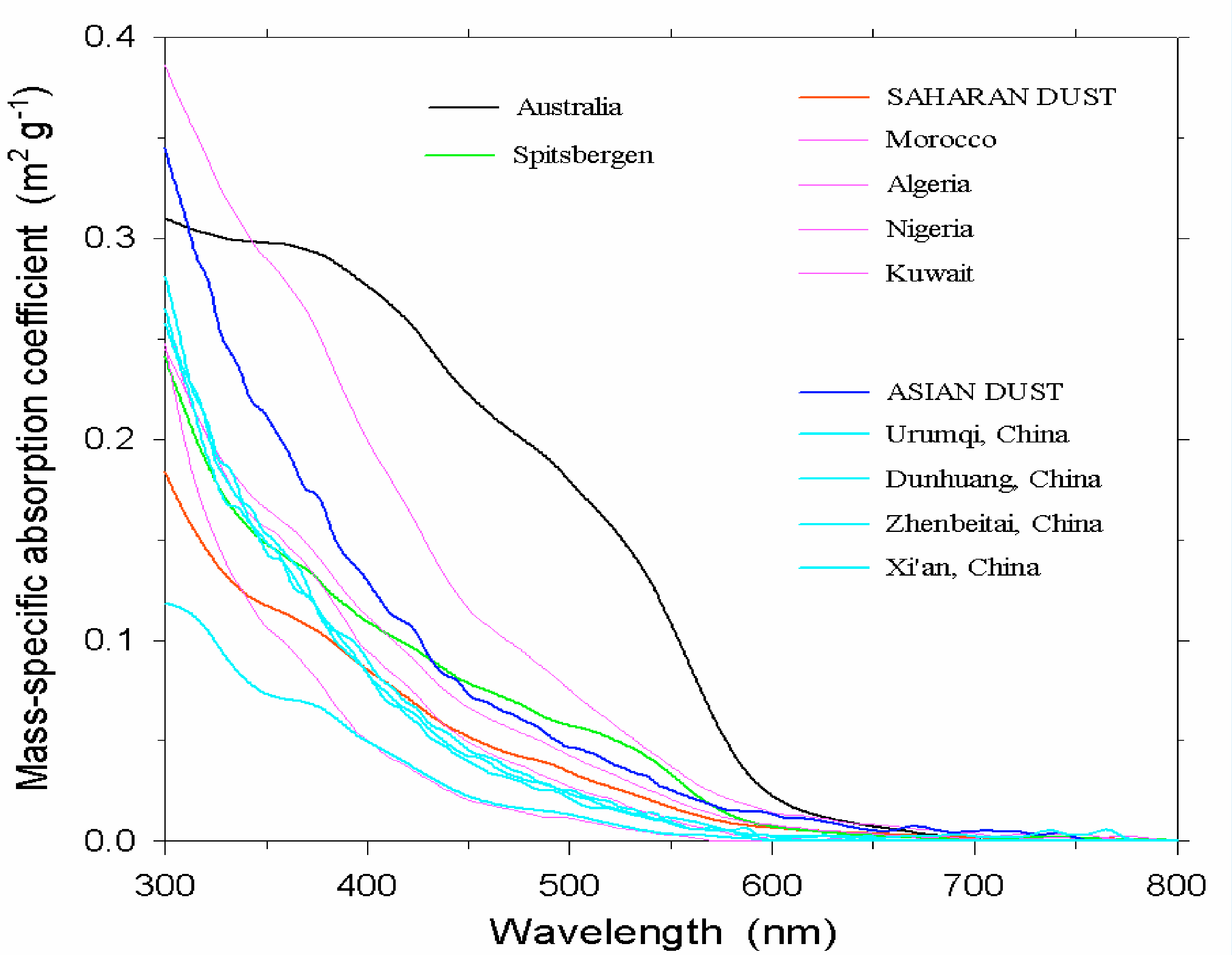
Stramski et al. (2001)

Absorption of mineral particles



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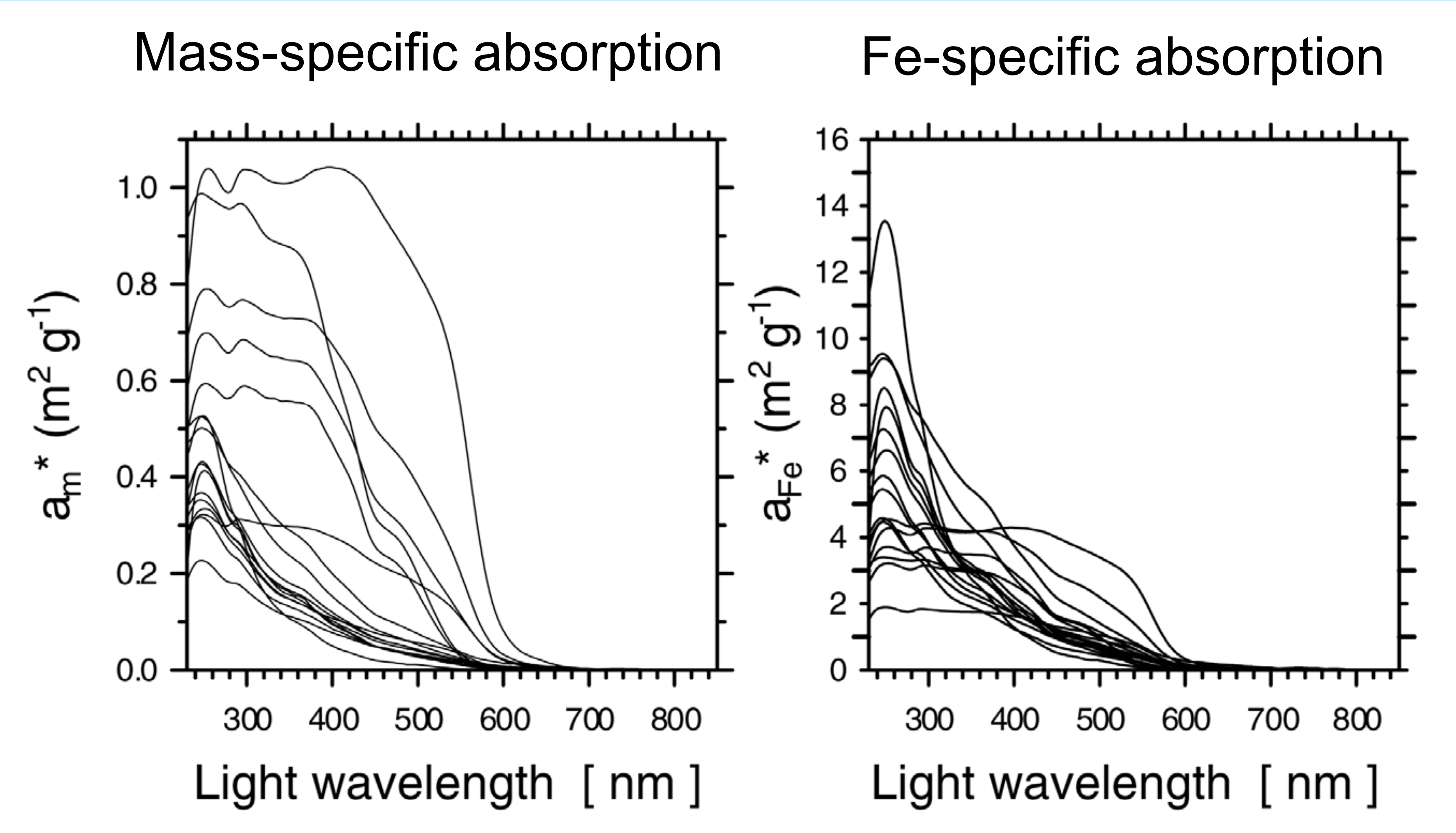
Babin and Stramski, 2004; Stramski et al., 2004



Babin and Stramski, 2004

Reductionist approach requires a very broad suite of measurements/analyses

- Optical measurements
  include $\beta(\psi, \lambda)$; target specific water constituents
- Particle identification and characterization
  particle species composition, size distribution, particle chemistry, biology, mineralogy, etc.
- DOM characterization
- Laboratory experiments
- Techniques and instrumentation

The complexity of seawater as an optical medium should not deter us from pursuing the proper course in future research.

"The reductionist worldview has to be accepted as it is, not because we like it, but because that is the way the world works"

Steven Weinberg

1979 Nobel Prize in Physics