# The global view of marine phytoplankton from ocean colour satellites

**Nick Hardman-Mountford, Takafumi Hirata, Robert Brewin and Jim Aiken**

**nick.hardman-mountford@csiro.au**

PML PLYMOUTH MARINE LABORATORY

CSIRO

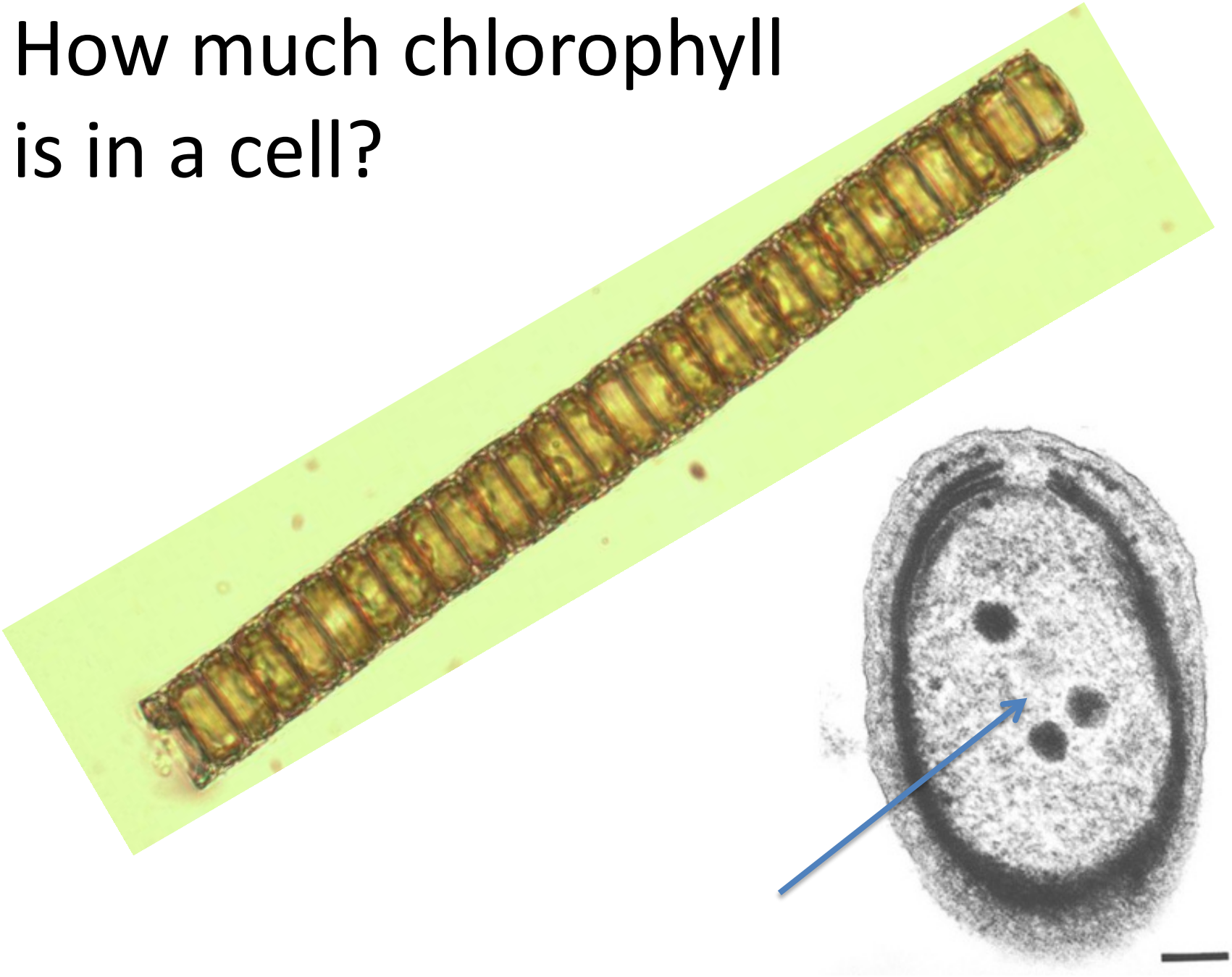
HOKKAIDO UNIVERSITY

# How can we detect phytoplankton community structure from satellites?

1. Spectral approaches
   - Exploiting influence of different pigments associated with different taxonomic groups on spectral shape
   - Brewin *et al.* (2010) *Oceanol. Acta Sin.*
2. Abundance-based approaches
   - Exploiting relationship between Chlorophyll (Chl) concentration or magnitude of absorption and size class/functional type
   - Aiken *et al.* (2007) *IJRS*; Hirata *et al.* (2008) *Rem Sens. Env.*; Brewin *et al.* (2010) *Ecol. Mod.;* Hirata *et al.* (2011) *Biogeosci.*
3. Optical scattering approaches
   - Exploiting relationship between optical scattering and particle size distribution
   - Hirata *et al.* (2009) *Appl. Optics*; Dall'Olmo *et al.* (2011) *Biogeosciences*; Brewin *et al.* (2012) Optics Express; Hirata *et al.* (in rev.) *Rem. Sens. Env.*

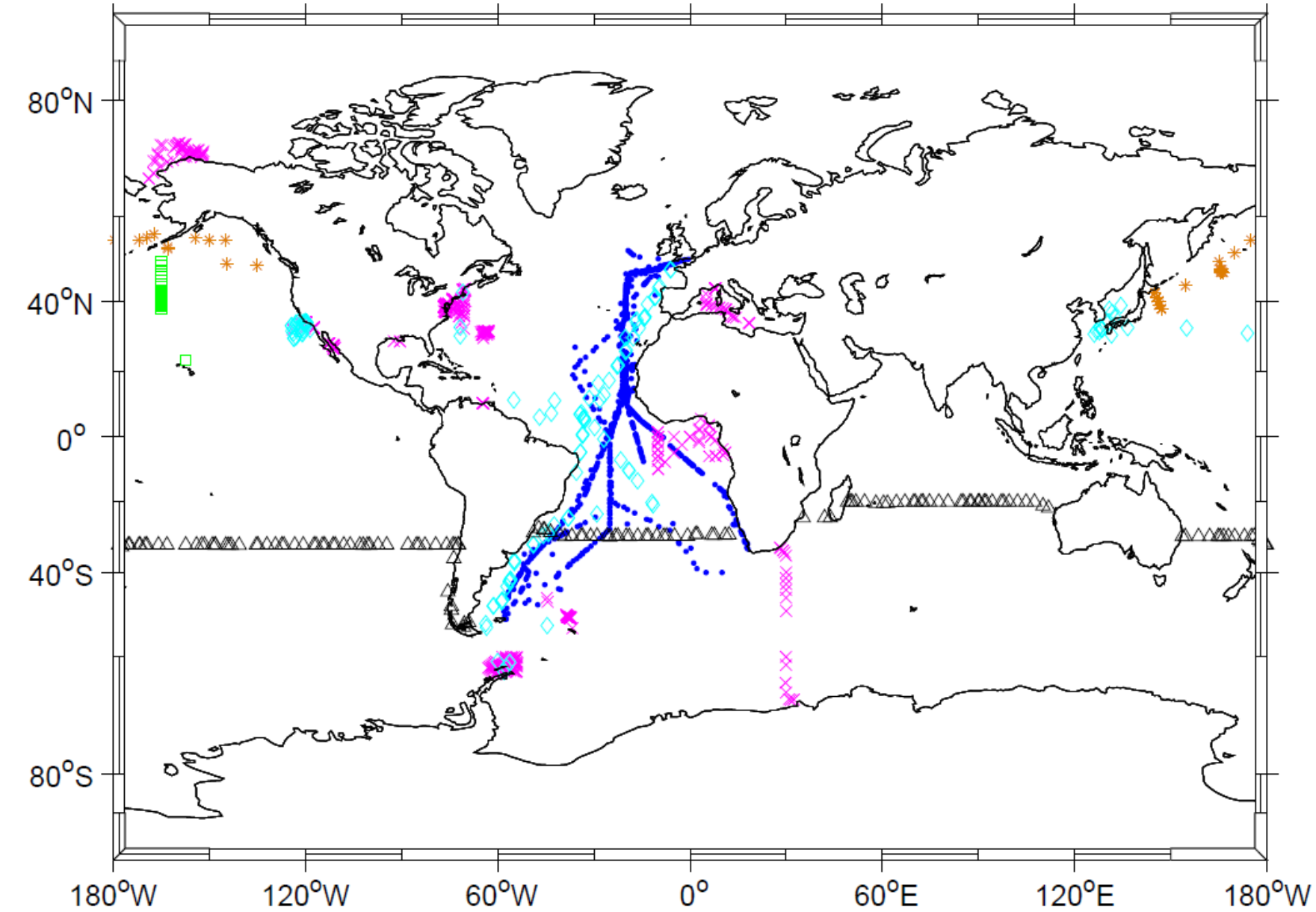
*Further reading: IOCCG 2014. Phytoplankton Functional Types from Space.*

# How much chlorophyll is in a cell?

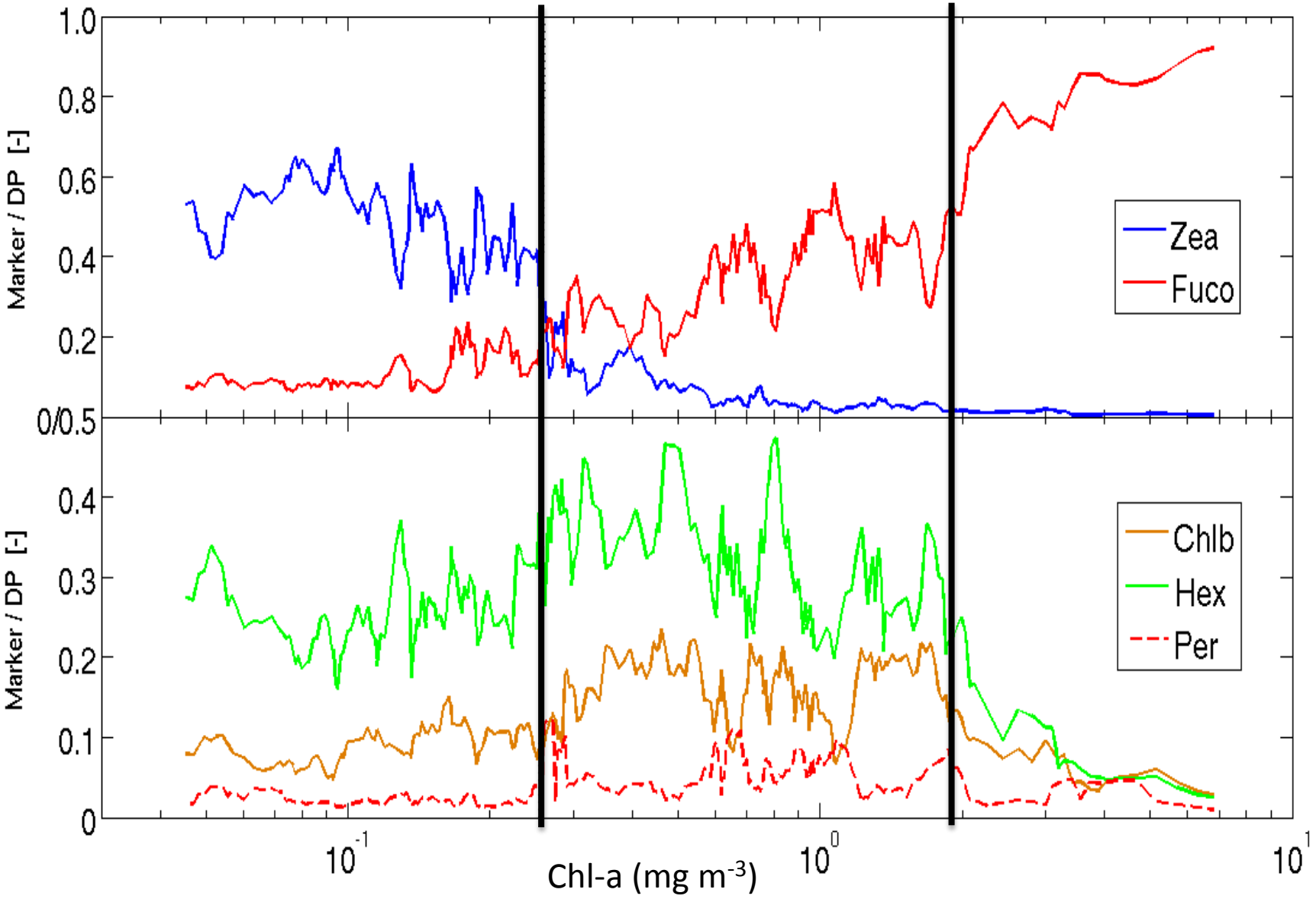


# Q: WHAT CONTRIBUTION DO DIFFERENT TYPES OF PHYTOPLANKTON MAKE TO THE TOTAL CHLOROPHYLL CONCENTRATION?

# Global analysis requires lots of *in situ* data …



# Size class dominance




Hirata *et al.*, 2008 *Rem. Sens. Env.*

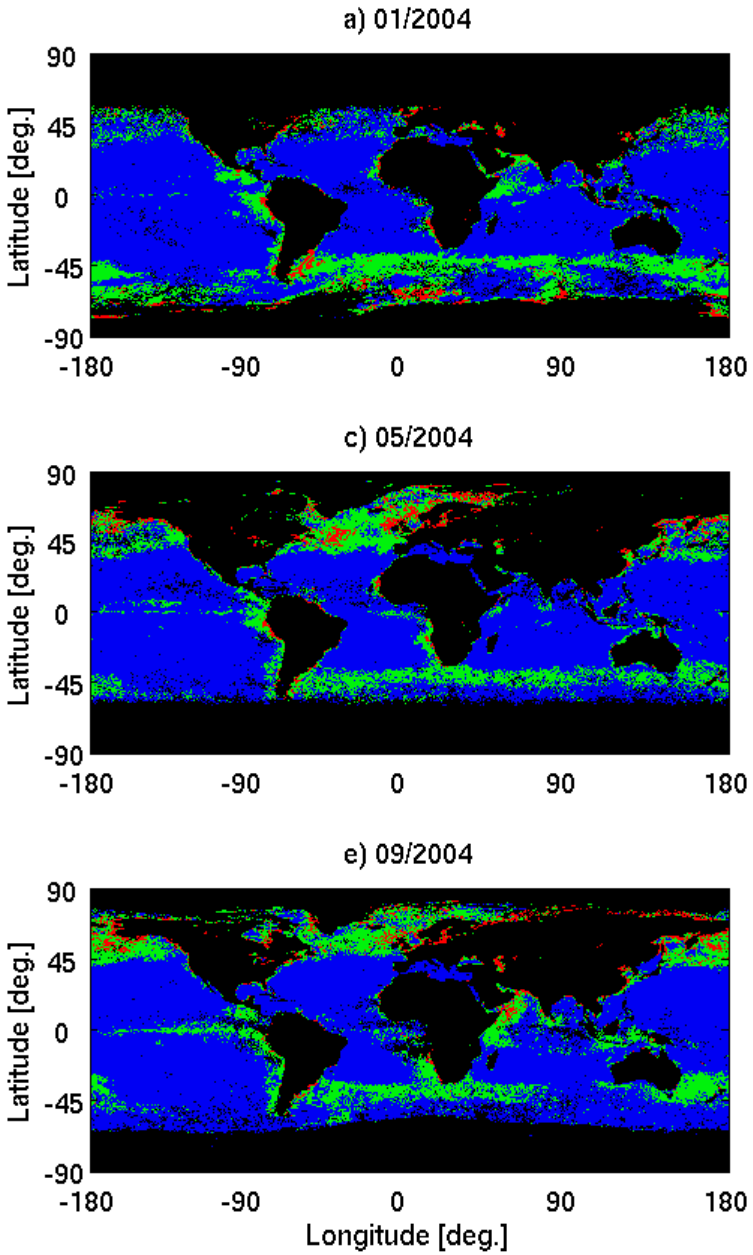
# Size class dominance

2004

Jan

May

Sep




**Dominant spatial coverage**

**Micro = 2 %**

**Nano = 19 %**

**Pico = 79 %**

**% Chl a**

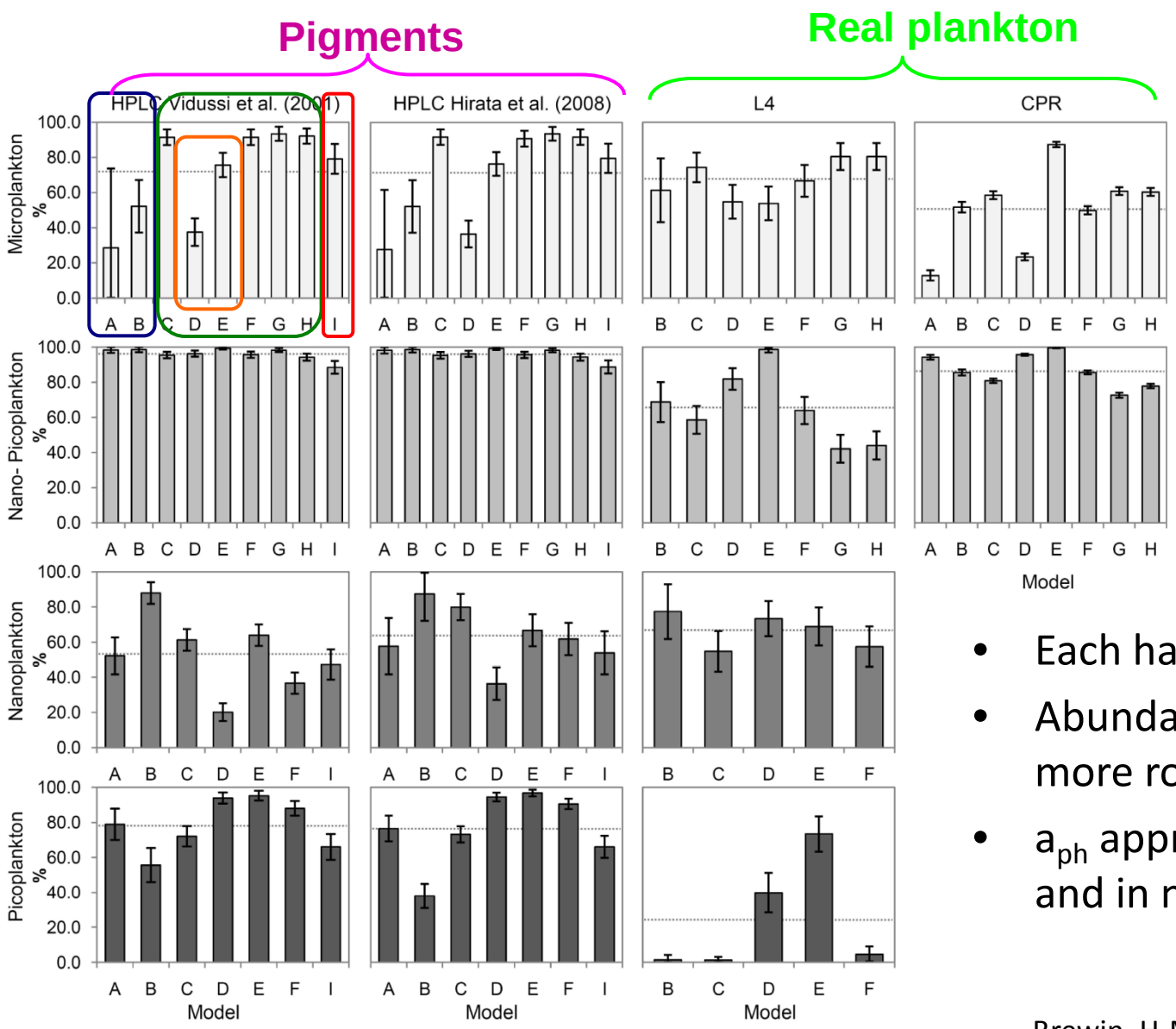
**Micro = 22 %**

**Nano = 45 %**

**Pico = 33 %**

Hirata *et al.*, 2008 *Rem. Sens. Env.*

# Intercomparison of models




**Spectral**

**Abundance**

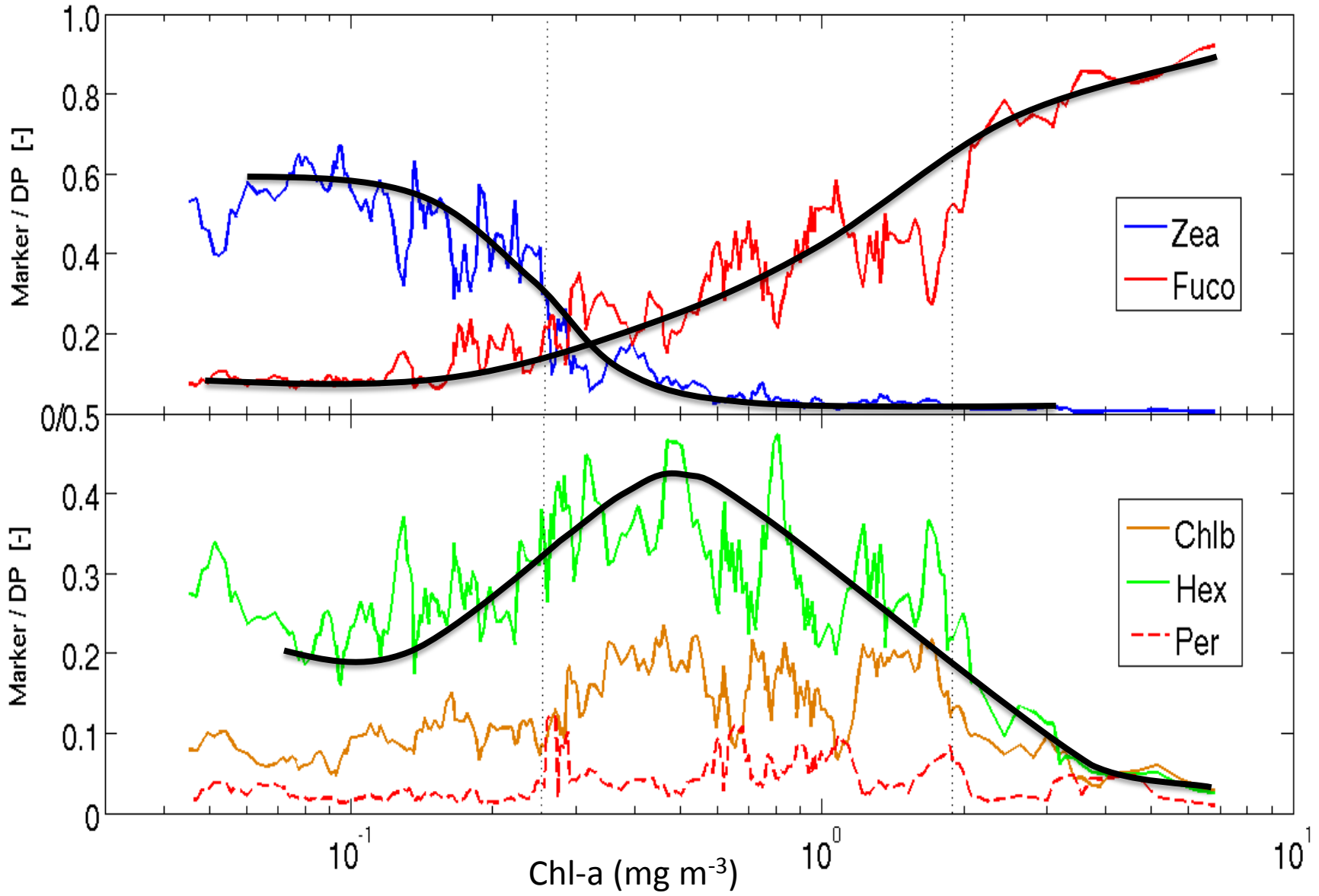
**IOP: $a_{ph}(443)$**

**Ecological (NN)**

- Each has pros & cons
- Abundance approaches are more robust
- $a_{ph}$ approaches better for pico and in near-coastal waters

Brewin, H-M *et al.* (2011) *Rem. Sens. Env.*

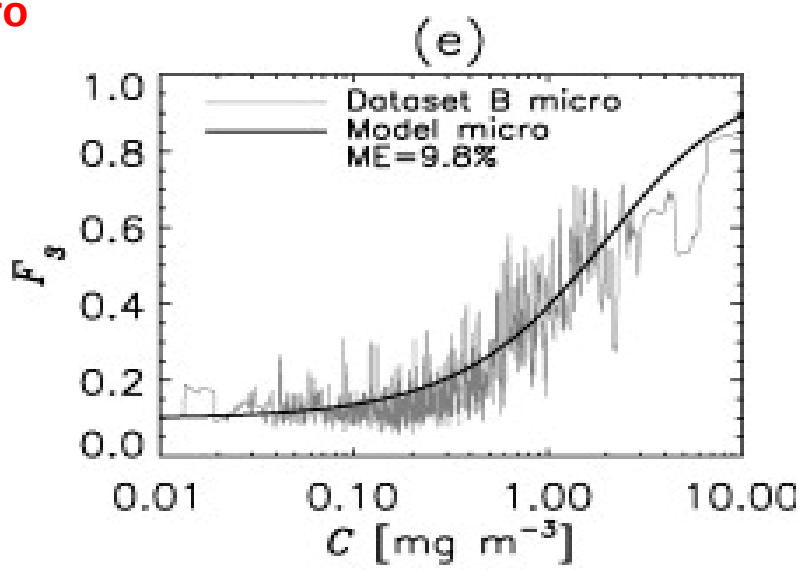
# Size class fraction



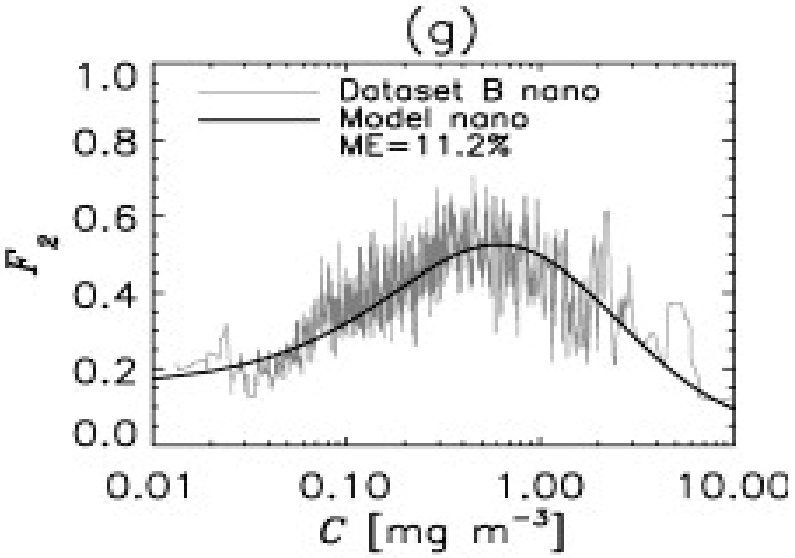

Hirata *et al.*, 2008 *Rem. Sens. Env.*

# Size class fraction: logistic model

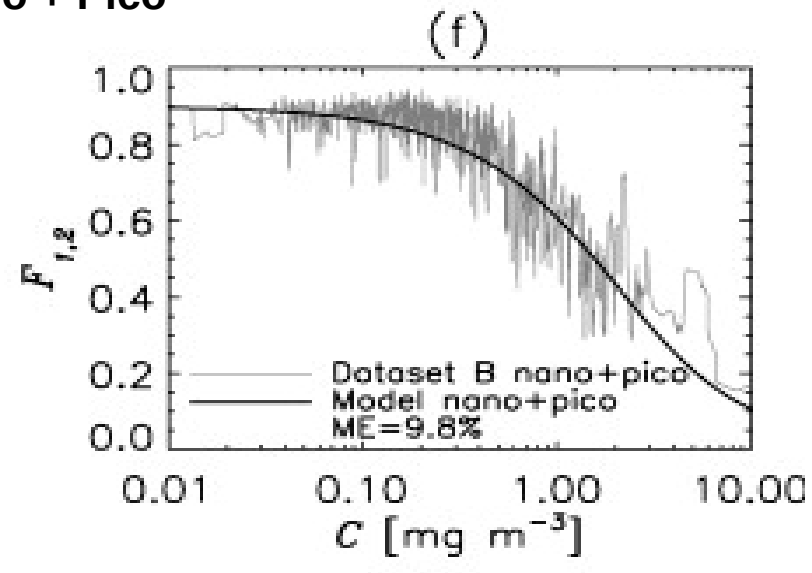
**Micro**



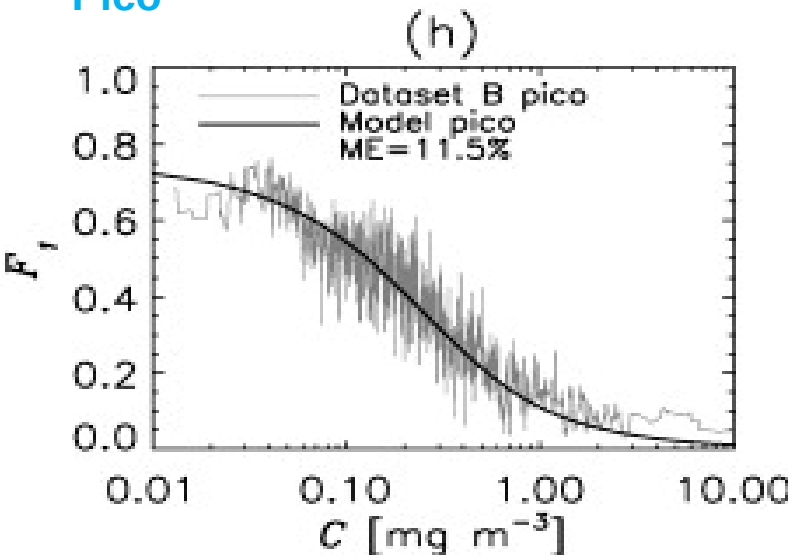

**Nano**




**Nano + Pico**

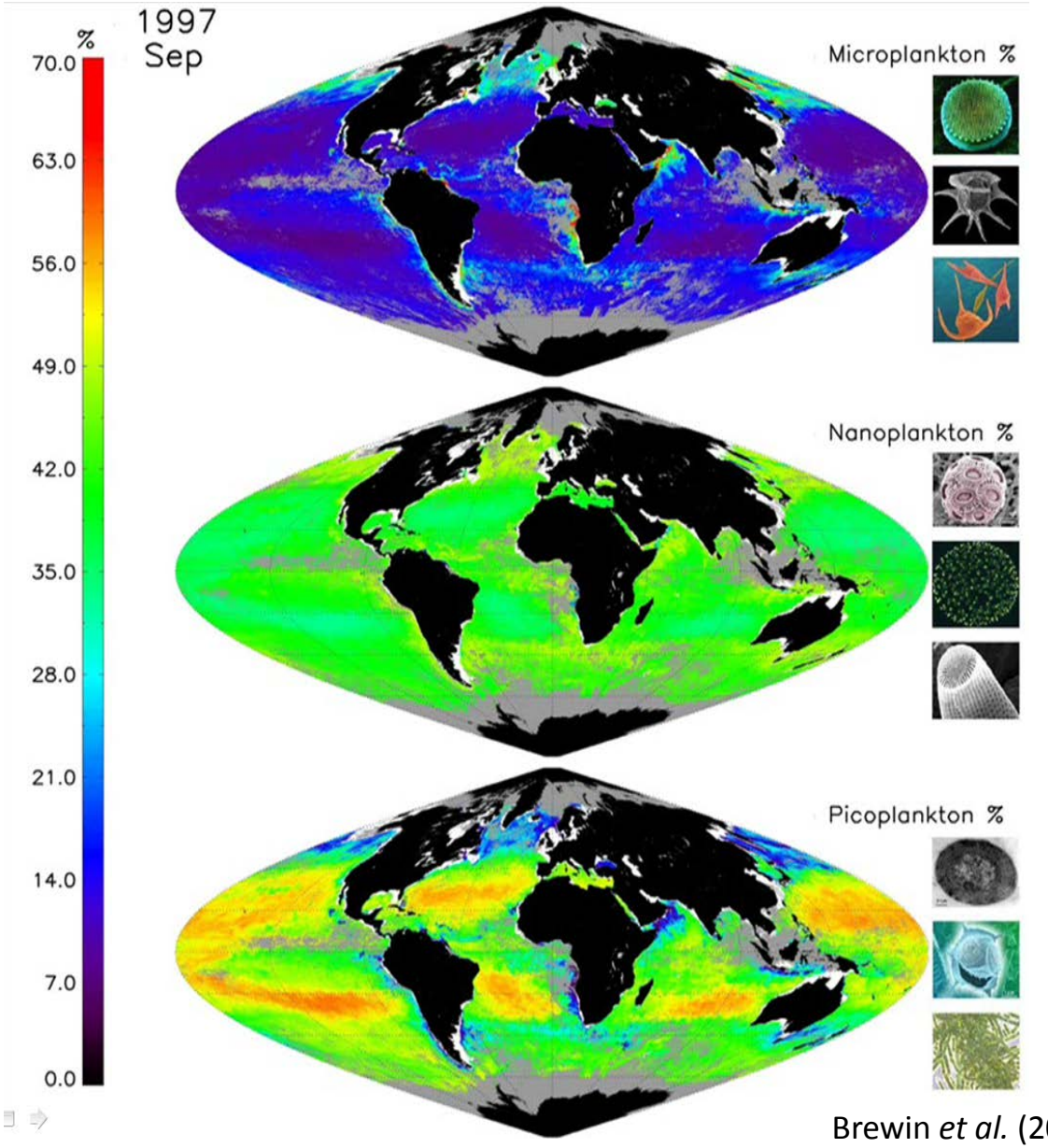



**Pico**




Brewin *et al.* (2010) *Ecol. Mod.*

# Size class fraction



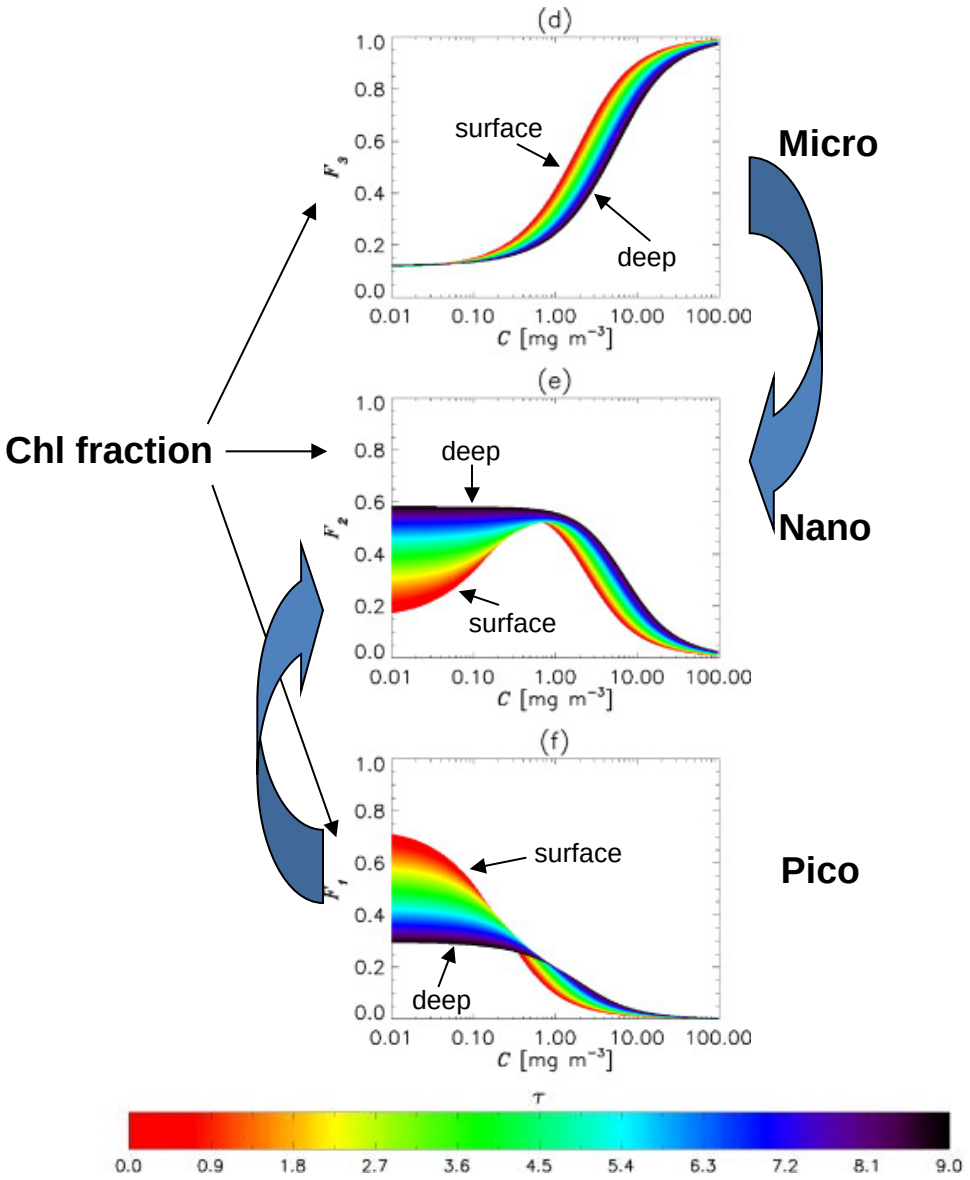

**Bigger cells (>20µm)**

**Medium cells (2-20 µm)**

**Smaller cells (<2 µm)**

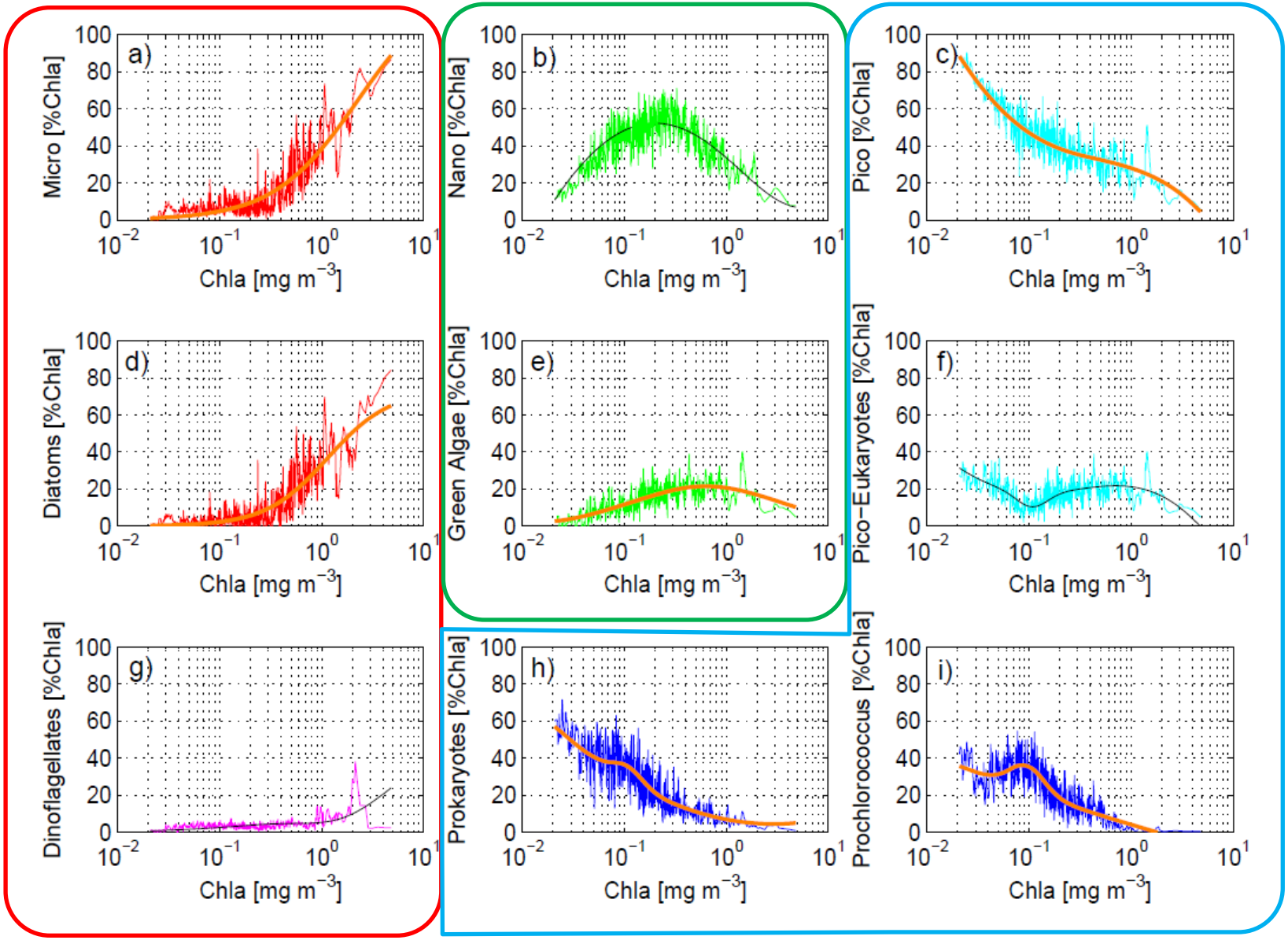
Brewin *et al.* (2010) *Ecol. Mod.*

# Effects of light-attenuation with depth



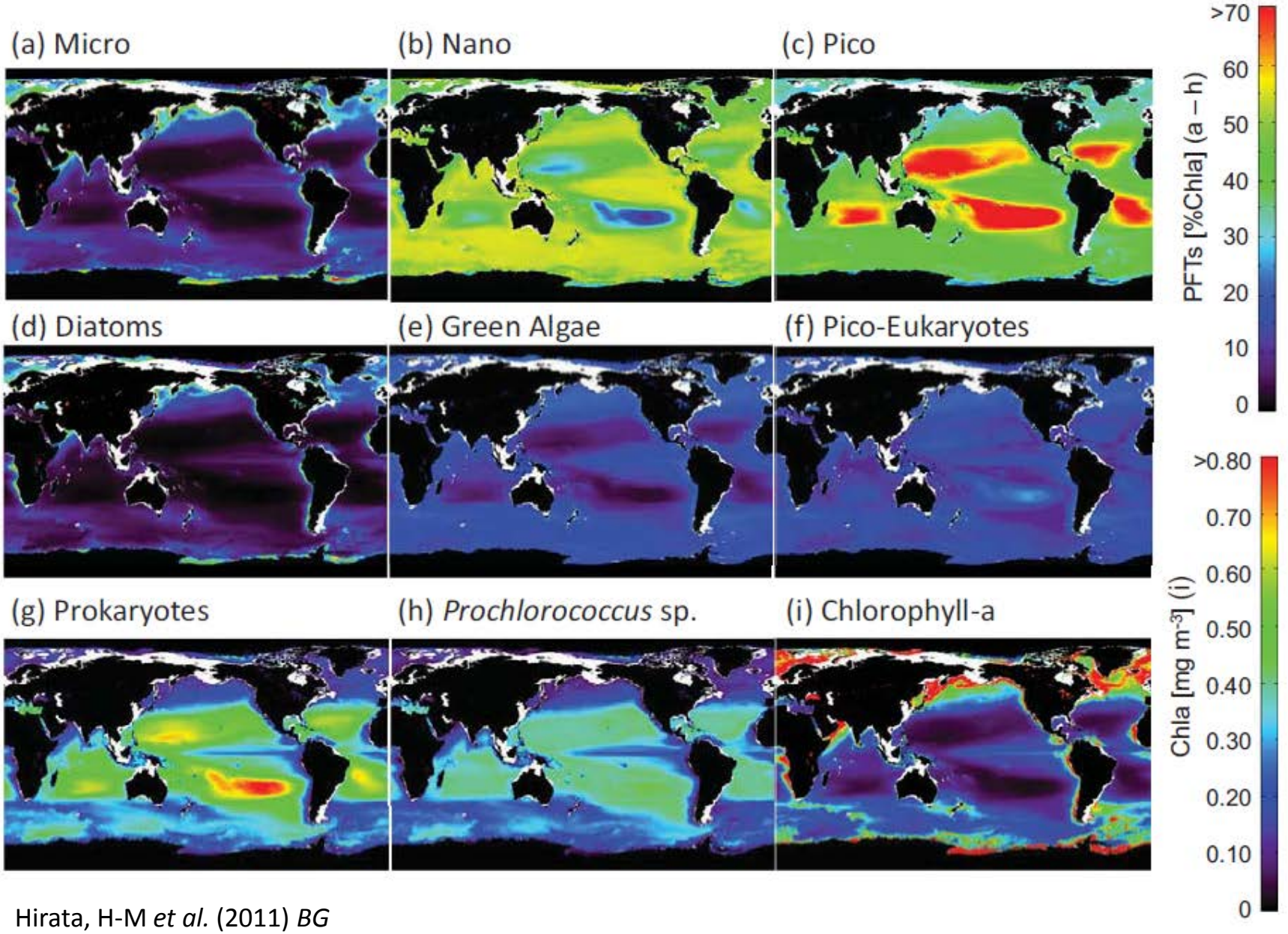

Brewin *et al.* (2010) *Ecol. Mod.*

# PFTs / Taxonomic Groups



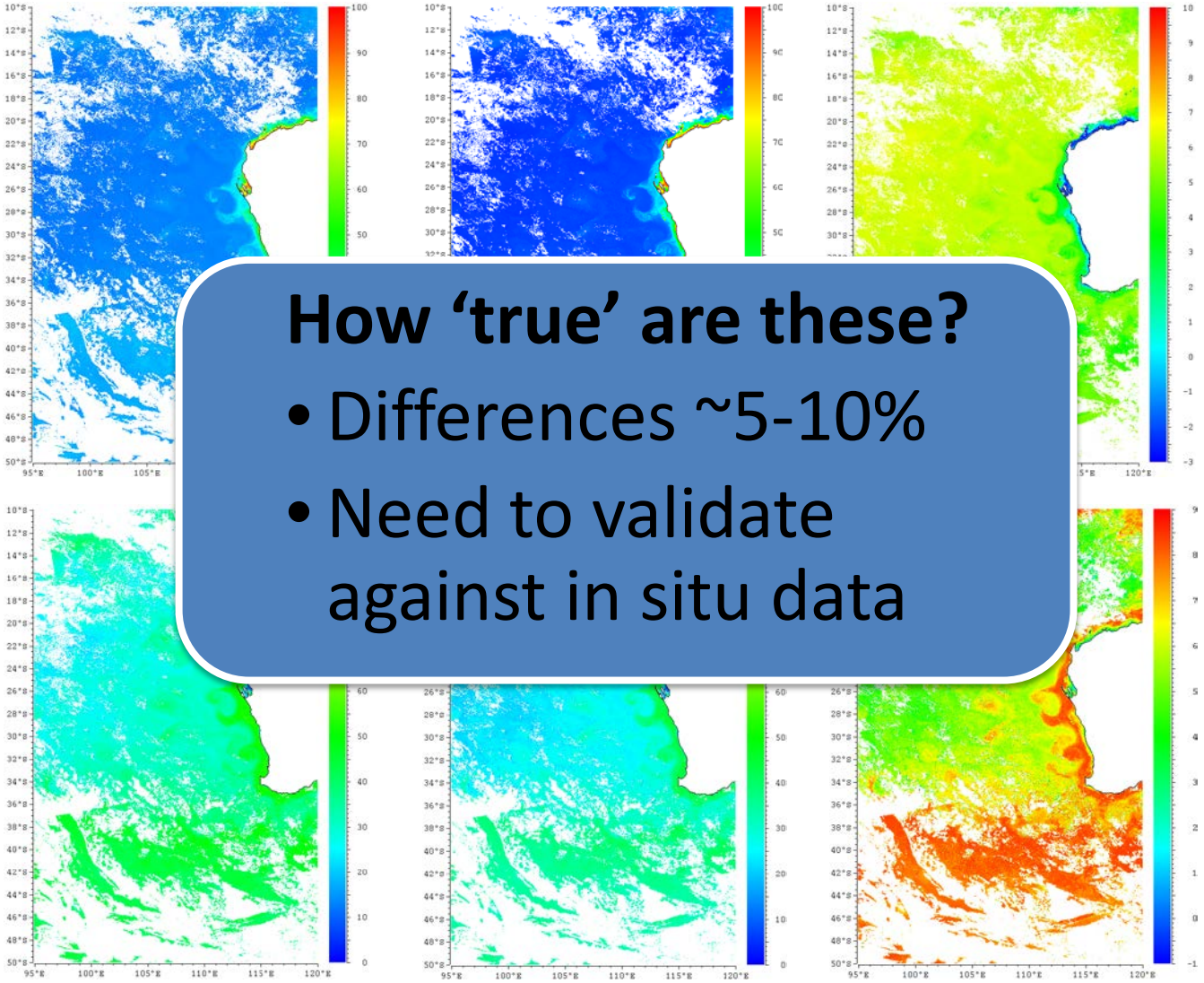

Hirata, H-M *et al.* (2011) *BG*

# Global PFT Distribution




Hirata, H-M *et al.* (2011) *BG*

# Australian phytoplankton products



**How 'true' are these?**

- Differences ~5-10%
- Need to validate against in situ data

Compare 2 parameterisations:

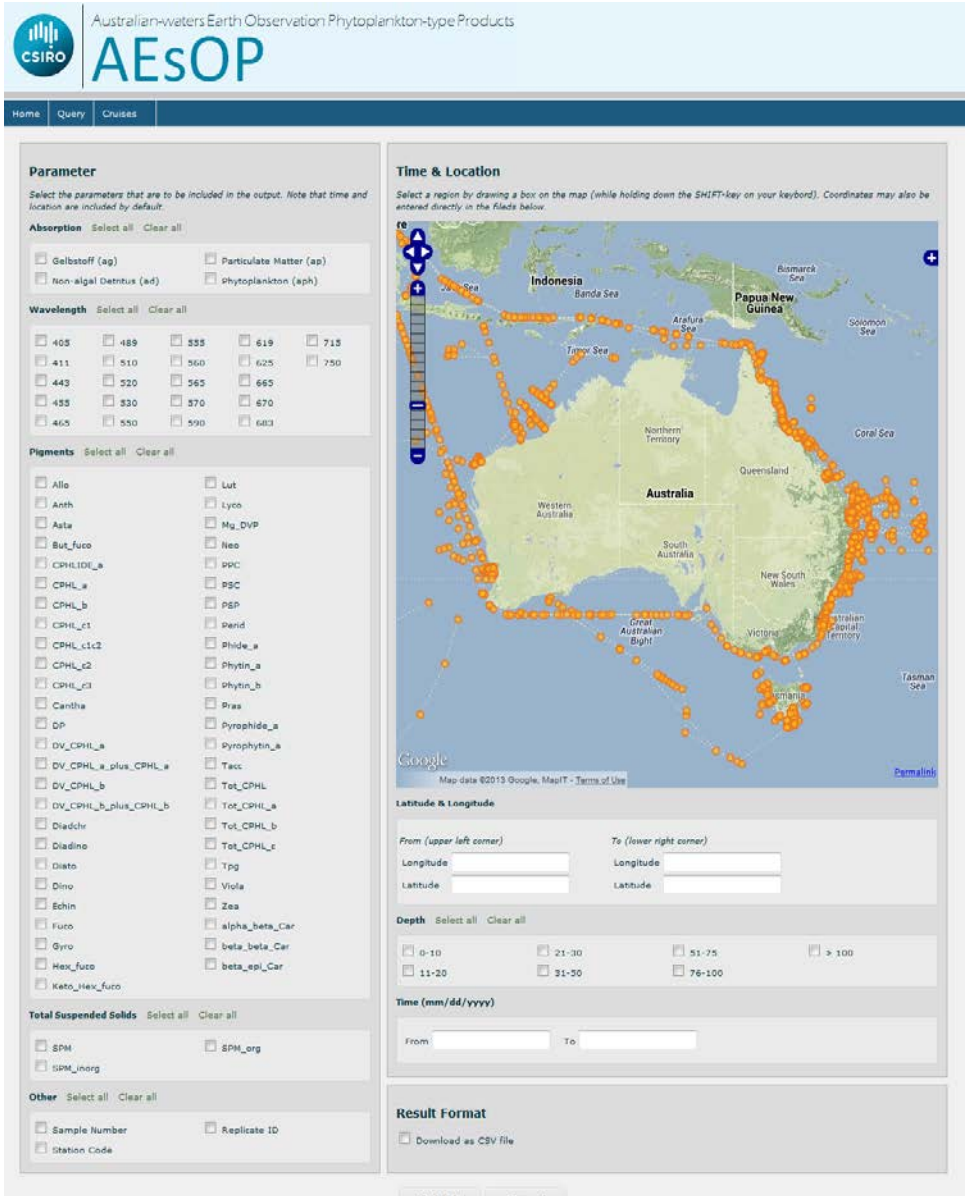
- Global (Brewin et al. 2010)
- Indian Ocean (Brewin et al. 2012)

Courtesy of Edward King

# AEsOP Database

Currently

- 4 absorption ($a_p$, $a_{ph}$, $a_d$, $a_g$)
- 51 HPLC pigments
- Spectral nLw at 22 wavelengths
- SPM (total, inorganic, organic)
- Searchable metadata
- Web hosted
- 85 field campaigns so far
- >11, 000 data points



# Backscattering-based approaches

## absorption

Optical proxy of POC

Optical proxy of DOC

$$a = a_w + \underbrace{a_{ph} + a_d} + a_{CDOM}$$

Optical proxy of M.biota

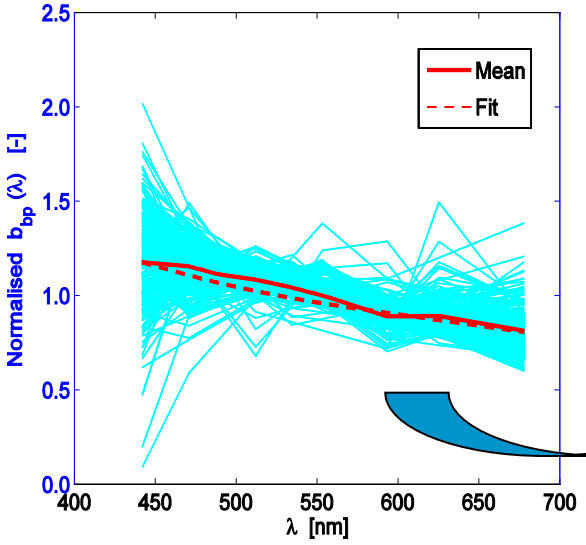
## scattering

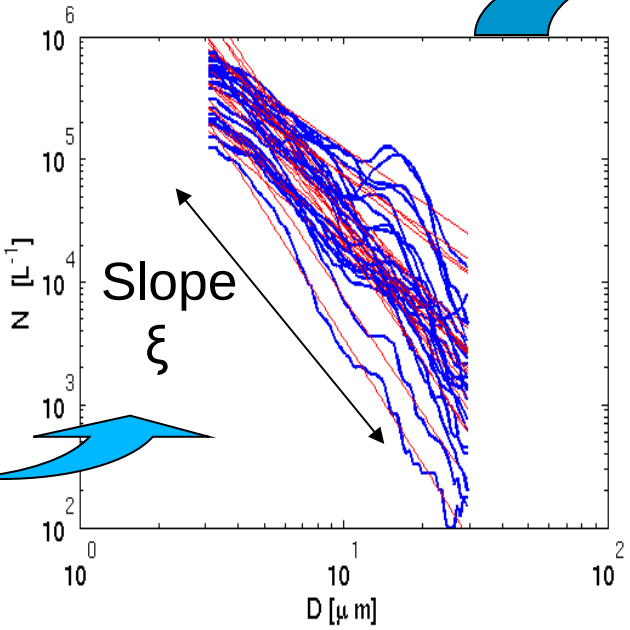
Optical proxy of POC

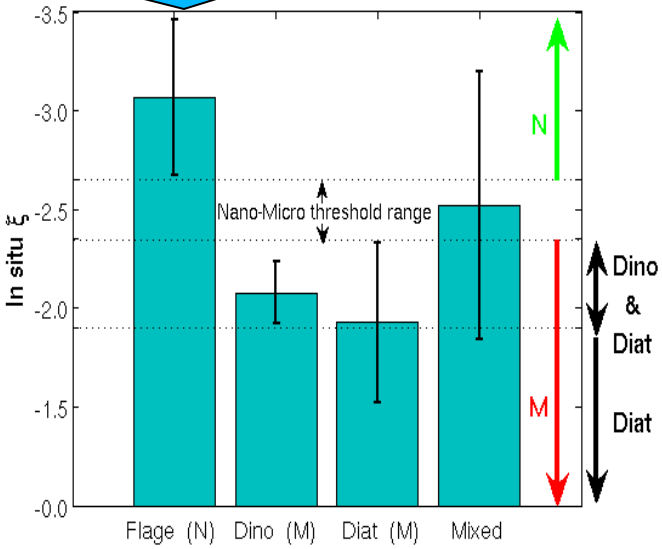
$$b = b_w + b_p$$

* Same for backscattering

Lorenz-Mie scattering theory will tell that spectral shape of scattering represents PSD which is also related to dominant phytoplankton size classes.



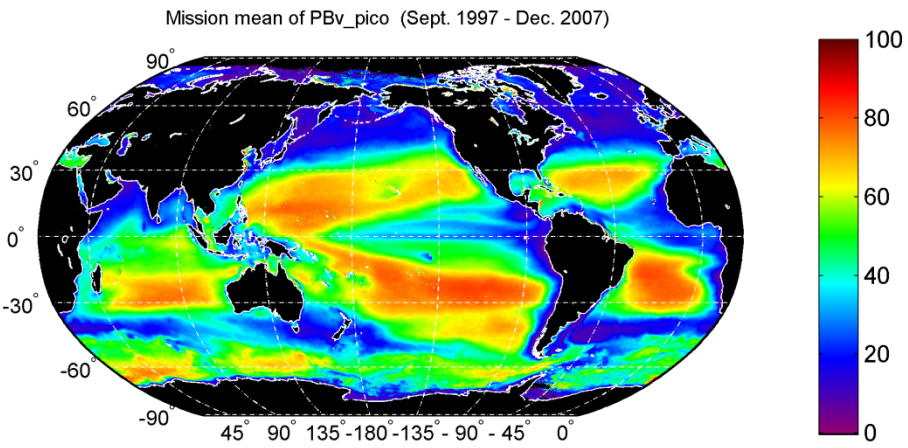



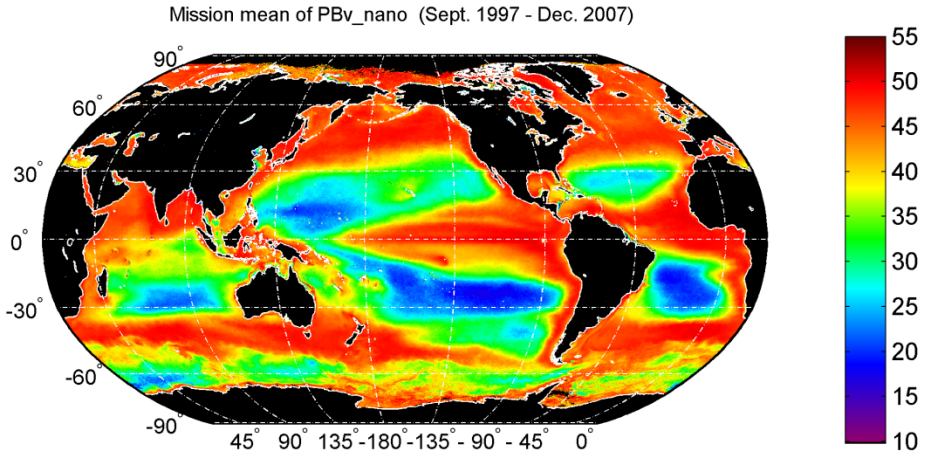

Hirata *et al.* In revision

# SeaWiFS PFT's = f(PSD slope)

## Picoplankton % (0.5 μm to 2 μm)




## Nanoplankton % (2 μm to 20 μm)

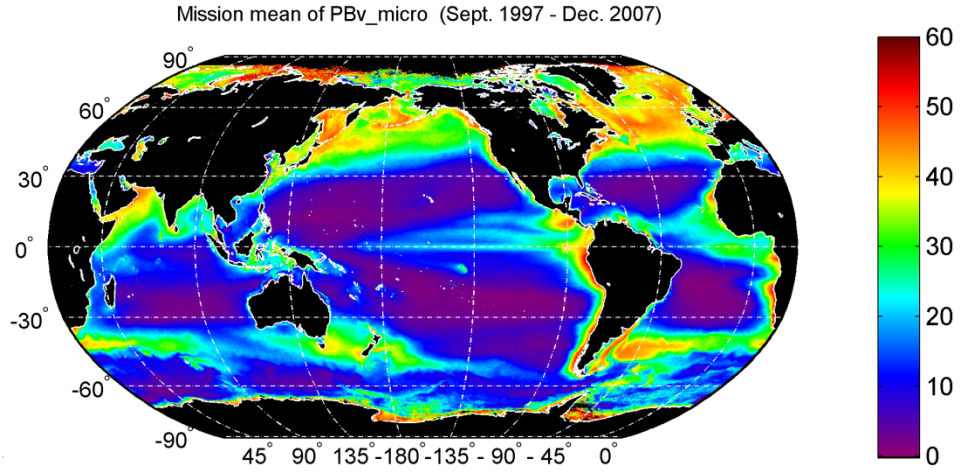



Pico's dominate oligotrophic ocean (>90%)

Nano's in transition regions (~50%)

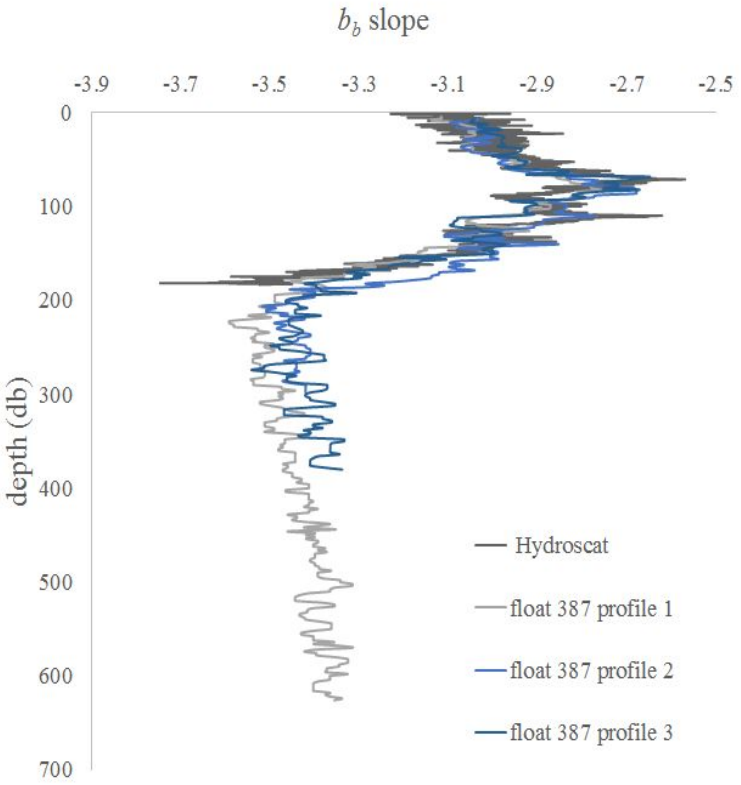
Micro's only found in upwelling zones & high latitudes (<60%)

## Microplankton % (20 μm to 50 μm)

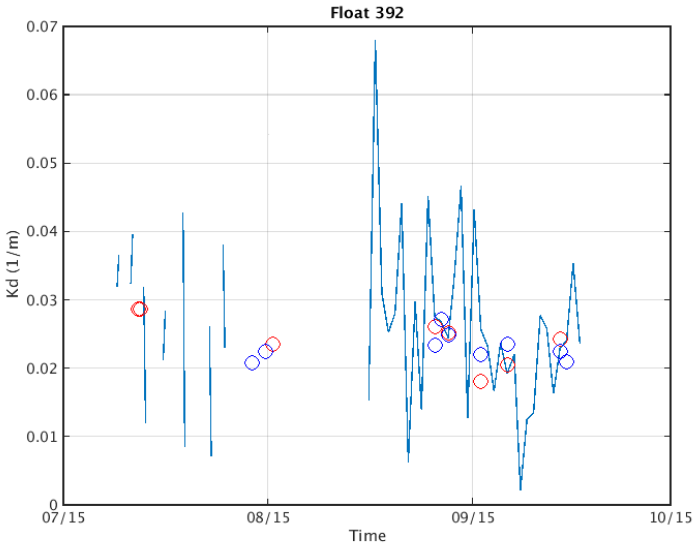


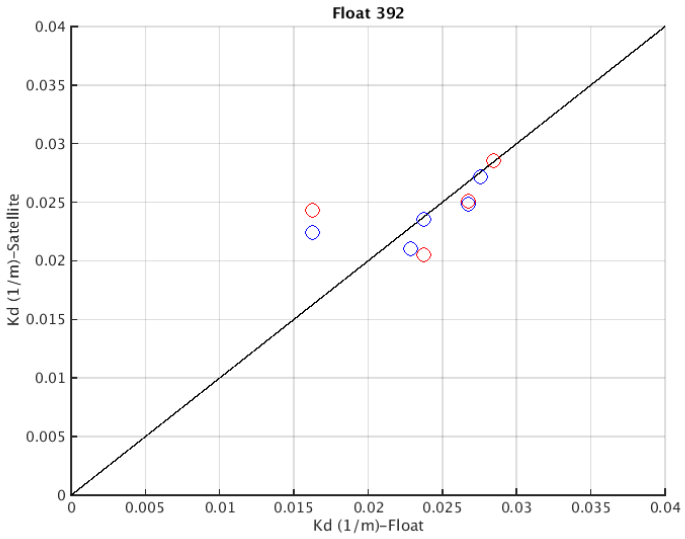

Kostadinov et al., 2009, JGR
Kostadinov et al., 2010, BG

# Backscattering slope from bioArgo




…and good radiometric match-ups!



# Conclusions

- Abundance-based size estimates – less sophisticated but more robust (for current satellites)
- Early results for Australian waters look promising
- Limiting factor globally is availability of co-located in situ data
- Bio-Argo may improve this for scattering approaches

# Acknowledgements


- UK Atlantic Meridional Transect Programme
- NASA NOMAD, SeaBASS, IMOS for in situ HPLC data
- NASA OBPG for the SeaWiFS and MODIS data record
- And all those who spent months to years at sea collecting the data required to derive these algorithms (all acknowledged in the papers)

- Funding: NERC National Centre for Earth Observation, NERC Oceans 2025, NERC MarQuest, JAXA GCOM-C algorithms, DOI AISRF BioArgo, CSIRO EOI-TCP/FSP (AEsOP, BioArgo).


JAXA Japan Aerospace Exploration Agency

National Centre for Earth Observation

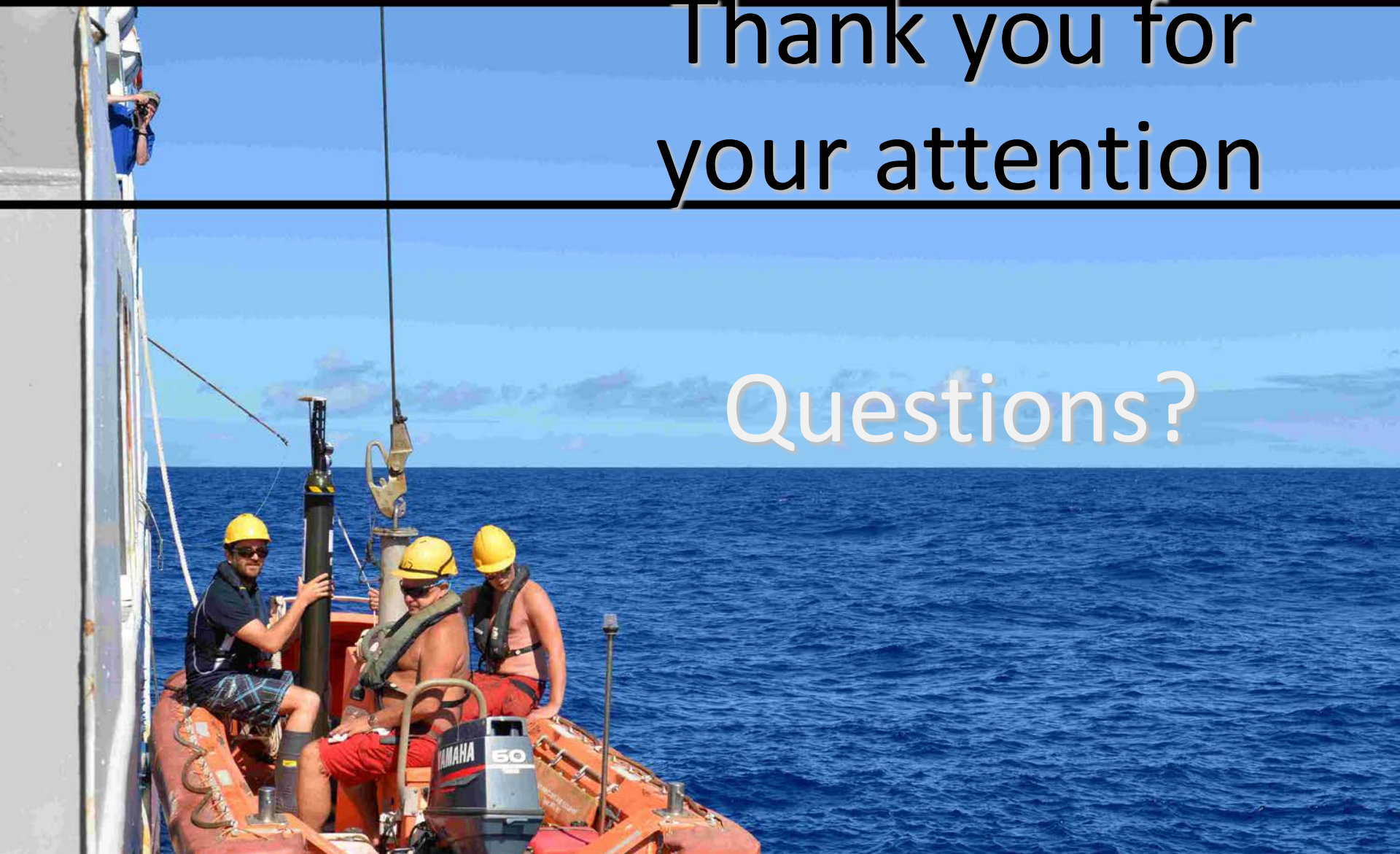
CSIRO

Australian Government Department of Industry, Innovation and Science

NATURAL ENVIRONMENT RESEARCH COUNCIL

Oceans 2025

IMOS Integrated Marine Observing System



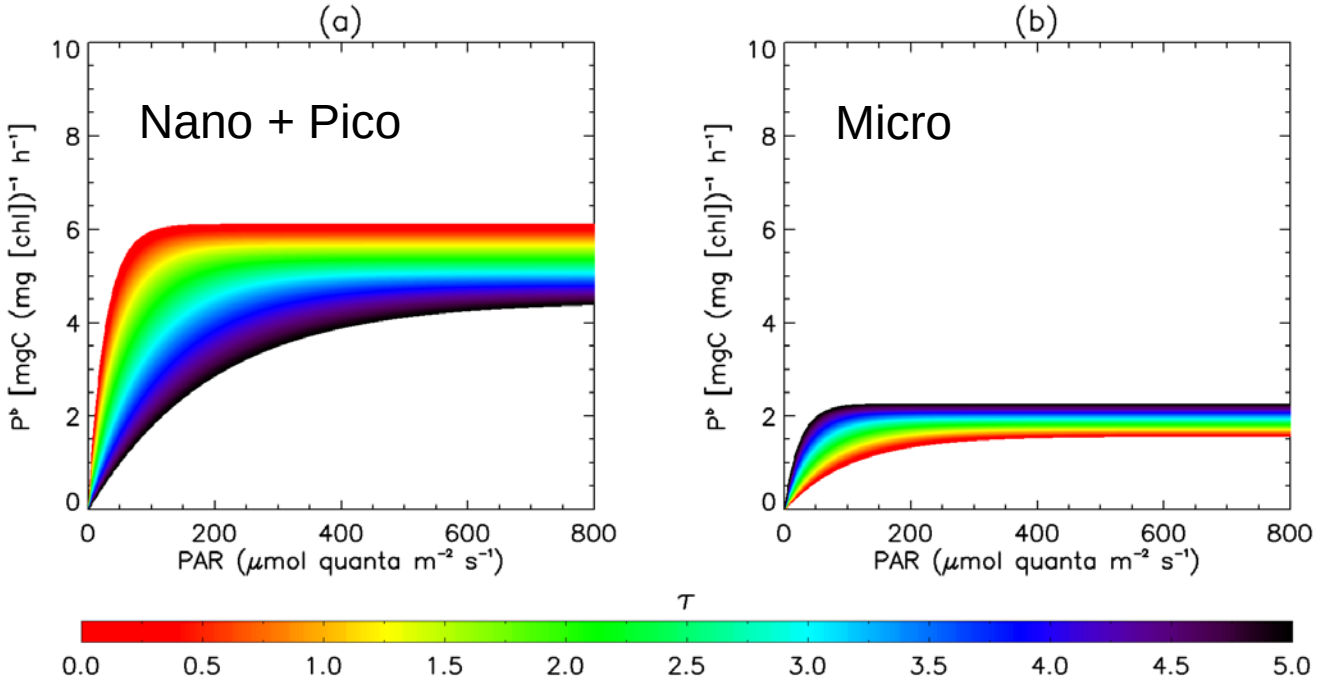

# Thank you for your attention

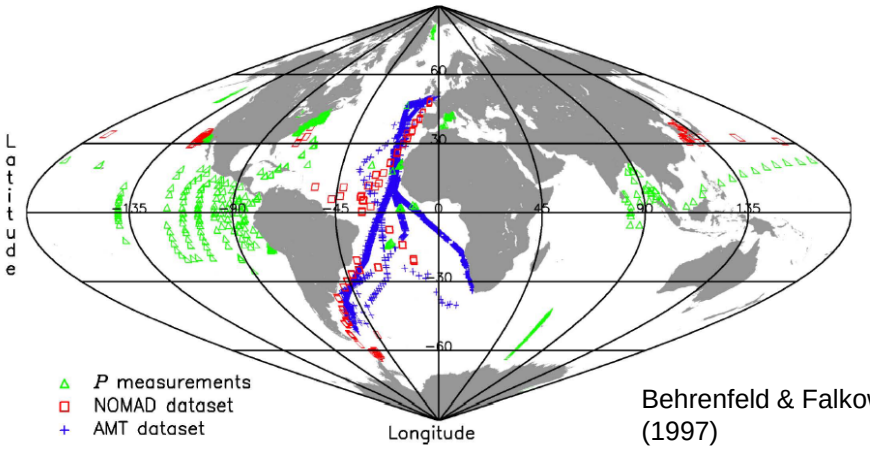
Questions?

# References


1. Brewin, R.J.W., Dall'Olmo, G., Sathyendranath, S., **Hardman-Mountford, N.J.** (2012). Particle backscattering as a function of chlorophyll and phytoplankton size structure in the open-ocean. *Optics Express*.
2. Hirata, T., **N. Hardman-Mountford**, and R.J.W. Brewin (2012), Comparing satellite-based phytoplankton classification methods. *Eos Trans. AGU*, **93**(6): 59, doi:10.1029/2012EO060008.
3. Brewin, R.J.W., Hirata, T., **Hardman-Mountford, N.J.**, Lavender, S.J., Sathyendranath, S., Barlow, R. (2012). The influence of the Indian Ocean Dipole on interannual variations in phytoplankton size structure as revealed by Earth Observation. *Deep Sea Research II – SeaWiFS Special Issue.* In press. doi: 10.1016/j.dsr2.2012.04.009.
4. Dall'Olmo, G., Westberry, T.K., Behrenfeld, M.J., Boss, E., Courties, C., Prieur, L., **Hardman-Mountford, N.J.** and Moutin, T. (2011). Inferring phytoplankton carbon and eco-physiological rates from diel cycles of spectral particulate beam-attenuation coefficient. *Biogeosciences.*
5. Brewin, R., Devred, E., Sathyendranath, S., **Hardman-Mountford, N.J.**, Lavender, S.J. (2011). A model of phytoplankton absorption based on three size classes. *Applied Optics* **50**: 4535-4549.
6. Hirata, T., **Hardman-Mountford, N.J.**, Brewin, R.J.W., Aiken, J., Barlow, R. (2011). Synoptic relationships quantified between surface Chlorophyll-a and diagnostic pigments specific to phytoplankton functional types. *Biogeosciences* **8**: 311-327, doi:10.5194/bg-8-311-2011.
7. Brewin, R.J.W., **Hardman-Mountford, N.J.**, Lavender, S.J., Raitsos, D.E., Hirata, T., Uitz, J., Devred, E., Bricaud, A., Ciotti, A., Gentili, B. (2011). An intercomparison of bio-optical techniques for detecting phytoplankton size class from satellite remote sensing. *Remote Sensing of Environment* **115**: 325-339.
8. Brewin, R.J.W, **Hardman-Mountford, N.J.**, Hirata, T. (2010). Detecting Phytoplankton Community Structure from Ocean Colour. In Morales, J., Stuart, V., Platt, T., Sathyendranath, S. (2010). *Handbook of Satellite Remote Sensing Image Interpretation: Applications to Marine Living Resources Conservation and Management.* EU PRESPO Project, Spain.
9. Brewin, R.J.W., Lavender, S.J., **Hardman-Mountford, N.J.** (2010) Mapping size-specific phytoplankton primary production on a global scale. *Journal of Maps* Full Edition 2010, 1-15.
10. Brewin, R.J.W., Sathyendranath, S., Hirata, T., Lavender, S.J., Barciela, R.**, Hardman-Mountford, N.J** (2010).. A three-component model of phytoplankton size class for the Atlantic Ocean. *Ecological Modelling*. **221**, 1472-1483.
11. Brewin, R.J.W., Lavender, S.J., **Hardman-Mountford, N.J.**, Hirata, T. (2010). A spectral response approach for detecting dominant phytoplankton size class from satellite remote sensing. *Acta Oceanologica Sinica* **29**(2):14-32.
12. Hirata, T., **Hardman-Mountford, N.J.**, Barlow, R., Lamont, T., Brewin, B., Smyth, T. and Aiken, J. (2009). An inherent optical property approach to the estimation of size-specific photosynthetic rates in eastern boundary upwelling zones from satellite ocean colour: An initial assessment. *Progress in Oceanography*, 83: 393-397.
13. Aiken, J., Pradhan, Y., Barlow, R., Lavender, S.J., Poulton, A., Holligan, P. & **Hardman-Mountford, N.J.** (2009). Phytoplankton pigments and functional types in the Atlantic Ocean: a decadal assessment, 1995-2005. AMT Special Issue. *Deep-Sea Research II* **56**: 899–917. 10.1016/j.dsr2.2008.09.017.
14. Hirata, T., Aiken, J., **Hardman-Mountford, N.J.**, Smyth, T.J. & Barlow, R.G. (2008). An absorption model to determine phytoplankton size classes from satellite ocean colour. *Remote Sensing of Environment* **112** (6): 3153-3159.
15. Aiken, J., **Hardman-Mountford, N.J.**, Barlow, R., Fishwick, J., Hirata, T. & Smyth, T. (2008). Functional links between bio-energetics and bio-optical traits of phytoplankton taxonomic groups; an overarching hypothesis with applications for ocean colour remote sensing. *Journal of Plankton Research* 30: 165-182.
16. Aiken, J. Fishwick, J.R., Lavender, S.J., Barlow, R., Moore, G.F., Sessions, H., Bernard, S., Ras, J. & **Hardman-Mountford, N.J.** (2007). Validation of MERIS reflectance and chlorophyll during the BENCAL cruise October, 2002: preliminary validation and new products for phytoplankton functional types and photosynthetic parameters. MERIS Special Issue. *International Journal of Remote Sensing,* **28**: 497-516.

# Size and primary production rates

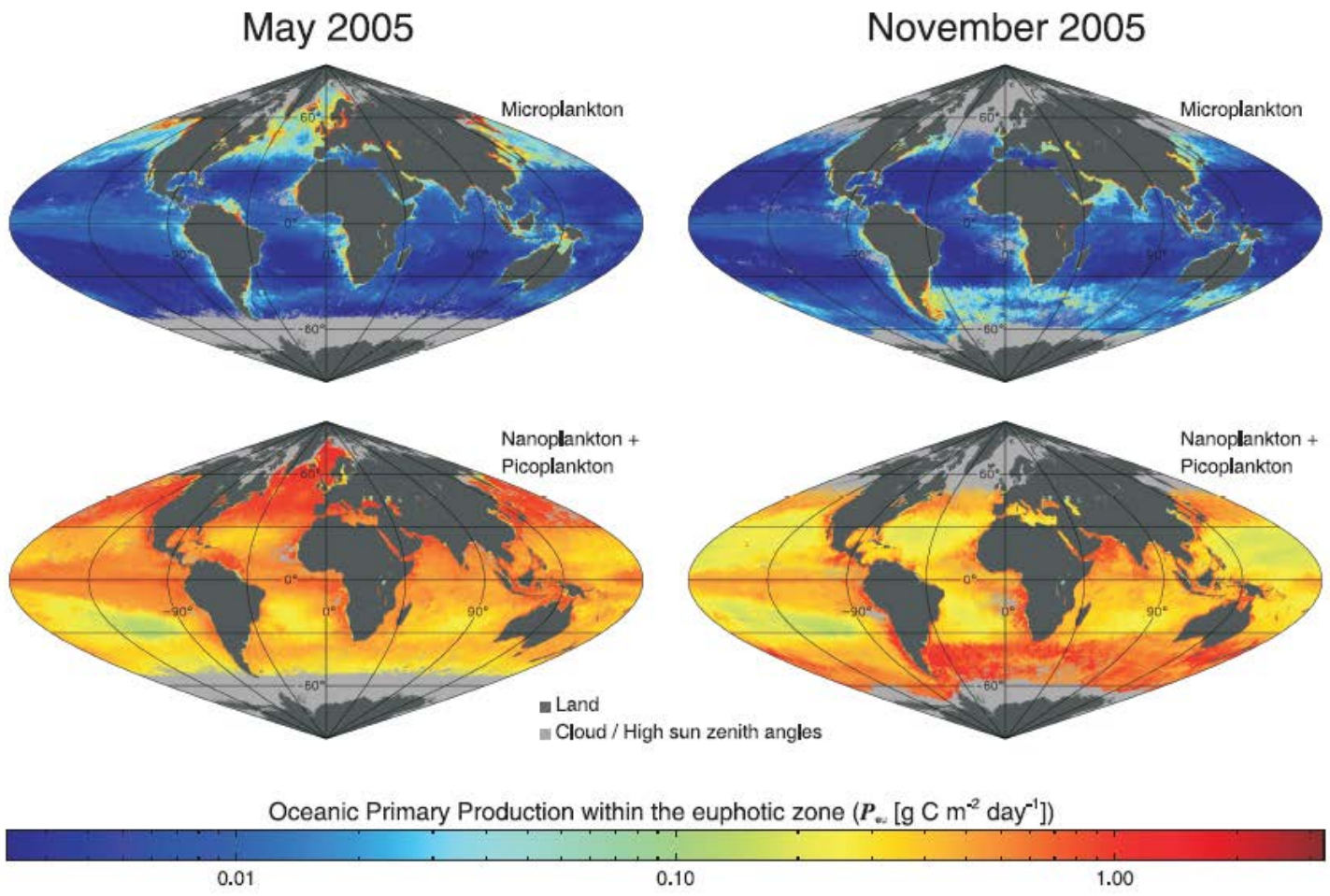



Behrenfeld & Falkowski (1997)

Brewin *et al.* (2010) *J. Maps*

# Size and primary production rates

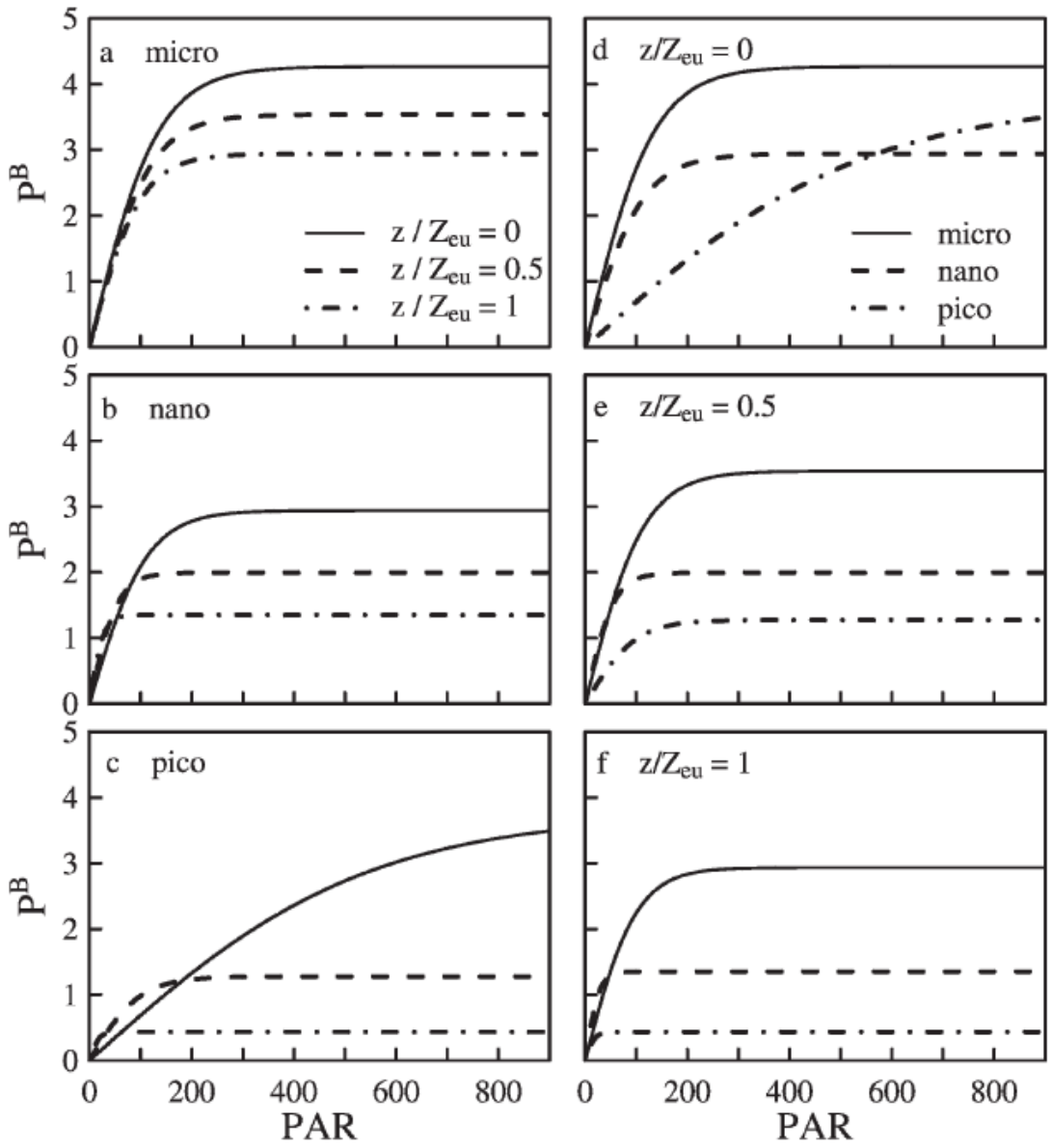


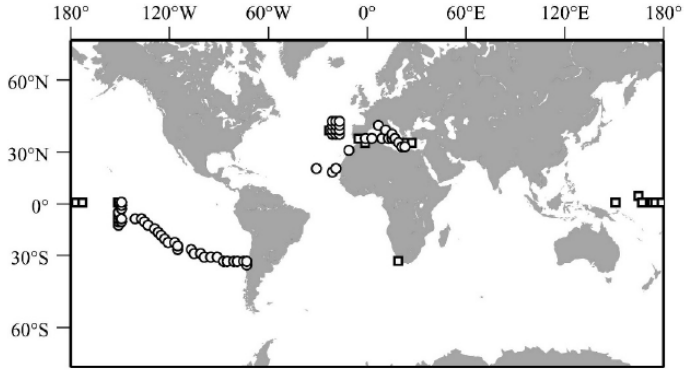

**Micro** — **5-8%**

**Nano-Pico** — **92-95%**

Brewin *et al.* (2010) *J. Maps*

# Or maybe ...



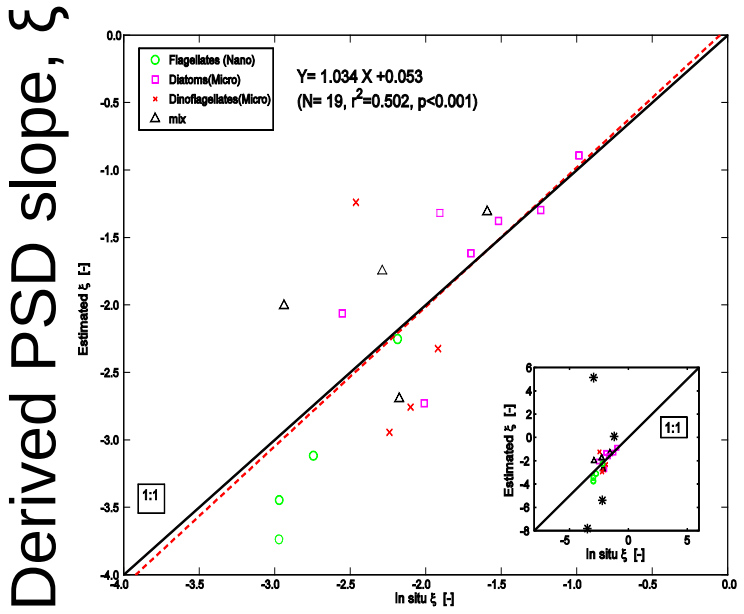

Uitz *et al.* (2008) *L&O*

**Global annual total:**

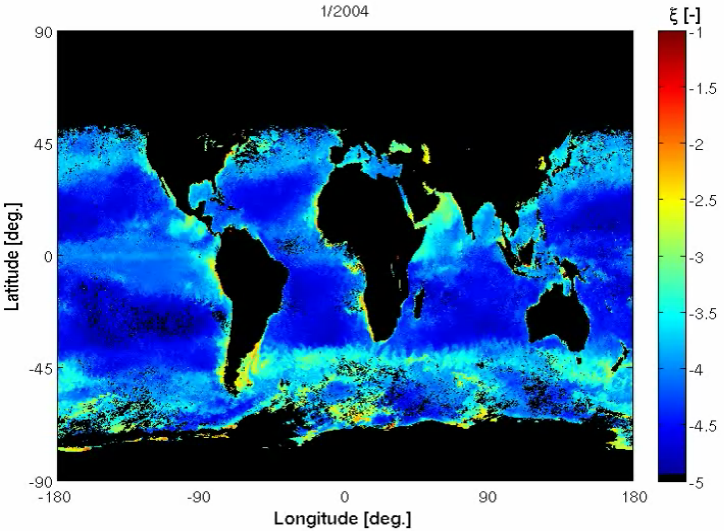
Micro = 32%

Nano = 44%

Pico = 24%



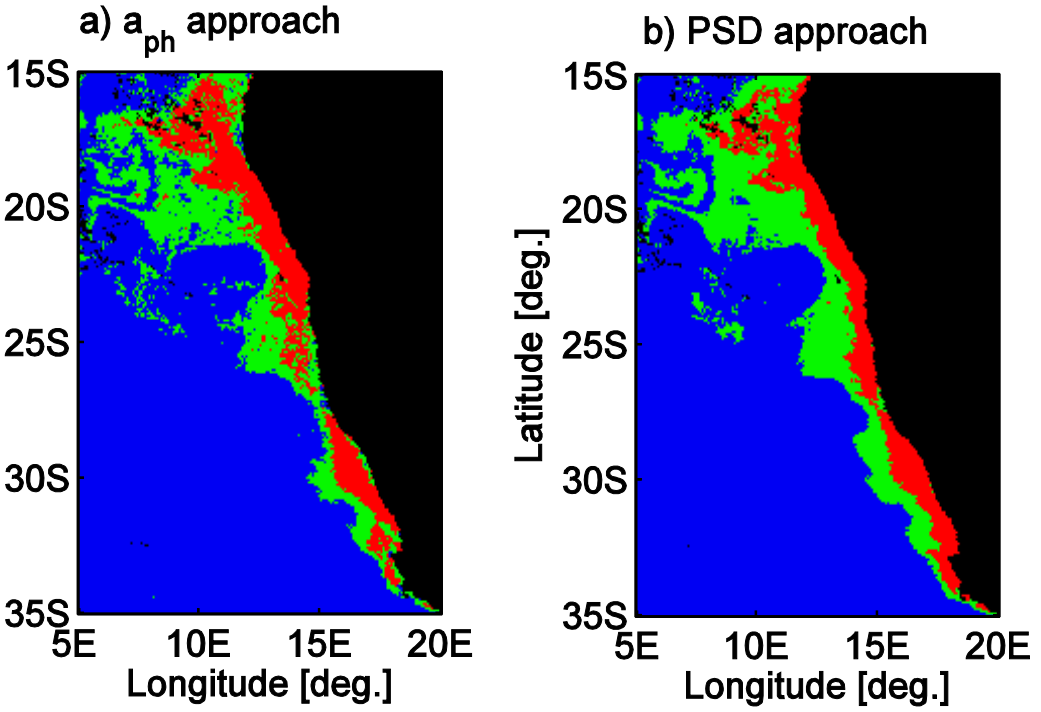

Global Picture of PSD slope ξ




In situ PSD slope, ξ

Validation shows reasonable result (success rate of retrieval ~ 83%)

Comparison with $a_{ph}$ approach shows consistency




Hirata *et al.* In revision