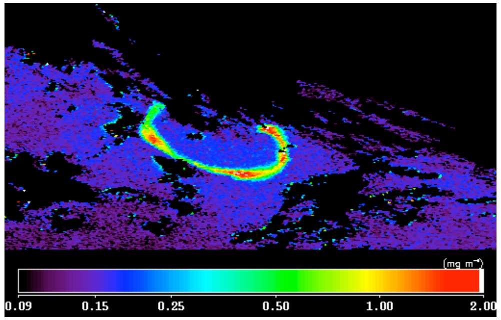
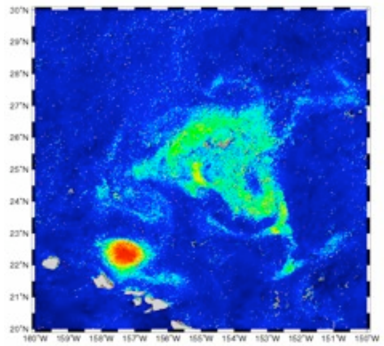
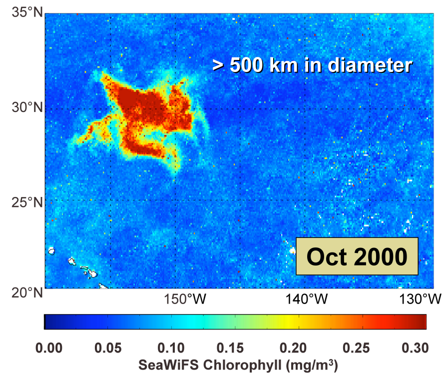
School of Ocean and Earth Science and Technology

UNIVERSITY OF LIVERPOOL







Promoting phytoplankton blooms in the open ocean:

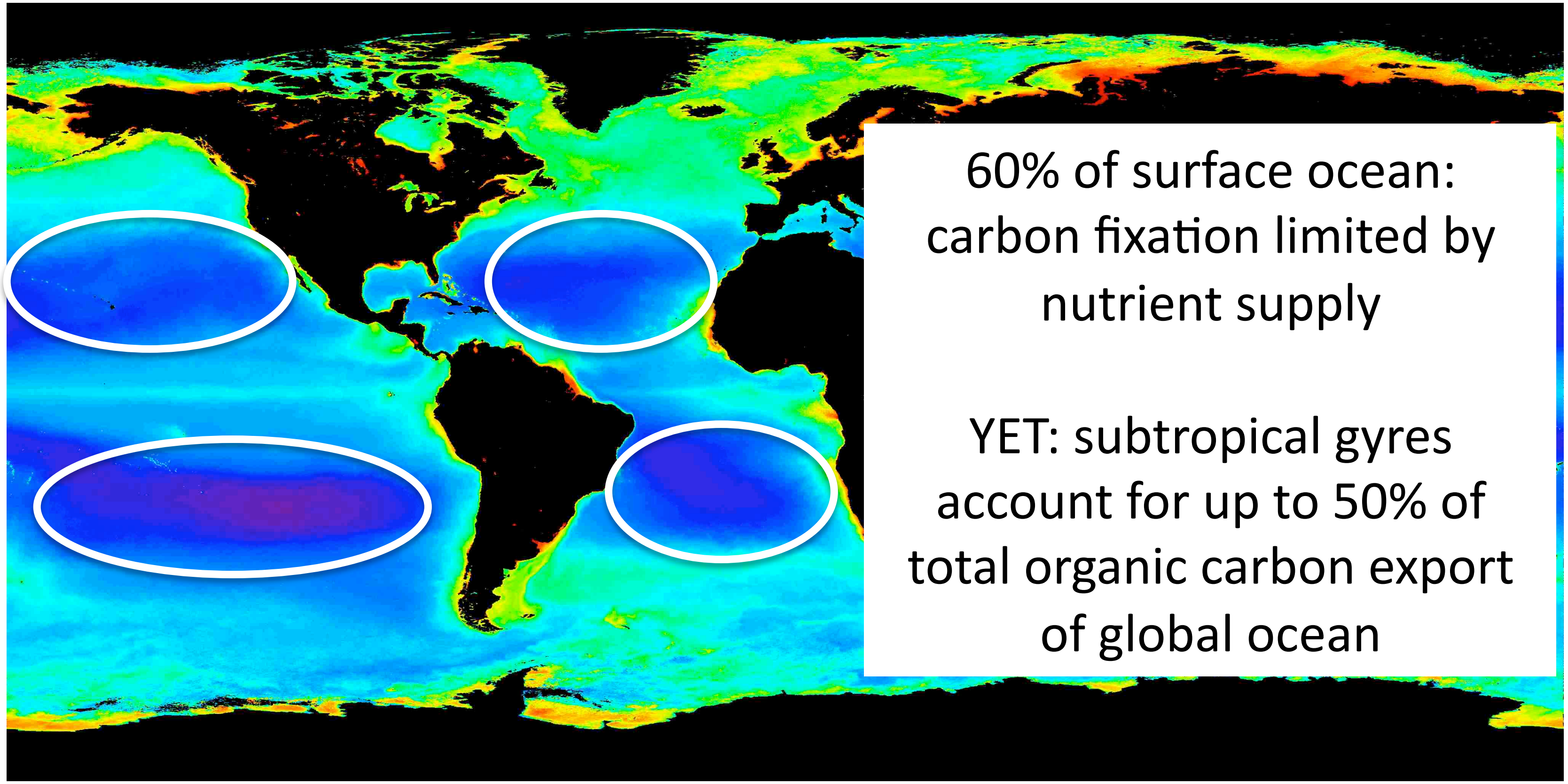
Results from nutrient addition experiments

Dr. Claire Mahaffey

Dr. Karin Bjorkman and Prof. David Karl

Introduction

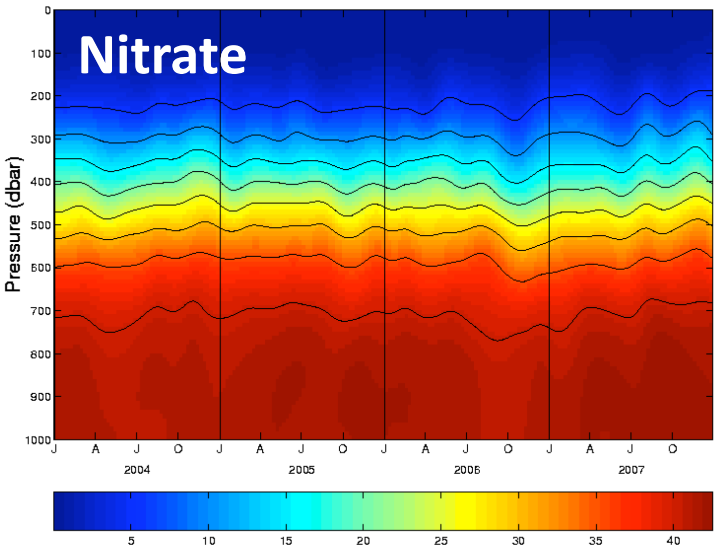
• Fixation of CO_2 by phytoplankton (PRIMARY PRODUCTION) dependent upon two factors: **light and nutrients**



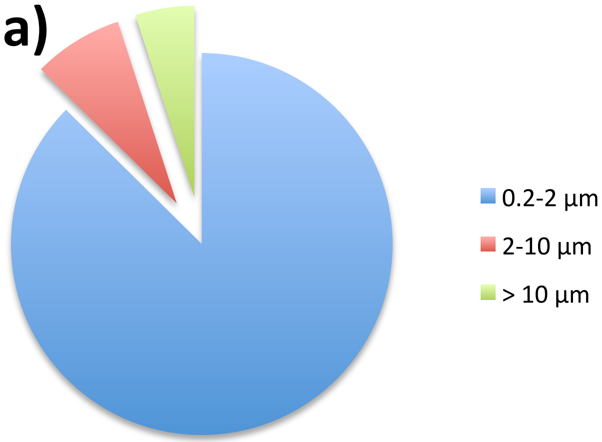
SEA SURFACE COLOUR AS A PROXY FOR CHLOROPHYLL *A* CONCENTRATIONS

(Sub) tropical ocean environment

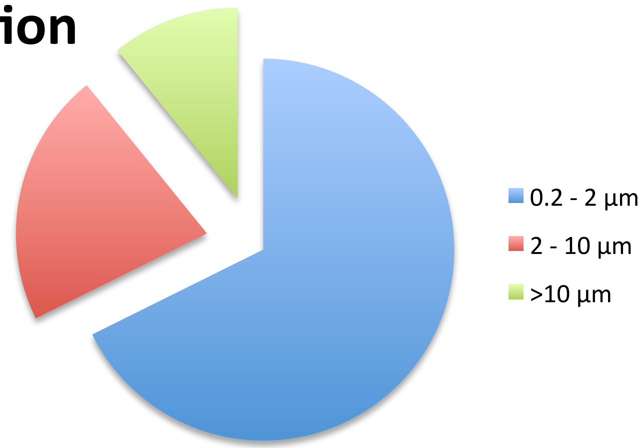
- Permanently stratified
- Nutrient impoverished surface ocean
- Picoplankton (< 2 µm) responsible for > 90% of chlorophyll a and > 70% of carbon fixation



Phytoplankton biomass (Chlorophyll a)

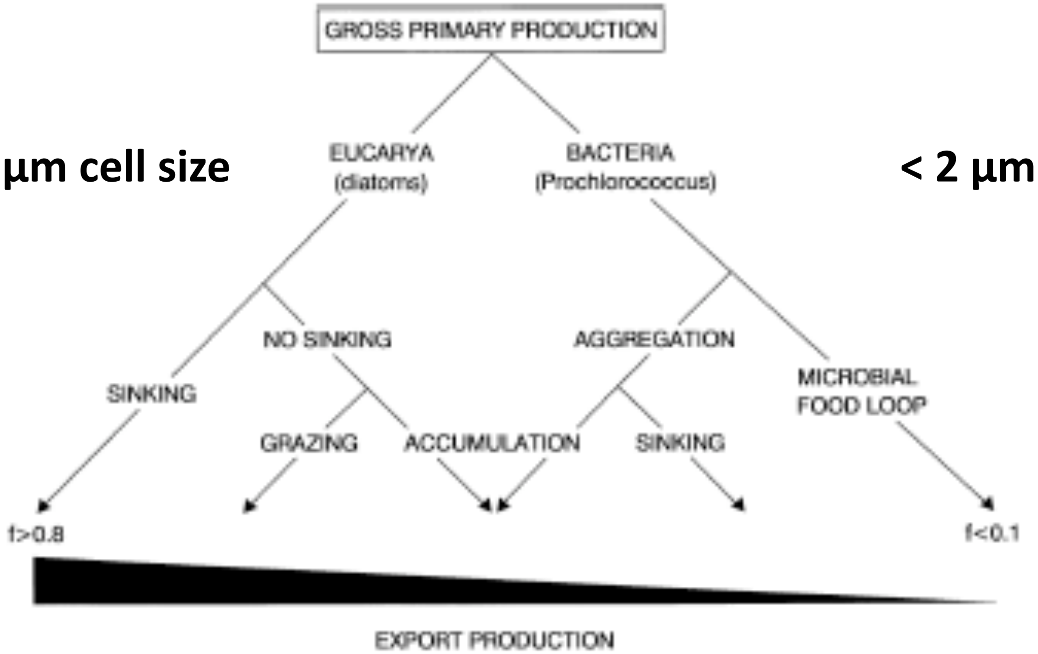


Carbon fixation



Community size structure and export

> 10 µm cell size **< 2 µm cell size**

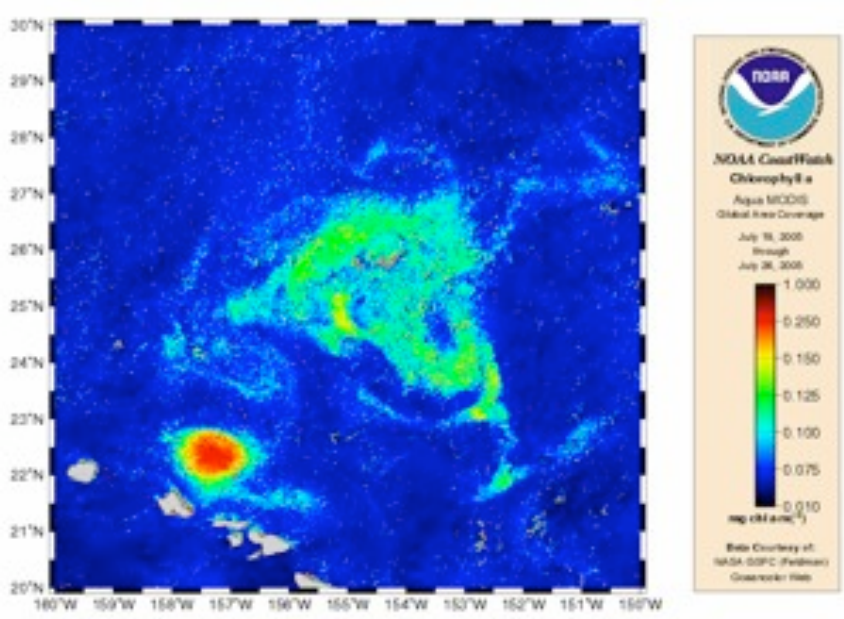


HIGH EXPORT PRODUCTION

LOW EXPORT PRODUCTION

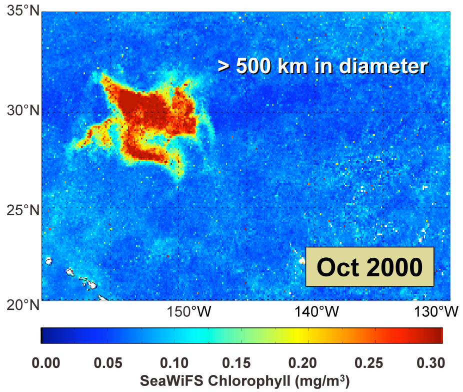
From Karl, 1999

Blooms in “ocean deserts”



• Episodic blooms of diatoms and nitrogen fixing cyanobacteria (Church et al., 2008, Dore et al., 2008,

WHAT DRIVES THESE BLOOMS?



• Summer time increase in water column stability

• Mesoscale eddies and Rossby waves (Church et al., 2008, Wilson et al., 2003)

• Winter time supply of phosphorus (Dore et al., 2008)

Why do we need to understand blooms in ocean deserts?

- Ocean deserts represent **60 %** of total ocean area (Eppley and Peterson, 1979)
- Responsible for **~50%** of global ocean carbon export (Emerson et al., 1997)
- Periodic blooms drive up to **50%** of annual export (Karl et al., 1997, Dore et al., 2008)

HOWEVER:

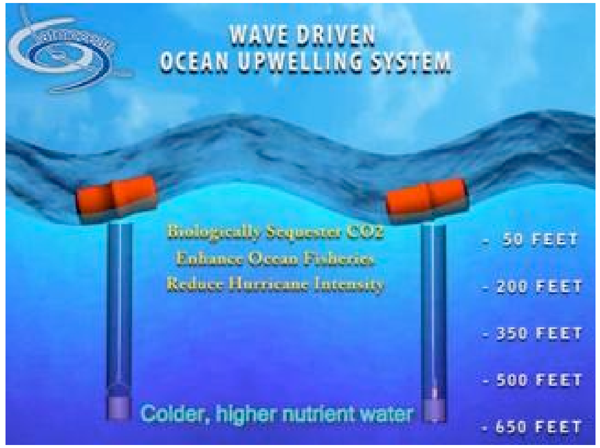
• Few direct observations of blooms due to their stochastic nature

• Uncertainty surrounding:

- Species composition and succession
- Carbon fixation and fate
- Speed of development
- Reproducibility

Ocean fertilisation

- Addition of nutrient cocktail or deep-sea water to surface ocean to stimulate carbon fixation and sequestration



Nitrogen fixation-enhanced carbon sequestration in low nitrate, low chlorophyll seascapes

David M. Karl[1,*], Ricardo M. Letelier[2]

[1]Department of Oceanography, University of Hawaii, Honolulu, Hawaii 96822, USA
[2]College of Oceanic and Atmospheric Sciences, Oregon State University, Corvallis, Oregon 97331, USA

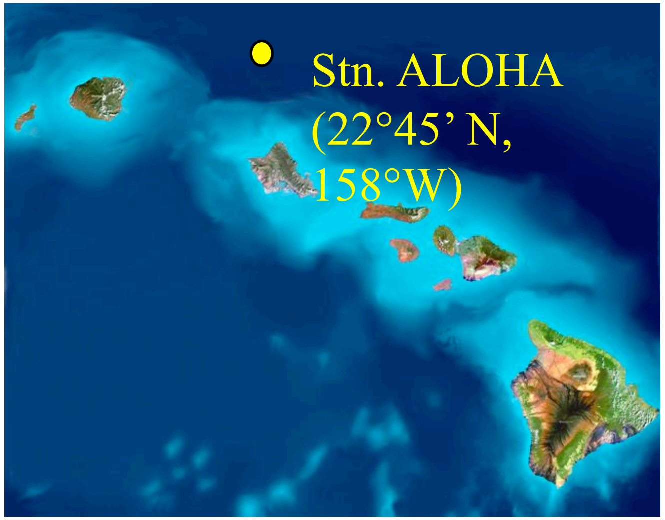
Ocean fertilization: a potential means of geoengineering?

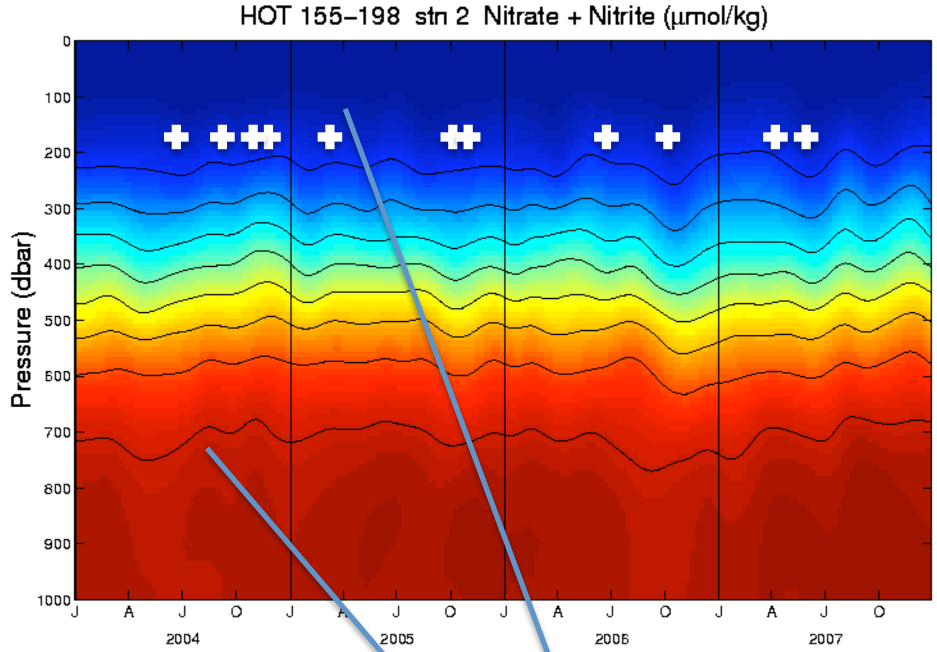
By R. S. Lampitt[1,*], E. P. Achterberg[1], T. R. Anderson[1], J. A. Hughes[1], M. D. Iglesias-Rodriguez[1], B. A. Kelly-Gerreyn[1], M. Lucas[2], E. E. Popova[1], R. Sanders[1], J. G. Shepherd[1], D. Smythe-Wright[1] and A. Yool[1]

Ocean pipes could help the Earth to cure itself

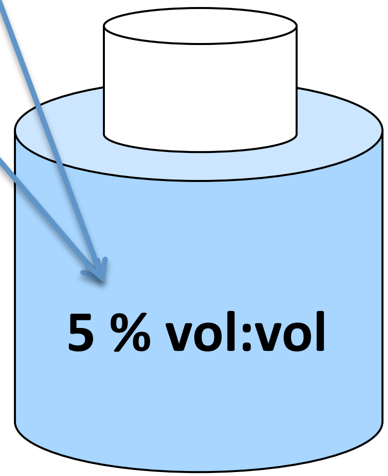
James E. Lovelock*, Chris G. Rapley†
*Green College, University of Oxford, Woodstock Road, Oxford OX2 6HG, UK
†Science Museum, Exhibition Road, South Kensington, London SW7 2DD , UK

Nutrient addition experiments





- **Dissolved nutrients**
- Biomass parameters (**chlorophyll a)**
- **Community size structure, 0.2, 2 and 10 µm**
- Species composition (pigments and flow cytometry)
- Rate measurements **(carbon fixation)**



Question: In a nutrient limited system, can we predictably stimulate a phytoplankton bloom by adding nutrient-rich deep seawater:

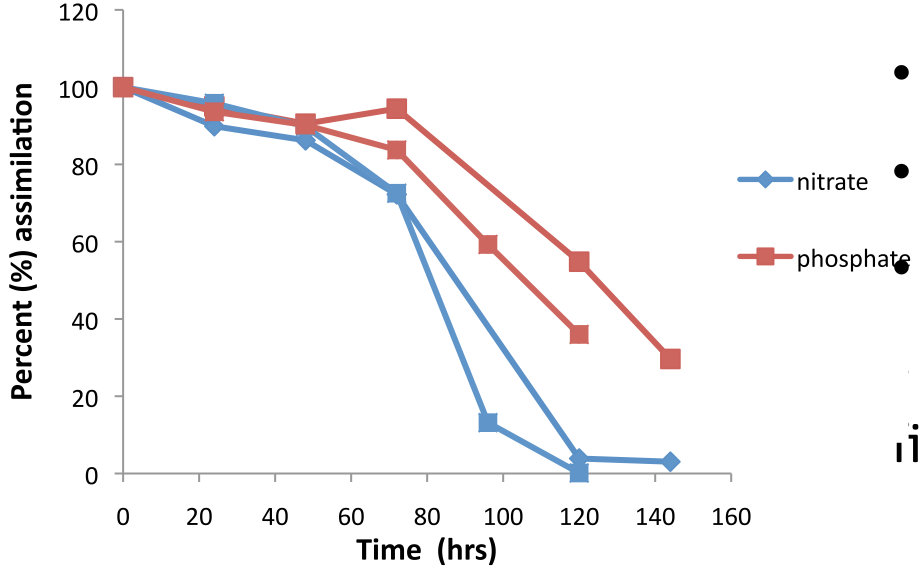
- increase in biomass (chlorophyll *a*)

- increase rate of carbon fixation

- change community size structure from small (0.2-2 µm) to large (> 10 µm) cells

- increase the potential for export of organic carbon?

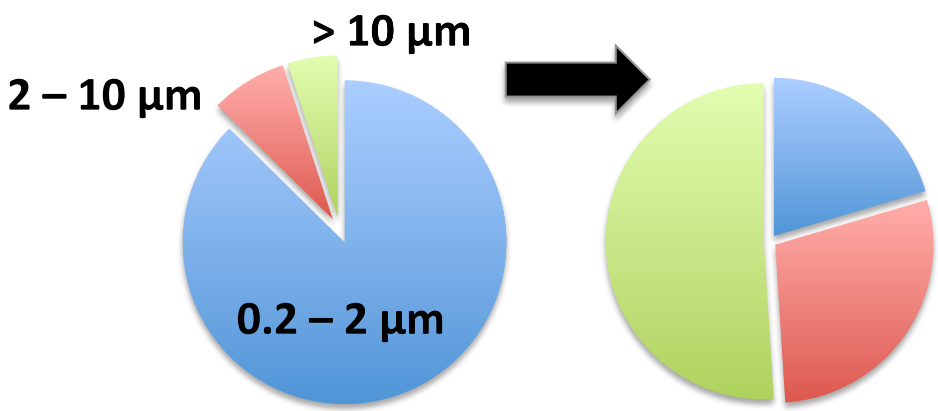
Bloom response



- 3 cruises
- 70-100% nutrient assimilation
- 20 ± 4 fold increase in chlorophyll
- 23 ± 7 fold increase in carbon fixation

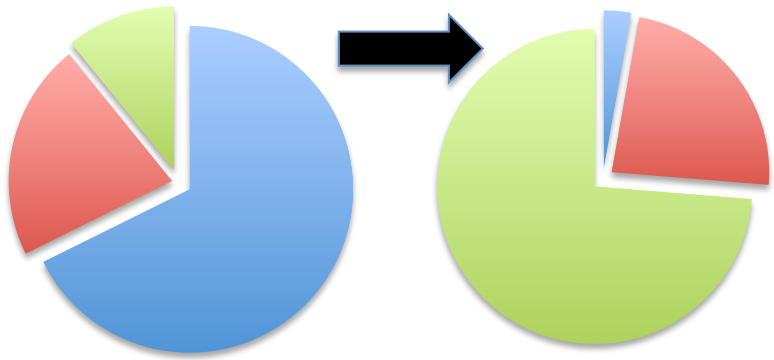
Size structure

Chlorophyll *a*



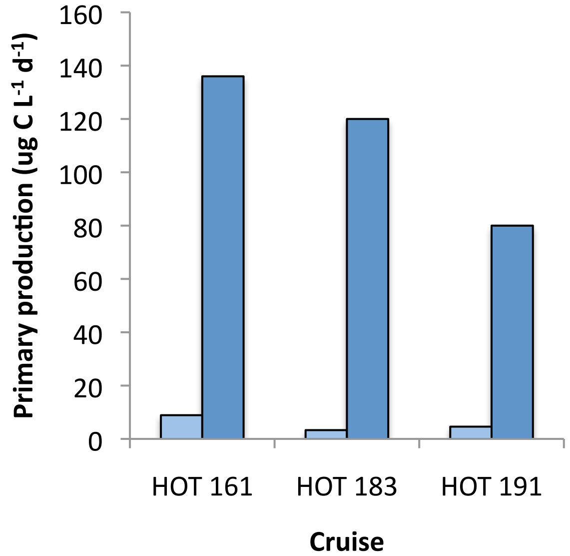
INITIAL FINAL

Carbon fixation



INITIAL FINAL

Bloom response



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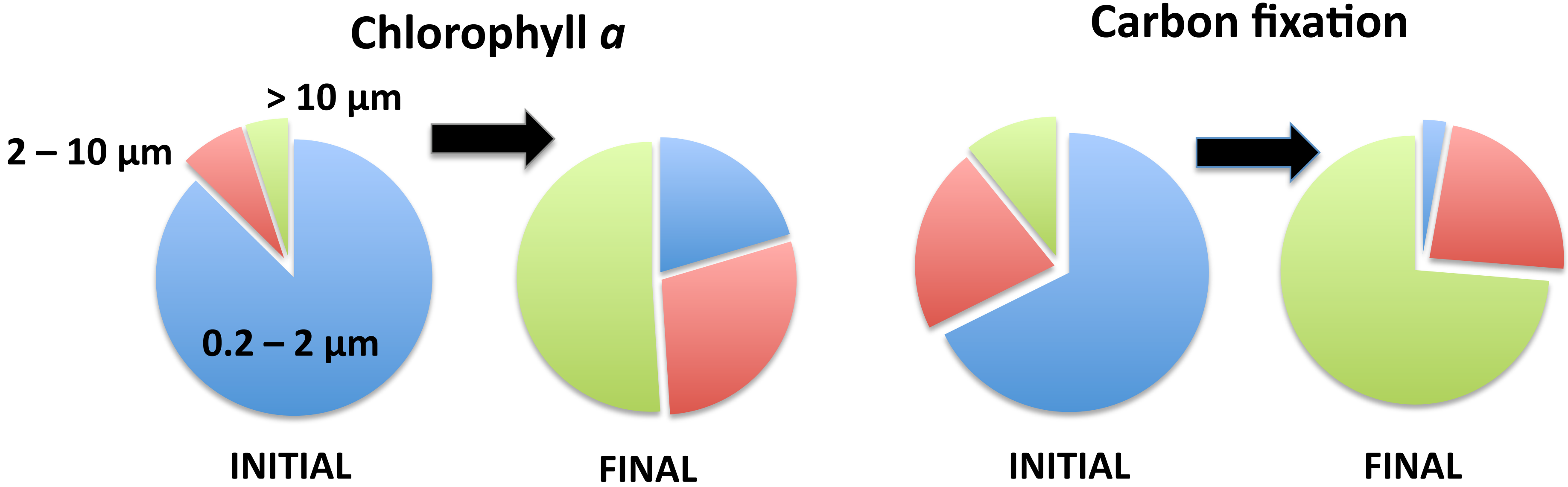
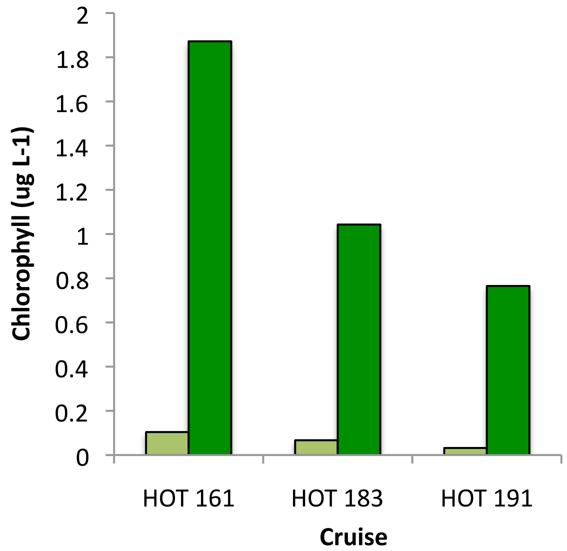


Bloom response



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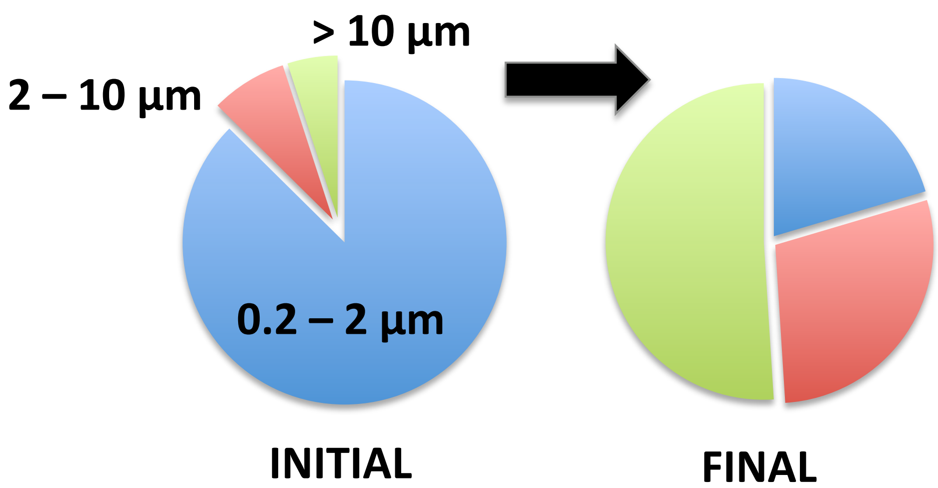
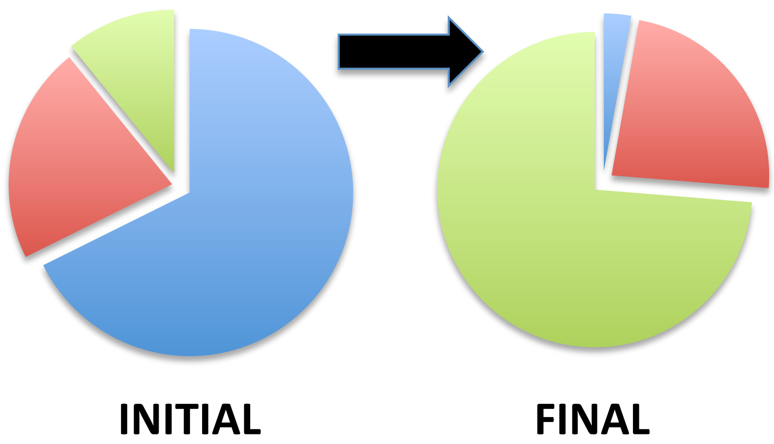
<u>Size structure</u>

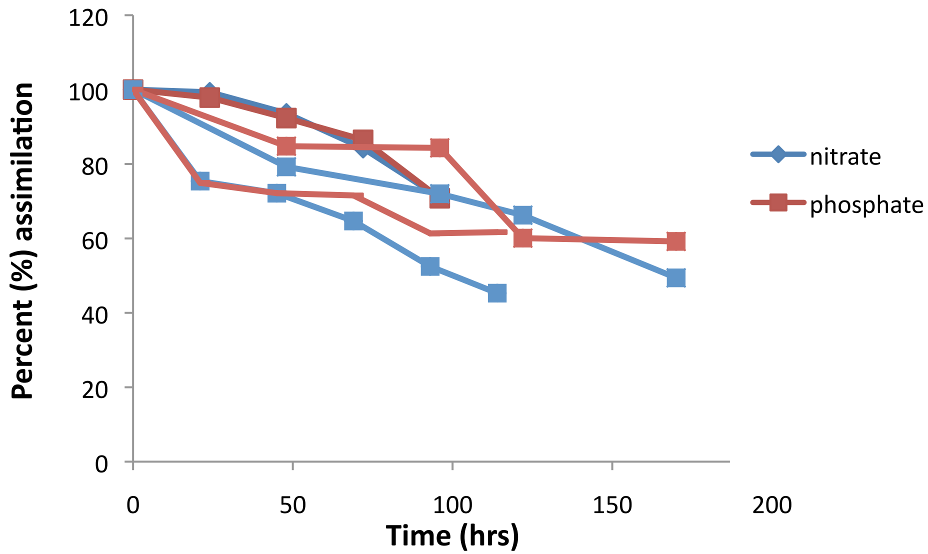
Chlorophyll *a*



Carbon fixation

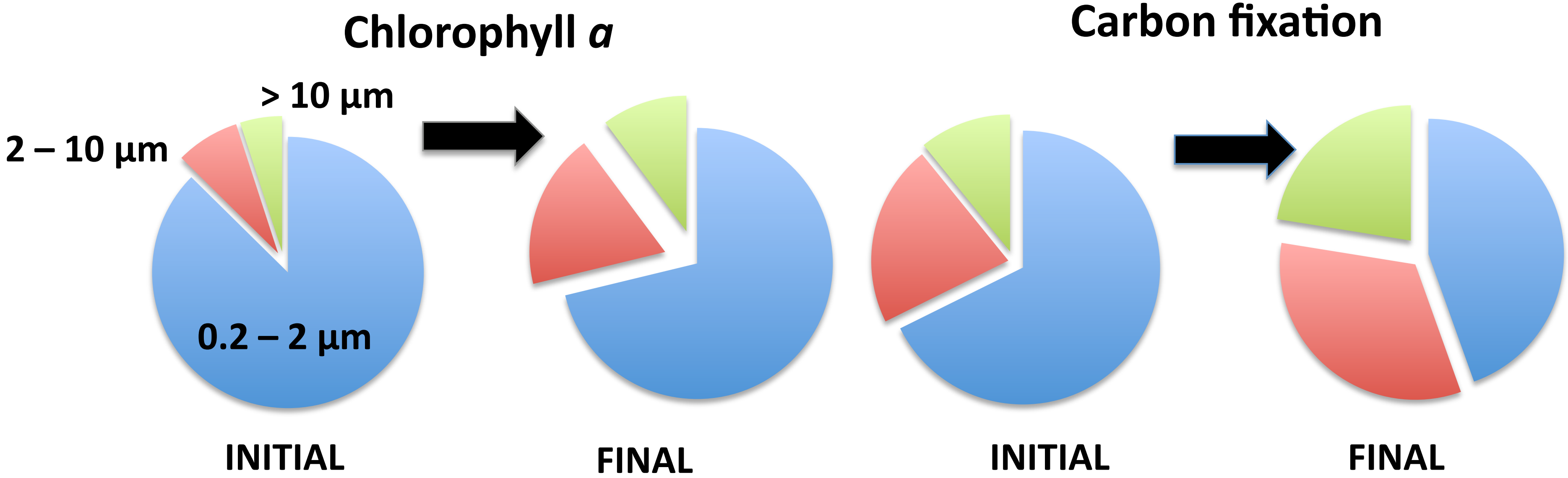


Non-bloom response

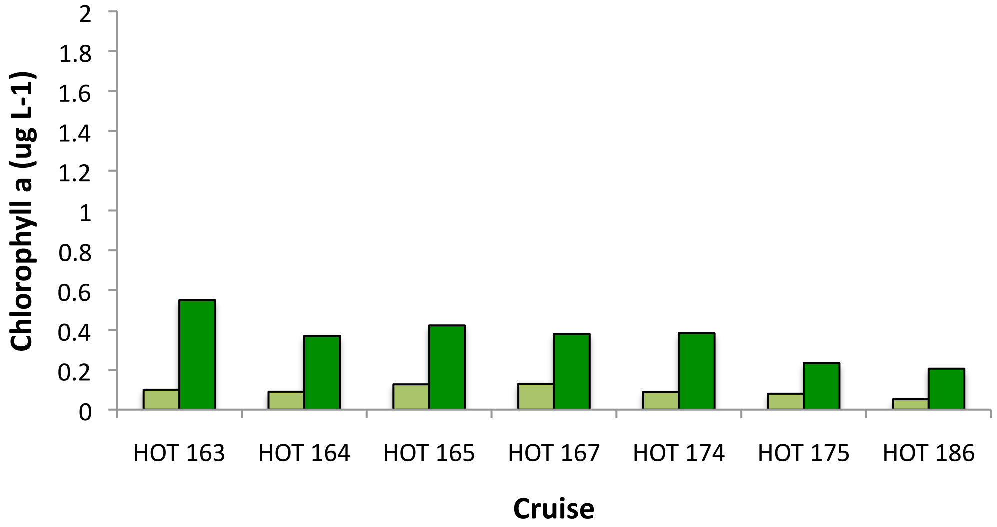


- 7 cruises
- < 50% of nutrients assimilated
- 4 ± 1 fold increase in chlorophyll
- 5 ± 1 fold increase in carbon fixation

Size structure



Non-bloom response



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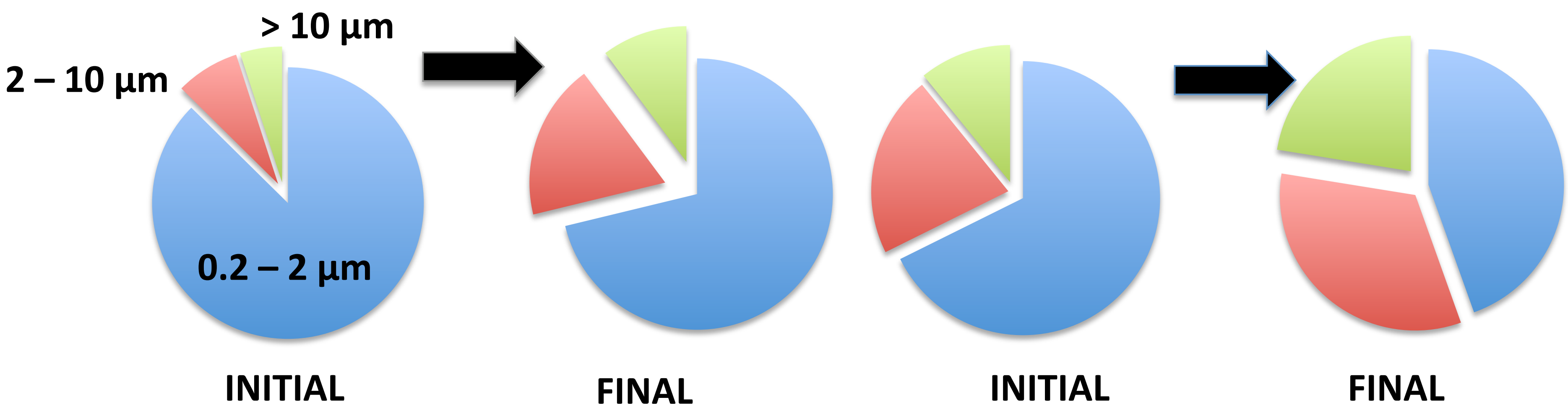
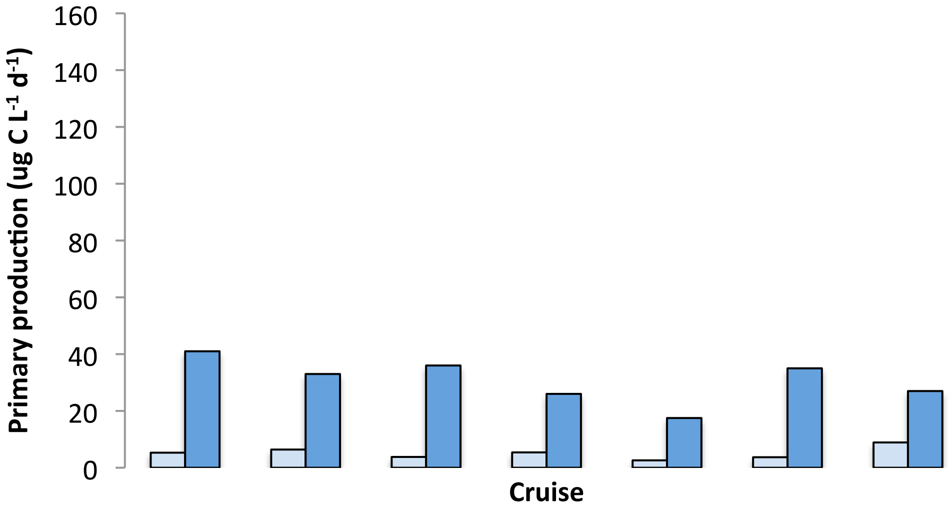
Size structure

Chlorophyll *a* **Carbon fixation**



Non-bloom response



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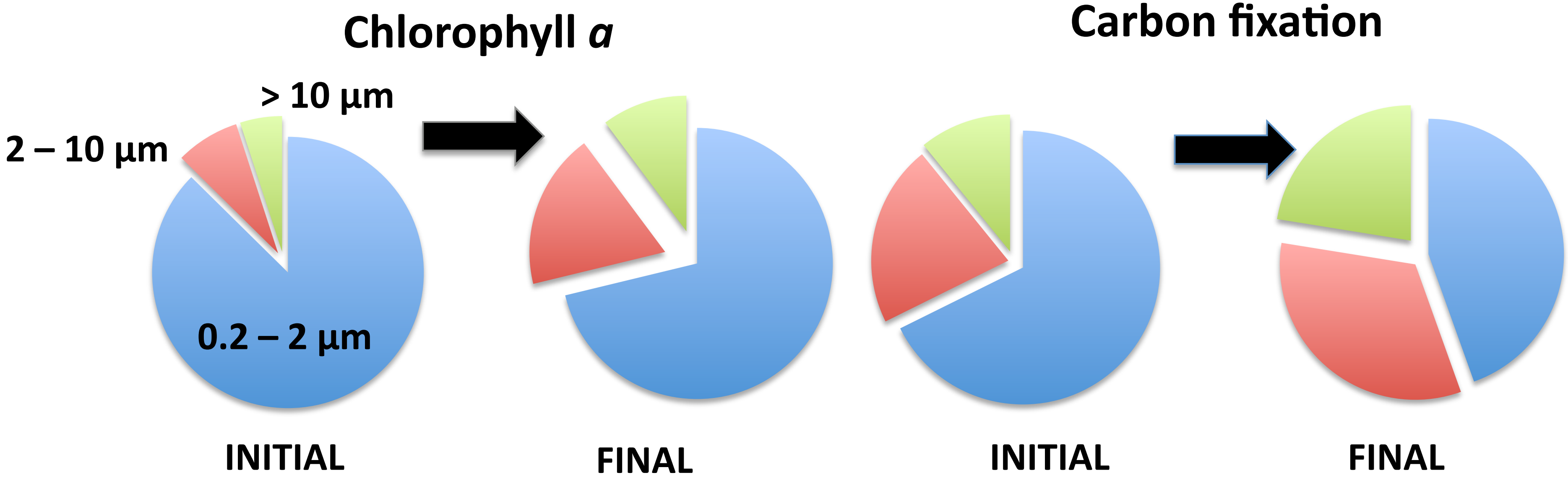
Size structure



Experiment summary

Parameter	Bloom response	Non-bloom response
Nutrients	70-100% assimilation	< 50% assimilated
Chlorophyll	20 ± 4 fold increase	4 ± 1 fold increase
Carbon fixation	23 ± 7 fold increase	5 ± 1 fold increase
Size composition	Dominated by > 10um	Dominated by 0.2 – 2 um
Months	May to July	September to January

Bloom response, Summer (May to July) – rapid and complete assimilation of nutrients and bloom formation

Non-bloom response, Winter (September to January) – slow and incomplete assimilation of nutrients and no bloom formed

Potential carbon fixed

- Nitrate added = 2 μM
- Maximum potential carbon fixed = **174 ± 19 μg C L^{-1}**

Accumulated carbon fixed during summer and winter incubations

Season	Whole community *	> 10um cells *
Summer	115 ± 18	59 ± 15
Winter	31 ± 4	5 ± 1

* Expressed as percent (%) of maximum potential carbon fixed (174 μg C L^{-1})

Comparing summer and winter carbon potential:

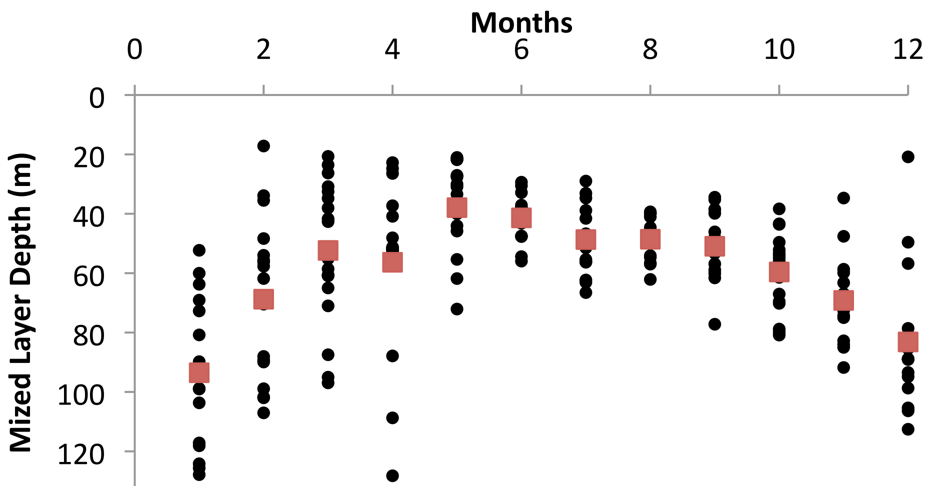
3x carbon fixed for whole community
10x more carbon fixed by large cells (> 10 μm)

What are the mechanisms driving this variation in community response?

- Initial nutrient conditions
- Community structure and composition
- Size composition

NO SIGNIFICANT DIFFERENCE BETWEEN WINTER AND SUMMER CRUISES

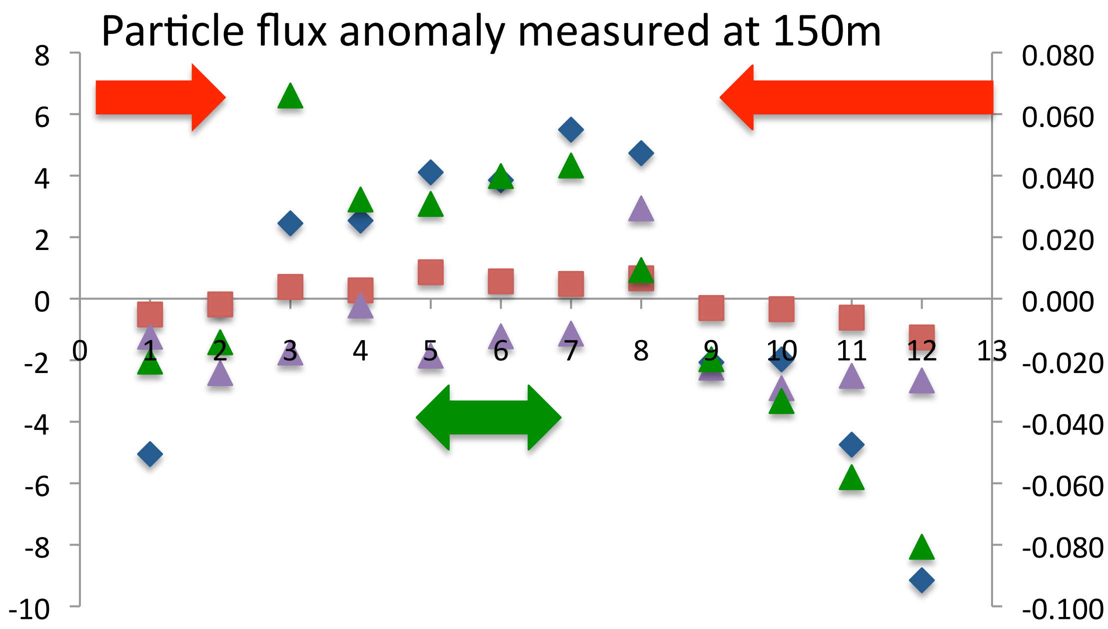
- Water column stability and structure



Seasonal alteration of water column stability may cause FINE-SCALE changes in nutrient fields and community structure

Potential mechanisms

- Water column sweeping by export events



- Summer-time blooms drive large export event

- "Sweep" the water column of seed populations capable of rapid assimilation of nutrients

- Light flux E m^{-2} d^{-1}
  - Summer: 47.3 ± 2.3
  - Winter: 31.2 ± 3.1

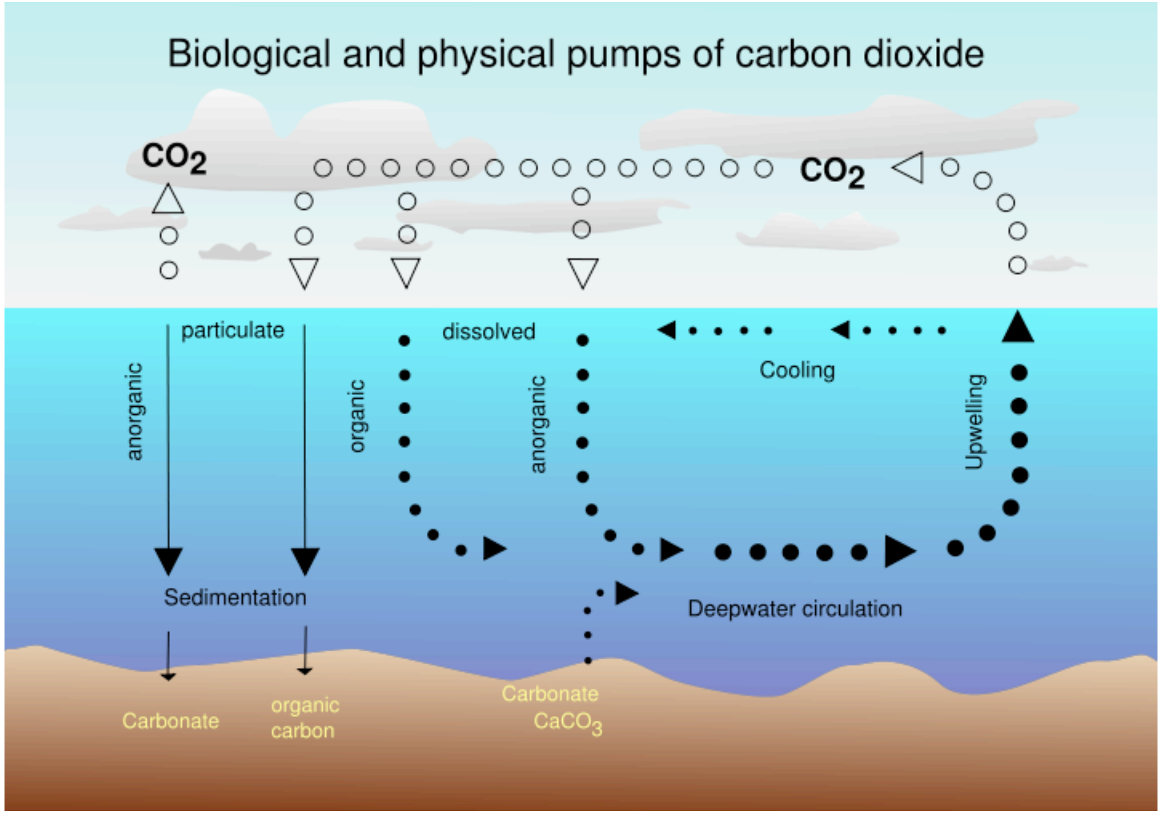
SIGNIFICANT DIFFERENCE IN LIGHT FLUX

Conclusions

- Addition of nutrient-rich deep seawater to surface phytoplankton community generated blooms during summer only
- Mechanisms underlying variation in phytoplankton community response between summer and winter remains uncertain
- IMPLICATIONS:
  - fine scale upwelling, e.g. mesoscale eddies
  - Artificial fertilisation of the open ocean

Thank you

Carbon pumps



- Solubility pump:
  - seawater temperature
  - thermohaline circulation
- Biological pump